Chapter 6: Landforms and their Evolution

Landforms and Their Evolution

Landforms are defined as small to medium-sized sections of the Earth's surface, characterised by their own physical shape, size, and composition. These natural features, including mountains, hills, plateaus, and plains, result from the actions of geomorphic processes and agents like running water, groundwater, wind, glaciers, and waves.
The formation of landforms begins with weathering, which alters Earth materials, followed by erosion and deposition by these geomorphic agents, leading to changes on the Earth's surface. Landforms can evolve over time, changing in shape, size, and nature due to the continuous influence of these processes. Landscapes, larger tracts of Earth's surface, are composed of several interconnected landforms. The evolution of landforms is also influenced by climatic changes and the vertical or horizontal movements of landmasses, altering the intensity or type of geomorphic processes. This evolution can be likened to stages in life, such as youth, maturity, and old age, reflecting the ongoing transformation and development of these natural structures.

Example:
The Grand Canyon in the United States serves as a striking example of landform evolution. Formed by the erosive power of the Colorado River, the canyon showcases the gradual but profound transformation of landforms. Over millions of years, the river carved through layers of rock, creating a deep, expansive canyon that illustrates the dynamic processes of erosion, weathering, and deposition.

Short Pointers for Revision:

- Definition of Landforms: Natural sections of Earth's surface with distinct physical characteristics.
- Formation: Begins with weathering, followed by erosion and deposition.
- Types: Include mountains, hills, plateaus, and plains.
- Geomorphic Agents: Running water, groundwater, wind, glaciers, waves.
- Evolution: Continuous change in shape, size, and nature due to geomorphic processes.

- Landscapes: Composed of multiple interconnected landforms.
- Influences: Climate changes and landmass movements affect landform evolution.
- Example: The Grand Canyon – a demonstration of erosion and weathering.

Evolution of Landforms

The evolution of landforms refers to the stages of transformation that a section of the Earth's surface undergoes, either changing from one type of landform into another or altering the characteristics of individual landforms after their initial formation. This process is analogous to the stages of life – ***youth***, ***maturity***, and ***old age*** – indicating that every landform has its own developmental history and undergoes changes over time. Factors influencing these changes include ***climatic conditions*** and the ***vertical*** or ***horizontal movements*** of landmasses. These factors can alter the intensity or even the nature of geomorphic processes. Powerful erosional and depositional agents such as ***running water***, ***wind***, ***waves***, ***glaciers***, and ***groundwater***, aided by ***weathering*** and ***mass wasting processes***, play a significant role in shaping and transforming the Earth's surface.

Example:

The Himalayan mountain range presents a compelling case study of landform evolution. This majestic range, formed by the collision of the Indian and Eurasian tectonic plates, demonstrates the impact of landmass movement on landform development. Over millions of years, this monumental collision has resulted in the uplift and formation of some of the world's highest peaks, illustrating the dynamic processes of landform evolution.

Short Pointers for Revision:

- ***Transformation Stages***: Landforms evolve from one form to another or change over time.
- ***Life Stage Analogy***: Development stages like ***youth***, ***maturity***, ***old age***.
- ***Development History***: Each landform has its own history and timeline of changes.

- ***Influencing Factors***: ***Climate changes***, and landmass movements (***vertical/horizontal***).
- ***Erosional/Depositional Agents***: ***Running water***, ***wind***, ***waves***, ***glaciers***, ***groundwater***.
- ***Weathering and Mass Wasting***: These processes aid in landform transformation.
- ***Example***: The Himalayas – formed by tectonic plate collision, showing stages of mountain formation and evolution.

Running Water Landforms

In humid regions receiving substantial rainfall, running water is a key geomorphic agent responsible for altering the land surface. Running water operates through two main components: overland flow, which moves as a sheet across the general land surface, and linear flow, which follows a defined path as streams and rivers within valleys.

Most erosional landforms created by running water are associated with young, vigorous rivers flowing over steep gradients. Over time, these steep gradients become gentler due to continuous erosion, causing a reduction in the river's velocity and enhancing deposition activities.

While deposition can occur in areas with steeper slopes, it is more significant in rivers flowing over moderate to gentle slopes. As erosion continues and stream beds become gentler, downward cutting decreases, leading to increased lateral erosion of river banks. This process gradually transforms hills and valleys into plains.

Short Pointers for Revision:

- Running Water as Geomorphic Agent: Predominant in humid, heavy rainfall areas.
- Components: Overland flow (sheet-like) and linear flow (streams and rivers in valleys).
- Erosional Landforms: Typically associated with young rivers on steep gradients.
- Evolution of River Gradients: Steep to gentle due to ongoing erosion.

- Deposition Activities: More significant in gentler river slopes.
- Transformation to Plains: Hills and valleys evolve into plains due to lateral erosion and deposition.
- Example: Mississippi River Delta – Illustrates sediment deposition and delta formation.

Formation of Running Water Landforms

Running water landforms are shaped through a series of erosional and depositional processes. Initially, most erosional landforms are associated with youthful rivers flowing along steep gradients. Over time, these steep gradients become gentler due to continuous erosion, reducing the river's velocity and encouraging deposition. Depositional landforms are more common in rivers flowing over medium to gentle slopes, although they can also occur on a smaller scale in steep areas. The gentler the slope, the greater the deposition. This erosion process leads to gentler stream beds, reducing downward cutting and increasing lateral erosion of banks, which gradually transforms hills and valleys into plains.

Additionally, overland flow contributes to sheet erosion, which may become concentrated into paths of varying widths based on the land's irregularities, removing material from the land's surface and forming rills. These rills develop into gullies, which deepen, widen, lengthen, and unite to form a network of valleys.

In the early stages, down-cutting is significant, removing features like waterfalls and cascades. In later stages, as stream beds are cut more slowly, lateral erosion becomes more severe, lowering valley sides. Eventually, the divides between drainage basins flatten, resulting in a lowland area with faint relief, known as a peneplain, marked by some low resistant remnants called monadnocks.

Example:

The Mississippi River is an excellent example of the formation of running water landforms. Its extensive river system has shaped the landscape through erosion and deposition, creating features such as the Mississippi River Delta. Over time, the river has transformed steep regions into gentler slopes, contributing to the development of vast floodplains and the delta at its mouth.

***Short Pointers for Revision*:**

- Erosional Landforms: Initially associated with young, steep-gradient rivers.
- Depositional Landforms: More common in rivers on medium to gentle slopes.
- Erosion to Deposition Transition: Steep gradients become gentler, leading to increased deposition.
- Sheet Erosion: Caused by overland flow, resulting in the formation of rills and gullies.
- Valley Network Development: From rills to gullies to valleys.
- Stages of Development: Early down-cutting, middle-stage lateral erosion, final-stage peneplain formation.
- Peneplain: A low-relief plain formed by stream erosion.
- Example: Mississippi River's landscape shaping through erosion and deposition.

Youth Stage of Stream Development

In the youth stage of stream development, streams are relatively scarce, with limited interconnection and flow primarily over original slopes, creating shallow, V-shaped valleys. These young streams typically do not have floodplains, or if present, the floodplains are very narrow along the main streams. Stream divides at this stage are broad and flat, often characterised by features such as marshes, swamps, and lakes. Meanders, which are winding courses, can develop on these broad upland surfaces, though they mainly form into the uplands. Waterfalls and rapids are common features, especially where local hard rock bodies are exposed, indicating a stage of active and youthful topographical development.

Example:

A classic example of a youthful stream can be seen in the upper reaches of the Colorado River, where it flows through steep, V-shaped valleys with narrow floodplains. This region is known for its rapid and waterfall features, as well as the formation of meanders that start to entrench into the uplands, vividly illustrating the characteristics of the youth stage of stream development.

***Short Pointers for Revision*:**

- Scarcity of Streams: Few streams with poor integration.

- Flow Patterns: Streams flow over original slopes, forming shallow, V-shaped valleys.
- Floodplains: Typically absent or very narrow along main streams.
- Stream Divides: Broad and flat, with features like marshes, swamps, and lakes.
- Meander Formation: Develops on broad upland surfaces, may entrench into uplands.
- Waterfalls and Rapids: Common where local hard rock bodies are exposed.
- Example: Upper Colorado River - Illustrates youth stage characteristics.

Mature Stage of Stream Development

In the mature stage of stream development, the number of streams increases significantly, and they exhibit good integration. The valleys formed by these streams are still V-shaped but become deeper, and the main streams have broadened sufficiently to accommodate wider floodplains. In these floodplains, streams often flow in meanders confined within the valley. The landscape during this stage sees a notable transformation; the previously flat and broad inter-stream areas, along with swamps and marshes characteristic of the youth stage, disappear. Stream divides become sharp and distinct. Additionally, features such as waterfalls and rapids, which are typical in the youth stage, diminish or disappear entirely, indicating a more evolved and stable topography.

Example:

The River Thames in England is an example of a stream in its mature stage. As it flows through London, the river features a broad valley with a well-developed floodplain, and the stream meanders significantly within this floodplain. The absence of features like waterfalls and rapids and the presence of sharp stream divides are indicative of the mature stage of stream development.

Short Pointers for Revision:

- Increased Number of Streams: Plenty of streams with good integration.
- Valley Characteristics: Deeper V-shaped valleys with broader main streams.
- Floodplains: Wider floodplains present, allowing for meanders within valleys.

- Stream Divides: Become sharp, contrasting with the youth stage.
- Disappearance of Youthful Features: Flat inter-stream areas, swamps, marshes, waterfalls, and rapids diminish or vanish.
- Example: River Thames – Demonstrates characteristics of a mature stream.

Old Stage River Landforms

In the old stage of a river, **smaller tributaries** become scarce and possess **gentle gradients**. The river meanders extensively across expansive floodplains, characterised by features like **natural levees** (sediment ridges formed naturally along the river) and **oxbow lakes**. The landscape around stream divides is typically broad, flat, and includes various water bodies such as **lakes**, **swamps**, and **marshes**. Most of this terrain is situated slightly above sea level. The landforms in this stage result from a combination of **erosion** and **deposition** processes undertaken by the running water.

Example: The **Mississippi River Delta** exemplifies the old stage of a river. Here, the river meanders slowly, forming numerous **oxbow lakes** and **natural levees**. The wide, flat divides are home to **swamps** and **marshes**. This region demonstrates the typical features of an old river stage, where the interaction of **erosion** and **deposition** shapes the landscape.

Short Pointers for Revision:

- Tributaries in old stage: **Fewer** and **gently graded**.
- River meanders freely over **large floodplains**.
- Features include **natural levees** and **oxbow lakes**.
- Stream divides: **Broad**, **flat** with **lakes**, **swamps**, and **marshes**.
- Landscape mostly **slightly above sea level**.
- Combination of **erosion** and **deposition** in landform creation.
- Example: **Mississippi River Delta**.

Erosional Landforms of Running Water

Valleys

Valleys are extensive natural depressions in the landscape formed by the progressive **erosion** of the earth's surface. They originate from small, narrow **rills**, which evolve into wider and longer **gullies**, eventually developing into **valleys**. Key types of valleys include **V-shaped valleys**, **gorges**, and **canyons**. **V-shaped valleys** are typically created by fast-flowing rivers in areas with steep gradients. A **gorge** is a deep, narrow valley with **steep** or straight sides, similar in width from top to bottom. In contrast, a **canyon**, a variant of a gorge, features **steep, step-like side slopes** and is generally **wider at the top** than the bottom. Canyons often form in **horizontally bedded sedimentary rocks**, while gorges are more common in **hard rocks**.

Example: The **Grand Canyon** in the United States is a prime example of a **canyon**. Formed by the **Colorado River**, it showcases **steep, step-like sides** and is **wider at its top**, fitting the typical characteristics of **canyons**. Its formation in **horizontally bedded sedimentary rocks** aligns with the typical geological conditions for **canyon** formation.

Short Pointers for Revision:

- **Origin**: Valleys begin as **rills**, develop into **gullies**, then into **valleys**.
- **Types**: **V-shaped valleys**, **gorges**, **canyons**.
- **V-Shaped Valley**: Formed by fast-flowing rivers, **steep gradients**.
- **Gorge**: **Deep**, **narrow**, **steep sides**, consistent width.
- **Canyon**: Variant of gorge, **wider at top**, **steep step-like sides**.
- **Geology**: Canyons in **sedimentary rocks**, gorges in **hard rocks**.
- **Example**: **Grand Canyon** - a classic example of a **canyon**.

Potholes and Plunge Pools

Potholes are circular depressions formed in the rocky beds of hill streams, caused by stream erosion and the abrasive action of rock fragments. These depressions are further enlarged by the rotation of pebbles and boulders driven by the flow of water, which collects in these depressions.

Over time, a series of these depressions can join together, contributing to the deepening of stream valleys. **Plunge pools** are large and deep potholes found at the base of waterfalls. They form due to the intense impact of water and the rotational movement of boulders at the waterfall's foot, playing a significant role in valley deepening.

Example: **Niagara Falls**, located on the border between the United States and Canada, presents a classic example of **plunge pools**. The powerful impact of the falling water at **Niagara Falls** has created a significant **plunge pool** at its base, illustrating the process of **plunge pool** formation and its contribution to valley deepening.

Short Pointers for Revision:

- **Potholes**: Circular depressions in rocky beds of hill streams caused by **erosion** and **abrasion**.
- **Formation**: Enlarged by rotating pebbles and boulders.
- **Contribution**: Joining of depressions aids in **valley deepening**.
- **Plunge Pools**: Large, deep potholes at waterfalls' base.
- **Impact**: Formed by water's sheer impact and boulder rotation.
- **Example**: **Niagara Falls** – exemplifies **plunge pool** formation.

Incised or Entrenched Meanders

Incised or entrenched meanders are deep and wide meandering courses found in streams, particularly in hard rocky terrains. In streams flowing rapidly over steep gradients, erosion primarily occurs at the bottom of the stream channel. However, in streams with low and gentle slopes, lateral erosion on the sides of valleys is more prominent, leading to the development of sinuous (twisting or curving) courses, known as **meandering**. These meandering courses are typically observed over floodplains and delta plains where stream gradients are very gentle. **Incised or entrenched meanders** are distinct due to their significant depth and width, formed as a result of this lateral erosion in hard rock settings.

Example: The **Colorado River** in the **Grand Canyon**, USA, exemplifies **incised meanders**. The river's course through the hard rocky terrain of the **Grand Canyon** has led to the formation of deeply cut, wide meanders, illustrating the characteristics of **entrenched meanders**.

Short Pointers for Revision:

- **Location**: Predominantly in **hard rocky terrains**.
- **Formation**: Due to lateral erosion in gently sloping streams.
- **Characteristics**: **Deep, wide, sinuous courses**.
- **Erosion Types**: Bottom erosion in steep gradient streams; lateral erosion in gentle slopes.
- **Common Sites**: Floodplains, delta plains with gentle gradients.
- **Example**: **Colorado River in the Grand Canyon** – a classic case of **incised meanders**.

River Terraces

River terraces are surfaces that represent the former levels of a valley floor or floodplain. They are formed either as bedrock surfaces without any alluvial cover or as alluvial terraces composed of stream deposits. Essentially, river terraces are products of **erosion**, specifically resulting from the vertical erosion of a stream into its own depositional floodplain. These terraces can be found at various heights, each indicating a previous level of the river bed. When river terraces occur at the same elevation on both sides of the river, they are referred to as **paired terraces**.

Example: The terraces along the **River Thames** in **London** are an excellent example of river terraces. These terraces, at different elevations, indicate the historical levels of the **Thames** and demonstrate the process of **terrace formation** through vertical erosion and subsequent deposition.

Short Pointers for Revision:

- **Nature**: Surfaces marking old valley floors or floodplain levels.
- **Types**: Either bedrock surfaces without alluvial cover or alluvial terraces.
- **Formation**: Result of vertical erosion by streams into their floodplains.
- **Variation**: Terraces at different heights represent former river bed levels.
- **Paired Terraces**: Terraces at the same elevation on both sides of a river.
- **Example**: Terraces along the **River Thames** in **London**.

Depositional Landforms

Alluvial Fans

Alluvial fans are geological formations created when streams flowing from higher elevations descend into foot slope plains with low gradients. These streams, often carrying very coarse materials over mountain slopes, find the load too heavy to be carried over gentler slopes. As a result, this material is deposited and spread out, forming a broad, cone-shaped deposit known as an **alluvial fan**. The streams on these fans tend not to stay confined to their original channels and often shift position, creating multiple channels known as **distributaries**. The shape of alluvial fans varies with climate: in humid areas, they typically have low cones with gentle slopes, whereas in arid and semi-arid climates, they appear as **high cones** with steep slopes.

Example: The **Panamint Fan** in **Death Valley National Park**, **USA**, is a classic example of an alluvial fan in an arid environment. It exhibits the typical characteristics of a **high cone** with a **steep slope**, shaped by the streams descending from the **Panamint Mountains**.

Short Pointers for Revision:

- **Formation**: Occur where streams descend from higher elevations to low-gradient plains.
- **Material**: Streams carry coarse material over mountain slopes.
- **Deposition**: Material deposited as **broad, cone-shaped deposits**.
- **Distributaries**: Streams often change course, forming **distributaries**.
- **Climate Influence**: **Low, gentle cones** in humid areas; **high, steep cones** in arid areas.
- **Example**: **Panamint Fan** in **Death Valley National Park**, **USA**.

Deltas

Deltas are large, roughly triangular bodies of sediment deposited at the mouths of rivers, similar in shape to alluvial fans but occurring in a different location. The sediment load carried by rivers is dumped into the sea, forming **deltas**. If this sediment is not carried far into the sea or distributed along the coast, it accumulates as a low cone. Unlike in alluvial fans, the deposits that make up **deltas**

are well-sorted with clear stratification. The coarsest materials settle out first near the river mouth, while finer materials like silts and clays are carried further out into the sea. As a delta grows, the river distributaries continue to lengthen, and the delta progressively builds out into the sea.

Example: The **Nile Delta** in **Egypt** is a prominent example of a river delta. This delta has been formed by the sediment deposited by the **Nile River** as it flows into the **Mediterranean Sea**, showcasing the typical deltaic formation with well-sorted sediment layers.

Short Pointers for Revision:

- **Formation**: Occur at river mouths, depositing sediment into the sea.
- **Shape**: Large, roughly triangular, similar to alluvial fans.
- **Sediment Sorting**: Well-sorted with clear stratification.
- **Material Deposition**: Coarse materials settle first, finer materials carried out into the sea.
- **Growth**: River distributaries lengthen as delta builds into the sea.
- **Example**: **Nile Delta** in **Egypt**.

Flood Plains

Flood plains are significant landforms created by river deposition. When a stream channel with large-sized materials breaks into a gentle slope, these materials are deposited first.

Then, fine-sized materials like sand, silt, and clay, carried by slower moving waters in gentler channels typically found in plains, are deposited over the bed. These deposits form flat alluvial landforms, constructed largely by the present river's flow regime and are susceptible to flooding. An **active flood plain** is the river bed composed of these river deposits.

The flood plain above the bank level is known as an **inactive flood plain**, containing two types of deposits: **flood deposits** (comprising finer materials like silt and clay) and **channel deposits** (coarser materials from abandoned or cut-off channels). In plains, river channels may shift laterally and change their courses, leaving behind filled-up, cut-off courses. **Flood plains** in delta regions are referred to as **delta plains**.

Example: The **Mississippi River Flood Plain** in the **USA** is an exemplar of a vast and well-formed **flood plain**. It demonstrates the typical features of **flood plains**, with areas of both **active and inactive flood plains**, and is subject to regular flooding.

Short Pointers for Revision:

- **Nature**: Major landform of river deposition.
- **Material Deposition**: Large materials deposited first, then fine materials like sand, silt, and clay.
- **Formation**: Created by slow-moving waters in gentler channels.
- **Types**: **Active flood plain** (river bed) and **inactive flood plain** (above bank level).
- **Deposits**: **Flood deposits** (finer materials) and **channel deposits** (coarser materials).
- **Channel Shifts**: Lateral shifts and course changes in plains.
- **Delta Plains**: **Flood plains** in delta regions.
- **Example**: **Mississippi River Flood Plain**, **USA**.

Natural Levees

Natural levees are distinctive landforms found along the banks of large rivers. They manifest as low, linear, and parallel ridges of coarse deposits, often segmented into individual mounds. These levees gently slope away from the river, with the sediment size becoming progressively finer as the distance from the channel increases. **Natural levees** form when rivers overflow their banks, depositing heavier sediments closest to the bank and finer sediments further away. Additionally, when rivers shift laterally, multiple **natural levees** can develop in succession.

Short Pointers for Revision:

- **Location**: Along the banks of large rivers.
- **Appearance**: Low, linear, and parallel ridges, sometimes cut into mounds.
- **Sediment Gradation**: Coarsest near the river, becoming finer with distance.
- **Formation**: From river overflows and lateral shifts.
- **Purpose**: Provide natural flood protection.

- **Example**: **Natural levees** along the **Mississippi River**, **USA**.

Point Bars

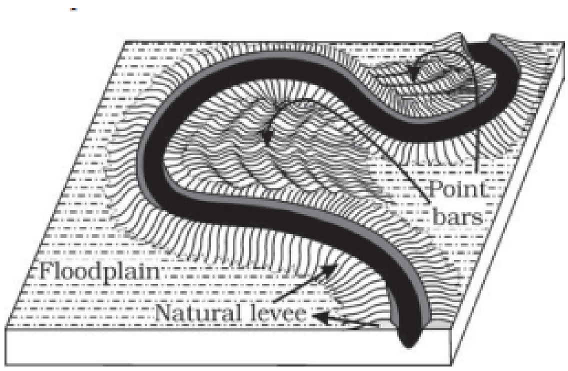


Figure 6.5 : Natural levee and point bars

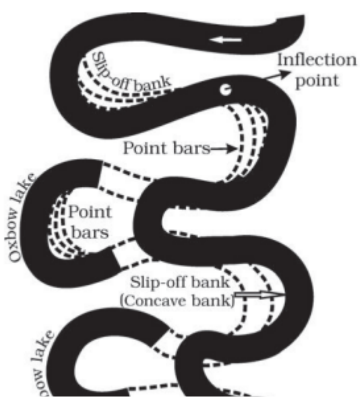
Point bars, also known as **meander bars**, are sedimentary features found on the concave side of meanders in large rivers. These are formed by the deposition of sediments in a linear fashion along the riverbank by flowing water. Point bars are characterised by a nearly uniform profile and width and contain sediments of mixed sizes. The formation of point bars is influenced by the river's water flow and sediment supply. As point bars develop on the concave side of a meander, active erosion typically occurs on the opposite convex side of the meander.

Example: The point bars along the **Amazon River**, particularly visible in its meandering sections, exemplify these features. They demonstrate the continuous deposition of mixed sediments along the river's meandering paths.

Short Pointers for Revision:

- **Also Known As:** Meander bars.
- **Location:** On the concave side of meanders in large rivers.
- **Formation:** Linear sediment deposition by flowing waters.
- **Characteristics:** Uniform in profile and width, mixed sediment sizes.
- **Associated Erosion:** Active erosion on the opposite convex side of the meander.
- **Example:** Point bars in the Amazon River.

Meanders



Meanders are loop-like channel patterns that develop in large flood and delta plains. They are not landforms themselves but are a type of channel pattern formed due to several factors: the propensity of water to work laterally on banks when flowing over gentle gradients, the unconsolidated nature of alluvial deposits comprising the banks, and the Coriolis force affecting the fluid water.

When the gradient of the channel is extremely low, water starts flowing laterally, transforming bank irregularities into small curvatures. These curvatures deepen as deposition occurs on the inside of the curve and erosion on the outside. In large river meanders, active deposition is found along the concave bank (cut-off bank) and undercutting along the convex bank (slip-off bank). Deep meander loops may get cut off due to erosion at inflection points, forming ox-bow lakes.

Short Pointers for Revision:

- **Formation:** In flood and delta plains.
- **Factors:** Gentle gradient flow, unconsolidated alluvial deposits, Coriolis force.
- **Process:** Lateral flow creates curvatures; deposition inside the curve, erosion outside.
- **Bank Types:** Concave (cut-off bank), Convex (slip-off bank).
- **Ox-Bow Lakes:** Formed from cut-off meanders.
- **Example:** Mississippi River meanders, USA.

Groundwater Landforms

Horizontal and Vertical Movement of Water

The horizontal and vertical movement of water refers to the process by which surface water and groundwater permeate, percolate, and flow through permeable rocks over time. As water moves vertically downward due to gravity and then horizontally along bedding planes, joints, or cracks, it causes chemical weathering and erosion of the rock. This ultimately leads to the formation of distinctive landforms made of limestone, dolomite, and other rocks susceptible to dissolution.

Example: The karst topography found in the limestone formations of Karnataka exhibits classic landforms created by the horizontal and vertical movement of slightly acidic groundwater dissolving the bedrock. Features like sinkholes, uvalas, caverns, stalagmites, and lapiez developed over thousands of years display the impacts of this process.

Short Pointers for Revision:

- Water moves downward due to gravity, then horizontally along bedding planes or cracks.
- Causes chemical weathering and erosion over time.
- Forms landforms like sinkholes, caves, stalactites/stalagmites in limestone and dolomite.

Formation of Karst Landforms

Karst landforms are unique geological formations created through the processes of solution and precipitation in rocks rich in calcium carbonate, such as limestones or dolomites. Groundwater and surface water contribute to these processes. The water seeps through permeable, thinly bedded, highly jointed, and cracked rocks, moving vertically down and then horizontally through bedding planes or joints.

In karst regions, this leads to the development of distinctive erosional and depositional landforms. Erosional features include swallow holes (small to medium-sized depressions on limestone surfaces), sinkholes (circular openings that are funnel-shaped towards the bottom), uvalas (formed when sinkholes and dolines join together), and lapies (corrugated and rough surfaces with low ridges and pinnacles).

Depositional features in karst landscapes include stalactites (limestone columns hanging from cave roofs), stalagmites (rising from cave floors), and pillars (formed when stalactites and stalagmites fuse together).

Example : A notable example from India is the limestone karst region in the Khasi Hills of Meghalaya, which includes extensive cave systems with stalactites, stalagmites, and other karst features.

Short Pointers for Revision:

- **Rock Types:** Primarily in limestone or dolomite.
- **Water Action:** Surface and groundwater seepage, solution, and precipitation.
- **Erosional Landforms:** Swallow holes, sinkholes, uvalas, and lapies.
- **Depositional Features:** Stalactites, stalagmites, and pillars.
- **Indian Example:** Karst landscapes in the Khasi Hills, Meghalaya.
- **Movement of Water:** Vertical and horizontal through rocks, causing erosion and deposition.

Erosional Landforms of Karst Topography

Sinkholes

Sinkholes, also known as *swallow holes*, are a type of landform commonly found in *limestone* or *karst areas*, formed through the chemical processes of **solution** and **precipitation**.

They are characterised by openings in the ground that are **circular** at the top and **funnel-shaped** towards the bottom. Sinkholes occur when surface water or groundwater seeps through *permeable*, *thinly bedded*, *highly jointed*, and *cracked rocks*, dissolving the *limestone* or *dolomite* and creating **voids**.

These voids can either form purely through the solution process (*solution sinks*) or start as solution forms and later collapse if they form the roof of an underground void or cave (*collapse sinks*). Sinkholes vary in size and depth, and they can lead to the formation of **underground streams** that re-emerge downstream. When covered with soil, they may appear as **shallow water pools**, resembling *quicksands*.

Example: The plains of northern and central Florida contain thousands of sinkholes due to the underlying limestone bedrock. Sinkholes periodically and suddenly form, often damaging buildings and infrastructure.

Short Pointers for Revision:

- **Formation**: In *limestone/karst areas* through **solution** and **precipitation**.
- **Characteristics**: **Circular**, **funnel-shaped** openings.
- **Types**: *Solution sinks* (formed solely by solution) and *collapse sinks* (formed by collapse of a void's roof).
- **Size Variation**: Vary in size and depth.
- **Underground Streams**: Often lead to **underground streams**.
- **Appearance**: May resemble **shallow water pools** when covered with soil.
- **Indian Example**: Sinkholes in *Khasi Hills, Meghalaya*.
- Formed on soluble rocks like limestone by dissolution
- Round, shallow depressions ranging greatly in size
- Often connect to underground caves and voids
- Can be hazardous, suddenly collapsing to form deeper holes

Pools

Pools are **shallow**, **circular depressions** formed on the surface of *limestone* when **sinkholes** become covered with soil. They appear as temporary **water pools** that can be hazardous to step in, similar to *quicksand*.

Example: The **Bhandardara region** in *Maharashtra* contains *karst topography* with numerous **sinkholes**, some of which form **pools** during the rainy season that can be dangerous.

Short Pointers for Revision:

- **Formation**: **Pools** form in *karst landscapes*, often over **sinkholes**.
- **Location**: Common in *limestone* and *dolomite areas*.
- **Sinkholes**: Created by **solution** and **precipitation** processes in groundwater.
- **Appearance**: Can look like **shallow water pools**, covering deeper sinkholes.
- **Safety Concern**: May be hazardous like *quicksands*.
- **Indian Example**: *Karst pools* in the *limestone regions* of *Meghalaya*.
- **Formed when sinkholes covered by soil fill with water**
- **Circular depressions** that look like harmless pools
- Can be risky to step in, like quicksand
- Found in regions underlain by karst limestone

Playas

Playas are nearly flat plains that form at the centre of **endorheic basins** due to the gradual deposition of sediments from the surrounding mountains and hills. When sufficient water is available, these plains are temporarily covered by shallow lake water bodies called playas. However, the water quickly evaporates due to the desert conditions, leaving behind salt deposits known as **alkali flats**.

Short Pointers for Revision:

- Form at the centre of **endorheic basins**
- Formed by deposition of sediments
- Temporary shallow salt lakes
- Water evaporates rapidly
- Salt deposits left behind are called **alkali flats**

Doline in Karst Topography

A **doline**, also known as a *sinkhole* or *swallow hole*, is a **small to medium-sized, round to sub-rounded depression** that forms on the surface of *limestone* regions.

Dolines are characterised by their varying sizes and depths, and they can evolve into larger formations like **uvalas** when multiple dolines join together due to further erosion and collapse.

Short Pointers for Revision:

- **Formation**: Dolines are formed by the dissolution of *limestone* or *dolomite*.
- **Characteristics**: *Round to sub-rounded depressions* of varying sizes and depths.
- **Process**: Created by surface and groundwater seeping through rocks, causing *dissolution*.
- **Evolution**: Can join to form *uvalas* in areas of extensive karst activity.

Uvalas

Uvalas are **long, narrow to wide trenches** formed when numerous adjacent *sinkholes* and *dolines* coalesce due to slumping of materials along their margins or collapse of cave roofs. Uvalas form an **extremely irregular surface** on *limestone* with a maze of ridges.

Example: *Meghalaya* in northeast India has extensive *karst landscapes* with features like *sinkholes*, *caves*, and *pits* formed in the predominant *limestone* geology. Uvalas likely exist in the area but specific examples are unavailable.

Short Pointers for Revision:

- Formed by **coalescing** of multiple *sinkholes* and *dolines*
- **Long, narrow to wide trenches**
- Create an **extremely irregular limestone surface**
- Formed by **slumping** of materials or **cave roof collapse**
- Maze of ridges left called *lapies*

Lapies in Karst Topography

Lapies are unique erosional landforms found in *karst topography*, characterised by their highly corrugated, rough surfaces consisting of **ridges**, **grooves**, and **pinnacles**. They form predominantly in *limestone* or *dolomite-rich* areas, where the chemical process of **solution** and **precipitation** by groundwater and surface water is active.

Lapies are created when most of the surface of the limestone is eroded away, leaving behind an irregular landscape of pits, grooves, and sharp ridges. This process is influenced by differential solution activity along parallel or sub-parallel joints in the rock.

Short Pointers for Revision:

- **Formation**: Occur in *limestone* and *dolomite regions* through the process of **solution** and **precipitation**.
- **Appearance**: characterised by a rough surface with **ridges**, **grooves**, and sharp pinnacles.
- **Chemical Erosion**: Formed by chemical erosion, primarily in regions rich in **calcium carbonate**.
- **Indian Example**: Lapies in the *Khasi and Jaintia Hills, Meghalaya*.

Limestone Pavements

Limestone pavements refer to the relatively smooth surfaces created when *limestone lapies fields* are worn down over time by ongoing *solution activity* along *joints*.

Example: The *karst landforms* with extensive limestone in the *Meghalaya region* of India likely feature *limestone pavements* in areas where *sinkholes* and *lapies* have extensively eroded the surface.

Short Pointers for Revision:

- *Smooth limestone surfaces*
- Formed from *limestone lapies fields*
- Created by long-term *solution activity* along *joints*
- Represents a *mature karst landscape*

Caves

Caves are naturally occurring underground spaces with openings that form where layers of rocks like *shales*, *sandstones*, *quartzites*, *limestones*, or *dolomites* are exposed and then weather over time.

They usually form in places where there are thick beds of *limestone* or *dolomite*. In this process, water moves horizontally along *bedding planes* by moving through rock materials or cracks and joints.

The carbon dioxide-rich water movement breaks down the *limestone*, making caves that are *long and narrow to wide*. These caves can form at different heights depending on the rocks that are between the *limestone* beds. A lot of caves have *holes* in them where water can flow. Some caves may even have *holes at both ends*, which are called ***tunnels***.

Example : A prominent example of cave formation in India can be found in the *limestone regions* of *Meghalaya*, such as the *Krem Liat Prah*, one of the longest natural caves in the Indian subcontinent.

Short Pointers for Revision:

- *Formation:* Occurs in areas with *limestone* or *dolomite* layers, involving *water percolation* and *dissolution of rock*.
- *Characteristics: Long and narrow to wide gaps*, sometimes forming *complex mazes*.
- *Location:* Common in *karst topographies*.
- *Indian Example: Krem Liat Prah cave* in *Meghalaya*.
- *Importance:* Indicates underlying *geological and hydrological processes*.

Depositional Landforms of Karst Topography

Depositional landforms in *karst topography* are primarily formed by the action of groundwater in regions with rocks like *limestones* or *dolomites*, which are rich in *calcium carbonate*.

These landforms result from the chemical process of *solution*, where *calcium carbonate* is dissolved by carbonated water, and *precipitation*, where it is re-deposited.

Key depositional features in karst landscapes include *stalactites* and *stalagmites* within caves, formed by the dripping of mineral-rich water and its subsequent deposition.

Short Pointers for Revision:

- **Composition:** Formed in *limestone* or *dolomite* areas rich in *calcium carbonate*.
- **Process:** Involves *solution* and *precipitation* of *calcium carbonate*.
- **Features:** Includes *stalactites* (hanging from ceilings) and *stalagmites* (rising from floors) in caves.
- **Formation:** Caused by the evaporation or degassing of carbonated water carrying dissolved minerals.
- **Example:** *Limestone caves* in *Meghalaya*.

Stalactites

Stalactites are icicle-shaped mineral formations that hang from the ceilings of caves. These formations are primarily composed of calcium carbonate minerals, often found in limestone-rich areas. Stalactites develop gradually over many years as water, enriched with minerals, drips down from the rocks above the cave. As this mineral-laden water drips, it leaves behind small deposits of minerals that accumulate over time, eventually forming these distinctive hanging stalactites.

Example: An excellent example of stalactites can be observed in the Borra Caves, located in India. These caves boast numerous exquisite stalactites that have taken thousands of years to form.

Short Pointers for Revision:

- **What They Are:** Icicle-shaped mineral formations hanging from cave ceilings.
- **Composition:** Primarily composed of calcium carbonate minerals from limestone.
- **Formation Process:** Gradually developed by mineral-rich water dripping down over many years.
- **Location Example:** Borra Caves in India.

- **Understanding:** Stalactites grow from the cave ceiling downward, and their formation is a slow, time-consuming process.

Stalagmites

Stalagmites are mound-like or columnar mineral formations found on the floors of caves. These formations are primarily composed of calcium carbonate minerals, often originating from limestone deposits. Stalagmites develop as a result of the gradual deposition of minerals carried by dripping water from the cave ceiling.

When this water, enriched with dissolved minerals, lands on the cave floor and subsequently evaporates, it leaves behind mineral deposits. Over an extended period, these deposits accumulate, giving rise to the distinctive mound-like or columnar shape of stalagmites.

Example : Notable stalagmites can be observed in the Arvalem Caves located in Goa, India. These stalagmites have formed over thousands of years, serving as a captivating example of this geological phenomenon.

Short Pointers for Revision:

- **Formation:** Stalagmites grow upwards from cave floors due to mineral-rich water dripping from the cave ceiling.
- **Composition:** Mainly composed of calcium carbonate minerals typically sourced from limestone.
- **Shape:** Mound-like or columnar, varying in size.
- **Understanding:** Stalagmites form slowly over time and can be valuable for studying past environmental conditions.
- **Indian Example:** Arvalem Caves in Goa, India, showcase impressive stalagmites that have developed over millennia.

Pillars and Columns

Pillars and columns are cylindrical mineral formations discovered within limestone caves. They come into existence through the gradual fusion of stalagmites that rise from the cave floor and stalactites that hang from the cave roof. These formations exhibit varying diameters depending on the size of the stalactite and stalagmite structures that contribute to their formation.

Example: The Borra Caves, located in the Visakhapatnam district of Andhra Pradesh, India, showcase remarkable pillars that have developed over thousands of years as a result of the fusion of stalagmites and stalactites.

Short Pointers for Revision:

- **Formation:** Created by the merging of stalagmites and stalactites.
- **Location:** Typically found in limestone caves.
- **Structure:** Cylindrical in shape with diameters that differ based on the contributing stalactite and stalagmite sizes.
- **Timeframe:** Formed over extended periods.
- **Example:** Prominent pillars can be observed in the Borra Caves, Andhra Pradesh, India.

Glacier Landforms

Glacier landforms refer to distinct geographical features shaped by the erosional and depositional processes resulting from the movement of flowing ice masses, including mountain glaciers, valley glaciers, and continental ice sheets. The sheer weight and gradual motion of ice lead to substantial erosion, giving rise to landforms such as cirques, U-shaped valleys, hanging valleys, horns, and serrated ridges. Additionally, as glaciers melt, they deposit materials, forming features like moraines, drumlins, outwash plains, and eskers.

Example: The Himalayan region showcases some of the world's most striking glacier landforms, characterised by deeply carved U-shaped valleys, jagged mountain peaks shaped by glacial erosion, and the presence of moraines and outwash deposits.

Short Pointers for Revision:

- **Formation:** Result from erosion and deposition processes associated with flowing glaciers.
- **Erosional Landforms:** Include cirques, U-shaped valleys, hanging valleys, horns, and serrated ridges.
- **Depositional Landforms:** Comprise moraines, drumlins, outwash plains, and eskers.
- **Glacial Impact:** Movement and weight of ice cause significant abrasion on the land surface.

- **Melting Ice:** Leads to the deposition of materials and the formation of depositional landforms.
- **Example:** Notable glacier landforms can be found in the valleys of Uttarakhand, Himachal Pradesh, and Kashmir.

Erosional Landforms of Glaciers

Cirques

Cirques are prominent geological features primarily found in glaciated mountainous regions, typically situated at the heads of glacial valleys. These distinctive landforms result from the erosive action of moving glacier ice as it descends from mountain peaks. Cirques are characterised by their deep, elongated, and wide basin-like shape, featuring steep, concave to nearly vertical walls both at the head and along the sides. After glaciers retreat, these depressions often transform into lakes, known as cirque or tarn lakes. It's common to observe a series of cirques arranged one above the other, forming a stepped sequence.

Real-life Case Study Example: The Lake District of England provides a noteworthy example of cirques formed through glacial activity. Within the Helvellyn Range, classic cirque formations with steep headwalls can be found, and some of these cirques host tarns like Red Tarn within their basin-like structures.

Short Pointers for Revision:

- **Location:** Typically situated at the upper ends of glacial valleys in mountainous terrains.
- **Formation:** Result from the erosive processes caused by moving glacier ice.
- **Shape:** Exhibits deep, elongated, and wide basin shapes with steep, concave, or nearly vertical walls.
- **Tarn Lakes:** Frequently contain lakes within their depressions following glacier retreat.
- **Arrangement:** Multiple cirques can be arranged in a stepped sequence, with one leading into another.
- **Example:** The Helvellyn Range in the Lake District, England, showcases cirque formations, including the presence of Red Tarn within these cirques.

Horns and Serrated Ridges

Horns: Horns are tall, sharp-edged peaks created when three or more adjoining cirques erode backward into a mountain.
Horns are distinctive geological features characterized by their steep, sharp, and pointed peaks, typically found in glaciated mountain regions. These formations result from the headward erosion of cirque walls by glaciers.
Notable examples of horns include the Matterhorn in the Alps and Mount Everest in the Himalayas.

Serrated Ridges (Arêtes): Serrated ridges are narrow, jagged divides that form between cirque walls due to ongoing glacier erosion.
Over time, the narrowing of these divides due to erosion leads to the formation of sharp, jagged, and saw-toothed ridges with a distinctive zig-zag outline.

Real-life Case Study Example: The Matterhorn, situated in the Alps, stands as an iconic illustration of a horn formation, resulting from the convergence of multiple glaciers. Its pyramid-like shape serves as a classic representation of horn landforms. Additionally, Mount Everest, the highest peak in the Himalayas, is another prominent example, shaped by the intersection of several glaciers.

Short Pointers for Revision:

- **Horns Formation:** Created through headward erosion of cirque walls by glaciers.
- **Characteristics of Horns:** Notable for their high, sharply pointed, and steep-sided peaks.
- **Horns Examples:** Prominent instances include the Matterhorn in the Alps and Mount Everest in the Himalayas.
- **Serrated Ridges (Arêtes):** Result from the narrowing of divides between cirque walls due to erosional processes.
- **Features of Serrated Ridges:** Exhibits sharp, jagged, saw-toothed ridges with a distinctive zig-zag outline.
- **Relation to Glaciers:** Both horns and arêtes are geological formations arising from glacial erosion in mountainous regions.

Glacial Valleys/Troughs

Glacial valleys, also known as **troughs**, are U-shaped valleys formed by the erosive action of glaciers. They feature broad floors with relatively smooth yet steep sides. These valleys often contain debris such as rocks and soil, which can form **moraines** with a swampy appearance.
Additionally, lakes may form within these valleys, either gouged out of the rocky floor or created by the accumulation of debris. **Hanging valleys** are a common feature, situated at a higher elevation on one or both sides of the main **glacial valley**.
The divides or spurs of these **hanging valleys**, when they open into the main valley, are often truncated, giving them a triangular facet-like appearance. In higher latitudes, deep **glacial troughs** filled with seawater form **fjords** or **fiords**, which are characteristic of glacial landscapes along coastlines.

Example: The **fjords** of Norway are a prime example of **glacial valleys** filled with seawater. These deep, U-shaped valleys extend below sea level and are lined with steep cliffs, showcasing the classic features of **glacial troughs**.

Short Pointers for Revision:

- Shape: U-shaped with broad floors and steep sides.
- Formation: Created by the erosive action of glaciers.
- Debris and **Moraines**: Often contain littered debris, forming **moraines** with a swampy look.
- Lakes Formation: Lakes may form within these valleys, either by erosion or debris accumulation.
- **Hanging Valleys**: Elevated valleys on the sides of the main **glacial valley**, often with triangular facet-like divides.
- **Fjords/Fiords**: Deep **glacial troughs** filled with seawater, typically found in higher latitudes.
- Example: **Fjords** of Norway.

Depositional Landforms of Glaciers

Depositional landforms of glaciers primarily consist of **glacial till** and outwash deposits. **Glacial till** refers to the unassorted mix of coarse and fine debris left behind by melting glaciers. The rock fragments within this **till** typically range from angular to sub-angular shapes. Additionally, streams generated by the melting of ice at the bottom, sides, or lower ends of glaciers transport smaller rock debris. This material, small enough to be carried by melt-water streams, is then deposited downstream, forming what are known as **glacio-fluvial** or outwash deposits. Unlike **glacial till**, outwash deposits are roughly stratified and sorted, with rock fragments that are somewhat more rounded at their edges.

Example: The Moraine Park in Rocky Mountain National Park, Colorado, USA, serves as a real-life example. Here, the landscape is shaped significantly by **glacial till** and outwash deposits, showcasing the typical characteristics of these **depositional landforms**.

Short Pointers for Revision:

- **Glacial Till**: A mixture of unsorted coarse and fine debris from melting glaciers.
- Rock Fragment Shapes in **Till**: Angular to sub-angular.
- Formation of Melt-Water Streams: From melting ice at various glacier parts.
- **Glacio-fluvial**/outwash Deposits: Deposited by melt-water streams; roughly stratified and sorted.
- Comparison with **Till**: Outwash deposits have somewhat rounded rock fragments.
- Example Site: Moraine Park in Rocky Mountain National Park, Colorado, USA.

Moraines

Moraines are distinctive long ridges formed by deposits of **glacial till**.

They come in several types:

- **Terminal moraines** are ridges of debris deposited at the glacier's end, typically at the lowest point the glacier has reached.
- **Lateral moraines** are found along the sides of glacial valleys, parallel to the glacier's flow, and sometimes connect with terminal moraines to form a horse-shoe shaped ridge.
- **Ground moraines** are irregular sheets of till covering valley floors, varying in thickness and topography, formed by valley glaciers retreating rapidly.

- **Medial moraines** appear in the center of glacial valleys, flanked by lateral moraines. These are imperfectly formed compared to lateral moraines and can sometimes be indistinguishable from ground moraines.

The formation of these moraines is influenced partly or wholly by **glacio-fluvial waters** that push materials to the glacier's sides.

Example: The Glacier National Park in Montana, USA, showcases various types of moraines, with distinct **terminal** and **lateral moraines** marking the landscape, providing a real-world representation of these glacial formations.

Short Pointers for Revision:

- Types of Moraines: **Terminal**, **lateral**, **ground**, and **medial**.
- **Terminal Moraines**: Debris ridges at the glacier's end.
- **Lateral Moraines**: Form along the sides of glacial valleys.
- **Ground Moraines**: Irregular till sheets over valley floors.
- **Medial Moraines**: Located centrally in glacial valleys, flanked by lateral moraines.
- Formation Influences: Partly due to **glacio-fluvial waters** moving materials to glacier sides.
- Example Location: **Glacier National Park**, Montana, USA.

Eskers in Glacial Geology

Eskers are **sinuous ridges** formed as a result of the melting of glaciers during the summer. When glaciers melt, water either flows on the surface of the ice, seeps down along the margins, or moves through holes in the ice. This water accumulates beneath the glacier and flows like streams in a channel beneath the ice. As these streams flow over the ground (not in a valley cut into the ground), ice forms their banks.

Large, coarse materials such as boulders and blocks, along with some smaller rock debris, carried into these streams, settle in the ice valley beneath the glacier. After the ice melts, these accumulated materials create **sinuous (twisting) ridges** known as **esk**ers.

Example : Imagine a glacier slowly melting during the summer season. The water from the melting glacier flows underneath it, collecting debris and rocks along the way. Once the glacier completely melts, a **winding ridge** composed of these materials is left behind, resembling a snake-like formation. This ridge is what we call an **esker**.

Short Pointers for Revision:

1. **Eskers** form during the summer when glaciers melt.
2. Water from melting glaciers flows beneath the ice.
3. This water accumulates debris and rocks, creating a **sinuous ridge**.
4. **Eskers** have a **winding, snake-like** appearance.
5. They are formed by the accumulation of materials carried by the water beneath the glacier.

Real-Life Case Study/Example: A notable example of an esker is the "**S-shaped ridge**" located in the southern part of Ireland. This esker, known as the **Esker Riada**, extends for approximately **180 kilometers**. It was formed thousands of years ago by the melting of glaciers during the last Ice Age. The ridge is composed of **gravel, sand, and boulders**, showcasing the typical features of an esker. It serves as a significant geological landmark and is a testament to the powerful glacial processes that shaped the landscape.

Outwash Plains - Glacial Landforms

Outwash plains are broad, flat areas located at the base of glacial mountains or beyond the edges of continental ice sheets. These plains are covered with deposits formed by glacial meltwater, known as **glacio-fluvial deposits**. They take the shape of expansive, alluvial fans that can merge together to create extensive outwash plains comprising various materials, including **gravel, silt, sand, and clay**.

Example : An excellent real-life example of outwash plains can be found in the northeastern United States, particularly in the state of Connecticut. The **Connecticut River Valley** boasts extensive outwash plains that were formed during the last Ice Age when massive glaciers covered much of the region. As the glaciers melted, they released a tremendous amount of meltwater that carried sediments and debris. This meltwater spread out and deposited materials like **gravel, silt, sand, and clay**, creating the fertile and flat Connecticut River Valley that we see today. These outwash plains have become crucial agricultural regions due to their rich and well-drained soils.

Short Pointers for Revision:

1. **Outwash plains** are flat areas at the base of glacial mountains or beyond continental ice sheets.
2. They are covered with **glacio-fluvial deposits**.
3. **Glacio-fluvial deposits** are materials formed by glacial meltwater.
4. These deposits shape broad, alluvial fans.
5. Multiple alluvial fans can merge to form extensive outwash plains.
6. Materials found on outwash plains include **gravel, silt, sand, and clay**.
7. **Example**: **Connecticut River Valley** in the northeastern United States as a real-life instance of outwash plains formation.

Drumlins

Drumlins are smooth, oval-shaped, ridge-like landforms predominantly composed of **glacial till**, interspersed with **gravel** and **sand**. These features are oriented with their long axes parallel to the direction of past ice movement.
Typically, drumlins can be up to **1 kilometer** in length and about **30 meters** in height. They are formed by the accumulation and compression of **rock debris** beneath heavily loaded glacial ice, which enters through fissures in the glacier.
A notable feature of a drumlin is its **asymmetry**: the **stoss end**, which faces the advancing glacier, is blunter and steeper, while the opposite end, known as the **tail**, is more tapered. This shape is a result of the ice's pushing action, which blunts the stoss end. Drumlins are significant as they provide clues about the direction of glacier movement.

Example: The Drumlin Field in Ontario, Canada, is a classic example. This area contains numerous drumlins, which collectively indicate the direction of ice movement during the last Ice Age.

Short Pointers for Revision:

1. **Shape and Composition**: Smooth, oval, ridge-like; made of **glacial till**, **gravel**, and **sand**.
2. **Orientation**: Long axes parallel to glacier movement direction.
3. **Size**: Up to **1 km** in length and around **30 m** in height.
4. **Formation**: From **rock debris** compressed beneath glacial ice.
5. **Asymmetry**: Blunter, steeper stoss end facing the glacier; tapered tail end.

6. **Indicative Value**: Shows the direction of past glacier movement.
7. **Real-world Example**: Drumlin Field in Ontario, Canada.

Waves and Currents in Coastal Processes

Coastal processes, primarily driven by **waves** and **currents**, are dynamic and can be highly destructive, leading to rapid changes along coastlines.
These changes, such as erosion and deposition, can occur swiftly, varying from one season to another.
The primary agents of coastal transformation are **waves**. When they break, waves exert a strong force on the shore and churn sediments on the sea bottom. The constant impact of breaking waves significantly alters coastal landscapes.

Extreme events like **storm waves** and **tsunamis** can induce drastic changes in a short time, more so than regular wave action. The intensity and impact of these waves vary with the changing wave environment. Besides wave action, coastal landforms are influenced by the configuration of the land and sea floor, and whether the coast is advancing seaward (emerging) or retreating landward (submerging). Assuming a constant sea level, two main types of coasts are recognized: **high, rocky coasts** (submerged coasts), and **low, smooth, gently sloping sedimentary coasts** (emerged coasts).

Example: The erosion of the cliffs at the Great Ocean Road in Australia exemplifies the impact of **waves and currents**. The constant wave action has shaped the iconic limestone structures over time, demonstrating the powerful forces of coastal processes.

Short Pointers for Revision:

1. **Dynamic Nature**: Rapid and often destructive changes.
2. **Primary Agents**: **Waves** and **currents**.
3. **Wave Impact**: Strong force and churning of sea bottom sediments.
4. **Effects**: Erosion, deposition, and altering of coastal landscapes.
5. **Extreme Events**: **Storm waves** and **tsunamis** cause drastic changes.
6. **Influencing Factors**: Land and sea floor configuration, and the direction of coastal movement (emerging or submerging).
7. **Types of Coasts**: **High, rocky** (submerged) and **low, smooth sedimentary** (emerged) coasts.

8. **Real-world Example**: Erosion of cliffs along the Great Ocean Road, Australia.

High Rocky Coasts (Submerged Coasts)

High Rocky Coasts, also known as **Submerged Coasts**, are characterized by a highly irregular and indented coastline. These coasts typically show the effects of river valleys being drowned, with features like glacial valleys (fjords) extending into the land.
The terrain is marked by steep hillsides that drop sharply into the water. On these coasts, erosional processes dominate over depositional ones, and shores initially lack depositional landforms. The powerful force of waves striking these coasts shapes the terrain into **cliffs**.
Over time, these cliffs are eroded by constant wave action, leading to the formation of **wave-cut platforms** in front of the cliffs.
As the process continues, the coastline gradually becomes smoother, and with the accumulation of eroded materials offshore, **wave-built terraces** develop in front of the wave-cut platforms. The eroded material also contributes to the formation of **beaches** along the shore and **bars** (long ridges of sand or shingle parallel to the coast) in the nearshore zone.

These bars, when submerged, are known as **barrier bars**, and when they emerge above water, they form **spits**, particularly when attached to the headland of a bay. The formation of barrier bars and spits at the mouth of a bay can lead to the creation of a **lagoon**, which may gradually fill up with sediments to form a coastal plain.

Example: The West Coast of India is an example of a high rocky retreating coast, where the features described above are prominently seen.

Short Pointers for Revision:

1. **High rocky coasts** have irregular, indented shorelines with steep drops.
2. Erosion dominates, with minimal initial depositional landforms.
3. Features include **fjords**, **cliffs**, **wave-cut**, and **wave-built terraces**.
4. Cliffs erode due to wave action, leading to smoother coastlines over time.
5. Eroded materials form offshore deposits, **beaches**, and **bars**.
6. Bars submerged underwater are known as **barrier bars**.

7. Barrier bars connected to headlands form **spits**; blocking a bay's mouth creates **lagoons**.
8. Lagoons may evolve into coastal plains filled with sediment.

Low Sedimentary Coasts (Emerged Coast)

Low Sedimentary Coasts, also known as **Emerged Coasts**, are characterized by their smooth, gently sloping terrain, where rivers extend their reach by building coastal plains and deltas.
These coasts are primarily dominated by depositional forms, with occasional water incursions in the form of lagoons and tidal creeks. The land here gently slopes into the water, often accompanied by marshes and swamps.

Depositional features such as **bars**, **barrier bars**, **spits**, and **lagoons** are predominant, formed by the churning and movement of bottom sediments when waves break over the coast.
These lagoons can evolve into swamps, which may then turn into coastal plains. The persistence of these depositional features relies on a steady supply of sediments. However, their structure can be drastically altered by storms or tsunami waves, regardless of sediment supply. Large rivers play a crucial role in building deltas along these coasts by bringing and depositing large amounts of sediments.

Example: The East Coast of India exemplifies a low sedimentary coast, showcasing depositional landforms such as coastal plains and deltas.

Short Pointers for Revision:

1. Low sedimentary coasts are smooth and gently sloping.
2. Dominated by depositional forms, less by erosion.
3. Features include **lagoons**, **tidal creeks**, **marshes**, and **swamps**.
4. Formation of **bars**, **barrier bars**, **spits**, and **lagoons** due to sediment movement.
5. Lagoons can transition into swamps and then coastal plains.
6. Features depend on a continuous supply of sediments.
7. Susceptible to alterations caused by **storms** and **tsunamis**.
8. Large rivers contribute to delta formation on these coast

Erosional Landforms of Waves and Currents

Cut Cliffs and Terraces

Wave-cut cliffs and terraces are coastal features formed primarily through the erosive action of waves. These steep cliffs can extend from a few meters to over **30 meters** in height.
At their base, a flat or gently sloping platform often exists, covered with rock debris eroded from the cliff itself. These platforms, known as **wave-cut terraces**, are typically found at elevations above the average wave height. The constant wave action against the cliff base not only creates these terraces but also carves out **sea caves** in the cliffs.
Over time, the roofs of these caves may collapse, causing the cliffs to recede inland. This retreat can leave behind isolated rock formations known as **sea stacks**, which are remnants of the original cliff or hill.
However, these features are temporary as continuous wave erosion will eventually transform coastal hills and cliffs into narrow coastal plains. These plains may then be covered by **alluvium**, **shingle**, or **sand**, forming wide beaches.

Example: A notable example of wave-cut cliffs and terraces can be observed along the Great Ocean Road in Victoria, Australia. The **Twelve Apostles**, a series of limestone stacks off the shore, are remnants of the ancient cliffs eroded over time by the waves of the Southern Ocean. These formations exemplify the process of wave erosion leading to the creation of **sea stacks** and the gradual retreat of cliffs.

Short Pointers for Revision:

1. **Formation:** Wave-cut cliffs and terraces are created by wave erosion.
2. **Cliff Height:** Ranges from a few meters to over **30 meters**.
3. **Wave-cut Terraces:** Flat platforms at cliff base, above average wave height.
4. **Sea Caves:** Formed by waves smashing against cliffs.
5. **Cliff Recession:** Roofs of sea caves collapse, causing cliffs to recede inland.
6. **Sea Stacks:** Isolated rock formations left after cliff retreat.
7. **Temporary Nature:** Continuous erosion turns cliffs into coastal plains.
8. **Coastal Transformation:** Coastal plains may develop into wide beaches covered with **alluvium**, **shingle**, or **sand**.

Sea Caves

Sea caves are large, natural hollows formed in coastal cliffs by wave erosion, with horizontally oriented openings. The constant hydraulic action of waves causes rock and debris to collide with the cliff base, carving out cave formations.
As this erosional process continues, cave roofs may eventually collapse under their own weight, resulting in the inland retreat of the sea cliffs.

Example: The island of Staffa located off the western coast of Scotland contains prime examples of *sea caves* such as *Fingal's Cave*. This large sea cave features impressive hexagonal columns formed from ancient lava flows which have been eroded out by ongoing wave action over time.

Short Pointers for Revision:

1. **Found along coasts with erosion-prone cliffs**
2. **Formed by wave collision and debris impact**
3. **Roof collapse leads to cliff recession**
4. **Show continued coastal change processes**

Sea Stacks

Sea stacks are isolated rock formations, resembling small islands, located near the shore. They are remnants of cliffs or hills that have become separated due to the gradual retreat of the cliff. Formed primarily through wave erosion, *sea stacks* are temporary geological features.
Over time, as coastal hills and cliffs erode, these stacks may eventually disappear, contributing to the formation of narrow coastal plains. Additionally, deposits from inland, such as *alluvium*, *shingle*, or *sand*, can cover the land, leading to the creation of wide beaches.

Example: The *Old Man of Hoy*, located in the Orkney Islands, Scotland, serves as a classic example of a *sea stack*. It dramatically stands apart from the coast, showcasing the effects of coastal erosion.

Short Pointers for Revision:

- **Definition:** Isolated rock formations near the shore, remnants of eroded cliffs or hills.
- **Formation:** Created through wave erosion and the retreat of cliffs.

- **Nature:** Temporary geological structures.
- **Consequence:** Erosion leads to the formation of narrow coastal plains.
- **Impact:** Inland deposits may create wide beaches.
- **Example:** *Old Man of Hoy* in Scotland – a prominent *sea stack* illustrating coastal erosion effects.

Depositional Landforms

Beaches and Dunes

Beaches are parts of shorelines where deposition dominates, often seen as sandy stretches but sometimes existing as patches along rugged shores. The sediment composing beaches is mainly derived from land-based materials transported by streams and rivers or from material eroded by waves. Beaches are changeable features; a sandy beach may seem permanent but can transform into a narrow strip of coarse pebbles in different seasons. Typically, beaches consist of sand-sized particles.

Shingle beaches, however, are characterised by the presence of very small pebbles and cobbles. Adjacent to beaches, sands that are lifted and separated from the beach surfaces are deposited as *sand dunes*, which often form long ridges parallel to the coastline, especially along low sedimentary coasts.

Example: The *Great Dune of Pyla* in France is an example of sand dunes adjacent to a beach. It is the tallest sand dune in Europe and illustrates the dynamic nature of sand movement and dune formation along the coastline.

Short Pointers for Revision:

- **Definition:** Shoreline areas dominated by deposition are variable in composition.
- **Sediment Source:** From land (streams, rivers) and wave erosion.
- **Variability:** Sandy beaches may change to pebble strips seasonally.
- **Beach Types:** Sandy beaches and shingle beaches (small pebbles/cobbles).
- **Sand Dunes:** Formed from beach sands, often parallel to coastlines.
- **Example:** *Great Dune of Pyla*, France – showcases sand movement and dune formation.

Offshore Bars

Offshore bars are elongated ridges of sand and shingle formed by waves and currents, located in the nearshore zone parallel to the coastline. They extend from the low tide waterline out towards deeper water.

Example: *Chesil Beach* found along the English Channel in Southern England is a cobble and gravel barrier beach over 18 km long. It exemplifies an offshore sediment bar that has built up sufficiently to emerge above the high tide line. This sheltered the area behind to form the *Fleet lagoon*.

Short Pointers for Revision:

- Underwater ridges offshore
- Comprised of sand and shingle
- Oriented parallel to the coast
- Formed by waves and currents
- Found from low tide line seawards

Spits

Spits are elongated ridges of sediment that extend from the coastline out to sea. They commonly form when barrier bars or offshore sediment accumulations become attached to a bay's headland or at a river mouth. Continuous deposition causes these *spits* to gradually stretch across bays, leaving only a narrow entrance opening. The resulting enclosed bay progresses into a sheltered lagoon, which eventually infills with sediment from land and coastal sources, transitioning into a coastal plain.

Example: *The Hook sand spit*, located on the southern coast of England, juts out over 4 miles into the English Channel. This sweeping, curved landform developed as longshore drift extended sediments westward from erosion-prone cliffs to the east. The spit's growth has led to the transformation of the waters behind it into *Christchurch Harbour*, protected from channel waves.

Short Pointers for Revision:

- Sediment ridges protruding out to sea
- Barrier bars/offshore bars attach to headlands

- Grow through longshore drift
- Shut bays into lagoons
- Lagoons infill, becoming coastal plains

Wind Landforms in Deserts

In hot deserts, wind acts as a primary agent of erosion and deposition. The desert floors, being dry and barren, heat up significantly, causing the air above to warm and rise, creating turbulence such as eddies, whirlwinds, updrafts, and downdrafts.

Winds moving across the desert surface can be swift and turbulent, especially when encountering obstructions. Wind erosion in deserts involves three main processes: ***deflation*, *abrasion*, and *impact*.**

- Deflation is the lifting and removal of dust and small particles from rock surfaces.
- Abrasion happens during the transportation of sand and silt, which abrade the land surface.
- Impact involves the force of wind-driven sand striking rock surfaces, akin to sand-blasting.

Additionally, desert features are shaped by mass wasting and torrential sheet floods, as desert rains, though infrequent, can be heavy and sudden. These rains facilitate the removal of weathered debris, contributing to the formation of broad, smooth, and often temporary stream channels.

Example: The *Sahara Desert* is a prime example, showcasing various wind landforms such as sand dunes and eroded rock formations, illustrating the powerful effects of wind in shaping desert landscapes.

Short Pointers for Revision:

- **Dominant Agent:** Wind in hot deserts.
- **Processes:** *Deflation* (removal of fine particles), *abrasion* (sand acting as a tool to erode surfaces), *impact* (sand striking surfaces).
- **Weathering:** Enhanced by drastic temperature changes and torrential rains.
- **Erosional and Depositional Features:** Created by wind and water action.

- **Stream Channels:** Formed after brief, heavy rains, are broad and temporary.
- **Example:** *Sahara Desert* exhibits diverse wind landforms.

Erosional Landforms of Wind

Pediments

Pediments are gently inclined rocky floors located near mountain bases, with or without a thin cover of debris. They form through erosion of the mountain front via a combination of lateral erosion by streams and sheet flooding. This parallel retreat causes the *pediment* to expand backwards into the mountain, gradually reducing relief into a low, featureless plain called a *pediplain*.

Example: The *pediments* found across the desert landscapes of the American Southwest expanded through stream and sheet flooding erosion of the nearby mountain ranges. Over millennia, this erosion etched away at the mountain fronts, expanding the *pediments* farther into the ranges and lowering the overall relief.

Short Pointers for Revision:

- *Pediments* are gently sloping rocky landforms found at a mountain's base.
- Formed by lateral erosion from streams and flooding wearing away the mountain front.
- Parallel retreat causes *pediments* to expand into mountains, lowering relief.
- Creates low, flat plains called *pediplains* after long erosion timescales.

Pediplains

Pediplains are low, flat, featureless plains formed when *pediments* extensively expand through parallel retreat of slopes and backwasting erosion. This erosion causes the steep wash slopes and free faces above the original *pediment* to retreat backwards into the mountain front. Over time, the mountain is reduced leaving only an occasional *inselberg hill* that is a remnant of the original mountain.

Example: The expansive, flat shrub-dotted plains stretching out from the bases of the Atlas Mountains in Morocco are *pediplains*. Over millions of years, *pediment* erosion and backwasting of the mountain fronts led to parallel retreat that flattened and widened the plains, reducing the tall Atlas Range to isolated *inselberg peaks*.

Short Pointers for Revision:

- *Pediplains* form when *pediment* erosion flattens high relief.
- Steep wash slopes and cliffs retreat backwards, eroding mountain front.
- Parallel retreat and backwasting expand *pediments* into mountains.
- After long time periods, mountains are reduced to low flat plains with occasional *inselberg hills*.