DEMOCRATIC AND POPULAR ALGERIAN REPUBLIC
Ministry of Higher Education and Scientific Research
University August 20, 1955 Skikda
Faculty of Sciences
Department of Ecology and Environment

Geology course elements, 1st year

Common Core L1: Natural and life sciences

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Summary

Course objectives

This course is designed for first-year students in the common core science of nature and life, following the curriculum established within the framework of this training.

The program is organized into three main chapters:

Chapter I: General Geology

Chapter II: External Geodynamics

Chapter III: Internal Geodynamics

The objective of the geology instruction is to instill fundamental knowledge of the major phenomena shaping the Earth, demonstrating that the Earth is a dynamic planet with processes that we aim to comprehend.

The general geology module primarily seeks to position geology within the natural sciences and underscore its relevance to biological requirements. In the first part of this module, students will be introduced to basic concepts concerning the fundamental understanding of the Earth's structure through various investigative methods. The second part will cover notions related to external phenomena (erosion and alteration) influencing changes in topography, and finally, structural geology in connection with internal and external geodynamics. The module will also explore the stratigraphic scale of geological times based on various methods of geochronological dating.

Chapter I:
GENERAL GEOLOGY

I. GENERAL GEOLOGY

I. 1. Introduction to geology

I. 1. 1. Definition

Geology, or Earth Science (in Greek, Geo means Earth, Logos means Science). is the study of the Earth (its origin, structure, composition and history), which includes its interior and exterior processes, rocks, minerals, fossils, and all the surface processes that have shaped the landscape around us and continue to shape our lives today. These processes take place over different time scales, from hundreds of millions of years to hundreds of thousands of years

I. 1. 2. Different branches of geology

For studying the earth in detail, the subject of Geology has been divided into various branches. They are as follows:

- **Mineralogy**

This deals with the study of minerals. Minerals are basic units with different rocks and ores of the earth are made up of. Details of mode of formation, composition, occurrence, types, association, properties uses etc. of minerals form the subject matter of mineralogy.

- **Stratigraphy**

The climatic and geological changes including tectonic events in the geological past can also be known from these investigations. This kind of study of the earth's history through the sedimentary rock is called historical geology. It is also called stratigraphy (Strata = a set of sedimementary rocks, graphy description).

- **Paleontology**

As a branch of geology, it deals with „the study of fossils" and the ancient remains of plants and animals are referred to as fossils. Fossils are useful in the study of evolution and migration of animals and plants through ages, ancient geography and climate of an area.

- **Petrology**

Petrology deals with the study of rocks. The earths crust also called lithosphere is made up of different types of rocks. Hence petrology deals with the mode of formation, structure, texture, composition, occurrence, and types of rocks. This is the most important branch of geology from the civil engineering point of view.

- **Structural Geology**

The rocks, which from the earths crust, undergo various deformations, dislocations and disturbances under the influence of tectonic forces. The result is the occurrence of different geological structures like folds, fault, joints and unconformities in rocks. The details of mode of formation, causes, types, classification, importance etc of these geological structures from the subject matter of structural geology

- **Geophysics**

The study of physical properties like density and magnetism of the earth or its parts. To know its interior form the subject matter of geophysics. There are different types of geophysical investigations based ion the physical property utilized gravity methods, seismic methods, magnetic methods.

- **Geochemistry**

This branch is relatively more recent and deals with the occurrence, distribution, abundance, mobility etc, of different elements in the earth crust.

I. 1. 3. Areas of application of geology

The fields of geology are:

- Exploration of hydrocarbons (oil and gas).
- Exploitation of mining resources such as gold, iron, diamond, silver, uranium, marble.
- Hydrogeology: exploitation of surface water resources (rivers, valleys, lakes, etc.) and groundwater.
- Geotechnics: geology applied in civil engineering (soil study for the construction of buildings, roads, bridges, tunnels, dams, etc.).
- Seismotectonics and seismology: studies of seismically active zones (seismogenic faults).

I. 2. The earth globe

Earth is the 3rd interior planet of the solar system, it is located approximately 150 million km from the sun. It gravitates around the sun by rotating on it self, It is slightly flattened at the poles. That is why, its shape is described as a Geoid. Geoid means an earth-like shape.

Conditions favourable to support life are probably found only on the earth. The earth is neither too hot nor too cold. It has water and air which are very essential for our survival. The air has life-supporting gases like oxygen. Because of these reasons, the earth is a unique planet in the solar system. From the outer space, the earth appears blue because its two-thirds surface is covered by water it is, therefore, called a blue planet.

The age of the Earth is approximately 4.6 billion years. Its radius is approximately 6371 kilometers.

I. 3. The Earth's crust

Outer layer; covers the whole earth; varies in thickness from 5 to 60 Km.
There are 2 kinds of crust: continental crust and oceanic crust (Fig 1).

- **Continental Crust**
  - ✓ Exists under continents
  - ✓ Average thickness is 30-50 Km (thickest under mountains), although it can be as thin as 10 Km in places
  - ✓ Chemical composition: rocks rich in silica and aluminium **(SIAL)**
  - ✓ Common rock types: granite and rhyolite
  - ✓ Rocks are less dense, lighter in color than oceanic crust

The continental crust can be subdivided into three layers.

- **The surface crust:** with variable thickness (up to several thousand meters in large sedimentary basins), it consists of sedimentary and/or volcanic rocks. Sometimes, erosion has completely removed this layer.
- **The upper crust:** composed of metamorphic and magmatic rocks.
- **The lower crust:** due to its depth (15 km), it is the least understood layer. It is composed of metamorphic rocks.

- **Oceanic Crust**
  - ✓ Exists under oceans
  - ✓ Average thickness is 7 Km
  - ✓ Chemical composition: rocks rich in is rich in silica and magnesium **(SIMA)**
  - ✓ Common rock types: basalt, obsidian, gabbro
  - ✓ Rocks are more dense, darker in color than continental crust

In the ocanic crust three distinct layers can be identified from top to bottom:

- **Layer 1:** Comprising sediments, this layer is thicker near mid-ocean ridges and tapers to a few kilometers near continents. On average, it is approximately 300 m thick. its density varies between 1.93 and 2.3.
- **Layer 2:** The basement, composed of basalts, ranges between 4 and 6 km/s, with a density of 2.55.
- **Layer 3:** The oceanic layer is formed by gabbros, with a thickness of 4.8 km. the density is 2.95.

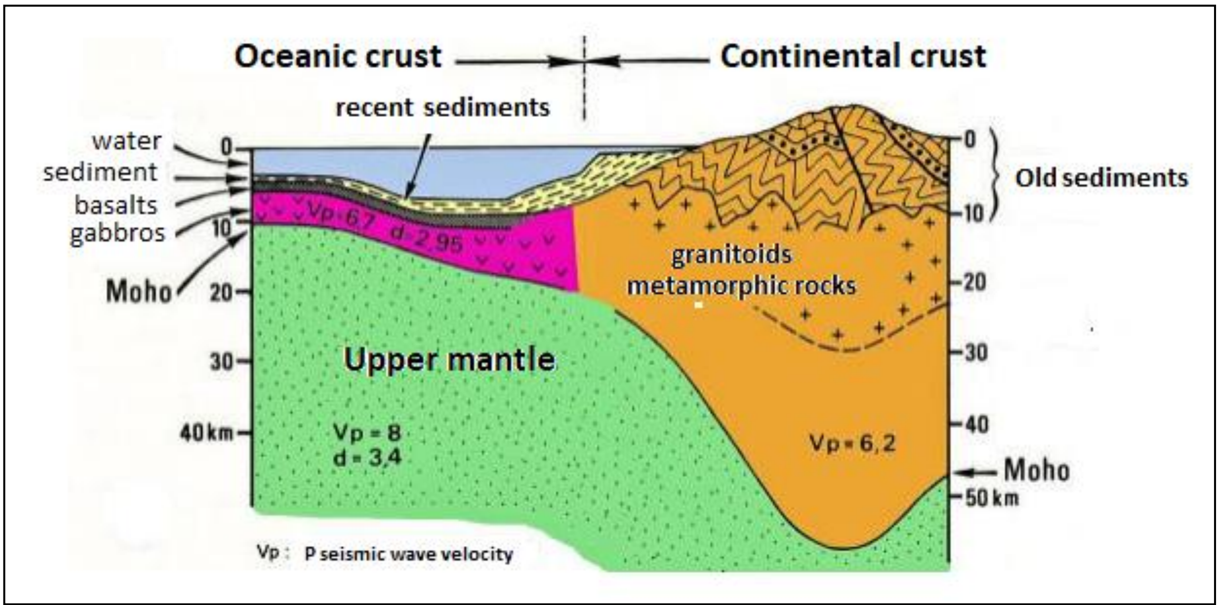


Figure 1. Continental and oceanic crust

I. 4. Structure of the earth

Geologists use two types of evidence to learn about Earth's interior. This includes direct evidence through rock samples and indirect methods through seismic waves.

I. 4. 1. The direct methods

They allow us to observe the structure and properties of the Earth directly. Logically, we can easily do this in the rocks that make up the earth's surface. But we can also know what the interior of the Earth is like through:

- **Surveys and mines**

The deepest survey that has been done was carried out by the USSR and reached 12,262 meters deep, a very small distance if we compare it with the 6,371 km depth that the Earth has.

- **Volcanic eruptions**

They expel materials from the earth's interior that are expelled with the magma.

- **Erosion**

The erosion leaves the bare rocks formed deeper.

I. 4. 2. The indirect methods

The seismic method is one of the main indirect study methods that allows us to know what the Earth's interior is like. It is based on the study of seismic waves produced in earthquakes or by controlled explosions. When the waves reach the earth's surface (epicenter) they propagate concentrically. As they move away from the hypocenter, the seismic waves attenuate. Analyzing the speed and trajectory of the waves we can know the chemical composition, physical state and structure of the materials that make up the internal parts of our planet.

Several types of seismic waves are distinguished (Fig 2):

- **P or primary waves**

They are the fastest waves, the first to be received by seismographs. The particles vibrate in the same direction as the propagation of seismic waves. They are transmitted through solid and liquid media, although they are faster in solid materials.

- **S or secondary waves**

They are slower than P waves (Fig 3). The particles vibrate in a direction perpendicular to the propagation of the waves. They are only transmitted through solid media.

- **L and R waves**

They appear when P and S waves reach the Earth's surface. They are the slowest, the last to be recorded by seismographs. They are the most destructive waves, since they have a longer wavelength. As they are superficial, they do not provide information about the earthquake.

On the basics of seismic investigation the earth interior has been broadly divided into three different layers: crust, mantle, and core.

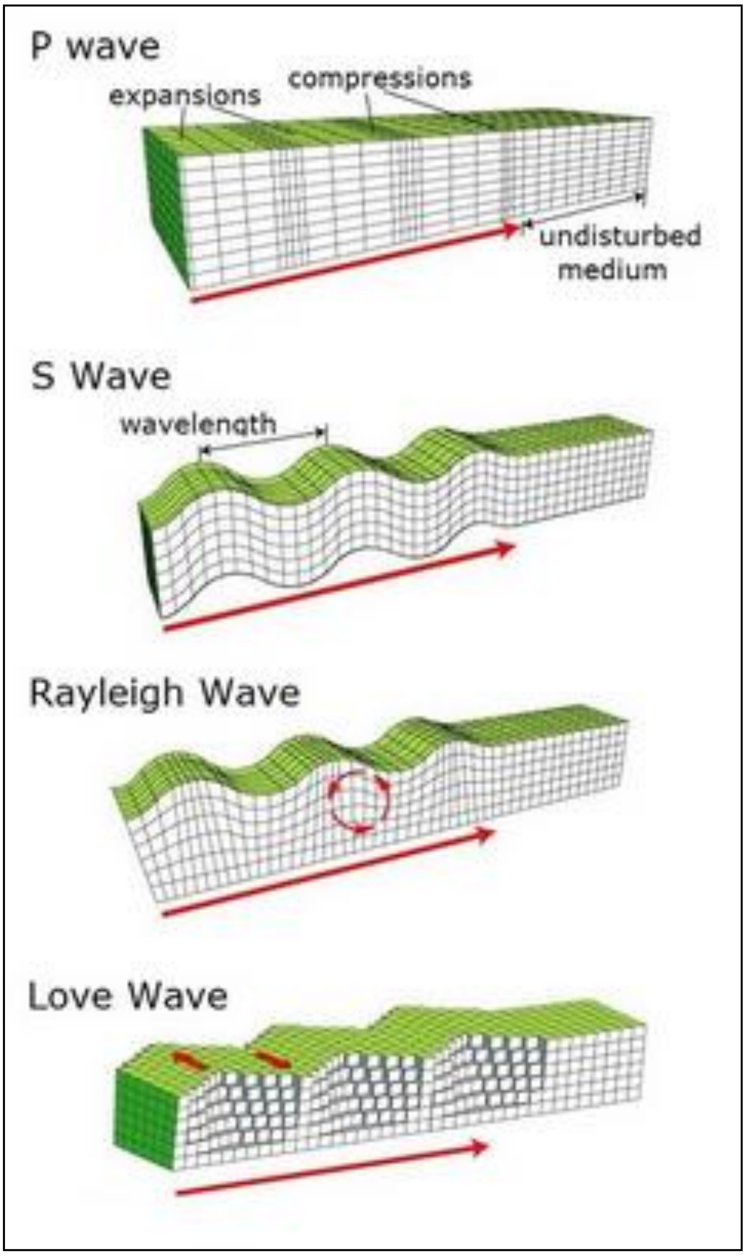


Figure 2. Types of seismic waves

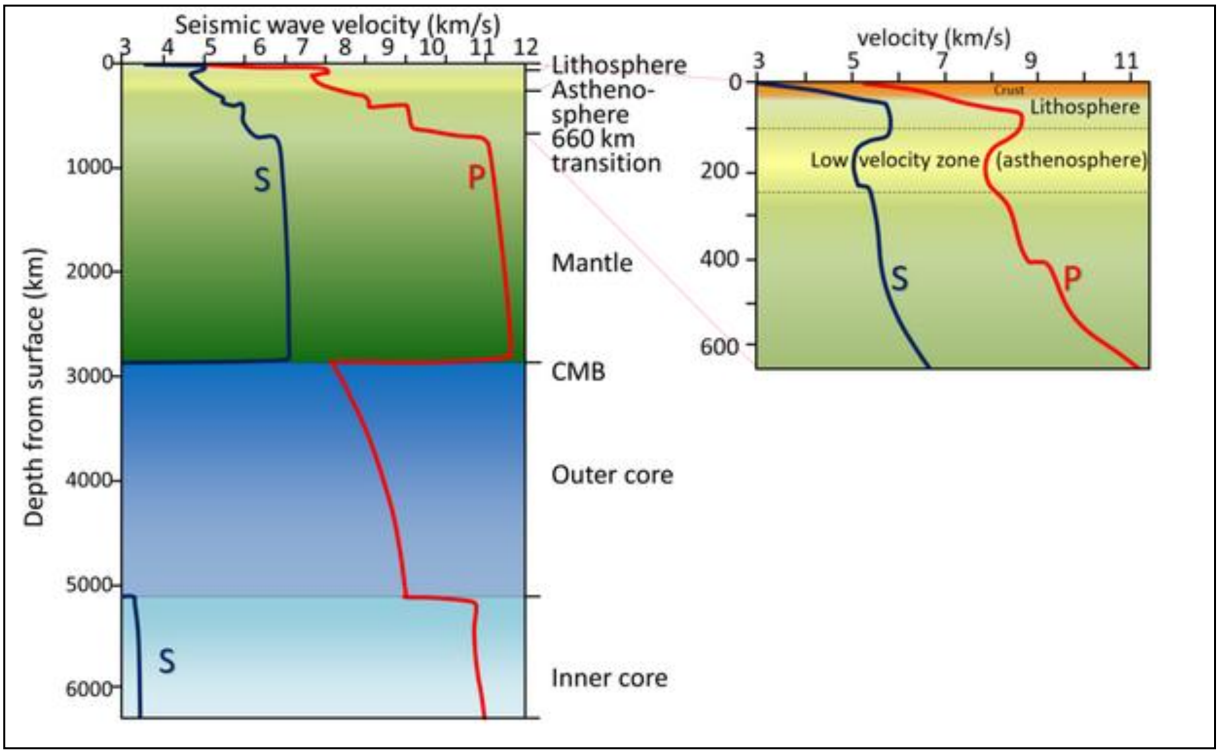


Figure 3. P wave (red) and S wave (blue) velocity variations with depth in Earth. The diagram on the right shows an expanded view of the upper 660 kilometres of the curves in the diagram on the left

The internal structure of the Earth consists of several layers with distinct properties. These layers, from the outermost to the innermost, are the crust, mantle, outer core, and inner core (Fig 4):

I. 4. 3. The crust

The Crust is the outermost layer representing 1.5% of the Earth's volume. It is bounded at the base by the major discontinuity known as the Mohorovicic discontinuity (or Moho). The crust is divided into two parts: the continental crust and the oceanic crust.

- **The Continental Crust**

It extends from 30 to 70 km (maximum thickness is reached under mountainous regions) and has, near the surface, the average composition of granites.

- **The Oceanic Crust**

It is 8 to 10 km thick and forms the floor of the oceans. Its composition is basaltic.

The **Mohorovicic Discontinuity**, commonly called the “Moho” is recognized as the boundary zone between Earth's crust and the mantle.

I.4.4.The Mantle

Beneath the Moho, the mantle extends, occupying 83% of the Earth's volume and representing 67% of its mass. It extends in depth to approximately 2900 km. The average composition of the mantle is that of a rock called peridotite (an ultrabasic rock rich in magnesium and iron silicates), composed of olivine, pyroxene, and garnet. The mantle is composed of two parts: the upper mantle and the lower mantle.

- **Upper Mantle**

The upper mantle is less viscous (more ductile) than the lower mantle; the physical conditions prevalent there make it partially plastic. It is primarily composed of rocks such as peridotite.

- **The lithospheric mantle** : The lithospheric mantle is part of the Earth's upper mantle and extends from the base of the lithosphere to a certain depth, typically ranging from about 100 to 200 kilometers below the Earth's surface.is relatively rigid and contributes to the strength of tectonic plates.
- **The asthenospheric mantle** : he asthenospheric mantle lies just below the lithospheric mantle and extends to a depth of about 700 kilometers beneath the Earth's surface.is more ductile and allows for the slow, plastic flow of material, influencing the dynamics of plate tectonics. The transition between the lithospheric and asthenospheric mantle is marked by a decrease in rigidity and an increase in ductility.

- **Lower Mantle**

The lower mantle is a layer within the Earth's interior that extends from approximately 670 kilometers to 2900 kilometers in depth below the Earth's surface. At these depths, the lower mantle experiences extremely high temperatures and pressures. The conditions in the lower mantle lead to solid-state deformation of rocks, and it is generally considered to be solid, though at extremely high temperatures and pressures. A discontinuity located at a depth of 2900 km separates the lower mantle from the core called the **Gutenberg discontinuity.**

I. 4. 5. The core

The core is the innermost layer of the Earth, consisting mainly of iron and nickel. It is divided into two distinct regions: the outer core and the inner core.

- **Outer core**

the outer core is primarily composed of liquid iron and nickel. Extending from a depth of about 2900 kilometers to approximately 5150 kilometers beneath the Earth's surface, the outer core surrounds the solid inner core.

- **Inner core**

The inner core is the solid, innermost layer of the Earth, composed primarily of iron and nickel. extends from a depth of about 5150 kilometers to the center of the Earth at approximately 6371 kilometers

The Lehmann Discontinuity is situated at a depth of approximately 2900 kilometers beneath the Earth's surface. It marks a transition between the liquid outer core and the solid inner core.

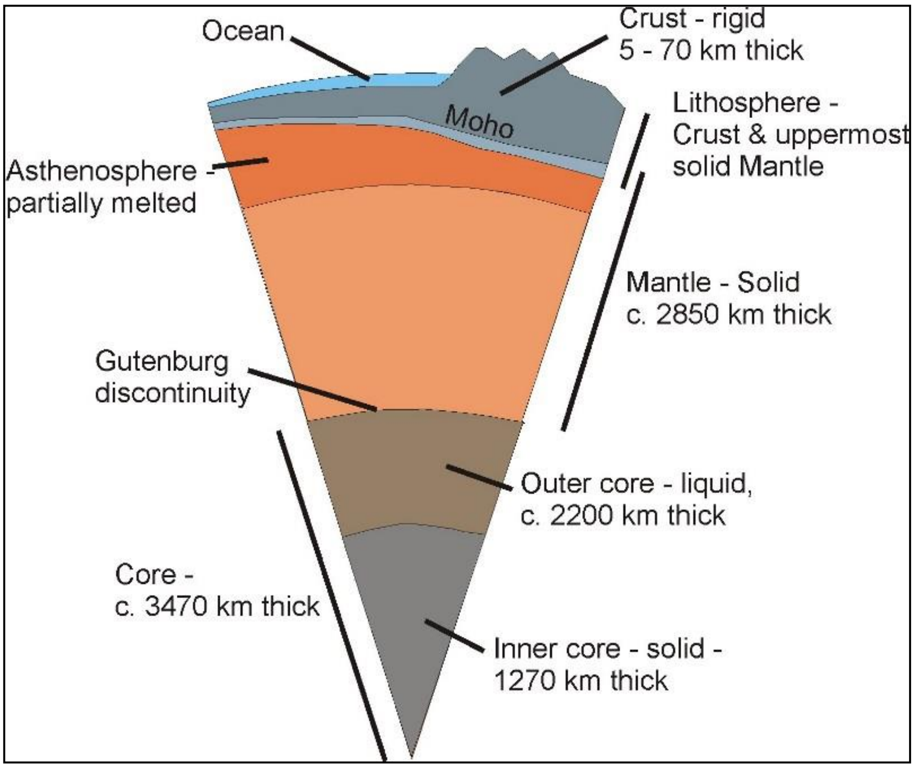


Figure 4. Structure of the earth

Chapter II:
EXTERNAL GEODYNAMIC

II. ETERNAL GEODYNAMICS

III. 1. Weathering

Weathering is the breakdown of **rocks** and minerals at or near the Earth's surface. It is caused by chemical and physical interactions with air, **water**, and living organisms.

➢ **Physical or mechanical weathering**

Physical weathering is the breakdown of rock into smaller pieces without altering the chemical composition of the rock.

- **Frost Action**: Repeated freezing and thawing of water in cracks cause rocks to break apart.
- **Root Expansion**: Plant roots grow into crevices, exerting pressure and contributing to rock fragmentation.
- **Abrasion**: Wind and water transport particles that erode rock surfaces upon impact.

➢ **Chemical weathering**

Chemical weathering is a geological phenomenon where rocks and minerals undergo alteration and breakdown due to chemical reactions with substances in their environment. Unlike mechanical weathering, which involves physical forces, chemical weathering operates at the molecular level, leading to changes in the composition of rocks.

- **Hydration:** Water molecules are absorbed by minerals, causing them to expand and, over time, disintegrate. Common minerals affected include those containing iron and magnesium.
- **Oxidation:** Minerals react with oxygen, altering their composition (e.g., rusting of iron).
- **Carbonation:** Carbon dioxide from the atmosphere or dissolved in water combines with minerals to form carbonic acid. This acid can dissolve minerals like limestone, leading to the creation of features such as caves and sinkholes.
- **Hydrolysis:** Water molecules react with minerals, breaking them down into new minerals and dissolved ions. Common minerals affected include feldspar, which transforms into clay minerals.

- **Solution:** Minerals are directly dissolved in water, resulting in the complete removal of certain components. This process is particularly effective for soluble minerals like halite (salt).

- **Biological weathering**

It is widely acknowledged that plants and organisms play a significant role in the substantial decomposition and disintegration of rocks within the Earth's crust.

- **Plants and Organisms*:*** Plant roots release acids and mechanically break down rocks, contributing to their decomposition.
- **Burrowing Organisms*:*** Animals that burrow into the ground accelerate mechanical weathering through their activities.

Man himself is known to be the greatest destroyer of rocks. He breaks them daily for a variety

- **Factors affecting weathering**

Following are the factors which affect weathering:

- **Nature of Rock:** Some rocks are easily affected by weathering, while some remain unaffected even under the same conditions. Chemical composition of rocks is a major factor which determines the stability of rock in a given environment. For example, A hard rock (such as granite) will erode more slowly than a soft rock (like clay).
- **Climate:** Same types of rocks exposed in three or more types of climates may show entirely different trends of weathering. Cold and humid conditions favour both mechanical and chemical weathering. Dry and cold climates, on the other hand will not favour any type of weathering due to absence of moisture. Chemical weathering will be predominant in hot and humid climate, while mechanical weathering is predominant in hot and arid areas (due to expansion and contraction of rocks).
- **Topography:** In areas with steeper slopes, there is a higher susceptibility to increased erosion, as water and other agents exert greater force when descending steep slopes.

- **Vegetation:** Vegetation acts as a natural barrier against erosion by slowing down the movement of wind and water across the landscape.

II. 1. 1. Action of water

Water erosion is a natural process by which water wears away the Earth's surface, leading to the removal and transport of soil and rock particles. This phenomenon is a significant geological force that shapes landscapes over time. Water erosion is primarily caused by rainfall, rivers, streams, and other forms of flowing water. There are different types of water erosion, each with its specific characteristics:

- **Splash Erosion**

This is the first stage in the erosion process that is caused by rain (Fig 5). Raindrops basically “bombard” the exposed and bare land, moving its particles and destroying the structure of the top layer. Eventually, it causes the formation of surface crusts, negatively affects soil infiltration ability, and eventually results in runoff formation.

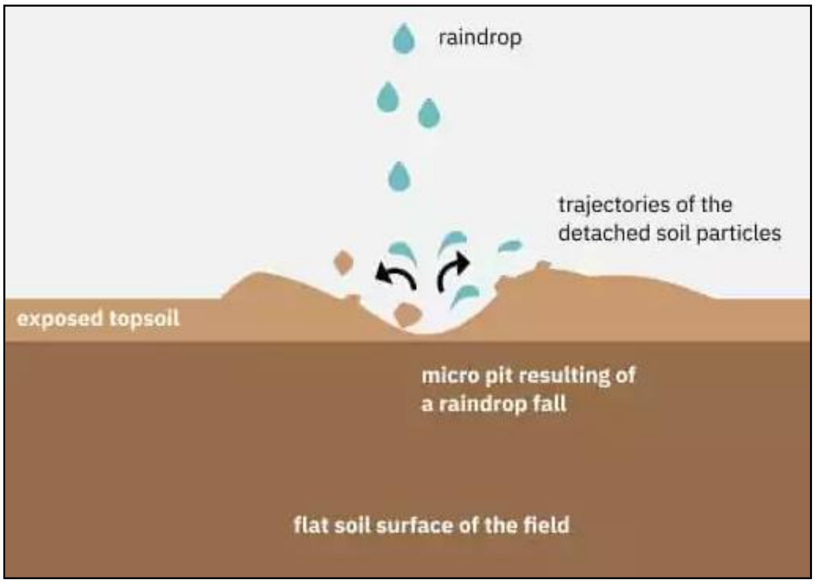


Figure 5. Splash erosion.

- **Sheet Erosio**

This type of soil degradation by water occurs when the rainfall intensity is greater than the soil infiltration (Fig 6) ability and results in the loss of the finest soil particles that contain nutrients and organic matter. It usually follows after crusting that is caused by the previous stage of soil damage by water. If not prevented timely, one of the most negative effects of sheet erosion will be the formation of rills.

Figure 6. Sheet Erosion.

- **Rill Erosion**

Rill erosion follows after, when the water concentrates deeper in the soil and starts forming faster-flowing channels (Fig 7). These channels can be up to 30cm deep and cause detachment and transportation of soil particles. Rill erosion can eventually evolve into gully erosion. That is when the rills become at least 0.3m deep.

Figure 7. Rill Erosion

➢ **Gully Erosion**

This is an advanced stage of land damage by water when the surface channels are eroded to the extent when even tillage operations wouldn't be of any help (Fig 8). Apart from causing huge soil losses and destroying farmland, it also results in reduction of water quality by increasing the sediment load in streams.

Figure 8. Gully Erosion.

a) Hydraulic transport

The products of the weathering of rocks of various sizes (from large rock blocks to fine particles) and dissolved ions rarely stay in place. This transport is a stage in the erosion process. Water is the primary agent for transporting particles along streams, rivers, and rivers, eventually reaching the sea. The transport of weathering products occurs from the upstream to the downstream of a watercourse. The transportation is influenced by the size of solid particles and the speed of the water current. The current speed is high in upstream mountain torrents, for instance, and then decreases along rivers and streams until their mouth downstream. When the current speed becomes insufficient relative to the size of the solid element, it settles.

The type of flow has a direct influence on transport and erosion. Below we explain different types of flow:

- **Sheet flow:** Only the finest elements will be transported by floating or suspension.

- **Runoff :** Runoff displaces small particles but leaves large blocks in place.
- **Turbulent river flow (channel erosion) :** Larger particles advance through saltation, while pebbles advance through rolling. For torrents, three zones can be defined (fig 9):
  - ✓ **The catchment basin**: It receives runoff water.
  - ✓ **The flow channel**: This is the actual torrent.
  - ✓ **The alluvial fan**: This is where transported elements are deposited.

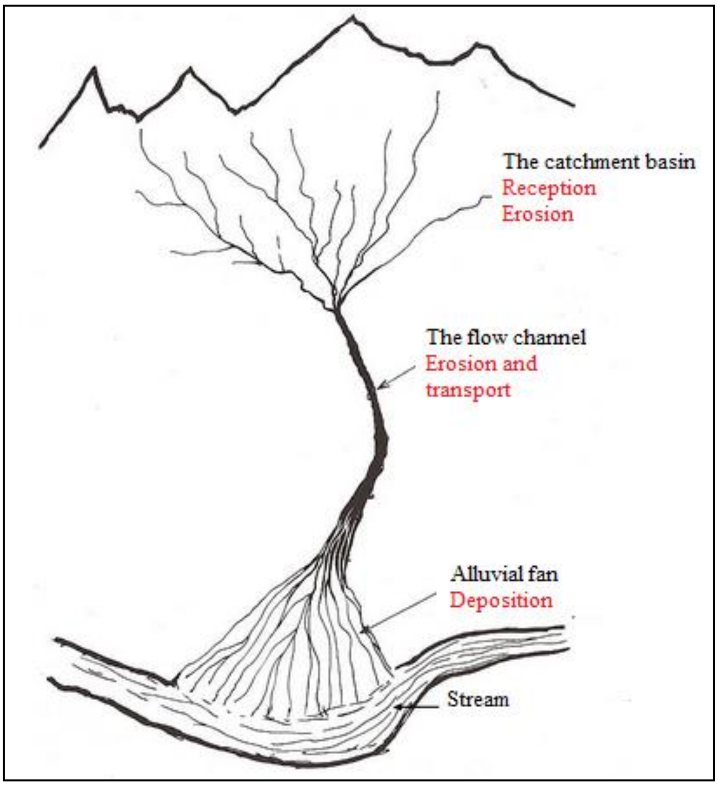


Figure 9. A torrent.

The Hjulström diagram illustrates the behavior of particles, for example, based on their size and the speed of the current (Fig 10).

For high water velocities, as in torrents, for example, particles are dislodged from the bed and transported. At lower velocities, suspended particles with a small diameter are transported. They settle when the current is insufficient to carry them or if their diameter is too large.

Let's take the example of 1 mm diameter particles.

- When the water velocity is high (> 60 cm/s), the current is powerful enough to alter the rock and transport the particles (point 1 on the graph).

- When the water velocity is approximately between 8 cm /s and 60 cm/s, the particles are transported (point 2 on the graph).
- When the water velocity is lower (< 8 cm/s), the particles no longer move and settle in place: they sediment (point 3 on the graph).

This sorting of particles along watercourses based on their size is called granulometric sorting.

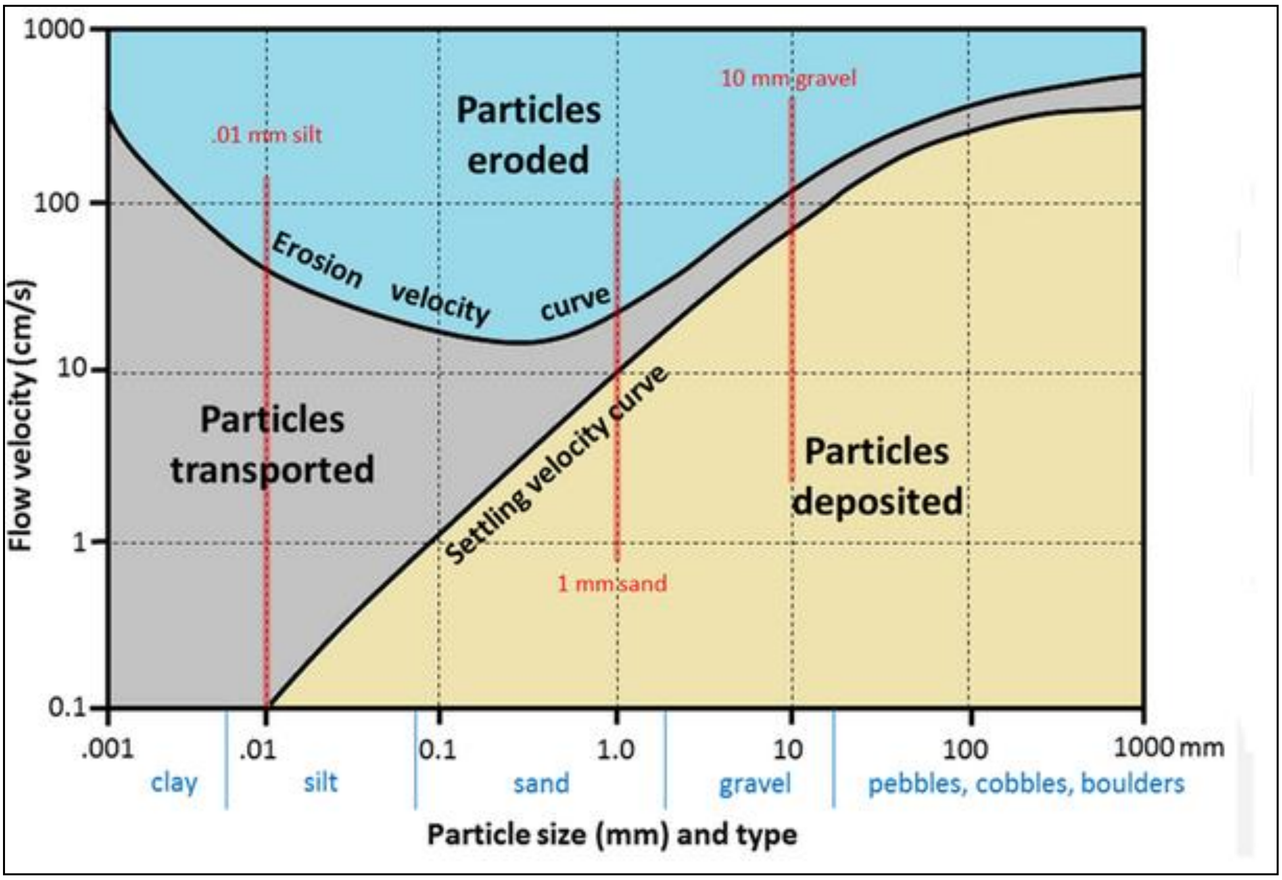


Figure 10. The Hjulström diagram.

- **Water deposition**

Water deposition refers to the process by which water, typically in the form of rivers, streams, or ocean currents, deposits sediments, minerals, or other materials it carries onto a surface or bed. This can occur when the velocity of the water decreases, causing it to lose its transporting capacity, leading to the settling of particles.

- **Stream Deposition:** As a stream gets closer to base level, its gradient lowers and it deposits more material than it erodes. On flatter ground, streams deposit material on the inside of meanders (Fig 11). Placer mineral deposits are often deposited there. A stream's floodplain is much broader and shallower than the stream's channel. When a stream flows onto its floodplain, its velocity slows and it deposits much of its load. These sediments are rich in nutrients and make excellent farmland.

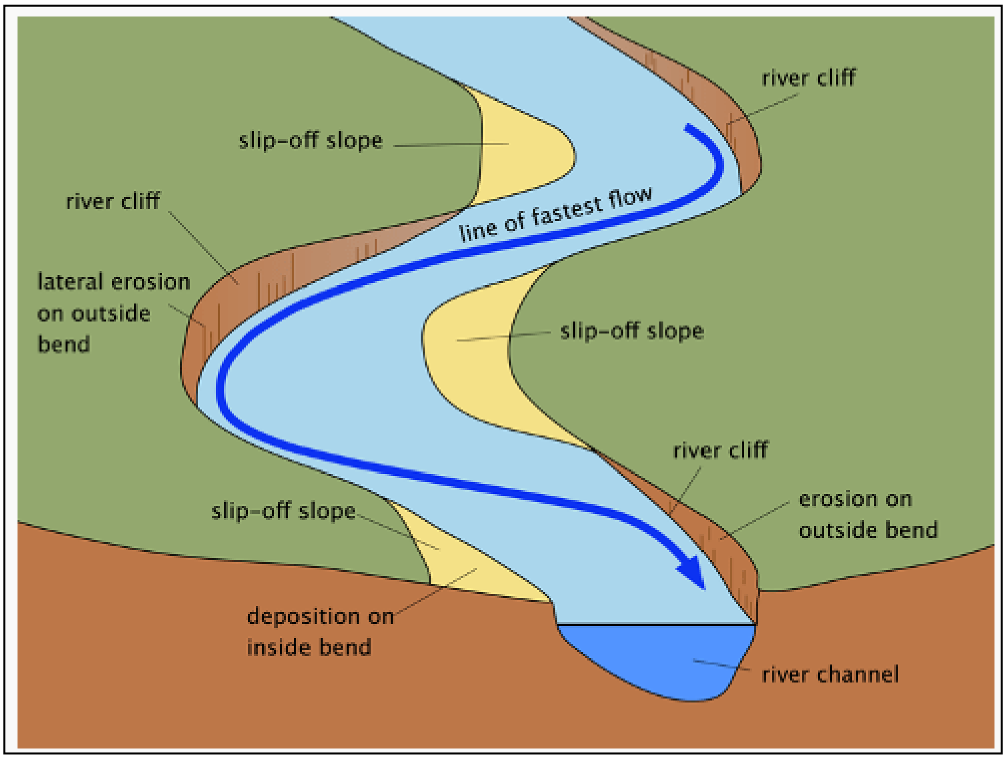


Figure 11. A meander.

- **Ground water deposition**

Working slowly over many years, ground water travels along small cracks. The water dissolves and carries away the solid rock gradually enlarging the cracks. Eventually a cave may form. Ground water carries the dissolved minerals in solution. The minerals may then be deposited, for example, as **stalagmites** or **stalactites.** If a stalactite and stalagmite join together, they form a **column**. One of the wonders of visiting a cave is to witness the beauty of these amazing and strangely captivating structures. Caves also produce a beautiful rock, formed from calcium carbonate, **travertine**. An area with cave systems beneath the land surface is called **Karst topography** (Fig 12).

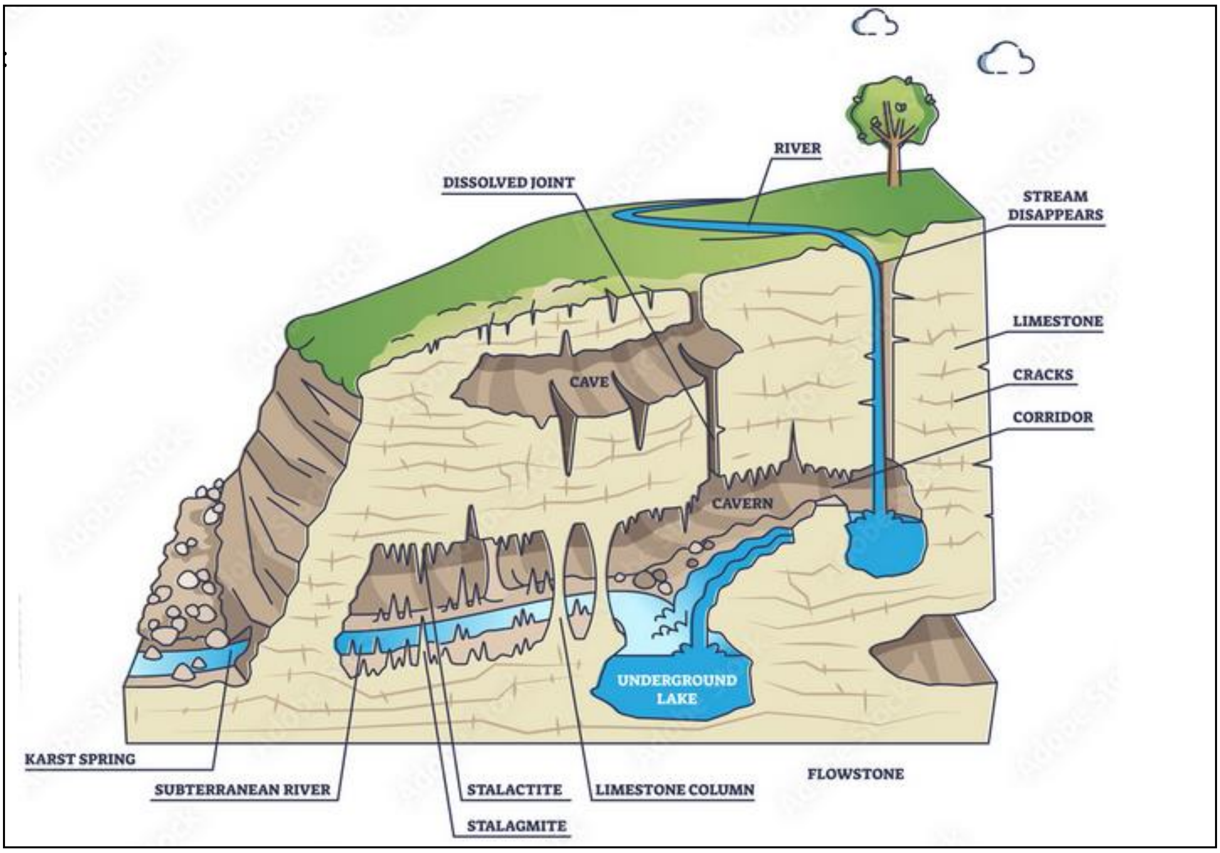


Figure 12. Karst topography.

II. 1. 2. Action of Wind

Wind Erosion is the natural process of transportation and deposition of soil by the wind. It is a common phenomenon occurring mostly in dry, sandy soils or anywhere the soil is loose, dry, and finely granulated. Wind erosion damages land and natural vegetation by removing soil from one place and depositing it in another. The main mechanism of wind erosion is wind propelling sand and dirt causing erosion.

Field conditions conducive to erosion include:

- Loose, dry, and finely granulated soil
- Smooth soil surface that has little or no vegetation present
- Sufficiently large area susceptible to erosion
- Sufficient wind velocity to move soil

- **Wind erosion processes**

Wind erosion occur by deflation (Fig 13) and the material left behind forms a desert pavement (Fig 14). It can also occur by abrasion.

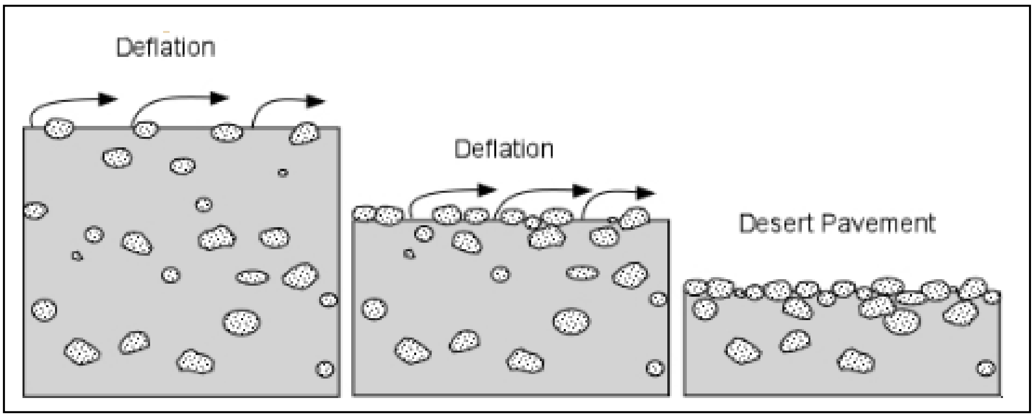


Figure 13. Wind deflation diagram.

Figure 14. Desert pavement..

The sand grains carried by the wind can alter the rocks upon which they are projected, creating numerous impacts. For instance, they are responsible for the formation of geometrically shaped stones, shaped by the wind, such as tetrahedral stones or "dreikanters" (Fig 15).

Figure 15. Dreikanters.

➢ Sediment transport by wind

The three processes of wind transport are: surface creep, saltation and suspension (fig 16). Characteristics of each are outlined below.

- **Surface creep**: in a wind erosion event, large particles ranging from 0.5 mm to 2 mm in diameter, are rolled across the soil surface. This causes them to collide with, and dislodge, other particles. Surface creep wind erosion results in these larger particles moving only a few metres.
- **Saltation**: occurs among middle-sized soil particles that range from 0.05 mm to 0.5 mm in diameter. Such particles are light enough to be lifted off the surface, but are too large to become suspended. These particles move through a series of low bounces over the surface, causing abrasion on the soil surface and attrition (the breaking of particles into smaller particles).
- **Suspension**: tiny particles less than 0.1 mm in diameter can be moved into the air by saltation, forming dust storms when taken further upwards by turbulence. These particles include very fine grains of sand, clay particles and organic matter. However, not all dust ejected from the surface is carried in the air indefinitely. Larger dust particles (0.05 to 0.1 mm) may be dropped within a couple of kilometres of the erosion site. Particles of the order of 0.01 mm may travel hundreds of kilometres and 0.001 mm sized particles may travel thousands of kilometres.

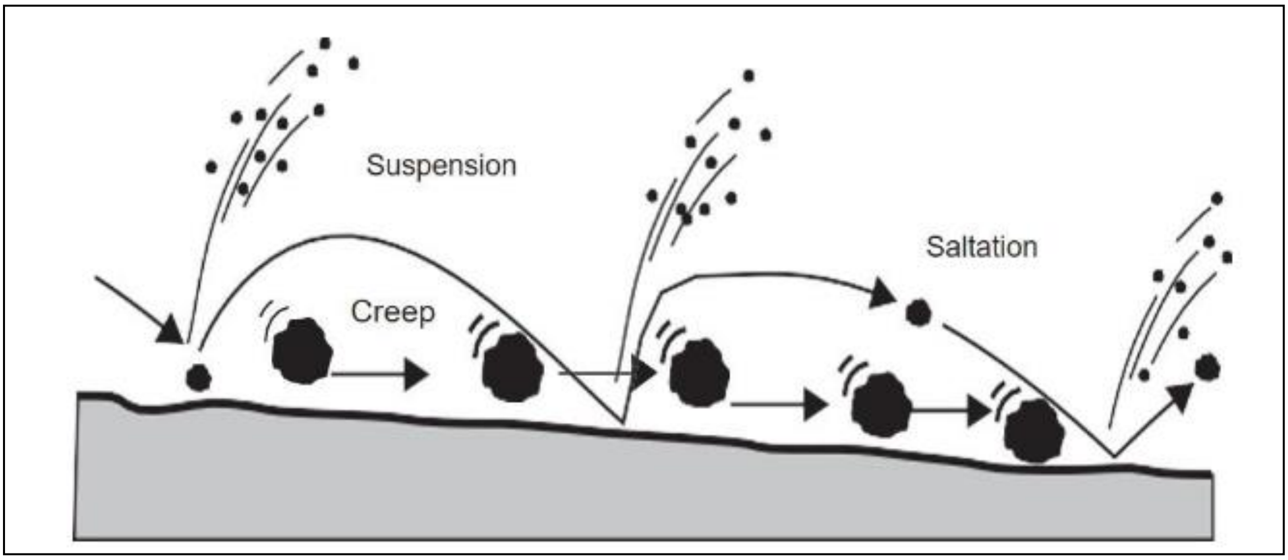


Figure 16. The three processes of wind transport.

- **Aeolian deposits**

Sediments once picked up by the wind from any source on the surface are carried towards to varying distance depending on the carrying of the wind. Landforms and deposits made by accumulation of wind-blown sediments are commonly referred as Aeolian deposits.

- **Dunes:** These are v- shaped deposits of sand-grade particles accumulated by winds. A sand dune is defined as a broadly conical heap of sand characterized with two slopes on either side of a medial ridge or crest.

- A typical dune is characterized with a gentle windward side and a steep leeward side meeting at the crest

- Sand dunes show great variation in their shape and size.

✓ **Barchan Dunes:** crescent-shaped dunes (Fig 17) with the points of the crescents pointing in the downwind direction, and a curved slip face on the downwind side of the dune. They form in areas where there is a hard ground surface, a moderate supply of sand, and a constant wind direction

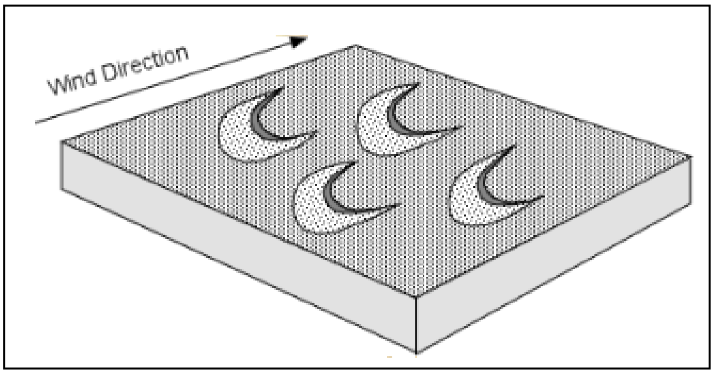
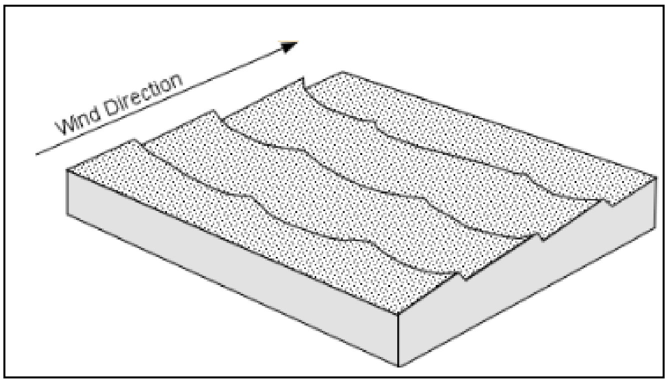


Figure 17. Barhan Dunes.

✓ **Transverse dunes:** large fields of dunes that resemble sand ripples on a large scale (fig 18). They consist of ridges of sand with a steep face in the downwind side, and form in areas where there is abundant supply of sand and a constant wind direction



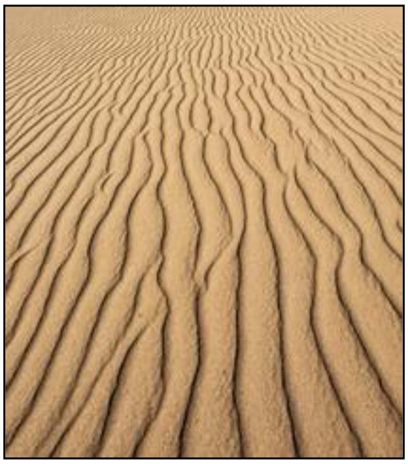


Figure 18. Transverse dunes.

- ✓ **Linear Dunes:** long straight dunes that form in areas with a limited sand supply and converging wind directions (Fig 19).

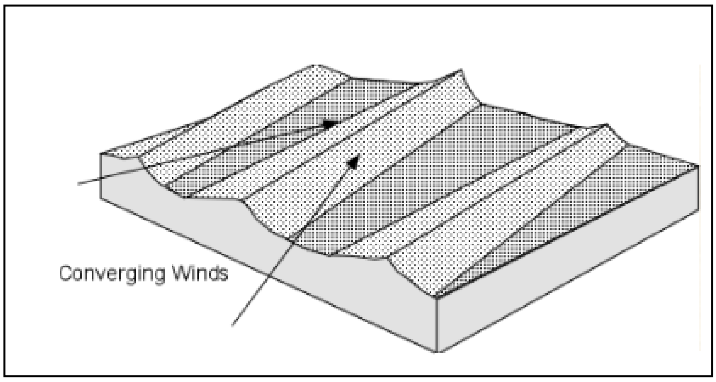


Figure 19. Linear dune.

- ✓ **Star Dunes:** are dunes with several arms and variable slip face directions (Fig 20) that form in areas where there is abundant sand and variable wind directions.

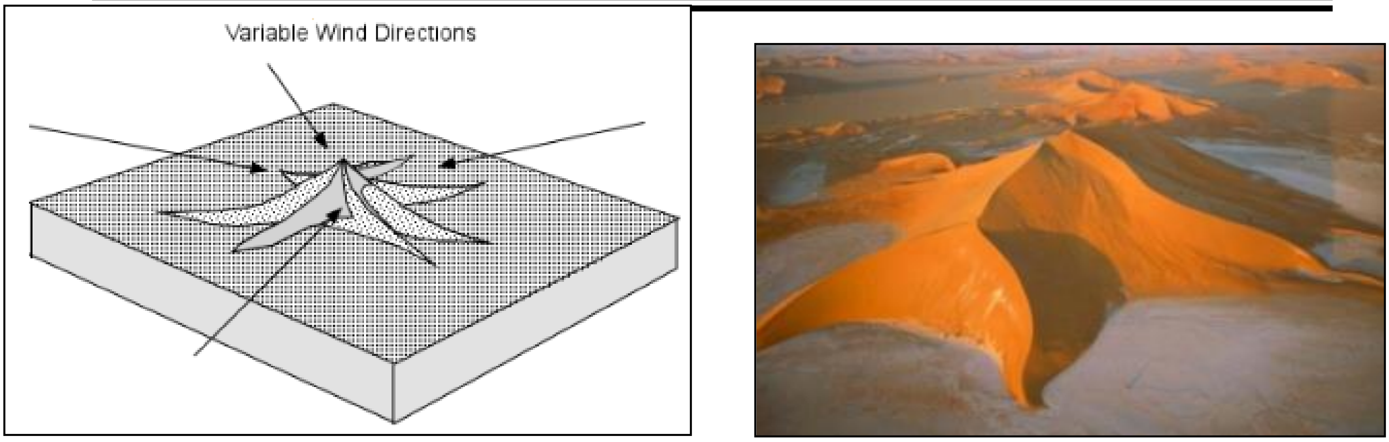


Figure 20. Star dunes.

✓ **Parabolic dunes:** A “U” or “V” shaped dune with long trailing arms common in coastal areas with abundant sand, and prevailing ocean winds. Migrate landward. Typically vegetated (Fig 21).

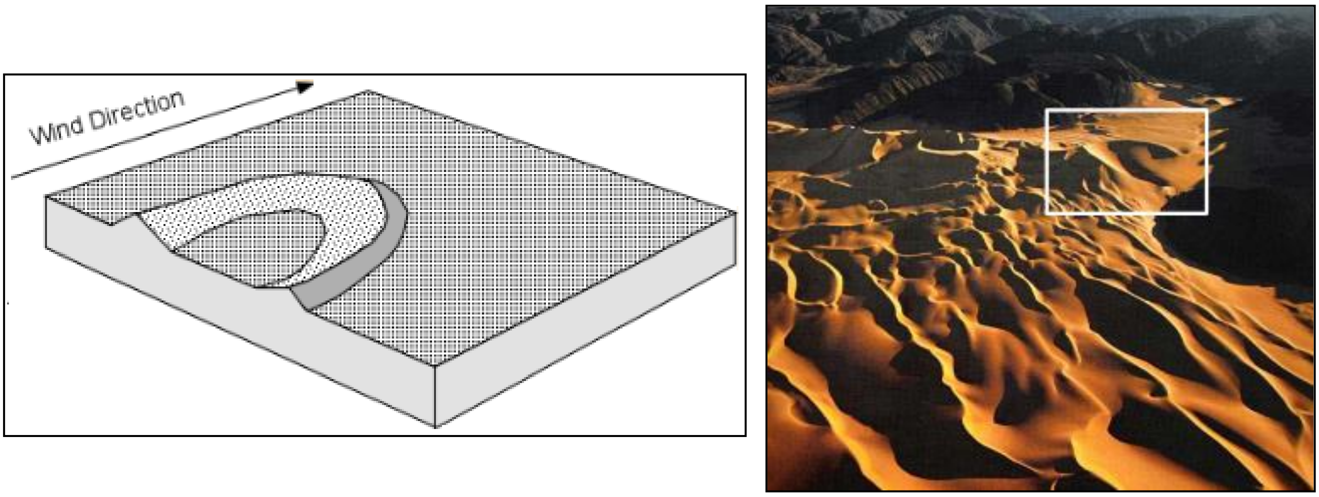


Figure 21. Parabolic dunes.

- **Loess**: loess is wind-laid dust consisting largely of silt. Important ressource in countries where is thick and widespread because it provides rich agricultural lands.

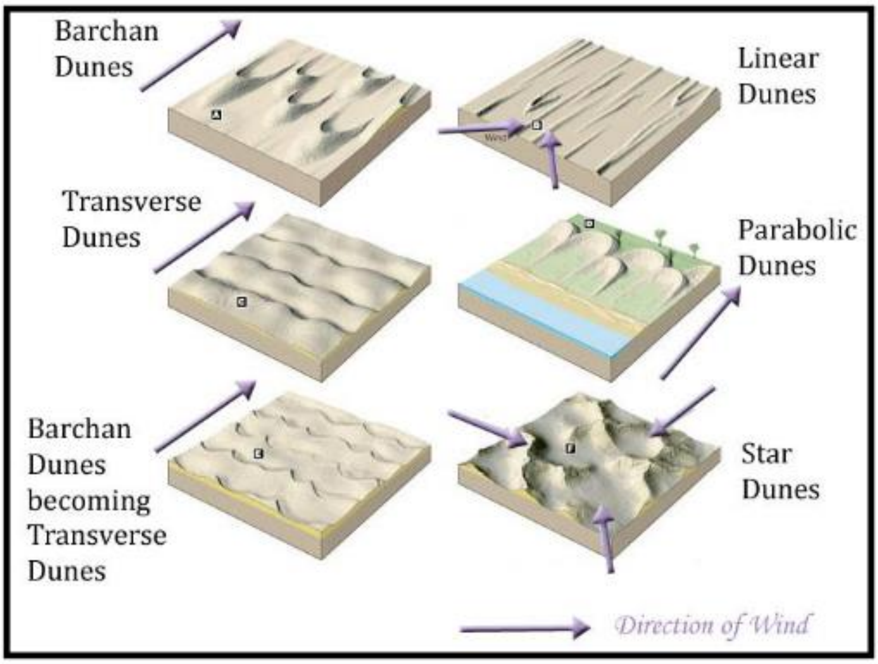


Figure 22. Aeolian deposits.

It should also be noted that the action of glaciers plays an important role in erosion. *Glaciers* are incredibly powerful agents of *erosion*. Glaciers *erode the underlying rock by abrasion and plucking.* When glaciers melt, they deposit the solid material they carry in unsorted piles known as glacial till. Glacial till takes different forms, with linear rock deposits referred to as moraines.

II. 2. Deposits

Deposition is the laying down of sediment carried by wind, water, or ice. Sediment can be transported as pebbles, sand & mud, or as salts dissolved in water. Salts may later be deposited by organic activity (e.g. as sea-shells) or by evaporation. Depositional environment is part of earth surface that has certain chemical, biology, and physics characteristics where sediments are laid on. There are 3 kinds of depositional environments, they are terrestrial, shallow marine, and marine environments (fig 23).

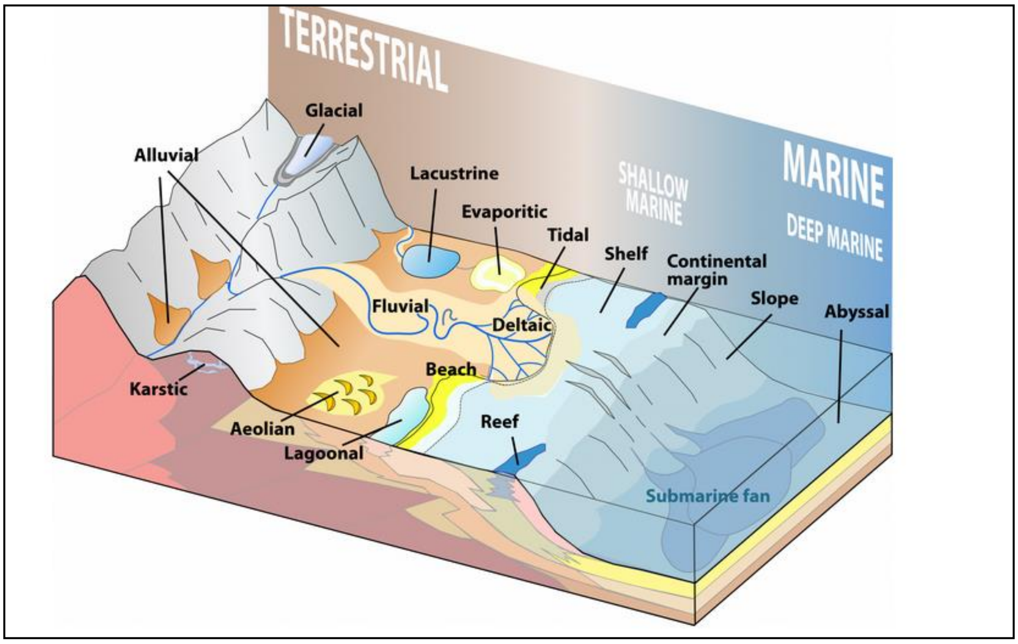


Figure 23. The different deposition environments.

II. 2. 1. Methods of studying

- **Classification according to sediment size**

Depending on the nature and hardness of the parent rock, the sedimentary rock resulting from its erosion is composed of debris of various sizes and shapes. Based on size, sediments can be classified into: **boulders, cobbles, gravel, sand, silt, and clays** (fig 24)

Clast Size	Size Class*	Sediment/Rock Name
>256 mm	boulders	sediment = gravel rock = conglomerate
64-256 mm	cobbles	
4-64 mm	pebbles	
2-4 mm	granules	
1-2 mm	very coarse sand	sediment = sand rock = sandstone
.5-1 mm	coarse sand	
.25-.5 mm	medium sand	
.125-.25 mm	fine sand	
.063-.125 mm	very fine sand	
.032-.063 mm	silt	sediment = mud rock = mudstone, siltstone and shale
<.032 mm	clay	

Figure 24. Classification of sediments by size of clasts (rock fragments).

➢ **Granulometric analysis**

Granulometry is the measurement of the size distribution in a collection of grains. It is also called particle size distribution test. It is often characterized by the percentage of particles with certain diameter ranges (in micron meters). This is a fundamental data that provides information about the origin and the mode of formation and transportation of the studied material. Granulometry has become a common technique in many laboratories. The employed techniques are varied.

- **Manual sieving granulometry:** This is an old, simple, and easy-to-implement technique. It is still used today, although other modern techniques are much more precise and faster. The principle involves using a series of nested sieves (referred to as a 'sieve column') (fig 25), with increasing mesh sizes (the sieves at the bottom are the finest). The sediment is placed at the top of the column, and then the sieves are shaken, either dry or in the presence of water. After a few minutes, the sediment separates into several fractions based on the size of its constituents: these are the granulometric fractions. These fractions are then weighed, and these measurements are used to construct granulometric curves that provide information about the sediment's depositional environment.

Figure 25. Procedure of grain size analysis of aggregates.

- **A modern technique: the laser granulometer:** This technique was developed in the 1970s. Like other granulometry techniques, it is based on Stokes' law, which relates the falling speed of a particle to its size. Indeed, the finer the size, the longer the falling speed (sedimentation). Compared to sieving granulometry, the laser granulometer technique has several advantages: it is very fast and highly precise. The analysis is completed in just a few minutes, and the granulometric curves are automatically provided by the machine. The drawback of this method is its high cost. Additionally, the devices are rare, and few university laboratories possess them.
- **Granulometric curves:** Granulometric curves are developed based on granulometry results, and they are created either manually or automatically (fig 26). Various types of curves are used, such as histograms or cumulative curves. The goal is to determine the different granulometric classes of the sediment and several parameters like the mean size (Md). These results will later be interpreted, providing valuable information about the sediment's depositional environment (Was it an aquatic, aeolian, or marine environment? What was the current velocity? etc.).

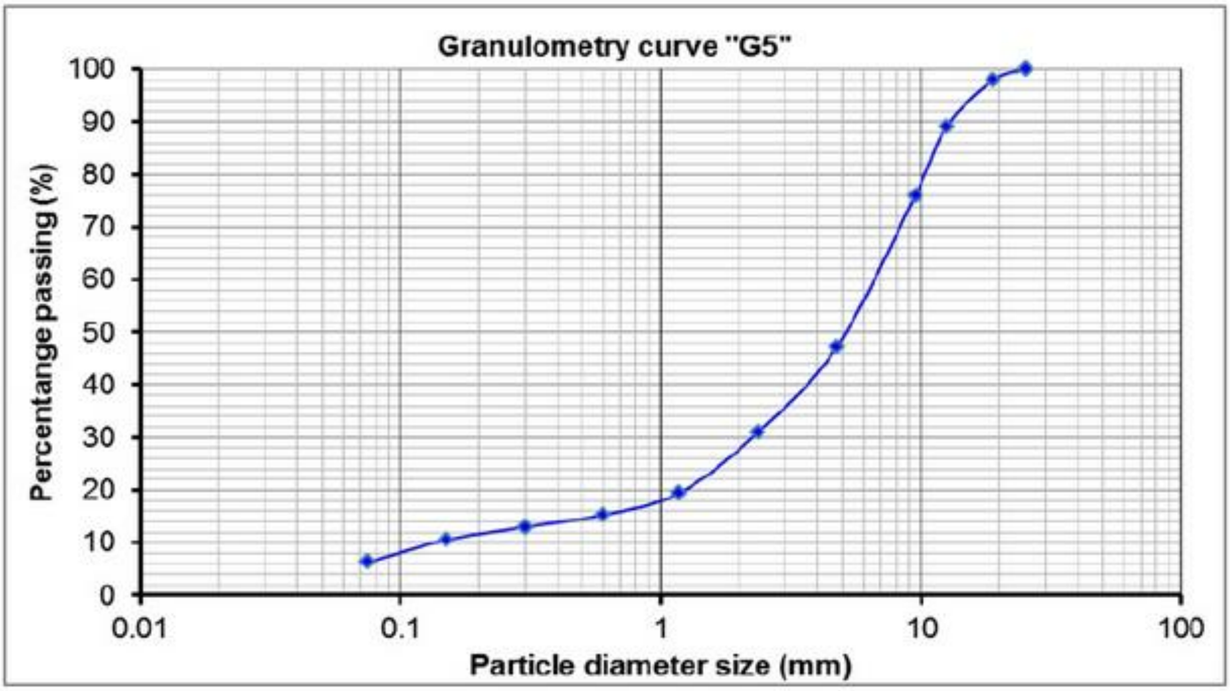


Figure 26. Granulometric curves.

- **Morphoscopy and exoscopy of quartz grains:** Morphoscopy is a technique established in 1942 by a French scientist, while exoscopy is more recent (in the 1970s). Both of these techniques are widely used nowadays. Morphoscopy, being older, is straightforward to implement (requiring only a simple binocular loupe), but it yields less precise results. On the other hand, exoscopy provides high precision but demands sophisticated and expensive equipment (such as a electron-scanning microscope) Through the examination of the shape and surface characteristics of quartz grains, these two techniques allow for the reconstruction of the origin and sedimentary history of the grains and, consequently, the sediment. Indeed, depending on the environment they are in, quartz grains acquire different shapes and surface appearances.

  - The acute angles of grains indicate that they are recent and have been transported over a short distance. The transporting agent is water.

  - The worn angles of grains suggest erosion during transportation over a relatively long distance. The transporting agent is water.

  - The rounded shape and the absence of angles of grains indicate transportation over a very long distance, signifying aged grains. The primary transporting agent is predominantly the wind.

II. 2. 2. Sedimentary rock

Sedimentary rocks are formed from pre-existing rocks (sedimentary rocks, ignous rocks and metamorphic rocks) or pieces of once-living organisms. They form from deposits that accumulate on the Earth's surface. Sedimentary rocks often have distinctive layering or bedding.

Sedimentary rocks are the product of weathering of preexisting rocks, transport of the weathering products, deposition of the material, followed by compaction, and cementation of the sediment to form a rock. The latter two steps are called lithification (fig 27) .

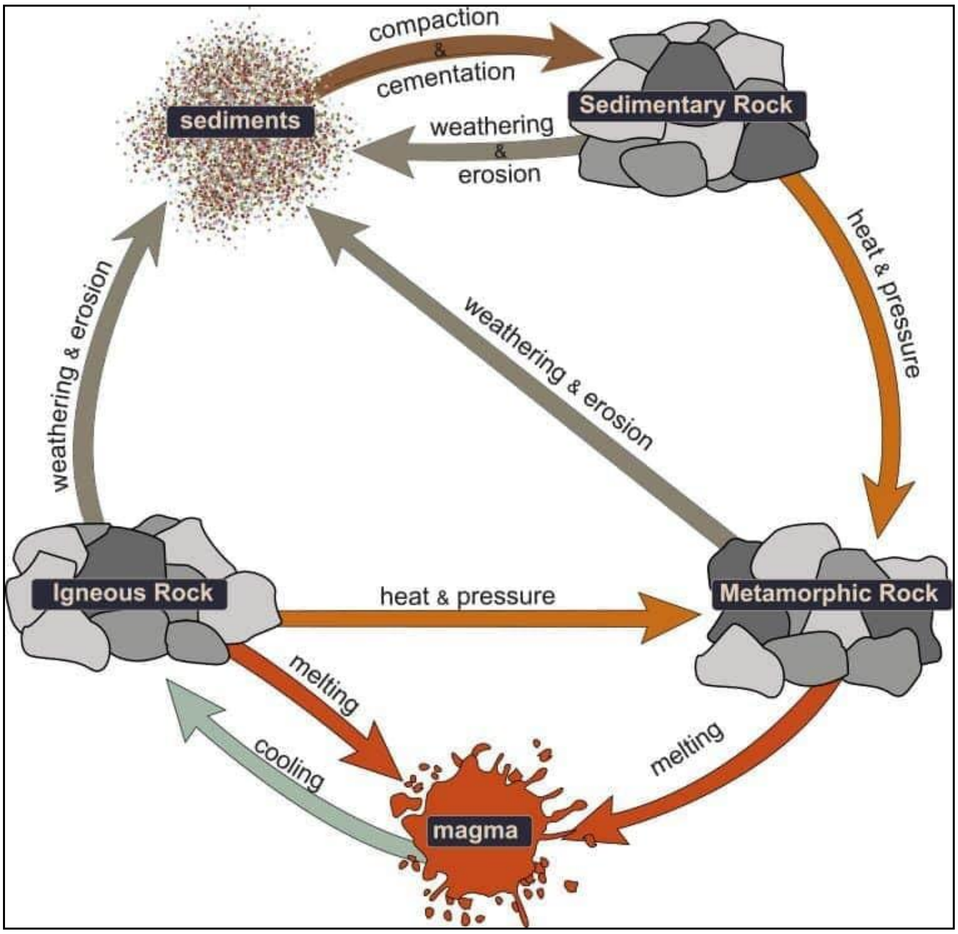


Figure 27. Sedimentary rock cycle.

Sedimentary rocks can be organized into three categories

- **Detrital rock**

Which comes from the erosion and accumulation of rock fragments, sediment, or other materials categorized in total as detritus, or debris. Detritus is classified by its grain size. Grains larger than 2 millimeters are called gravel. Grains between 1/16 mm and 2 mm are called sand. Grains smaller than 1/16 mm are in the silt and clay size ranges, often referred to as mud.

- **Chemical rock**

Chemical sedimentary rocks form by chemical precipitation that begins when water traveling through rock dissolves some of the minerals. These minerals are carried away from their source and eventually redeposited, or precipitated, when the water evaporates away.

Based on chemical composition, we distinguish:

- **Siliceous Rocks:** Formed by the precipitation of silica (SiO_2) in saturated waters (chemical origin) or by the extraction of silica from seawater by organisms to create their tests, which, through accumulation and lithification, result in hard rocks (biochemical origin). These rocks are mainly composed of opal (hydrated silica) and chert. Radiolarites, formed by the tests of radiolarians (marine zooplankton), and diatomites, formed by the accumulation of diatom tests (siliceous algae), are examples of siliceous rocks of biochemical origin. Flint is a primary example of siliceous rock of chemical origin.
- **Carbonate Rocks:** Composed mainly of calcite (CaCO3), aragonite (CaCO3), or dolomite CaMg(CO3)2. Calcareous rocks rich in calcite (or aragonite) are called limestones, while those rich in dolomite form dolomites. Limestones make up more than 10% of sedimentary rocks. Evaporitic rocks, such as gypsum (CaSO4 -2H2O), anhydrite (CaSO4), rock salt or halite (NaCl), and potash salt or sylvite (KCl), precipitate from highly concentrated solutions, often in shallow waters or salt lakes in desert environments.

➢ **Organic Sedimentary Rocks**

This category includes rocks whose formation is directly or indirectly linked to the intervention of living organisms in the sea. Carbonate rocks can also have a biological origin. Many animals and plants in seas and oceans use dissolved limestone to build their skeletons. When these organisms die, the limestone skeletons they produce accumulate in sedimentary deposits. Some rocks are formed not only by the accumulation of shells and skeletons but also by biological processes; these are called shell limestones. An example of such a rock is chalk, a widely distributed limestone. It is almost entirely composed of skeletons of microscopic algae called coccoliths, which can form extensive layers with a planetary extension. These deposits form in warm seas, rich in phytoplankton (vegetal plankton), and are shallow (a few tens of meters deep). Types of organique sedimentary rock include coal (accumulated plant material that is carbon-rich), or limestone and coquina (rocks made of marine organisms).

II. 2. 3. Notion of stratigraphy

Stratigraphy is a branch of Geology and the Earth Sciences that deals with the arrangement and succession of strata, or layers, as well as the origin, composition and distribution of these geological strata. The study of archaeological and natural stratification therefore involves the assessment of TIME and SPACE. Specifically, the vertical arrangement of layers represents the time dimension (oldest at the bottom, youngest at the top), while the horizontal (lateral) distribution of layers represent the space dimension (i.e. spatial variations in the stratigraphy).

- **Geological time scale**

In stratigraphy, the vertical sequence reflects the passage of time (fig 28) . On the basis of fossils, the geological time has been classified into units, which are then grouped together into larger units. The process is similar to our daily classification of time into seconds, minutes, hours and days.

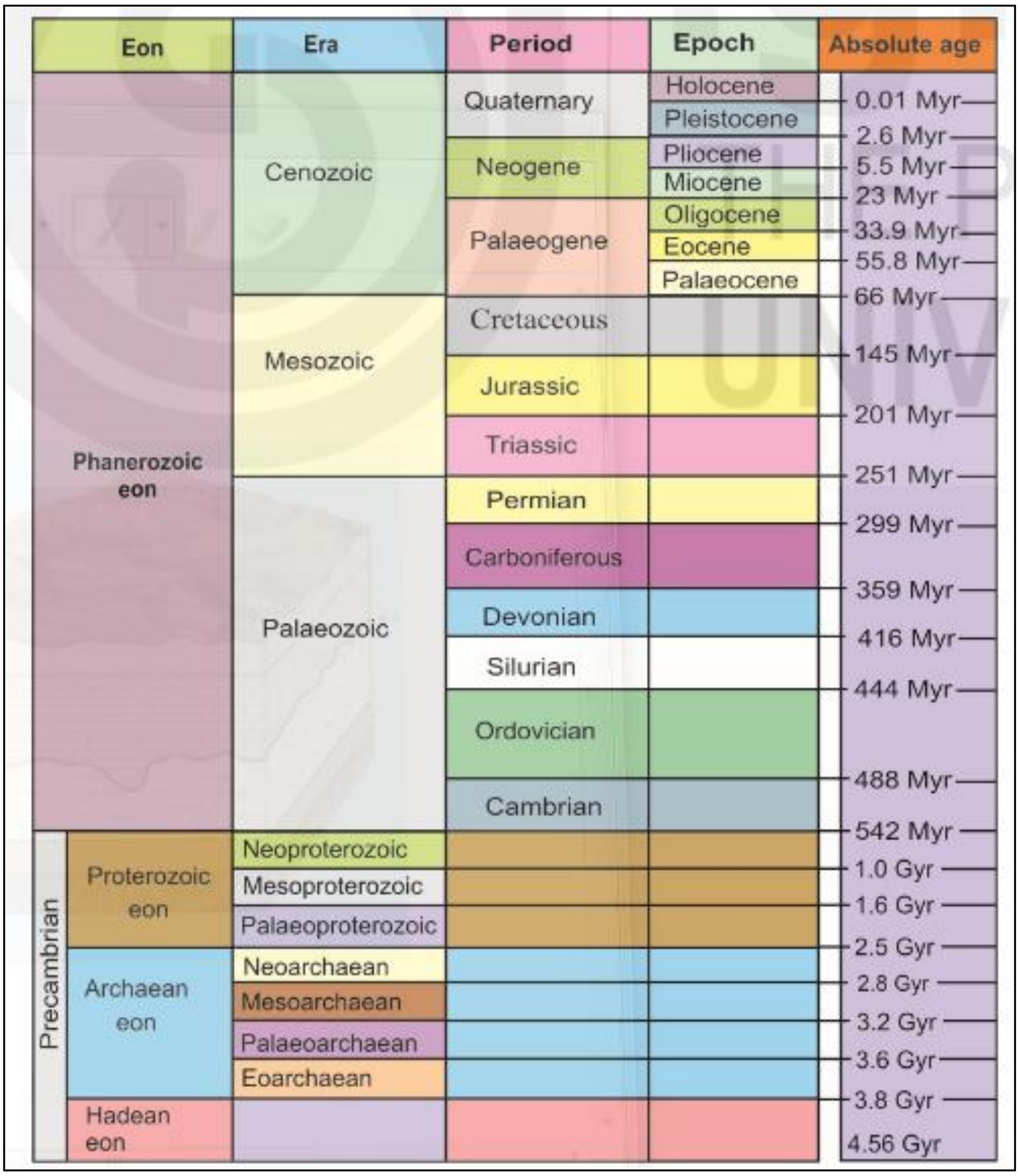


Figure 28. Geological time scale.

- **Principles of stratigraphy**

Stratigraphy is based on a set of principles that govern the processes of sedimentation. There are six basic principles or laws of stratigraphy:

- **Principle of superposition:** This law states that in sequence of sedimentary layers, each layer must be younger than the one below and older than ones above it (fig 29). Because of earth gavity, deposition of sediment will occur depositing older layes first followed by successively younger layers. Thus, in sequence of layers that have not been overturned by a later deformational event.

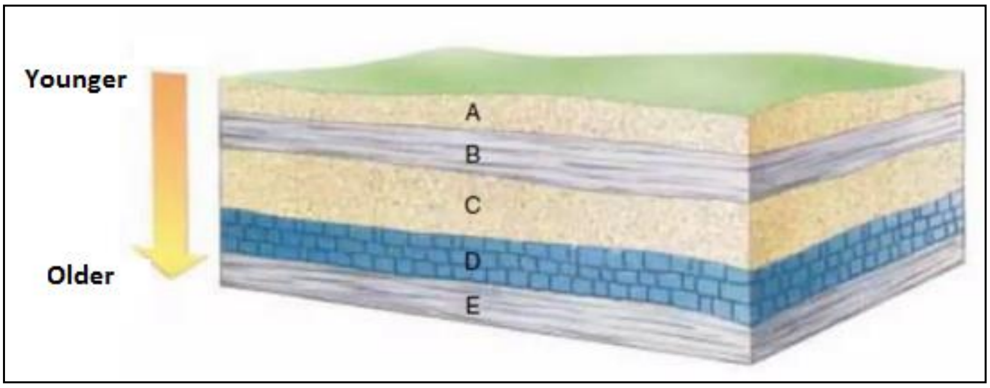


Figure 29. Principle of superposition.

- **Principle of horizontality:** It is based on the fact sediment usually accumulates in horizontal layers (fig 30). All sedimentary rocks are originally deposited horizontally if sedimentary rocks lie at an angle, we can infer that tectonic forces tilted them after they formed.

Figure 30. Principle of horizontality.

- **Principle of lateral continuity**: It states that if layers are deposited horizontally over the sea floor (fig 31), then they would be expected to be laterally continuous over some distance. Sedimentary rocks are laterally continuous over large areas.

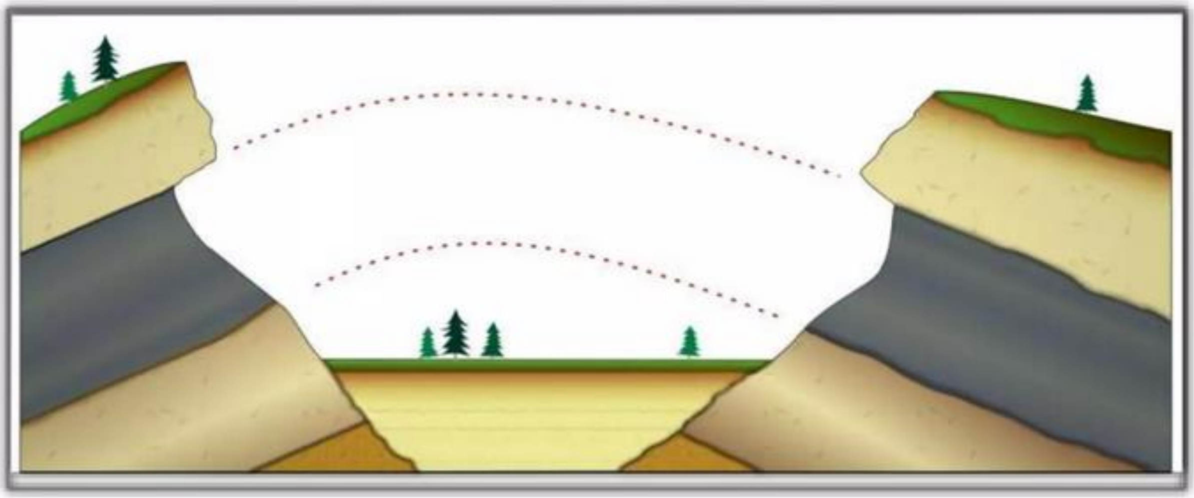


Figure 31. Principle of lateral continuity.

➢ **Principle of Cross-Cutting Relationships:** The basic principle of cross-cutting relationship is that when something cross cuts a sedimentary sequence, it is always younger than that sequence (fig 32). In other words, all cross-cutting features are produced after the sediment is deposited. The cross-cutting feature may be a structural feature like a fault or an igneous intrusion like a dyke

Figure 32. Principle of Cross-Cutting Relationships.

- **Principle of inclusion**: The principle of inclusion states that fragments, or inclusions, of one rock unit that are enclosed within another rock unit must be older than the rock unit containing them (fig 33). This principle relies on the idea that the rock containing the inclusions must have formed after the inclusions themselves. The inclusions represent older material that was incorporated into a newer rock during its formation.

Figure 33. Principle of inclusion.

➢ **Principle of faunal succession**

Law of faunal succession states that fossils represent living creatures that have evolved through time, so when we found a fossil of the same type in two different sections that are not laterally continuous, so the rock are about the same age (fig 34).

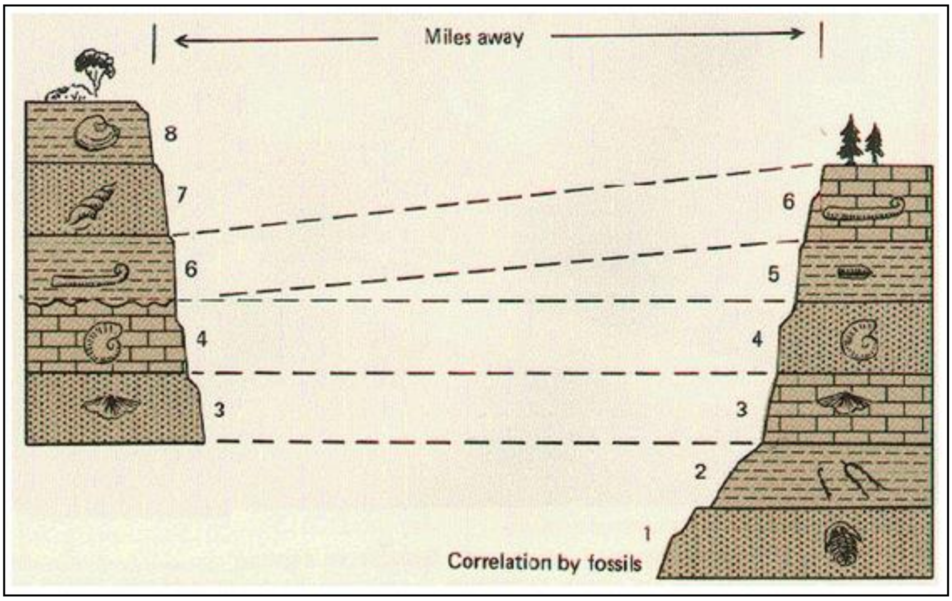


Figure 34. Principle of faunal succession.

- **Unconformities**

An unconformity represents an interruption in deposition, usually of long duration. In other words, an unconformity is indicative of either a break in sedimentation or a period of erosion separating the two strata. These periods can be long or short. The unconformities are of various types and generally can be easily identified.

Following are some of the common types of unconformities:

- **Angular Unconformity**

Angular unconformity is one of the most easily identifiable unconformities. In an angular unconformity, the two sets of strata are at an angle and not parallel to each other. The older rock layers are tilted or folded, and the overlying younger rock layers are deposited horizontally on top of them (fig 35). The angular relationship between the older and younger rocks is a key feature, signifying a period of deformation or tectonic activity between the deposition of the two sets of rocks.

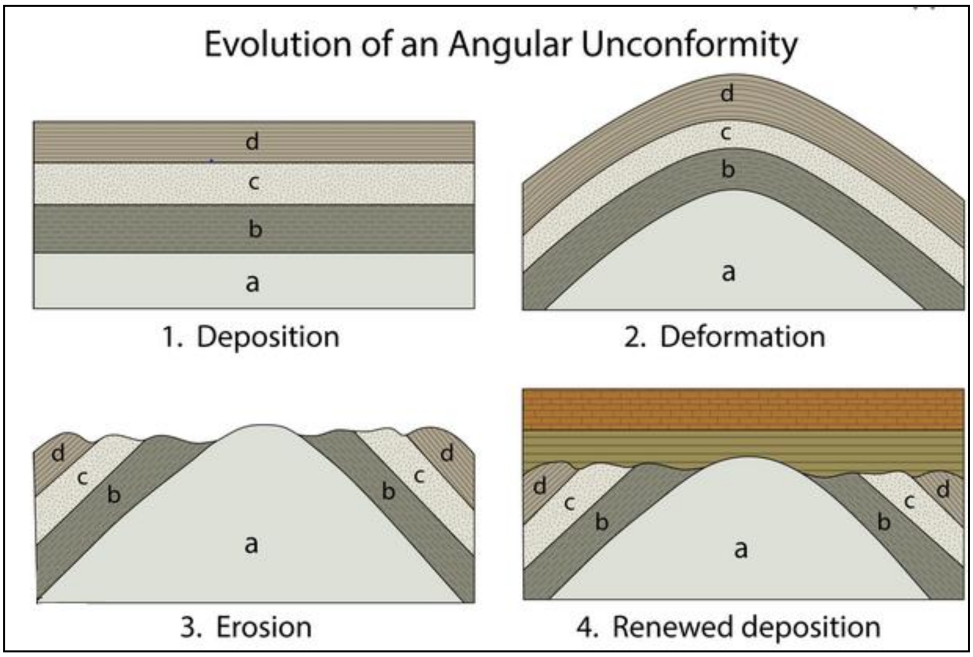


Figure 35. Angular Unconformity.

- **Nonconformity**

Nonconformity is a type of unconformity in geology, representing a surface where rocks of different ages come into contact, and the younger rocks rest on the eroded surface of older rocks that are not of a sedimentary origin. This contact often involves intrusive igneous or metamorphic rocks beneath sedimentary rocks (fig 36). Nonconformities indicate a significant gap in the geological record where erosion and uplift have removed existing rocks, and subsequent deposition has occurred.

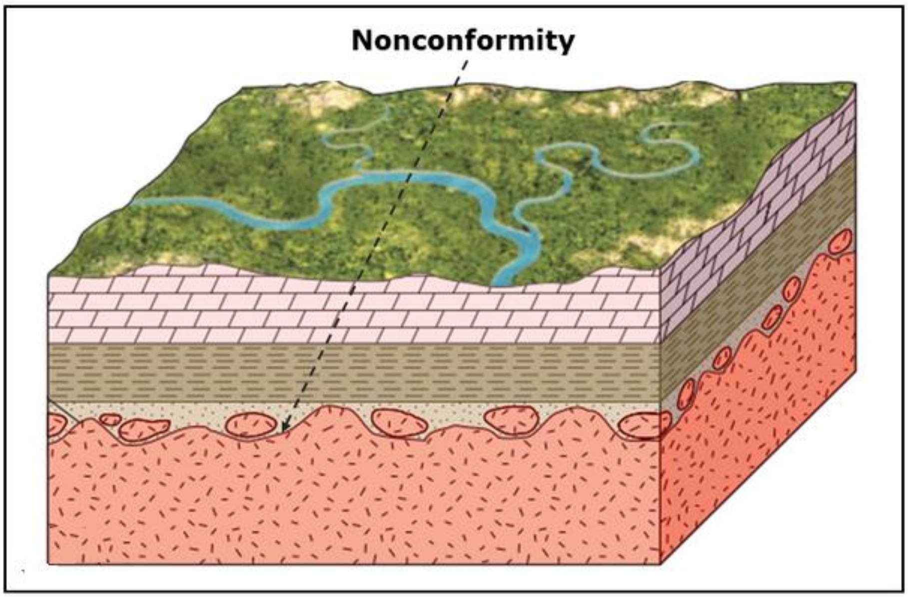


Figure 36. Nonconformity.

- **Disconformity**

Disconformity is marked by an erosional surface but there is no angular difference between the underlying and overlying beds (fig 37). The erosion may be indicated by the presence of a pebble or boulder bed or the development of a layer of old soil called palaeosol.

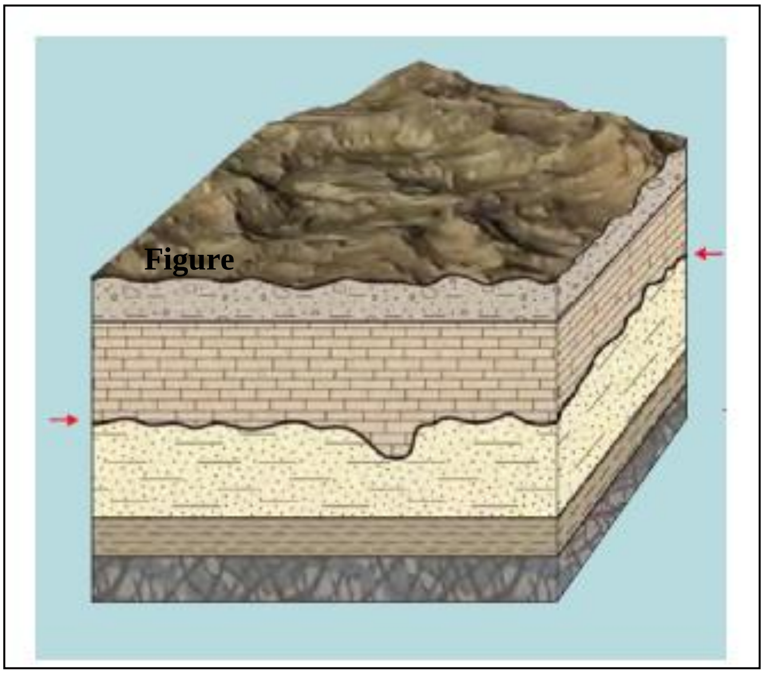


Figure 37. Disconformity

- **Paraconformity**

In paraconformity, the bedding planes in lower as well as the upper set of rocks are parallel and there is no apparent break or evidence of erosion that could indicate a period of non-deposition (fig 38). This type of unconformity is very difficult to recognise since it marks a period of non-deposition that has not left any evidences. The only way of recognising such an unconformity is by the fossil content in the two strata that may indicate the time span of non-deposition.

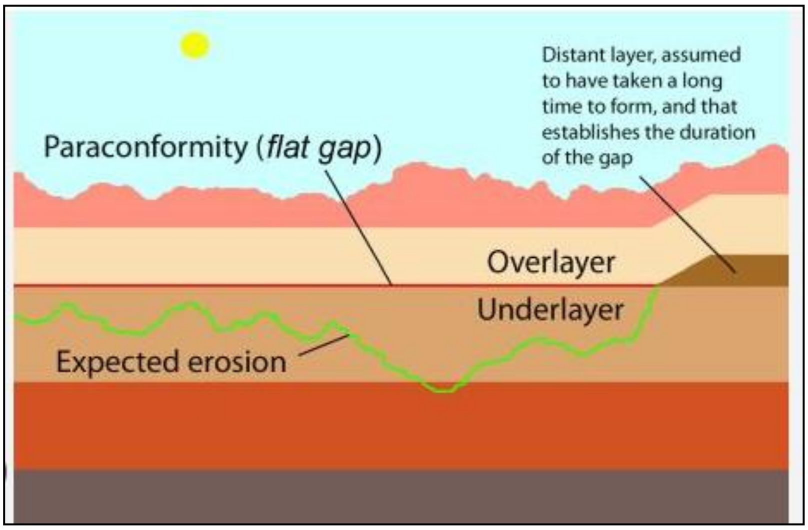


Figure 38. Paraconformity.

- **Methods of dating rocks**

There are several methods used by geologists to determine the age of rocks, each based on different principles and suitable for different time ranges. Here are some common methods of dating rocks:

- **Relative dating:** Using fundamental principles of geology to determine the relative ages of rock. Determining which rocks are older and which are younger with respect to each other.
- **Absolute dating:** In this method, it is possible to obtain a precise dating with a numerical age. In this context, physical methods such as radiocronology are mainly used. Radiocronology is a dating method for minerals or rocks based on the study of their radioactive elements and their decay products. Several radioactive elements can be used depending on the type of material to be dated

(such as the Uranium 238/Lead 206 pair, Potassium 40/Argon 40, Carbon 14/Nitrogen 14).

II. 2. 4. Notion of paleontology

Paleontology is the science that studies the remains of extinct organisms. At the intersection of two important disciplines, geology and biology, this science aims to understand the lifestyle and evolution of organisms that lived in ancient ecosystems and environments, with rocks and sediments serving as their last witnesses. It involves the study of ancient beings or their traces preserved in sedimentary rocks. The preservation state of these fossils depends on physico-chemical parameters during sedimentation (during diagenesis) and modifications caused after fossilization by metamorphism or deformations.

- **Definition of a Fossil**

A fossil can consist of any remains (skeletons, shells (in bivalve lamellibranches), tests, carapaces, imprints, or traces (fig 40) of an organism that lived in the past.

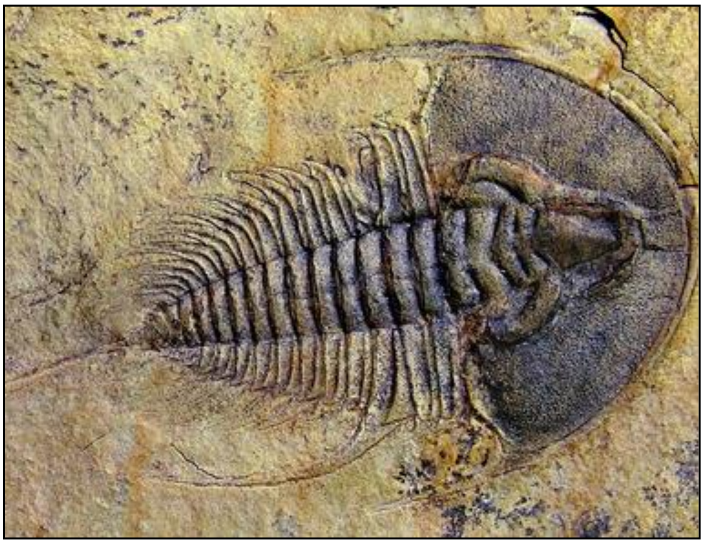


Figure 40. A fossil

- **Fossilization**

It depends on the starting materials, physico-chemical conditions of the fossilization environment, requiring:

- Fine sediments
- Rapid burial of fossils in sediments (flood, storm, volcanic eruption...)

- Favorable environment for the preservation of organisms, such as isolation of the environment from oxygen (reducing environment)
- Organism constitution: hard parts are better preserved than soft parts.
- Small size and large quantity: small and numerous organisms have proportionally much more chance of fossilization than larger, much rarer organisms.

➢ **Use of Fossils**

In paleontology, useful fossils are distinguished into two main categories.

➢ **Facies fossils**

Facies fossils are characteristic of a particular environment and thus help reconstruct ancient ecological environments.

➢ **Stratigraphic fossils**

Stratigraphic fossils are characteristic of a specific time period and help determine the age of layers. A good stratigraphic fossil must be characterized by a short life and a wide geographical distribution.

➢ **Modes of fossilization**

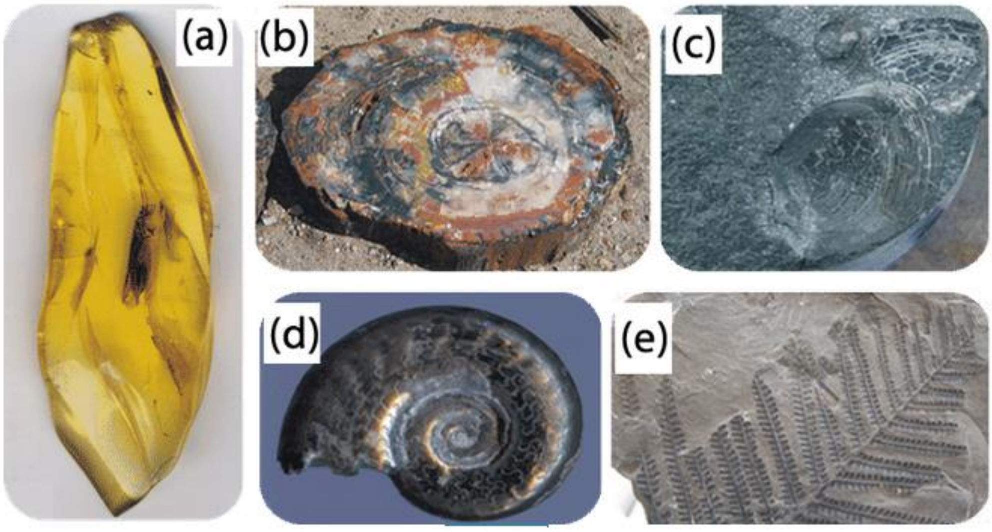
Fossilization is the process by which organic remains or traces of organisms become preserved in the Earth's crust as fossils. There are various modes of fossilization (fig 41), each associated with specific conditions and circumstances. Here are some common modes of fossilization:

- **Petrification or Mineralization** : This occurs when organic material is replaced by minerals, typically silica, calcite, or pyrite, turning the remains into a stony substance. The original organic structures may be retained, creating a fossilized replica.
- **Carbonization** : Carbonization involves the preservation of the organic residue in the form of a thin carbon film. This process is common in the fossilization of leaves, feathers, and other delicate organic structures.
- **Impression or Compression:** This involves the preservation of an organism's shape or structure through the creation of an impression or compression in the

surrounding sediment. This can occur when an organism's body or trace is pressed into soft sediment, leaving a negative impression.

- **Amber Fossilization** : Amber is fossilized tree resin that can preserve small organisms such as insects, spiders, or plant material in remarkable detail. The resin hardens over time, creating a transparent fossil.
- **Freezing (Ice Fossilization):** In rare cases, organisms are preserved by freezing, especially in polar regions or high-altitude environments. This mode of fossilization is more common for small organisms or parts of larger ones.
- **Desiccation:** Desiccation involves the removal of water from an organism, often through drying or dehydration. This can occur in arid environments or in sediments with low water content.
- **Mummification:** Similar to desiccation, mummification involves the preservation of soft tissues through the prevention of decay. It often occurs in dry, low-humidity environments.
- **Trace Fossilization:** Trace fossils are indirect evidence of past life activities, such as footprints, burrows, or coprolites (fossilized feces). These traces can be preserved in sediments and provide insights into the behavior of ancient organisms.

The specific mode of fossilization depends on factors such as the type of organism, the environment in which it lived, and the geological processes that occurred after its death. Fossils provide valuable information about Earth's history and the evolution of life over geological time.



Five types of fossils: (a) insect preserved in amber, (b) petrified wood (permineralization), (c) cast and mold of a clam shell, (d) pyritized ammonite, and (e) compression fossil of a fern.

Figure 41. Mode of fossilization.

- **Brief History of Life on Earth**

The history of Earth spans over approximately **4.6 billion** years. This vast timeline is divided into several geologic eons, eras, periods, and epochs. Here is a brief overview of the major events and stages in the history of Earth (fig 42):

- **Origin of Life** : Life starting with simple, single-celled organisms.
- **Prokaryotic Life:** The earliest life forms were prokaryotes like bacteria and archaea, thriving in ancient oceans.
- **Oxygen Revolution:** Cyanobacteria, around 2.5 billion years ago, triggered the "Great Oxygenation Event," leading to atmospheric oxygen.
- **Eukaryotic Cells:** Eukaryotic cells evolved around 2 billion years ago, paving the way for more complex life.
- **Multicellular Life:** Multicellular organisms emerged around 1 billion years ago, introducing diverse body plans.
- **Cambrian Explosion:** Roughly 541 million years ago, the Cambrian Explosion saw a rapid diversification of complex life forms, including various animal phyla.
- **Land Colonization:** Plants and arthropods transitioned to land around 500 million years ago.

- **Age of Fishes:** Fishes dominated during the Devonian period, 416 to 359 million years ago.
- **Age of Reptiles:** Reptiles, including dinosaurs, thrived during the Mesozoic Era (252 to 66 million years ago).
- **Mass Extinctions:** Events like the Permian-Triassic and Cretaceous-Paleogene extinctions shaped evolutionary trajectories.
- **Age of Mammals:** Mammals rose to prominence after the dinosaur extinction around 66 million years ago.
- **Evolution of Primates:** Primates, including early humans, evolved during the Cenozoic Era, leading to Homo sapiens.
- **Holocene Epoch:** The Holocene Epoch, starting 11,700 years ago, signifies the current geological phase.

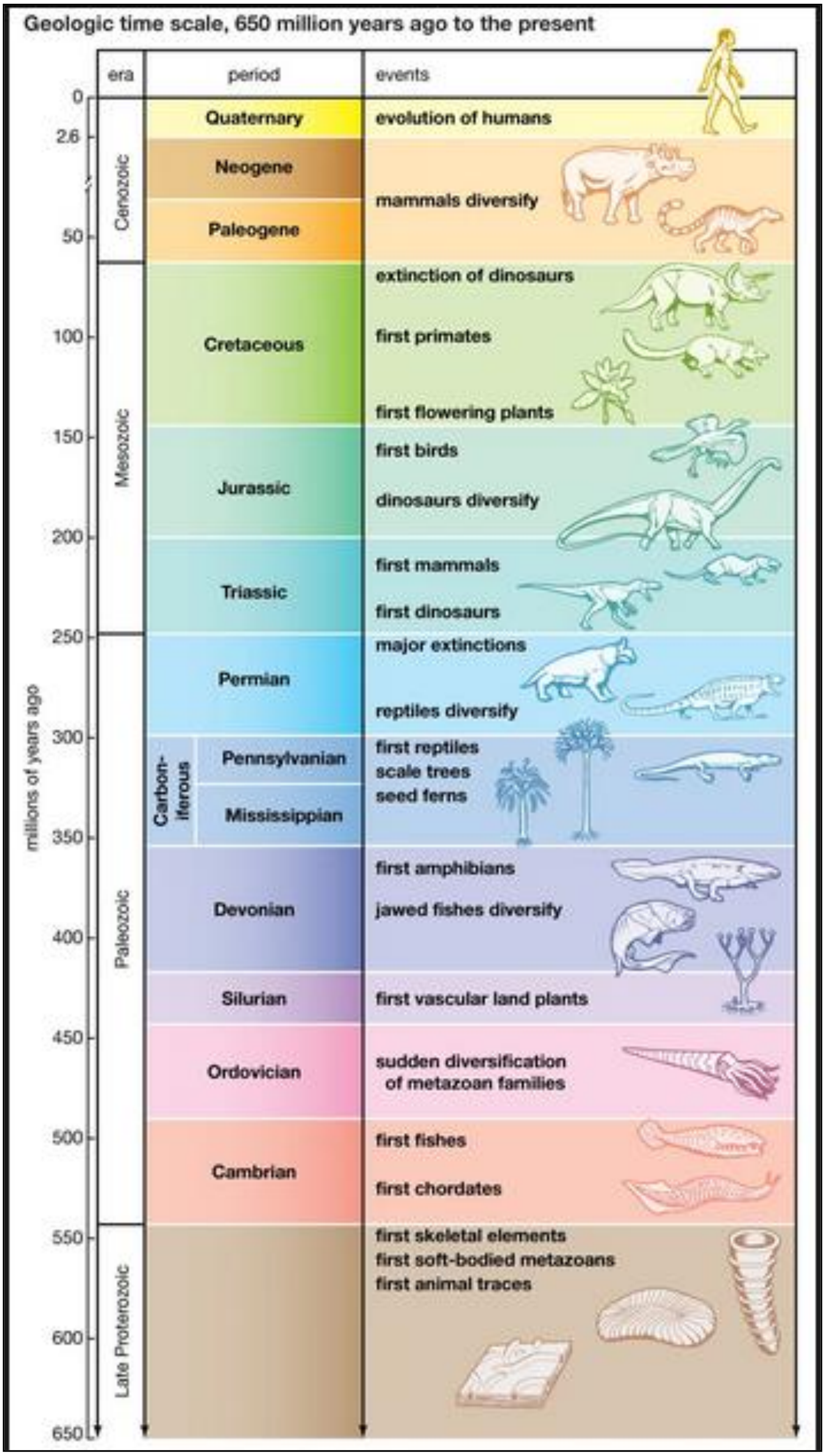


Figure42. Major events and stages in the history of Earth.

Chapter III:
Internal Geodynamics

III. INTERNAL GEODYNAMICS

III. 1. Seismology

Seismology is the scientific study of earthquakes and the behavior of Earth's interior through the analysis of seismic waves

III. 1. 1. Study of earthquake

An earthquake is what happens when two blocks of the earth suddenly slip past one another. The surface where they slip is called the fault or fault plane. The location below the earth's surface where the earthquake starts is called the hypocenter, and the location directly above it on the surface of the earth is called the epicenter (fig 43). While the edges of faults are stuck together, and the rest of the block is moving, the energy that would normally cause the blocks to slide past one another is being stored up. When the force of the moving blocks finally overcomes the friction of the jagged edges of the fault and it unsticks, all that stored up energy is released. The energy radiates outward from the fault in all directions in the form of seismic waves like ripples on a pond. The seismic waves shake the earth as they move through it, and when the waves reach the earth's surface, they shake the ground and anything on it.

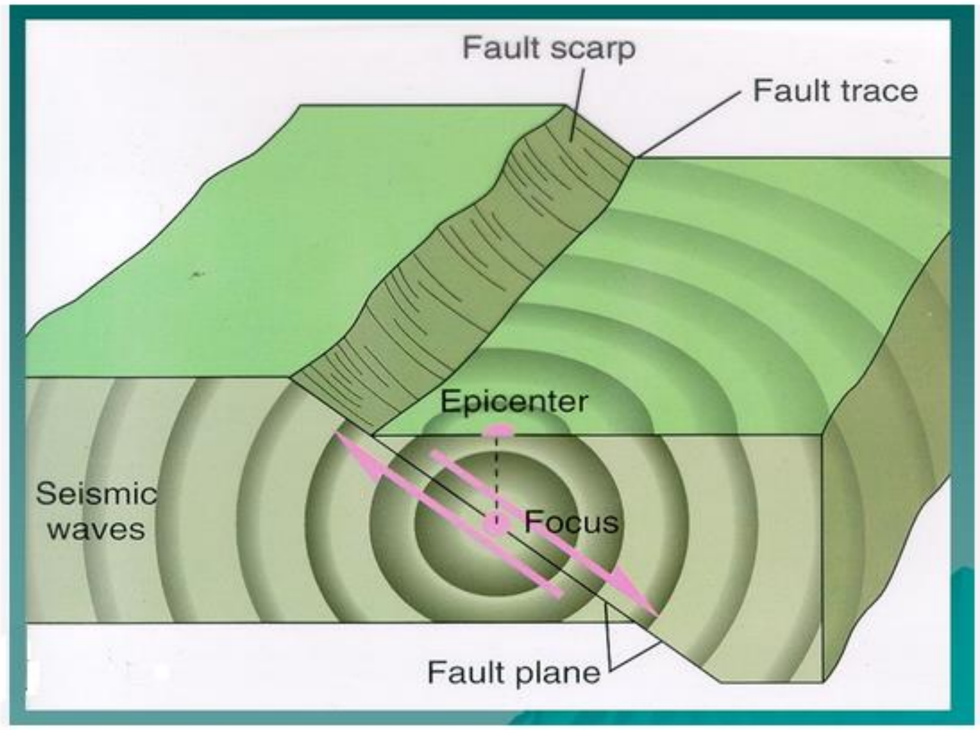


Figure 43. Earthquake.

Earthquakes are recorded by instruments called **seismographs** (fig 44). The recording they make is called a **seismogram**.

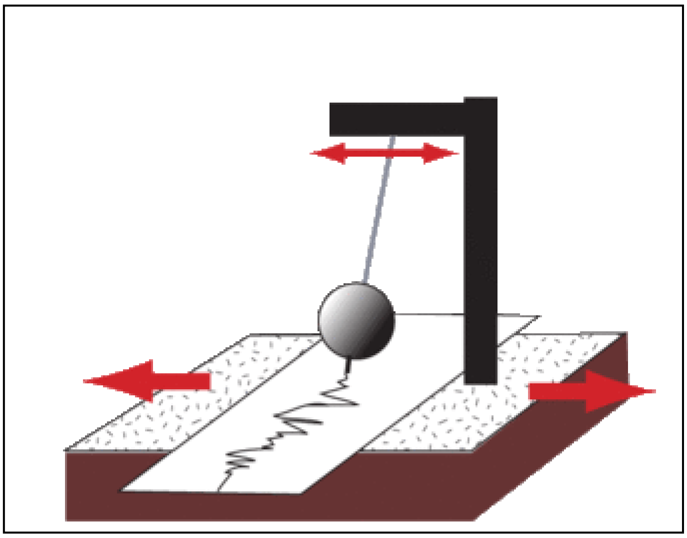


Figure 44. Seismograph.

- **Earthquake intensity**

For a long time, scientists have attempted to categorize earthquakes, thus developing several scales to characterize seismic activity (fig 45): Intensity scales are based on observing the effects and consequences of an earthquake on common indicators in a given location (impact on people, objects, furniture, structures, the environment). However, earthquake intensity is not a reliable measure as it depends not only on the distance from the epicenter but also on factors such as the type of soil, constructions, the time of the earthquake, etc. The most well-known intensity scales are those of Mercalli (1902) include 12 intensity degrees. The Richter scale (1935) is measured on an open logarithmic scale; the strongest recorded earthquake reached 9.5 degrees (Chile).

Richter Magnitude	Earthquake effects
0-2	Not felt by people
2-3	Felt little by people
3-4	Ceiling lights swing
4-5	Walls crack
5-6	Furniture moves
6-7	Some buildings collapse
7-8	Many buildings destroyed
8-Up	Total destruction of buildings, bridges and roads

Modified Mercalli Scale		Richter Magnitude Scale
I	Detected only by sensitive instruments	1.5
II	Felt by few persons at rest, especially on upper floors; delicately suspended objects may swing	2
III	Felt noticeably indoors, but not always recognized as earthquake; standing autos rock slightly, vibration like passing truck	2.5
IV	Felt indoors by many, outdoors by few, at night some may awaken; dishes, windows, doors disturbed; autos rock noticeably	3
V	Felt by most people; some breakage of dishes, windows, and plaster; disturbance of tall objects	3.5, 4
VI	Felt by all, many frightened and run outdoors; falling plaster and chimneys, damage small	4.5
VII	Everybody runs outdoors; damage to buildings varies depending on quality of construction; noticed by drivers of autos	5
VIII	Panel walls thrown out of frames; fall of walls, monuments, chimneys; sand and mud ejected; drivers of autos disturbed	5.5
IX	Buildings shifted off foundations, cracked, thrown out of plumb; ground cracked; underground pipes broken	6
X	Most masonry and frame structures destroyed; ground cracked, rails bent, landslides	6.5, 7
XI	Few structures remain standing; bridges destroyed, fissures in ground, pipes broken, landslides, rails bent	7.5
XII	Damage total; waves seen on ground surface, lines of sight and level distorted, objects thrown up in air	8

Figure 45. Richter and Mercalli scale.

III. 1. 2. Origin and repartition

The origin and distribution of earthquakes are closely tied to the Earth's tectonic activity. Earthquakes primarily occur along plate boundaries, where tectonic plates interact. The geographical distribution of earthquakes is not random across the Earth's surface. Three main seismic activity zones are identified (fig 46):

- **Mid-ocean ridges**

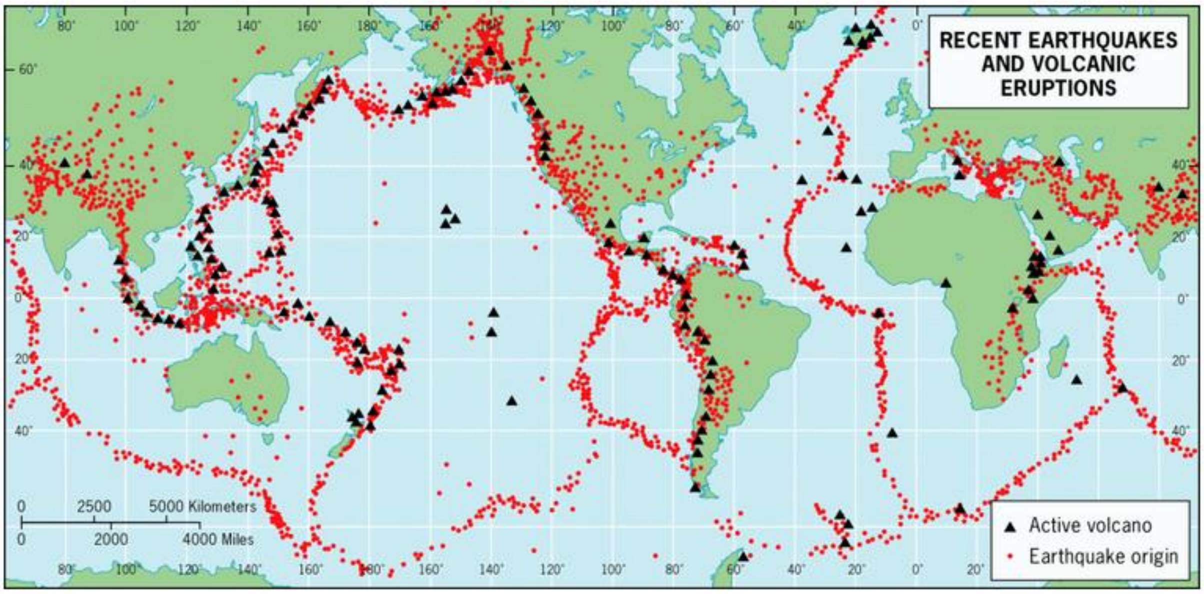
They are located in the middle of the oceans, corresponding to the zone where oceanic crust is formed. Earthquakes in this region are generally shallow (focus < 20 km) and of relatively low magnitude. They result from stretching and sliding movements.

- **The peri-Alpine belt**

Encompasses the entire Alpine orogenic system, extending from North Africa (including the Maghreb) to the mountain ranges of Central Asia. (Himalaya, Indonesia). Earthquakes in these regions may occur at greater depths (up to 70 km) and are indicative of convergent movements (= convergence).

- **The area surrounding the Pacific Ocean**

The area **is** characterized by seismic activity concentrated around major oceanic trenches. This region releases 80% of the total seismic energy. The depth of seismic foci varies significantly, ranging up to 300 to 700 km.



A map to show recent major earthquakes and volcanic eruptions

Figure 46. Map of recent major earthquakes and volcanic eruption.

III. 1. 3. Soft and brittle tectonics

Rocks change their dimensions, or deform, in response to forces that act on them after their formation. These forces arise from the tectonic plate interactions, so deformation occurs mainly near plate boundaries

➢ **Ductile Deformation Structures (Folds)**

When rocks respond to incident forces in a ductile manner, folds are created in the rock layers. These folds are defined by a *fold axis* that separates two *limbs* on either side of the axis, with the upward fold called an anticline and the downward fold called a syncline . Due to erosion at the surface, anticlines can be recognized by the exposure of older rock layers at the centre of the fold and of the youngest rocks in a syncline.

Folds develop due to compressional forces associated with convergent plate boundaries. When seen in igneous rock, folds usually indicate deep crust conditions at the base of mountain ranges associated with episodes of *orogeny* (mountain building).

- **Elements of folds**

✓ **Axial Plane:** The imaginary surface that divides a fold into two symmetrical halves. It is the plane along which the fold is essentially mirrored.
✓ **Axial Line:** The line of intersection between the axial plane and any horizontal plane. It represents the axis of the fold.
✓ **Crest:** The highest point on a fold where the curvature is directed upwards.
✓ **Trough:** The lowest point on a fold where the curvature is directed downwards.
✓ **Limb:** Each side of the fold, extending from the crest to the trough.
✓ **Hinge:** The line of maximum curvature along the fold, typically found along the axial line (fig 47).

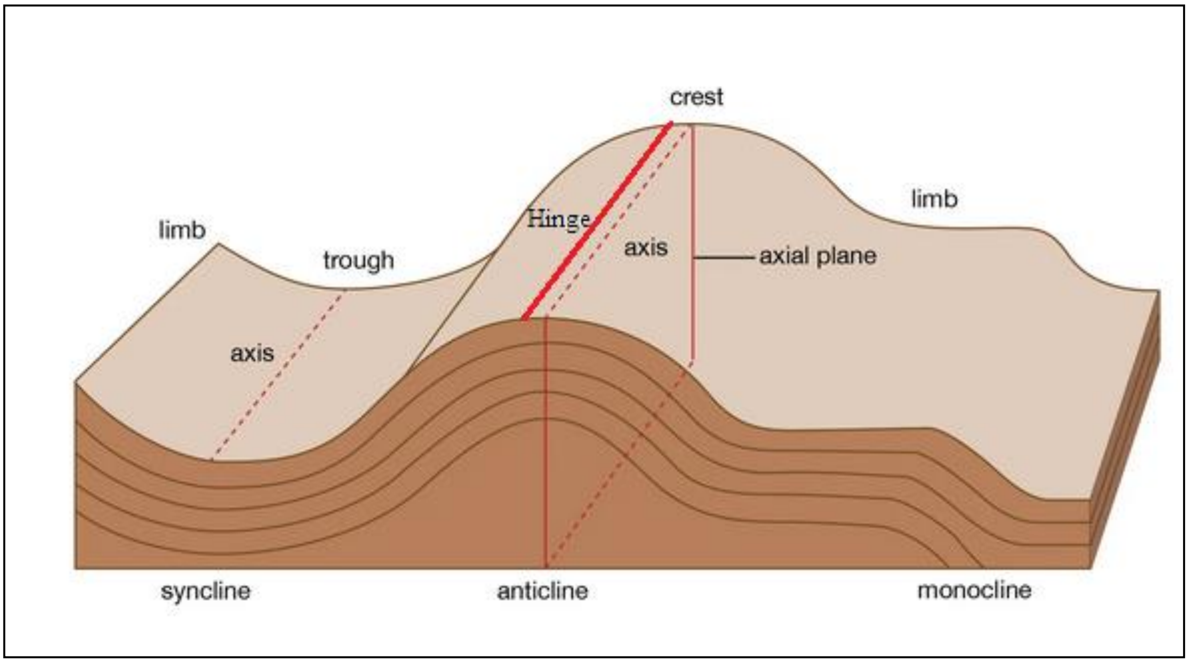


Figure 47. Elements of folds.

- **Classification of Folds:** Folds are generally classified according to the attitude of their axes and their appearance in cross sections perpendicular to the trend of the fold. The axial plane of a fold is the plane or surface that divides the fold as symmetrically as possible. The axial plane may be vertical, horizontal, or inclined (fig 48).
  - ✓ **A symmetrical fold:** is one in which the axial plane is vertical.
  - ✓ **An asymmetrical fold** is one in which the axial plane is inclined.
  - ✓ **An overturned fold**, **or overfold**, has the axial plane inclined to such an extent that the strata on one limb are overturned.
  - ✓ **A recumbent fold** has an essentially horizontal axial plane. When the two limbs of a fold are essentially parallel to each other and thus approximately parallel to the axial plane, the fold is called isoclinal.

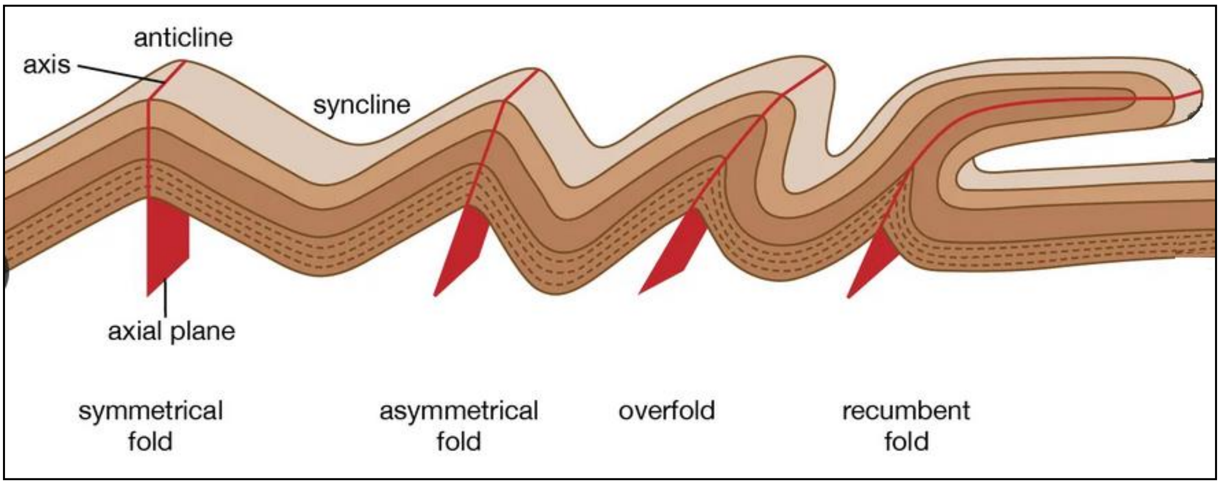


Figure 48. Types of folds.

- **Brittle deformation (faults)**

Brittle deformation is a type of deformation that occurs in rocks when they are subjected to stress beyond their elastic limit. This means that the rocks break rather than bend or flow. Brittle deformation is typically associated with tectonic forces, such as those that cause earthquakes and mountain building. Brittle deformation can occur in a variety of rock types, but it is most common in hard, brittle rocks such as sandstone, limestone, and granite.

- **Faults:** Faults are one of the most common examples of brittle deformation. Faults can be found all over the world, and they can range in size from a few meters to hundreds of kilometers. Some famous examples of faults include the San Andreas Fault in California, the Dead Sea Fault in the Middle East, and the Alpine Fault in New Zealand. A fault is characterized by several elements (fig 49):

  - ✓ **Hanging Wall:** The block of rock above the fault plane. If movement has occurred, it may appear to hang over the lower block.
  - ✓ **Footwall:** The block of rock below the fault plane. It is the side upon which miners would walk or stand.
  - ✓ **Fault Plane:** The surface along which the movement has occurred, separating the rocks on either side of the fault.
  - ✓ **Fault Line:** The intersection of the fault plane with the Earth's surface.

✓ **Heave and Throw:** Heave refers to horizontal displacement, and throw refers to vertical displacement.

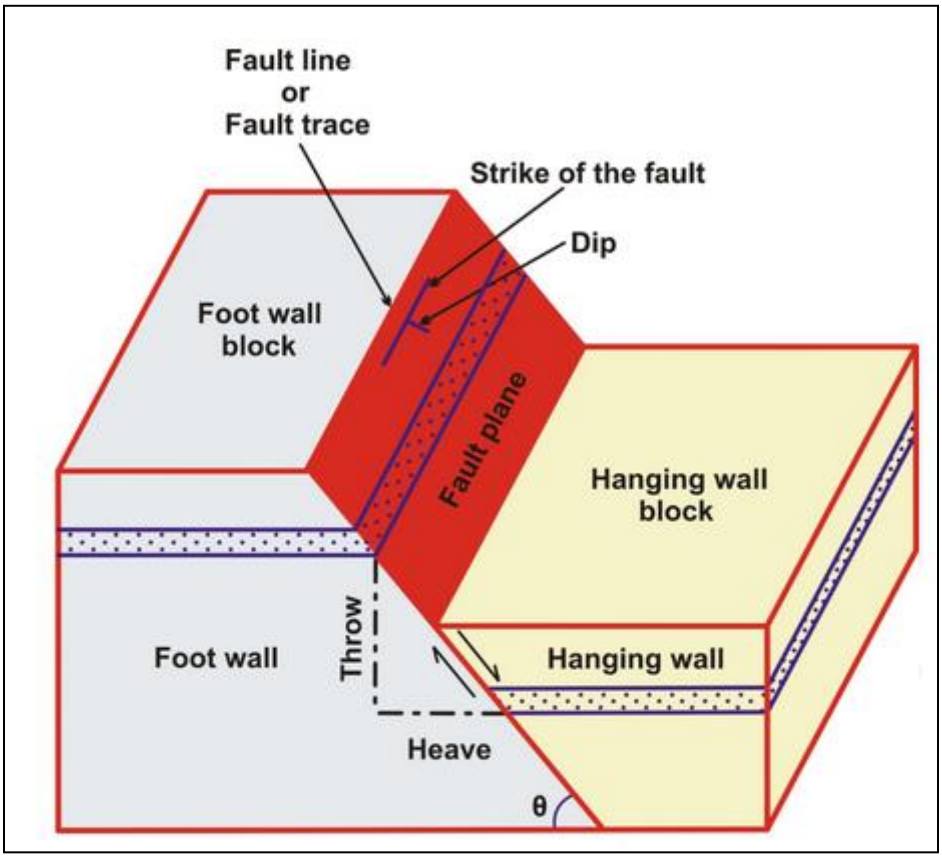


Figure 49. Elements of faults

- **Types of fault**

There are several types of faults, each characterized by the direction of movement between the blocks of rock on either side (fig 50).

✓ **Normal Fault:** In a normal fault, the hanging wall moves downward relative to the footwall. This type of fault is associated with extensional tectonic forces, typically found at divergent plate boundaries.

✓ **Reverse Fault (Thrust Fault):** In a reverse fault, the hanging wall moves upward relative to the footwall. Reverse faults are associated with compressional tectonic forces and are commonly found at convergent plate boundaries.

✓ **Strike-Slip Fault:** In a strike-slip fault, the movement is primarily horizontal, with minimal vertical displacement. The rocks on either side of the fault slide past each other horizontally. Examples include the San Andreas Fault in California and the North Anatolian Fault in Turkey.

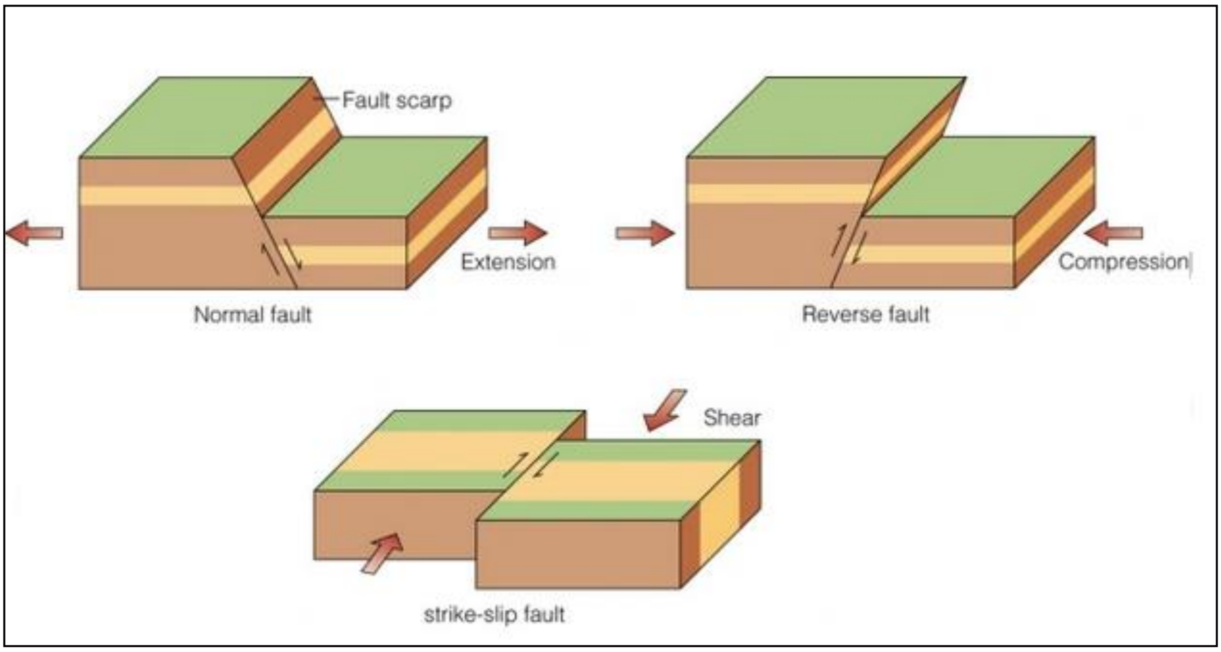


Figure 50. Types of faults

III. 2. Volcanology

Volcanology discipline of the geologic sciences that is concerned with all aspects of volcanic phenomena. Volcanology deals with the formation, distribution, and classification of volcanoes as well as with their structure and the kinds of materials ejected during an eruption.

III. 2. 1. Volcano

A volcano is an opening in the earth's crust through which lava, volcanic ash, and gases escape. It can be located on solid ground or underwater. The magma results from the partial melting of the mantle and occasionally from the Earth's crust. The majority of volcanoes in the world form along the boundaries of Earth's tectonic plates.

During a volcanic eruption, lava, tephra (ash, lapilli, volcanic bombs and blocks), and various gases are expelled from a volcanic vent or fissure.

➢ **Lava**

The most important product of volcanic eruption is the lava**.** The lava is the molten magma which reaches the surface. The nature of lava also determines the form of volcanic cone.

➢ **Tephra**

These are fragments entrained by gases and ejected during volcanic eruptions, ranging in size from a few tenths of a millimeter to several cubic meters. They are classified into:

- **Blocks and volcanic bombs**

Varied in size (> 64 mm). Blocks are angular, solid projectiles, while bombs are more rounded and ejected in a semi-liquid state. Their dimensions can reach several meters in length (record of 8.5 meters).

- **Lapilli and ash:**

Lapilli have a size < 64 mm, ash < 2 mm, and dust < 0.2 mm. The fragments are irregularly shaped, often very porous, and of low density. Ash can disperse into the upper atmosphere globally.

➢ **Gases**

The major part of gases consists of hydrogen (H), carbon (C), oxygen (O), sulfur (S) and nitrogen (N). The hydrogen is largely present as water (H_2O). Volcanoes also emit methane (CH_4) and ammonia (NH_3) but in trace amounts. They also have an important effect on the regional and global environment and may contribute greenhouse gases to the atmosphere.

a) Structure of volcanoes

Volcanoes have distinctive features (fig 51):

- ✓ **magma chamber:** this is where the molten rock is stored beneath the ground
- ✓ **main vent:** this is the channel through which *magma* travels to reach the Earth's surface

- ✓ **secondary vent:** some magma may escape through the side of the volcano, particularly if the main vent becomes blocked
- ✓ **crater :** this is found at the top of the volcano, where the magma erupts from

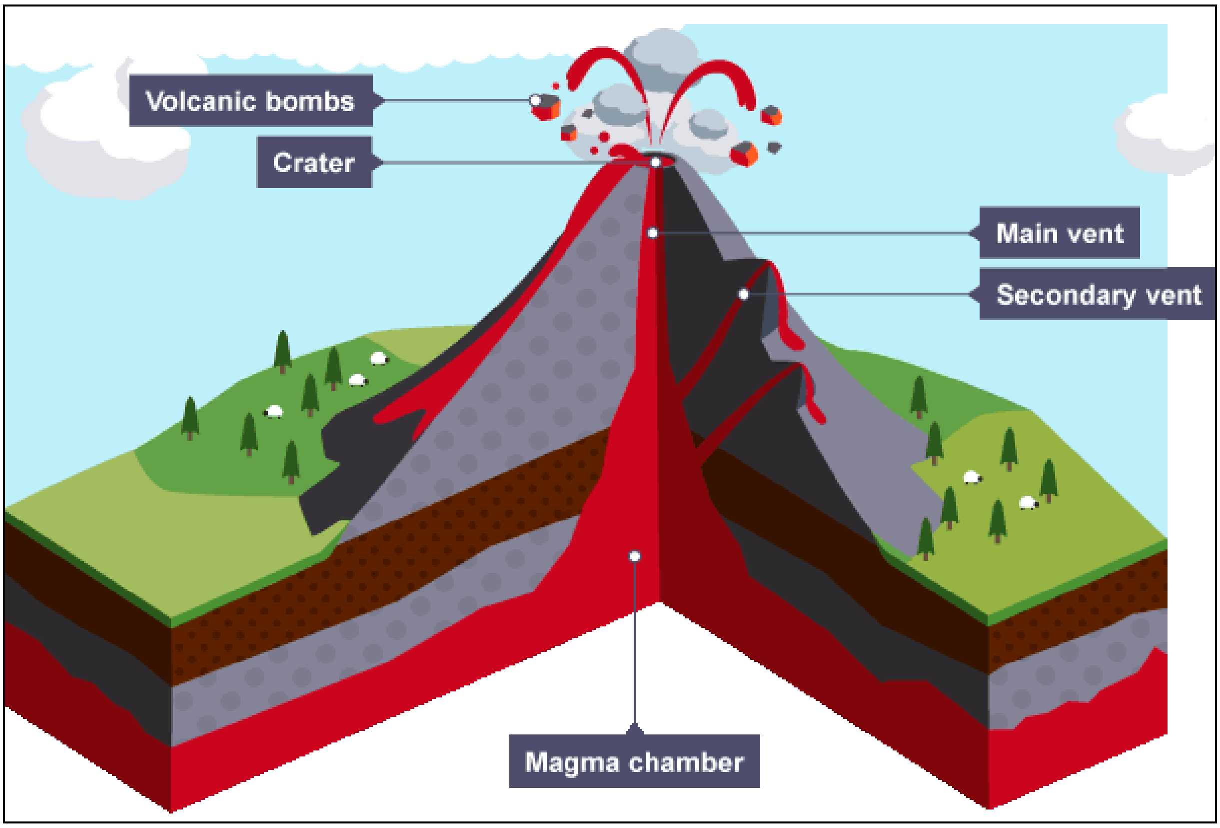


Figure 51. Structure of volcanoes

b) Types of Volcanoes

Volcanic eruptions can be categorized into several types based on their characteristics and the nature of the eruptive activity. Here are some common types of volcanic eruptions (fig 52):

- ✓ **Strombolian Eruption:** Characterized by intermittent and relatively mild explosions of lava fragments and gases. The eruptions are named after the volcano Stromboli.
- ✓ **Hawaiian Eruption:** Involves the effusion of highly fluid basaltic lava, typically with low gas content. It often results in the formation of shield volcanoes.

- ✓ **Vulcanian Eruption:** Marked by explosive eruptions with the release of volcanic gases and the ejection of fragmented rocks. The explosions are more violent than Strombolian eruptions.
- ✓ **Pelean eruption**: is a type of volcanic eruption characterized by its catastrophic and explosive nature. It is named after the volcanic activity observed at Mount Pelée on the Caribbean island of Martinique in 1902.

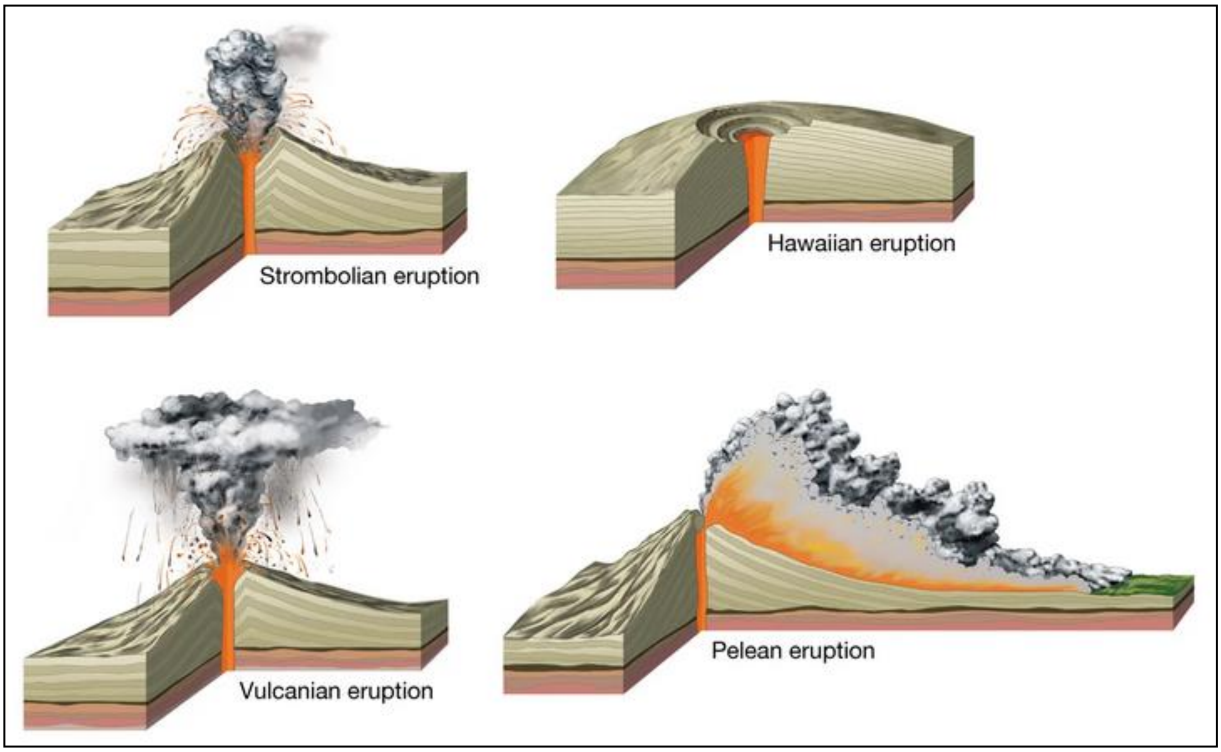


Figure 52. Types of volcanoes

III. 2. 2. Ignous rocks

Igneous rock or magmatic rock is one of the three main rock types, the others being sedimentary and metamorphic. Igneous rocks are formed through the cooling and solidification of magma or lava.

The magma can be derived from partial melts of existing rocks in either a planet's mantle or crust. Typically, the melting is caused by one or more of three processes: an increase in temperature, a decrease in pressure, or a change in composition. Solidification into rock occurs either below the surface as intrusive rocks or on the surface as extrusive rocks. Igneous rock may form with crystallization to form granular, crystalline rocks, or without crystallization to form natural glasses.

Igneous rocks occur in a wide range of geological settings: shields, platforms, orogens, basins, large igneous provinces, extended crust and oceanic crust.

- **Classification of ignous rocks**

Igneous rocks are classified according to mode of occurrence, texture, mineralogy and chemical composition.

- **Based on Mode of occurrence and grain size**: Three types of rock can be identified:
  - ✓ **Volcanic rocks**: solidify close to the Earth's surface. Because they cool quickly they have a finer-grained matrix (called groundmass). They may contain some larger crystals that formed earlier further down (called phenocrysts).
  - ✓ **Hypabyssal or subvolcanic rocks**: form at intermediate depths (generally as dykes and sills) and so tend to be medium-grained.
  - ✓ **Plutonic rocks**: form deeper within the Earth and the slower cooling allows them to crystallise as coarse-grained rocks.
- **Based on texture :** Textures reflect rate of cooling reflect rate of cooling
  - ✓ **Phaneritic:** mineral crystals are visible e.g. Granite & Gabbromineral crystals are visible e.g. Granite and Gabbro.
  - ✓ **Aphanitic:** crystals not visible e.g. Rhyolites & Basaltcrystals not visible e.g. Rhyolites and Basalt.
  - ✓ **Volcanic glass:** Volcanic glass very rapid cooling very rapid cooling.
- **Based on chemical composition**
  - ✓ **Silica content:** Silica (SiO_2) content also controls the minerals that crystallise and is used to further classify igneous rocks as follows:
    - **Acid**: rocks with above 63% silica (mostly feldspar minerals and quartz), e.g. granite.
    - **Basic**: rocks that are about 45 to 55% silica (mostly mafic minerals plus plagioclase feldspar and/or feldspathoid minerals), e.g. basalt.
    - **Ultrabasic**: rocks that are usually less than 45% silica (mostly mafic minerals such as olivine and pyroxene), e.g. peridotite.

III. 2. 3. The study of magmas

Magma is extremely hot liquid and semi-liquid rock located under Earth’s surface. Earth has a layered structure that consists of the inner core, outer core, mantle, and crust. Much of the planet’s mantle consists of magma. This magma can push through holes or cracks in the crust, causing a volcanic eruption. When magma flows or erupts onto Earth’s surface, it is called lava.

Like solid rock, magma is a mixture of minerals. It also contains small amounts of dissolved gases such as water vapor, carbon dioxide, and sulfur. The high temperatures and pressure under Earth’s crust keep magma in its fluid state.

There are three basic types of magma: basaltic, andesitic, and rhyolitic, each of which has a different mineral composition. All types of magma have a significant percentage of silicon dioxide. Basaltic magma is high in iron, magnesium, and calcium but low in potassium and sodium. It ranges in temperature from about 1000^{o}C to 1200^{o}C.Andesitic magma has moderate amounts of these minerals, with a temperature range from about 800^{o}C to 1000^{o}C. Rhyolitic magma is high in potassium and sodium but low in iron, magnesium, and calcium. It occurs in the temperature range of about 650^{o}C to 800^{o}C. Both the temperature and mineral content of magma affect how easily it flows.

The viscosity (thickness) of the magma that erupts from a volcano affects the shape of the volcano. Volcanoes with steep slopes tend to form from very viscous magma, while flatter volcanoes form from magma that flows easily.

III. 3. Plate tectonics

The Earth's crust is composed of various continental plates that slide on the asthenosphere. The movements affecting these continental plates are known as continental drift.

The continental drift is a theory proposed by the German physicist Alfred Wegener, who was the first to suggest that continents must move relative to each other. Several pieces of evidence and arguments were put forth to support his hypothesis:

➢ Morphological Arguments

Wegener studied the current shape of continents and observed that they could fit together like puzzle pieces. For example, North and South America fit well into Europe and Africa. Hence, he proposed the idea that in a certain geological era, today's continents formed a single mega-continent called Pangaea. Pangaea then broke apart due to internal geodynamic forces, separating into several units over geological time, resulting in the current configuration of Earth's surface.

➢ Geological Arguments

- **Distribution of Fossils** : On both sides of the Atlantic, there are fossils of plants and land animals dating back 240 to 260 million years. These organisms couldn't have crossed such a wide ocean, implying that all these continents were once connected. Two examples include the aquatic reptile *Mesosaurus* and the plant *Glossopteris*.
- **Traces of Ancient Glaciations:** Some regions of current continents show signs of glaciation dating back 250 million years, indicating that these areas were once covered by ice sheets. Finding glaciations in tropical zones (such as South Africa and India) is improbable without the continents being part of a larger landmass.

- **Correspondence of Geological Structures:** There is a concordance between geological structures within continents, for example, the Caledonian mountain range in Europe perfectly matches with a corresponding structure in America.

Plate tectonics is a scientific theory that explains the movement and interactions of Earth's lithospheric plates. The Earth's lithosphere, which includes the rigid outer layer of the planet, is divided into several large and small plates that float on the semi-fluid asthenosphere beneath them. These plates are in constant motion, driven by the heat generated from the Earth's interior. All these plates move relative to each other and exhibit three types of boundaries or frontiers.

These movements define three types of plate boundaries (fig 3): divergent, convergent, and transform.

a) **Divergent boundaries:** where plates move away from each other, leading to the production of new oceanic crust through the cooling of mantle rising from the asthenosphere. These are zones with volcanic activity.

b) **Convergent boundaries:** refers to a movement bringing two plates closer to each other. Three types of convergent plate boundaries accommodate this approach:

- Collision between two oceanic plates: In this type of collision, one of the plates (usually the denser and older one) sinks beneath the other to form a subduction zone.
- Collision between an oceanic plate and a continental plate: In this type of collision, the denser oceanic plate sinks beneath the continental plate.
- Collision involving two continental plates: As the oceanic space closes gradually during the convergence of two continental plates, mountain ranges form.

c) **Transform Boundaries:** Transform boundaries are characterized by plates sliding past each other horizontally. The friction between the plates prevents them from easily moving, resulting in the accumulation of stress. When this stress is released, it can lead to earthquakes along fault lines. The San Andreas Fault in California is an example of a transform boundary.

These plate boundaries play a crucial role in shaping the Earth's surface and are often associated with geological phenomena such as earthquakes, volcanic eruptions, and the creation of mountain ranges.

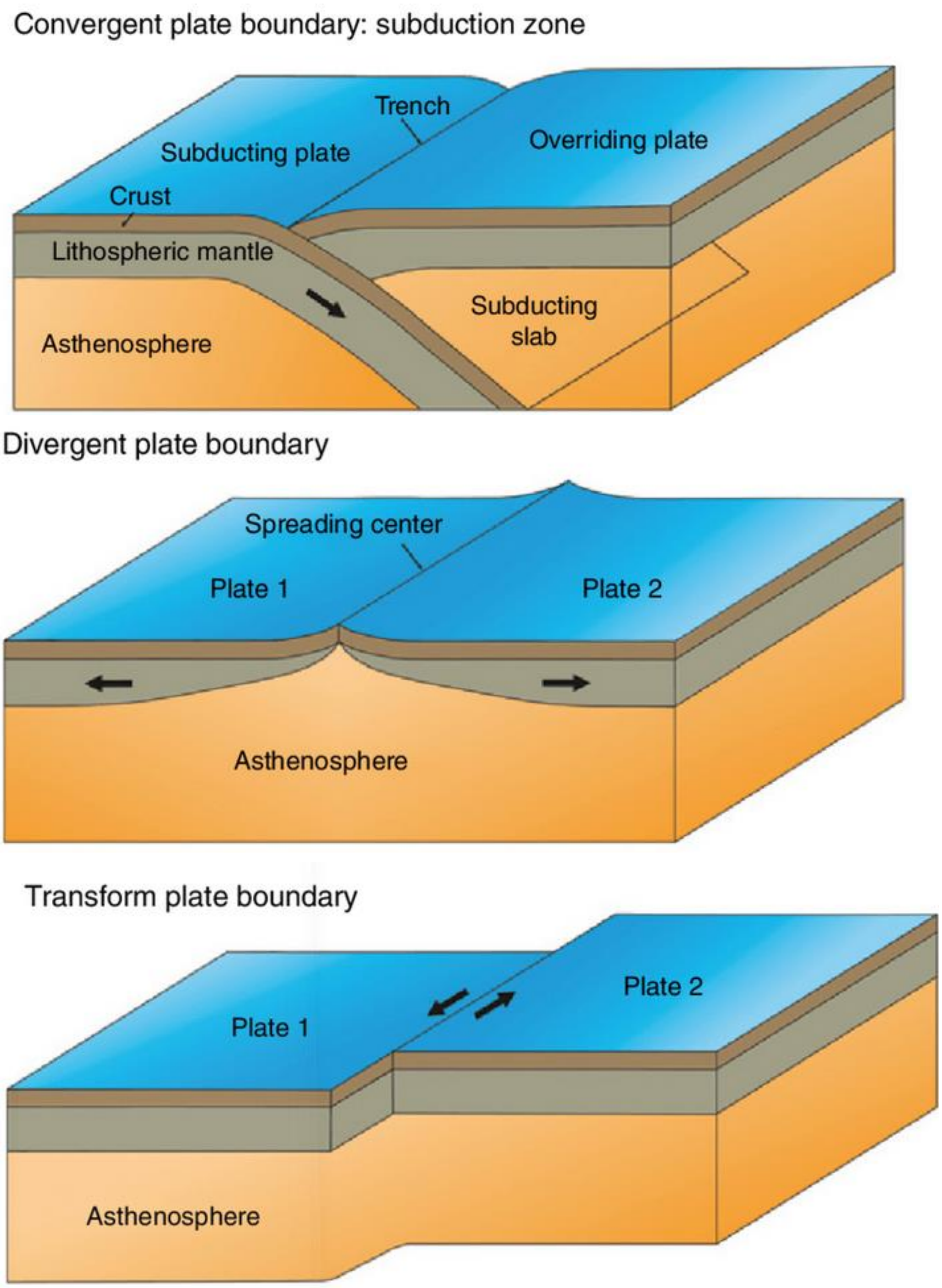


Figure 53. Plates boundaries.

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Annex

Semestre : 1er Semestre

UE: Unité d'Enseignement Méthodologique 1

Matière : GÉOLOGIE

Objectifs de l'enseignement
La matière permet aux étudiants de voir les constituants et la structure du globe terrestre, les interactions entre ces constituants, la géodynamique externe et interne.

Connaissances préalables recommandées *(descriptif succinct des connaissances requises pour pouvoir suivre cet enseignement – Maximum 2 lignes)*.

Sans pré-requis

Contenu de la matière

1. Géologie générale
- 1.1. Introduction
- 1.2. Le globe terrestre
- 1.3. La croûte terrestre
- 1.4. Structure de la terre

2. Géodynamique externe
- 2.1. Erosion
  - 2.1.1. L'action de l'eau
  - 2.1.2. L'action du vent
- 2.2. Dépôts
  - 2.2.1. Méthodes d'études
  - 2.2.2. Les roches sédimentaires
  - 2.2.3. Notion de stratigraphie
  - 2.2.4. Notion de paléontologie

3. Géodynamique interne
- 3.1. Sismologie
  - 3.1.1. Etude des séismes
  - 3.1.2. Origine et répartition
  - 3.1.3. Tectonique souple et cassante (plis et failles)
- 3.2. Volcanologie
  - 3.2.1. Les volcans
  - 3.2.2. Les roches magmatiques
  - 3.2.3. Etude des magmas
- 3.3. La tectonique des plaques