# Geomorphology Course (437G)

**Geomorphology & Sedimentary Environment (437G) for**

**4th Geology, Geophysics and Geochemistry**

**Course syllabus:**

1. The scope of geomorphology
2. Some fundamental concepts and principle
3. Arid (Aeolian-Desert) land scape
4. The fluvial geomorphologic sycle
5. Krasting and krast topography
6. Infelunse of geologic structure upon topography
7. Applied Geomorphology

**Refrences**

Rice,R.j.,1988 Fundemental of geomorphology

Goudi ,A.G.2004 Encycolopedia og geomorphology

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# GEOMORPHOLOGY

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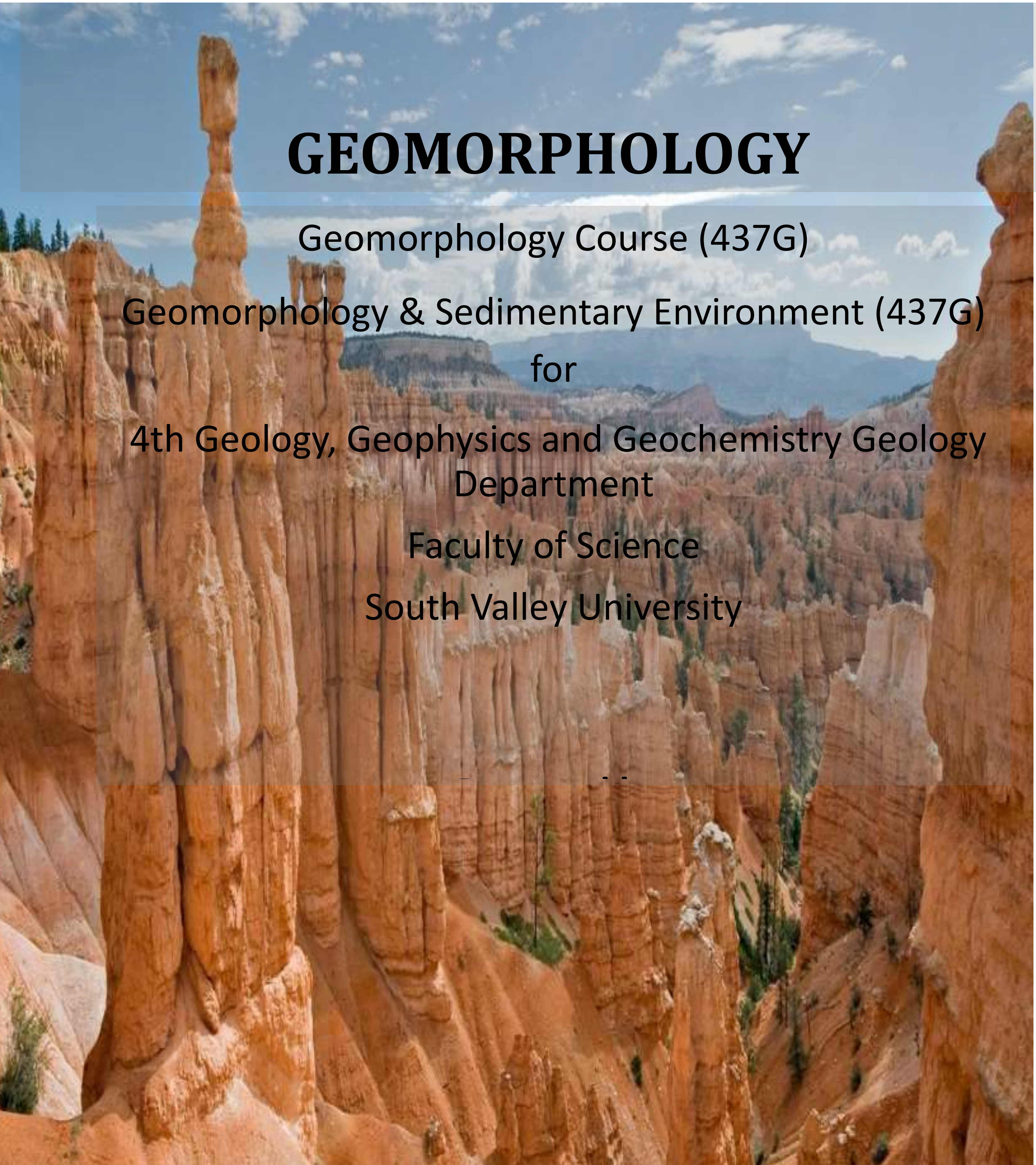
for

4th Geology, Geophysics and Geochemistry Geology Department

Faculty of Science

South Valley University



## Introduction

We see various types of landforms on the Earth's surface which includes mountains, hills, plateaus, plains, deserts, river valleys, river deltas, flood plains, cliffs, volcanoes etc (Fig 1). Landforms are natural physical features of the Earth's surface. Landforms are the most visible features of the Earth and occur everywhere.

They range in size from molehills to mountains to major tectonic plates, and their 'lifespans' range from days to millions of years.

**Fig (1):** Various types of landforms on the Earth's surface

## What is Geomorphology?

- The word Geomorphology derived from three Greek words: *geo*: "earth"; *morph*: "form"; and *logos*: "study"; **is the study of landforms and the processes that create them.**
- Geomorphology is the science that studies the origin and development of landforms (such as hills, valleys, sand dunes, caves), and how those landforms combine to form landscapes.
- ***Geomorphology*** is the ***discipline***, which studies these ***landforms***.
- It is concerned with the ***description*** and the ***explanation*** of ***surface configuration*** of the ***Earth***, the ***processes*** responsible for their ***formation***, and their ***spatial*** and ***temporal distribution***.
- In the words of William D.Thornbury (1985), ***geomorphology*** is the ***study of landforms***, including their ***classification, description, nature, origin, development,*** and ***relationships*** to ***underling structures,*** as well as the ***history of geologic changes*** as recorded by these surface features.

## What is the focus/scope of geomorphology?

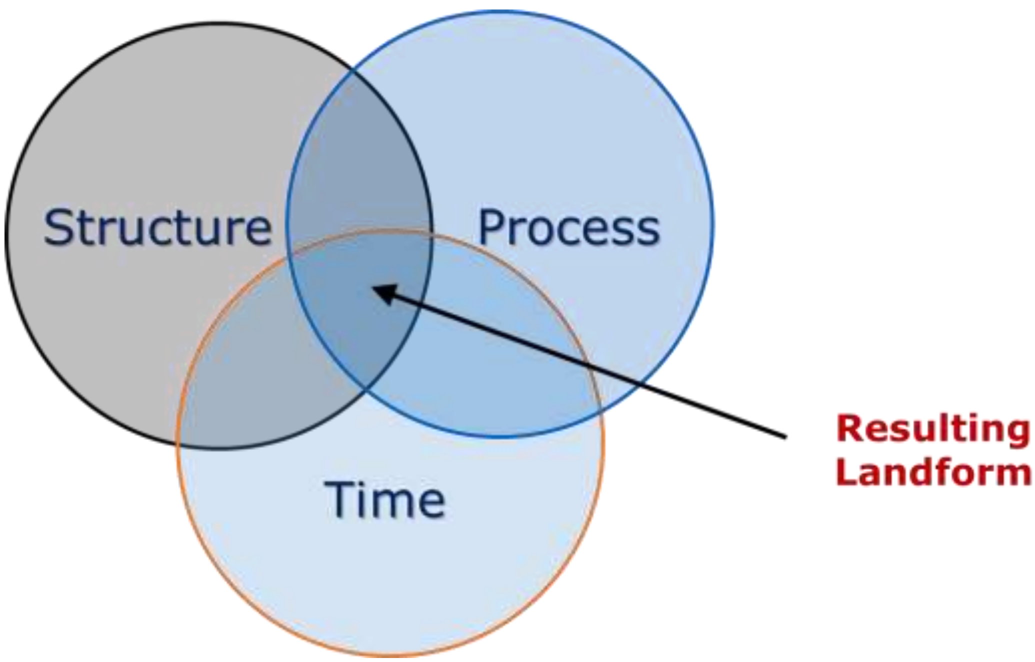
- ***Traditionally***, ***geomorphology*** has been concerned with the ***features*** associated with ***terrestrial environments.***
- ***Recently***, however, it includes the study of ***all features*** associated with both ***terrestrial*** and ***aquatic environments***.
- Geomorphology is ***interdisciplinary*** in the sense that it may be approached for different reasons and for different applications
- In the past, it used to ***focus on*** the ***classification*** and ***description*** of ***landforms***. While this is very important, however, it is also necessary to know ***what processes***, ***which shape*** these landforms.

Geomorphology is an important topic in the field of physical geography, geology, geodesy, engineering geology, archaeology and geotechnical engineering

**Factors responsible for Landform Formation**

**William Morris Davis** introduced idea that landforms can be explained by one or usually a combination of the following : (Fig2)

- **Structure:** rock mass (or unconsolidated material mass).
- **Process:** constructive or destructive process (es) acting now or previously on structure.
- **Time (stage):** landforms evolve through stages from continued actions of geomorphic process (es).



## Agent, Process & products

### 1- Agents of Geomorphic Processes

An agent is a mobile medium (like running water, moving ice masses, wind, waves and currents etc.) which removes, transports and deposits earth materials. For example River -Humid Geomorphic Environment, Wind - Arid Environment , Glacier/ice - Polar Environments and Wave - Coastal Environment

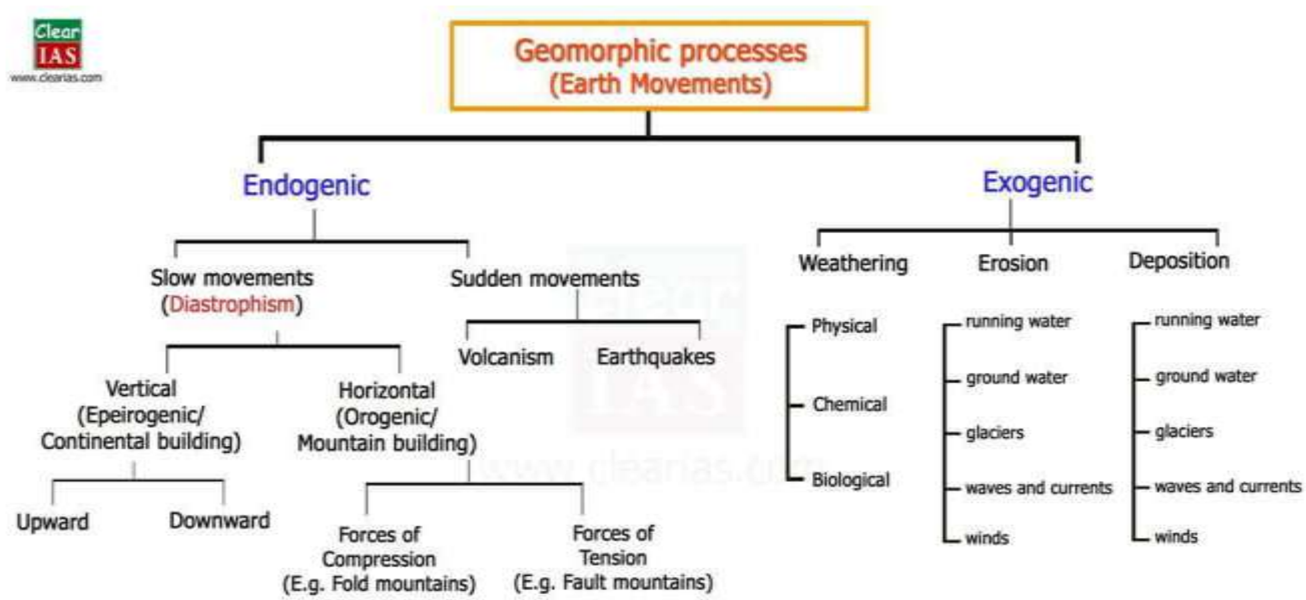
### 2- Geomorphic processes:

A process is a force applied on earth materials affecting on them for example Erosion. Transportation and Deposition

Endogenic processes and Exogenic processes

A- Endogenic processes: which produced from forces within earth crust (ex. Diastrophism and Volcanisms).

B-: which produced by external forces such as erosion, weathering and mass wasting



## Constructive and Destructive Processes

- **Constructive processes** build landforms through tectonic and depositional processes.
  - **Tectonic processes** include movements at plate boundaries, earthquakes, orogeny, deformation, and volcanic activity.
  - **Deposition** is the accumulation or accretion of weathered and eroded materials.
- **Destructive processes** break down landforms through weathering, erosion, and mass wasting.
  - Weathering is the disintegration of rocks by mechanical, chemical, and biological agents.
  - Erosion is the removal and transportation of weathered material by water, wind, ice, or gravity.
  - Mass wasting is the rapid down-slope movement of materials by gravity.

## 2- Geomorphic products

Geomorphic products is the resulting landforms after applying geomorphologic processes such as Erosional landform features, Transportation and Depositional landform features

- Other Agents and Processes that Affect Landform Development
  - **Climate**: temperature, precipitation, water cycle, atmospheric conditions
  - **Time**: fast and slow rates of change
  - **People:** influences on natural resources and earth surface processes

## Concepts in Geomorphology

**Concept 1:** (uniformitarianism): Presence is the key to the past.

The same physical processes and laws that today, operated throughout geologic time, although not necessarily always with the same intensity as now.

**Concepts 2:** Geologic structure is a dominant control factor in the evolution of landforms and is reflected in them.

Geologic structure in geomorphology means: various r ways by which the rock differs from other at earth crust including:

Rock attitudes, presence or absence of joints, bedding planes, faults, folds, rock massiveness, the physical hardness of the constituent minerals, the susceptibility of mineral constituents to chemical alteration, the permeabiliy and impermeability of rocks and various other ways by which the rock differs from other at earth crust.

**Concept 3:**

Geomorphic processes leave their distinctive imprint upon landforms, and each geomorphic process develops its own characteristic assemblage of landforms.

Geomorphic process means physical and chemical ways by which the earth crust undergoes modification.

**Geomorphic processes include:**

A- Endogenic processes: which produced from forces within earth crust (ex. Diastrophism and Volcanisms).

B- Exogenic processes: which produced by external forces such as erosion, weathering and mass wasting

**Concept 4:**

As the different erosional agencies (force) act upon the earth surface, there is a sequence of landforms having distinctive characteristics at successive stages of their development. The stages include youth, maturity and old age.

**Concept 5:**

Most of geomorphic features we meet in present time were made in quaternary age (Pleistocene).
“Proper interpretation of present day landscapes is impossible without a full appreciation of the main fold influences of the geologic and climatic changes during the Pleistocene” .Most of the world topography is the recognition that the geologic and climatic changes during the Pleistocene have the far reaching effects upon present day topography

**Concept 6:**

Complexity of geomorphic evolution is more common than simplicity.

**Simple landscapes** are the product of a single dominant geomorphic process.

**Compound landscapes** are the product of two or more geomorphic process.

**Monocyclic landscapes** are those that bear the imprint of only one cycle of erosion. It is restricted to such newly created land surfaces as a recently uplifted portion of the ocean floor, surface volcanic cone or areas buried beneath a cover of Pleistocene glacial materials.

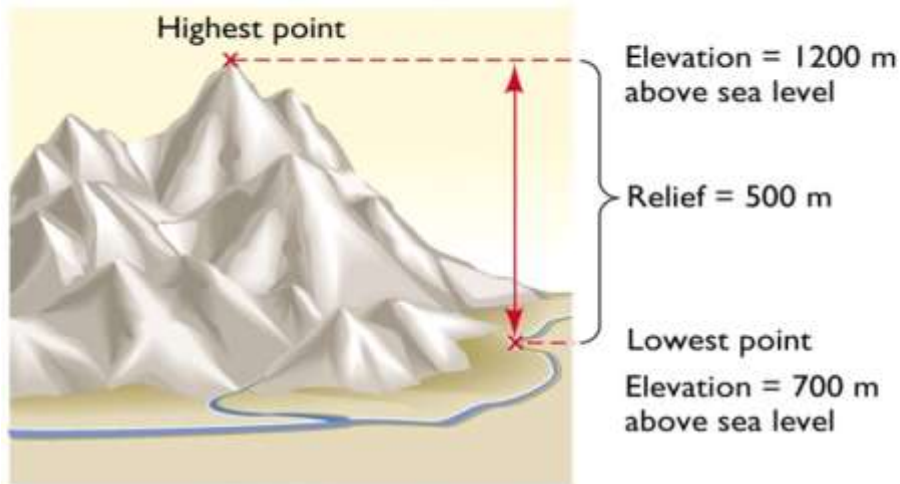
**Multicyclic landscapes** have been produced during more than one erosion cycle.

**Exhumed or resurrected landscapes** are those that were formed during some past period of geologic time, buried beneath a cover and then at recent time, exposed to the surface by weathering.

Rare to find an landscape that influenced by single geomorphic process. More multicyclic is more common than monocyclic landscapes. Older topography also seen on the new landscapes is called exhumed or resurrected landscapes also seen.

Some important items in Geomorphic

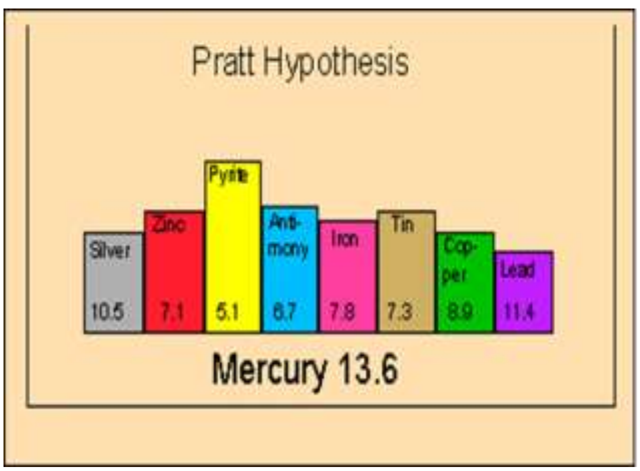
- **Elevation:** height above sea level
- **Slope:** spatial gradients in elevation
- **Relief:** the contrast between minimum and maximum elevation in a region

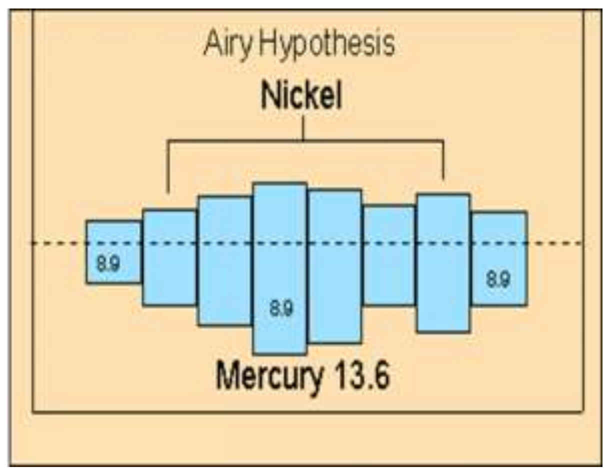



- Important: a *mountain* is a feature of relief, not elevation (a high area of low relief is a *plateau*)
    - Slope controls the local stability of hillsides and sediment transport
    - Relief controls the regional erosion rate and sediment yield
    - Elevation directly affects erosion and weathering only through temperature

**Isostasy**
1. the state in which pressures from every side are equal.
2. Geology . the equilibrium of the earth's crust, a condition in which the forces tending to elevate balance those tending to depress.

- Variation in topography can be compensated through two end-member mechanisms: differences in the *thickness* of layers or differences in the *density* of layers.
  - Isostatic compensation through *density* differences is *Pratt* isostasy (in the pure form each layer is of constant thickness).
  - Isostatic compensation through differences in the *thickness* of layers (where the layer densities are horizontally constant) is *Airy* isostasy.
  -

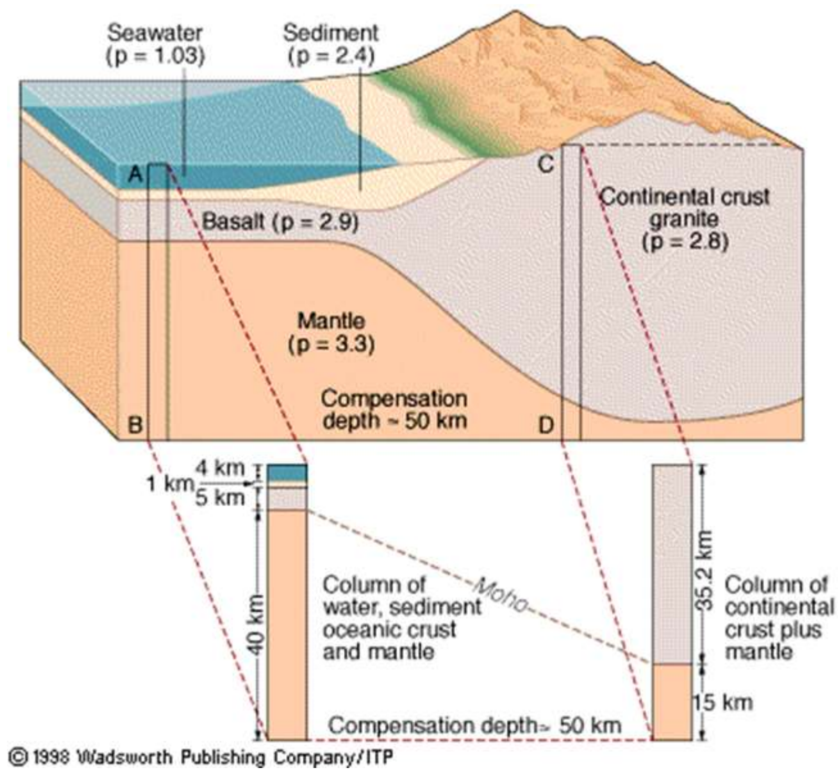


**The dominant mechanism of isostatic compensation.**

- In reality, both mechanisms operate together: neither the thickness nor the density of the crust is constant.

However, since the density contrast between crust and mantle is larger than most internal density differences within either crust or mantle, the dominant mechanism of isostatic compensation is variations in crustal thickness, i.e. Airy isostasy



## Igneous landforms

### 1- EXTRUSIVE VOLCANIC LANDFORMS

Volcanic landforms are controlled by the geological processes that form them and act on the after they have formed. Thus, a given volcanic landform will be characteristic of the types of material it is made of, which in turn depends on the prior eruptive behavior of the volcano. Although later processes can modify the original landform, we should be able to find clues in the modified form that lead us to conclusions about the original formation process. Here we discuss the major volcanic landforms and how they are formed, and in some cases, later modified.•

**Types of lava:**

-  Basaltic ( Basic) Lava: formed from magma low in silica, fluid magma, prevents sudden explosiveness
-  Andesitic/Rhyolitic (Acidic): formed from magma rich in silica, very viscous, violent explosive

**The main types of extrusive volcanic landforms are volcanoes, caldera, lava plateau and lava dome**

**1- Volcanoes**

There are three main type of volcanoes including Shield Volcanoes, Stratovolcanoes (also called Composite Volcanoes) and Cinder Cones (also called Tephra Cones)

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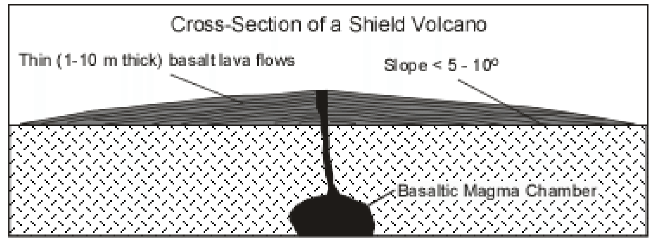
## Shield Volcanoes




1- A shield volcano is Characterized by gentle upper slopes (about 5°) and somewhat steeper lower slopes (about 10°).

2- Shield volcanoes are composed almost entirely of relatively thin lava flows built up over a central vent.

3- Most shields were formed by low viscosity basaltic magma that flows easily down slope away form the summit vent.

4- The low viscosity of the magma allows the lava to travel down slope on a gentle slope, but as it cools and its viscosity increases, its thickness builds up on the lower slopes giving a somewhat steeper lower slope.

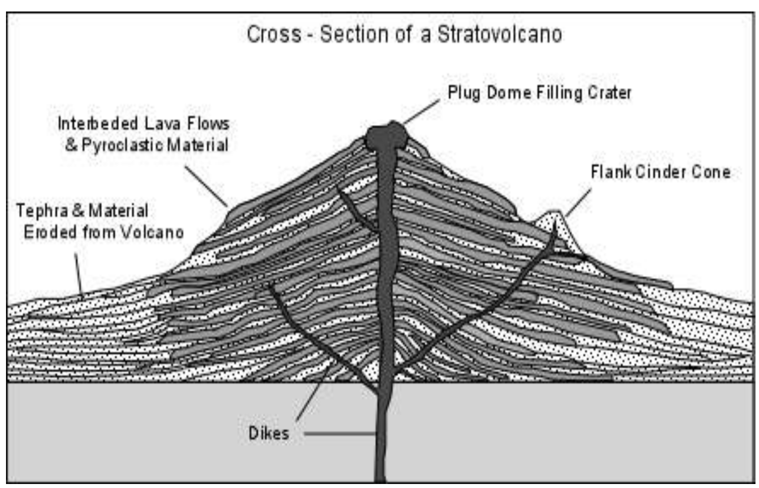
5- Most shield volcanoes have a roughly circular or oval shape in map view.

6-Very little pyroclastic material is found within a shield volcano, except near the eruptive vents, where small amounts of pyroclastic material accumulate as a result of fire fountaining events.

7- Shield volcanoes thus form by relatively non-explosive eruptions of low viscosity basaltic magma.

### **Stratovolcanoes** (also called **Composite Volcanoes**)

1. Have steeper slopes than shield volcanoes, with slopes of 6 to 10° low on the flanks to 30o near the top.
2. The steep slope near the summit is due partly to thick, short viscous lava flows that do not travel far down slope from the vent.



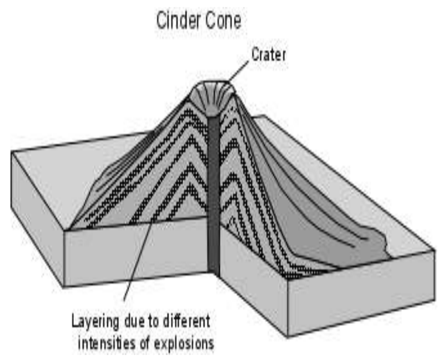

3. The gentler slopes near the base are due to accumulations of material eroded from the volcano and to the accumulation of pyroclastic material.

4. Stratovolcanoes show inter-layering of lava flows and pyroclastic material, which is why they are sometimes called composite volcanoes. Pyroclastic material can make up over 50% of the volume of a stratovolcano.

5. Lavas and pyroclastics are usually andesitic to rhyolitic in composition.

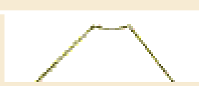
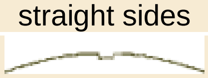
6. Due to the higher viscosity of magmas erupted from these volcanoes, they are usuallymore explosive than shield volcanoes.

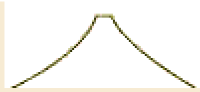
**Cinder Cones** (also called **Tephra Cones**)

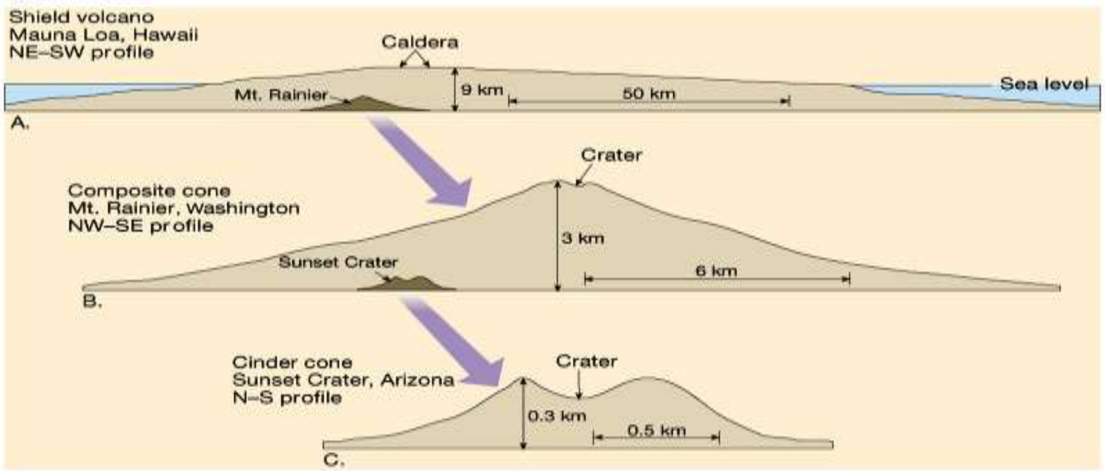



1. Cinder cones are small volume cones consisting predominantly of tephra that result from strombolian eruptions. They usually consist of basaltic to andesitic material.
2. They are actually fall deposits that are built surrounding the eruptive vent.
3. Slopes of the cones are controlled by the angle of repose (angle of stable slope for loose unconsolidated material) and are usually between about 25 and $35^{o}$.
4. Cinder cones often occur in groups, where tens to hundreds of cones are found in one area
5.

***comparison of the three main types of volcanoes***

| **Three Main Types of Volcanoes*** | | | | | |
|---|---|---|---|---|---|
| The three main types of volcanoes differ in shape, size, and make-up; the differences partly result from the different types of eruptions. | | | | | |
| **Volcano Type** | **Volcano Shape** | **Volcano Size** | **Volcano Materials** | **Eruption Type** | **Utah Example** |
| Cinder Cone |  Steep conical hill with straight sides | Small less than 300m high | cinders | Explosive | Diamond Cinder Cone, Washington County |
| Shield Volcano |  Very gentle slopes; convex upward (shaped like a warrior's shield) | Large over 10s of kms across | fluid lava flows (basalt) | Quiet | Cedar Hill, Box Elder County |

| | | | | | |
|---|---|---|---|---|---|
| Stratovolcano |  Gentle lower slopes, but steep upper slopes; concave upward | Large 1-10 km in diameter | numerous layers of lava and pyroclastics | Explosive | Mount Belknap, Tushar Mountains, Paiute County |

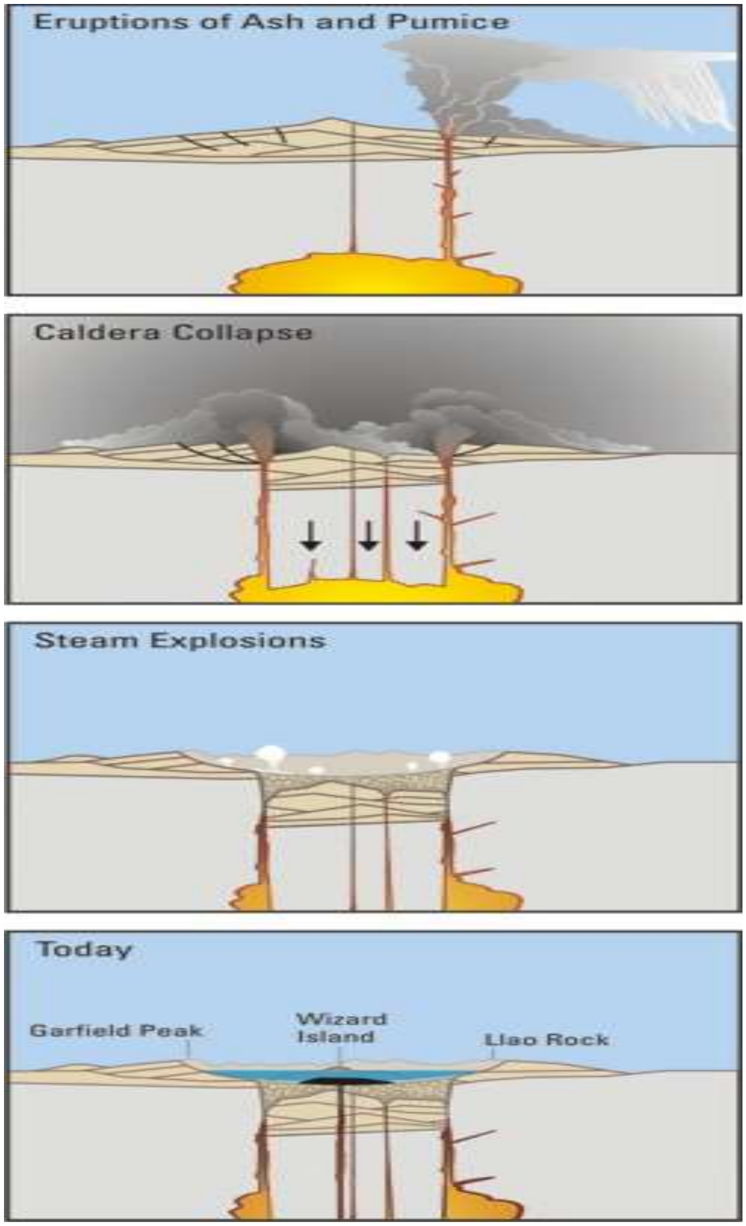



## 2- Caldera

Caldera is a cauldron-like volcanic feature usually formed by the collapse of land following a volcanic eruption. They are sometimes confused with volcanic craters. The word comes from Spanish caldera, and this from Latin caldaria, meaning "cooking pot". In some texts the English term cauldron is also used

Calderas - occur when gas builds up and huge explosion removes cone summit = a hole, may become flooded by the sea from lake within it

- Calderas are bowl-shaped collapse depressions formed by volcanic processes.
- Calderas most likely result from one of three collapse type events:
  - 1. Collapse of the summit following an explosive eruption of silica-rich pumice and ash pyroclastics
  - 2. Collapse of the summit following the subterranean or fissure drainage of the magma chamber
  - 3. Collapse of a large area following the discharge of silica-rich pumice and ash along ring fractures that may or may not have been previously active volcanoes

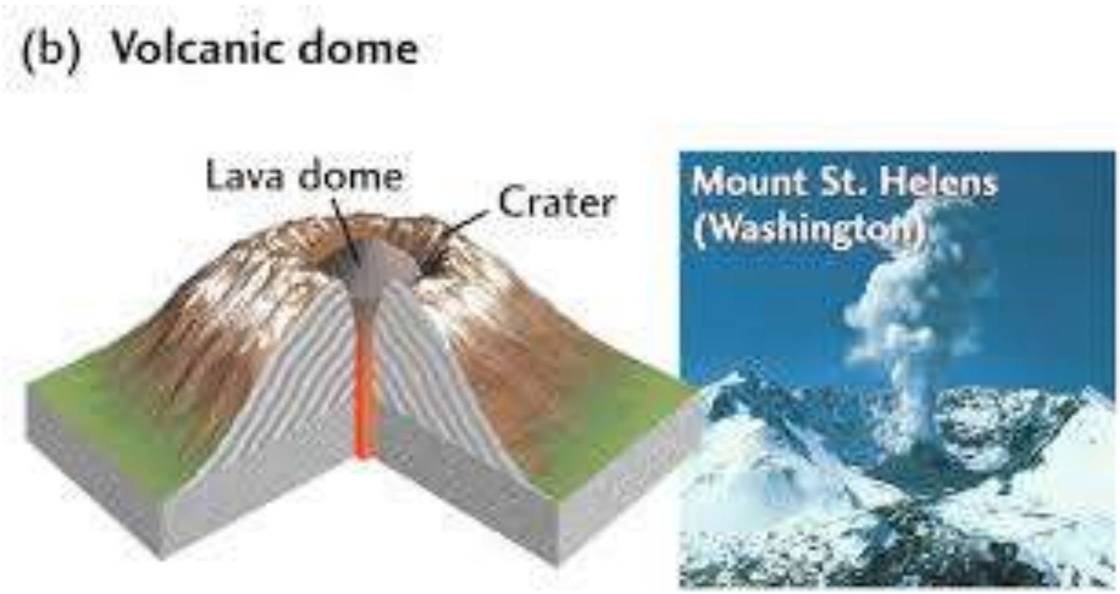



**3-Lava Plateaux** - formed from fissure eruptions, lava flows are basaltic in nature so flow for miles

**4- Lava domes** are rounded, steep-sided mounds built by very viscous magma that is resistant to flow and builds up forming a dome.

The magma does not move far from the vent before cooling and it crystallizes in very rough, angular basaltic rocks.

A single lava dome may be formed by multiple lava flows that accumulate over time



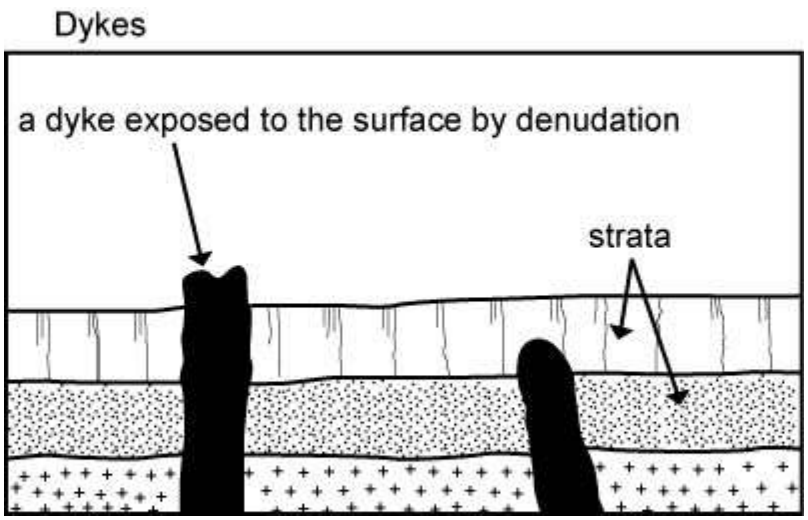

## 2- INTRUSIVE VOLCANIC LANDFORMS

These are formed when magma solidifies underground. Magma forms in many different shapes and sizes, the most common are: -

*1. **Batholiths**: A batholith is an exposed area of (mostly) continuous plutonic rock that covers an area larger than 100 square kilometers Areas smaller than 100 square kilometers are called stocks However, the majority of batholiths visible at the surface (via outcroppings) have areas far greater than 100 square kilometers. These areas are exposed to the surface through the process of erosion accelerated by continental uplift acting over many tens of millions to hundreds of millions of years. This process has removed several tens of square kilometers of overlying rock in many areas, exposing the once deeply buried batholiths.*

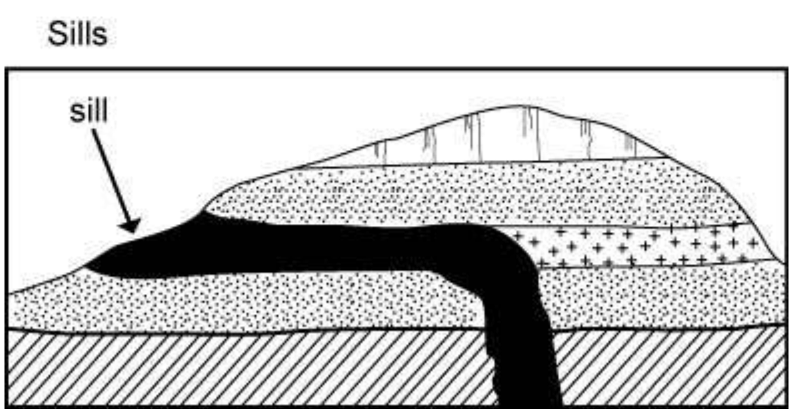
2. **Dykes**: formed when magma solidifies into vertical cracks, cutting across rock layers. When affected by erosion dykes may stand as a ridge.

A dyke (also spelled dike) is a tabular body usually of igneous rock discordant to, and intrusive into, the bedding, schistosity, or other primary structure of its host rock Depending on the attitude of the host rocks, the dyke may be vertical, horizontal, or inclined, but most are vertical or steeply inclined, and were so intruded.



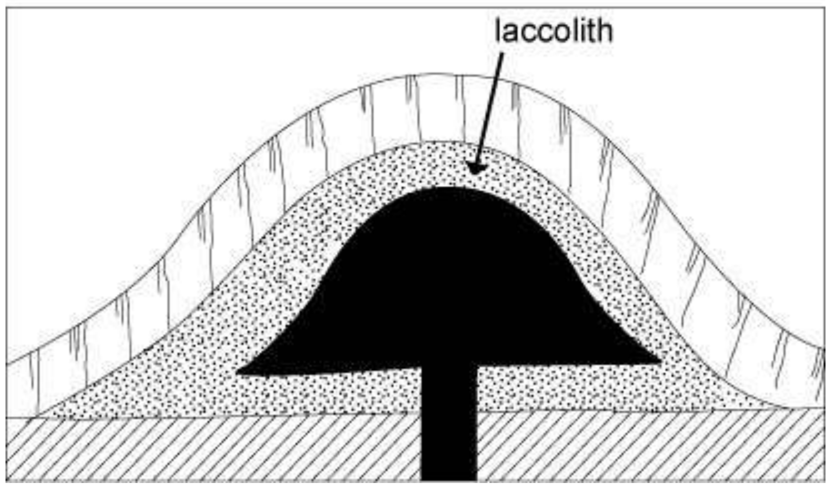

3. **Sills**: formed when lava solidifies in between rock layers, after prolonged erosion, Sills may be exposed as escarpments and while they occur across a river valley they cause waterfalls and rapids.

In geology, a sill is a tabular sheet intrusion that has intruded between older layers of sedimentary rock, beds of volcanic lava or tuff, or along the direction of foliation in metamorphic rock. A sill is a concordant intrusive sheet, meaning that a sill does not cut across preexisting rock beds. Stacking of sills builds a sill complex



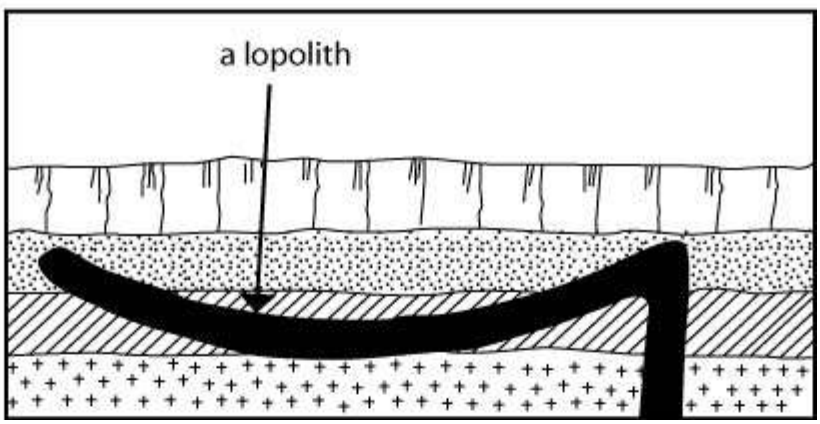
4. **Laccolith**: this is magma which solidifies in a shape similar to a mushroom. After prolonged erosion, it may form upland.

Laccolith




5. **Lappolith**: This is a lenticular shaped magma, after erosion. It can be exposed as a shallow basin. Examples are the Bushveld igneous complex of South Africa

a lopolith



## 3 -Minor Volcanic Forms

☐ **Solfatara** - small volcanic areas without cones, produced by gases escaping the surface

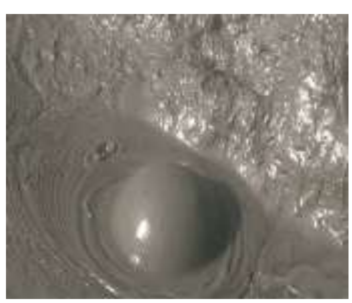
☐ **Geysers** - occur when water, heated explodes onto the surface

☐ **Hot springs/Boiling mud** - sometimes water heated below does not explode

☐ **Fumaroles –**

A fumarole (or fumerole) is a vent in the surface of the Earth or other rocky planet from which hot volcanic gases and vapors are emitted, without any accompanying liquids or solids. It consider.,an opening in or near a volcano, through which hot sulfurous gases emerge and super-heated water, turning to steam as pressure drops when it emerges from the ground

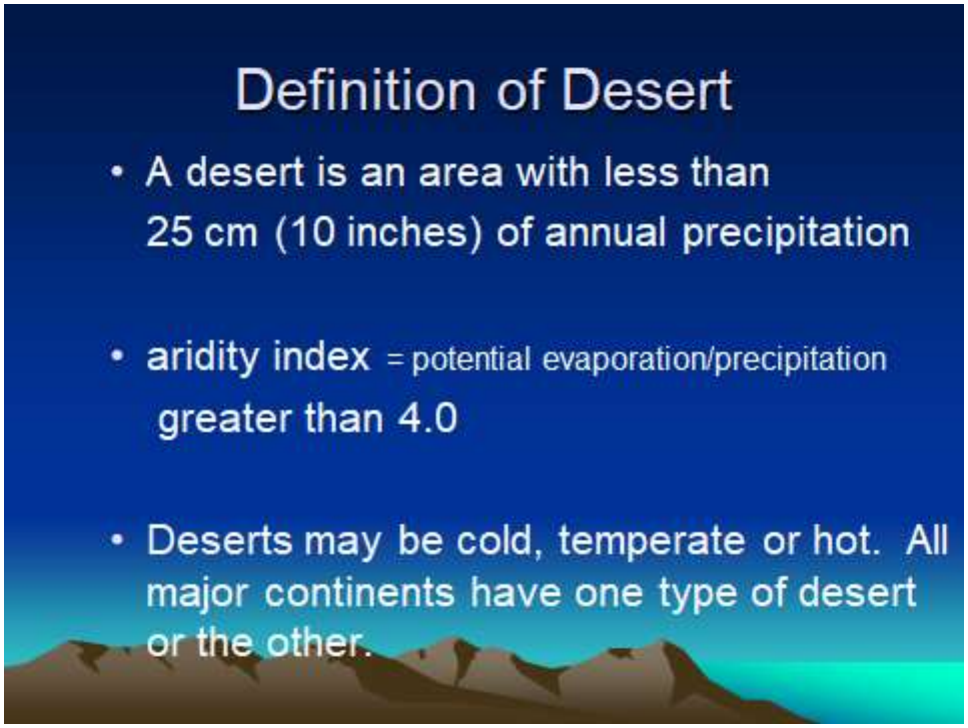
  

# Desert Geomorphology

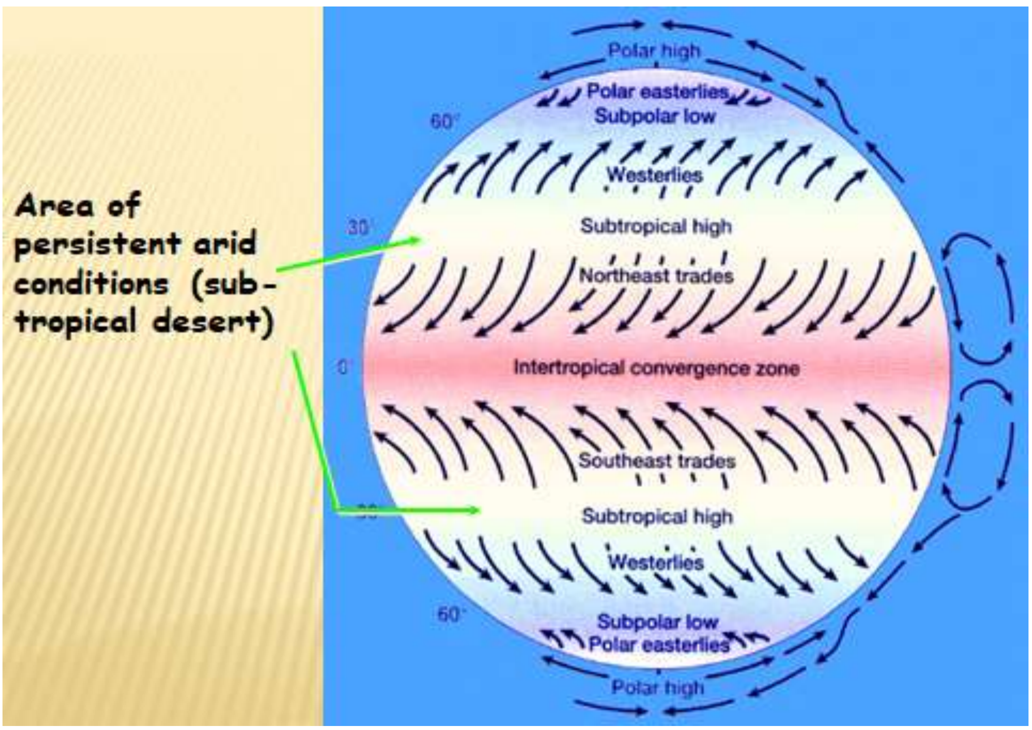
Deserts and Wind

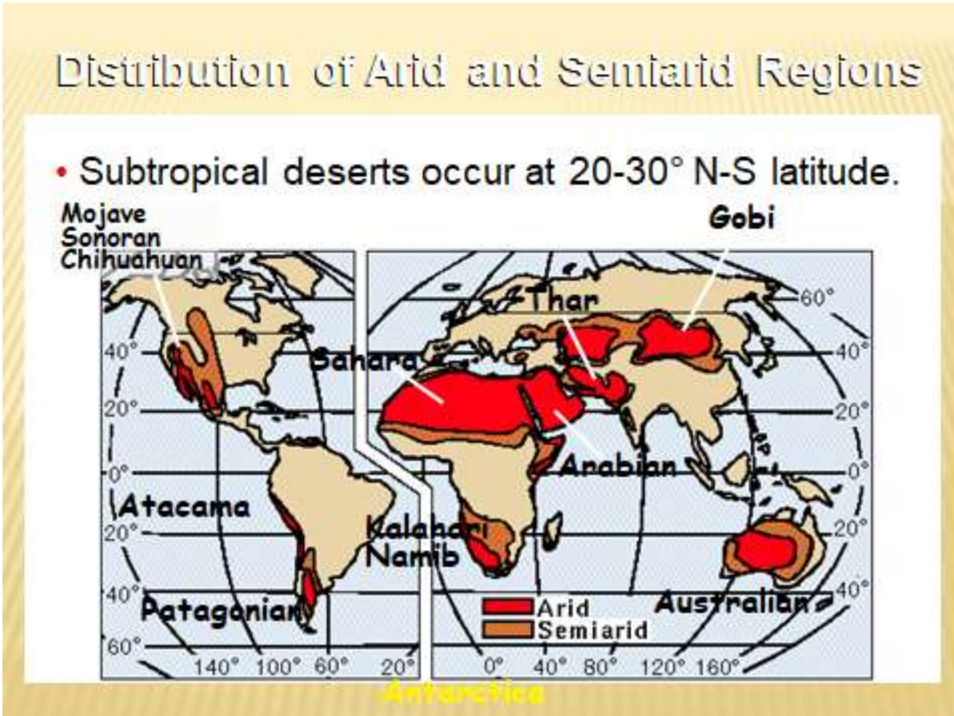
1. Deserts form in land areas with low precipitation (typically less than 25 cm of rain per year).
2. Wind: The movement of air on the Earth's surface stems from the uneven distribution of solar heat. Hot air rises over the equator, drops out moisture, and descends as cool, dry air over latitudes 30 N and 30 S. Deserts are found at these latitudes.



## SEMIARID, ARID AND DESERTS

- Semiarid lands, also called steppes, typically receives 250 to 500 millimeters (10 to 20 inches) of rain per year
- Arid lands receive less than 250 millimeters (10 inches) of rain per year
- Deserts are formally defined as regions that rarely receive precipitation, typically less than 100 millimeters (4 inches) per year






## Mechanism of Desert/Arid Erosion

1. **Weathering**

- Most potent factor in reducing rocks to sand in arid regions.
- Even though the amount of rain that falls in a desert is small, but manages to penetrate into rocks & sets up chemical reactions in various minerals it contains.
- Intense heating during the day & rapid cooling during the night by radiations, set up stresses in already weakened rocks, hence they eventually crack.
- When water gets into cracks of a rock, it freezes at night as the temperature drops below the freezing point & expands by 10 % of its volume.
- Successive freezing will prise of fragments of rocks which get accumulated as screes.
- As heat penetrates rock, its outer surface gets heated & expands, leaving its inner surface comparatively cool.

- Hence, outer surface prise itself from the inner surface & peels off in successive thin layers, known as exfoliation.

## 2. Action of Wind

- Efficient in arid regions as little vegetation or moisture to bind the loose surface materials.
- It is carried out in the following ways:
- **Deflation**
- Involves lifting & blowing away of loose materials from the ground
- Blowing capacity depending largely on the size of the material lifted from the surface
- Finer dust & sands may be removed miles away from their place of origin & may get deposited even outside the desert margins.
- Deflation results in the lowering of the land surface to form large depressions called Deflation hollows.
- **Abrasion التاكل**
- Sandblasting نحت الرمال of rock surfaces by the wind when they hurl قذف- القى sand particles against them
- This results in rock surfaces being scratched, polished & worn awayوتنقله بعيدا
- Abrasion is most effective near the base of the rocks, where the amount of material the wind is able to carry is greatest.
- This explains why telegraphic poles in the deserts are protected by covering of metal for a foot or two above the ground.
- **Attritionالبرى**
- When wind-borne particles roll against one another in the collision, they wear each other away
- Hence their sizes are greatly reduced & grains are rounded

Types of Wind Erosion
Erosion by wind is most efficient in the deserts due to the aridity. With very little moisture and sparse vegetation there is nothing to bind the surface material together hence the wind erosion takes place virtually unhindered.
Sand/soil being blown away by winds
Deflation
Concentration of Larger Pebbles
Desert Pavement
1 Deflation
Lifting and blowing away of loose materials from the ground causing lowering of land surface and depressions
2 Abrasion
Scratching, polishing and wearing away of rock when sand particles are hurled against the rocks in the desert.
3 Attrition
Wearing and rounding of wind borne particles when they collide against each other constantly.
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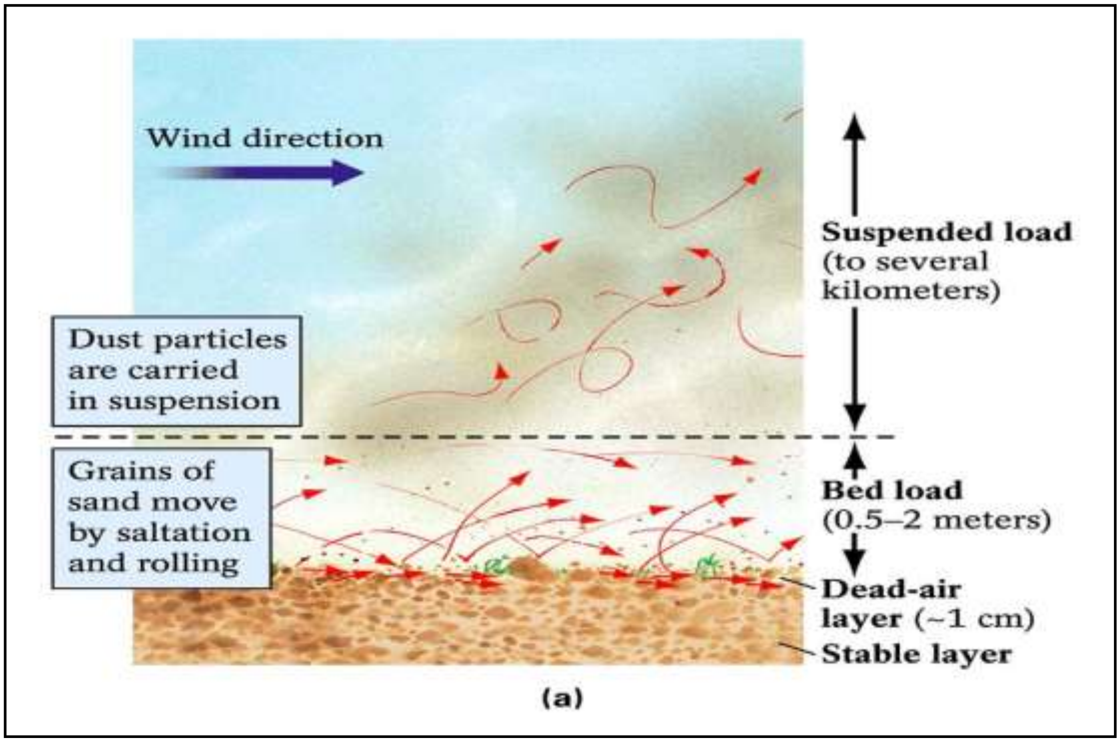
Wind-Created Features

Wind is a strong sculpting agent. It carves away rocks and sediments and deposits sediments elsewhere.

1. Bed load: The sand grains (> 0.25 mm) and other particles that wind (or water) carries on or just above the ground.
2. Suspended load: The fine particles (< 0.25 mm) that wind keeps aloft.
3. Saltation: The “jumping” of sand grains due to strong wind. Wind blowing perpendicular to a surface decreases the pressure on that surface. When the inertia of a sand grain is overcome, it begins to roll. When it hits other grains, they bounce into the air, where they are carried forward until gravity pulls them back down.




4. Deflation: A process by which wind carries fine particles away and leaves a compact surface of larger pebbles.

## Types of desert

- **Hamada/Rocky Desert**
- Consist of large stretches of bare rocks, swept clear of sand & dust by wind.
- Exposed rocks are thoroughly smoothened, polished & highly sterile
- **Reg/Stony Desert**
- Composed of extensive sheets of angular pebbles & gravels which the wind is not able to blow off.
- Stony deserts are more accessible than sandy deserts & large herds of camels kept there.
- **Erg/Sandy Desert**
- Also known as the sea of sand
- Winds deposit vast stretches of undulating sand dunes in the direction of winds
- **Badlands**
- Consists of gully & ravines formed on hill slopes & rock surfaces by the extent of water action
- Not fit for agriculture & survival
- Finally leads to the abandonment of the entire region by its inhabitant
- **Mountain Deserts**
- Deserts which are found on the highlands such as on plateaus & mountain ranges, where erosion has dissected the desert highland into rough chaotic peaks & uneven ranges.
- Their steep slopes consist of Wadis (dry valleys) with sharp & irregular edges carved due to the action of frost.

# Desert Landforms I


Generally confined within the parallels of 15° to 30° north and south of the equator these deserts cover about a fifth of the land surface.

They are arid (dry) regions. Insufficient rainfall, very high temperatures, rapid rate of evaporation are the main causes of aridity.

## Types of Deserts

Erosion by wind (*eolian processes*) and water, transportation of the eroded material and its deposition has created five types of deserts.

Very high temperatures during the day and sub-zero temperatures in the night build up stresses in the rocks. This causes them to crumble due to frost action, exfoliation, etc.

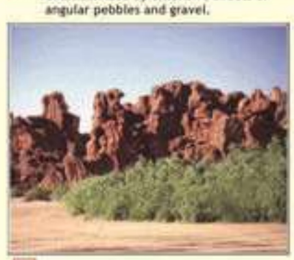
The rock fragments, also known as regoliths, become the tools of wind erosion.

1 **Hamada or Rocky Desert**
Bare rocks, land swept clean of sand and dust due to strong winds.

2 **Reg or Stony Desert**
Characterized by extensive sheets of angular pebbles and gravel.

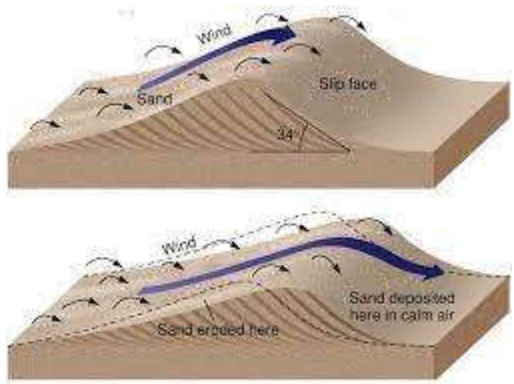
3 **Erg or Sandy Desert**
Vast stretches of sand dunes in the heart of the desert

4 **Badlands**
Land badly eroded into gullies and ravines by occasional rain storms.

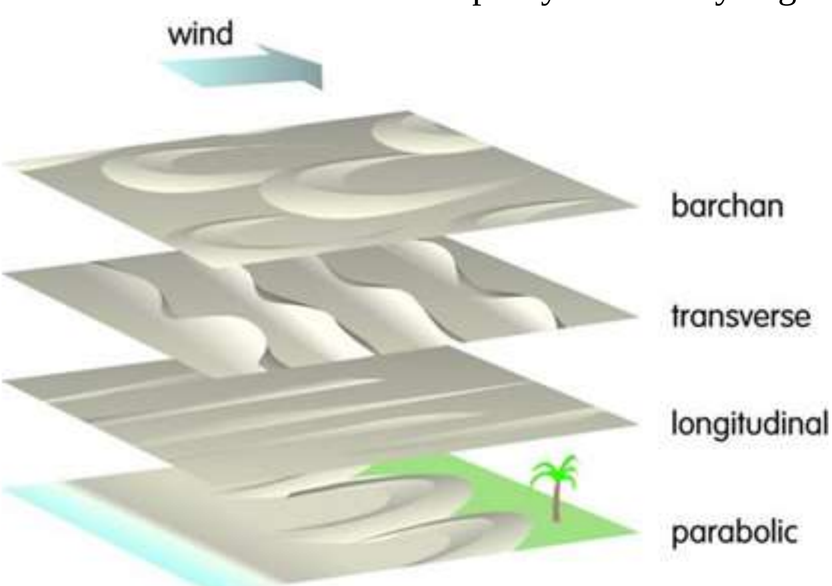


5 **Mountain Desert**
Found on plateaus and mountain ranges. Steep slopes, sharp and irregular peaks.

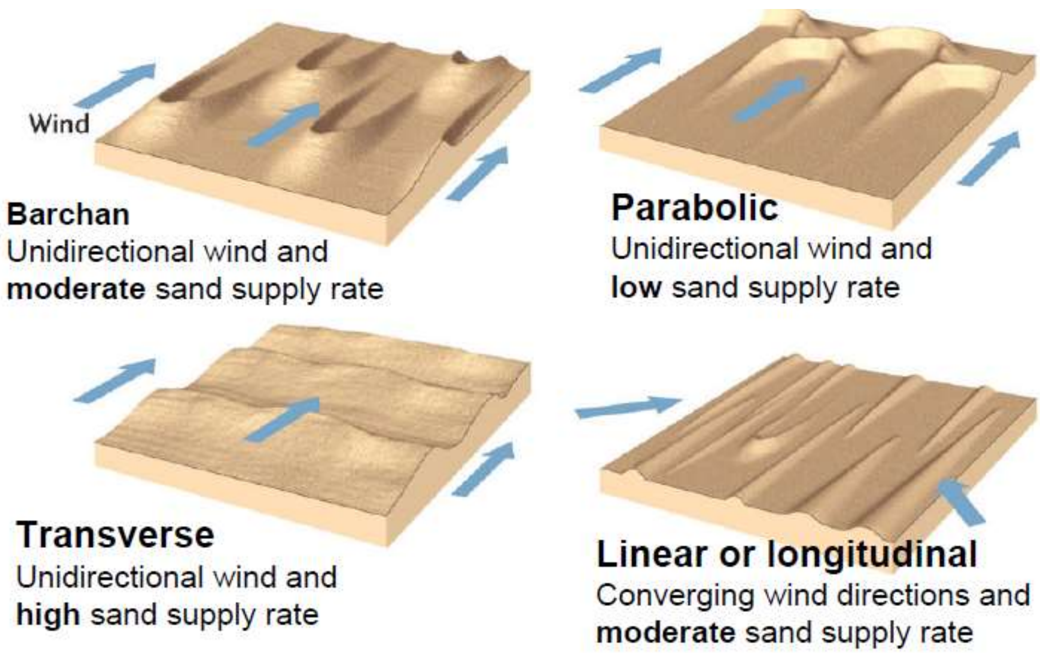
Dunes: Sand mounds or ridges that the wind creates. Dunes have a steep side called a slip face. Types of dunes include:




1. Barchan dune: A solitary dune shaped like a horseshoe, with its tips pointing away from the wind. Barchan dunes form on flat surfaces where sand supply is low.
2. Transverse dune: A long ridge of sand oriented perpendicular to the direction of the wind. Transverse dunes form where wind is steady and sand is plentiful.
3. Longitudinal dune: A dune that forms parallel to wind direction, in places where sand supply is limited.
4. Parabolic dune: A dune shaped like a barchan dune but with its tips pointing into the wind. Parabolic dunes form on beaches with abundant sand and are partly covered by vegetation.

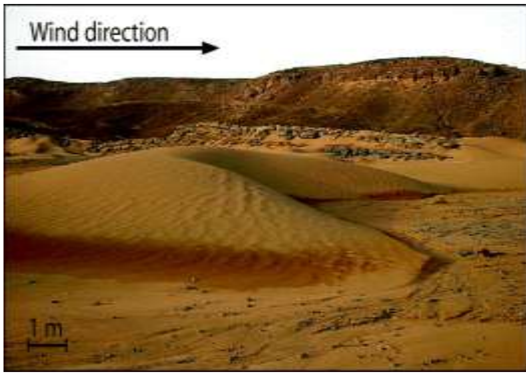


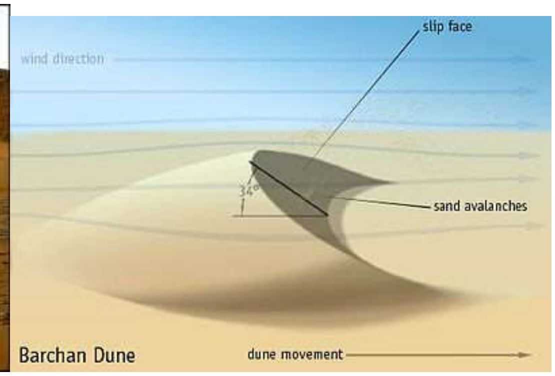
Desert dunes classification is based upon shape and include barchan dunes, parabolic dunes, transverse dunes, linear (longitudinal) dunes, seif dunes, star dunes




Barchan dunes

Crescent-shaped sand dunes .Barchans face the wind, appearing convex and are produced by wind action predominately from one direction. They are highly common, characteristic in sandy deserts all over the world and are arc-shaped, markedly asymmetrical in cross section, with a gentle slope facing toward the wind sand ridge, comprising well-sorted sand. This type of dune possesses two "horns" that face downwind, with the steeper slope known as the slip face, facing away from the wind, downwind, at the angle of repose of sand, approximately 30–35 degrees for medium-fine dry sand




Parabolic Dune

**Parabolic** or **blowout dunes** are caused by breaching of partially stabilized ridges. With the arms anchored at the ridge, the center of the dune migrates downwind. As a result, the arms point upwind rather than downwind as with barchan dunes

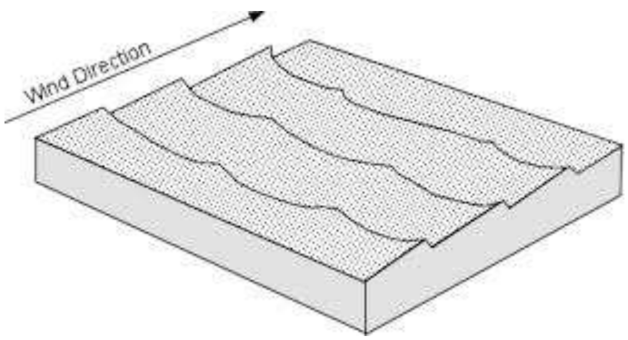

## Longitudinal (Seif) dunes

Longitudinal dunes (also called Seif dunes, after the Arabic word for "sword"), elongate parallel to the prevailing wind, possibly caused by a larger dune having its smaller sides blown away. Seif dunes are sharp-crested and are common in the Sahara. They range up to 300 m in height and 300 km in length..

Seif dunes are thought to develop from barchans if a change of the usual wind direction occurs. The new wind direction will lead to the development of a new wing and the over development of one of the original wings. If the prevailing wind then becomes dominant for a lengthy period of time the dune will revert to its barchan form.

### Transverse dune

A large, strongly asymmetrical, elongated dune lying at right angles to the prevailing wind direction. Transverse dunes have a gently sloping windward side and a steeply sloping leeward side. They generally form in areas of sparse vegetation and abundant sand. Most beach dunes are transverse dunes




### Star dunes

Radially symmetrical, star dunes are pyramidal sand mounds with slipfaces on three or more arms that radiate from the high center of the mound. They tend to accumulate in areas with multidirectional wind regimes. Star dunes grow upward rather than laterally.

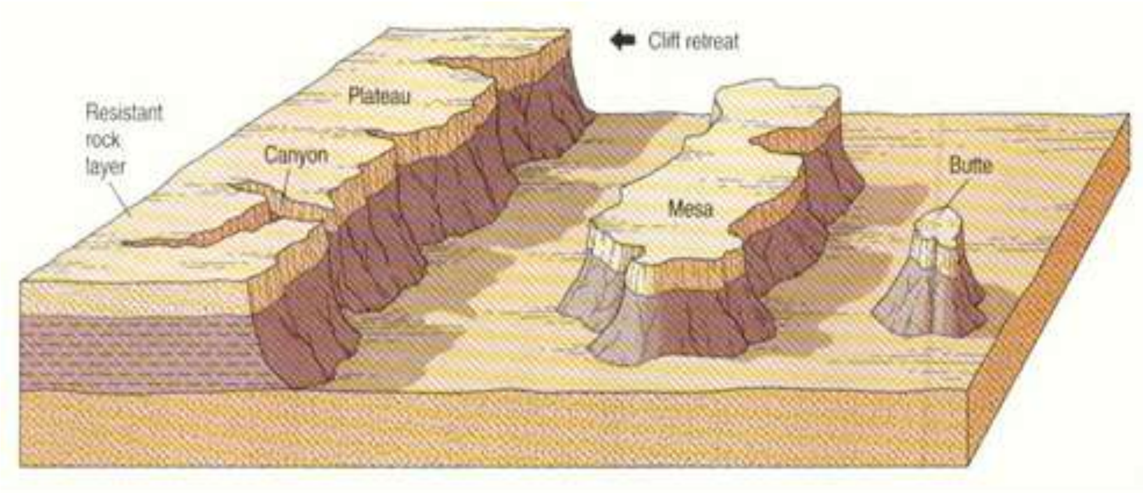
**Sand sheets**

Sand sheets are flat, gently undulating plots of sand surfaced by grains that may be too large for saltation. They form approximately 40 percent of aeolian depositional surfaces .Sand sheets exist where grain size is too large, or wind velocities too low, for dunes to form.

# Loess

Loess is an Aeolian sediment formed by the accumulation of wind-blown silt, typically in the 20–50 micrometer size range, twenty percent or less clay and the balance equal parts sand and silt, that are loosely cemented by calcium carbonate. Loess is homogeneous, porous, friable, pale yellow or buff, slightly coherent, typically non-stratified and often calcareous. Loess grains are angular with little polishing or rounding and composed of crystals of quartz, feldspar, mica and other minerals. Loess can be described as a rich, dust-like soil

Desert erosional landforms




## plateau

plateau (a high plain or tableland )is an area of highland, usually consisting of relatively flat terrain. A plateau is an elevated land. It is a flat topped table standing above the surrounding area. A plateau may have one or more sides with steep slopes.

## Mesa

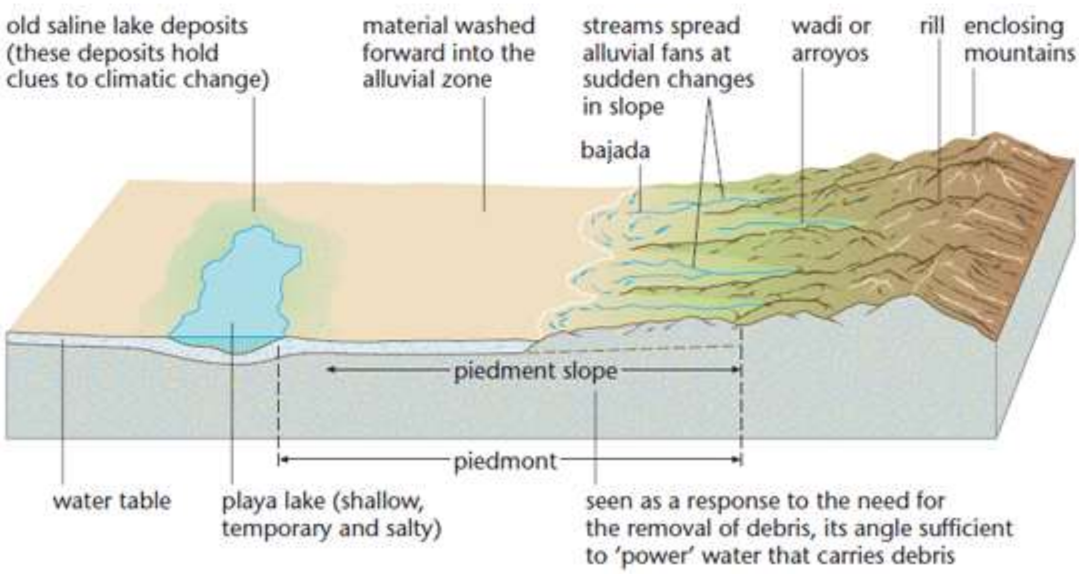
A mesa (Portuguese and Spanish for table) an elevated area of land with a flat top and sides that are usually steep cliffs. It takes its name from its characteristic table-top shape. a broad, flat-topped hill bounded by cliffs and capped with a resistant rock layer

## Butte

Butte is an isolated hill with steep, often vertical sides and a small, relatively flat top; buttes are smaller than mesas, plateaus, and table landforms

In differentiating mesas and buttes, geographers use the rule of thumb that a mesa has a top that is wider than its height, while a butte has a top that is narrower than its height

Pediment and pagada




A pediment is a very gently sloping (.5°-7°) inclined bedrock surface It typically slopes down from the base of a steeper retreating desert cliff, or escarpment, but may continue to exist after the mountain has eroded away. It is caused by erosion. It develops when sheets of running water (laminar sheet flows) wash over it in intense rainfall events. It may be thinly covered with fluvial gravel that has washed over it from the foot of mountains produced by cliff retreat erosion. It is typically a concave surface gently sloping away from mountainous desert areas

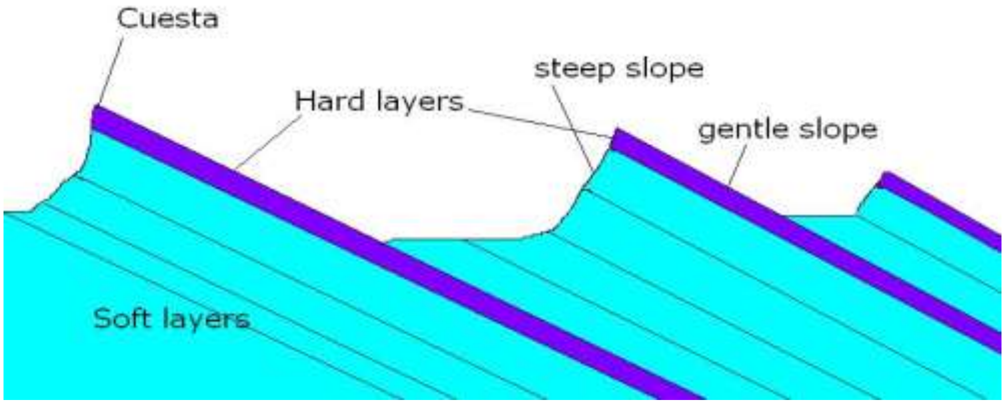
Bajadas merged groups of alluvial fans, which also may appear to gently slope from an escarpment, but are composed of material eroded from canyons, not bedrock.

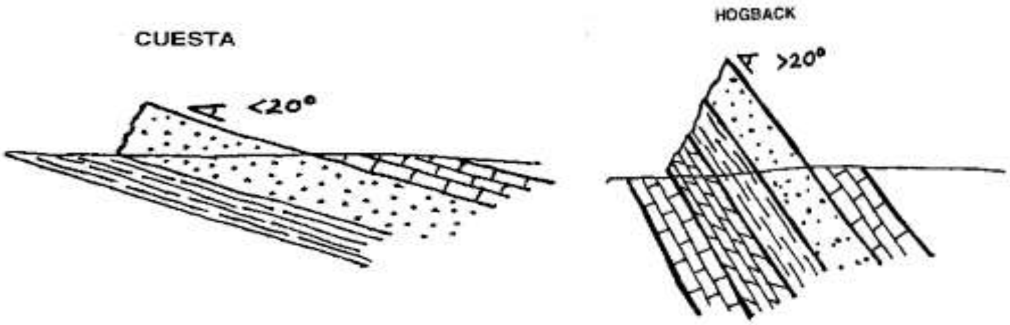
There are two features that can help differentiate between a pediment and bajada. First, pediments will likely have common exposures of bedrock sticking up through a thin veneer of sediment while bajadas will not have these exposures. Second, the major drainages of bajadas can be traced back to a few steep narrow canyons that are the source of the material deposited on the surface of the bajada. Pediments will not have these source canyons and erosion will be removing sediment from the entire surface

**playa,** ( Spanish: shore or beach) , flat-bottom depression found in interior desert basins and adjacent to coasts within arid and semiarid regions, periodically covered by water that slowly filtrates into the ground water system or evaporates into the atmosphere, causing the deposition of salt, sand, and mud


**alluvial fan**

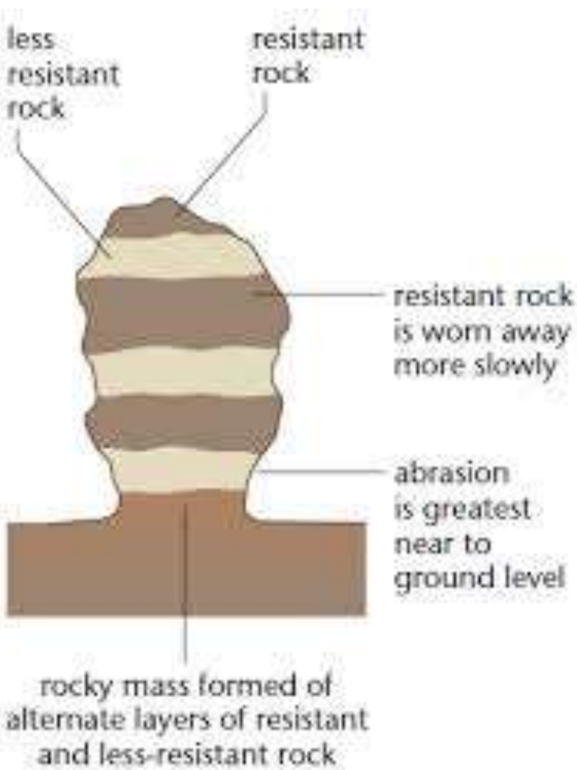
An alluvial fan is a triangle-shaped deposit of gravel, sand, and even smaller pieces of sediment, such as silt. This sediment is called alluvium. Alluvial fans are usually created as flowing water interacts with mountains, hills, or the steep walls of canyons.

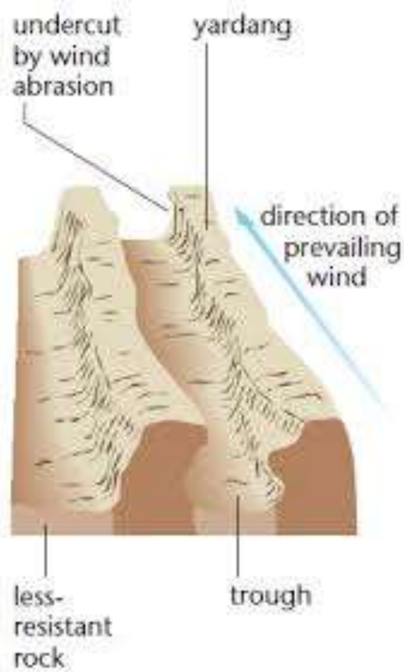



**Hogback** is a long narrow ridge or series of hills with a narrow crest and steep slopes of nearly equal inclination on both flanks. Typically, this term is restricted to a ridge created by the differential erosion of outcropping, steeply dipping (greater than 20°),

**Cuestas** are similar formations with dip slopes of less than 20 degrees; escarpment slopes of cuestas are much steeper than the dip slopes.


less resistant rock
resistant rock
resistant rock is worn away more slowly
abrasion is greatest near to ground level
rocky mass formed of alternate layers of resistant and less-resistant rock


undercut by wind abrasion
yardang
direction of prevailing wind
less-resistant rock
trough

**zeugen** Mushroom-shaped rock that has been eroded by the abrasive action of windblown sand. The undercutting effect is concentrated near ground level, where sand movement is greatest, and is enhanced in areas of near-horizontal strata when the lowest bed is relatively weak Streams

**A yardang** is a streamlined hill carved from bedrock or any consolidated or semiconsolidated material by the dual action of wind abrasion, dust and sand, and deflation. Yardangs become elongated features typically three or more times longer than wide, and when viewed from above, resemble the hull of a boat. Facing the wind is a steep, blunt face that gradually gets lower and narrower toward the lee end.[2] Yardangs are formed by wind erosion, typically of an originally flat surface formed from areas of harder and softer material. The soft material is eroded and removed by the wind, and the harder material remains. The resulting pattern of yardangs is therefore a combination of the original rock distribution, and the fluid mechanics of the air flow and resulting pattern of erosion.

# Alluvial land forms

Streams are channeled flows of any amount of water. Although streams hold only a small percentage of the Earth's water at any given time, the energy of streams has done much to sculpt the landscape. Stream energy is controlled by channel size and slope.

1. Gradient: The steepness of land over which a stream flows. As a stream flows down a slope, its potential energy converts to kinetic energy. The steeper the gradient, the faster the stream flows.
2. Base level: The lowest level to which a stream can erode its channel. Oceans are considered the ultimate base level because they are the final destination of streams. More often, local base levels like lakes, dams, or stream junctions control stream flow.
3. Cross section: The area of water in a cross-sectional slice of a stream. For a flat stream, cross section is calculated by multiplying depth by width. For a semi-circular stream, it is calculated using stream radius: $(1/2)\pi r^2$.
4. Discharge: The volume of water that flows past a certain point in a stream over a measured time interval. Discharge is calculated by multiplying the cross section of the stream by the velocity of the stream.

Stream Flow and Transport

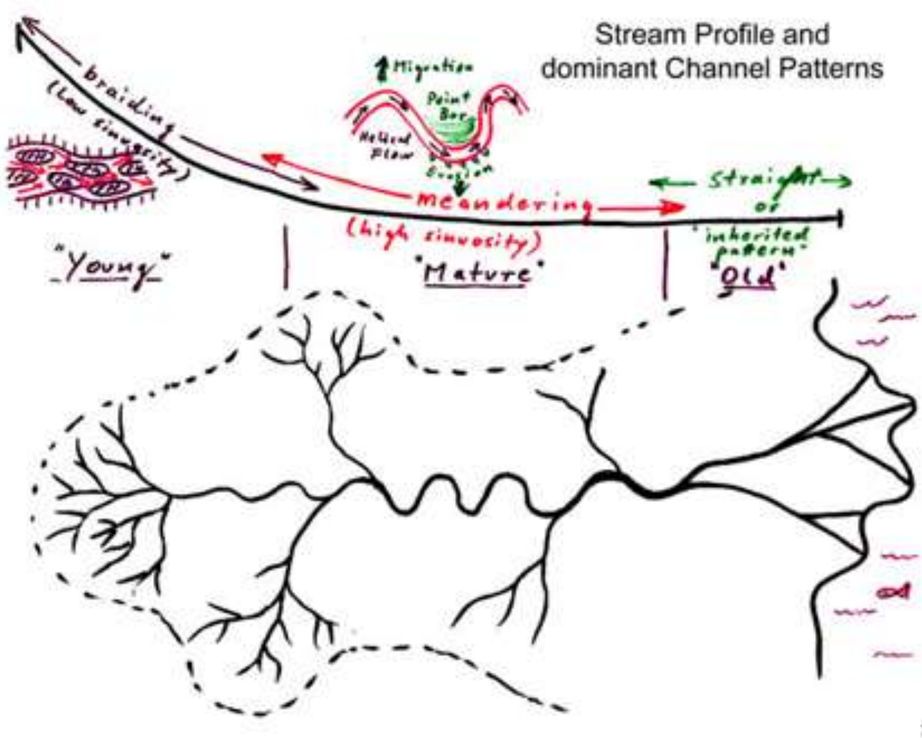
1. Water can flow within a stream in two ways:
    1. Laminar flow: In slow-moving streams, water flows in parallel paths.
    2. Turbulent flow: In fast-moving streams and in rough stream channels, water swirls around as it moves down a gradient.

2. Capacity: The amount of sediment a stream can carry past a certain point in a given time.
3. Competence: A measure of how strong a stream is, based on the biggest size of an object the stream can move.
4. Saltation: Skipping and bouncing of particles on the bottom of a stream caused by water flow pushing the particles.
5. Load: The material a stream carries. There are several types:
    1. Bed load: Heavy objects dragged along a stream bottom.
    2. Suspended load: Fine particles carried suspended in a stream's moving water.
    3. Dissolved load: Material (salt, carbonate, or other ions) dissolved in the stream water.
6. Graded stream: A stream with a slope and channel that have adjusted enough over time so that the stream has just enough energy to carry its load, but no excess energy so that it erodes its banks.

## Stream Settings

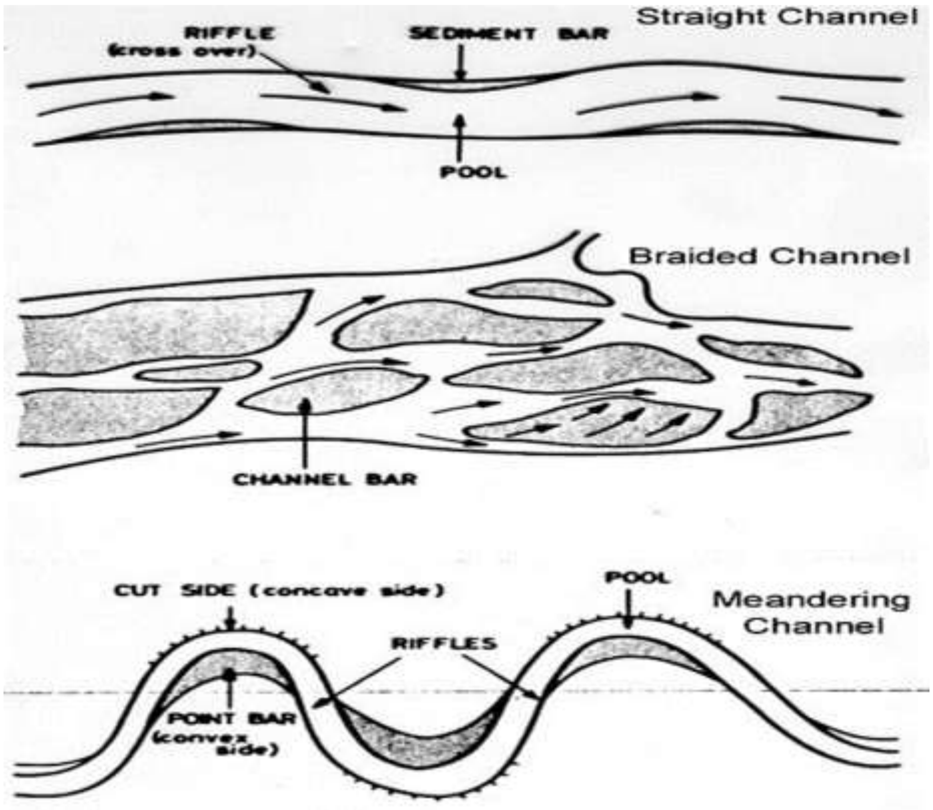
1. Alluvial fan: A gently sloping blanket of alluvium, or sediment deposited by a stream, where it exits a gully onto a flatter surface
2. Flood plain: A plain surrounding a stream. Streams periodically overflow their banks or move laterally across surrounding flood plains, leaving layers of sediments in their wake.
3. Delta: The mouth of a stream, where the stream slows due to a gentler gradient and deposits much of its sediments as it moves to base level.
4. Tributary: A small stream that flows into a larger stream.

5. Drainage system:

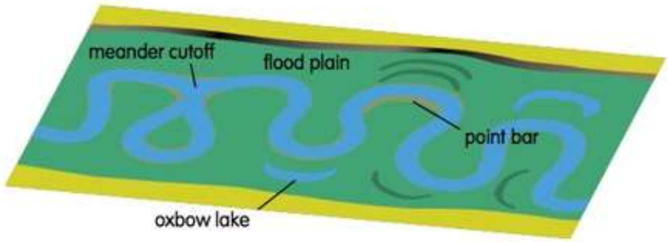



## Stream Shapes and Patterns

There are several types of streams and drainage patterns, which are dictated by landforms and also shape those landforms. Whereas glaciers carve flat-bottomed, U-shaped valleys, streams carve sharp canyons, or V-shaped valleys.




1. Braided stream: A stream that divides into smaller streams. When a stream gradient decreases, its flow slows, causing the stream to branch into smaller subchannels. Braided streams are common on alluvial fans and glacial outwash plains.
2. Meandering stream: A stream that carves a path sideways and forms wide loops, called meanders, as it flows downstream. Often, when water in a stream flows over a bump, ripples are created that deflect water toward one side of the stream and carve into the side. This sideways flow creates a bend in the channel, and water flowing out of this bend then deflects toward the opposite side of the stream, carving a bend there.
    1. Point bar: Sediment deposited in the inner curves of a meandering stream. The stream moves slowest in these inner curves, so the stream drops sediment here.
    2. Oxbow lake: A lake that splits off from a meandering stream when erosion carves a straight channel that cuts off the flow into one of the stream's meanders.



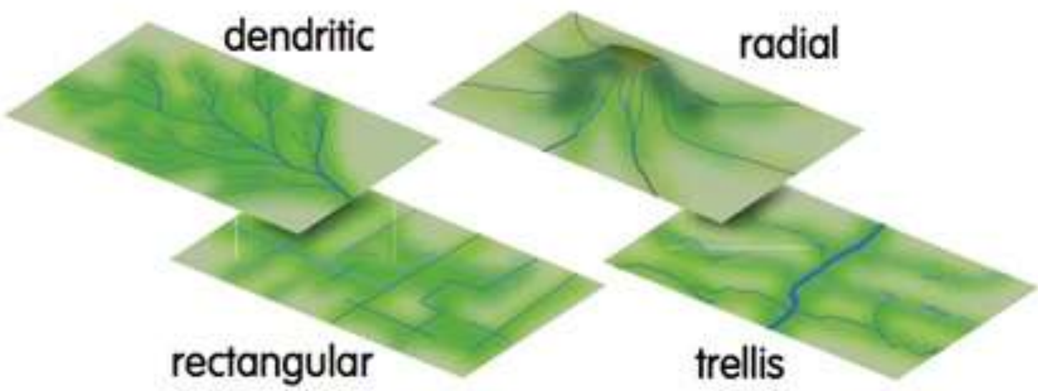

3. Streams can follow several different drainage patterns:

   1. Dendritic drainage: Several substreams branch out from a main stream in a treelike pattern.

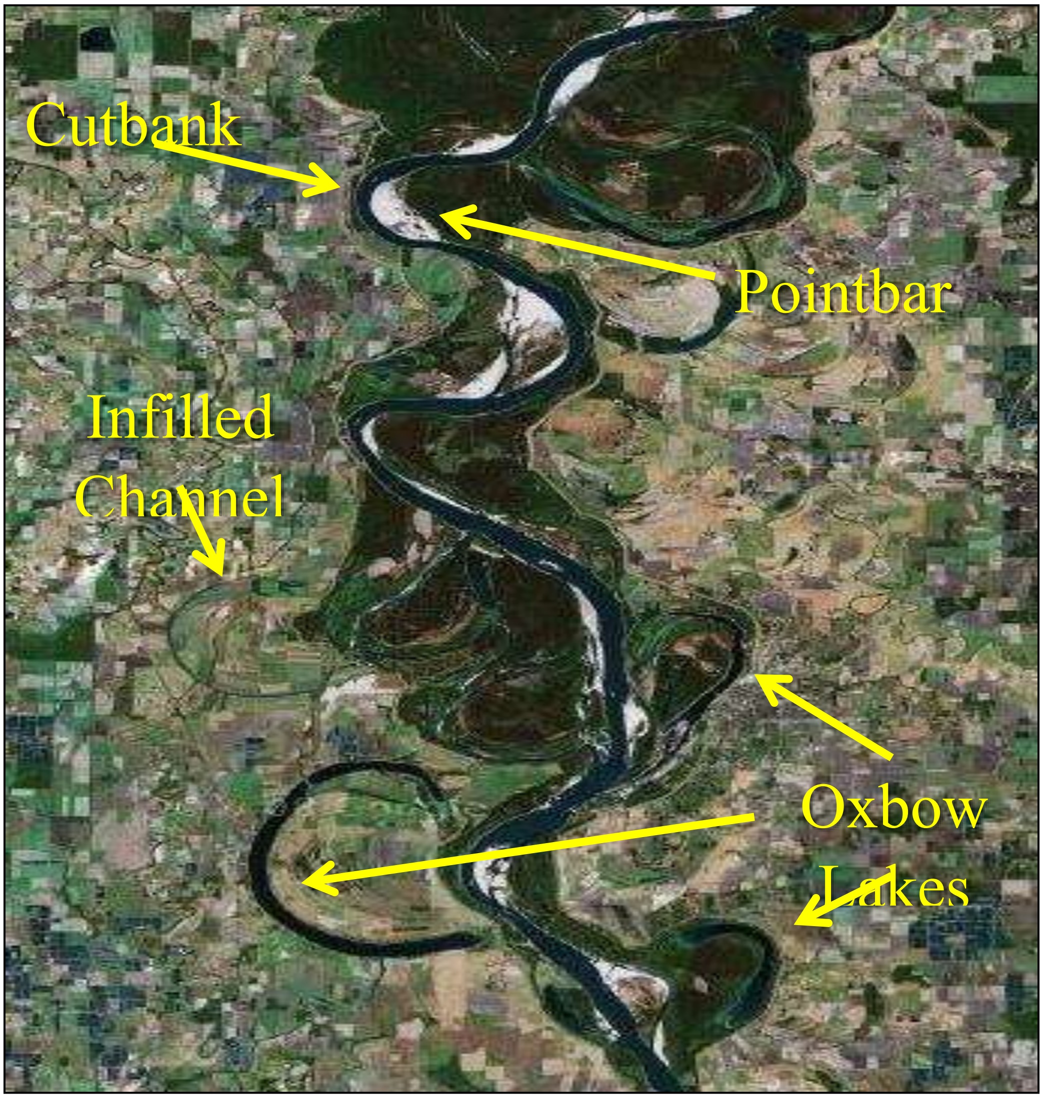
   2. Radial drainage: Streams run in all directions from a central high point.

   3. Rectangular drainage: Streams make right-angled turns, following rectangular fracture patterns in the bedrock over which they flow.

   4. Trellis drainage: Tributaries flow perpendicular to the main channel, following parallel beds of weak strata. Trellis drainage often occurs in tilted or folded rocks.



Flood plain environments are composed of a mosaic of different landform features including cutbanks, pointbars, natural levees and and oxbow lakes




- Cutbanks form along the outer convex margin of meander bends. Cutbanks , unlike most floodplain landforms are actually erosional features formed by the lateral movement of the channel across the flood plain. Flood plain sediments are eroded from the cutbank and deposited on pointbar surfaces.

- Pointbars are concave, depositional landforms that form opposite of the eroding cutbanks, and they develop in concert with the laterally migrating river channel. Pointbars are typically composed of sands, gravel, silts, and clay deposits, that form arcuate, meander-scroll ridges.

  - Natural levees are depositional landforms formed from the vertical accumulation of sediments deposited during flood events. Natural levees form topographically higher surfaces adjacent to the river channel, that generally consist of stratified, well-sorted sands, silts, and clays. Natural levees deposits are thickest and coarsest close to the channel and they become progressively thinner, and finer with increasing distance from the channel.
  - Oxbow lakes or infilled channels form when a meander bend is cut off from the main river and abandoned in the floodplain. Abandoned meanders can occur in various stages from flooded oxbow lakes to being completely infilled with sediment deposits.

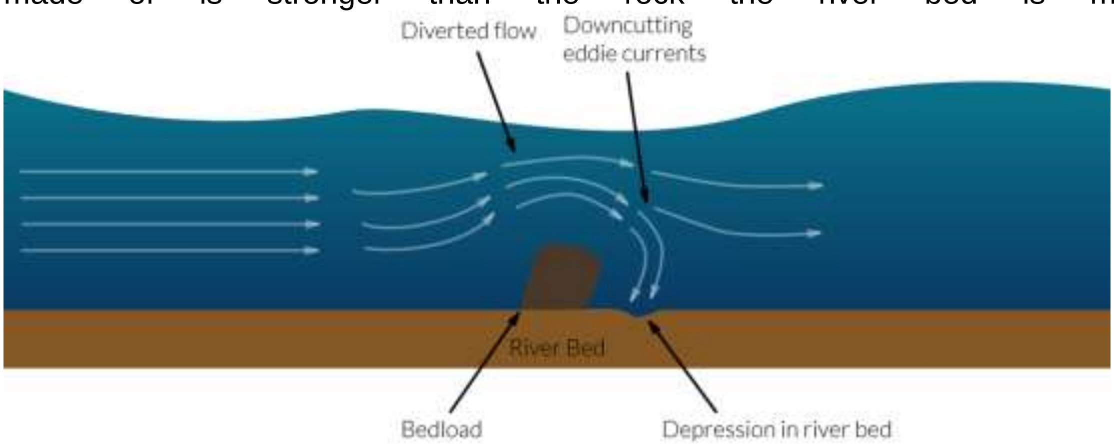
  .

# Potholes الحفر الوعائية

Potholes are cylindrical holes drilled into the bed of a river that vary in depth & diameter from a few centimetres to several metres. They're found in the upper course of a river where it has enough potential energy to erode vertically and its flow is turbulent. In the upper course of a river, its load is large and mainly transported by traction along the river bed. When flowing water encounters bedload, it is forced over it and downcuts behind the bedload in swirling *eddy currents*. These currents erode the river's bed and create small depressions in it.

The creation of eddy (swirl حلزونى) currents as a result of bedload in a river.

As these depressions deepen, pebbles can become trapped in them. As a result of the eddy currents, the pebbles drill into the depressions making them more circular, wider & deeper. Pebbles will only be able to erode a river's bed though if the rock the pebble's made of is stronger than the rock the river bed is made of.



A pothole that has formed along the River Clyde.

## V-Shaped Valleys

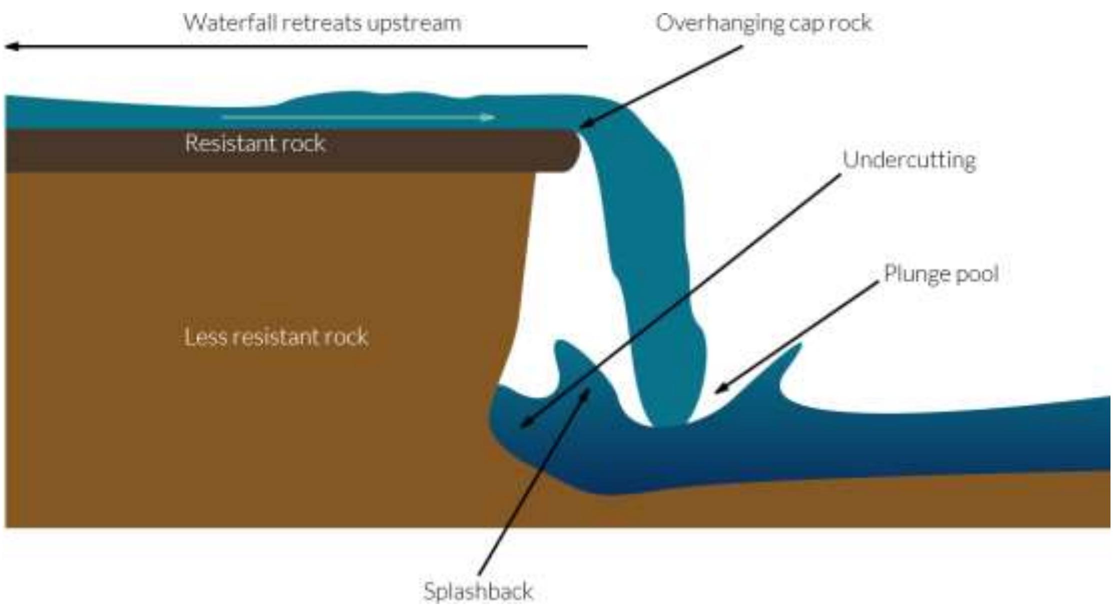
V-Shaped valleys are found in the upper course of the river and are a result of both erosion by the river and weathering. V-Shaped valleys are deep river valleys with steep sides that look like a letter V when a cross section of them is taken, hence the name. They're found in the upper course because this is where the river has the greatest gravitational potential energy and so the greatest potential to erode vertically. It does so during periods of high discharge. When the river's discharge is high, it is able to transport its large bedload by traction eroding the river's bed and valley by corrosion, deepening it. Not much lateral erosion takes place so the channel and valley remains relatively narrow.

As the channel and valley deepens the sides of the valley are exposed and become susceptible to weathering. The valley's sides also undergo mass movements resulting in large volumes of material falling into the river's channel, adding to its erosive power and causing the valley sides to take up a V shape. The steepness of the valley sides and whether the valley actually looks like a V is dependent on the climate, vegetation and rock structure among things. In cold, wet climates, freeze thaw weathering is abundant and rainwater can act as a lubricant, aiding mass movements. Vegetation can impede mass movements because it will help bind the soil. If the valley is composed of hard rock the valley sides will be very steep because they won't be weathered easily.

## Waterfalls (Geological) المساقط المائية

Waterfalls develop when a change of lithology (rock type) takes place along the river's course resulting in differential erosion. When the rock type of the river's channel changes from a resistant rock to a less resistant one (e.g. granite to limestone), the river erodes the less resistant rock faster producing a sudden drop in the gradient of the river with the resistant rock being higher up than the less resistant rock. As the river flows over the resistant rock, it falls onto the less resistant rock, eroding it and creating a greater height difference between the two rock types, producing the waterfall.

When water flows over the waterfall it creates a plunge pool at its base and the splashback from the falling water undercuts the resistant rock. The unsupported rock is known as the cap rock and it eventually collapses into the plunge pool causing the waterfall to retreat upstream. Over thousands of years, the repeated collapse of the cap rock and retreat of the waterfall produces a *gorge of recession*.




## Rapids

Rapids are sections of a river where the gradient of the river bed is relatively steep resulting in an increase in the river's turbulence and velocity. They form where the gradient of the river is steep and the bed is composed mainly of hard rocks.

## Meanders

Meanders are bends in a river that form as a river's sinuosity increases. The sinuosity of a river is a measurement of how much a river varies from a straight line. It's a ratio between the channel length and displacement (straight line distance) between two points in the river's course:

$$\text{Sinuosity} = \text{Channel Length} / \text{Displacement}$$

A sinuosity of 1 means that the channel is perfectly straight. A sinuosity greater than 1 means that the river meanders.

Meanders develop when alternating riffles & pools form along a river channel. A riffle is a a shallow section of a channel while a pool is a deep section. These riffles and pools develop at equal points along the river channel with each pool being about 5× the length of the channel.

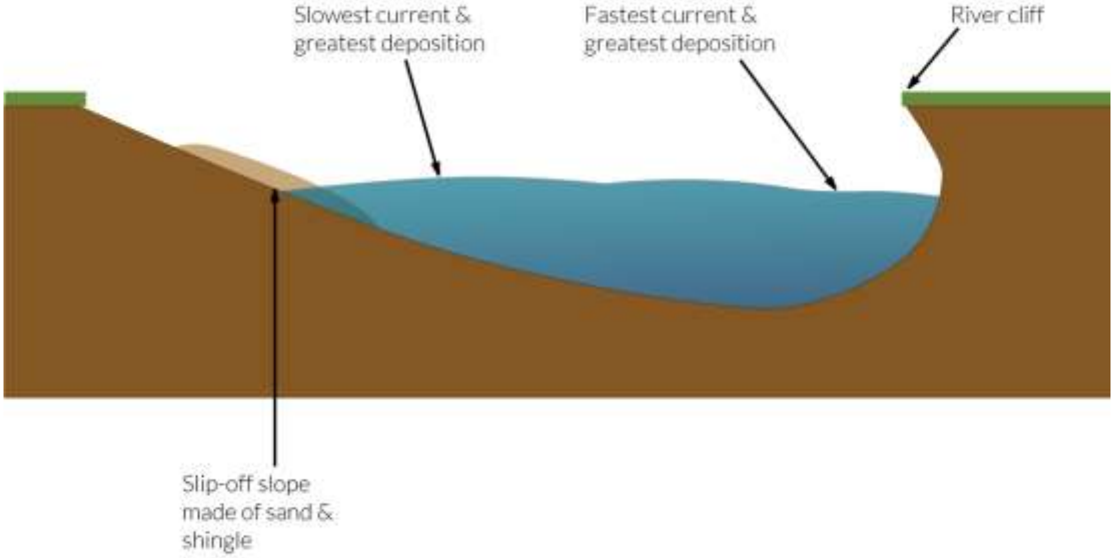
In a pool, the channel is more efficient while at a riffle, the channel is less efficient. This causes the flow of the river to become irregular and the maximum flow is concentrated on one side of the river. This increases erosion on one side of the river and increases deposition on the other causing the river's channel to appear to bend. Erosion is greatest on the outside bend and deposition is greatest on the inside bend.

The alternating riffles & pools have another affect, they increase the turbulence of the river and produce a special type of flow known as *helicoidal* flow. This is a corkscrew like movement which spirals from one side of the channel to another between pools. The helicoidal flow erodes the pools along the channel and increases deposition on the next inside bend after a pool.

**Characteristics**

A cross section of a meander would show that on the outside bend, the channel is very deep and concave. This is because the outside bend is where the river flows fastest and is most energetic, so lots of erosion by hydraulic action and corrasion takes place. *River cliffs* form on the outside bend as the river erodes laterally. The inside bend is shallower with a gentle *slip-off slope* made of sand or shingle that is brought across from the outside bend by the helicoidal flow of the river. The river flows much slower on the inside bend so some deposition takes place, contribution to the slip-off slope.

A cross section of a meander

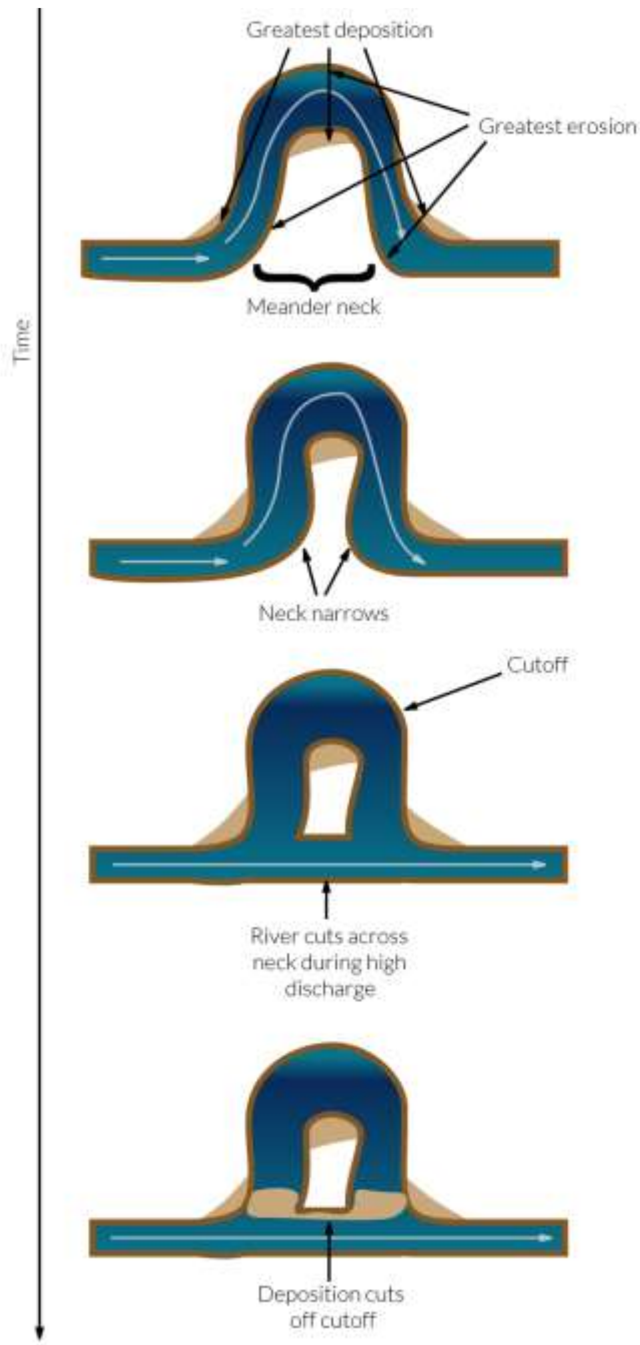




A river cliff on a meander that has had rocks placed near it to slow down erosion.

## Oxbow Lakes

Oxbow lakes are an evolution of meanders that undergo extensive deposition and erosion. As strong erosion takes place on the outside bend of a meander while deposition takes place on the inisde bend. As a result, the neck of a meander narrows. During extremely high discharge (e.g., a flood), it's more efficient for a river to flow accross the neck of a meander rather than around it. When discharge returns to normal levels, the river continues follow this new course. The meander is left connected to the channel as a *cutoff*. Deposition eventually separates the cutoff from the main channel leaving behind an *oxbow lake*. With its main source of water disconnected, the lake eventually dries up leaving behind a *meander scar*.



## Braided Channels

A braided channel is a type of channel that is divided into smaller sub-channels by small, temporary islands called *eyots*. Braided channels develop in rivers with a lot of sedimentary load, a steep gradient and where the discharge of the river changes regularly. When the volume of load exceeds the river's capacity or the discharge of the river drops, the river is forced to deposit its load in the channel and islands of sediment (eyots) form.

A heavily braided section of the Tagliamento's channel in Italy.

## Floodplains

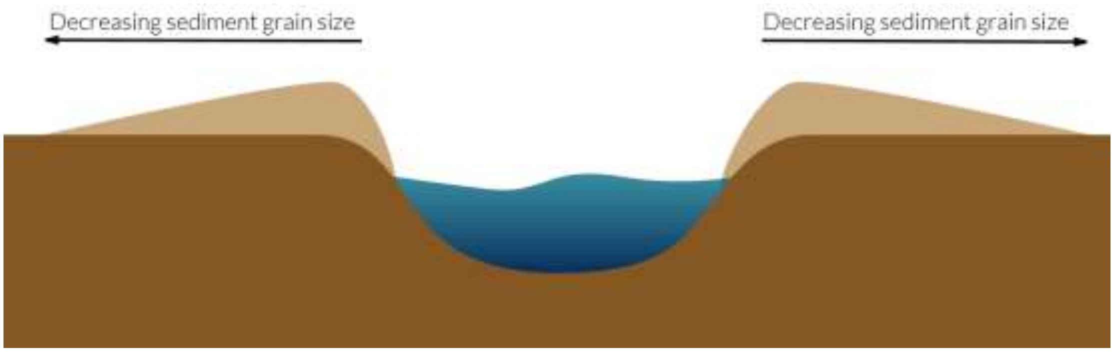
Floodplains are large, flat expanses of land that form on either side of a river. The floodplain is the area that a river floods onto when it's experiencing high discharge. When a river floods, its efficiency decreases rapidly because of an increase in friction, reducing the river's velocity and forcing it to deposit its load. The load is deposited across the floodplain as *alluvium*. The alluvium is very fertile so floodplains are often used as farmland.

The width of a floodplain is determined by the sinuosity of the river and how much meander migration takes place. If there's a lot of meander migration, the area that the river floods on will change and the floodplain will become wider.

## Levees

Levees are natural embankments produced, ironically, when a river floods. When a river floods, it deposits its load over the flood plain due to a dramatic drop in the river's velocity as friction increases greatly. The largest & heaviest load is deposited first and closest to the river bank, often on the very edge, forming raised mounds. The finer material is deposited further away from the banks causing the mounds to appear to taper off. Repeated floods cause the mounds to build up and form levees.

Levees aren't permanent structures. Once the river's discharge exceeds its bankfull discharge[1], the levees can be burst by the high pressure of the water. Levees increase the height of the river's channel though, so the bankfull discharge is increased and it becomes more difficult for the river to flood.

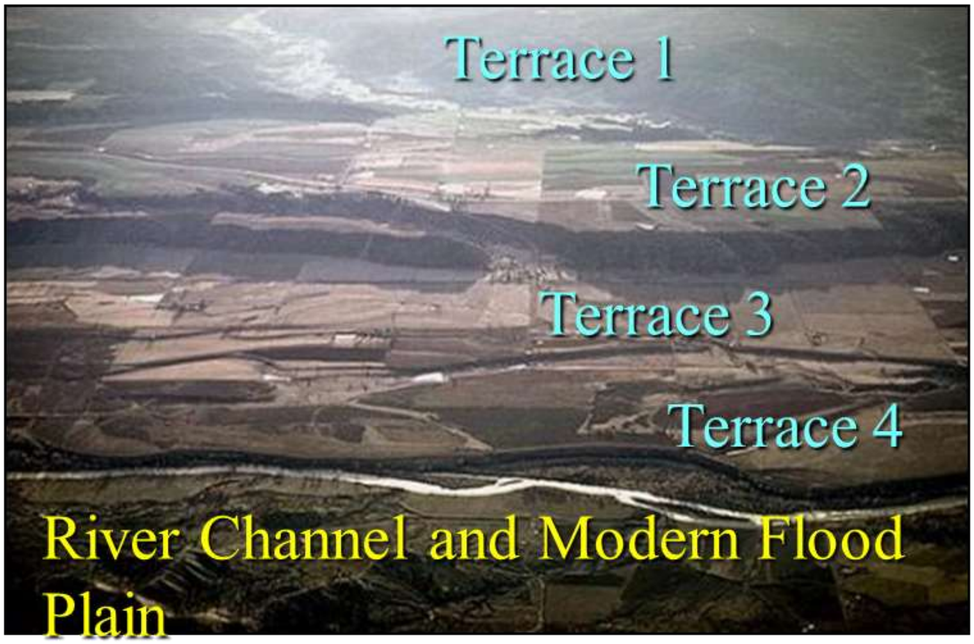



## River Terraces

River terraces are older remnant flood plain surfaces that are higher in elevation than the modern flood plain. They may occur on one or both sides of the valley.

Terraces are formed when the river channel cuts down into the flood plain and laterally erodes the alluvial valley, carving a new river channel and flood plain entrenched within the older flood plain surfaces. Down cutting can occur because of hydrologic or sedimentary changes in the headwaters or valley gradient changes caused by a retreating sea-level and lowered or extended base-level. Terraces can also form from tectonics and valley uplifting.

Terraces are generally isolated from the more recent river processes and may only flood during 100 or 500 year flood events. River terraces are often archeological hot spots because they contain artifacts from historic colonies that used the river and flood plain.



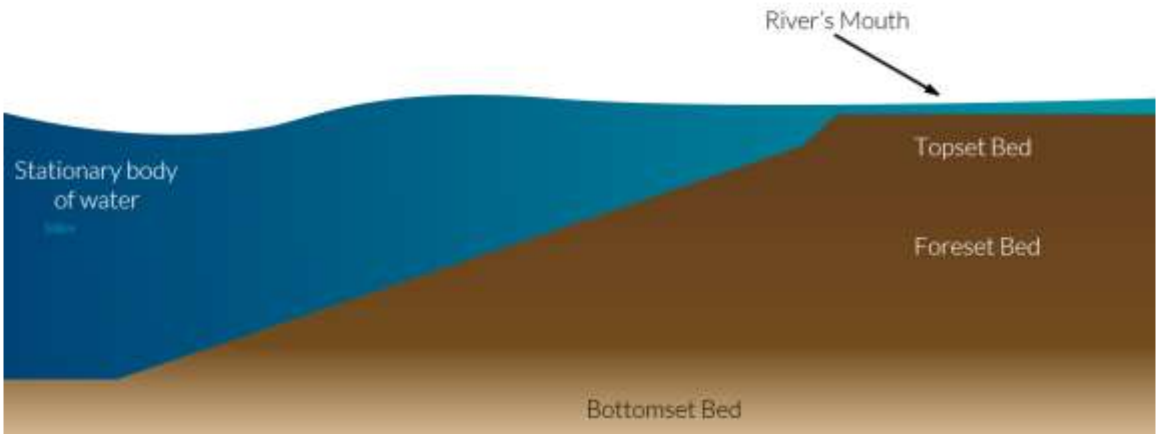

## Deltas

Deltas are depositional landforms found at the mouth of a river where the river meets a body of water with a lower velocity than the river (e.g. a lake or the sea). For a delta to develop, the body of water needs to be relatively quiet with a low tidal range so that deposited sediment isn't washed away and has time to accumulate.

When a river meets a stationary body of water, its velocity falls causing any material being transported by the river to be deposited. Deltas are made up of three sediment beds that have been sorted by the size of the sediment. The bottom most bed, the *bottomset* bed, is composed primarily of clay and some other fine grained sediments. Clay is the main constituent because when clay meets salt water a process called flocculation takes place where clay & salt particles clump together (flocculate) due to an electrostatic charge developing between the particles. This makes the clay particles sink due to their increased weight producing the bottomset bed. The bottomset bed stretches a fair distance from the mouth of the river as the fine sediments can be transported a reasonable distance from the river's mouth.

The foreset bed lies on top of the bottomset bed. The foreset bed is composed of coarser sediments that are deposited due to a fall in the river's velocity and aren't transported very far into the stationary body of water that the river flows into. The foreset bed makes up the majority of the delta and is dipped towards deep water in the direction that the river is flowing in.

The topset bed is, as the name suggests, the topmost bed of the delta. It too is composed of coarse sediment but, unlike the foreset bed, the topset bed doesn't dip, it's horizontally bedded.




Deltas can take on many different shapes. The three primary shapes of delta are *cuspate*, *arcuate* and *bird's foot*.

Arcuate deltas (e.g. The Nile Delta, Egypt) are shaped like a triangle (which is where the term delta comes from, the Greek letter delta Δ) and form when a river meets a sea with alternating current directions that shape the delta so that it looks like a triangle.


Cuspate deltas (e.g. Ebro Delta, Spain) are vaguely shaped like a V with curved sides. Cuspate deltas form when a river flows into a sea with waves that hit it head on, spreading the deposited sediment out.

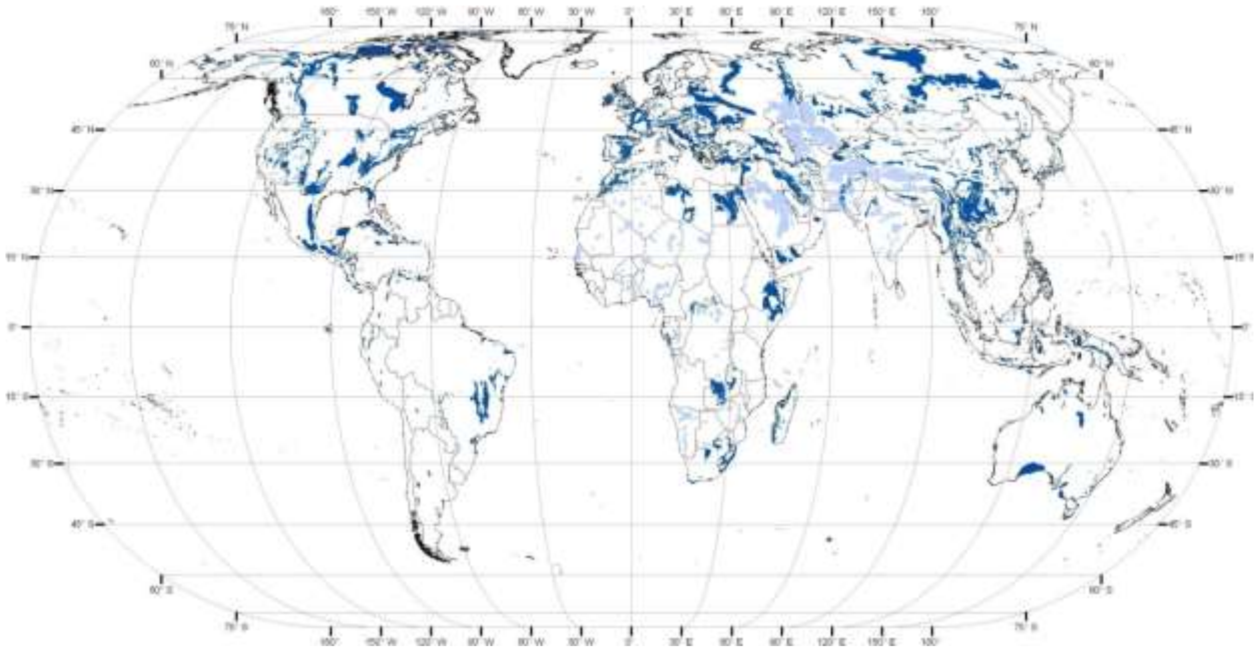

Bird’s foot deltas (e.g. The Mississippi Delta) are shaped like (as the name suggests) a bird’s foot. They extend reasonably far into a body of water and form when the river’s current is stronger than the sea’s waves. Bird’s foot deltas are uncommon because there are very few areas where a sea’s waves are weaker than a river’s current.

# Karst Processes and Landforms

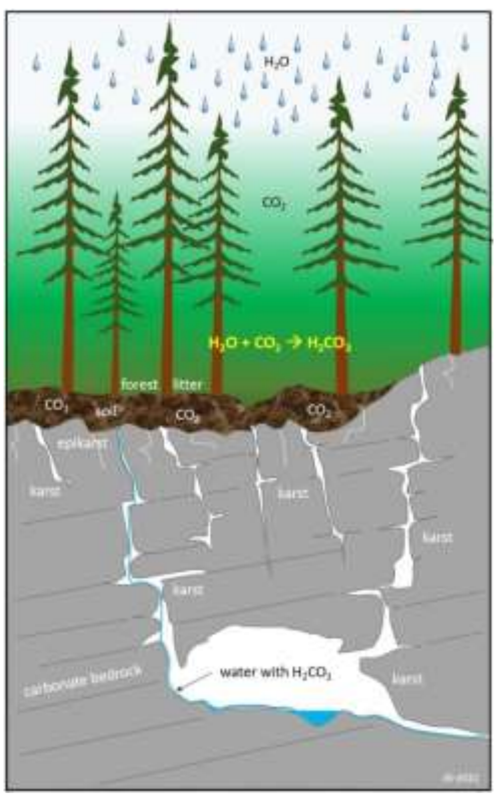
Karst landforms are produced by weathering and erosion in regions of carbonate rocks and evaporites. The processes involved are collectively described as **karstification**, and happened mainly below the ground surface.

## Karst Values, Systems, and Ecosystems

Karst is important for a wide variety of reasons. On a global scale a significant portion (15-20%) of the Earth's surface is underlain by limestone (and other soluble bedrock types) that have the potential to form karst.[1] An understanding of karst processes is therefore important, particularly where humans interact with this landscape. Karst landscapes have certain features and resource values that are not present in non-karst landscapes. Karst aquifers provide the main source of water in many parts of the world, for example, 25% of US groundwater come from karst.



# Karstification



Karstification is a process dominated by chemical dissolution of soluble bedrock (Figure 12.1.1). It starts as carbon dioxide from the atmosphere dissolves in rainwater falling to the surface of the Earth. The water becomes further enriched in carbon dioxide as it infiltrates the soil, and the result is slightly acidic surface water and groundwater. Slightly acidic water when in contact with limestone (or other soluble bedrock types) promotes a chemical reaction which slowly dissolves the bedrock. Existing fractures or crevices in the rock are preferentially widened forming larger cracks allowing for more water flow and dissolution. As the cracks widen, mechanical erosion takes place as loose rock fragments transported by water rub against the sides of the openings, some of which eventually form caves.

A critical requirement for the development of karst is water. Without water there would be no karst or caves! Carbon-dioxide ($CO_2$) is another key component as it dissolves in water forming a weak carbonic acid solution ($H_2CO_3$) as shown below. This carbonic acid reacts with the solid limestone (predominately $CaCO_3$) to form the ions $Ca^{2+}$ and $HCO_3$.

$H_2O + CO_2 \text{ -> } H_2CO_3$

$CaCO_3 + H_2CO_3 \text{ -> } Ca^{2+} + 2HCO_3^-$

Several other factors also play important roles in the development of karst such as: the type and nature of the soluble bedrock, the thickness and type of soil cover, and the hydraulic head or difference in elevation from top to bottom of a karst landscape (Figure 12.1.2). Some of the prime bedrock attributes that play a role in karst development include chemical purity, fracturing, thickness, and geometrical shape. In general, the greater the percentage of calcite ($CaCO_3$) in a limestone, the greater the potential for dissolution. Fracturing in karst bedrock enhances the flow of water and provides preferential sites for conduit development. The thickness of the soluble bedrock unit as well as its geometrical configuration (e.g., tilted, folded, interbedded) can determine the three-dimensional shapes of the karst landscapes.

Solution process:

$CO_2$ dissolved in water reacts to form weak carbonic acid ($H_2CO_3$):

$$CO_2 + H_2O \rightleftarrows H_2CO_3$$

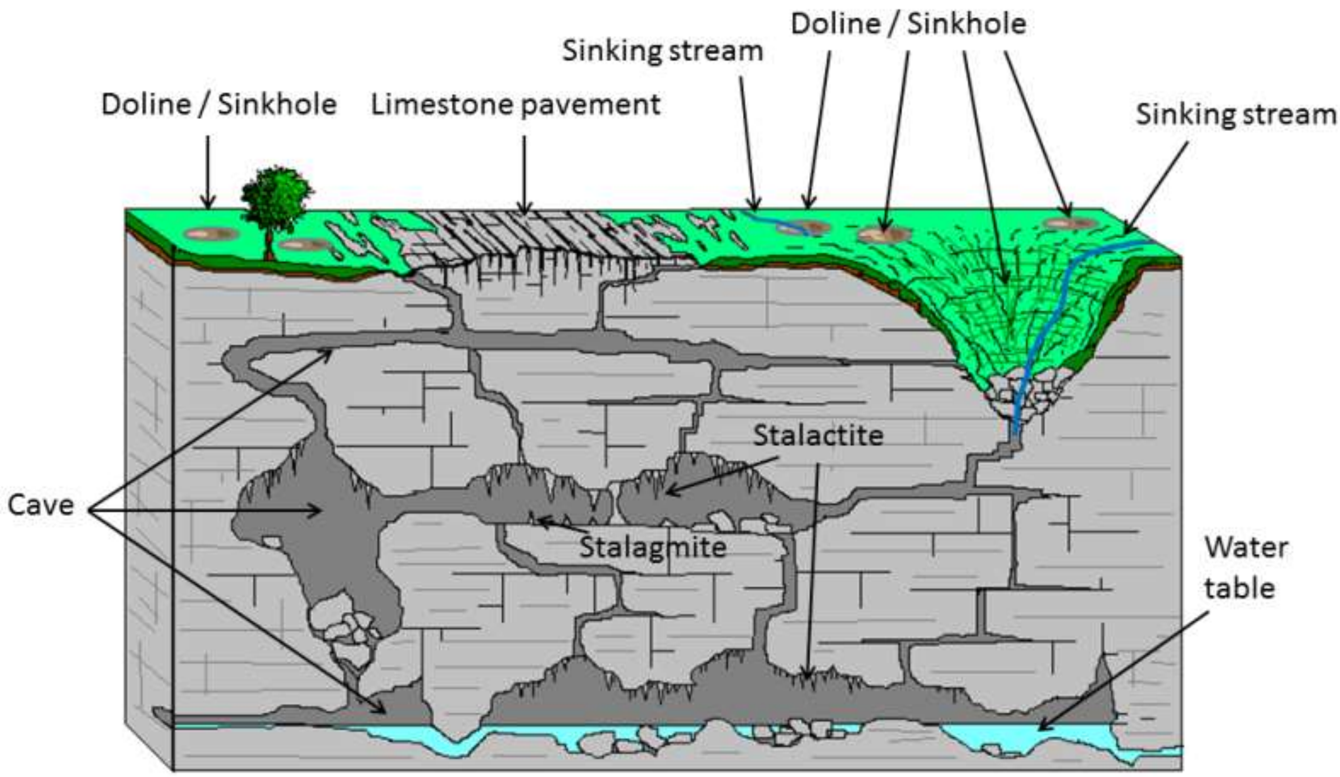
amount of $CO_2$ dissolved in water is function of $P_{CO2}$ & water temperature

$CO_2$ increases as $P_{CO2}$ increases & $T_{water}$ decreases

$$CaCO_3 + H_2O + CO_2 \rightleftarrows Ca^{2+} + 2HCO_3^-$$

# Karst landforms

Karst comprises some of the most unique landscapes in the world, but it is also characterised by distinctive landforms. These characteristic landforms can be found both on the surface and below ground. Surface landforms commonly include enclosed depressions, sinkholes, sinking streams and springs.

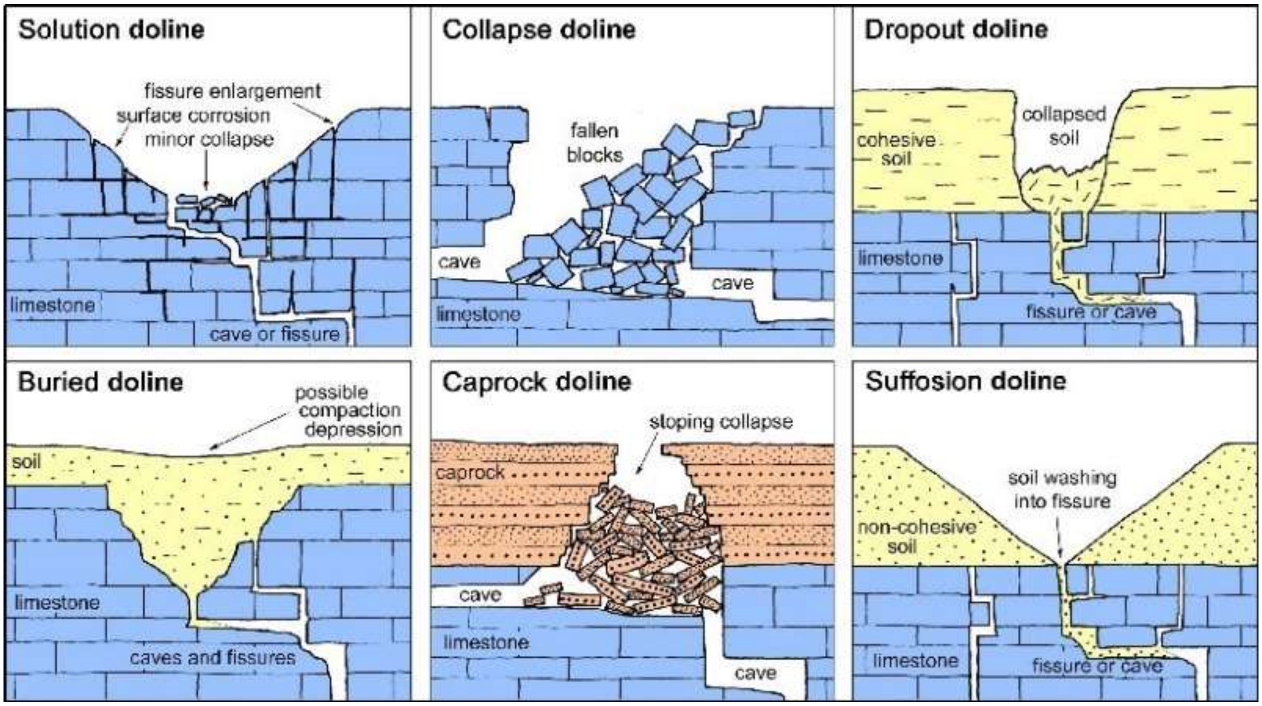



### What is a doline or sinkhole?

A doline (or sinkhole as it is more commonly called in North America) is a natural enclosed depression found in karst landscapes. Dolines are the most common landform in karst areas. They are described as small to medium sized closed depressions, ranging from metres to tens of metres in both diameter and depth. Once created dolines function as funnels, allowing the direct transmission of surface water into the underlying karstic bedrock aquifer. They may occur as isolated features or in clusters causing a pock-marked land surface (Ford and Williams, 2007).

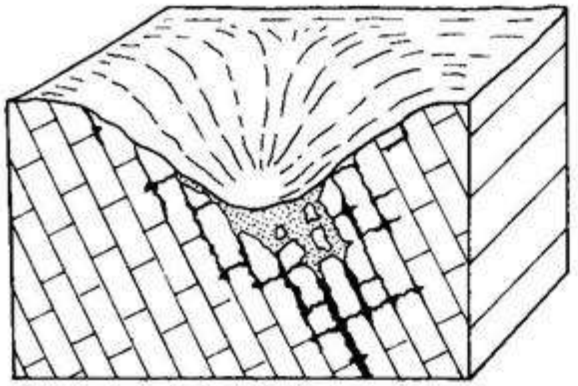
### How do dolines form?

Dolines are formed by two main methods: the slow solutional removal of rock from the surface downward (solution doline), or by the collapse of overlying rock or overlying material into an underground cave or chamber (collapse doline). Most dolines are considered polygenetic in origin and are usually formed from a combination of solution and collapse; however one of these processes usually dominates their appearance, whether it is catastrophic or gradual.

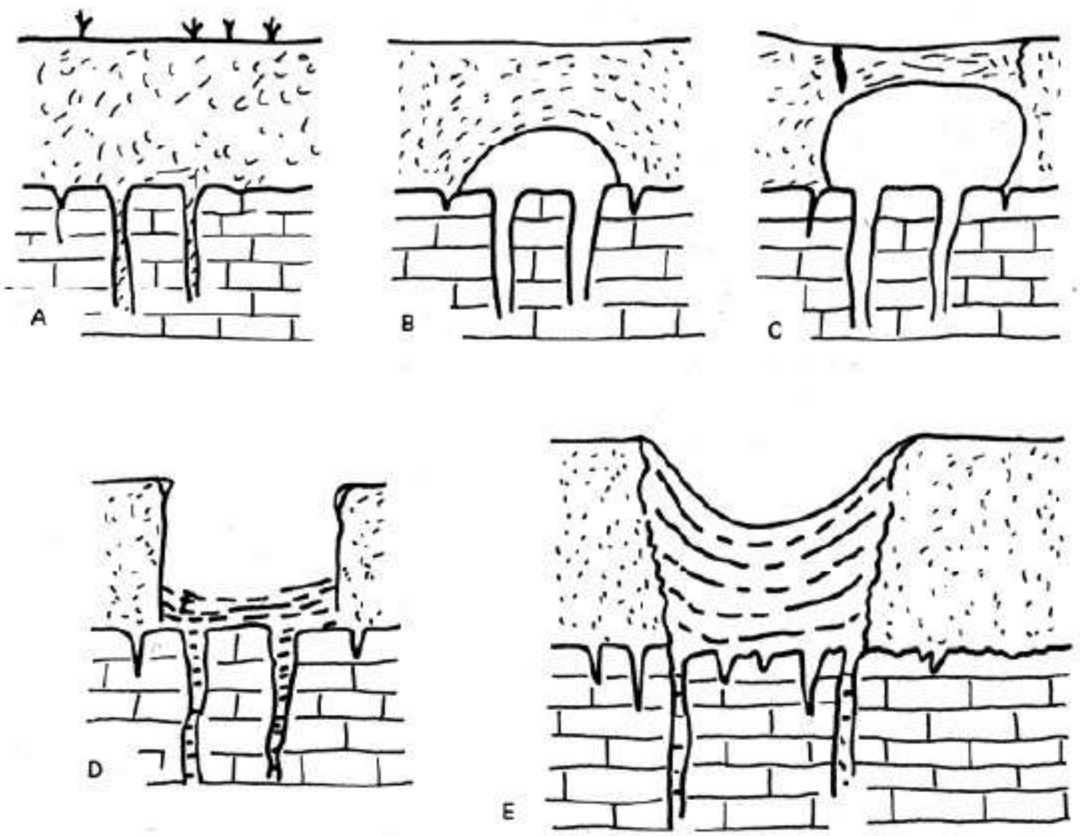



Source Waltham, A., Fell F. and Culshaw M. 2005. Sinkholes (or dolines) and subsidence: karst and cavernous rocks in engineering and construction. Springer. Berlin.

*Solution dolines* form in such places such as joint intersections. Surface runoff will focus at these areas of weakness, leading to the solution of the bedrock. Water and solutes will then move downwards through the bedrock openings (such as at joints and bedding planes). The result is a funnel-shaped depression on the surface. Solution dolines are considered to be formed by a gradual process of sagging or settling of the overlying deposits into the hollow left by an area of dissolving rock. Solution dolines are usually characterised by gentle slopes with no obvious rupturing of the soil or surface.

|  |  |
|---|---|
| Solution doline formation (Jennings 1985) | Solution dolines in County Roscommon |

*Collapse dolines* usually occur very suddenly where the bedrock or subsoil material collapse into and underlying void. *Cover collapse dolines*, sometimes known as dropout dolines are very common in Ireland. They occur in karst areas covered by unconsolidated material, such as glacial till. They form by the sudden downward movement of the overburden and usually form in areas where the overburden is somewhat cohesive. They occur in a process called 'piping', where a soil or subsoil arch, which has formed due to removal of material at the bottom of a layer of overburden, suddenly gives way (White, 1988). Although there must be a highly efficient pathway established for sediment transportation in order for the soil arch to form and grow, a large bedrock hollow is not necessary for their development. Cover collapse dolines are characterised by vertical or steep-sided collapses, with a very sharp break in slope and often have stepped sides, where soil is exposed. Over time, however, their slopes may degrade and infilling sediment may build up giving these dolines the morphology of solution dolines (Ford and Williams, 2007).




The formation of a cover collapse doline:

A) Solutional openings in the bedrock wash material downward,
B) An small arch forms in the subsoil where the material is being washed away from,
C) The void grows in size as more material is being down-washed until it reaches a critical point and starts to rupture,
D) The arch suddenly collapses as it can no longer support its own weight,
E) Overtime the vertical sides will degrade and the hole will become less deep.


doline

An **uvala** is a collection of multiple smaller individual sinkholes that coalesce into a compound sinkhole. These landforms are often shallow and irregular in their overall shape, due to the merging of smaller sinkholes.

An **uvala**

A **poljes** is an elongated basin having a flat floor and steep walls, formed the coalescence of several sinkholes

A **poljes**

2) **Karst valleys** - allogenic valleys; pocket valley; dry valleys
•**Allogenic valley** is a karst valley incised by a watercourse originating on impervious rock with a volume sufficient for it to traverse a limestone area on the surface. The valley is incised from the limestone contact and with the passage of time the river is increasingly likely to pass underground as the waters enlarge joints.

**Blind valley** is a deep, narrow, flat bottomed valley with an abrupt ending. Such valleys arise in karst landscapes, where a layer of permeable rock lies above an impermeable substrate. They are created by a stream flowing within the permeable rock and eroding it from within, until the rock above collapses opening up a steep narrow valley which is then further eroded by the stream running across the impermeable valley floor.

**Dry valley** is a valley found in no longer has a surface flow of water because the water sinks through the limestone and flows underground in caverns .

**Minor solution features:**

•Karren are minor forms of karst due to solution of rock on its surface. The name Karren is German,. Lapies is the same thing, the term originates from the French. In English both terms are used equally and synonymously.

Karren are formed when water runs down a rock surface with a slope, dissolving the rock while it runs. Thus karren can be found on any soluble rock like limestone, dolomite or gypsum. Water always takes the direction of the highest gradient, which is commonly described by the term steepest slope. When solution of the surface forms a shallow furrow in this direction, water is flowing into the furrow and through it, deepening it more and more. Finally the whole rock surface is drained through karren.

**Karren**

**Subsurface Features/Landforms Caves** form by the dissolution of limestone. Rainwater picks up carbon dioxide from the air, and more especially from the soil (where micro-organisms and the decay of organic matter generate high levels of carbon dioxide), combining to form carbonic acid. As this acidic water percolates through the limestone, it gradually enlarges the bedding planes, joints and fissures within the rock, eventually creating caves.

**Cave Deposits** Once cave has been formed, it may become partially or totally infilled with cave deposits. Two major types of deposit are **stalactites** and **stalagmites** (‘speleothems’). Once percolating water reaches the underlying cave atmosphere, which has generally lower levels of carbon dioxide, it degasses and by doing so, becomes supersaturated with calcium carbonate, which is deposited as speleothem. A variety of different types of speleothem can develop, but the majorities are composed of calcite. Near the entrances to many caves, evaporation of the drip waters can enhance stalagmite deposition, which is why many of the caves are almost choked by calcite near their entrances

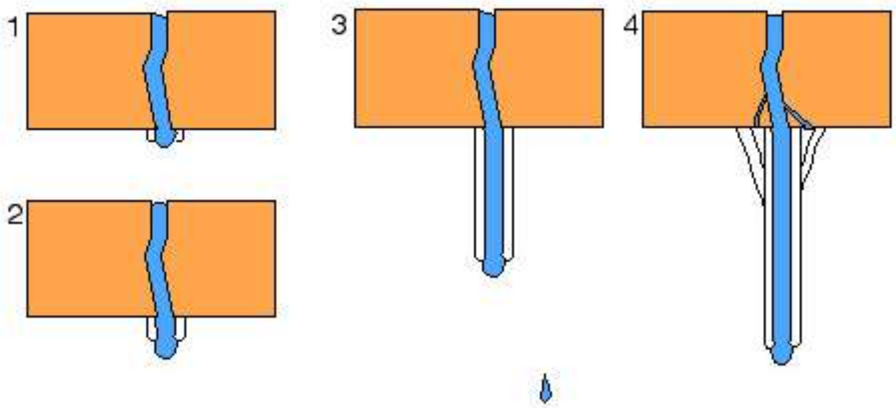
# STALAGMITES AND STALACTITES

**Stalactites** hang from roofs of caves.

They are commonly $CaCO_3$ (Calcite or aragonite)

They are usually pointed.

They often begin growth as a "soda straw".




**Stalagmites** grow from the floors of caves

They are usually round-topped.

They are commonly $CaCO_3$

(calcite or aragonite)