NATURE, SCOPE, TRENDS AND DEVELOPMENT OF GEOMORPHOLOGY

INTRODUCTION

Geomorphology is the branch of Earth science that focuses on the study of landforms, their formation, evolution, and their spatial distribution. Geomorphology is an interdisciplinary field that combines aspects of geology, geography, physics, and ecology to understand the processes that shape the Earth's surface. Geomorphology is crucial in understanding how landscapes change over time and in predicting the effects of natural and human-induced changes.

Definition of Geomorphology:

Throughout history, several ancient and modern geographers have contributed to the development of geomorphology as a scientific discipline. Here are some of the definitions of geomorphology given by ancient to modern geographers:

- **Strabo (64 BCE - 24 CE):** Strabo was a Greek geographer and historian who wrote extensively about the geography of the ancient world. In his book, "Geographica," he defined geomorphology as the study of the physical features of the earth's surface, including mountains, rivers, and valleys.

- **Leonardo da Vinci (1452-1519):** Da Vinci was a renowned Italian artist, inventor, and scientist. He was one of the first to recognize the importance of water in shaping the Earth's surface. He defined geomorphology as the study of the effects of water on the Earth's surface, including erosion and sedimentation.

- **William Morris Davis (1850-1934):** Davis was an American geographer who is often referred to as the father of modern geomorphology. He defined geomorphology as the study of the processes that shape the Earth's surface and the landforms that result from these processes. Davis emphasized the concept of a "cycle of erosion," which describes the process by which landscapes evolve.

- **Walther Penck (1888-1923):** Penck was a German geographer who developed a quantitative approach to geomorphology. He defined geomorphology as the study of the Earth's surface in terms of its relief, which is the three-dimensional shape of the land surface. Penck believed that the Earth's surface could be described using mathematical models.

- **Richard Chorley (1927-2002):** Chorley was a British geographer who made significant contributions to the study of geomorphology. He defined geomorphology as the study of the Earth's surface in terms of its form, function, and history. Chorley emphasized the importance of understanding the processes that shape landscapes and how these processes vary across different spatial and temporal scales.
- **Robert W. Young (born 1942):** Young is an American geomorphologist who has made significant contributions to the study of geomorphology. He defines geomorphology as the study of the Earth's surface in terms of its physical and biological processes, and how these processes interact to produce landscapes. Young emphasizes the importance of interdisciplinary approaches to understanding geomorphic processes.

Geomorphology has a long history, with early theories of landform development proposed by prominent scientists such as Charles Darwin and James Hutton. However, the modern field of geomorphology emerged in the early 20th century, with the pioneering work of scientists such as William Morris Davis, who developed the cycle of erosion model to explain how landscapes evolve. Since then, geomorphology has advanced significantly, with the development of new technologies, such as remote sensing and computer modelling, allowing for more detailed and accurate analysis of landforms.

The study of geomorphology involves a range of methods and techniques, including field observations, laboratory experiments, and computer modelling. Geomorphologists also use a variety of tools, including GPS, LIDAR, and satellite imagery, to collect data and analyze landscapes. This data is used to develop models and theories to explain landform evolution and to identify patterns in landscape change over time

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NATURE OF GEOMORPHOLOGY

The nature of geomorphology is complex and multifaceted, drawing on principles from a wide range of disciplines and involving the study of a wide range of phenomena. Geomorphology is fundamentally concerned with understanding the form, processes, and evolution of the Earth's surface, and with developing a conceptual framework for interpreting and explaining these phenomena.

At its core, geomorphology is a *scientific discipline* that is driven by a commitment to empirical observation, hypothesis testing, and the development of conceptual models. Geomorphologists use a range of observational and analytical tools to collect data on the Earth's surface and to develop and test hypotheses about the processes that shape it.

Geomorphology is a scientific discipline that is concerned with the study of landforms, the processes that shape and modify them, and the interactions between landforms and other aspects of the Earth system. Geomorphologists study a wide range of phenomena, including mountains, valleys, plateaus, plains, coastlines, rivers, glaciers, and permafrost.

One of the key characteristics of geomorphology is its *interdisciplinary nature*. Geomorphology draws on principles and techniques from a range of fields, including geology, geography, physics, ecology, and engineering, among others to understand the evolution of the Earth's surface.

. This interdisciplinary approach is critical to understanding the complex interactions between physical and biological processes that shape the Earth's surface.

SCOPE OF GEOMORPHOLOGY

The scope of geomorphology is broad and encompasses a wide range of phenomena related to the Earth's surface. Geomorphology is concerned with the study of landforms, including mountains, valleys, plateaus, plains, and coastlines, as well as the processes that shape and modify these landforms, such as weathering, erosion, deposition, tectonic activity, and climate change.

One of the key principles of geomorphology is that landforms are the result of the interaction between different processes acting on the Earth's surface. These processes include weathering, erosion, deposition, tectonic activity, climate change, and human activity. Geomorphologists seek to understand the mechanisms and rates of these processes, and how they interact to produce the diverse range of landforms observed on Earth.

Another important aspect of geomorphology is the study of landscape evolution. Geomorphologists seek to understand how landscapes change over time, including the effects of long-term tectonic activity, climate change, and human impacts. They use a variety of approaches, including geochronology, landscape modelling, and spatial analysis, to reconstruct the history of landscape evolution and predict future changes.

One of the primary areas of focus in geomorphology is the study of fluvial systems, which include rivers, streams, and other forms of running water. Geomorphologists study the behaviour of fluvial systems, including their erosion and sediment transport processes, and their interactions with human activities such as dam construction and channelization.

Another area of focus in geomorphology is the study of glacial and periglacial systems, including glaciers, ice sheets, and frozen ground. Geomorphologists study the formation and movement of glaciers and their interactions with the landscape, as well as the impacts of climate change on these systems.

Geomorphology also encompasses the study of coastal and marine systems, including beaches, cliffs, and estuaries. Geomorphologists study the dynamics of coastal and marine systems, including erosion, sediment transport, and sea level change, and their interactions with human activities such as coastal development and sea level rise.

Geomorphology seeks to understand the Earth's geological history and how it has influenced the evolution of its landforms. This involves studying the rock types, structures, and stratigraphy of the Earth's surface.

Geomorphology is concerned with understanding how environmental changes, both natural and human-induced, affects the Earth's surface. This includes studying the impacts of climate change, land use changes, and natural disasters such as floods, earthquakes, and landslides.

Classification of Landform

Landforms are the physical features of the Earth's surface, created by natural processes such as erosion, weathering, and tectonic activity. They can be classified in various ways, depending on their size, shape, origin, and the processes that have shaped them. In this response, we will discuss the main ways in which landforms are classified.

BASED ON THE PROCESSES THAT SHAPE THEM:

a. **Fluvial landforms:** These are landforms created by the action of rivers, such as valleys, floodplains, meanders, and deltas.
b. **Glacial landforms:** These are landforms created by the movement of glaciers, such as cirques, horns, aretes, and U-shaped valleys.
c. **Coastal landforms:** These are landforms created by the action of waves and currents along coastlines, such as cliffs, beaches, spits, and barrier islands.
d. **Karst landforms:** These are landforms created by the dissolution of soluble rocks such as limestone and dolomite, such as sinkholes, caves, and disappearing streams.
e. **Tectonic landforms:** These are landforms created by the movement of the Earth's crust, such as mountains, plateaus, rift valleys, and fault scarps.

BASED ON THEIR SHAPE AND SIZE:

a. **Mountains:** These are landforms with a peak or summit that rises significantly above its surroundings, typically with steep slopes and rugged terrain.
b. **Plateaus:** These are large, flat-topped areas that are elevated above their surroundings, typically with cliffs or escarpments around their edges.
c. **Hills:** These are landforms that are smaller and less steep than mountains, with rounded or conical summits.
d. **Valleys:** These are low-lying areas between hills or mountains, typically with a river or stream running through them.
e. **Plains:** These are large, flat areas that are generally low-lying and often covered with sedimentary deposits.

BASED ON THEIR ORIGIN:

a. **Structural landforms:** These are landforms created by the internal forces of the Earth, such as mountains and rift valleys.

a. **Depositional landforms:** These are landforms created by the deposition of sediment, such as dunes, river deltas, and alluvial fans.

b. **Erosional landforms:** These are landforms created by the erosion of rock or sediment, such as canyons, cliffs, and waterfalls.

c. **Volcanic landforms:** These are landforms created by volcanic activity, such as lava flows, cinder cones, and volcanic calderas.

The classification of landforms is important in understanding the processes that shape the Earth's surface and in predicting the impact of natural disasters such as earthquakes, landslides, and floods. It is also useful in planning and managing land use, as different landforms have different characteristics and vulnerabilities.

SUMMARY

Geomorphology is a field of study that focuses on the processes that shape the Earth's surface, including landforms and landscapes. The field emerged in the early 20th century and has since become an interdisciplinary field that combines aspects of geology, geography, physics, and ecology.

Geomorphologists use a range of methods and techniques, including field observations, laboratory experiments, and computer modelling, to study landforms and landscapes. They also use a variety of tools, such as GPS, LIDAR, and satellite imagery, to collect data and analyze landscapes.

Application of Geomorphology

The study of geomorphology has many applications, including in natural resource management, land-use planning, and hazard mitigation. Geomorphology can help predict the location and magnitude of natural hazards, such as landslides and floods, allowing for the development of effective mitigation strategies. Geomorphology can also inform land-use planning decisions by identifying areas that are prone to erosion or other forms of landscape change.

Geomorphology also has important practical applications, in environmental planning and landscape design. Geomorphologists work with a range of stakeholders, including policymakers, engineers, and the general public, to develop strategies for managing and protecting the Earth's surface.

GLOSSARY

- **Anthropogenic:** Refers to human activities or impacts on the environment, often used to describe the human influence on geomorphic processes and landforms.

- **Applied geomorphology:** The application of geomorphic knowledge and methods to address practical problems, such as natural hazard management, environmental planning, or resource management.
- **Dynamics:** The study of the processes that shape the Earth's surface and the interactions between those processes.
- **Evolution:** The process of change over time, often used to describe the development of landscapes and landforms.
- **Geomorphic systems:** The Earth's surface and the interconnected processes that shape it, including tectonics, weathering, erosion, sediment transport, and landscape evolution.
- **Geomorphic thresholds:** The points at which a geomorphic system undergoes a significant change in behaviour or state, often as a result of a feedback mechanism.
- **Geomorphological mapping:** The production of maps that depict the distribution and characteristics of landforms, often using field observations or remote sensing data.
- **Geomorphology:** The study of the Earth's surface and the processes that shape it.
- **Landform evolution:** The study of how landforms change over time due to geomorphic processes and external drivers, such as climate change or human activities.
- **Landforms:** The physical features that make up the Earth's surface, such as mountains, valleys, and coastlines.
- **Morphology:** The study of landforms and their characteristics, such as shape, size, and spatial distribution.
- **Paleogeomorphology:** The study of ancient landforms and geomorphic processes, often using methods such as sediment analysis or paleoclimate reconstruction.
- **Processes:** The physical and chemical forces that shape the Earth's surface, including erosion, weathering, tectonics, and sediment transport.
- **Spatial analysis:** The study of the spatial distribution of landforms, processes, and environmental variables, often using geographic information systems (GIS) or remote sensing.
- **Sustainability:** The ability of a system to persist over time without degrading the natural resources or ecological functions that support it.
- **Temporal analysis:** The study of how geomorphic processes and landforms change over time, often using methods such as dendrochronology, radiocarbon dating, or stratigraphy.

Threshold: The point at which a system undergoes a significant change in behaviour or state, often as a result of a feedback mechanism.

LANDSCAPE VS. LANDFORM: WHAT'S THE DIFFERENCE?

Landscape refers to the visible features of an area of land, including its physical elements, human influence, and aesthetic aspects, while landform is a specific natural feature on the Earth's surface, such as

mountains, valleys, or plains.

A landscape encompasses the overall appearance and composition of a specific area, integrating both natural and human-made elements. It includes mountains, rivers, buildings, roads, and vegetation, forming a cohesive visual scene. A landform, in contrast, is a single natural feature on the Earth's surface, shaped by geological processes such as erosion, weathering, and tectonic activity. Examples of landforms include mountains, hills, plateaus, valleys, and plains.

While landscapes represent the broad, integrated view of an area, incorporating multiple elements and their interactions, landforms focus on individual physical features. Landscapes provide a holistic perspective on an area's natural and cultural environment, whereas landforms offer a detailed examination of specific geological features.

Landscapes can be altered by human activities like agriculture, urban development, and conservation efforts, reflecting cultural and historical contexts. Landforms, however, are primarily shaped by natural forces, although human actions can influence their formation and stability.

In terms of appreciation, landscapes are often valued for their beauty and recreational opportunities, influencing tourism and local economies. Landforms are crucial for scientific study, helping geologists and geographers understand Earth's processes and history.

Landforms are specific shapes and structures within the earth's topography, such as hills or deltas, landscapes represent the composite of various elements, including these landforms, creating a distinct visual and environmental character for a region. Landscapes can be natural, like a forested area with rivers, or modified by human activities, such as a cityscape with parks and buildings.

The study of landforms, or geomorphology, focuses on understanding the processes that shape the earth's surface. In contrast, landscape studies, or landscape ecology, consider the interactions between physical, biological, and cultural components within an area. This includes how landforms influence the distribution of plants and animals, as well as human land use.

GEOMORPHIC PROCESSES

A Geomorphic Process is a force that is applied to the components of the earth and brings changes in the configuration of the earth. Geomorphic Processes are the internal and external factors that stress earth materials, react and modify how the earth's surface is shaped.

Geomorphic agents are natural forces that move and deposit earth materials. Examples include running water, glaciers, wind, waves, ocean currents, and groundwater. These movements happen due to differences in height or pressure.

A moving medium that gathers, moves, and deposits earth materials are referred to as a geomorphic agent.

Geomorphic Process Meaning and Types

Due to physical forces and chemical reactions on materials already present on Earth, the geomorphic process involves bringing about changes in the shape of the planet’s surface. There are two main geomorphic processes. Endogenic Forces and Exogenic Forces.

Geomorphic Processes Exogenic Forces

Exogenic forces originate from outside the Earth's interior, mainly from its atmosphere, and are mostly powered by the Sun. Exogenic forces mainly wear down mountains and fill up low areas. They help shape the Earth's surface by breaking down rocks and soil, moving sediment, and changing the landscape. The processes caused by exogenic forces include weathering (breaking down materials), erosion (removing materials), transportation (carrying materials), and deposition (dropping materials). Together, these processes create different landforms like valleys, deltas, and beaches. Some examples of exogenic forces:

1. Weathering

Weathering is the process that breaks down and wears away rocks on the ground. This happens because of weather factors like rain, changes in temperature, and frost. These forces cause the rocks to break apart and become smaller over time.

2. Erosion

Soil erosion is the loosening and displacement of topsoil from the land due to the action of agents like wind and water.

3. Transportation

Transporting eroded debris means moving broken-down materials to new places. In geology, deposition is when these sediments, soil, and rocks are added to a landform. Soil compaction happens when soil particles are pressed together, reducing the space between them.

4. Deposition

On gentle slopes, erosion slows down, and the materials being carried start to settle. This is how erosion leads to deposition. Coarser materials settle first, then the finer ones. Erosional forces like running water, wind, glaciers, waves, and groundwater also help deposit these materials, filling up low areas.

Geomorphic Processes Endogenic Forces

Endogenetic forces come from deep inside the Earth. They are caused by movement in the mantle, the Earth's rotation, and heat from radioactive decay. These forces create major changes in the Earth's landscape, like forming mountains, breaking apart continents, and causing volcanic eruptions and earthquakes. Important processes linked to endogenetic forces include tectonics (movement of Earth's plates), volcanic activity, and seismic events (earthquakes). These can uplift landforms, create new land, and change the Earth's crust. Some examples of Endogenic Forces:

1. Volcanism

Volcanism is the process of molten rock (magma) erupting onto the surface of the Earth or another planet with a solid surface. Lava and volcanic gases are released via an opening in the surface known as a vent.

2. Diastrophism

Also called tectonism, large-scale deformation of Earth's crust by natural processes, which leads to the formation of continents and ocean basins, mountain systems, plateaus, rift valleys, and other features by mechanisms such as lithospheric plate movement (that is, plate tectonics), volcanic loading etc.

3. Metamorphism

It is a process by which the recrystallisation and reorganisation of minerals occur within a rock. This occurs due to pressure, volume and temperature.

4. Earthquake

The natural shaking of the Earth is known as an earthquake. This occurrence is the result of energy being released, which creates waves that go in all directions. The epicentre of an earthquake is a location under the Earth's surface.

5. Landslides

A landslide happens when soil, rocks, or debris slide down a slope due to gravity. This can be caused by factors like the steepness of the ground and is usually triggered by heavy rain or earthquakes.

6. Faulting and Folding:

Faulting occurs when the Earth's crust breaks and the rocks slide past each other, often moving in opposite directions. Folding creates fold mountains when the Earth's crust bends instead of breaking

TOPIC: FLUVIAL PROCESSES AND LANDFORMS

The term 'fluvial' (from Latin *fluvius*, river) refers to the work of rivers but in the context of landscape development it includes the work of both overland flow and stream flow.

Thus, landforms shaped by running water are called fluvial landforms. They constitute the largest proportion of the environment of terrestrial life and the major areas of food production, as almost all the land under crop cultivation as well as grazing has been shaped by fluvial processes.

Running water is a dynamic geomorphic agent. Flow of water has a force/energy and velocity to generate power. There are many natural and dynamic processes happening along a river. For instance, flowing water has the ability to dissolve the soluble mineral substances available on its way. The processes enacted by streams are called as fluvial processes. Fluvial processes entail the erosion, transportation, and deposition of earth materials by running water. Fluvial processes and fluvial landforms dominate land surfaces the world over, as opposed to the limited effects of glacial, coastal, and wind processes.

Streams are flowing water bodies. The flow of water originates after every rain, glacial melt or outpouring of underground water to the surface. Rain water falling on all the slopes of a land gets collected and start flowing on the land as overland flow/ surface run off. They merge together along the converging slopes and run as a main stream. The main stream, normally contains the cumulative volume of flow. The water flows out through a single outlet called river mouth. The entire area encompassing the catchment zone up to the river mouth, contributing to this cumulative flow, is known as a river basin. It is also called as a drainage basin.

River Valley development

Every stream has its own valley. A valley is a depression/trough on the earth surface drained by, and whose form is changed by, water under the attractive force of gravity, between two adjacent uplands.

Valley development is a unique hydraulic process. It happens due to three concomitant/ related processes as

a) Valley deepening

b) Valley widening and

c) Valley lengthening.

Valley Deepening

Valley deepening is effected by

a) Hydraulic action

b) abrasion of the floor of the valley

c) Pothole drilling along the valley floor and at the base of waterfalls

d) Corrosion

e) Weathering of the stream bed.

Valley Widening

Valley widening is accomplished by

a) Lateral erosion or planation by the stream in a valley

b) Hydraulic action

c) Corrosion.

e) Gullying on valley sides.

f) Weathering and mass-wasting

g) Role of incoming tributaries.

Valley Lengthening

Valley lengthening may take place due to:

a) Extension by headward erosion

b) Increase in size of their meanders

c) Extension at the confluence due to subsidence

RIVER PROCESSES

The processes of erosion, transportation and deposition play a huge role in shaping river valley landscapes.

EROSION

This is the wearing away of rocks and other materials along the bed and banks of the river valley. There are 4 specific processes by which rivers erode their valleys:

Hydraulic action erosion: This occurs when the force of the water flowing in a river wears away the bed and banks of the river. This can cause the river to widen or deepen over time. Hydraulic action erosion occurs when rushing water puts pressure on rocks and other objects in its path, causing them to break apart and be transported away by the current. The power of the water can dislodge the particles, which can then be taken downstream by the river. The kinetic energy of the water drives the hydraulic action erosion process, which rises as the flow speed increases.

- The process of hydraulic action erosion can create a range of features in river landscapes, including waterfalls, rapids, and canyons and potholes
- **Abrasion -** this is where small boulders and stones being transported by the river may scratch and scrape the river banks and bed. Stones which have recently fallen into the river have angular, sharp, jagged edges; and are particularly good for abrasion. Ongoing abrasion is responsible for both vertical erosion and lateral erosion.

  This process can create features such as potholes and grooves in the river bed, as well as smooth rock surfaces along the river banks.

  The process of abrasion erosion is driven by the kinetic energy of the fluid, which causes the particles carried by the fluid to grind the surface being eroded.

- **Attrition -** this is where stones being carried along by the river will collide with each other, and the river banks and bed. As they do this their jagged edges will be knocked off or smoothed down. Some stones may smash into several smaller ones, which will be eroded further into smooth and more rounded pebbles.

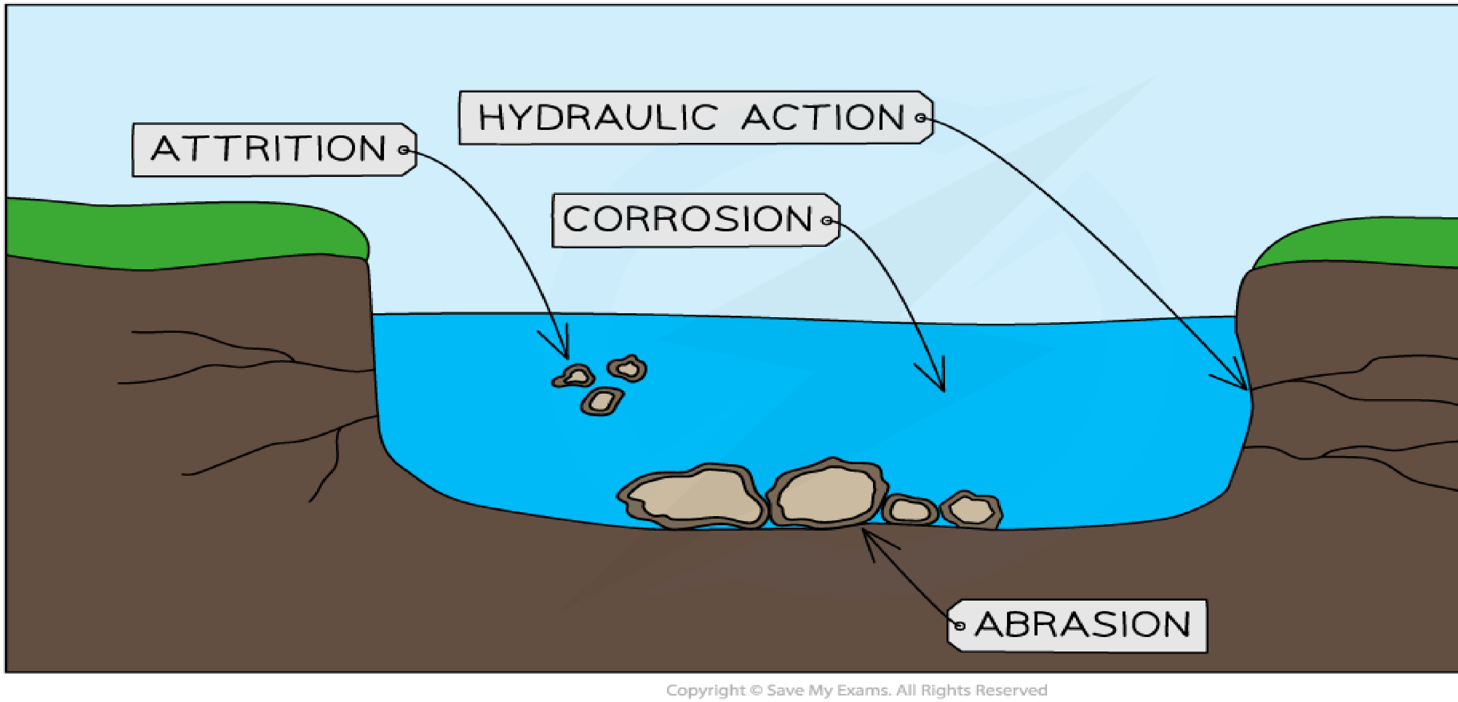
  Attrition erosion is particularly effective when the particles being carried by the fluid are hard and angular, as they are more likely to collide with each other and break down into smaller fragments. The process of attrition erosion can result in the creation of sediment with a range of different sizes and shapes, depending on the composition and properties of the particles being eroded.

- **Solution or corrosion -** this is where carbon dioxide in the atmosphere dissolves in the river to form a weak acid. As the water flows through the channel, it reacts with the rocks on the river banks and bed. This chemical reaction will cause the rocks to dissolve, particularly chalk and limestone.

  This process can create features such as underground caves and sinkholes.

  Corrosion erosion can be caused by a range of factors, including the presence of minerals in the rock or soil that are susceptible to chemical reactions, as well as changes in the acidity or salinity of the fluid in contact with the material.

The process of corrosion erosion is particularly effective in environments where the fluid is highly acidic or alkaline, as these conditions can increase the rate of chemical reactions between the fluid and the material.



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FORMS OF RIVER EROSION

- **Vertical erosion -** this is downwards erosion that makes the river bed deeper. It is usually caused by hydraulic action and occurs in the upper course of the river, causing steep-sided v-shaped valleys
- **Lateral erosion -** this is sideways erosion, wearing the river bank away to make the channel much

wider. It occurs in the middle and lower courses of the river and leads to wide flat valleys

- **Headward erosion** it is a process by which a river increases its upstream length. This is achieved by a river cutting back at its source

TRANSPORTATION PROCESS

River transportation refers to the movement of sediments by the flow of water in a river valley. This process plays an important role in shaping the morphology of rivers and their surrounding landscapes. The transportation of sediments by rivers is driven by a combination of factors, including the *flow velocity of the water, the size and characteristics of the sediment particles*, and *the gradient and roughness of the riverbed*. As water flows over the riverbed, it exerts a force on the sediment particles, which can cause them to become dislodged and transported downstream.

The transportation of sediments by rivers has important environmental and economic implications. For example, it can affect water quality by introducing sediments and other pollutants into the river system and can impact the stability and safety of river ecosystems and infrastructure such as bridges and dams. In addition, river transportation work can play a key role in the formation and maintenance of aquatic habitats and can have significant impacts on the movement of nutrients and organic matter within river ecosystems.

Mechanisms of river transportation

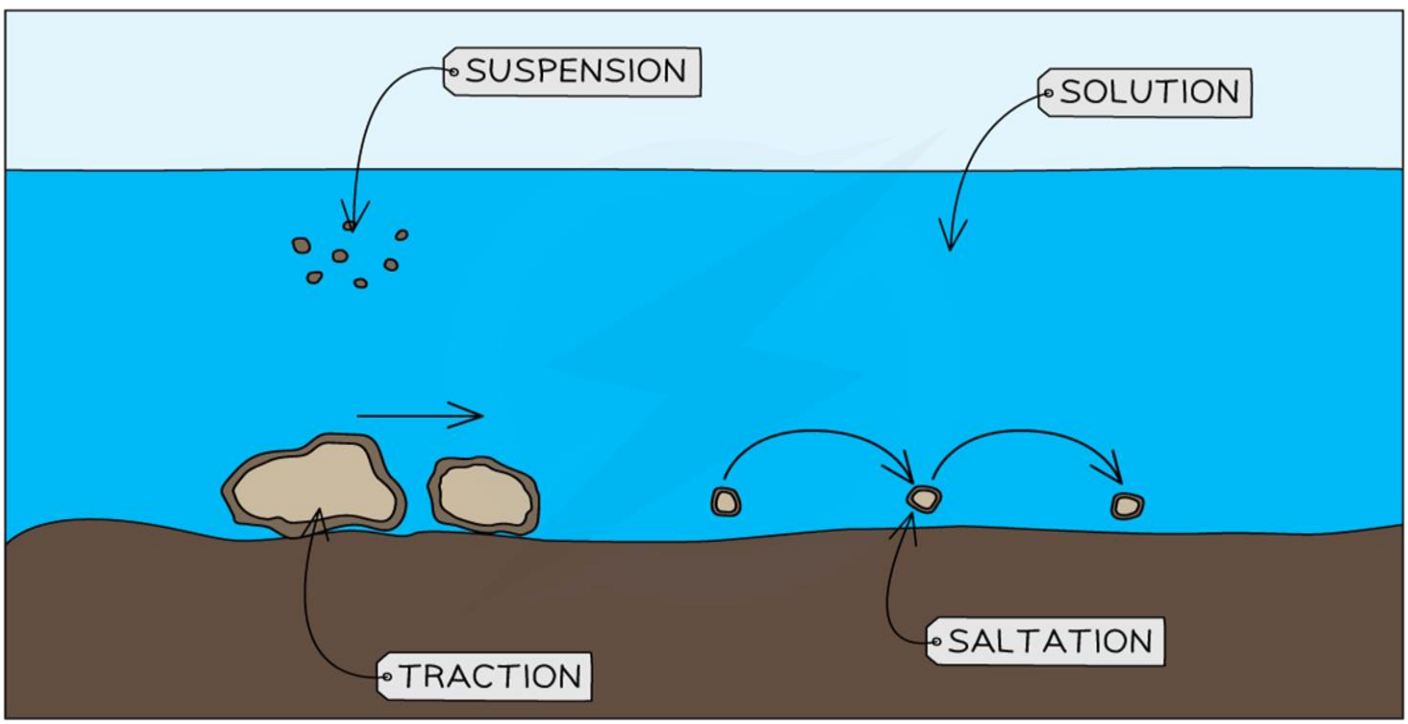
River Transportation by traction: refers to the movement of sediments along the bed of a river as a result of the force of flowing water. In this process sediment particles rolling or sliding along the riverbed. The amount of sediment transported by traction depends on factors such as flow velocity, sediment size and shape, and riverbed roughness.

River Transportation by Saltation: refers to the movement of sediment in a river by bouncing along the riverbed. This process occurs when sediment particles are lifted from the riverbed by the force of flowing water and then fall back downstream, causing other particles to be lifted and carried along in a chain reaction. Saltation is most commonly observed in rivers with moderate flow velocities and is an important process in the transportation of sand-sized sediment.

River Transportation by Suspension: refers to the movement of sediments in a river by being carried along in the water column. This process occurs when the force of flowing water is strong enough to suspend sediment particles in the water, allowing them to be transported downstream. Suspension is most commonly observed in rivers with high flow velocities and fine sediment particles such as silt and clay.

River Transportation by Solution: refers to the movement of soluble sediments in a river by being dissolved in the water. This process occurs when water with dissolved carbon dioxide, comes into contact with rocks or sediments containing minerals that can dissolve. The dissolved minerals are then carried downstream in the water column. This process is most commonly observed in limestone or other carbonate-rich rivers. The amount of sediment that can be transported by solution depends on factors such as the water chemistry, the mineral content of the sediment, and the river flow rate.

Flotation: It refers to the transportation of light and insoluble materials on the surface of a river.



DEPOSITION

- This is the process of a river dropping its transported load. The bigger the particles being transported the greater the velocity that is needed to keep the load moving, so once the river starts to lose energy the largest boulders are the first to be dropped onto the river bed. This is why you see large boulders in the river bed in the middle course of the river, close to the source, but fine silt in the lower course, closer to the mouth of the river.

- When a fast-flowing hill stream emerges from the mountains and reaches a relatively level surface, there is deposition of a huge amount of stony debris, sand and silt, and alluvial cones and fans are formed here.
- In times of flooding when the river water overtops its banks and inundates/submerge the neighbouring areas, there is deposition of sand and silt outside the confines of its channel – flood plain
- Maximum deposition takes place at the mouth.
- The largest amount of given size of debris that a river can move in traction as bed load is called its 'capacity'
- The largest diameter of particles that it can carry as bed load measures its 'competence'
- Both the capacity and competence of a river increase with increase in volume and velocity.

Causes of depositional work

The depositional work of a river is a result of several factors that influence the transport and deposition of sediments.

Sediment supply: The amount and type of sediment available for transport is a critical factor that influences the depositional work of a river. The sediment supply is affected by factors such as climate, geology, and human activities. For example, heavy rainfall and erosion from deforested areas can increase the sediment supply, leading to increased deposition.

Water velocity: When the water velocity decreases, it loses the energy to transport materials. Sediments settle out of the water column and are deposited. This often occurs when a river enters a larger body of water, such as a lake or an ocean, or when the river flows over a relatively flat area, such as a floodplain.

River gradient: The gradient of a river, or the slope of the riverbed, also affects the depositional work of the river. When the gradient of the river decreases, the velocity of the water also decreases, allowing sediment to settle out and be deposited.

Nature of the riverbed: The nature of the riverbed, including the presence of vegetation or other obstacles, can also influence the deposition of sediment. For example, if the riverbed is covered in vegetation, such as trees and shrubs, the roots can stabilize the sediment and promote deposition.

Base level

In Geomorphology, the term "river base level" refers to the lowest elevation point to which a river can erode its bed. There are two types of base levels: ultimate base level and local base level.

The ultimate base level is the lowest point that a river can erode its bed to, and it is typically the level of the sea or an inland lake. Once a river reaches its ultimate base level, it can no longer erode its bed any further. This means that the river's gradient will decrease, and its speed will slow down, causing sediment to be deposited on the riverbed.

Local base level, on the other hand, is a temporary or local constraint on a river's ability to erode. This can be caused by geological structures, such as dams, waterfalls, or resistant rock formations. When a river encounters a local base level, it will erode its bed upstream until it reaches the base level, and then deposit sediment downstream. Over time, the river will adjust its channel shape and gradient to accommodate the local base level.

The concept of base level is important because it influences how a river erodes and shapes the landscape. A river's gradient, or slope, is determined by the difference in elevation between its source and its base level. If the base level is low, the river will have a steep gradient and will erode its bed quickly, creating a deep V-shaped valley. If the base level is high, the river will have a gentle gradient and will erode its bed more slowly, creating a wider, U-shaped valley.

In addition to influencing erosion, the base level also plays a role in sediment transport and deposition. When a river encounters a local base level, sediment will be deposited downstream, creating features such as alluvial fans. When a river reaches its ultimate base level, sediment will be deposited on the riverbed, creating features such as floodplains or terraces.

Fluvial Erosional Landforms

Most of the erosional landforms associated with running water are made by youthful rivers vigorously flowing over steep gradients. With time, stream channels over steep gradients turn gentler due to continued erosion, and as a consequence, lose their velocity, facilitating active deposition.

River Valleys

The extended depression on the ground through which a stream flows throughout its course is called a river valley.

At different stages of the erosional cycle, the valley acquires different profiles

Valleys start as small and narrow rills

The rills gradually develop into long and wide gullies

The gullies further deepen, widen and lengthen to give rise to valleys.

Depending upon dimensions, shape, types and structure of rocks in which they are formed, many types of valleys like the V-shaped valley, gorge, canyon, etc. can be recognized.

V-shaped Valleys

V-shaped valleys: **V-shaped valleys** are made by the rivers in the youthful stage by vertical erosion. Due to the steep slope and large volume of water, the river cuts its bed vertically forming a narrow and deep river valley. These are the most common type of valleys, and are created by the erosive power of rivers. Over time, rivers can erode the surrounding rock and soil, creating a steep-sided channel. V-shaped valleys are often characterized by waterfalls, rapids, and meandering channels. Examples of v-shaped valleys include Yosemite Valley in California, USA, and the Valleys of the Seven Castles in Bulgaria. V-shaped valleys are important because they provide a window into the geological history of an area. By studying the rocks and sediments in the sides and bottom of a V-shaped valley, geologists can learn about the processes that formed the valley and the history of the landscape.

Gorge

A gorge is a narrow, deep valley with steep sides that is typically formed by the vertical erosion of rock by a river or stream. The process of gorge formation involves the gradual erosion of the rock and soil in an area by a river or stream, which causes the sides of the valley to become steeper and the channel to become deeper over time. Gorges are important geological features that provide insight into the history of the landscape and the processes that shaped it.

Canyon

A canyon is a deep, narrow valley with steep sides that is typically formed by the erosion of rock by a river or stream. The formation of a canyon begins with the gradual erosion of the surface of the earth by water. Over time, a river or stream may begin to cut a path through the eroded rock, gradually deepening and widening the valley. As the river or stream continues to erode the rock, the sides of the valley become steeper, and the channel becomes deeper.

A gorge is almost always steeper and narrower than a canyon. A canyon is a variant/ version of the gorge.

Waterfalls and Rapids

- When rivers plunge down in a sudden fall of some height, they are called waterfalls. Waterfalls are formed when a river or stream flows over a cliff or a steep slope, causing the water to fall freely and create a spectacular display of cascading water.
- Their great force usually wears out a plunge pool beneath
- Waterfalls are formed because of several factors like the relative resistance of rocks lying across the river, the relative difference in topographic reliefs e.g. in Plateau etc. The basic process of waterfall formation involves the gradual erosion of rock and soil by the flowing water of a river or stream. Over time, the water erodes the softer rocks, leaving behind harder rocks and creating a cliff or a steep slope. As the water flows over the cliff or steep slope, it falls freely and creates a waterfall.
- The speed and volume of the water flowing over a waterfall depend on several factors, including the height of the waterfall, the volume of water in the river, and the shape and angle of the rock face over which the water falls.
- One of the most famous waterfalls in the world is Niagara Falls, located on the Niagara River on the border of the United States and Canada. Niagara Falls is formed by the erosion of soft rocks such as shale and sandstone, which have been worn away by the water flowing over the falls for millions of years.

- A rapid is similarly formed due to an abrupt change in gradient of a river due to variation in resistance of hard and soft rocks traversed by a river
- Waterfalls are also transitory like any other landform and will recede gradually and

bring the floor of the valley above waterfalls to the level below.

Causes/conditions for formation of waterfalls

- A sharp change in the resistance of rocks i.e. from a hard to soft rock. The hydraulic action of water massively erodes away softer rocks ahead of the hard rocks thus causing a change in gradient which forms a waterfall. Examples are Bujagali and Owen falls (Nalubale) or when there is an uplift of the land.
- Faulting across the river bed may lead to vertical displacement of rocks along the fault lines. In this case a river flows from high to a low elevation thus a waterfall develops. Murchison fall along R. Nile was formed in this way.
- It is also formed where a lava barrier or landslide forms across a river where it may initially form a lake. Then a water fall is likely to form at the over spill from the lake where the river drops over the edge of the barrier e.g. Lily falls in Madagascar is formed this way.
- Waterfalls may also be formed at the point where the river enters the sea at cliff line. A fall may develop near the mouth of a river if wave erosion cuts back the cliff face or where the sea level has fallen. Examples occur in Cameroon Lobe river where Lobe falls were formed when it plunges over directly into the sea.

Potholes and Plunge Pools

- Potholes are more or less circular depressions formed over the rocky beds of hill-streams, because of stream erosion aided by the abrasion of rock fragments.
- Once a small and shallow depression forms, pebbles and boulders get collected in those depressions and get rotated by flowing water and consequently enlarging the depression
- Eventually, such depressions are joined leading to deepening of the stream valley.
- At the foot of waterfalls also, large hollows, quite deep and wide, form because of the sheer impact of water and abrasion by rotating boulders. These deep and large holes at the base of waterfalls are referred to as plunge pools. The formation of water plunge pools begins with the hydraulic action of the falling water, which creates eddies and swirls that erode the softer rock at the base of the waterfall. Over time, the erosive action of the water causes these depressions to deepen and widen, creating potholes that can be several meters deep and wide.
- These pools also help in the deepening of valleys

FLUVIAL DEPOSITIONAL LANDFORMS

- Rocks and cliffs are continually weathered and eroded in the youthful stage or upper course of the river.
- The river moving downstream on a level plain brings down a heavy load of sediments from the upper course.
- The decrease in stream velocity in the lower course of the river reduces the transporting power of the streams which leads to deposition of this sediment load.
- Coarser materials are dropped first and finer silt is carried down towards the mouth of the river
- This depositional process leads to the formation of various depositional landforms through fluvial action such as Delta, Levees and Flood Plain etc.

Deltas

- Deltas are fan-shaped alluvial areas, resembling an alluvial fan
- This alluvial tract is, in fact, a seaward extension of the floodplain
- The load carried by the rivers is dumped and spread into the mouth of the river
- . Further, this load spreads and piles up as a low cone
- Unlike in alluvial fans, the deposits making up deltas are very well sorted with clear stratification. The coarsest sediments are deposited first and the finer sediments are carried further towards the sea.
- Deltas extend sideways and seaward at an amazing rate
- As the delta grows, the river distributaries continue to increase in length
- Some deltas are extremely large. For example, the Ganges delta in West Bengal state, and Bangladesh. An area of 355km wide. It is covered by a network of streams forming the mouths of Ganges and Brahmaputra rivers. It is the largest delta in the world and probably the most fertile place on earth.

Deltas form under the following conditions

- Presence of large amounts of sediments within a river such as sand, gravel and silt
- Reduction in the gradient and speed of the river thus reduced competence
- Presence off a sheltered coast such that deposits laid are not washed a way
- Low tide currents such that the deposition is not carried away.
- Absence of obstruction or barrier like dykes at the mouth of the river.
- Presence of a shallow adjoining area/continental shelf along the sea where deposits are laid to accumulate.

Types of Deltas

- There are great variations in size, shape, growth and importance of Deltas. A great number of factors influence the eventual formation of deltas such as depth of the river, sedimentation, sea-bed, character of tides, waves and currents etc. owing to these factors several types of deltas can be found.

- **Bird’s foot delta** It s a kind of delta featuring long, stretching distributary channels, which branch outwards resembling the foot of a bird. Deltas that are less subjected to wave or tidal action culminate to a bird s foot delta. Example the Mississippi River has a bird s foot delta extending into the Gulf of Mexico
- **Arcuate delta** Arcuate is the most common type of delta. This is a fan-shaped delta. It s a curved or bowed delta with the convex margin facing the sea. Arcuate deltas have a smooth coastline due to the action of the waves and the way they are formed. Examples - The Nile, Ganges and Mekong river deltas
- **Cuspate delta** A few rivers have tooth-like projections at their mouth, known as the cuspate delta. Cuspate deltas are formed where the river flows into a stable water body (sea or ocean). The sediments brought down by the rivers collide with the waves. As a result, Sediments are spread evenly on either side of its channel. Example Ebro river delta in Spain

Meanders

River Meander: A river meander is a bend or curve in a river channel. In large flood/ **alluvial plains**, rivers rarely flow in straight courses. Loop-like channel patterns called meanders develop over flood and delta plains

They are formed as a result of the erosive and depositional works of rivers. Formation of meander is closely related to the variations in stream velocity. Meanders form in the middle and lower courses of a river where stream velocity is low causing the erosive power to be reduced and the depositional work to become more active. As a river flows, the Coriolis force deflects the water causing slightly more erosion on that side of the riverbank. River velocity is faster near the outer bank and slower near the inner bank. As a result, sediments are eroded from the outer banks and deposited on the inner banks which causes them to become more stable and resistant to erosion. The erosive power of water wears away the outer banks of a river bend and deposits sediment on the inner banks. Over time, this process causes the river to migrate back and forth across its floodplain (lateral migration), creating a sinuous, meandering path.

Over time, the meandering path of a river can become quite complex, with multiple bends and curves in the channel. Meandering rivers can also create features such as oxbow lakes, point bars, and cut banks, which are all shaped by the erosive and depositional forces of the river.

- The formation of meanders is influenced by a variety of factors, including the shape of the valley floor, velocity of the river, and the sediment load of the river.

Note: Baer's law describes the asymmetric erosion pattern in rivers due to earth's rotation

Alluvial Fans

- An alluvial fan is a cone-shaped depositional landform built up by streams, heavy with sediment load.
- Alluvial fans are formed when streams flowing from mountains break into foot slope plains of low gradient.
- Normally very coarse load is carried by streams flowing over mountain slopes. This load gets dumped as it becomes too heavy to be carried over gentler gradients by the streams
- Furthermore, this load spreads as a broad low to a high cone-shaped deposit called an alluvial fan.
- Alluvial fans in humid areas show normally low cones with a gentle slope and they appear as high cones with a steep slope in arid and semi-arid climates.

Alluvial fan

Floodplains

- Floodplain is a major landform of river deposition.
- Rivers in the lower course carry large quantities of sediments
- Large sized materials are deposited first when stream channel breaks into a gentle slope.
- Sand, silt and clay and other fine sized sediments are carried over gentler channels by relatively slow- moving waters
- During annual or sporadic floods, these materials are spread over the low-lying adjacent areas. A layer of sediments is thus deposited during each flood, gradually building up a floodplain
- In plains, channels shift laterally and change their courses occasionally leaving cut-off courses which get filled up gradually by relatively coarse deposits.
- The flood deposits of spilt waters carry relatively finer materials like silt and clay.

Natural Levees

- This is an important landform associated with floodplains.
- They are found along the banks of large rivers.
- They are low, linear and parallel ridges of coarse deposits along the banks of rivers on both sides due to deposition action of the stream, appearing as natural embankments.
- At the time of flooding, the water is spilt over the bank. As the speed of flow of the water comes down, large sized sediments with high specific gravity are dumped along the bank as ridges.
- They are high nearer the banks and slope gently away from the river.
- Generally, the levee deposits are coarser
- When rivers shift laterally, a series of natural levees can form.
- Artificial embankments are formed on the levees to minimize the risk of the floods.
- But sudden bursts in the banks due to the pressure of water can cause disastrous floods.
- An example of such flood can be seen in Hwang Ho river which is also called China s sorrow.

Point Bars

- Point Bar is also associated with floodplain
- Point bars are also known as meander bars.
- A point bar is a crescent shaped deposit of sediments that forms on the inside bend of a meander, where the water flow slows down, causing sediments to settle and accumulate. It consists of sand and gravel
- Point bars form inside the river bends where sediments eroded on the outer bank are deposited.

Oxbow Lakes

- An ox-bow lake is a crescent shaped free-standing body of water that forms when a river's meander is cut off. It happens when the river finds a shorter route, leaving behind a lake. It forms in gentle, low-lying plains in the lower course of rivers. Formation of ox-bow lakes begins with the meandering of a river due to erosion and deposition. Overtime the meander becomes a big loop. Through erosion, the river cuts a new channel through the narrow end of the meander, creating a short cut. The abandoned meander becomes an ox bow lake. Ox-bow lakes are still waters without inlets or outlets
- Through subsequent floods that may silt up the lake, oxbow lakes ar
- e converted into swamps in due course of time. It becomes marshy and eventually dries up as their water evaporates.

Braided Channels

- A braided channel consists of a network of river channels divided into multiple threads and separated by small and often temporary islands called **eyots** .
- Braided channels are commonly found where water velocity is low and the river is heavy with sediment load. Formation of braided channels begins with deposition of sediments as a river flows over relatively flat landscape. The deposits obstruct the water flow, forcing the river to split into multiple smaller channels around the alluvial bars. Overtime there develops a complex network of interwoven channels called braided channels.

TOPIC: AEOLIAN PROCESSES AND LANDFORMS

Objectives

After attending this lesson, the user would be able to comprehend the nature of wind as a geological agent and the role played by it in creating various landforms called as Aeolian landforms. This lesson highlights all the features of erosion, transportation and deposition that are made by wind. Wind is a powerful geological agent.

Introduction:

Earth is a dynamic evolving system. Many geological processes are active on the surface of the earth. They are called as exogenous processes. The notable surface geological processes are weathering, mass- wasting, erosion, transportation and deposition. These processes are capable of creating both constructional and destructional landforms. If any of these earth's processes are done by a natural system on the surface of the earth, then it is called as a geological agent.

Notable geological agents

The geological agents are capable of eroding, transporting and depositing the earth's surface materials from one place to the other. The prominent agents are:

a) Running Water
b) Glaciers
c) Wind
d) Waves & Currents
e) Ground water.

These are also responsible for creating numerous landforms all over the surface.

Work of wind

The work of wind is expressed in different climatic zones but is greatest in dry climatic zones. The dry climatic zones are characterized by

a) Sharp diurnal temperature variations
b) Low precipitation(200-250mm per year)
c) Excess of evaporation over precipitation (5 to 15 times)

d) Sparse vegetation or complete lack of it
e) Frequent winds of great force
f) Presence of unconsolidated, very loose, easily erodible surface materials.
g) dust storms,

Such conditions are specific to deserts. The work of wind is more pronounced in deserts and dry zones.

The deserts and semi-deserts occupy about 20 percent of the surface of continents. Especially great areas are occupied by deserts in Asia, Africa, and Australia, less in Europe, North and South America. The great “sand seas” that completely cover large areas of North Africa’s Sahara Desert, Saudi Arabia, and central Australia are the most spectacular examples of wind activity on Earth. Winds are the most widespread geomorphic agents in the desert environments, arid and semi-arid regions.

Wind as geological agent

Wind has the ability to shape the surface of the Earth. Wind is one of the greatest agents of land erosion and transportation. The action of wind is very significant in arid and semi-arid regions. Due to profound wetness, wind cannot act in humid regions. Wind is capable of eroding, transporting and depositing the surface materials, in drylands. The landforms created by wind action are called ***Aeolian landforms***. The word “Aeolian” is derived from the Greek word “Aeolus”, meaning, the god of the winds. Aeolian landforms are features of the Earth's surface produced by either the erosive or constructive action of the wind. Winds are effective agents in regions with sparse vegetation and a large supply of unconsolidated sediments. Arid regions have little or no soil moisture to hold such sediments, rock and mineral fragments.

Wind has the ability and force

The work of wind comprises the processes of deflation, corrosion or Abrasion, Saltation and accumulation or deposition. The velocity of wind is determined by the movement of air from an area of high pressure to an area of low pressure. The velocity will be highest when there is great difference between the high pressure and the low-pressure region. How close the two pressure regions are, will also affect the speed of the wind.

WIND EROSION

The power of wind to erode surface particles is controlled primarily by two factors: *wind velocity* and *surface roughness*. Erosive force increases exponentially with increases in wind velocity. For example, a velocity increase from 2 to 4 meters per second causes an eight-fold increase in erosive capacity, while an increase in wind speed from 2 to 10 meters per second generates a 125-fold increase in its erosional force.

Consequently, fast winds are capable of causing much more erosion than slow winds. At ground level, the roughness of the surface plays an important role in controlling the nature of wind erosion. Boulders, trees, buildings, shrubs, and even small plants like grass and herbs can increase the frictional roughness of the surface and reduce wind velocity. Vegetation can also reduce the erosional effects of wind by binding the soil particles to the roots of plants.

Factors affecting the extent of wind erosion

1. Aridity of climate.
2. Soil texture.
3. Soil structure.
4. State of the soil surface.
5. Vegetation.
6. Soil moisture.

Height of action

Wind erosion generally takes place above the ground and thus wind velocity plays a major role in determining the degree of Aeolian erosion.

Wind erosion is effective only up to 180cm above the ground surface. Unlike rivers and glaciers, winds erode the rocks from all sides because of their variable directions. Deflation and transportation develop parallel with accumulation, giving rise to specific relief forms and types of Aeolian continental deposits and landforms.

WIND EROSION PROCESSES

Deflation

Removing, lifting and blowing away of surface materials by winds

Deflation – wind blows loose soil away:

• leaves coarser pebbles & cobbles, called Desert Pavement

• Continued deflation removes most of loose materials and thus depressions or hollows are formed called Deflation

Hollow or Blowouts.

Deflation is the lifting and removal of fine, dry particles of silt, soil, rocks and sand by the blowing wind.

The blowing out and scattering of rock and sand particles by wind is called as deflation. This term is originated from the Latin word “Deflare” means “blow away”. The surface of any desert is covered by diverse fragments of rocks, sands, soils and dusts. In such arid zones, moving air can blow-out the sand and rock particles. First, the blowing wind clears the sandy and fine-grained materials, and leaves the coarser fragments behind. These form the rocky deserts. Such rocks are again weathered or fragmented and then, once again, deflation becomes active.

Deflation lowers the land surface due to removal of fine-grained particles by the wind. Deflation concentrates the coarser grained particles at the surface, eventually resulting in a surface composed only of the coarser grained fragments that cannot be transported by the wind. Such a surface is called desert pavement.

Abrasion

Wearing down of surfaces by the grinding action and sand blasting of windborne particles

 Maximum abrasion occurs at the height between 20-25 cm from the ground surface.

Abrasion is the mechanical scraping of a rock surface, by friction between rocks and airborne solid particles. The particles being transported by wind can strike the obstructing materials along its path. This forceful action of wind, with such particles, on rocks is called corrasion.

Corrasion can do grooving, scarring, polishing and grinding of rocks. The intensity of corrasion, depends on the size and density of carried materials, and also the nature of the earth's surface rocks. If the rocks are very soft, their removal is rapid.

Attrition: it occurs when hard objects hit against each other and are eroded as a result. In other words, it is an act of rubbing things together and, in the process, wearing them down. It involves the solid particles being transported colliding with each other and consequently being eroded. Mechanical tear and wear of the particles suffered by themselves while they are being transported by wind

 Results into gradual reduction in the size of rock particles (size of grains)

Erosional landforms

The erosional landforms of the wind are:

a) Blowouts and Deflation basins
b) Desert pavements
c) Desert varnish
d) Ventifacts
e) Mushroom rocks or Pedestal rocks.

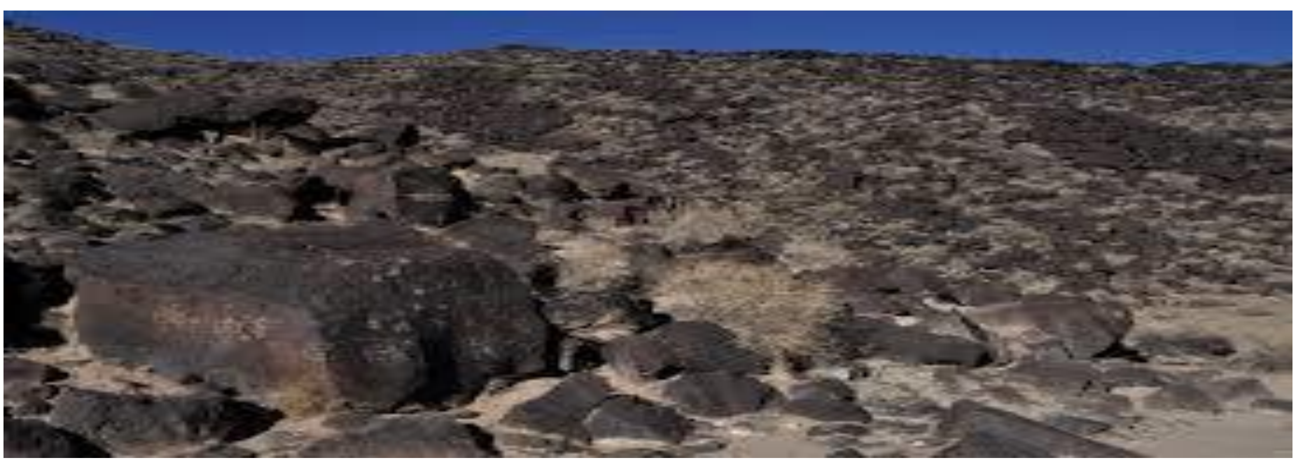
Blow Outs and deflation basins or hollows

(ii) **Deflation basins or hollows**: Deflation basins also called blowouts, are hollows or depressions in the land surface formed by wind erosion where sand and other loose particles are removed by wind. They are depressions formed in the deserts due to removal of sands to a greater extent. Deflation by strong wind scoops out sand sized particles producing shallow depressions of varying shapes. This may cause depression sometimes with its base touching quite depth. These evacuated depressions are up to 1.5 Km long and a few meters deep. These blowouts when intersect the water horizon, they get partially filled with water, resulting in development of swamp or oases. Deflation basins also commonly develop where calcium carbonate cement, in sandstone formations, is dissolved by groundwater, leaving loose sand grains that are picked up and transported by the wind. Large deflation basins, covering areas of several hundred square kilometers, are associated with the greatest desert areas of the world, particularly in Sahara Desert.

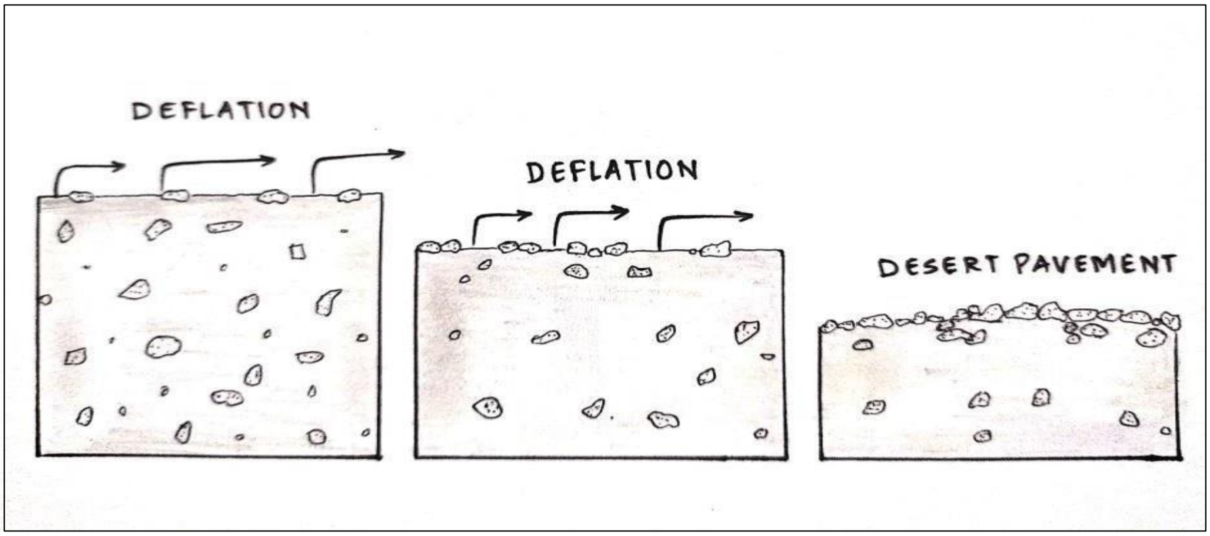
Deflation hollow

Desert Varnish

It is a dark coating on rocks found in arid regions, composed dominantly of fine-grained clay minerals containing black manganese oxide and red iron oxide. Desert varnish forms only on physically stable rock surfaces that are no longer subject to frequent precipitation, fracturing or sandblasting.



Desert pavement: It is a typical desert surface covered with closely packed, interlocking angular or rounded rock fragments of pebble and cobble size. They are formed by gradual removal of sand, dust and other fine grained material by wind and intermittent rain. Wind blows away finer particles like clay, silt and sand on deflation leaving behind the bigger fragments. Boulders or pebbles are too large for wind to transport. Accumulated coarser material (having fairly smooth shinning surface) are left behind as desert pavement also known as lag deposits. It marks the maximum limit of aeolian activity by deflation. Desert pavement also known as stone pavement forms a coarse gravelly ground surface that protects the soil or sediments below from further erosion.



Ventifacts:

Ventifacts are rocks which have been cut, and sometimes polished, by the abrasive action of wind. These geomorphic features are most typically found in arid environments where there is little vegetation.

Ventifacts are stones faceted (planed) by abrasion. With changing direction of dominant winds, different facets merge along sharp ridges to transform rounded stones to angular ventifacts. The facets can be worn into the face of the rock oriented into the prevailing wind direction.

Mesas and buttes

Mesa is a flat, table-like landmass. It is a flat-topped hill with steep sides, while a buttes is a smaller, similar formation, essentially a smaller version of a mesa. It has a resistant horizontal top layer with steep sides and a softer rock layer beneath. The hard top layer protects the soft layer from agents of denudation. Both are foemed by erosion, where softer rock surrounding a harder caprock is weathered away by agents of denudation. A flat, resistantant hill is left behind,

Yardangs:

- They are elongated, streamlined ridges, that are less than 10m high and more than 100m long
- They are formed where vertical layers of resistant and less resistant rock are aligned to the direction of the prevailing wind
- The less resistant rock is eroded by abrasion, forming deep troughs and leaving behind vertical ridges of the hard rocks known as yardangs.
- They form in environments where water is very scarce, and the prevailing winds are strong and unidirectional. The abrasive loads carried by the wind carve out elongated ridges that extend out in one direction. They form from generally soft surfaces that get eroded over time. The soft material gets carried away while the hard surface remains behind. They come in diverse shapes depending on the composition of the original material. Some even resemble human beings. They come in various sizes and are categorized as mega-yardangs, meso-yardangs, and micro-yardangs. The mega ones are very extensive covering several kilometers and several meters in height. They are developed in arid areas that experience strong winds.

Yardang

Mushroom Rocks:

They are the exposures having broad upper part and narrow base carved by the action of wind over an existing standing rock mass. The heavier and larger particles remain near the ground and only smaller lighter particles move above with the wind at higher level which results in the formation of pedestal rock. When the larger particles strike the homogeneous rock they differently abrade the upstanding rock mass such that rock head or cap balances over a very slender neck resulting into a pedestal fan like shape.. A mushroom rock is a naturally occurring rock whose shape, as its name implies, strikingly resembles a mushroom. These are usually found in desert areas. They are formed over thousands of years when wind erosion of an isolated rocky outcrop progresses at a different rate at its bottom to that at its top. Occasionally, the chemical composition of the rocks can be an important factor; if the upper part of the rock is more resistant to erosion and weathering, it will erode more slowly than the base.

- Mushroom rocks form primarily due to the **differential erosion of rocks**.
- The pedestal or base of the formation usually consists of softer rock that erodes more quickly than the capstone, which is typically composed of harder, more resistant rock.
- In arid and desert regions, the **abrasive action of sand-laden winds** can wear away the softer

rock at the base of the structure.

- The harder capstone protects the underlying portion from erosion, resulting in the pedestal shape.

Zeugen

A tabular mass of a rock with a layer of soft rocks lying beneath a surface layer of hard rock lies horizontally to the direction of wind. The process of formation starts with mechanical weathering which opens up joints of the surface hard rocks. The mass of rock is then acted upon by wind abrasion and wears the mass along the joints. With continued abrasion, the joints become deeper and wider. Overtime, the rock is transformed into a ridge and furrow landscape known as zeugen.

Inselberg

Inselberg is a German word which means "island mountains",i.e. Inselbergs look like an island situated in the sea.

The inselbergs are isolated hills of resistant rock standing is area that is relatively flat. The processes of wind erosion results in much of the surrounding sand and dust being eroded leaving behind a mass of resistant rock masses standing out from the surface of the desert. Such a feature is known as inselberg. Sometimes these hills are like pyramids with a cap of hard rock and sometimes they are dome-shaped having been made out of granite. Inselbergs are found in abundance in South Africa, Nigeria, Uganda, Algeria

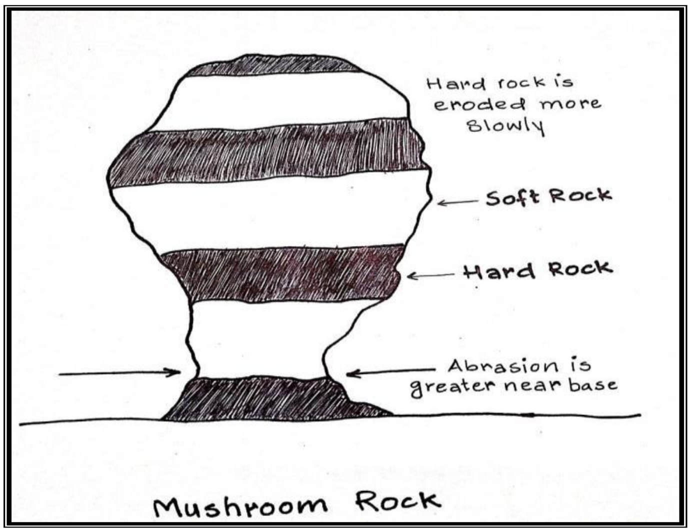
Inselberg

Oasis

Below the desert surface there could be an impermeable aquifer that prevents further downward seepage of water. Wind defation removes considerable quantity of sand leading to formation of a deflation basin. With time, the basin expands and enlarges, eventually reaching the aquifer underneath. Water oozes out of the aquifer into the depression forming an oasis.

Pedestal rocks

Rock pedestals are formed by wind abrasion on a block of rock outcrop with alternate horizontal layers of hard and soft rocks. The block lies along the path of sand laden wind. The softer layers are rapidly abraded than the harder layers. Abrasion is mor pronounced nearer the desert surface. This results in formation of an irregularly shaped feature called rock pedestal



<u>Demoiselles</u> - A French word meaning 'young lady'

- Demoiselles are formed due to differential erosion of hard and soft rocks.
- They represent rock pillars having relatively resistant rocks at the top and soft rocks below.
- Winds subject the upper parts of the rocks to abrasion but the lower parts remain protected.
- The protected soft rock stands like a pillar below the land rock and is known as Demoiselle or Earth Pillars.

TRANSPORTATIONAL EFFECTS

Wind transports sediment near the surface by saltation. Just as in the bed load of streams, saltation refers to short jumps of grains dislodged from the surface and jumping a short distance. As the grains fall back to the surface they may dislodge other grains that then get carried by wind until they collide with ground to dislodge other particles. Smaller particles can become suspended in the wind and may travel for longer distances

How Does Wind Transport Sediment?

Bed load are the sediments that are too large or heavy to be carried away by water in suspension by water or wind. The Suspended load is the silt- and clay-sized particles that constitute most of this load, held aloft for many miles. The particles that are transported by winds may go through suspension, saltation (skipping or bouncing) and creeping (rolling or sliding) along the ground. Small particles may be held in the atmosphere in suspension. Upward currents of air support the weight of suspended particles and hold them indefinitely in the surrounding air. Typical winds near Earth's surface suspend particles less than 0.2 millimeters in diameter and scatter them aloft as dust or haze.

Once the wind picks the loose particles in the deserts, they are transported to different locations through the following processes (Figure 9.10) discussed here

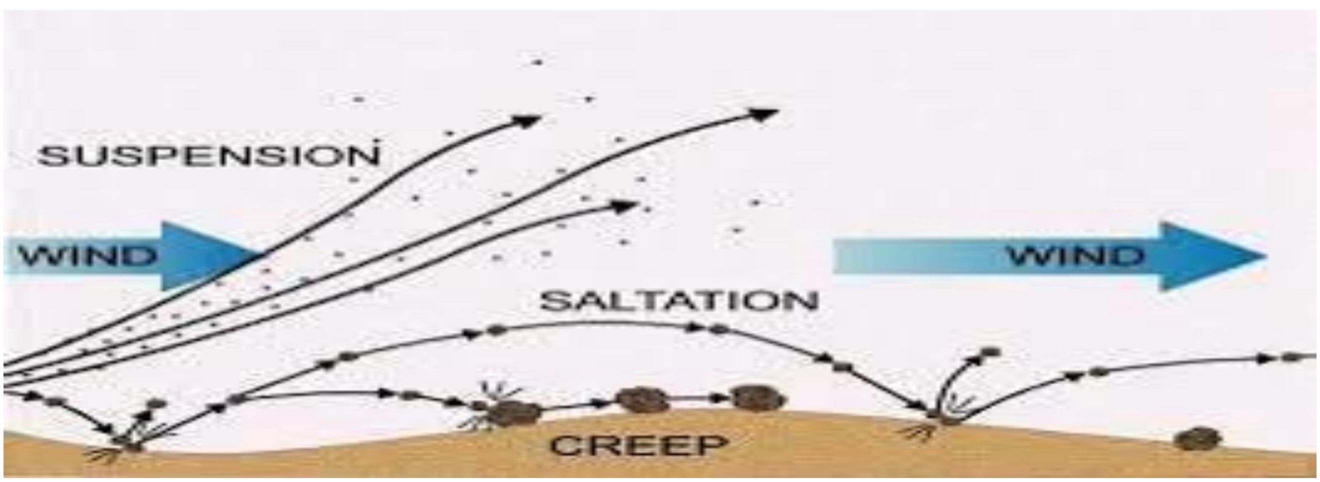
Suspension: Smaller particles with a diameter of less than 100micrometers are light and can be lifted above the ground by wind. Once lifted they keep moving at a height until the force of wind dies out. silt and clay sized particles are carried in suspension, above the ground surface. The suspended grains travel thousands of kilometers and reach to great altitudes. The force of the wind lifts clay and silt particles of lighter density from the ground and carries high up to upper layers. This is called suspension because the particles once lifted are not allowed to rest on the ground again till the velocity of wind in those upper layers is checked.

***Saltation*:** This process involves the lifting of heavier and coarser sediments such as sand grains, pebbles and gravels etc. only for short distance and for smaller heights above the ground periodically during high wind velocity. This movement takes place close to the Earth's surface and the picked up and lifted materials may be dropped and picked up again and again during the process of transportation. The lifted particles fall and they transmit an impact to another stationary particle resting on the ground. The size and shape of the grain control the height and distance to which these sediments are transported in one cycle.

Surface Creep: Is the movement of relatively bigger particles along the ground surface
The larger and bigger particles of gravels and rocks are too heavy to be carried away by the wind. They move along the ground and also collide with each other.
• They are hit by smaller particles, which cause them to creep forward, very slowly by sliding and rolling

Reptation

This process is closely related to saltation. As particles fall to the ground, after being lifted, they cause a splash and smaller particles are displaced in different directions



DEPOSITION OF WIND

Like water, when wind also slows down, it leaves the particles it has carried. It often happens when there is an obstruction in the movement of the wind. Deposition of sediments occurs due to:

- marked reduction in wind speed
- obstructions caused by bushes, forests, marshes and swamps, lakes, big river, walls, etc

Deposition takes place with a sorting action (larger particles drop first due to reduced wind velocity)

Wind-deposited sand bodies occur as sand sheets, ripples and dunes. Several landforms are formed depending on the size of the deposited particles.

Depositional Landforms

Aeolian deposits are relatively small in size. The particles may range from 0.05 to 0.25mm in diameter. Dust particles are almost completely absent at the locations of deposition. The grains of Aeolian sands are generally well-rounded due to prolonged transportation by wind. Sometimes, they are well-polished.

The depositional landforms of wind are:

a) **Ripples**
b) **Sand Dunes**
c) **Sand sheets**
d) **Sand shadows**
e) **Loess and**
f) **Takyrs.**

Ripples

Ripples are small sand waves created with a wavelength of about 1 m, i.e. the typical path length of saltating grains. When a wind current flows across the surface, loose sand is picked, dragged along the bottom and piled to form small wavy ridges known as ripples. Ripples form in lines perpendicular to wind direction.

Ripples are shorter than dunes. They are ephemeral and mobile, i.e. move, disappear and reform during wind storms. These are common in the windward slopes of sand dunes.

Dunes

Sand dune is a mound or ridge of sand deposited with a crest. Dunes are not permanent structures. A sand dune often moves or migrates forward windward from one place to the other in desert region. However, grasses anchor the dunes with their roots and hold them temporarily in place. If dune is devoid of vegetation, winds can regularly change its form and location. An ideal dune has a gentle windward slope of about 10 to 15°and much steeper leeward slope of 30 to 35°. Wind lifts sand grains from windward side and drops them on leeward side also known as slip side and consequently the migration takes place. Dune advances by movements of individual grains of sand has been observed in Thar Desert.

The following conditions are essential for the formation of dunes:

i) Abundant supply of sand

ii) Strong sand-moving wind

iii) Direction and velocity of the wind

iv) An obstacle for the dune to form against v)Suitable particle size

These are commonly known as *hills of sand*. In the following paragraphs, we will learn about different types of dunes.

The most common typology of dunes is based on their shape, and on this basis, there are five types of dunes. These are: **Dunes-classified**

Dunes are further classified into the following types:

a) Barchans dunes
b) Parabolic dunes
c) Transverse sand dunes and
d) Longitudinal dunes.
e) Star dunes

a) Parabolic dunes are most common dunes occurring in coastal areas where there is abundant sand supply, strong onshore winds, and a partial cover of vegetation. Parabolic dunes have a crescent shape like dunes with their tip pointing upwind. Parabolic dunes form when there is abundant supply of sand and vegetation cover is broken and erosive action by deflation creates a deflation hollow or blowout. As the wind transports sand out of depression, it builds up on convex downwind dune crest. Central part of dune is excavated by wind, while vegetation holds the ends and sides fairly well in place. Sediments comprising parabolic dunes are very fine to medium and well-sorted.

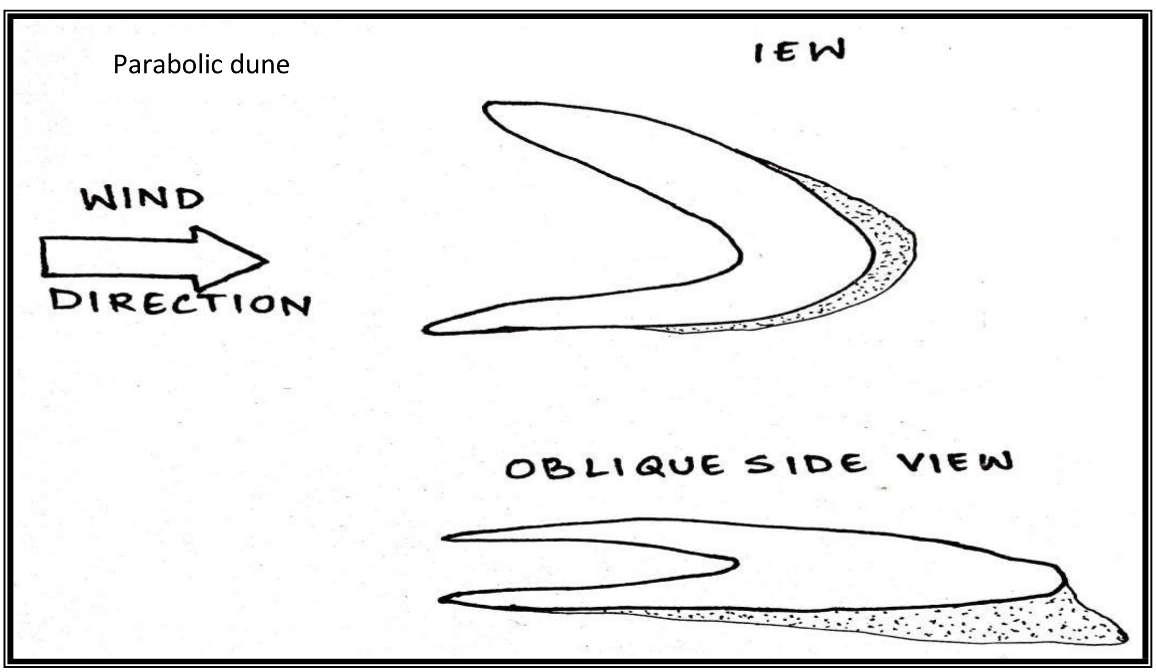
- U-shaped mounds of sand with convex noses trailed by elongated arms
- also called U-shaped, blowout, or hairpin dune
- common in coastal deserts
- their crests point upwind
- they are fixed by vegetation
- the dune points in the leeward direction

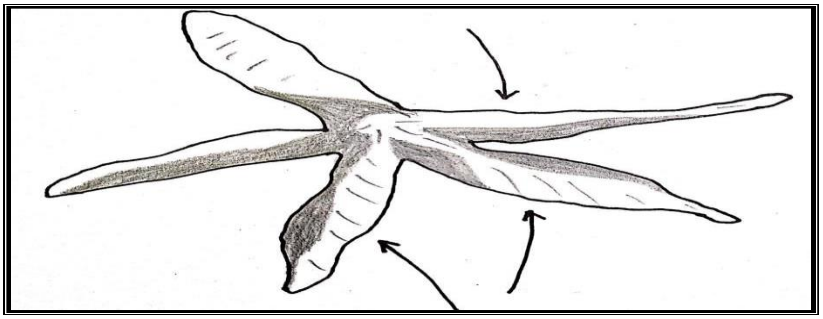
the longest known parabolic dune has a trailing arm 12 kilometers long

b) Star Dune is commonly found in the deserts of North Africa and Saudi Arabia. Star dune is so named because of its resemblance to a multi-pointed star (Figure 16). It is pyramid shaped with three or more arms radiating from a peaked centre, and they develop where wind direction is variable. They grow taller rather than migrating. Star dunes are sometimes more than 100 m above the surrounding desert plain. Star dune comprises very fine to medium sand. Star dune for its formation requires wind blowing from several different directions.

- rare dunes that are radially symmetrical
- look like a pyramidal sand mound with slip faces on three or more arms that radiate from the mound's high center
- tend to accumulate in areas with multidirectional wind regimes
- grow upward rather than laterally
- makeup to 8.5 % of all dunes on the planet (Kollegger and Grunert, 2017)

common in the Sahara and Badain Jaran Desert of China





Star dune

c) Barchan or Crescentic –

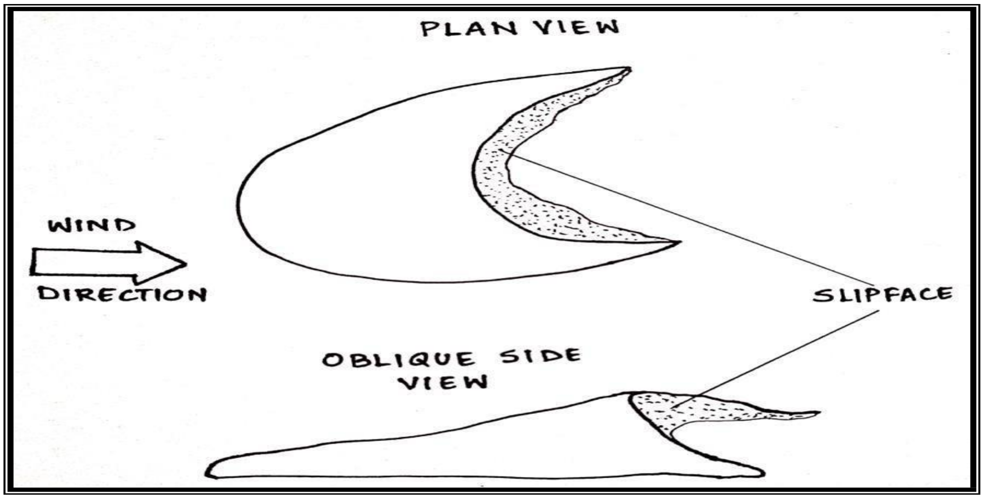
- are crescent or half-moon shaped
- They form where conditions are ideal.
  - i. a flat landscape,
  - ii. winds from only one direction, and
  - iii. limited sand
- found in all types of deserts

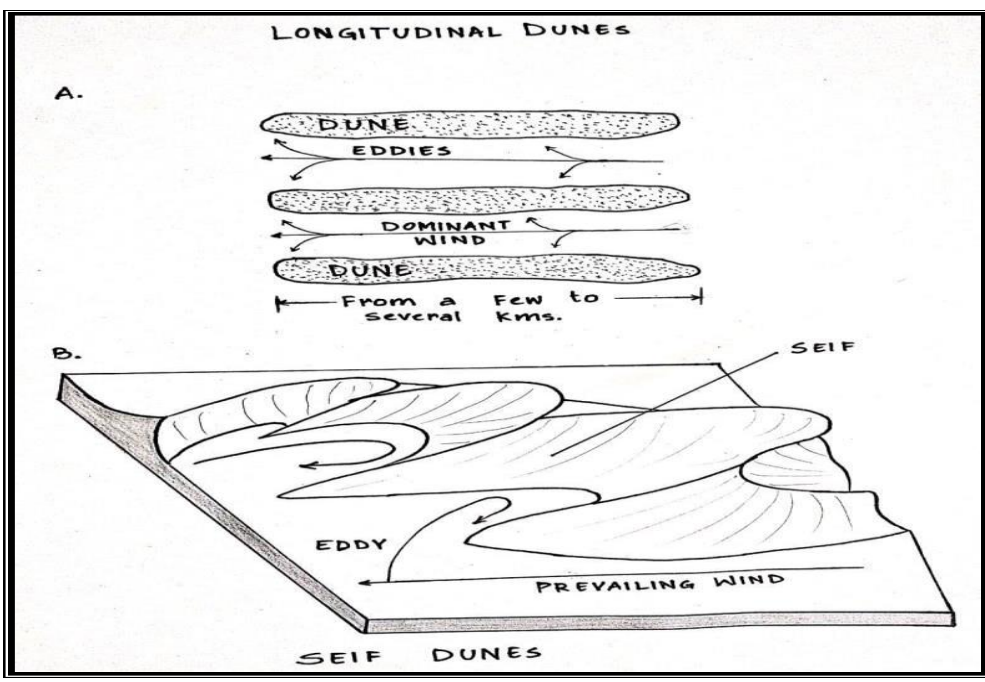
- they point against the wind
- their faces are steep, but their trailing sides are not. They will often join up with other barchans to form barchanoid ridges.

Common in the Sahara and the Turkestan deserts

Barchans

Barchan dunes are classic asymmetric crescent shaped desert dunes. They develop perpendicular to the prevailing wind. These are isolated, freely migrate across desert plains maintaining their forms. Their characteristic feature is their wings. They have a long and gentle (10 to 15 degrees) windward slope and short and steep leeward slope. Barchans range in height from 1-2 to 15 meters. Occasionally, they rise to a height of 20 to 30 meters. Their width may go up to 140 m.





Transverse dunes

d) Transverse dunes form long, wavy, linear ridges perpendicular or transverse to the prevailing wind direction in areas that have abundant sand and little or no vegetation. In plan view transverse dunes have a wavelike appearance and are therefore called sand seas. The dunes may be as wide as 3 km with crests of as high as 200 m. With stronger winds, they may evolve into barchans.

e) Longitudinal Dunes

Longitudinal dunes (also called *seif dunes*) consists long, linear or slightly sinuous sand ridges aligned, generally much longer than wide, parallel to direction of prevailing winds. Long axis of sand ridges is parallel to direction of net sand movement. They form where sand supply is somewhat limited (Figure 13). Sediments in longitudinal dunes are well sorted with grain size varying from very fine to medium grained sand. Longitudinal dunes result when winds converge from slightly different directions to produce the prevailing wind. They range in height from about 3 m to more than 100 m, and some stretch for more than 100 km. The longitudinal dunes cover extensive areas in Saudi Arabia, Egypt, and Iran.

Ergs

Ergs are "sand seas". They are very vast sand sheets. They cover about 1/4 - 1/3 of the area of true deserts. These sandy deserts overlie the poorly consolidated sandy bedrocks.

Sand Sheets

Sand sheets are flat, gently undulating sandy plots of sand surfaced by grains that may be too large for saltation. The surface is usually rippled. Pits generally display layers of two distinct grain sizes. This is due to the fact that larger grains are transported by creep, while smaller ones saltate. Sand sheets are formed on borders of deserts having scanty vegetation. The Fixed Sand Sheets are undulating sandy

hills in subhumid environments. The Selima Sand Sheet, which occupies 60,000 square kilometers in southern Egypt and northern Sudan, is one of the Earth's largest sand sheets.

Sand shadows

Formation of this feature depends on the presence of an obstacle in the path of the wind. The velocity of the wind reduces on the leeward side of the obstacle. As a result, the weak flow fails to remove any of the sand materials deposited on the lee side of the obstacle. This allows asnd to collect and form a depositional feature called sand shadow of the obstacle.it is formed close to the obstacle on the sheltered side.

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Loess:

Most of the dust carried by dust storms is in the form of silt-size particles. Deposits of this windblown silt are known as loess. Loess is a homogeneous, typically non-stratified, porous, friable, slightly coherent, often calcareous, fine-grained, silty, pale yellow or buff, windblown (aeolian) sediment. It generally occurs as a widespread blanket deposit that covers areas of hundreds of square kilometers and tens of meters thick.

Loess deposits are unusually fertile. They are also used for building construction. The thickest known deposit of loess, 335 meters, is on the Loess Plateau in China. Loess tends to develop into highly rich soils. Loess deposits are geologically unstable by nature, and will erode very readily.

Takyrs:

Takyrs are flat smooth clayey deserts, ranging in size from a few sq.m to several sq. kms. They develop as separate basins. A takyr is usually formed in a shallow depressed area with a heavy clay soil, which is submerged by water after seasonal rains. After the water evaporates, a dried crust with fissures forms on the surface. It forms through a combination of intense drying and cracking of clay rich soil.

TECTONIC PLATE PROCESSES AND LANDFORMS

EARTH'S STRUCTURE

The interior of the Earth is divided into layers based on chemical and physical properties. The Earth has an outer silica-rich, solid crust; a highly viscous mantle, and a core comprising a liquid outer core that is much less viscous than the mantle, and a solid inner core. The inner core is a solid sphere about 1220 km in radius situated at Earth's center. The inner core is believed to be composed mainly of a nickel-iron alloy, with small amounts of some other elements. The temperature is estimated at 5,000-6,000 degrees centigrade and the pressure to be about 330 to 360 Pascals (newton per $m^{2)}$ (which is over 3,000,000 times that of the atmosphere.

The liquid outer core is 2300 km thick and like the inner core composed of a nickel-iron alloy (but with less iron than the solid inner core). The mantle is approximately 2,900 km. The mantle is divided into sections based upon changes in its elastic properties with depth. In the mantle, temperatures range between 500-900 degrees at the upper boundary with the crust to over 4,000 degrees at the boundary with the core. Due to the temperature difference between the Earth's surface and outer core, there is a connective material circulation in the mantle (mantle convection cell). Hot material rises up as mantle plumes (like a lava lamp!), while cooler (and heavier) material sinks downward to be reheated and rise up again.

The Earth has two different types of crust:

Continental crust forms the land (the continents, as the name suggests) that we see today. Continental crust averages about 35 km thick. Under some mountain chains, crustal thickness is approximately double that thickness (about 70 km thick). Continental crust contains some of the oldest rocks on Earth.

Oceanic crust: - As the name already suggests, this crust is below the oceans. Compared to continental crust, Oceanic crust is thin (6-11 km). It is more dense than continental crust and therefore when the two types of crust meet, oceanic crust will always sink under continental crust. The rocks of the oceanic crust are very young compared with most of the rocks of the continental crust. They are not older than 200 million years. Continental crust is mostly of granitic composition. This means that the rocks contain an abundance of quartz and feldspars, which are called felsic (meaning light-coloured) minerals. Oceanic crust, on the other hand, is of basaltic composition. Basalts contain minerals such as olivine and plagioclase feldspar, which are called mafic (meaning dark- coloured) minerals. The two different types of crust differ in density and thickness as well as in composition.

- Continental crust (avg. density = 2.8 gcm-3) is much less dense than oceanic crust (avg. density = 3.3 gcm-3).
- Oceanic crust is 7-10 km thick, while continental crust is 35-70 km thick.
- Finally, continental crust is very heterogeneous. In contrast, oceanic crust, which all forms in the same way at mid-ocean ridges, has the same overall structure everywhere on the planet. Specifically, continental crust consists of a great variety of different igneous, metamorphic, and sedimentary rocks formed at different times and in different tectonic settings during Earth history.

The outer 100 km or so is a hard layer called the lithosphere, which is made up of the crust and uppermost mantle. *The lithosphere is broken into a number of large and small plates* that move over the more fluid asthenosphere below. Earthquakes and volcanoes are concentrated at the boundaries between lithospheric plates. If you look at a map of the world, you may notice that some of the continents could fit together like pieces of a puzzle-the shape of Africa and South America are a good example. The Earth as we see it today was not always like it is now. Land masses have pulled apart and joined together by the process we call **Plate Tectonics.**

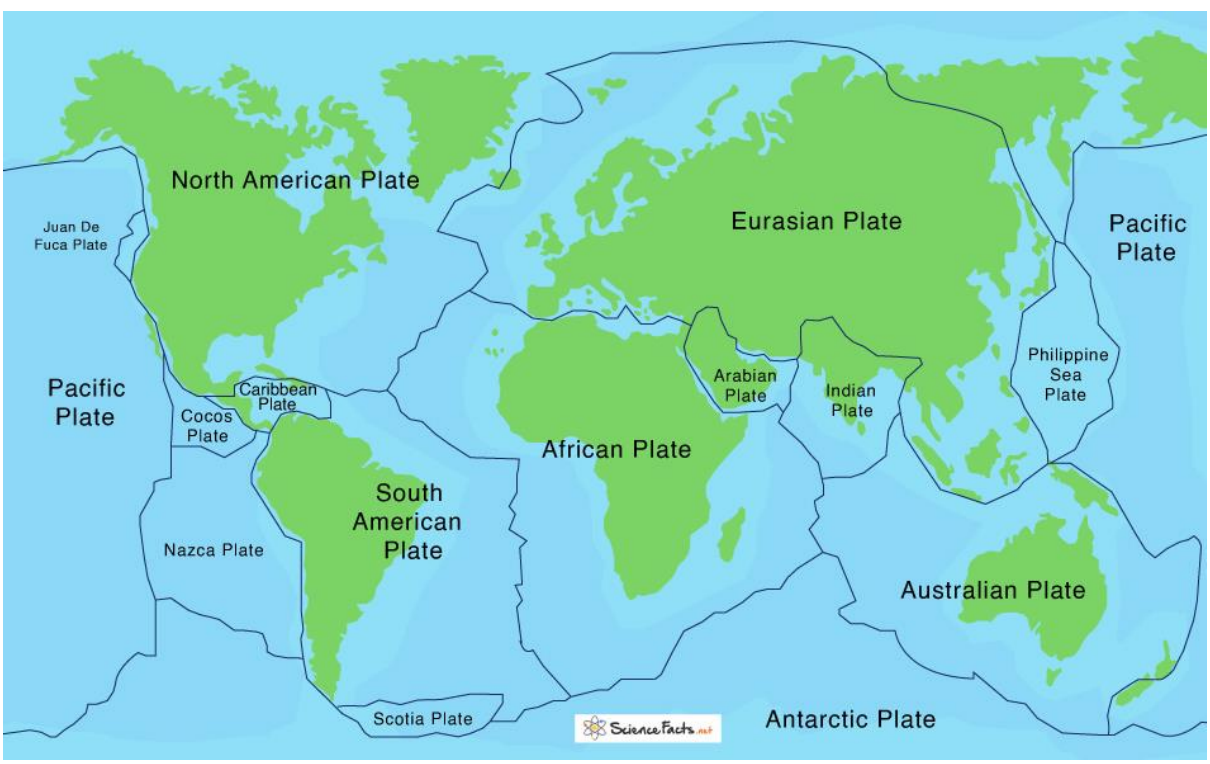
Plate tectonism

Tectonics is the scientific theory that the Earth's lithosphere comprises a number of large and small tectonic plates, which have been slowly moving since 3–4 billion years ago. The model builds on the concept of *continental drift*, an idea developed during the first decades of the 20th century. Plate tectonics came to be accepted by geoscientists after seafloor spreading was validated in the mid-to-late 1960s. Tectonic plates also occur in other planets and moons. Earth's lithosphere, the rigid outer shell of the planet including the crust and upper mantle, is fractured into seven or eight major and many minor plates.

Tectonic plates are essentially rigid segments or slabs of the Earth's lithosphere. They range in size from a few hundred to thousands of kilometers across. The tectonic plates connect the parts of Earth's lithosphere, much like the pieces of a jigsaw puzzle. Unlike puzzle pieces, tectonic plates do not rest on a stable surface. Instead, they float on the moving, semi-liquid portion of the mantle, called the asthenosphere.

There are seven major tectonic plates:

1. The African Plate
2. The Antarctic Plate
3. The Eurasian Plate
4. The Indo-Australian Plate (sometimes divided into two plates: Indian Plate and Australian Plate)
5. The North American Plate
6. The Pacific Plate
7. The South American Plate



1. Pacific Plate

The Pacific main plate is the largest plate located at Pacific Ocean. It stretches across the western coasts of North America to the east coasts of Japan and Indonesia. The activity of the volcanoes that occur in the Hawaiian Islands is caused by an internal hot spot in the Pacific Plate.

2. North American Plate

The North American plate includes the continent of North America as well as a portion of the Atlantic Ocean.

3. Eurasian Plate

The majority of Europe, Russia, and parts of Asia are part of the Eurasian main plate.

4. African Plate

The African plate covers the whole African continent as well as the adjacent oceanic crust of the Atlantic Ocean.

5. Antarctic Plate

The Antarctic plate contains the whole Antarctic continent, including its surrounding oceanic crust. Parts of the African, Australian, Pacific and South American plates surround it. The main plate of Antarctica is thought to move roughly 1 centimeter every year.

6. Indo-Australian Plate

The Indo-Australian plate combines the Australian and Indian plates. However, they are commonly regarded as two distinct plates It also includes the Indian Ocean's oceanic crust. The Australian plate meets the Pacific plate on its northeast side.

7. South American Plate

The South American plate is a big plate that covers the continent of South America as well as a large part of the Atlantic Ocean.

1. Somali Plate – 16,700,000 sq km
2. Nazca Plate – 15,600,000 sq km
3. Philippine Sea Plate – 5,500,000 sq km
4. Arabian Plate – 5,000,000 sq km
5. Caribbean Plate – 3,300,000 sq km
6. Cocos Plate – 2,900,000 sq km
7. Caroline Plate – 1,700,000 sq km
8. Scotia Plate – 1,600,000 sq km
9. Burma Plate – 1,100,000 sq km
10. New Hebrides Plate – 1,100,000 sq km
11. Juan De Fuca Plate – 250,000 sq km

Movement of tectonic plates

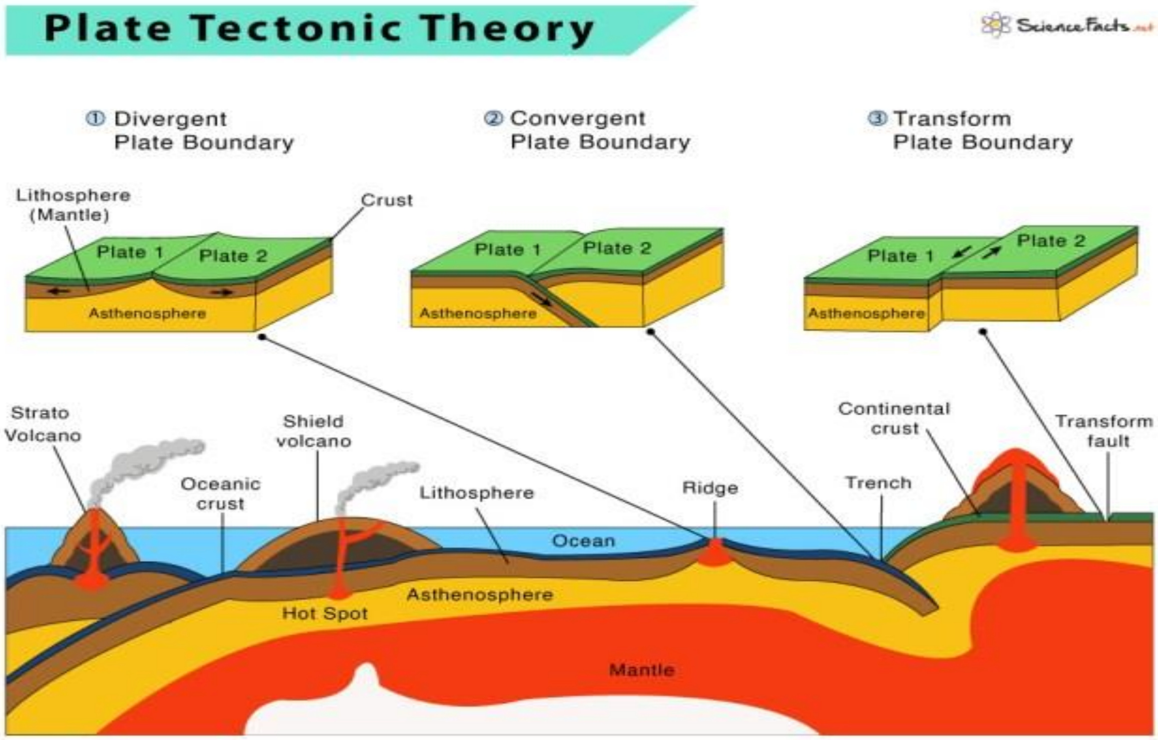
The theory of plate tectonics proposes that the Earth's lithosphere consists of several large and small plates that float on the semi-fluid asthenosphere beneath. These plates move usually due to the mantle's convective currents, driven by the heat escaping from the Earth's interior. These currents push and pull the plates along, supplemented by other processes like slab pull (the gravitational pull on a subducting plate) and ridge push (the force exerted by rising magma at divergent boundaries). The interactions of tectonic plates form mountains, cause earthquakes, and create volcanic activity. Plate motion refers to the movement of tectonic plates relative to each other. The study of plate motion is called plate kinematics. Plate kinematics involves measuring the direction, rate, and style of movement of tectonic plates. The movement of plates can be measured using a variety of techniques, including GPS (Global Positioning System) and satellite imagery.

What makes the plates to move?

1. Ridge push: This force is caused by the upward push of magma at mid-ocean ridges, which creates new oceanic crust. As the new crust forms, it pushes the older crust away from the ridge, causing it to move.
2. Slab pull: This force is caused by the weight of subducting oceanic lithosphere, which pulls the rest of the plate towards the subduction zone.
3. Other possible driving forces of plate tectonics include mantle convection, which is the slow movement of the Earth's mantle due to heat from the core.
4. gravitational force aids the subducting oceanic plate to sink into the mantle. As the plate descends, it pulls the rest of the plate with it.

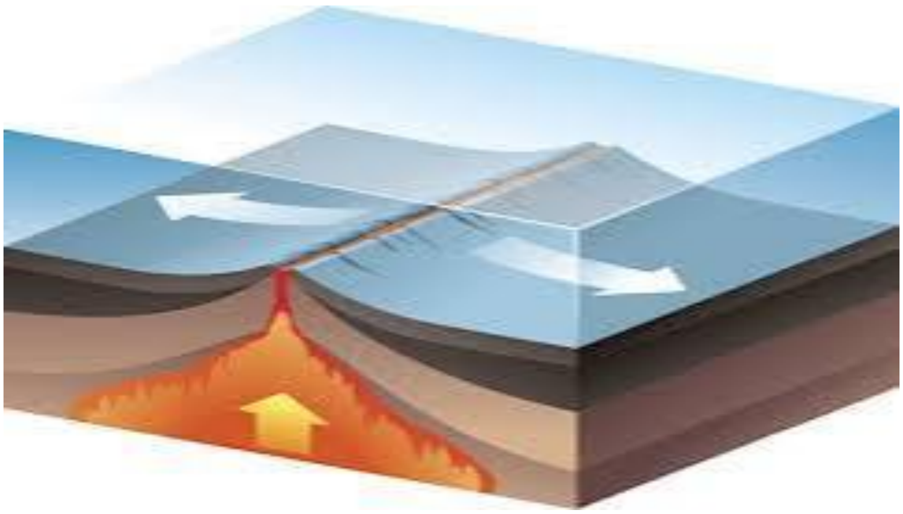
PLATE BOUNDARIES AND RESULTANT LANDFORMS

Plate boundaries refer to the zones where the tectonic plates that make up the Earth's lithosphere interact. There are three main types of plate boundaries: divergent, convergent, and transform. Each type is characterized by specific features and geological processes.



DIVERGENT PLATE BOUNDARIES: These occur where plates move away from each other under tensional stress. Magma rises from the mantle and creates new crust as it cools and solidifies. This process is called seafloor spreading and results in the formation of mid-ocean ridges. Sea Floor spreading is a process that occurs at mid-ocean ridges, where new oceanic crust is formed through volcanic activity and then gradually moves away from the ridge. Seafloor spreading helps explain continental drift in the theory of plate tectonics. When oceanic plates diverge, tensional stress causes fractures to occur in the lithosphere. Basaltic magma rises up the fractures and cools on the ocean floor to form new sea floor. Older rocks will be found further away from the spreading zone while younger rocks will be found nearer to the spreading zone.

Divergent boundaries also occur on land, where they create rift valleys. Examples of divergent boundaries include the Mid-Atlantic Ridge and the East African Rift Zone. You do not get the traditional cone-shaped volcanoes with a central vent forming at these locations, but magma moving up to the surface at the fissure cracks forming new crust. Shallow, low to medium magnitude earthquakes occur at divergent plate boundaries. When the process begins on land, it is called **continental rifting,** and a rift valley will develop, such as the Great Rift Valley in Africa. Over time that valley can fill up with water creating linear lakes. If divergence continues, a sea can form like the Red Sea and finally an ocean like the Atlantic Ocean. Check out the eastern half of Africa and notice the lakes that look linear. Eastern Africa is separated from these linear lakes by the Great Rift Valley and the Red Sea. Notice how the Red Sea looks like it could be put back together again. The ultimate divergent boundary is the Atlantic Ocean, which began when Pangea was breaking.



Features of Divergent Boundaries:

- Mid-ocean ridges: Underwater Mountain ranges that form at divergent boundaries between oceanic plates. The most extensive and best-known mid-ocean ridge is the Mid-Atlantic Ridge.
- Rift valleys: Deep valleys that form on land at divergent plate boundaries, such as the East African Rift Valley.
- Volcanoes: When magma rises to the surface at divergent boundaries, it can form volcanoes, especially in areas where the boundary is under the ocean. These volcanoes are typically shield volcanoes, which are broad and gently sloping.

Examples of Divergent Boundaries:

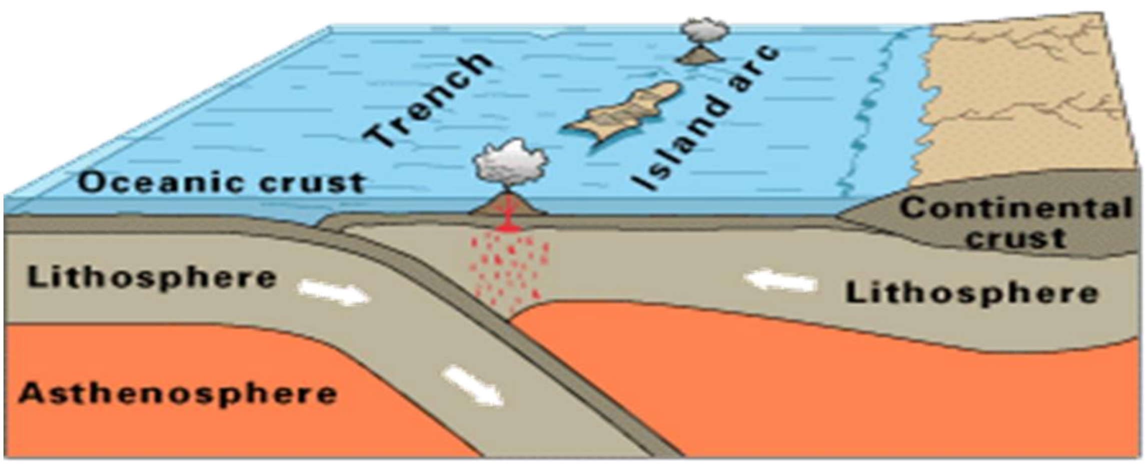
- Mid-Atlantic Ridge: The boundary between the North American Plate and the Eurasian Plate.
- East African Rift Valley: The boundary between the African Plate and the Arabian Plate.

- Iceland: A volcanic island that sits on the Mid-Atlantic Ridge at the boundary between the North American Plate and the Eurasian Plate.

CONVERGENT PLATE BOUNDARIES: These occur where plates move towards each other. There are three types of convergent boundaries, depending on the type of plates involved: ***oceanic-oceanic, oceanic-continental, and continental-continental.***

a) Oceanic-oceanic convergence

Recall that oceanic crust (basaltic) is denser than continental rock (granitic). At an oceanic-oceanic convergent boundary, one plate slides under the other in a process called subduction and **a deep-sea trench** is formed. As the subducting plate descends into the asthenosphere, part of it begins to melt, generating magma. The magma is less dense than the surrounding rock and begins to rise toward the surface. The rising magma creates a line of volcanic islands on the non-subducted plate. These islands are known as **volcanic arcs** (Sub-marine volcanoes) on the overriding plate. Examples of oceanic-oceanic convergent boundaries include the Aleutian Islands (a chain of 14 large volcanic islands and 55 smaller ones found in Alaska, USA) and the Mariana Islands (15 peaks of sub-marine volcanoes in the Pacific). The colliding frictional forces between the two plates create **earthquakes** starting around the trench and progressing inward along the subduction plate.



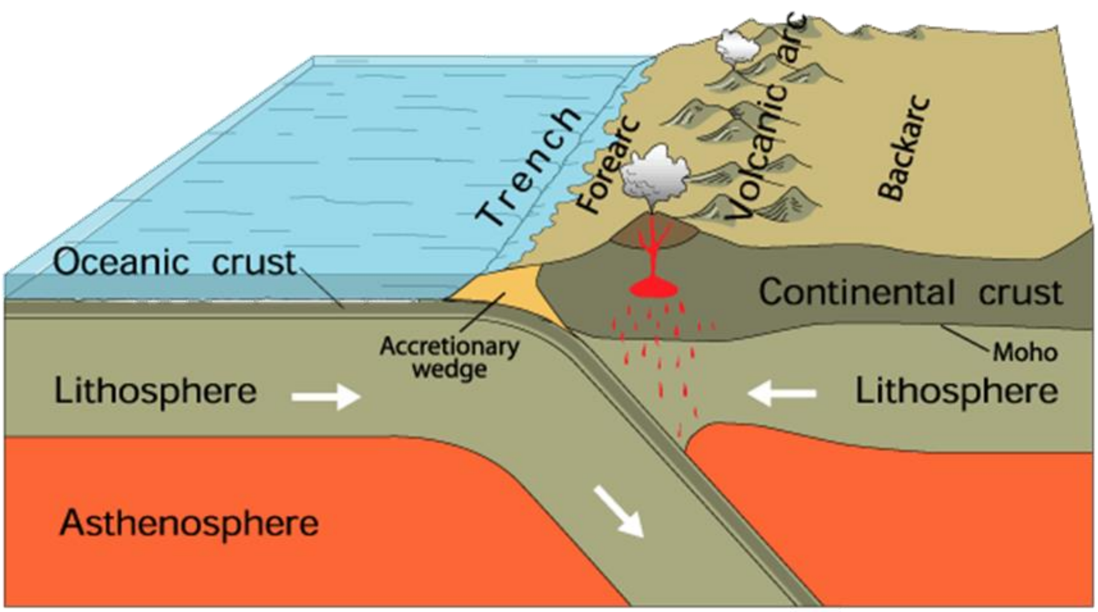
Oceanic-oceanic convergence

b. Oceanic-Continental Convergence

At an oceanic-continental convergent boundary, the denser oceanic plate subducts beneath the less dense continental plate forming a trench. As the subducted material sinks further, it will begin to melt under great heat and pressure, becoming less dense as it melts and rises up as magma to form dangerous **composite volcanoes** on the continental plate. The oceanic crust slides down into the mantle at a rate of 1.27centimetres per year. This oceanic crust is called the “Subducting Slab” Pacific plate are areas of convergence leading to the formation of volcanoes. For this reason, the area is often referred to as the **Ring of Fire**. The Ring of Fire is also known for intense earthquake activity.

Mountain ranges created by **oceanic-to-continental convergence** include the Andes mountains in South America, the Cascades in the western United States, and the Ring of Fire in the Pacific Ocean.

If the subducting rock becomes stuck, vast amounts of energy build up. Once the pressure and energy accumulated exceed the resistance of the rock slab, the rock will rupture, creating powerful earthquakes.

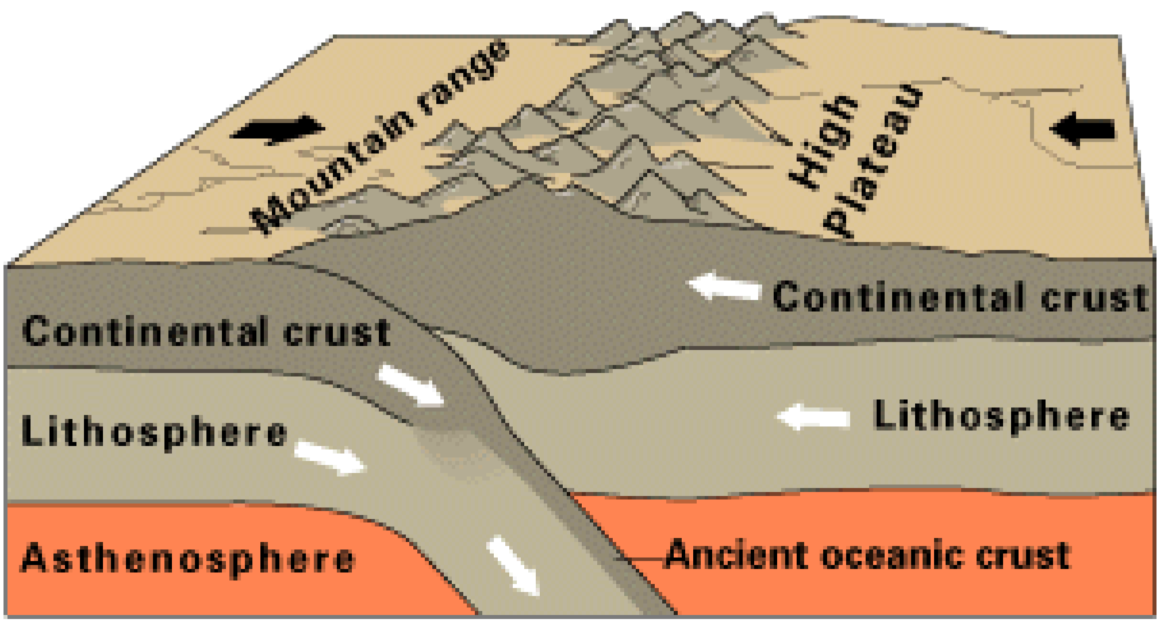


Oceanic-Continental Convergence

c. Continental-Continental Convergence

At a continental-continental convergent boundary, neither plate subducts because they are too buoyant. Instead, they crumple and fold, creating large mountain ranges. It creates intense folding and faulting rather than volcanic activity. Examples of mountain ranges created by this process are the Himalayan mountains as India collided with Asia, the Alps in Europe, and the Appalachian mountains in the United States as the North American plate collided with the African plate. If the subducting rock becomes stuck, vast amounts of energy build up. Once the pressure and energy accumulated exceed the resistance of the rock slab, the rock will rupture, creating powerful earthquakes. For instance, the Kashmir India earthquake of 2005 killed over 80,000 people because of this process. And most recently, the 2008 earthquake in China killed nearly 85,000 people before the Summer Olympics because of this tectonic force.

At convergent boundaries, earthquakes, volcanic eruptions, and the formation of mountain ranges are common features due to the intense geologic activity that occurs at these locations



Continental-continental convergence

- **TRANSFORM BOUNDARIES** occur when two tectonic plates slide (or grind) past each other. Transform plate boundaries form when two plates slide past each other under shear stress. These boundaries are also known as conservative boundaries since there is no net creation or destruction of lithosphere. There is no subduction, so volcanoes do not form. However, tremendous frictional stress can create large, destructive earthquakes. The most famous example of a transform plate boundary is the San Andreas Fault running through California. This fault marks the boundary between the North American and Pacific plates which are sliding at the rate of 3 inches a year. Recently, geologists have stated that San Francisco should expect another disastrous earthquake in the next 30 years.

- The Alpine Fault in New Zealand is another example of a transform boundary, marking the boundary between the Pacific Plate and the Australian Plate.
- The Dead Sea Transform in the Middle East is a complex system of transform faults that connect the Red Sea Rift to the East Anatolian Fault Zone.

Features:

- Transform boundaries are typically characterized by a series of parallel faults or fractures in the lithosphere The faults associated with transform boundaries can range from a few meters to hundreds of kilometers in length.
- The movement of the plates along transform boundaries can create earthquakes.

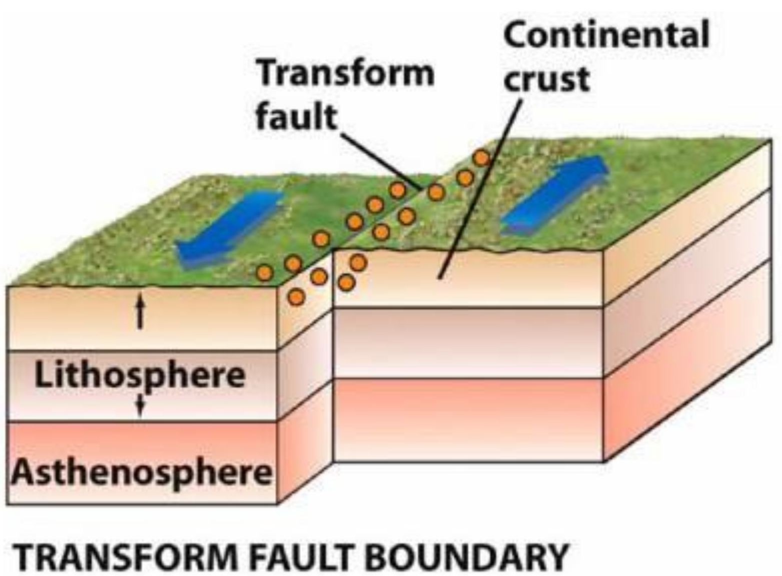


Plate Tectonics and Earthquakes

Plate tectonics and earthquakes are closely related phenomena. Earthquakes occur when two plates interact at their boundaries. Plate boundaries are classified into three types: divergent, convergent, and transform. Earthquakes occur at all three types of boundaries, but the characteristics of the earthquakes differ depending on the boundary type.

At divergent boundaries, earthquakes tend to be shallow and low-magnitude. This is because the plates are moving apart and there is relatively little friction and stress on the rocks. However, as the plates move further apart, the depth of the earthquakes can increase.

At convergent boundaries, earthquakes can be deep and high-magnitude. This is because the plates are colliding, and the rocks are under high stress and pressure. Subduction zones, where one plate is forced beneath another, are particularly prone to strong, destructive earthquakes.

Transform boundaries also experience powerful earthquakes. These boundaries occur where two plates are sliding past each other horizontally. The friction and pressure on the rocks can lead to large earthquakes.

Overall, plate tectonics is the driving force behind most earthquakes on Earth, and understanding the movement and interactions of tectonic plates is crucial for predicting and mitigating earthquake hazards.

Plate Tectonics and Volcanism

Plate tectonics and volcanism are closely related because the majority of Earth's volcanic activity occurs at plate boundaries. Magma rises from the mantle and is forced upward by tectonic plate movement, creating volcanic eruptions. The type of volcano and eruption style is determined by the composition and viscosity of the magma.

At divergent plate boundaries, magma rises from the mantle to create new crust, forming shield volcanoes that are typically non-explosive. Mid-ocean ridges are examples of this type of volcanic activity.

At convergent plate boundaries, the denser oceanic plate subducts beneath the less dense continental plate, melting the subducted plate to form magma. This type of volcanic activity can result in explosive eruptions and the formation of stratovolcanoes. The Pacific Ring of Fire is a zone of intense volcanic activity that occurs at convergent plate boundaries.

Transform plate boundaries do not typically produce volcanic activity, but they can create volcanic features such as fissure eruptions and volcanic vents.

In summary, plate tectonics plays a significant role in the formation and location of volcanoes, and the type of volcanic activity is determined by the plate boundary type and magma composition.

Plate Tectonics and Mountain Building

Plate tectonics plays a significant role in mountain building or orogeny. Mountains are formed by the deformation and uplift of the Earth's crust. There are two types of mountain-building processes: 1) convergent boundary mountain building and 2) intraplate mountain building.

1. Convergent boundary mountain building occurs where two tectonic plates collide and cause uplift and deformation. The most prominent example of this type of mountain building is the Himalayan Mountain range. The Indian subcontinent collided with the Eurasian plate, causing the uplift of the Himalayas.
2. Intraplate mountain building occurs where a tectonic plate moves over a mantle plume. As the plate moves over the plume, magma rises to the surface, creating volcanic islands and a chain of mountains. The Hawaiian Islands are an example of intraplate mountain building.

Plate tectonics also plays a role in the formation of other geological structures, such as rift valleys and oceanic trenches. In rift valleys, the crust is pulled apart by tectonic forces, causing the formation of a valley. Oceanic trenches form at subduction zones, where one tectonic plate is pushed under another and into the mantle. As the plate descends, it bends and forms a deep trench.

Plate Tectonics and the Rock Cycle

Plate tectonics and the rock cycle are closely related processes that shape the Earth's surface and the composition of its crust. The rock cycle describes the transformation of rocks from one type to another through geologic processes such as weathering, erosion, heat and pressure, and melting and solidification. Plate tectonics plays a significant role in the rock cycle by recycling and changing the Earth's crust through subduction, collision, and rifting processes.

Subduction zones are areas where one tectonic plate is being forced beneath another, and they are associated with the formation of volcanic arcs and island arcs. As the subducting plate descends into the mantle, it heats up and releases water, which lowers the melting temperature of surrounding rocks and generates magma. This magma rises to the surface and forms volcanoes, which release new minerals and gases into the atmosphere.

Collision zones occur where two tectonic plates converge and uplifts the crust, leading to the formation of mountain ranges. The collision of the Indian and Eurasian plates, for example, created the Himalayan Mountain range. This process also causes metamorphism of rocks, as the intense heat and pressure of the collision transforms them into new types of rocks.

Rifting zones are areas where tectonic plates are moving apart, leading to the formation of new ocean basins and mid-ocean ridges. As plates move apart, the crust is thinned, and magma rises to fill the gap, eventually solidifying and forming new crust. This process produces volcanic activity and can lead to the formation of new mineral deposits.

In summary, plate tectonics drives the rock cycle by creating new crust, recycling old crust, and transforming rocks through subduction, collision, and rifting processes.

Plate Tectonics and Mineral Resources

Plate tectonics plays a significant role in the formation and distribution of mineral resources. Ore deposits, including precious metals such as gold, silver, and platinum, as well as industrial metals such as copper, zinc, and lead, are often associated with tectonic plate boundaries.

At convergent plate boundaries, subduction zones can generate large-scale mineral deposits, including porphyry copper, epithermal gold, and silver, and massive sulfide deposits. These deposits are formed by hydrothermal fluids that are released from the subducting slab. Hydrothermal vents are under water fissures in the earth's crut usually found along the mid ocean ridge, where geothermally heated water escapes from beneath the seafloor. Thes vents are formed by volcanic activity. Sea water seeps through and gets heated by underlying magma, and then rises back up, carrying dissolved minerals and gases.

In addition, mid-ocean ridges, where new oceanic crust is created, can host deposits of sulfide minerals that are rich in copper, zinc, and other metals. These deposits are formed by hydrothermal vents that release mineral-rich fluids into the surrounding seawater.

Plate tectonics also influences the formation of hydrocarbon deposits, such as oil and gas. These deposits are often found in sedimentary basins that are associated with rift valleys, passive margins, and convergent margins. Organic-rich sedimentary rocks are buried and heated over time, leading to the formation of hydrocarbons.

Hotspots

Although most of Earth's volcanic activity is concentrated along or adjacent to plate boundaries, there are some important exceptions in which this activity occurs within plates. Linear chains of islands, thousands of kilometres in length, that occur far from plate boundaries are the most notable examples. These island chains record a typical sequence of decreasing elevation along the chain, from volcanic island to fringing reef to atoll and finally to submerged seamount. An active volcano usually exists at one end of an island chain, with progressively older extinct volcanoes occurring along the rest of the chain. Canadian geophysicist J. Tuzo Wilson and American geophysicist W. Jason Morgan explained such topographic features as the result of hotspots.

Hot spots are places where plumes of hot mantle material are upwelling beneath the plates.

A small amount of geologic activity, known as **intraplate activity**, does not take place at plate boundaries but within a plate instead. Mantle plumes are pipes of hot rock that rise through the mantle. Eruptions at the hotspot create a volcano. Hotspot volcanoes are found in a line. Can you figure out why? Hint: The youngest volcano sits above the hotspot and volcanoes become older with distance from the hotspot. Geologists use some hotspot chains to tell the direction and the speed a plate is moving.

CASE STUDY OF THE CRETE ISLAND IN GREECE

Crete, Greece, is located along the Hellenic arc, a prominent seismic zone resulting from the subduction of the African plate beneath the Aegean Sea plate. It is one of the most seismically active regions in Europe, frequently experiencing earthquakes and tsunamis due to subduction. This tectonic setting renders the region susceptible to significant seismic activity, influencing both the natural environment and human settlements. The island's position above this convergent boundary has led to numerous earthquakes through out history. Some of these include the 365 AD earthquakes measuring 8.5 magnitude, 1303, 2021 September, and 2021 October. There is a deep-sea trench south of Crete which part of the subduction system where the African plate is forced under the Aegean plate,

Active fault zones such as Crete in Greece, have significant impacts on the environment, infrastructure and local communities. Some of the key effects include:

- Earthquakes and ground shaking: active fault zones are prone to frequent earthquakes which cause ground shaking leading to structural damage, landslides and soil liquefaction. Earthquakes originating from active fault zones can cause intense ground shaking leading to building collapse and severe damage to transport networks, damage to pipelines and utilities. Severe earthquakes can result in injuries and loss of life.
- Landslides and soil instability: seismic activity can trigger landslides, particularly on hilly regions leading to habitat destruction and disturbance of ecosystems. Landslides can obstruct roads and railways hindering movement. Soil erosion increases, affecting soil quality and agriculture.
- Ground raptures and surface deformations: Movements along fault lines can create surface raptures, forming scarps, fissures and ground displacement. These changes impact vegetation, water flow and infrastructure such as roads pipelines and buildings.
- Impact on water systems: fault activity can disrupt drainage systems. Rivers may change course leading to water shortage in the affected areas.
- Tsunamis and coastal deformation: underwater earthquakes may trigger tsunamis which have a devastating effect on coastal environments and human settlements. This phenomenon can erode beaches, re-shape coastlines, destroy human environments and cause long term ecological changes. Tsunamis cause flooding in coastal areas leading to salt water intrusion which contaminate fresh water sources and agricultural lands.

- Formation of unique geological features: over time, fault zones may create valleys, ridges and mountain ranges which can influence local climate and human activities.
- Human economic impacts: damage to infrastructure, homes and cities leads to economic losses and displacement of communities. People living near active faults face ongoing risks requiring careful planning and disaster preparedness. Certain areas may be designated as non-buildable in order to mitigate hazards.
- On a positive note, active fault zones can create fertile soils in some regions supporting agriculture

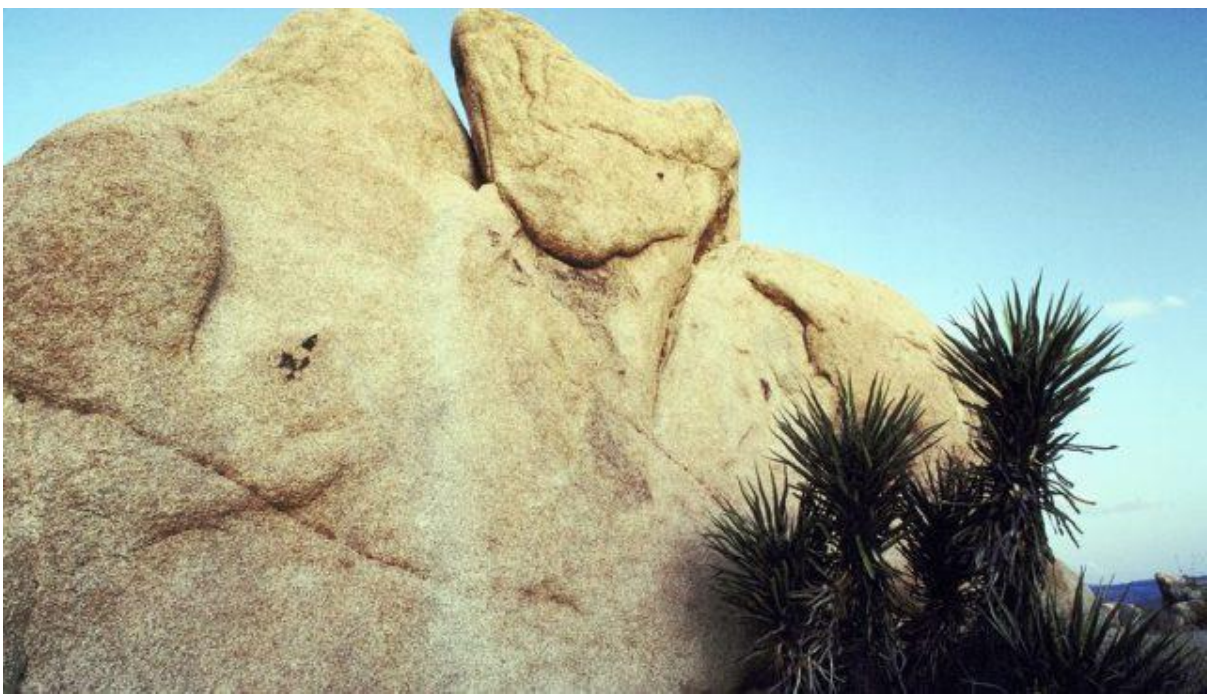
WEATHERING OF ROCKS: TYPES, FACTORS AND PRODUCTS

Weathering is a geological process that naturally breaks down rocks and minerals at or near the Earth's surface. It occurs over time scales ranging from years to millennia. Weathering plays a pivotal role in shaping the Earth's landscapes and influencing the cycling of nutrients and elements.

Weathering is a denudation process which involves physical disintegration and chemical decomposition of rocks in situ (one place) by natural agents on the surface or near the Earth's surface

Weathering is the combination of processes that breaking down of rocks, soil and minerals, eventually transforming into sediment. It may also be said to be the disintegration or alteration of the rock surface in its natural or original position through physical, chemical and biological processes induced or modified by wind, water and climate.

It is a process of in-situ disintegration of rocks into smaller fragments and particles.



Types of Weathering:

Mechanical (Physical) Weathering:

Also known as mechanical weathering, physical weathering involves the breakdown of rocks and minerals into smaller pieces without changing their chemical composition. Various environmental factors drive this process, including temperature fluctuations, pressure changes, and biological activity. Mechanical weathering is one of the very common geological processes of slow natural rock disintegration in all parts of the world. Temperature variations and organic activity are two important factors that bring about this change under specific conditions.

A single rock block on a hill slope or a plain, for instance, may be disintegrated gradually into numerous small irregular fragments through frost action that in turn may break up naturally into fragments and particles of still smaller dimensions.

These loose fragments and particles may rest temporarily on the surface if it is a plain. On slopes, however, the end product fragments and particles may roll down under the influence of gravity and get accumulated at the base as heaps of unsorted debris. All these fragments and particles, however, have the same chemical composition as the parent rock.

The major processes of physical weathering include; ·

- **Thermal Stress Weathering/Exfoliation/onion peeling** which is the peeling off of surface rock layers due to heating during the day causing expansion and cooling at night causing contraction. This results from unequal expansion and contraction of the surface and inside of the rock causing the rock to peel off in shells.
- In arid/semi-arid areas, there is large diurnal ranges of temperature.
- During the day, a homogenous rock is intensely heated.
- At night, the rock loses heat rapidly.
- Alternate heating and cooling of the rock causes stress in the rock leading to peeling off of the outer shell.
- When this expansion and contraction takes place repeatedly, stress develops in the outer layer of rocks.
- Cracks appear on the surface layer.
- Eventually the outer layer peels off, a process called *Exfoliation.*
- The peeling off leaves behind a rounded mass of rock known as Exfoliation dome.

Block disintegration occur in hot regions and involves breakdown of homogenous jointed rocks into rectangular shaped blocks due to heating during day causing expansion and cooling at night causing contraction. This results from alternate heating and cooling, causing rock breakage along the lines of weakness into blocks.

- It is common in arid and semi-arid lands with large diurnal temperature ranges
- During the day, the temperatures are high causing the rocks to expand along the bedding planes and joints.
- At night, the temperatures fall leading to contraction of the rocks along the bedding planes and joints.
- This repeated expansion and contraction causes the rock mass to break along the lines of weakness into blocks

Block disintegration

- **Granular disintegration** is a form of physical weathering where a rock breaks into small particles called granules. It is mainly observed in rocks with different minerals for instance granite rocks constitute of mica, quartz and feldspar which have different heat absorption and linear expansivity capacities. The minerals expand at different rates which causes stress in the roc leading to disintegration.

- This results from alternate heating and cooling that make rocks to break into small particles/grains.
- During the day when temperatures are high, different minerals forming the rocks are heated and expand at different rates.
- At night, the minerals lose heat and contract at different rates.
- The repeated differential expansion and cooling causes strain and stress within the rocks causing individual rock grains to break off from the main rock mass as *granular disintegration*

- **Aridity shrinkage or slaking**- is common in rocks which contain clay. Such rocks absorb water during rainy season and swell/expand, while during dry season they lose water through evaporation and shrink. This causes alternate wetting and drying of the rock mass. Repeated alternate expansion and contraction eventually cause them to weaken and crumble into small elongated pieces. This kind of weathering is common in swamps or areas with clay.

- **Frost wedging/Frost** shattering -Frost weathering or freeze-thaw weathering occurs in regions with temperature fluctuations around the freezing point. It is common in places where temperature falls below 0^0C such glaciated mountain tops. During the day snow or ice melts and water enters into rock crevices/ cracks. At night water in these cracks solidifies and expands causing the cracks to widen. During the day ice in the cracks melts and moves deeper into the crack. This alternate freeze and thaw process builds pressure that causes breaking up of rocks into small pieces.

Unloading/ pressure release Deeply seated igneous and metamorphic rocks are under pressure from the overlying rocks.

Pressure release weathering happens when overlying rock layers erode away, reducing the pressure on underlying rocks. Lowering the pressure makes the rock expand and fracture parallel to the surface. Granite domes are an example of a feature that results from this process.

Salt crystallization/ Salt Weathering

- Occurs due to growth of salt crystals after evaporation of water that contained dissolved minerals from the cracks.
- During the long dry season, water in the rocks is drawn to the surface through capillary action.
- High temperatures make the water to evaporate depositing tiny salt particles in the rock cracks and pores.
- The salt crystals accumulate and grow inside, exerting pressure and widening the cracks further.
- Eventually the rock pieces fall off leading to weathering. This process is known as

Biological Contributions to mechanical weathering

Plants and animals also contribute to physical weathering. Roots growing into rock crevices exert pressure and cause mechanical fracturing. Burrowing animals drill rocks and aid in their breakdown.

Root wedging: As roots grow and penetrate rocks, they apply pressure, and can push joints open eventually causing weathering

Animal impact: Animal life also contributes to physical weathering: burrowing creatures, from earthworms to gophers, push open cracks and move rock fragments.

When we excavate quarries, foundations, mines, or roadbeds by digging and blasting, we shatter and displace rocks that might otherwise have remained intact for millions of years more.

Chemical Weathering

Chemical weathering is the decomposition of rocks due to chemical reaction that takes place between the rock minerals, water and atmospheric gases like oxygen and carbon dioxide causing changes in chemical composition. Chemical weathering dominates areas of heavy rainfall and high temperatures

It is a process of alteration of rocks of the crust by chemical decomposition brought about by atmospheric gases and moisture. The chemical change in the nature of the rock takes place in the presence of moisture containing many active gases from the atmosphere such as carbon dioxide, nitrogen, hydrogen and oxygen.

Rocks are made up of minerals, all of which are not in chemical equilibrium with the atmosphere around them. Chemical weathering is, essentially a process of chemical reactions between the surfaces of rocks and the atmospheric gases in the direction of establishing a chemical equilibrium. The end product of chemical weathering has a different chemical composition and poorer physical constitution as compared to the parent rock.

Chemical weathering eats up the rocks in a number of ways depending upon their mineralogical composition and the nature of chemical environment surrounding them.

Chemical weathering changes the composition of rocks, often transforming them when water interacts with minerals to create various chemical reactions. Chemical weathering is a gradual and ongoing process as the mineralogy of the rock adjusts to the near surface environment. New or secondary minerals develop from the original minerals of the rock. In this the processes of oxidation and hydrolysis are most important. Chemical weathering is enhanced by such geological agents as the presence of water and oxygen, as well as by such biological agents as the acids produced by microbial and plant-root metabolism.

Chemical weathering involves the chemical alteration of minerals within rocks, forming new minerals and soluble salts. This type of weathering contributes to soil formation.

The following are some of the main processes of chemical weathering:

(a) Solution,

(b) Hydration and Hydrolysis,

(c) Oxidation and Reduction,

(d) Carbonation

(e) biotic impact

(a) Solution:

Some rocks contain one or more minerals that are soluble in water to some extent. Rock salt, gypsum and calcite are few common examples. It is also well known that though pure water is not a good solvent of minerals in most cases, but when it (the water) is carbonated, its solvent action for many common minerals is enhanced. This process involves removal of solids in solution and depends upon solubility of a mineral in water or weak acids.On coming in contact with water many solids disintegrate and mix up as suspension in water. Soluble rock forming minerals like nitrates, sulphates, and potassium etc. are affected by this process. So, these minerals are easily leached out without leaving any residue in rainy climates and accumulate in dry regions. Minerals like calcium carbonate and calcium magnesium bicarbonate present in limestone are soluble in water containing carbonic acid (formed with the addition of carbon dioxide in water), and are carried away in water as solution. Carbon dioxide producedby decaying organic matter along with soil water greatly aids in this reaction. Common salt (sodium chloride) is also a rock forming mineral and is susceptible to this process of solution.

(b) Hydrolysis:

This is a process in which hydrogen ions/hydroxyl ions in water react with mineral ions in a rock. This reaction leads to formation of new chemical compounds in the rocks.

With alteration of the original minerals, the rock becomes weak and disintegrates/decays. For example, when felspar reacts with hydrogen, it decomposes into clay. The clay weakens the rock making it more likely to break.

c) Hydration is the chemical addition of water.

Certain minerals in a rock absorb water causing them to swell and expand. As they swell, the rock mass expands creating internal stress within the rock that leads to disintegration of the rock. For example, Calcium sulphate takes in water and turns to gypsum, which is more unstable than calcium sulphate.

(d) Oxidation

Iron is a chief constituent of many minerals and rocks. The iron bearing minerals (and hence rocks) are especially prone to chemical weathering through the process of oxidation and reduction.

Oxidation: In weathering, oxidation means a combinationof a mineral with oxygen to form oxides or hydroxides. Oxidation occurs where there is ready access to the atmosphere and oxygenated waters. The minerals mostcommonly involved in this process are iron, manganese, Sulphur etc. In the process ofoxidation rock breakdown occurs due to the disturbance caused by addition of oxygen. Red color of iron upon oxidation turns to brown or yellow. Oxidation reactions in rocks transform iron bearing minerals (such as biotite and pyrite) into a rusty brown mixture of various iron-oxide and iron-hydroxide minerals. In effect, iron-bearing rocks can "rust."

Ferric iron is not stable and is further oxidized to a stable ferric hydroxide:

(i) $4Fe + 3O_2 \rightarrow 2Fe_2O_3$

(ii) $Fe_2O_3 \rightarrow Fe_2O_3.H_2O$

e) Reduction:

When oxidized minerals are placed in an environment where oxygen is absent, reduction takes place. Such conditions exist usually below the water table, in areas of stagnant water and waterlogged ground or swampy places. Anaerobic bacteria uses up the limited oxygen leaving behind hydrogen which reacts with rock minerals to form new compounds. The redcolour of iron upon reduction turns to greenishor bluish grey.

f) Carbonation:

Carbonation occurs when carbon dioxide dissolves in water and forms weak carbonic acid. The acid reacts with minerals like calcium carbonate in rocks and breaks them up. It is the process of weathering of rocks under the combined action of atmospheric carbon dioxide and moisture, which on combination form a mildly reacting carbonic acid. The acid so formed exerts an especially corrosive action over a number of silicates bearing rocks. The silicates of potassium, sodium and calcium are particularly vulnerable to decay under conditions of carbonation. Similarly, Calcium carbonates and magnesium carbonates in rocks are dissolved in carbonic acid and are removed in a solution without leaving any residue resulting in cave formation

A typical example is that of felspar orthoclase, a very common and important constituent of many igneous, sedimentary and metamorphic rocks, which decomposes according to following reaction-

$$\underset{\text{(Orthoclase)}}{2KalSi_3O_8} + \underset{\text{Carbonic acid}}{2H_2O + CO_2} \longrightarrow \underset{\text{(Kaolinite)}}{Al_2Si_2O_5(OH)_4} + \underset{\text{(Pot. Carbonate)}}{K_2CO_3} + \underset{\text{Silica}}{4SiO_2}$$

The end products in the above reaction are a clay mineral, a soluble bicarbonate and silica. Further, in the above equation, Na or Ca may be present instead of K if the mineral in question is another type of felspar. The main end product, Kaolinite, is formed in all such cases.

Only the soluble carbonate differs in accordance with the metallic ions of the felspar type. This chemical change in the rock produces definite alteration in the physical constitution of the rock- a soft (H = 1) clay mineral is formed in place of a hard mineral (felspar, H = 6), thereby affecting the strength of the rock very significantly.

Carbonates are removed in solution and silica forms colloids; this may result in partial or total conversion of a strong igneous rock like granite into a mass of soft clay like product in the zone of weathering. Many igneous rocks like granites, granodiorites, syenites, basalts and porphyries suffer this type of weathering on a massive scale, as felspars are their chief constituent minerals.

g) Spheroidal Weathering:

It is a complex type of weathering observed in jointed rocks and characterized with the breaking of original rock mass into spheroidal blocks. Both mechanical and chemical weathering is believed to actively cooperate in causing spheroidal weathering.

The original solid rock mass is split into small blocks by development of parallel joints due to thermal effects (insolation). Simultaneously, the chemical weathering processes corrode the borders and surfaces of the blocks transforming their shapes roughly into spheroidal contours.

BIOLOGICAL ACTIVITY AND WEATHERING

- Decaying plant and animal matter help in theproduction of humic, carbonic and other acidswhich enhance decay and solubility of some elements. Plant roots exert a tremendous pressure on the earth materials mechanicallybreaking them apart. Plants use their roots to extract nutrients from rocks and therefore cause a change in the composition of those rocks. Also the decaying of plants and animals results in the formation of humus, which mixes with rain water and forms humic acid that further decomposes rock minerals.
- Human activities have led to disintegration/decay of rocks such as quarrying, application of fertilizers, garbage/sewage disposal, industrialization etc.
- Burrowing animals such as rodents also break surface *rocks* as they create passages in rocks through which water vapour, gases pass to react chemically with minerals. In particular, these animals create holes in the ground by excavation and move the rock fragments to the surface. As a result, these fragments become more exposed to other environmental factors that can further enhance their weathering.
- An animal called the **Piddock shell** can drill into rocks for it to protect itself. By producing acids that can disintegrate the rock and turn it into fragments, it can create cracks and fractures and eat the minerals found in it

- The roots of plants/trees can force apart joints and cracks in rocks as they grow and enlarge
  - Hooved animals like cattle and elephants exert pressure on the rocks as they walk directly on them leading to breaking and disintegration.
  - Some animals also excrete chemical substances/acids that when in contact with the rocks may lead to chemical weathering

The minerals in rocks are liberated when a fungus releases chemicals that can break them down. Such minerals are then consumed by the alga, further causing the wearing and development of cracks and gaps in the rock. As a result, cracked rocks become more prone to disintegration.

Bacteria existing in leguminous plants absorb nitrogen to produce nitric acid which reacts with parent rock to form new compounds

Hydrogen ions (H^+) are known to be released at the roots of plants during their growth and metabolism. These ions are capable of replacing K+, Ca++ and Mg++ ions from the minerals and rocks surrounding the root system and make them available for use in plant growth. But in this process, the original minerals and rocks around the root system start undergoing decomposition and disintegration. Root systems of conifers and other big trees creep into pre-existing cracks in the nearby rocks. Often this results in loosening apart of the stone fragments followed by their rolling down slope.

Plants, fungi, and bacteria contribute to chemical weathering through the production of organic acids which enhance mineral breakdown. Bird droppings and bat guano and the chemicals released by lichens also cause chemical weathering.

A number of plants and animals may create chemical weathering through release of acidic compounds, i.e. the effect of moss growing on roofs is classed as weathering. Mineral weathering can also be initiated or accelerated by soil microorganisms. Lichens on rocks are thought to increase chemical weathering rates.

Chelation/humification-The decomposition of the remains of dead plants in the soil can form organic acids such as humic acid which can penetrate rocks through cracks and decompose them.

Human impact on weathering

Human activities can have a significant impact on weathering processes. Here are some ways in which human activities can affect weathering:

1. Land use changes: Human activities such as deforestation, urbanization, and agriculture can alter the natural landscape and affect the rate and type of weathering that occurs. For

example, deforestation can lead to increased soil erosion and decreased plant cover, leading to increased chemical weathering of rocks and soil.

2. Mining and excavation: Mining and excavation activities can remove large quantities of rocks and minerals, leading to significant changes in the local geology and weathering patterns. These activities can also increase the exposure of rocks and minerals to natural agents such as water and air, leading to accelerated weathering.
3. Industrial activities: Industrial activities such as fossil fuel combustion and manufacturing can release pollutants into the air and water, which can react with rocks and minerals and contribute to chemical weathering. Additionally, the construction of buildings and infrastructure can alter the local landscape and affect the natural processes of weathering and erosion.
4. Climate change: Human activities such as the burning of fossil fuels and deforestation can contribute to global climate change, which can alter the temperature and precipitation patterns in a given area. These changes can affect the type and rate of weathering that occurs, as well as other natural processes such as erosion and sedimentation.
5. Bush fires caused by human cause differential heating rocks leading to exfoliation.

Factors Affecting Weathering:

(i) Nature of the Rock:

Rocks vary in chemical composition and physical constitution. Some rocks are easily affected by weathering processes in a particular environment whereas others may get only slightly affected and still others may remain totally unaffected under the same conditions.

Thus, of granite and sandstones exposed to atmosphere simultaneously in the same or adjoining areas having hot and humid climate, the sandstone will resist weathering to a great extent because they are made up mainly of quartz (SiO_2) which is highly weathering resistant mineral.

Granites, on the other hand, are likely to undergo a lot of chemical decay due to carbonation, hydration and hydrolysis etc. Hence, chemical composition of the rock is an important factor in determining the stability or otherwise of a rock in a given environment.

The type of rock being weathered is also an important factor. Some rocks, such as granite and basalt, are more resistant to weathering due to their dense and hard composition. In contrast, sedimentary rocks, such as sandstone and limestone, are often more susceptible to weathering due to their porous nature and the presence of minerals that can dissolve in water. Additionally, rocks that contain iron and other minerals that are prone to oxidation are more susceptible to chemical weathering. This is because gases and moisture find easy pathways into the body of rock through the fractures and act from many places.

(ii) Climate:

The process of weathering is intimately related to the climatic conditions prevailing in an area. Same types of rocks exposed in three or more types of climates may show entirely different trends of weathering.

Thus, cold and humid conditions favour both chemical and mechanical types of weathering, whereas in totally dry and cold climates, mechanical weathering may be quite conspicuous (due to absence of moisture). Similarly, in hot and humid climates, chemical weathering processes predominate whereas in hot and dry climates (the arid areas) mechanical breakdown due to expansion and contraction of the rocks at the surface may be more pronounced.

The climate of a particular area can greatly influence the type and rate of weathering that occurs. In regions with high rainfall and high humidity, chemical weathering is more common, as water reacts with minerals in rocks to create new compounds. In contrast, areas with extreme temperature changes, such as those that experience freeze-thaw cycles, experience mechanical weathering due to the expansion and contraction of water in rocks. Additionally, areas with strong winds can cause abrasion and wear on exposed rock surfaces.

ROLE OF CLIMATE IN WEATHERING OF ROCKS

Climate plays a significant role in the process of weathering, which is the breaking down or alteration of rocks and minerals on the Earth's surface through contact with the atmosphere, water, and biological activity. Climate controls the ***intensity and types*** of these processes, shaping the landscape and influencing the rate at which rocks and minerals are weathered. However, the specific ways in which climate affects weathering can vary depending on the specific climate conditions and the types of rocks and minerals present. There are several ways in which climate can affect weathering, including:

1. Temperature

Higher temperatures can increase the rate of weathering by promoting chemical reactions that break down rocks and minerals. For every 10°C increase in temperature, the rate of chemical reactions can double. Warm, humid climates facilitate rapid breakdown of minerals through increased rates of hydrolysis and oxidation

Fluctuations in temperature can cause minerals to expand and contract, leading to cracks and fractures that can further facilitate mechanical processes such as exfoliation.

A study published in the journal “Earth Surface Processes and Landforms” found that higher temperatures led to an increase in the rate of weathering, with the greatest effect occurring at temperatures above 35°C (95°F).

In colder climates, Frost Wedging is prevalent due to repeated freeze-thaw cycles that fracture rocks.

In contrast, warmer climates experience more thermal expansion-related weathering due to greater temperature fluctuations.

2. Precipitation / Rainfall

Rain, snow, and other forms of precipitation can also contribute to chemical weathering by providing water that can dissolve minerals and rocks by the process of hydrolysis. For example, water that contains dissolved carbon dioxide can create a weak acid that can dissolve limestone, leading to the formation of caves and other features by the process of carbonation.

Increased precipitation enhances chemical weathering rates as more water facilitates reactions like hydrolysis and carbonation.

In humid climates, abundant moisture leads to faster breakdown of rocks compared to arid regions where water availability is limited.

In arid climates, Limited precipitation results in slower rates of chemical weathering. Mechanical weathering processes like thermal expansion become more dominant due to significant temperature swings during day and night

A study published in the journal “Earth Surface Processes and Landforms” found that higher levels of precipitation led to an increase in the rate of weathering, with the greatest effect occurring at levels of precipitation above 100 mm (4 inches) per year.

4. Humidity

In tropical climates, which are characterized by high humidity and frequent precipitation, weathering processes can be driven by a combination of water and biological activity. High humidity can promote the growth of plants and other forms of vegetation, which aid chemical and mechanical processes of weathering. For example, vegetation can release acids and other chemicals that aid the breakdown of rocks and minerals.

In addition, frequent rainfall can provide water that facilitates chemical and mechanical breakdown of rocks.

One study published in the journal “Geomorphology” analyzed the rocks in humid and dry regions of Brazil and found that higher humidity levels were associated with faster rates of hygroscopic weathering, while lower humidity levels led to slower rates.

5. Dryness and winds

Arid climates, which are characterized by low humidity and little precipitation, can lead to these processes that are primarily driven by temperature and wind. For example, in desert regions, the intense heat and dryness can cause rocks and minerals to crack and break down due to thermal expansion and contraction.

In addition, strong winds can pick up and transport sand and other fine particles, which can act as abrasive tools and contribute to the breakdown of rocks and minerals.

6. Glacial climate affect weathering

In glacial climates, which are characterized by cold temperatures and the presence of glaciers, weathering can be driven by the mechanical force of ice. For example, glaciers can grind and abrade the surface of rocks and minerals as they move.

In addition, the melting of glaciers can produce large volumes of water that can promote faster weathering.

(iii) Physical Environment:

The topography of the area where rocks are directly exposed to the atmosphere also affects the rate of weathering to a good extent. Rocks forming bare cliffs, mountain slopes devoid of vegetation and valley sides are more prone to weathering than same rocks exposed in level lands in similar climates and/or under vegetable cover.

This is because in the first case the slopes assist in removal of the weathering end product comparatively faster and make fresh rock surface available for weathering. In the second case the weathered product accumulates over the parent rock and slows down the further destruction.

- **Topography**: Slope and aspect affect moisture retention and exposure to environmental forces, influencing weathering rates.
- **Vegetation**: Plant roots and organic acid production accelerate both physical and chemical weathering.
- **Time**: The duration of exposure to weathering processes affects the extent of rock degradation.

Bryce Canyon National Park

Landforms resulting from chemical weathering

Stalactite and stalagmite: These are formed through carbonation. Rain water combines with carbon dioxide in the atmosphere to form weak carbonic acid which dissolves calcium carbonate to form calcium bi carbonate. When solution reaches underground cave, calcium carbonate is deposited on roof of the cave to form stalagmite e.g. at Nyakasura in Western Uganda.

Pillars: These are vertical stands of calcium carbonate formed in underground caves when stalactites and stalagmites continue to grow towards each other and eventually join. Examples arc found at Nyakasura and Tanga.

Caves: A cave is a natural underground space. It is formed when there is chemical dissolution of limestone or dolomite. The rock is dissolved by natural acid in ground water that seeps through the bedding planes, faults and joints.

Grikes and Clints: Grikes are hollows or depressions while Clints are ridges formed as a result of carbonation. They form in limestone areas with rocks of different chemical composition. Lime stone is dissolved by acidic rain to form depressions/ hollows called Grikes while dissolved rocks form ridges called Clints/ Limestone pavement. Examples are found on the western side of Tororo rock, Karasuka in Karamoja, Nyakasura etc.

Arenas/Sink holes: A sink hole is a natural depression or hole in earth's surface formed when lime stone is dissolved. It is formed through the processes of removal of soluble rock by percolating water and the collapse of roof cave.

Dolines: These are larger than sinkholes. These are shallow circular depressions formed either by solution of the surface lime stone or by collapse of underlying caves. In latter case they are called collapse doline.

Polje: This is an elongated basin having a flat floor and steep walls. The poljes are formed by coalescence of several sinkholes when being formed through carbonation and solution. In some poljes, small residual hills known as hums are formed.

Limestone gorge is deep steep-sided valley formed when acid rain seeps into the cracks in limestone rocks or when a larger river erodes/ weathers soft limestone rocks by solution.

Duricrust is a hard crust (layer) found on the surface formed from mineral precipitation i.e. deposition of insoluble materials from a solution. The most common in East Africa is lateritic duricrust formed when the weathered layer become impregnated with iron solution due to leaching. On removal of top layer laterite hardens into duricrust like on flat topped hills of Buganda/ laterite terms·.

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TOPIC: VULCANIC PROCESSES AND LANDFORMS

Vulcanism or Vulcanicity is the phenomenon of eruption of molten rock (magma) onto the surface of the Earth or into the earth's crust. Lava, pyroclastic, and volcanic gases erupt through a break in the crust called a vent or fissure. Hence, during volcanism, liquid, semi-liquid, solid and gaseous materials are ejected from the mantle towards the earth's surface. Some of these volcanic materials may reach the earth's surface while others may get trapped in the rocks of the crust below the surface.

Vulcanicity takes place when high temperature and pressure build up in the mantle. The high temperature is due to radioactivity, geochemical reactions and friction at plate boundaries while high pressure results from the weight of overlying crustal rocks on the mantle, expansion of melting solid crust and evaporation of molten magma.

When magma outpours onto the surface it loses its gases and becomes lava. Lava/magma may be acidic due to high proportion of silica (above 66%) or basic due to low content of silica. Acidic lava is viscous and largely immobile. It solidifies quickly to form steep landforms and therefore does not spread over a wide area. Basic and ultra-basic lava is less viscous and hence takes long to solidify. It spreads over wide areas forming extensive lava plains and large shield domes (volcanoes with a broad base and gently sloping sides formed of basaltic lava). As it flows on the surface, it fills shallow valleys and may cover low hills to form relatively level land surface.

Products of Volcanic Eruption

Volcanic eruptions can produce a variety of materials that are collectively known as volcanic products. These materials can have significant impacts on the environment, climate, and human settlements. The main volcanic products include:

Gases

It is assumed that interactions between the gases contained in molten magma increase pressure and heat within the ascending lavas which results in explosive activity. Therefore, the most explosive eruptions are probably the consequence of gas-rich magmas.

- **Water Vapor:** The most abundant volcanic gas, released during the degassing of magma.
- **Carbon Dioxide (CO2):** A greenhouse gas that contributes to climate change when released in large quantities.
- **Sulfur Dioxide (SO2):** Can contribute to air pollution and acid rain when released into the atmosphere.
- **Hydrogen Sulfide (H2S):** Another sulfur-containing gas released during volcanic activity.

Volcanoes also emit methane (CH4), nitrogen and ammonia (NH3) but in trace amounts. They also have an important effect on the regional and global environment and may contribute greenhouse gases to the atmosphere.

Role of Gases in Volcanic Activity: Gases dissolved in magma play a critical role in determining the behavior of volcanic eruptions:

1. **Explosivity:** The presence of volatile gases, such as water vapor and carbon dioxide, can increase the pressure within the magma, leading to more explosive eruptions.

2. **Viscosity;** The amount of gas in magma can influence the magma's viscosity. Higher gas content tends to reduce magma viscosity, allowing it to flow more easily.

3. **Gas Release:** As magma approaches the surface, decreasing pressure allows gases to rapidly exsolve (separate) from the magma, forming bubbles that can propel magma fragments and ash into the air.

Solid

When fragments are blown out by explosive eruptions, solid materials are ejected, known generally as pyroclastic materials or pyro clasts (Pyro = Fire Clast = Fragments). The term tephra covers all the pyroclastic debris that collect through vertical air fall.

Solid volcanic products, also known as pyroclast or tephra, vary in size, composition and origin.

- ❖ Volcanic ash consists of very fine particles of less than 2mm across of shattered rock, glass and minerals. They can remain suspended in the air for a long time and can travel long distances affecting air quality and aviation.
- ❖ Lapilli- are pebble-sized fragments with a diameter of 2-64mm. can be formed from magma droplets that cool and solidify mid-air or from shattered rock. May fall around the vent or be carried some distance away by the wind
- ❖ Volcanic bombs- are large fragments that form from semi molten particles of lava that harden in the air before falling to the ground. They are more than 64mm across.

Liquid

Lava is molten rock that erupts from a volcano and flows across the Earth's surface. It can vary in composition, with basaltic lava being the most common type. Other types include andesitic and rhyolitic lava.

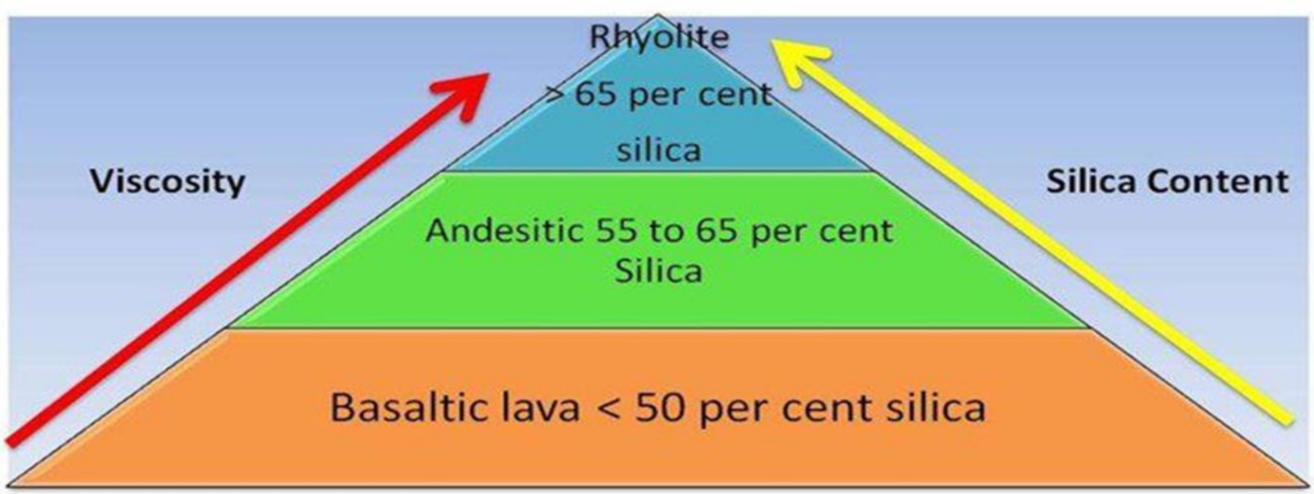
Lava flows can take different forms, such as pahoehoe (smooth, rope-like flows) and aa (rough, blocky flows). The viscosity of the lava plays a key role in determining the flow type.

Lava is classified into three types on the basis of proportion of silica content: Basaltic (or basic or mafic), Andesitic (or intermediate), and Rhyolitic (or silic).

The Figure shows that Basaltic lava has less than 50 per cent silica, Andesitic has 55 to 65 per cent Silica and the Rhyolite contains more than 65 per cent silica. The figure also demonstrates that with the increase in silica in the lava the viscosity of lava also increases.

Tephra: General Term that refers to any volcanic material ejected into the air during an eruption, including ash, lapilli, and volcanic bombs. Tephra can fall back to the ground near the vent or be carried by wind over long distances.

Lahar: A type of volcanic mudflow or debris flow, often triggered by the rapid melting of snow or ice on the volcano during an eruption. Lahars contain a mixture of water, volcanic ash, and rock debris. They can travel long distances from the source, posing a significant threat to downstream areas.



FORMS OF VOLCANIC ERUPTIONS

Volcanic eruptions are dynamic and complex events involving the release of magma, gases, and other volcanic materials from the Earth's interior towards the surface. Volcanic activity can take various forms, ranging from relatively gentle effusive eruptions to explosive, cataclysmic events.

1. **Effusive Eruptions:** are eruptions where magma reaches the surface and flows relatively gently, often producing lava flows. The viscosity of the magma plays a crucial role, with low-viscosity basaltic magma producing more fluid lava flows. Effusive eruptions are commonly associated with shield volcanoes, where basaltic lava can travel long distances, creating broad, low-angle slopes.

2. **Explosive Eruptions:** are eruptions that involve the rapid release of trapped gases creating powerful explosions of magma fragments, ash clouds, pyroclastic flows, and volcanic bombs. The explosiveness is often linked to higher-viscosity magmas, which trap gases until pressure is released.
Stratovolcanoes are frequently associated with explosive eruptions due to their composition, which includes more viscous magma types like andesite and rhyolite.

3. **Phreatomagmatic Eruptions:** These eruptions occur when magma comes into contact with water, such as groundwater, lakes, or oceans. The interaction between water and magma leads to explosive steam-driven eruptions, generating fine ash and forming craters. These eruptions can occur at various types of volcanoes.

VULCANIC PROCESSES

Volcanism/Extrusive vulcanicity- refers to the process where magma outpours onto the earth's surface, solidifies and forms various landforms such as lava flows, pyroclastic deposits and other surface volcanic features.

Plutonic/intrusive vulcanicity- refers to the process where magma cools and solidifies beneath the earth's surface forming various landforms. Intrusive activity takes place underground creating rock formations that may later get exposed through processes of denudation. The magma may spread, accumulate or remain in the passage within the crustal rocks where it cools, solidifies to form intrusive igneous landforms.

Extrusive Volcanic Landforms

Volcanic activity gives rise to a diverse range of landforms on the Earth's surface. These formations are a result of various volcanic processes, including the eruption of lava, the accumulation of volcanic debris, and the modification of the landscape over time.

When magma erupts to the surface as lava, it can form different volcanic landforms depending on:

- The viscosity or stickiness of the magma
- The amount of gas in the magma
- The composition of the magma (elements present) which determine the acidity of the magma
- The way in which the magma reaches the surface- through a central vent or side vent or fissures.

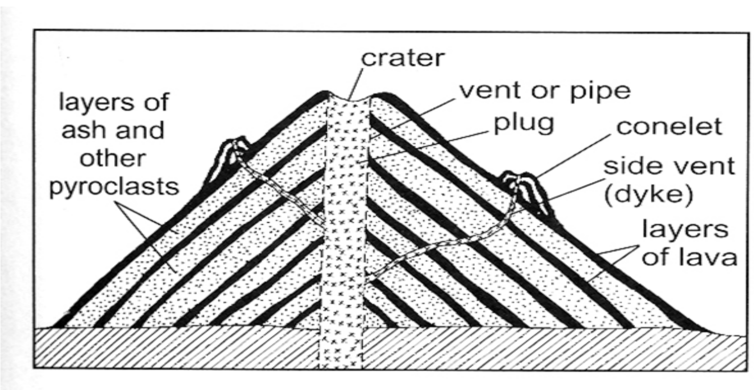
Viscosity is an important factor in volcanology. An eruption of highly viscous (very sticky) magma tends to produce steep-sided volcanoes. That's because viscous volcanic material does not flow far from where it is erupted, so it builds up in layers forming a cone-shaped volcano known as a stratovolcano. Shield volcanoes on the other hand have gentle slopes that are less than 10^{o} and erupt more fluid lavas called basaltic lava. When a shield volcano erupts, the basalt can flow great distances away from the vent to produce a broad-based hill with gentle slopes. Basaltic lava is runny and takes longer time to cool and solidify.

Ash and cinder cones

These are small steep-sided cone-shaped hills usually less than 200m formed by very violet eruption of many fragments of various sizes. The gas-charged lava is blown with great force into the air. It breaks into small fragments and solidifies. These solid materials fall back to the ground and build up around the vent. They are formed of loose pyroclastic fragments such as volcanic ash, solidified lava particles, clinkers and scoria which build up around a volcanic vent. These hills have slopes of between 30- 40^{0} and a nearly circular base. Most cinder cones have a bowl-shaped crater at the summit. Examples in East Africa include Teleki, Likaiyu, in Kenya and Muganza, sagitwe in Uganda

Composite volcanic cones/ strato-volcanoes

These are usually large volcanic cones with fairly steep slopes. They are made of alternate layers of ash and lava ejected through a central vent over a long period of time. Each layer of lava over ash represents a phase of eruption. They are tall and conical in shape. They rise in height with every subsequent eruption. Examples of composite cones/ strato volcanoes are Mt. Kilimanjaro, Meru, Mt Mubabura on Uganda – Rwanda border



Shield volcano

- A shield volcano is a broad volcano with gently-sloping sides that is formed mainly out of runny lava that flows out through a central vent.
- **Formation:**

  - A non-violent vent eruption leads to the outpouring of basic lava.
  - On reaching the earth surface, the fluid lava flows in all directions around the vent covering long distance before cooling and solidifying.
  - Successive eruptions release basic lava which covers the old lava.
  - This leads to the formation of a gently sloping volcanic cone that is short and has a broad base called **basic lava domes/cones.**

They are built by repeated eruptions of basic lava that occurred intermittently over vast periods of time. As such, shield volcanoes form from layers of lava. When these volcanoes erupt, the basic lava flows far from the vent since it is less viscous. Shield volcanoes are therefore much wider than they are tall. Examples include Nyamulangira volcano in Eastern DR Congo.

Lava plateaus

A lava plateau is upland with a monotonous relief formed by successive layers of lava. It's formed by quiet eruptions of basic and therefore highly fluid lava. The lava outpours to the surface through numerous vents/ fissures/ cracks without violent eruptions and spreads out over a long distance covering any original valleys and hills on the landscape before solidifying as a sheet of basalt. The lava eruption is non-violent due to the low viscosity and low gas content. Multiple successive and extensive lava flows cover the original landscape to eventually form a raised relatively flat landscape called lava plateau. Repeated fissure eruptions lead to the building of thick and high plateau which may reach 6000feet high. Examples include the Laikipia plateau in Kenya, Yatta plateau, Kisoro lava plateau, etc.

Volcanic plug or **volcanic neck or puys**

A Volcanic plug/ neck is a geographical formation that occurs when lava cools and hardens inside a vent of an active volcano and later exposed by the erosion of the surrounding cone. Volcanic plugs are revealed when the surrounding land is eroded. The plug is usually harder than the surrounding rock. Erosion removes the surrounding rock while the resistant plug remains upstanding. Examples include; Mawenzi peak on Mt. Kilimanjaro, Batian and Nelion peaks on Mt Kenya, etc

Volcanic islands

Volcanic islands are landforms created by the eruption of volcanoes beneath the ocean surface, leading to the accumulation of volcanic materials above sea level. Islands such as Hawaii, Iceland, and the Galápagos were formed through volcanic activity.

Aerial view of White Island, the volcanic island in the Bay of Plenty, North Island, New Zealand.

Cumulo lava dome

Cumulo dome is a steep-sided mound that is formed when lava reaching the Earth's surface is so viscous that it cannot flow away from the vent easily after it is extruded. Instead, it piles up around the vent forming a large, dome-shaped mass of volcanic material known as a lava dome. Some lava domes develop spines at the top while other may have a crater. Examples are Ntumbi cumulo dome in Tanzania, Gombe and Nakasongola domes in Uganda. In Kenya, they are found in the Tsavo National Park, Thalloids are found in a Caldera on top of Mt Rungwe in Tanzania.

parasitic cone/ conelet

- The pressure in the magma chamber reduces causing the magma from the earth's interior to fail to reach the top of the volcano.
- The upper part of the main vent of the volcano gets blocked by solidified lava.
- When Pressure builds up again, magma is forced to escape through a side vent.
- The successive outpouring of magma through the side vent builds alternate layers of ash and lava to form a conelet on the side of the composite volcano.
- This conelet is also **parasitic cone.**

Volcanic Depressions such as caldera and crater

During the formation of a volcano

Eruption of lava through a central vent cause building up of a volcanic cone.

The lava in the vent cools and contracts.

The cool lava retreats/ withdraws into the vent leaving a shallow depression at the top of the volcano known as **crater.**

Formation due to volcanic explosion

Out pouring of lava forms a volcanic cone. The central or side vents may be sealed when lava solidifies in them. This leads to piling of pressure below the plug.

The building of pressure underneath may lead to a violent explosion which blows the top of the volcanic cone leaving a funnel shaped depression called **a crater.**

Caldera

Magma is stored beneath a volcano in a magma chamber. When a very large volume of magma is extruded by an eruption, the magma chamber is emptied leading to collapse of the roof of the chamber. This forms a bowl-shaped depression with very steep walls known as a caldera. A caldera is a depression created after a volcano partially collapses after releasing the majority of its magma chamber in an explosive eruption. e.g. Ngorongoro.

Formation by violent eruption-

Lava pours out of a central vent to form a volcanic cone. The vent is sealed when lava solidifies in it. The solidified lava blocks the gases and steam beneath, preventing them from escaping. Pressure piles up below the lava. The pressure leads to violent eruption which blows off the top of the cone forming a depression. The depression is large and circular and it is known as **an explosion caldera.** Examples of explosion caldera are Sabino (Uganda), Nyamlagira and Nyiragongo (DRC), Trou au Natron (Chad), others are found on Mounts Suswa and Longonot

Hot springs, Geysers and Fumaroles

Hot springs are points on the surface where geothermally heated groundwater emerges from the earth’s crust. Rain water percolates into the ground through joints and cracks. The water gets into contact with hot rocks seated above magma. The water gets superheated. Pressure builds in the water as some turns into steam. The water finds a crack in the crustal rocks and flows to the surface forming a hot spring. Most hot springs discharge groundwater that is heated by shallow intrusions of magma (molten rock) in volcanic areas, or rocks heated by the magma. Examples are found at Kitagata and Sempaya, Rwagimba, Ilimbo and Kisizi in Uganda. Majimoto in Tanzania, etc.

Geyser is a rare kind of hot spring that is under pressure and erupts, sending jets of hot water and steam into the air. They involve periodical ejection of steam and hot water from the country rocks. They are formed when underground water is heated by super-heated rocks which are in contact with magma. The heat in the magma is generated by radioactive reactions in the mantle. The water becomes super-hot and begins to boil. The boiling water begins to steam or turn into gas. This builds a lot of pressure. This pressure powerfully ejects jets of water and steam through thin or narrow openings. The eruption continues until all the water is forced out or until the temperature drops. After the eruption, water slowly seeps back into the ground and the same process is periodically repeated. Examples of geyser are found at L. Bogoria and Olkaria in Kenya.

Fumaroles are openings in the earth's surface that emit steam/ water vapour and volcanic gases, such as sulfur dioxide and carbon dioxide. They can occur as holes, cracks or fissures near active volcanoes or areas where magma has risen into the crust without erupting. The steam is produced by ground water that is heated by hot crustal rocks while the gases are emitted by magma cooling deep below the surface. Examples are found in the craters of Mt. Kilimanjaro, Mt. Longonot in Kenya rift valley. A fumarole that gives off significant sulfur compounds is known as a **solfatara.**

Intrusive features formed by vulcanicity

Batholith

A batholith is a very large dome shaped intrusion of igneous rock that forms when magma rises into the earth's crust and solidifies below the surface without erupting. Batholiths are normally composed of hard and resistant granite rocks but may be exposed by denudation process such as erosion and weathering. Examples of Batholiths are Mubende Batholith, Nakasongola, Luwero and Singo Batholiths. In Kumi there is Kachumbala Batholith, and Kakamaya in Kenya. In Tanzania they are found at Mwanza (Bismack rock) and Sukuma land.

Inselbergs

The term inselberg comes from two German words, *insel* which means island and *berg* which means mountain. It was coined by Walter Bornhardt, a German naturalist and traveller, after observing isolated rocky hills that rose steeply from Eat Africa's savanna plains as though they were islands in the sea. An inselberg is an isolated hill of hard volcanic rocks that has resisted denudation processes such as erosion and weathering. Inselbergs are found sitting in relatively flat to gently sloping surrounding land area. Inselbergs rise abruptly from an extensive, nearly flat plain. An inselberg results when a mass of resistant rock, such as granite, occurring in an area of softer rocks, is exposed by differential erosion and lowering of the surrounding landscape.

Volcanic activity gives rise to a body of rock resistant to erosion in an area of softer rocks such as limestone, which is more susceptible to erosion. When the less resistant rock is eroded away, the more resistant rock is left behind standing as an isolated mountain. The strength of the hard rock is due to its jointing. Examples include exposed batholiths in Mubende, Singo, Parabong, Nakasongola, Labwor hills, kyenjojo, between Iringa and Mwanza in Tanzania etc.

Dykes.

These are vertical (wall -like) or steeply inclined igneous rock structures, cutting across rock strata. They are formed from intrusion of magma solidifying into igneous rock structure along vertical fissures/ lines of weaknesses. They vary from few centimeters to hundreds of meters. They are always discordant cutting across the bedding planes of rock strata.

Ridges

A ridge is a long, narrow, elevated geomorphologic landform, structural feature, or a combination of both separated from the surrounding terrain by steep sides. They are formed by linear accumulation of lava on the surface of the earth. Ridges may also form when a resistant dyke is exposed to the surface after the less resistant surrounding rock is eroded. Examples of ridges include those in Busia, Sukulu, Isingiro, Kisumu, Rungwa complex etc.

Trenches When soft dykes in comparison with neighboring rocks are worn away by denudation, long narrow ditch like depressions called trenches form on the surface e.g. linear trenches near Lake Turkana, in Kenya

Sills

These are horizontal sheets of igneous rock lying between the bedding planes. They are formed when magma rises into the crust, spreads horizontally and solidifies between the bedding planes of rock strata. They vary in thickness and may extend for many km. Where sills are hard compared to soft surrounding rocks, they are exposed by denudation forming flat topped hills. e.g. kakinzi in Luwero, at Thika falls where sills are crossed by river Chania etc.

Laccoliths These are mushroom/dome shaped igneous intrusions of magma with a flat base lying between the bedding plane of the country rock. They are formed when viscous magma is ejected into the rock layers. Since it is unable to spread far, it accumulates around the vent in a large mass. The viscous magma forces the overlying rock strata to bend upwards creating a dome shape as it solidifies.

World’s Distribution of Volcanoes and Volcanic Activity

Most of the world’s volcanoes and volcanic activity can be sighted along the plate boundaries. The distribution can be classified into one of the following tectonic settings:

(1) Subduction Zones in the Circum Pacific Belt

The zones where one plate goes down under the other due to density differences are the sites of most of the world’s active and explosive volcanoes. The oceanic plate having higher density is subducted under the continental crust. The subducted slab melts under increasing pressure and temperature to produce magma which comes out through the andesitic chain of volcanoes. The volcanoes are mainly situated on the continental side of the trenches.

(2) Divergence Zones: Volcanoes of the Mid-Atlantic Ridge and over the Continents

In plate tectonics, a divergent boundary is a linear feature that exists between two tectonic plates that are moving away from each other. For example, the Mid-Atlantic Ridge separates the North and South American Plates from the Eurasian and African Plates.

This pulling apart is causes new volcanic material to be added to the oceanic plates. The sea-floor spreading sites are the common sites of basaltic lava eruption. Magma rises through the cracks and leaks out onto the ocean floor like a long, thin, undersea volcano. As magma meets the water, it cools and solidifies, adding to the edges of the sideways-moving plates. This process along the divergent boundary has created the longest topographic feature in the form of Mid oceanic ridges under the Oceans of the world. Most of this activity is out of sight under the oceans, which is less hazardous to people.

The importance of vulcanicity

Vulcanicity has both positive and negative effects.

Positive effects

- Volcanic rocks weather into fertile soils for Agriculture for growth of bananas and Arabica coffee on the slopes of Mt. Elgon and Mt. Kilimanjaro.
- Minerals like diamond, limestone, salt are associated with vulcanicity e.g. Salt from L. Katwe in Uganda
- Igneous rocks are quarried into small pieces for concrete e.g. at Bukasa hill in Muyenga.
- Intrusive features such as sills when crossed by rivers form spectacular waterfalls e.g. Sezibwa and Bujagali falls in Uganda. Falls may be used to generate hydroelectricity.
- Hot springs water contains sulphur and other minerals that cure different diseases e.g. at Kitagata.
- Volcanic mountains like Mt. Kilimanjaro provide magnificent scenery that attracts tourists.
- Volcanic mountains influence formation of orographic rainfall on the windward side
- Volcanic features are homes of wild animals and plants gazzeted as game reserves for tourism and conservation

Negative effects

- Volcanic eruption leads to loss of life and properties
- Vulcanicity has produced rock deserts of lava around L. Turkana region in Kenya.
- Volcanic mountains promote arid conditions on the Leeward side.
- Landslides occur on volcanic mountains such as Elgon destroying lives and property.
- Volcanic mountains like Mt. Elgon and Kigezi highlands promote soil erosion
- Agricultural mechanization is limited in volcanic highlands
- Construction of roads and railways is very expensive in volcanic highlands and mountains.

TOPIC: COASTAL PROCESSES AND LANDFORMS

A coast refers to the land that borders the sea or ocean. It is a narrow zone where the land and the sea overlap and directly interact. Some coasts are made of broad sandy beaches, while others form rocky cliffs or low-lying wetlands. The nature of the coastline is determined by factors such as the types of rock present, the forces of erosion and the changes in sea level. Shore is the area where the land and the ocean meet. Different features are found in this area resulting from erosion and deposition of sediments, ocean waves as well as the effect ocean currents, including the long shore drift.

PROFILE OF COASTAL ZONES

When we talk about the coastal zone, the first thing to know about is the coastline.
A Coastline represents the boundary between the continental land masses and the oceanic water masses. A Coastal zone is the transition zone between terrestrial habitat and the marine habitat. It is the interface between land and oceanic water. Coastal belts may be very wide or narrow. They also vary with reference to their slope, beach profile, rock types, climate and vegetation. The climate of a coast is basically controlled by the land and sea breezes. The climate is also controlled by the humidity of generated by the marine waters.
If we look at the profile of a sea coast, we can see a shoreline belonging to the landward side. The width of this shore may vary from place to place. Along the coast, there are two distinct zones observable in a day. They are the high tide line and the low tide line. The average water level between the high tide and the low tide is the mean sea level. When there is a severe storm, the water line may come well above the high tide line in a beach.
Coastal belts are further divided into three divisions as

a) Backshore region
b) Foreshore region and
c) Offshore region.

The backshore is inland of the inter-tidal zone and is usually above the influence of the waves. The nearshore (sometimes called the breaker zone) is where the waves break; the offshore zone is further out to sea and is beyond the influence of the waves.
The Backshore region represents the beach zone starting from the limit of storm wave, above high tide shoreline. This zone includes a wave cut terrace and a storm scarp.

Beach is the basic area where much of the geological processes happening.

Beach is the sloping portion of the coast normally existing below the berms.

This area is partly exposed by the backwash of waves (swash zone).

Swash zone is the place where the waves backwash the materials. It is the place where up and down movement of beach materials take place.

Berms are sediments deposited over this region by swash and backwash actions of waves. Beach Berms exist above the wave-cut terrace. A berm is a bench-like feature containing sands. The landward side of the berm contains a belt of sand dunes. There are summer and winter berms. Accumulation of sand during summer forms the summer berms. This is the Sun-bathing zone with wave deposited sediments. A Sea cliff may exit above wave-cut terrace.

Foreshore:

The Foreshore region is the region between high tide water zone and low tide water zone. It includes a Beach face and a beach terrace. The surf zone exists above beach terrace. At the end of the surf zone, the breaker zone starts. The foreshore may be a sandy foreshore, shingle foreshore, muddy foreshore or a rocky foreshore.

The **Breaker zone** is the area where the incoming waves become unstable, raising to a peak and breaking down.

Breaker zone is an important zone within which waves approaching the coastline commence breaking. The breaker zone is also part of the surf zone. The Surf zone is an important zone where the waves of translation occur after the waves break. Sand Bars are created, inside the waters, along the zone of wave breakers.

The moving water masses shape the excess quantities of detritus sediments into sorted and layered deposits.

Long shore currents occur in this zone, which run parallel to the coastline.

Offshore:

The Offshore region represents the zone of oceanic shallow water zone extending fully inside the continental shelf.

It begins after breaker zone. At the base, it includes the longshore troughs and longshore bars.

Waves:

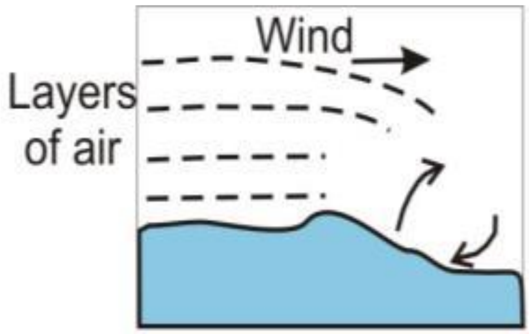
The seawater is constantly on motion due to waves, tides and currents. Waves are considered as the major source of energy in majority of the coasts and hence most important agent in shaping up coasts. Waves are undulations of sea water, and have well defined **crests** (i.e. highest point of the wave) and **troughs** (i.e. lowest point of the wave). It is better to define some terms here which will be used in forthcoming paragraphs. Difference between the crest and trough is called **wave height** and the distance between two crests or troughs is called **wavelength**. And, the time between two successive wave crests to pass a fixed point is called **wave period** or **wave period of time**.

Formation of waves: Waves are produced by the action of wind blowing over surface of the sea or from submarine shock waves produced by earthquakes or volcanic activity. Wind disturbs waterbody as it exerts frictional drags on the surface-water particles of more or less flat body of water. It results in setting up small orbital motions of water particles in the water with the largest ones near the surface and decreasing with depth. Wind pressing on the back of a developing wave makes it steeper and gradually the waves grow bigger. When wind blows strongly for many hours, it increases height of the waves. Size of waves is governed by the following three factors:

□ wind velocity,

□ duration of the wind, and

□ the **fetch** (the distance of open water surface over which the wave-generating wind blows).



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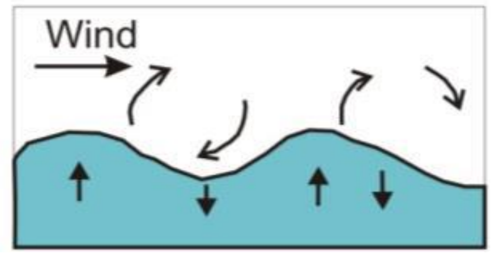

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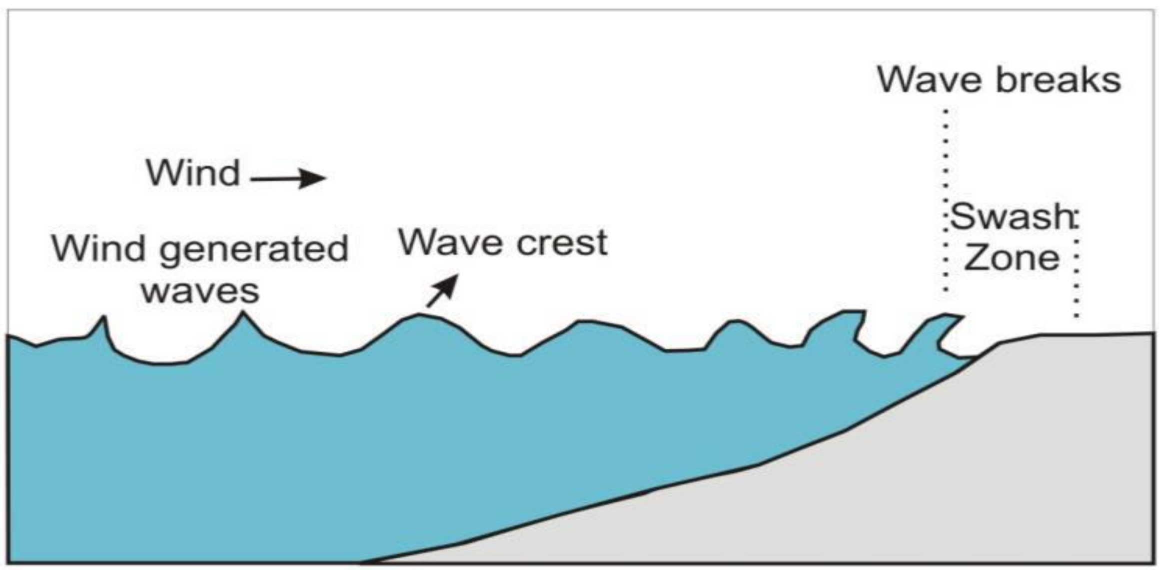
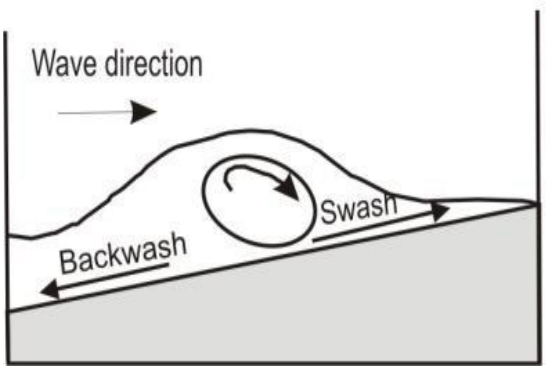


2c)

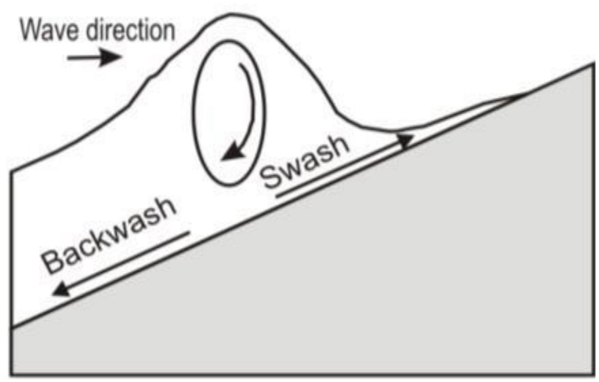
Figure 2: (a) and (b) show initial stages of formation of waves; and (c) wave modification near coast. Waves have circular movement away from coasts that turn to elliptical due to frictional drag when they approach coast.

When the wind is strong, **wave steepness** (the ratio of wave height to wavelength) increases and when it is not strong, the wave steepness decreases. If the wind is stronger, it will blow longer and when the fetch is greater, the wave will be more powerful, e.g. storm waves. So, length of the fetch is the limiting factor in wave development.

Wave modification near coast: Waves are generated in open Ocean and travel to coast where they break against the land. Wavelength, velocity of the waves and the wave period are the three closely related parameters that modify waves. When waves reach near coast, shallowing of water depth and irregularities of the shoreline result in change in form (dimensions) and mechanics of the waves (Figure 2c). The waves slow down but the wave period remains same. Wavelength is shortened but the wave height increases and these result in increase in **wave steepness**. The wave steepness keeps increasing until it becomes so steep that it breaks. The zone where the waves break is called **breaker zone** or **surf zone**. In the breaker zone, the wave force is translated up the beach due to which the water is thrown up the beach (i.e. **swash**). The water which drains down the beach under the influence of gravity is called **backwash,** which is either in a sheet flow (undertow) or as a rip-current (i.e. a localised concentration of backwash).



3a



3b

The initial movement of water in a wave is circular however, when waves move towards coast, water moves forward on the crest and backward in the trough changing the circular form to elliptical. Wave steepness is an important factor responsible for making waves either constructive or destructive. When most of the swash soaks into the beach with very little backwash, the waves are called constructive waves or spilling waves (Figure 3a). This happens on the gently sloping beaches where waves of long wavelength and low height approach and the ellipse becomes horizontal. When high waves of short wavelength break on steeply sloping beaches, the water plunges forward into the trough resulting in very powerful backwash that can carry material down the beach. These types of waves are called destructive waves or plunging waves.

Types of waves

From geomorphological point of view, sea waves are classified into

a) constructive waves and

b) destructive waves

Constructive waves

Constructive waves are low energy waves that tend to arrive at the coast at a rate of less than 8 waves per minute (their frequency is relatively low). Constructive waves are small/low in height. They have long wavelength. They have a strong swash (the uprush of water onto the beach) and a weak backwash (the return flow of water to the ocean). This means that constructive waves tend to deposit material and build up a beach. They deposit more sediments than they remove leading to the accretion of land. They play a vital role in the building up beaches and coastlines. These waves form in conditions of low wind speed and long fetches.

The construction wave gentle action allows it to carry a significant amount of sediments, including sand, gravel and shells. As the wave approaches the shore, it slows down due to friction with the sea bed. This causes the wave to become steeper and eventually spill, releasing its sediments load. The stronger swash carries the sediments further up the beach, depositing it as the wave energy dissipates. The weaker backwash is unable to remove all the deposited sediments, leading to a net accumulation. These waves are associated with the formation of depositional features such as:

- **berms,**
- **spits,**
- **bars and**
- **tombolo.**

Destructive waves

These waves represent a specific type of wave characterized by their powerful energy and their ability to inflict significant damage on coastlines and structures. Destructive waves have much higher energy and tend to arrive at the coast at a rate of more than 8 per minute. They are much larger in height (6-30 meters) than constructive waves, often having been caused by strong winds and a large fetch. The have a longer wavelength contributing to their increased energy and destructive potential. Destructive waves have a weak swash but a strong backwash so they erode the beach by pulling sand and shingle down the beach as water returns to the sea. This means that less beach is left to absorb wave energy. They break with immense force, generating significant surge and powerful currents that can easily sweep away people and objects.

Destructive waves, often referred to as rogue or storm waves, are generated by strong winds acting over a long fetch. Hurricanes and typhoons, with their intense winds and low pressure, generate powerful, destructive waves capable of inflicting catastrophic damage. Destructive waves are associated with the formation of erosional features such as: cliffs, wave-cut platforms, sea-caves, sea arches, stacks, headlands, bays etc

There are three types of changes that may occur to wave direction viz. wave reflection, wave refraction and wave diffraction. When waves approach a uniformly sloping coast at right angles to the shore, they break simultaneously and all the waves strike the shore in straight parallel lines. When the breaking waves hit a cliff or seawall, water in motion impinges against the structure and the waves are reflected. When waves approach coast, they are also subjected to refraction and or diffraction. Waves refract when waves approach shoreline (consisting of headlands and bays) at an angle and each wave impinges on the shallow sea floor before the rest of the wave. This results in slowing down of the section of the wave opposite the headlands but the section of the wave facing the bay moves shoreward at higher velocity that is still at some distance away from the shore. This relative difference in velocity leads to progressive bending of wave crest parallel to the shoreline. This is known as wave refraction. It causes the wave crest to converge on the headlands and diverge on the bay (Figure 4a). This results in high breaking waves and intense erosion at headlands and quieter waves at the bays thus producing cliffs on the headlands and beaches in bays. When waves approach a barrier obliquely, it results in diffraction of waves leading to shadow zone in the lee of the barrier. Waves also diffract when a segment of wave crest passes in river mouth or bay. The currents generated within bays and harbours by diffracted waves erode and transport sediment until the shoreline fits the diffraction pattern.

Tides

Nearly all marine coastlines experience the rhythmic rise and fall of sea level called tides. The daily oscillation in ocean level is a product of the gravitational attraction of the Moon and Sun on Earth's oceans and it varies in degree worldwide. Tidal action is an important force behind coastal erosion and deposition as the shoreline migrates landward and seaward. A tide is the periodic rise and fall of oceans and bodies of water connecting them. Tides are caused by the attraction of the sun and moon. Tides are a function of the sun's and moon's gravitational pull on the oceans on earth and the rotation of the earth.

Tidal processes are found more dominant on the coasts characterised by estuaries or other embayments. We have studied that shoreline does not remain constant and keeps changing with change in the level of the sea. The rhythmic periodic rise and fall of the sea water is called **tide**, which is caused by gravitational pull by moon and the Sun on Ocean. Rise of the sea water is called **flood** and is fall is called **ebb**. Effect of the Moon is more powerful than that of the Sun because Moon is comparatively much closer. Tide causes the sea level to move vertically by several meters daily. The gradual rise to the highest level is termed **high tide** and fall to the lowest level is called **low tide**. The difference between the level of the low and high tide on a given location is called tidal height or amplitude or range, which may vary from few meters to several meters e.g. over 15m in Bay of Fundy, Canada to less than 2m in southwestern coast of India. Variation in tidal height in different locations on the Earth is due to the different forms and depths of the ocean basins and the rotation of the Earth. The difference is more in shallow seas particularly in narrow channels and straits. Following four types of coasts are identified based on the tidal range, i.e.

- **megatidal** (tidal range >6m),

- **macrotidal** (tidal range between 4 and 6m),
- **mesotidal** (tidal range between 2 to 4m), and
- **microtidal** (tidal range <2m).

Following three factors affect tidal movement:

- change in the declination of the Moon and the Sun,
- distance from the Earth to the Sun and the Moon, and
- position of moon and the Sun in relation to each other and to the Earth.

Different locations on the Earth's surface are attracted by moon with varying strength because of the changing distance between these locations and the position of the Moon. It is also due to eccentricity of the orbit of the Moon round the Earth (ie during the orbit, the earth is not centrally positioned). When the Moon is closer to Earth, tides are bigger. When the Earth, Moon and the Sun are in a straight line then high tide (**spring tide**) is produced. When the Sun and the Moon are at right angles from the Earth then low tide (**neap tide**) is produced.

Tides are divided into following two types according to the period of rise and fall:

- Diurnal - tides occur once a day during the lunar day e.g. in Northern Pacific and Indian Ocean
- Semi diurnal - tides recur twice during the lunar day e.g. in Atlantic Ocean.

The coasts with large tidal range such as the Gulf of Kachchh and Gulf of Cambay are generally characterised by the presence of extensive mudflats with mangroves and salt marshes. In the coasts with lower tidal range, relatively smaller areas are subjected to daily wave action such as the south-western coasts of India.

Tidal range and topography of the coast determine velocity of tidal currents, which dominate the water movements particularly in bays, estuaries and tidal channels (called **creeks**). This results in tide dominated landforms. In small tidal inlets, water discharge is determined by the

tidal prism (i.e. the volume of water between the high and low tide surfaces) whereas in the large tidal creeks and estuaries, the tide progresses as a wave. In estuaries, flow is of two types:

 tidal currents – are the most important physical process

 residual currents - are chemical or diffusive processes due to the differences in the density of fresh water and salt water.

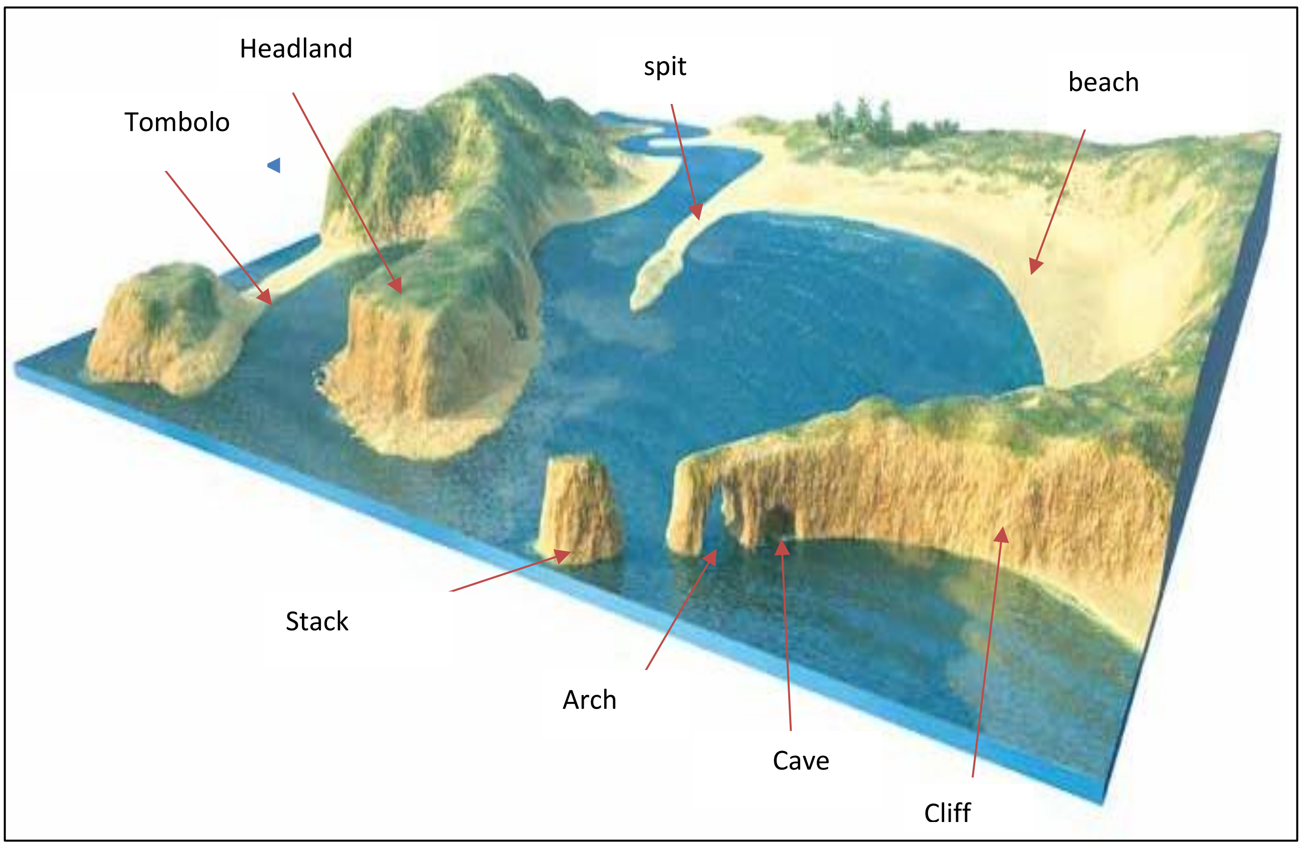
Currents

Besides, tides and waves, currents are also responsible for coastal modification. **Currents** are mass movements (vertical or horizontal) of ocean water (both surface and deep) in a continuous flow. Currents are largely generated due to surface winds but can also be created by tides, difference in the density of water (i.e. temperature and salinity gradients), gravity and Earth's rotation.

There may be several kinds of currents. There could be either **surface water currents** (the ones found in the upper 400 meters) or **deep-water currents** (found below 400 meters). Surface water currents make up about 10% of the ocean and deep-water currents make up about 90% of the ocean. The speed of surface currents is greatest closer to the ocean's surface and decreases at about 100 meters below the surface. While surface currents are generally caused by the wind because of the friction generated by its movement over the water and forcing the water to move in a spiral pattern and thus creating gyres. The gyres move clockwise in the northern hemisphere whereas they move counter-clockwise in the southern hemisphere. Gravity also plays a role in the movement of surface currents. In the areas where water meets land, or water is warmer, or where two currents converge, mounds in the water form. Water moves downslope on the mounds under the influence of gravity and thus resulting in creation of currents. The Coriolis force also plays a role in the movement of surface currents and deflects them, further aiding in the creation of their circular pattern. Major current systems typically flow clockwise in the northern hemisphere and counter-clockwise in the southern hemisphere, in circular patterns that often trace the

Longshore Drift

Longshore Drift are powerful geomorphic agents. They can erode, transport and deposit coastal sediments. As waves break on a beach, they throw water up onto the beach in an area called the swash zone. Because the waves approach at an angle, the water is thrown up at an angle. However, the water runs back down the beach under the influence of gravity perpendicular to the shore. Thus, the crashing of waves causes water to move along the beach in a step-like fashion in the direction of wave movement. This creates a longshore current. Sand is transported along the beach. This process is called as longshore drift. Longshore drift erodes and deposits sand masses continuously along the beach. The sand that is removed from one point along the beach is replaced by sand eroded from up current zone



Coastal landforms

COASTAL PROCESSES AND THEIR DISTINCTIVE FEATURES

In this section we will study about the erosion, transportation and deposition mechanisms of these processes and also the distinct features they develop.

Erosional Processes and Resulting Landforms

Although, erosion on coasts is a natural process, the rate of erosion is accelerated by tsunamis, storm surges and also human activities. Erosion on coasts depends on several factors such as:

- nature of coast
- nature of rock
- presence of joints and fissures in the rocks
- presence of rock particles within waves
- chemical action of seawater, and also
- wave strength.

Erosion is prominent in coasts where waves are not obstructed and dash directly whereas in shallow low-lying coastal plain, waves are obstructed before reaching shore thus resulting in reduced impact of waves. When waves dash against the shore, rock fragments present within waves also dash against the coastal rocks and wear them off. With the presence of dissolved materials seawater becomes better solvent thus enhancing chemical action on the coastal rocks. It is obvious that erosive action is more when wave strength is more.

Erosion on coasts takes place by the following mechanisms:

(i) Corrosion: It is process of chemical weathering by which coastal rocks e.g. limestone rocks change/ degrade into more chemically-stable form, such as its oxide, hydroxide, or sulfide due to pH of seawater. The soluble rocks (or parts of the rocks) are dissolved. The rate of reaction is further increased by wave action which continuously removes the reacted material. This process is not considered very significant because its influence is restricted mainly to limestones or other similar rocks.

(ii) Corrasion or **Abrasion**: It is the mechanical process and is considered as the most important process of erosion. When waves pound coasts, the rock fragments, sand, pebbles and boulders, present in the coasts act as tools of erosion as they break pieces of the coastal rocks and transport the broken pieces towards the sea. The forward and backward movement of sea water with these tools of erosion also cause corrasion of rock face and the floor. Abrasion is the actual physical break-up of cohesive rock similar to quarrying, in which sea cuts into unconsolidated materials and pulls away particles/ pieces.

(iii) Attrition: It is the mechanical process in which waves cause rock fragments to collide with each other and progressively grinding and chipping each other into smaller, smoother and rounder pieces. The rock fragments become very small that they are easily transported towards the sea by rip currents.

(iv) Hydraulic Action: The coastal rocks are eroded even without the presence of rock fragments in the seawater. Waves erode the rocks when they continuously strike against them and the impact is powerful enough to break and disintegrate the rocks.

(v) Shock pressure of breaking waves: When waves strike against the coastal rocks, they exert enormous pressure particularly on the rocks joints and cracks. Hence, the air trapped inside the rocks becomes compressed. With retreat of the waves, the pressure suddenly falls and the air expands. It causes stress in the rocks resulting into weakening of the rocks surrounding the air pocket leading to their exploding and breaking along the joints and cracks. Besides the mechanical process, solution activity also increases in the soluble rocks. In the process of solution, acids contained in the sea water dissolves some types of rock such as chalk or limestone.

EROSIONAL LANDFORMS

Landforms of coastal regions are classified into two major groups as erosional landforms and depositional landforms. The notable erosional landforms of the coastal areas are:

a) Sea cliffs

b) Sea caves

c) Sea Arches

d) Sea stacks

e) Wave-cut notches and

f) Wave-built terraces.

Sea Cliff and Caves

A cliff: Is a steep rock face along the sea coast.

A sea cliff is a vertical precipice (a very steep rock face) created by waves crashing directly on a steeply inclined slope. Hydraulic action, abrasion, and chemical solution all work to cut a notch at the high-water level near the base of the cliff. Through hydraulic action and abrasion, the notch is enlarged. Soon the rock on top of the notch is left hanging and collapses into the water forming a cliff face. The cliff steepens as its base is attacked by wave action again and again. Constant undercutting and erosion cause the cliffs to retreat landward.

Sea Cave. It's a cylindrical tunnel drilled in a cliff face or headland. Its wide at the entrance and narrow at the end. It commonly develops on cliff faces that have joints. Hydraulic action and solution contribute to the opening of the joint which overtime becomes a cave. When waves break at the cliff face, they compress air in the joints and when water withdraws, the air expands suddenly with shock waves which break the rocks along the joints. This enlarges the joint further to form a cave.

Blowhole

This is a vertical shaft linking a cave to the surface. It is formed when wave action attacks the roof of a cave. At the same time, weathering by solution acts on the line of weakness from the surface downwards to form a blowhole.

Geo

Wave erosion may continue on the roof of a cave along the blowhole. If the roof of the cave collapses, a long narrow sea inlet known as geo is formed.

Sea Arches and Stacks

A sea arch forms when sea caves merge from opposite sides of a headland. A sea arch is a natural opening eroded out of a headland by marine processes. Some arches appear to have developed from surge channels, which are created by wave refraction causing the focusing of wave fronts on the side of a headland. Caves produced on either side of a promontory(headland) may become joined over time to become a tunnel called an arch. Sea arches have been regarded as ephemeral forms (lasting for a short time) tending to survive over periods of just few decades to several centuries.

A stack

This is an isolated rock feature completely detached from the main land. A stack forms when an arch is gradually eroded until it collapses resulting in to a detachment of a mass of rock from the headland. The two are separated by part of the sea.

A stump

This is formed when a stack is gradually attacked by wave erosion to leave a residual feature called a stamp.

Wave cut platform

These are raised flat pieces of land that are formed at the foot of the cliff. They form between high and low water tides. During cliff formation, the combined effect of wave erosion at the base and weathering above leads to the collapse of the upper part of the cliff. The fallen rocks become further broken by being swept backwards by the backwash and forward by the swash. This results into the formation of wave cut platforms just at the foot of the cliff. Most wave cut platforms are buried under water and are only exposed during low tides. Example are found south of Mombasa port at Mama ngina

A notch.

The hydraulic and corrosive action of waves leads to the undercutting of the coast to form a small opening known as a notch. Notches are common in well-developed limestone rocks which have been removed by the chemical action of waves

Headland. A headland is the projection of land into the sea or lake. It's produced by differential wave erosion on coast with alternating hard and soft rocks. Through hydraulic action, corrosion and abrasion, soft rocks are eroded to form bays while the hard ones resist erosion and remain as jutting into the water as headlands

A bay

It is an extension of sea or lake into the land. Bays are formed as a result of differential erosion of rocks with different resistance levels. The soft rocks are removed or eroded off quickly by abrasion, hydraulic action and solution in case soluble rocks exist. This leads to the landward extension of water forming bays

Mechanism of Transportation

The eroded materials (e.g. sands, silts, gravels, pebbles, cobbles and even boulders) are transported by waves and currents. The eroded materials are transported seaward by backwash and undertow currents that move from coast to seaward. These materials are again picked up by breaker waves or surf currents that bring the materials back to coast. So, the material is transported from coast to seaward and from sea to coastward. Majority of the transportation takes place by movement at the bottom and the surface is continuously modified. Longshore currents also transport the materials but parallel to the shoreline.

Transportation takes place by one or more of the five transport mechanisms i.e. suspension, rolling, sliding, saltation and solution as in rivers. The materials are sorted by the seawater as it carries and transports them. The finest particles are carried away farthest and the coarser particles are left behind on the beach. The materials in solution are carried farther off either by reacting among themselves or by organisms, animals and plants that extract some of the dissolved matter to build their shells or tissues.

Depositional Processes and Resulting Landforms

The transported materials are deposited either in shallow waters near the shorelines in continental shelf and slope or in deep seas on the floor of the deep oceans. The common features developed due to depositional processes on coasts include beaches, spits, bars and barriers, lagoons, coastal dunes, mudflats, tidal marshes, wave-built terrace/platforms, etc.

Beach

The striking coastal depositional feature is the beach that occupies edge of a shoreline. **Beach** is a product of sediment deposition due to reduced wave energy. The sediments are derived from different sources such as erosion of cliff rocks, or brought by rivers and/or picked up by waves from the sea floor and moved shoreward. Beaches are formed in areas where either the cliff is either absent or not in direct contact with the wave cut platforms. Beach is a gently sloping feature and in profile it slopes towards sea but the gradient changes at different places. Shape of beaches could be either straight or concave. Most of the world’s beaches are formed by sand deposition. Such beaches generally appear dazzling white. However, in the areas of high energy the beach material could be pebbles or even boulders.

Spit and Tombolo

Spit is a ridge of deposited sediments that extends from land to sea cutting off a portion of water from the open sea and is generally elongated in shape. It generally extends as a continuation of a beach in the direction of sediment transport due to longshore drift and is composed primarily of sand. Spit could be of different sizes and may take various shapes. A growing spit that connects the mainland with an island or an island with another island is called **tombolo.** This is formed by deposition of sediment (primarily sand) due to wave refraction around island. In some cases, spits may extend right across the small bays or mouth of rivers forming a **lagoon**.

Coastal bars

These refer to ridges of sand, mud, gravel and shingles deposited offshore and parallel to the coast. They usually for on gently sloping coasts and irregular shorelines. A coastal bar forms when a spit grows across a bar or connects two landmasses such as headlands. Longshore drift laden with sediments approaches the shore. The sediments are laid down and accumulate forming a narrow, elongated ridge known as a spit. The spit may grow across the mouth of a bay, effectively connecting two headlands hence blocking the bay from the rest of the sea. This ridge is called a bay bar. The enclosed waters are termed as a lagoon. A spit may also grow to connect two headlands, forming a bar that runs parallel to the coast. Such a ridge is called barrier bar.

Tidal Flat and Salt Marsh

Tidal flat is not actually flat rather a very gently sloping sandy or muddy area that is exposed during low tide and inundated with water during high tide. Based on composition of the materials it is either called **sand flat** or **mud flat.**

Salt marshes are the flat wet tracts which are located in the upper intertidal area. They are marshy area that are flooded by seawater during high tide. Tidal waters enter tidal flats through tidal inlets, which are also known as **creek**