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Ferhat Abbas University - Setif 1
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كلية علوم الطبيعة و الحياة
قسم الدراسات القاعدية

**Common Base L1: Natural and Life Sciences**

**1st Year**

# General Geology

## *Course Elements*

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***Module: GEOLOGY***
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***Common Base L1: Natural and Life Sciences***

# Geology Course

The Module allows students to study the components and structure of the Earth, the interactions between these components, and both external and internal geodynamics.

**Content of the Module**



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# I. Introduction to Geology

## I.1. Definition

Geology is the science that aims to study:

*(1) The nature, distribution, and organization of materials on the Earth's surface.*

*(2) The phenomena responsible for their formation, arrangement, and evolution.*

*(3) Their history.*

Therefore, it is the science that deals with the composition, structure, history, and evolution of the Earth's outer and inner layers, as well as the processes that shape it.

## I.2. Fundamental Geology

Fundamental geology comprises numerous scientific disciplines. For example:

***Crystallography:*** It is the study of the properties, particularly geometric, of the crystalline state of matter.

***Mineralogy:*** It is the study of the composition and physicochemical properties of minerals.

***Petrography:*** It is the study and classification of rocks. Petrography is distinguished between sedimentary rock petrography, igneous rock petrography, and metamorphic rock petrography.

***Petrology:*** It is the study of rock genesis. Exogenous petrology refers to the study of sedimentary rocks, while endogenous petrology focuses on igneous and metamorphic rocks.

***Volcanology:*** It studies the structure, formation, and evolution of volcanoes.

***Sedimentology:*** It studies sediment deposition processes and the genesis of sedimentary rocks.

***Pedology:*** This discipline studies the characteristics and formation of soils, particularly from morphological and physicochemical viewpoints.

***Stratigraphy:*** It studies the succession of deposits and sedimentary layers to reconstruct successive **paleogeography's.**

***Geochronology:*** It enables the determination of a rock's age through physical methods.

***Paleontology:*** It studies fossilized animal (paleozoology) or plant (paleobotany) life: description, classification, evolution, extinction, ecology (paleoecology).

***Tectonics:*** It studies the deformations of the Earth's crust and their genesis.

***Geophysics:*** It is the study of the physical properties of the globe (such as magnetic field, gravity field, and seismic waves) to understand its structure and movements.

***Geochemistry:*** It studies the distribution of elements and the laws governing their chemical behavior in minerals, rocks, and various layers of the Earth.

***Geodynamics:*** It studies major geological processes, both external (erosion) and internal (seismic activity).

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## I.3. Applied Geology

Applied geology involves the use of geological data and methods for studying the conditions of deposits, formation, and exploitation of various subsurface resources, as well as for civil engineering projects. It includes:

***Hydrogeology:*** Deals with the movement of water underground, including the exploration of aquifers and assessment of reservoirs.

***Hydrochemistry:*** Specifically addresses the chemistry of water.

***Petroleum Geology:*** Concerns the application of geological disciplines to petroleum exploration.

***Geology of Ore Deposits:*** Encompasses ore deposit geology, which studies the structure of mineral concentrations, and metallogeny, which describes their genesis.

***Geotechnics:*** Studies the mechanical properties of rocks and rock masses. Geology of infrastructure and civil engineering focuses on the study of large structures (such as roads, bridges, tunnels, dams) and associated risks.

***Applied Geophysics:*** Provides a local image of the subsurface through the study of physical properties. It is widely used in the exploration of geological resources.

***Applied Geochemistry:*** Allows for the chemical characterization of water and soil, especially in cases of pollution.

***Cartography:*** Involves techniques and graphical arts used to create maps and produce printed versions.

***Remote Sensing:*** Utilizes aerial photographs or satellite images to study the electromagnetic properties of the Earth's surface from a distance.

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## II. The Earth Globe

### II.1. Generalities on the Solar System: Definition, Organization, and Dimensions of the Solar System

The solar system is the collection of objects governed by the gravitational attraction of the Sun. Thus, within the solar system, there are a certain number of objects orbiting around a star (the Sun); these include planets and their possible satellites, dwarf planets, asteroids, and comets. (Figure 01).

During its 26th General Assembly held in Prague from May 14 to August 25, 2006, the International Astronomical Union (IAU) redefined celestial objects within the solar system as follows:

**II.1.1. A planet:** is a celestial body that meets the following conditions:

a. orbits around the Sun
b. has sufficient mass for its gravity to overcome the cohesive forces of the solid body and maintain it in hydrostatic equilibrium, in a nearly spherical shape.
c. has cleared its orbit of any other bodies.

**II.1.2. A dwarf planet**: is a celestial body that:

a. orbits around the Sun
b. has enough mass for its own gravity to overcome rigid body forces so that it assumes a hydrostatic equilibrium shape (almost round)
c. has not cleared the neighborhood around its orbit and is not a satellite.

**II.1.3. Small bodies of the solar system:** correspond to any other object orbiting the Sun.

Thus, and in accordance with these definitions, the solar system consists of:

**II.1.3.1. The Sun:** which is a star.

**II.1.3.2. Eight (08) planets:** which orbit around the Sun in a plane called the ecliptic. They are **Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune.** Their orbits are nearly circular counterclockwise, except for Venus, and their axes of rotation are almost perpendicular to the ecliptic, except for Uranus, which is inclined. These planets are subdivided into two families:

***a. Terrestrial planets:*** Mercury, Venus, Earth, and Mars. They have solid rocky surfaces and are mainly composed of silicates and iron.

***b. Giant planets:*** also known as **giant** planets due to their large size compared to terrestrial planets: Jupiter, Saturn, Uranus, and Neptune. They are primarily composed of hydrogen and helium.

**II.1.3.3. The satellites of the planets: (205 satellites)** which orbit around the planets.

**II.1.3.4. Dwarf planets:** correspond to a new category that includes various objects such as **Pluto**, formerly classified as a planet but now considered a dwarf planet.

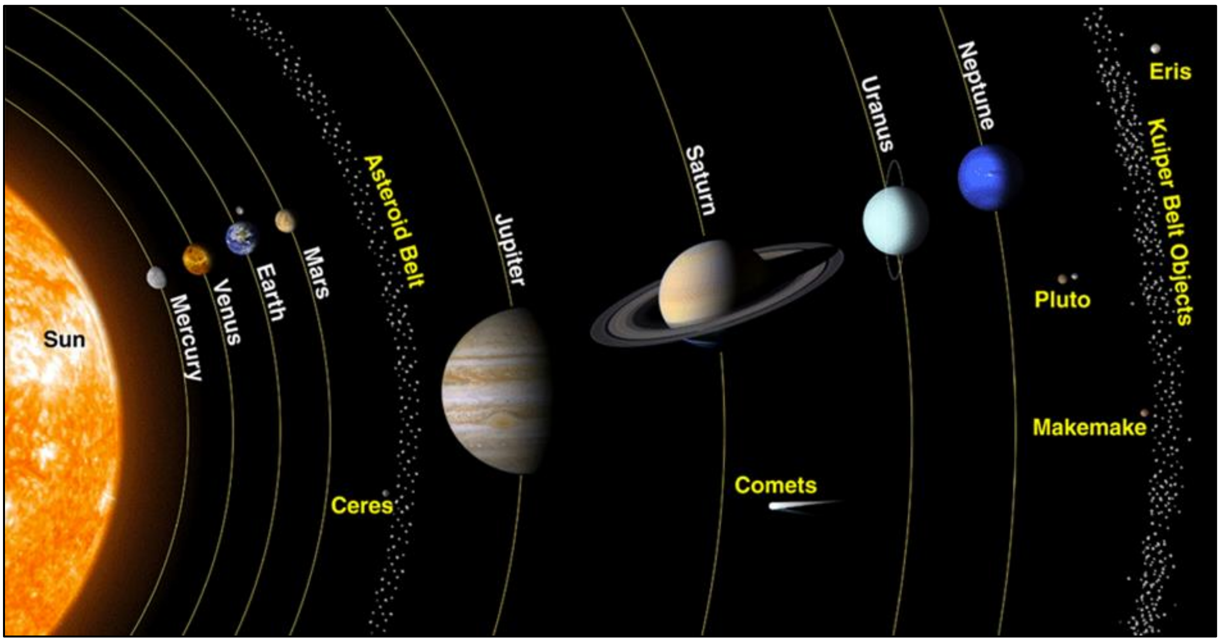
**II.1.3.5. Asteroids:** these are small rocky and irregular bodies; there are approximately **500,000** known asteroids, of which **230,000** are numbered. These asteroids have a composition similar to that of terrestrial planets (silicates and metals), but they are smaller, with a maximum size of 1000 km. The largest and most well-known are **Ceres, Pallas, and Vesta.** Most of them orbit within a belt located between the orbits of Mars and Jupiter, while others, more distant, form the Kuiper Belt.

**II.1.3.6. Comets:** are clusters of ice (frozen water and gases) and dust. There are approximately **1000** known comets with sizes ranging from 1 to 20 km, located much farther from the Sun than the planets. They have non-elliptical orbits around the Sun, outside the ecliptic plane. Their mass exceeds that of Earth by 50 times.

**II.1.3.7. The interplanetary medium:** it includes at least two (02) components:

a. Interplanetary dust, represented by microscopic solid particles.

b. Interplanetary gas, also called plasma, which is a stream of hot gas with charged particles, mostly protons and electrons.




***Source.*** *https://www.forbes.com/sites/startswithabang*

**Figure 01.** The main objects of the solar system

**In general, the distribution of mass within the solar system is as follows: Sun: 99.85%; Planets: 0.13%; Comets, Satellites, Asteroids, Interplanetary Medium: 0.02%.**

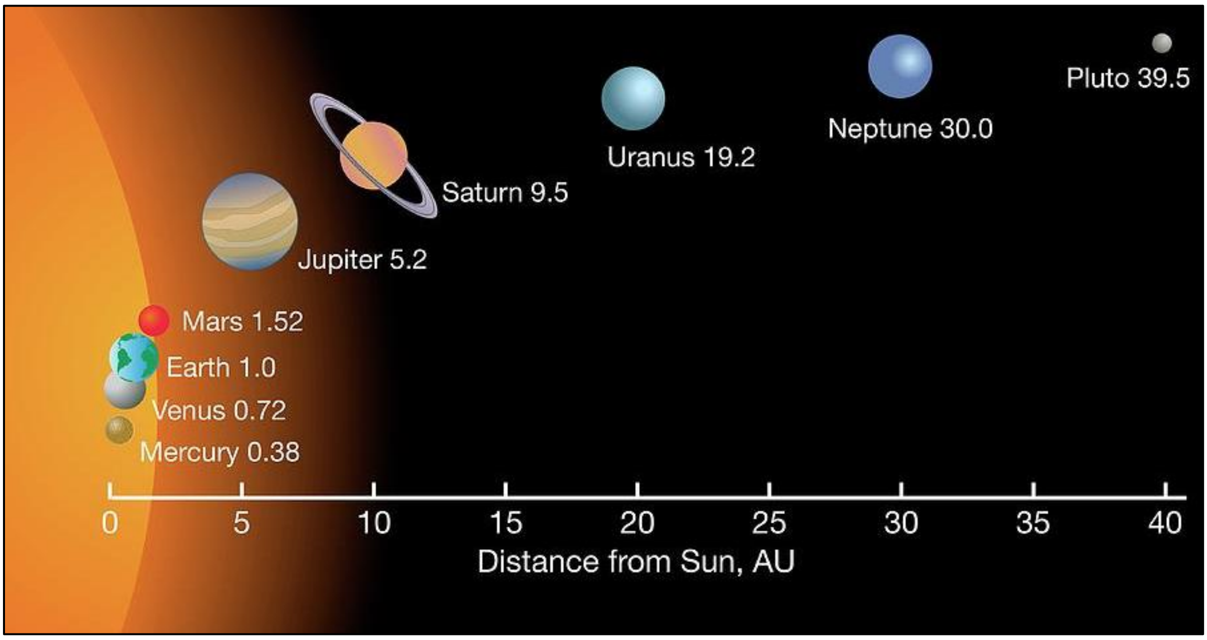
The dimensions of this system are specified in terms of the average distance from the Earth to the Sun, called the astronomical unit (1 AU = 150,000,000 km). The farthest known dwarf planet, which is Pluto, has its orbit at a distance of 39.44 AU. The distances from the Sun to the planets are established by Bode's law, where each planet is approximately twice as far from the Sun as its inner neighbor.

## II.2. Description of the planet Earth

### II.2.1. Description

It is the third planet of the solar system from the Sun. Located approximately **150 million**

**km** from it, it revolves around the Sun in a little over **365 days.** Earth rotates on its axis passing through the poles in **24 hours.** This axis is slightly inclined **(23°)** relative to the plane of the ecliptic (plane of revolution); this inclination is the cause of the existence of seasons. The age of the Earth is approximately that of the Sun, about **4.6 billion years**. Its radius is approximately **6371 kilometers.** The Earth is slightly flattened at the poles.



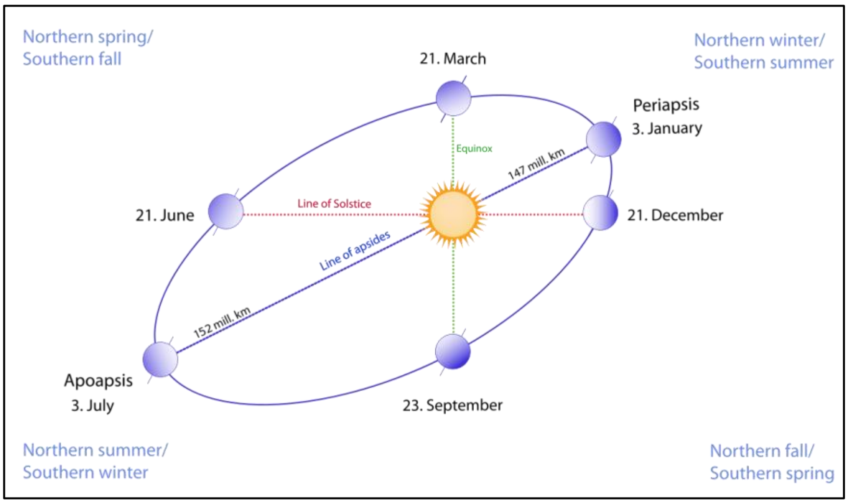

***Source.*** *https://www.britannica.com/science/solar-system*

**Figure 02.** The distance of the planets from the sun (AU)

### II.2.2. Aphelion and Perihelion

***Aphelion*** is the point of the Earth's orbit that is farthest away from the Sun. It always happens in early July, about two weeks after **the June solstice.** (Figure 03).

***Perihelion*** is the point of the Earth's orbit that is nearest to the Sun. This always happens in early January, about two weeks after **the December Solstice.** (Figure 03).




***Source :*** *https://www.universetoday.com/tag/aphelion-vs-perihelion*

**Figure 03.** Aphelion and Perihelion

## II.2.2. The shape of the Earth

The Earth is not truly spherical; Newton introduced the idea that this sphere was rather flattened at the poles and could thus be represented by an ellipsoid.

The polar flattening results in a reduction of the polar radius by **1/298** of the equatorial radius. (Figure 04).

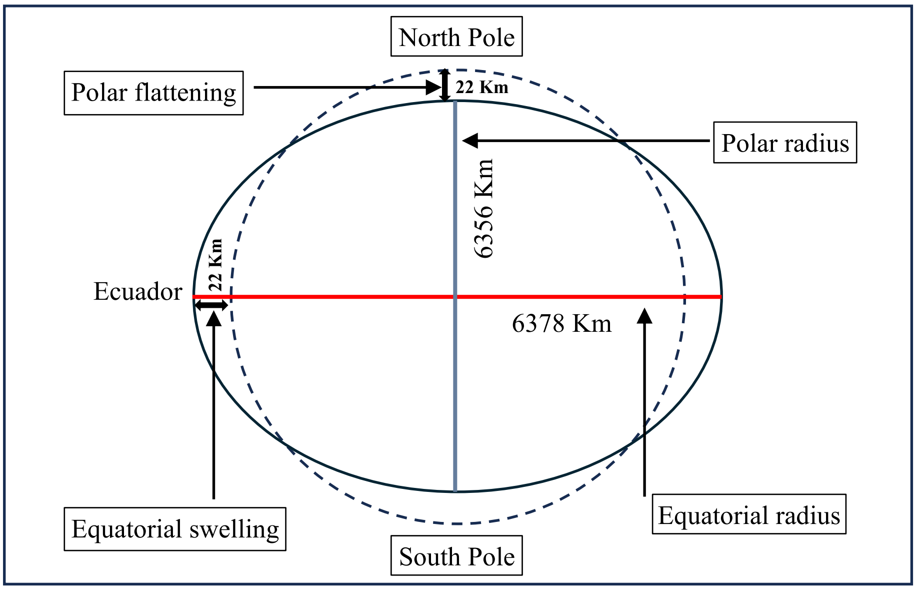
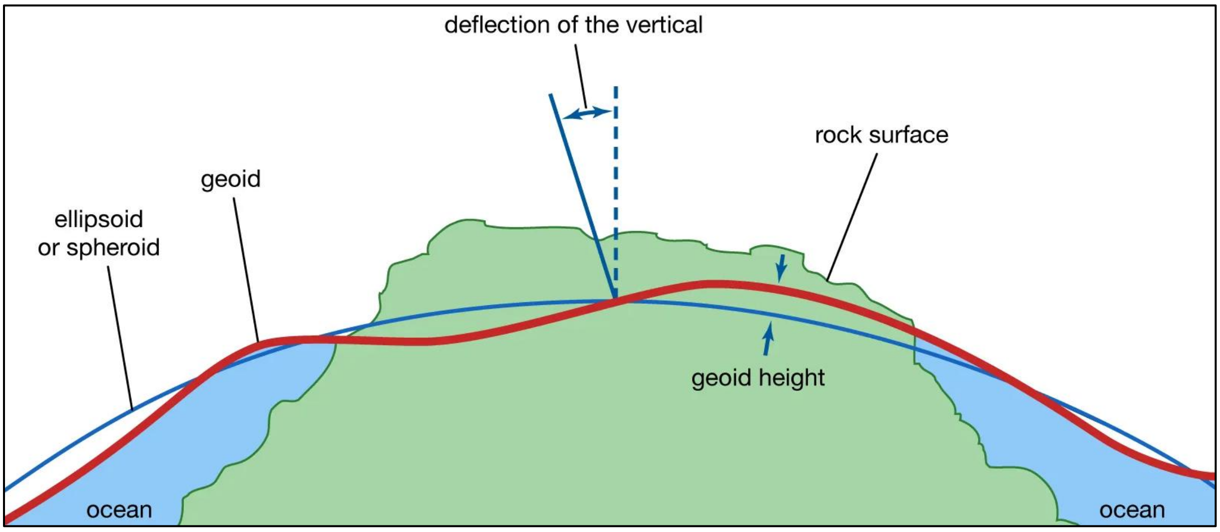



**Figure 04.** Shape and dimensions of the ellipsoid of revolution.

With the advent of artificial satellites in geodesy, it became possible to establish a global ellipsoid that could be used across the entire surface of the Earth. However, the ellipsoid does not account for all the heterogeneities of the Earth's surface (problem of measuring altitude).

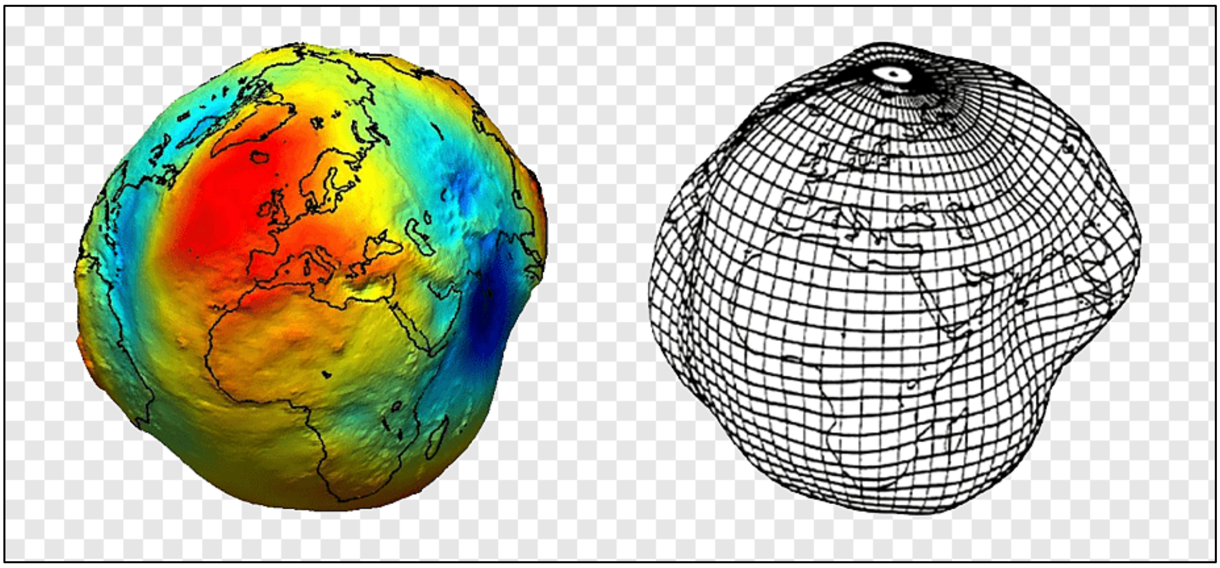
Altitude measurements must be based on the mean sea level identifiable along the coastlines (extending beneath the continents), and on a consistent Earth gravity force. This representation is called the **Geoid** (Figure 05 and 06). In geodesy, the Earth practically assumes the shape of a Geoid, defining it as a surface of equipotential gravity.

Among the infinity of equipotential surfaces meeting these criteria, the geoid is the one that coincides with the equilibrium level of the oceans, with an altitude **Z = 0 m,** ideally extended across the continents as well. This geoid is therefore one of the shapes of the Earth, a gravitational reference form.




***Source :*** *https://www.britannica.com/science/geoid*

**Figure 05.** The Geoid_ Earth's gravitational reference form



***Source :*** *https://www.pngwing.com/en/free-png-sgmhs*

**Figure 06.** Geoid reference circumference

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## II.3. The internal structure of the Earth

### II.3.1. Acknowledge about the internal structure of the Earth

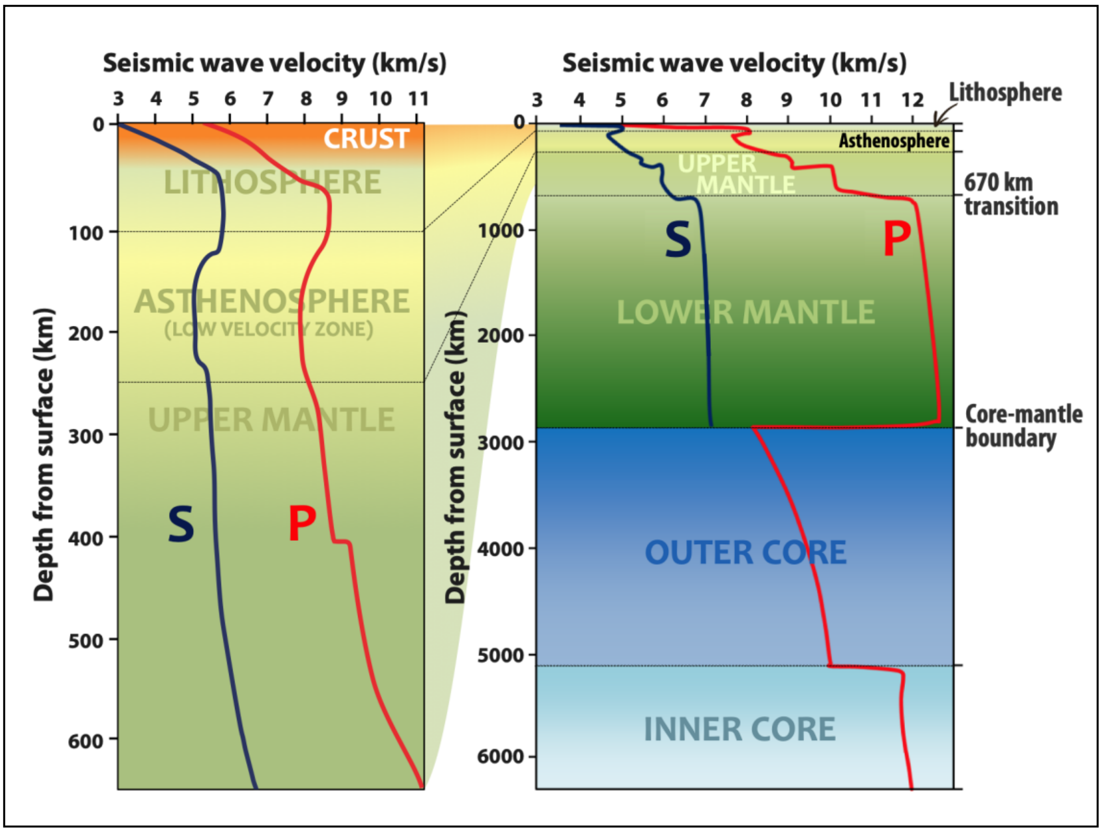
Understanding the deep structure of the Earth has been revealed through the contributions of several Earth sciences disciplines, including direct studies of drilling. However, our understanding remains incomplete because the deepest drilling has only reached a depth of **12 km,** whereas the Earth's radius is approximately **6370 km.**"

"The Earth is composed of a series of concentric layers with different chemical and/or physical properties. This internal structure of the Earth has been largely elucidated through the study of the propagation of seismic waves emitted during major earthquakes. During earthquakes, seismic waves are emitted, including:

**P waves:** which pass through all mediums,

**S waves:** which pass through solid mediums but do not propagate through liquid mediums."

After each earthquake, the results obtained regarding the velocity of P and S waves as a function of the depth of the Earth's interior remain consistent.




***Source.*** *https://opentextbc.ca/physicalgeologyh5p/chapter/imaging-earths-interior/*

**Figure 07.** Curves of seismic wave velocities as a function of Earth's depth.

These results are expressed in the form of a graph, known as the seismic wave velocity curves as a function of depth (Fig. 04). The abrupt increase in velocities Vp and Vs at certain depths, (as well as their decreases at certain levels), indicates that P waves and S waves have

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transitioned from one medium to another with very different physical characteristics, and have crossed boundaries, referred to as discontinuity surfaces, within the Earth.

**II.3.2. Seismological Models of the Earth's Internal Structure**

**II.3.2.1. Based on major and minor discontinuities:** Based on the major discontinuities highlighted by the abrupt variation in seismic wave velocity **(Figure 5)** three main parts are distinguished: the crust, with a thickness ranging from **8 to 70 km**, then the mantle, which extends from the base of the crust to a depth of **2900 kilometers**, and finally the core with a depth of **6371 km**.

***a) The crust:*** This is the outer layer that represents **1.5%** of the volume of the Earth. It is bounded at the base by the major discontinuity of **Mohorovicic** (known as the **Moho**). The crust is divided into two parts: continental and oceanic crust.

***The continental crust:*** It extends from 30 to 70 km (maximum thickness is reached under mountainous regions) and has near-surface composition like granite.

***The oceanic crust:*** It is 8 to 10 km thick and constitutes the ocean floor. Its composition is basaltic.

The base of the crust is characterized by a sudden change in density **(2.9 to 3.3 g/cm³)**. **Andrija Mohorovicic (1909)** discovered the existence of a discontinuity in the propagation of seismic waves. The seismic discontinuity marking the boundary between the crust and the mantle is called the Mohorovicic Discontinuity or Moho. The Moho is located at approximately **30 km** (up to **70 km** beneath major mountain ranges) beneath continents and approximately **10 km** beneath oceans.

***b) The mantle:*** Below the Moho lies the mantle, which occupies **82.5%** of the Earth's volume and represents **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). The average chemical composition of the mantle remains virtually unchanged, but the mineralogy of the mantle varies with depth. Within this mantle, two units can be distinguished:

***The upper mantle:*** which extends to a depth of **670 km.**

***The lower mantle:*** whose depth ranges between **670 km** and **2900 km.**

An ultimate discontinuity located at a depth of **2900 km** separates the lower mantle from the core. It is characterized by an increase in density from **5.5 g/cm³** to **10 g/cm³:** this is the ***Gutenberg Discontinuity***, discovered in **1913.**

***c) The core:*** It constitutes the central part of the Earth and represents **16%** of its volume. It is divided into two layers: the outer core (the abrupt cessation of S-wave propagation at the boundary between the mantle and the core indicates that the outer core is liquid) and the inner core, or seed (solid), separated by a discontinuity (Lehmann Discontinuity) at a depth of **5150 km.** At the boundary between these two layers, the density increases from **12.3 g/cm³** to approximately **13.3 g/cm³**, reaching **13.6 g/cm³** at the center of the Earth, at **6371 km** depth. The core is believed to be composed mainly of iron with a small amount of nickel. This

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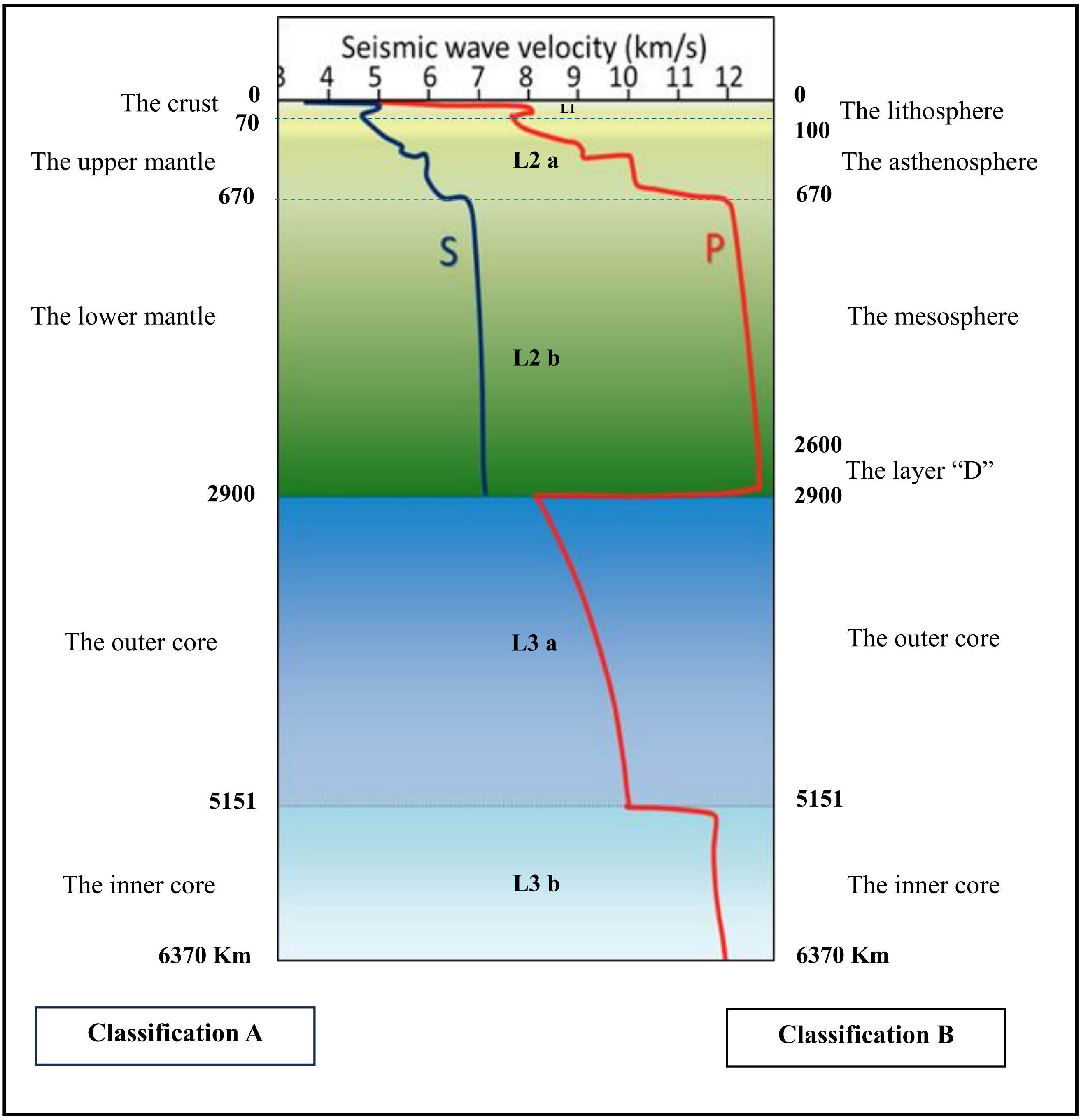
hypothesis is supported by the chemical composition of a class of meteorites (iron meteorites) considered to be the remnants of the cores of small, differentiated planets (asteroids).




**Classification A:** based on major and minor discontinuities

**Classification B:** based the physical behavior of the rocks

**Figure 08.** Internal structure of the Earth (seismic model)

### II.3.2.2. Based on the physical behavior of the layers

Taking into account the physical behavior of materials, depending on whether they behave as rigid or soft materials, we distinguish:

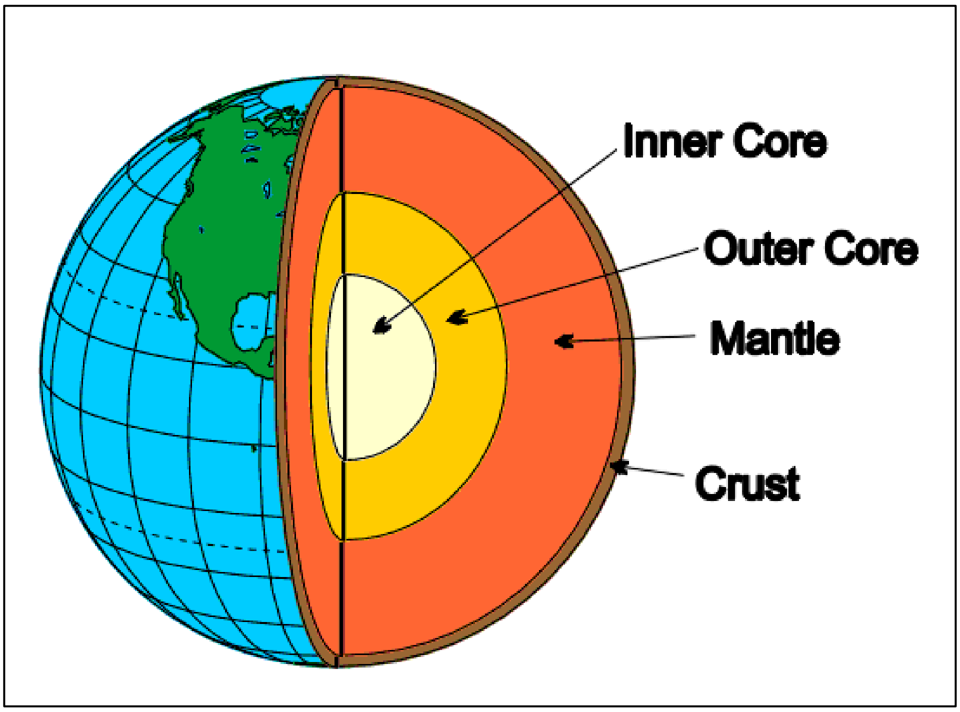
***a) - The Lithosphere:*** characterized by its rigidity and elasticity. The velocity of seismic waves is high. Its average thickness is **100 km** (**70 km** beneath oceans and **130 km** beneath continents). The lithosphere is composed of the Earth's crust (both oceanic and continental) and the rigid upper portion of the mantle.

***b) - The Asthenosphere:*** a **"soft"** or **"plastic"** zone extending from the lower boundary of the lithosphere to a depth of **670 km.** It is formed from the remainder of the upper mantle, with its upper portion being a zone of reduced seismic wave velocity **(LVZ)** with a thickness of about **200 km.** Its density is approximately **3.3 g/cm³.**

***c) - The Mesosphere:*** a rigid layer extending from **670 km** to **2900 km** in depth; characterized by a sudden increase in seismic wave velocities up to the Gutenberg Discontinuity **(2900 km),** its density also increases with depth, ranging from **3.3 to 5.5 g/cm³.**

***d) - The "D" layer:*** **The final 300 kilometers** of the lower mantle form a highly heterogeneous zone in terms of thermal and chemical properties. It is believed that the base of the mantle experiences significant chemical reactions between mantle silicates and the liquid iron of the core. This layer is named the "D" layer,

***e) - The Core:*** divided into two layers based on physical properties: a liquid outer core and a solid inner core, separated by a discontinuity (Lehmann Discontinuity) at a depth of **5150 km.**




***Source.*** *https://es.pinterest.com/pin/388436156502538971/*

**Figure 09.** Internal structure of the Earth (spherical model)

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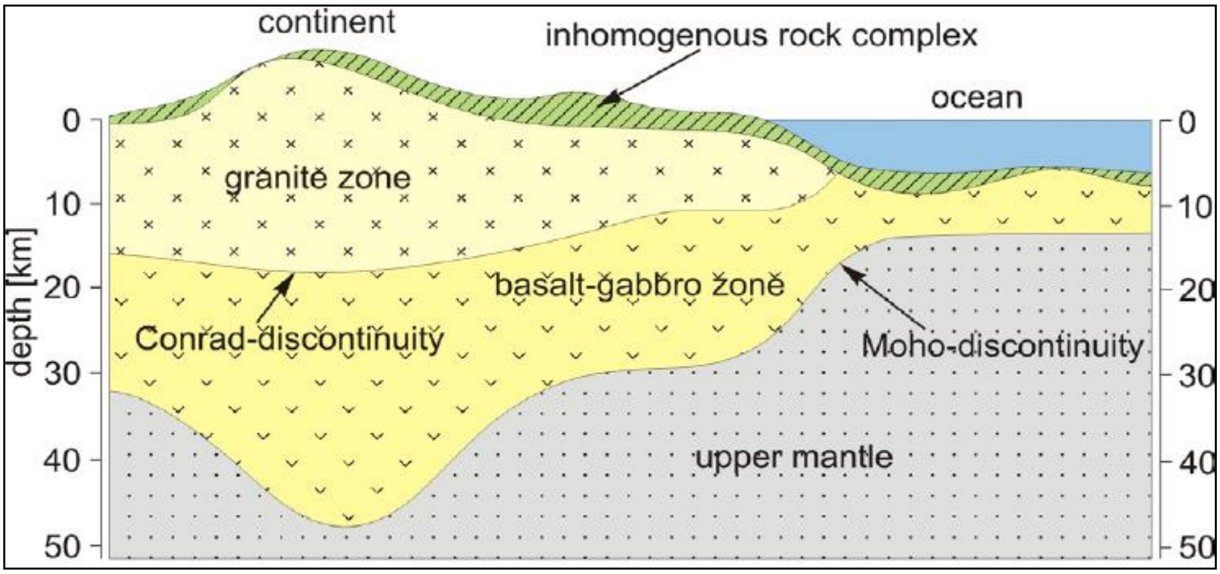
## II.4. The Earth's Crust

### II.4.1. Introduction

The superficial part of the Earth accessible by drilling or wells is called the crust. As we have already seen in the previous lesson, **71%** of the Earth's surface is covered by oceans and **29%** by land. Therefore, the Earth's crust consists of ***both continental and oceanic crust.***

The study of the propagation of seismic waves (natural or induced) provides valuable information about the thickness of this layer, the Earth's crust. The seismic wave velocity (Vp) is **5.6 km/s** in the continental crust and **6.5 km/s** in the oceanic crust. Then, a more pronounced discontinuity appears (Vp increases to **8 km/s**) at a variable depth: **8-10 km** beneath the oceans and **30-70** km beneath the continents. This is the Mohorovicic Discontinuity (or Moho), named after the scientist who identified it during the 1909 Croatia earthquake.

The continental crust and the oceanic crust differ in their thickness (typically **30 km** versus about **8 km**), average density **(2.7 versus 2.9 g/cm³),** average age of materials (mostly between **1 and 3 billion years** old versus less than **200 million years** old for oceanic crust). They also differ in the nature of the rocks that constitute them (the oceanic crust is mainly composed of **basalts** and **Gabbro,** while the continental crust is predominantly granitic). This difference in chemical composition leads to variations in their density and thus in the propagation of seismic waves passing through them. (Figure 10).




***Source.*** *The inner structure of the earth l. Völgyesi* and m. Moser, Article, 1982*

**Figure 10.** Structure of the Earth's crust (L. VÖLGYESI and M. MOSER, 1982)

The text describes the composition of Earth's crust, emphasizing that most rocks in it are silicates primarily made up of oxides, with oxygen being the most abundant element. It highlights that only chlorine, sulfur, and fluorine can form minerals in their reduced forms, resulting in their limited presence (rarely exceeding 69% in any rock). American geochemist **Frank Wigglesworth Clarke** calculated that oxygen constitutes around 47% of the Earth's crust, mainly as oxides. Key oxides include those of silicon, aluminum, iron, calcium, magnesium, potassium, and sodium. Silica, as silicates, is a major component of the crust,

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particularly in common igneous and metamorphic rocks. Clarke's findings on the percentage composition are based on analyzing 1,672 types of rocks, summarized in the following table.

**Tab.01.** Average chemical composition of the earth's crust.

| Oxyde | $SiO_2$ | $Al_2O_3$ | Cao | MgO | $Na_2O$ | FeO | $K_2O$ | $Fe_2O3$ | $H_2O$ | $TiO_2$ | $P_2O_3$ | Σ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 59.71 | 15.41 | 4.9 | 4.36 | 3.55 | 3.52 | 2.8 | 2.63 | 1.52 | 0.6 | 0.22 | 99.22 |
| * All other constituents are present in very small quantities (Total < 1 %) | | | | | | | | | | | | |

### II.4.2. Continental Crust

The geology of continents is highly complex. The continental crust is composed of **55% metamorphic rocks, 40% igneous rocks, and 5% sedimentary rocks.** Its composition is likened to that of granite, and its average density is close to **2.7.** We can distinguish the following fundamental units (Figure 11):

#### II.4.2.1. Shields or cratons

Outcrops of very ancient rocks (**+600 to millions of years** old), highly folded but eroded by erosion.

#### II.4.2.2. Platforms

Continental sectors where shields are covered by more recent marine sedimentary terrains sometimes thickened by **10 to 15 km**, with little or no folding and grooves.

#### II.4.2.3. Mountain ranges

Areas of more or less elevated relief, formed by intensely deformed rocks with folds and faults, but whose age is always less than **600 Ma.** They include:

a. ***The Caledonian chains (530 - 400 Ma).***
b. ***The Hercynian chains (400 - 250 Ma).***
c. ***The Alpine chains (250 Ma - présent).***

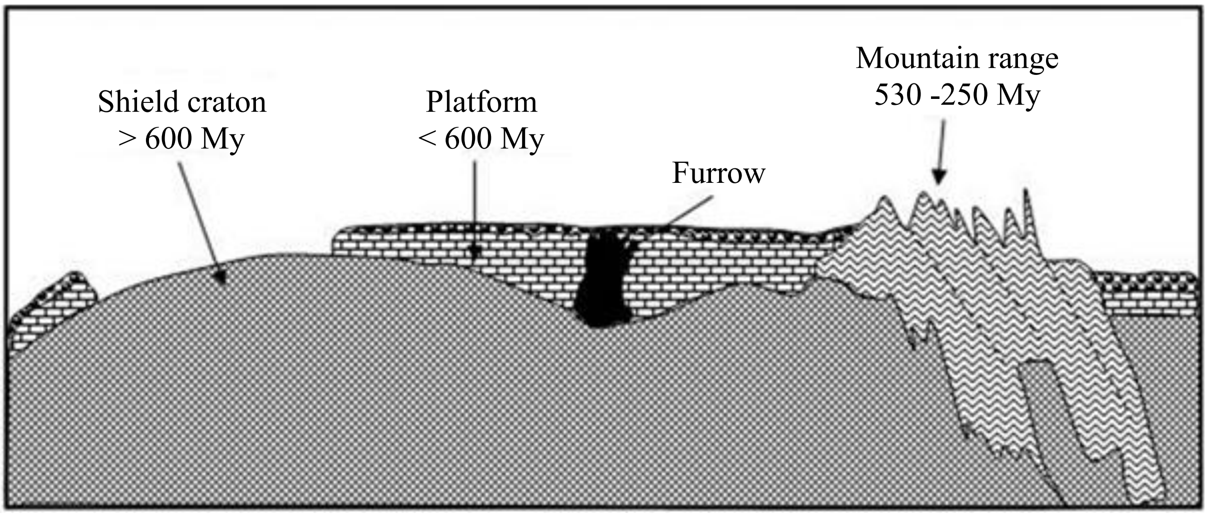


**Figure 11.** Structure and morphology of the continental crust.

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### II.4.3. Oceanic Crust

This crust essentially forms the floor and bottom of the oceans. It is much thinner **(8 to 10 km),** composed of basaltic rocks and gabbro, and is denser than continental crust with a density of **2.9 g/cm³.** The oceanic floors are now +/- well-known thanks to advances in drilling techniques and deep-sea dives. The structure of the ocean floor consists of: (Figure 12).

#### II.4.3.1. The continental shelf

Which is the submerged edge of the continent. It is a platform with depths gradually increasing from 30 to about 200 m. It varies in extent depending on the region and can range from a **few meters** to **several thousand kilometers.**

#### II.4.3.2. The continental slope (or shelf break)

Corresponds to the transition zone between the continent and the ocean. It is the outer limit of the continental shelf. It is marked by a steep slope, and the depth descends rapidly from about **250 m to 3000 m.**

#### II.4.3.3. The continental rise

It is located at the foot of the continental slope where materials from the continent are deposited.

#### II.4.3.4. The abyssal plain

Is a nearly flat expanse with a very gentle increase in depth from **3000 m to about 5000 m**, covered with fine sediments constituting the ocean floor on the oceanic crust.

#### II.4.3.5. The mid-oceanic ridge

Or ridge is a considerable relief generally found at the center of oceans and occupies nearly one-third of the marine floor's surface area. Some peaks may rise above sea level with a relative height of more than **5000 m** compared to the abyssal plain.

### II.4.4. Continental Margins

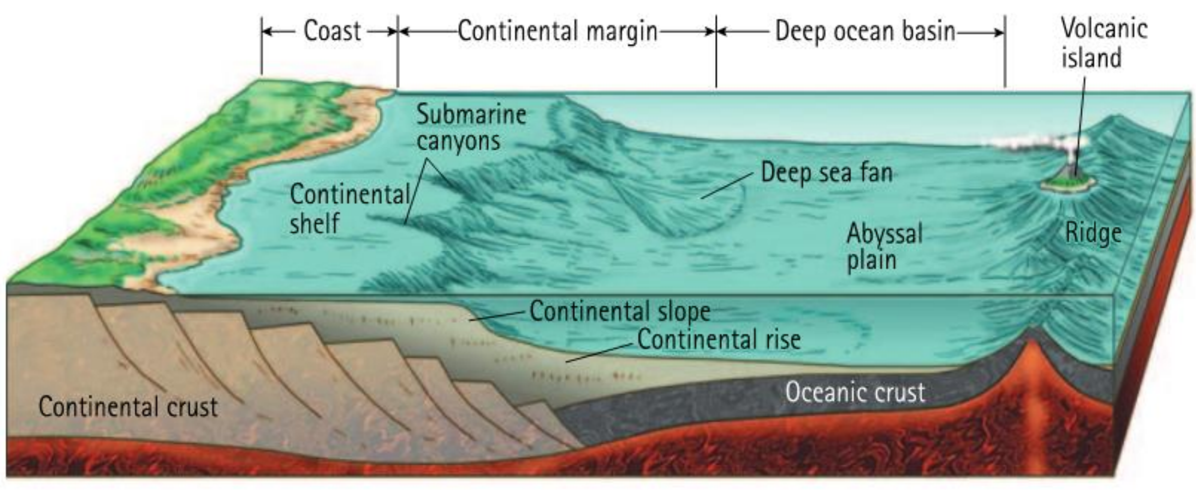
These are the boundaries of the marine domain (the ocean-continent boundaries); they are also called continental margins. Depending on their structure, we distinguish between passive, or stable, margins, and active margins.

#### II.4.4.1. Active continental margins

These have a deep oceanic trench **(-8 to -11 km)** bordering the continents. This type of margin is the site of intense seismicity and volcanism (e.g., the Western Pacific margin). These margins play a significant role in plate tectonics (subduction). The continental shelf and rise are reduced or absent. From the coastline, the continental slope plunges to a depth of **5000 to 10,000 m** to form a deep oceanic trench **11 km** wide (e.g., volcanic archipelago east of the Philippines).

#### II.4.4.2. Passive continental margins

Passive margins include a shallow continental shelf, maximum **200 m** deep, extending several tens or hundreds of kilometers and corresponding to the extension of the continent into the sea. The shelf is bordered by a gently sloping **(about 5°)** continental slope, descending to several thousand meters in depth, which is connected to the bottom of the ocean basin by a gentler sloping rise.




***Source.*** *https://geologylearn.blogspot.com/2015/07/ocean-basins.html*

**Figure 12.** Structure and morphology of the oceanic crust.

# Chapter II

# External Geodynamics

**I. Erosion**
**II. Sedimentary Deposits and Rocks**
**III. Concepts of Stratigraphy and Paleontology**

# I. Erosion

## I.1. Definition

Erosion is a physical or chemical phenomenon that shapes the landscape, most often through the action of wind, water, temperature changes, or gravity. It usually takes a long time for the result of erosion to become apparent.

## I.2. Factors controlling erosion

Generally, erosion depends on the following factors:

### I.2.1. The nature of the erosive agent

Erosive agents (wind, running water, temperature) each have their own methods of destruction. They thus shape the landscape into characteristic landforms.

### I.2.2. The nature of the rocks

Different rocks, when exposed to the elements, erode more or less easily depending on their nature. A hard rock (granite) will erode more slowly than a soft rock (clay).

### I.2.3. The shape given to the region by tectonics

Erosion does not attack folded regions, faulted regions, anticlines, synclines, etc., in the same way.

### I.2.4. Climate

Climate determines the intensity of erosion processes by amplifying the action of certain erosive agents and reducing the action of others. Two types of erosion processes have different importance depending on the climate: mechanical erosion processes, which predominate in cold and dry climates, and chemical erosion processes, which predominate in hot and humid climates.

### I.2.5. Duration of erosion work

Erosion generally acts extremely slowly. Therefore, an old mountain will not have the same shape as a young mountain.

## I.3. Main erosion agents and their actions

The various erosion processes listed below are actually combined with a force that causes the erosion materials to fall: gravity.

### I.3.1. Action of Heat and Cold

#### I.3.1.1. Mechanical Expansion

A rock block located deep underground is subjected to high pressure from the overlying rock layers. When erosion removes these overlying rocks, the pressure on the rock block in question decreases, causing the block to expand. This results in an increase in volume accompanied by the formation of fissures (also called joints). These fissures subsequently facilitate erosion processes.

### I.3.1.2. Thermal Expansion

When it is very hot, rocks expand; conversely, when it is very cold, they contract. In desert areas, the daily temperature variation can be significant (several tens of degrees difference between night and day). These repeated alternations of expansion and contraction can cause rocks to fracture.

### I.3.1.3. Frost Shattering

This is the fragmentation of rock due to the alternating freezing and thawing cycles. Water is present in the pores and fissures of rocks. When this water freezes, its volume increases, increasing the pressure within the rock. When the water thaws, the pressure decreases. After several freeze-thaw cycles, the fissures enlarge, and debris detach from the rock.

### I.3.2. Action of Wind

### I.3.2.1. Wind Erosion

Wind is particularly active in arid regions, such as hot deserts or cold deserts, and along certain coastal areas. It contributes to erosion through two processes: deflation and abrasion.

***a. Deflation:*** This is the action of wind sweeping away and carrying the lightest particles from the exposed surfaces of deserts. It is favored by the absence of vegetation cover. The wind leaves behind the coarser fragments, giving most deserts the appearance of vast fields of rocks known as "regs."

***b. Abrasion:*** of rocks is caused by sand striking against rock surfaces. It is particularly active near the ground, where sand is most abundantly transported. The phenomenon is well-known for the erosion of the base of telegraph poles in desert regions. If abrasion acts on rocks of different hardness, the softer ones are more rapidly excavated while the harder ones are left more prominent.

### I.3.2.2. Wind Transport

In regions composed of loose, dry formations without vegetation cover, the quantity and size of transported sand depend on the strength of the wind. Generally, there are three possibilities:

***a. Dust particles are carried suspended in the air,*** they can be lifted thousands of meters and fall very slowly, covering considerable distances. For example, the snow in the Alps is sometimes tainted by Saharan dust.

***b. Coarser grains are transported by saltation***, just above the ground, numerous vortices occur that are capable of lifting sand grains.

***c. The largest grains move by rolling on the ground,*** propelled by the wind and struck by the falling grains in saltation. Through impact, a grain can set in motion a grain six times its diameter. The movement of grains produces ripples perpendicular to the direction of the wind.

### I.3.2.2. Wind Deposition

In addition to being a significant factor in erosion, wind also contributes to accumulation. Indeed, sand carried by the wind accumulates in the form of dunes in certain regions. This leads to the formation of sand deserts, called ergs.

### I.3.3. Action of Water

Running waters, regardless of their origin, always tend to concentrate. They concentrate in an existing valley or in channels. From one channel to another, from one valley to another, water tends to flow towards the sea, at the lowest level it can reach. Water is both an agent of erosion, transport, and deposition.

#### I.3.3.1. Erosion by Running Water

a. ***Vertical Erosion:*** the river deepens its valley and retreats its slopes. The valley takes on a "V" shape profile.
b. ***Lateral Erosion:*** when the slope is gentle, rivers form meanders. Erosion is more significant on the concave bank, which becomes steep, while sediment is deposited where the velocity is lower, on the convex bank, often forming a gently sloping beach. Consequently, the valley slopes retreat gradually, and the valley widens.

#### I.3.3.2. Water Transport of Alluvium

Water has a transport capacity, which varies depending on location and time, representing the total mass of alluvium a river can carry. It is also characterized by its competence, varying according to location and time, which is the maximum size of alluvium a river can transport.

#### I.3.3.3. Deposition of Alluvium by Water

At certain times and in certain places, the river is no longer capable of transporting the alluvium it carries, usually due to a lower slope or reduced velocity. Therefore, it deposits them. These deposits form alluvial plains (flat surface located along the riverbanks and covered with alluvium). They can also form alluvial fans and deltas at the mouths of rivers or lakes.

Areas of alluvial deposition generally correspond to highly fertile lands, such as the Nile Delta in Egypt. However, these areas are often flood-prone and sometimes unstable, requiring human interventions to make them suitable for use.

### I.4. Conclusion

In an erosion process, there are three distinct phases:

***A phase of rock erosion,*** rocks are mechanically or chemically attacked.

***A phase of transportation*** of rock debris by wind or water.

***A phase of accumulation,*** the transported debris accumulates to form an alluvial fan, a plain, or a delta. They also deposit in underwater basins, forming sediments.

These phases illustrate the dynamic nature of erosion, where the landscape is continuously shaped by natural forces over time.

## II. Sedimentary Deposits and Rocks

### II.1. Introduction

Particles are most commonly transported by water. However, wind also carries them. They accumulate in the low points of the terrain or at the bottom of the sea. Regardless of the environment—marine, lacustrine (lakes), fluvial (rivers and streams), or terrestrial (deserts)—the particles eventually settle in successive layers, forming sedimentary deposits. Sedimentary deposits thus appear in the form of successive layers, with the lowest layers corresponding to the oldest deposits.

### II.2. Depositional Environments

Elements destined to form sediment are typically transported initially in solid or solution states. They then settle or precipitate in a depositional environment. A depositional environment is a geomorphological unit of a determined size and shape where a set of physical, chemical, and biological factors are sufficiently constant to form a characteristic deposit; examples include lacustrine environments, and deltaic environments.

However, these deposits are only transient in continental environments due to gravity's action. Sooner or later, they are picked up and ultimately transported to the lowest point, the sea, to form sedimentary basins. Therefore, continental sedimentary environments are local and transient compared to marine environments, which provide the majority of sedimentary rocks.

### II.3. Sedimentary Rocks

#### II.3.1. Definition

Sedimentary rocks, also known as exogenous rocks, form at the Earth's surface. These rocks result from the accumulation of sediments, often deposited in layers or beds, called strata. They are the product of diverse sediment accumulation, including solid elements (rock fragments, shell debris, etc.) and/or chemical precipitates from aqueous solutions. Generally, sedimentary rocks cover about 90% of the Earth's continental surface, but they make up only about 5% of its total volume.

The sedimentary material can originate from three sources:

***a) Terrigenous Source:*** When the particles come from the erosion of the continent

Erosion → Suspension → Transport Sedimentation → Detrital Sediment

***b) Allochthonous Source:*** When the particles come from the sedimentary basin, mainly shells or shell fragments of organisms.

***c) Orthochthonous Source:*** Corresponding to chemical precipitates in the sedimentary basin or within the sediment during diagenesis.

Erosion → Solution Transport → (Water) Organism Death → (Precipitation / Sedimentation) Biological Sediment

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### II.3.2. Formation of Sedimentary Rocks

Four processes lead to the formation of sedimentary rocks (Figure 13 and 14):

#### II.3.2.1. Surface Weathering

Surface weathering processes are of two types: mechanical and chemical. Mechanical processes involve the physical breakdown of rock, such as the action of freeze-thaw cycles, where water expands as it freezes in fractures, gradually opening them. Chemical weathering is also significant: several silicates, such as feldspars often abundant in igneous rocks, are easily attacked by rainwater, transforming into clay minerals to form mud. The combined action of these two mechanisms produces particles of all sizes. This is the starting point of the general sedimentation process.

#### II.3.2.2. Transportation

In addition to wind and, especially, water, which transport particles. Depending on the mode and energy of transport, the resulting sediment will exhibit various sedimentary structures. Particle transport can take a long time. Ultimately, all particles must end up in the ocean basin.

#### II.3.2.3. Sedimentation

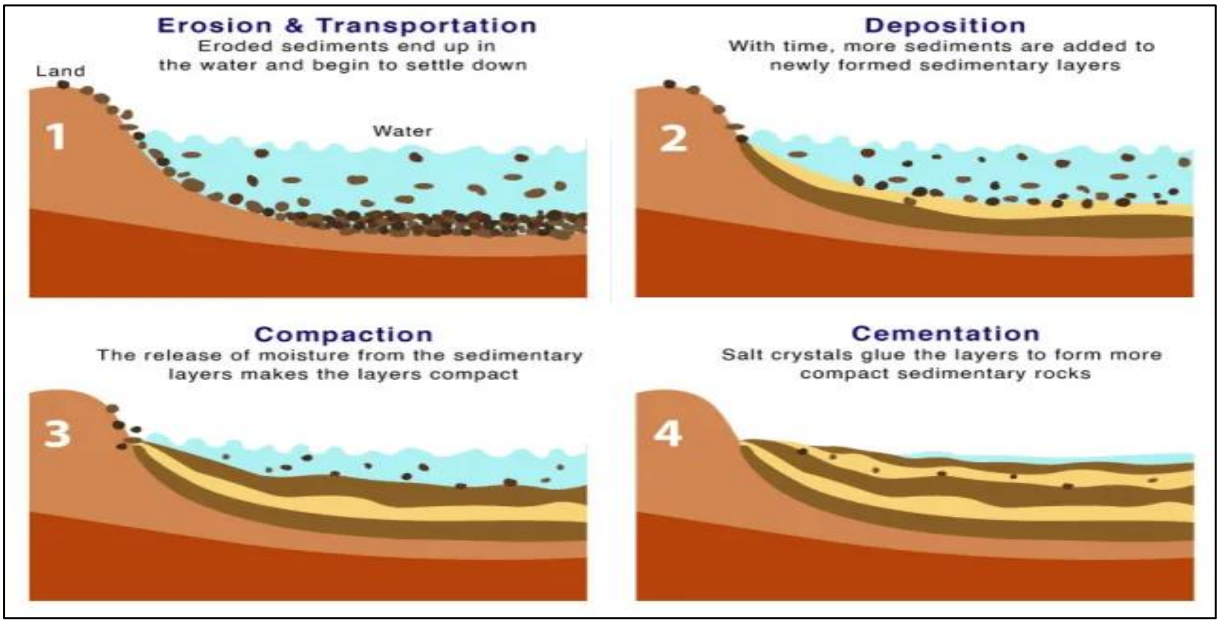
All transported material accumulates in a sedimentary basin, ultimately the marine basin, to form a deposit. Sediments are deposited in successive layers, with the composition, particle size, color, etc., varying over time depending on the nature of the sediments brought in. This is why sedimentary deposits are stratified, and sedimentary rocks derived from these deposits make up stratified landscapes.

#### II.3.2.4. Diagenesis

The transformation of sediment into rock occurs through the processes of diagenesis. Diagenesis encompasses all the chemical and mechanical processes that affect a sedimentary deposit after its formation. Diagenesis begins on the seafloor, in the case of marine sediment, and continues throughout its burial, as other sediments gradually cover the deposit and bring it deeper under several tens, hundreds, or even thousands of meters of material. Diagenetic processes are varied and complex: they range from sediment compaction to cementation, including phases of dissolution, recrystallization, or replacement of certain minerals.

***Cementation***

The diagenetic process primarily responsible for the transition from sediment to rock is cementation. This is a relatively simple process: if water circulating within a sediment, for example, sand, becomes supersaturated with respect to certain minerals, it precipitates these minerals into the pores of the sand, thereby cementing the sand particles together; this results in a sedimentary rock called sandstone. The degree of cementation can vary, resulting in either a friable rock or a very solid rock. Cementation can occur early on the seafloor (early diagenesis), or it may require burial under several hundred or even a few thousand meters of material (late diagenesis).




***Source.** https://eschooltoday.com/learn/sedimentary-rocks/*

**Figure 13.** Diagenesis phenomenon

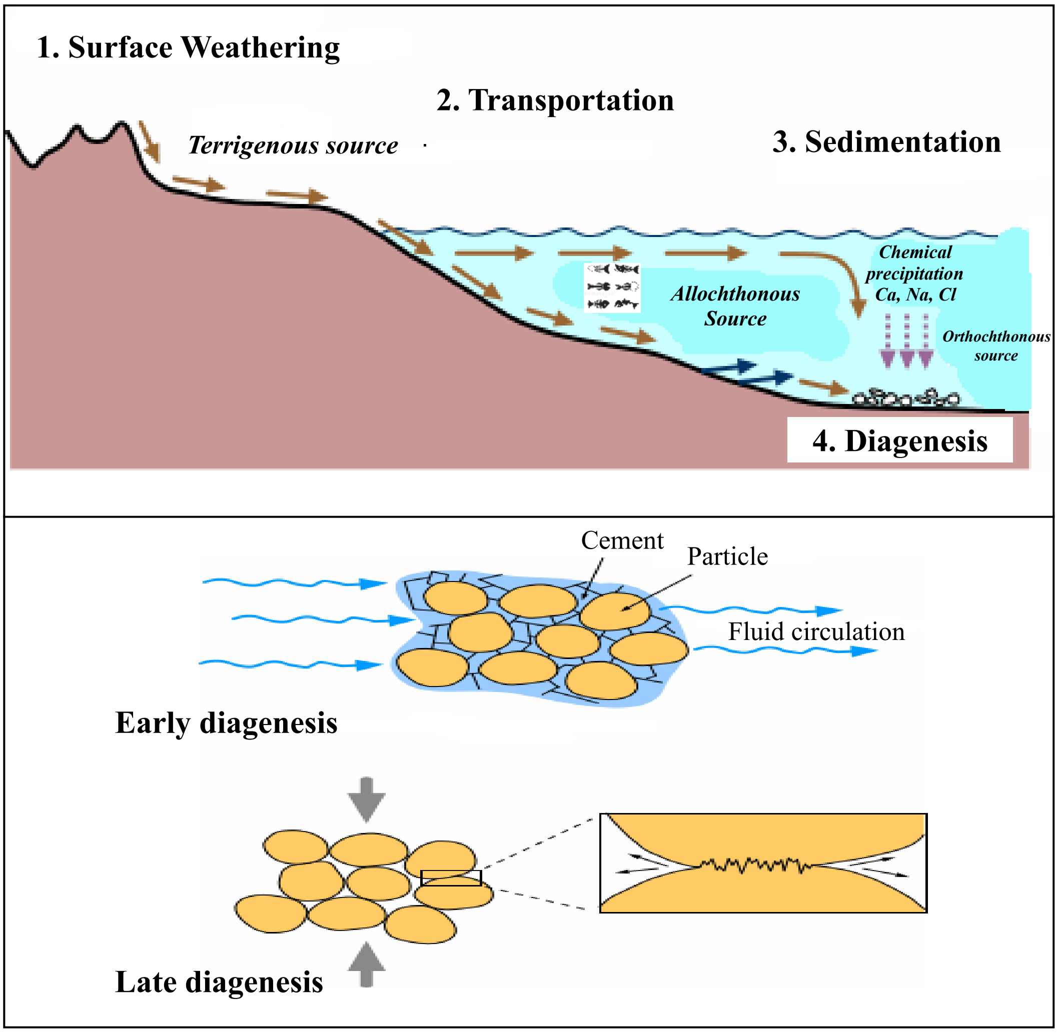



**Figure 14.** The diagenetic process (cementation)

The induration (cementation) of a sediment can occur early in its diagenetic history, before the stacking of several meters of sediments (pre-compaction), or later, when the pressure on the particles is high due to the stacking of sediments.

### II.3.3. Classification of Sedimentary Rocks

Sedimentary rocks are of different types, depending on the origin of the sediments that compose them:

#### II.3.3.1. Detrital Rocks

Examples of detrital rocks: sandstone, shale, clay.

They result from the accumulation and compaction of debris from the breakdown of other rocks. The process of transformation into rock is called diagenesis (or lithification).

In theory, sediments deposited at the bottom of the sea will be classified based on their size (grain size). The larger debris will settle closer to the coast, while finer debris will settle farther offshore, in less turbulent regions. The nature of the resulting rocks will therefore depend on the grain size of the sediments. The following grain size classes are distinguished:

***Pebbles (boulders, cobblestones, gravel, pebbles):*** > 2 mm

***Sands:*** from 0.05 to 2 mm

***Silts:*** from 0.002 to 0.05 mm

***Clays:*** < 0.002 mm

#### II.3.3.2. Organogenic Rocks

Examples of organogenic rocks: chalk, limestone.

After the death of marine organisms, the soft parts decay or are eaten, while the hard parts (shells, skeletal pieces) remain. Therefore, organogenic rocks result from the accumulation of these organism debris on the seafloor.

#### II.3.3.3. Organic Rocks (or Carbonaceous)

Examples of organic rocks: coal, petroleum, phosphate.

Organic rocks result from the transformation of plant or animal organic matter and are rich in carbon.

#### II.3.3.4. Evaporitic Rocks

Examples of evaporitic rocks: gypsum, salt (NaCl).

Evaporitic rocks originate from the precipitation of salts due to the evaporation of salty water. This precipitation results from the evaporation and concentration of salts until the point of saturation.

### II.3.4. Concepts and Methods of Studying Sedimentary Rocks (Figure 15)

The concepts and methods of studying sedimentary rocks are based on four fundamental principles:

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***Principle of Original Horizontality***

***Principle of Superposition***

***Principle of Lateral Continuity***

***Principle of Faunal Succession and Paleontological Correlation***

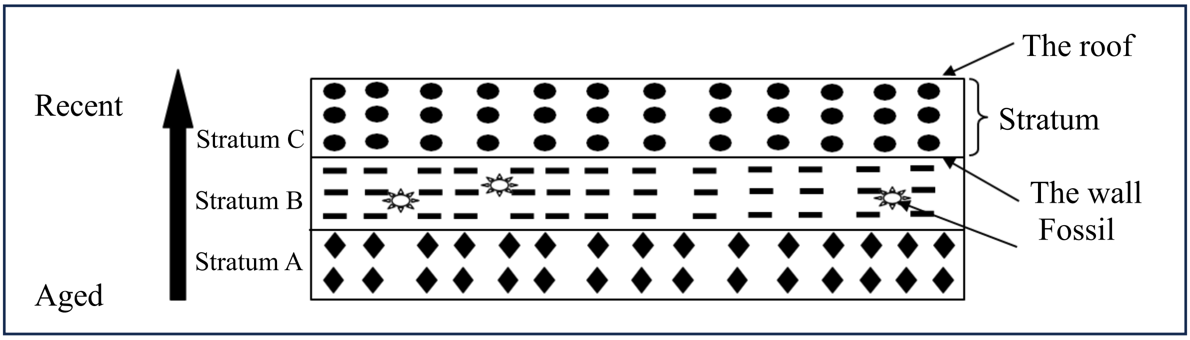


**Figure 15.** Explanatory diagram of a sedimentary sequence

***Principle of Original Horizontality:*** Layers result from sedimentary deposition, so their surface must be horizontal.

***Principle of Superposition:*** Layers are stacked on top of each other in chronological order from bottom to top (a layer is younger than the one it overlays).

**Principle of Lateral Continuity:** A continuous layer (bounded by two stratigraphic boundaries) is of the same age throughout its extent, even if its lithology changes.

**Principle of Faunal Identity:** Two lithostratigraphic units containing the same fossils are considered to be of the same age.

## III. Concepts of Stratigraphy and Paleontology

### III.1. Notions of Stratigraphy

#### III.1.1. Definition

Stratigraphy is the study of the succession of layers or rock formations in a region, which allows for the reconstruction of geological events. For example, the nature of sedimentary rocks informs us about the sedimentation environment and how this environment evolved over time. Therefore, stratigraphy provides an explanation of the organization and arrangement of various elements of the Earth's crust.

#### III.1.2. Objectives of Stratigraphy

The objectives of stratigraphy are:

**a)** Locating geological bodies in a 4-dimensional system: the three dimensions of space and the dimension of time. It must assign rocks a place in space (formation environment and initial geographical location) and in time (age).

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**b)** Establishing relationships between geological units and phenomena identified in different locations (lithological, paleontological, event correlations, and other local, regional, or global values).

**c)** Reconstructing the geological history of the Earth through detailed stratigraphy, combined with complementary approaches from geophysics, geochemistry, tectonics, etc.

## III.2. Notions of Paleontology

### III.2.1. Definition

The term paleontology (from Greek: palaios = ancient, ontos = being, logos = study) was coined in 1822 to refer to the science that studies the remains (fossils) of organisms that populated the biosphere during geological times.

### III.2.2. Objectives of Paleontology

Paleontological studies are either fundamental or applied. Thanks to knowledge of the current living world, the contribution of paleontology is crucial in several fields such as geology, biology, and even ecology.

### III.2.3. Basic Notions of Paleontology

#### III.2.3.1. Fossil

Since the appearance of life, organisms that have occupied different domains of the biosphere have left signs of their existence in various forms. These signs are closely related to the nature of the organism, its way of life, its habitat, the environment, and the mechanism of fossilization.

A fossil can take the form of:

**a)** ***Anatomical remains of animals or plants:*** mummies, hard parts, imprints of hard parts, internal molds, external molds,

**b)** ***Biogenic remains:*** fecal pellets or eggs,

#### III.2.3.2. Types de fossile

***a. Stratigraphic Fossil (good fossil)***

Characterized by:

- Wide geographic distribution;
- Rapid evolution rate;
- High frequency;
- Easy determination (recognition).

***b. Facies Fossil***

Characterized by:

- Limited geographic extent;
- Possible polymorphism depending on environmental conditions;
- Low evolution rate.

### III.2.3.3. Fossilization

Fossilization is the set of mechanisms and conditions that ensure the preservation of signs and remains of organisms (fossils). Fossilization is a very particular phenomenon because the probability of fossil preservation is about 1/5000. This low frequency arises from the fact that fossilization requires specific conditions:

The organism must have hard or mineralized parts.

Rapid burial by preferably fine sediments, a necessary condition to isolate the trace or remains from the destructive action of external agents, which rarely occurs.

The remains enclosed in sediment will undergo, along with the sediment, the effects of diagenetic processes (post-deposition alterations). The impact of these processes will either result in total or partial preservation of the remains or their definitive destruction.

### III.2.3.4. Species

The species is the fundamental unit of classification of living organisms (taxonomy). A species is thus a reproductive community of populations that occupies a particular niche in nature.

***a. Biological Species (bio-species):*** defined as a group of individuals incapable of reproducing with individuals of other species.

***b. Paleontological Species:*** materialized by a set of morphologically identical individuals.

***c. Individual:*** considered as one of the temporary carriers of a portion of the species' genetic heritage.

### III.2.3.5. Lifestyle and Fossilization

In present-day marine organisms, three lifestyles are distinguished (planktonic, nektonic, and benthic):

***a. Planktonic organisms:*** float at the surface, in the euphotic zone (phytoplankton and zooplankton), their dispersion is ensured by marine currents.

***b. Nektonic organisms:*** swimmers.

***c. Benthic organisms:*** live on the depositional surface (epibionts), attached (sessile) or mobile (vagile), and those that live buried in the substrate (burrowers or endobionts).

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# Chapter III

# Internal Geodynamics

**I. Tectonics: Ductile and Brittle (Folds and Faults)**
**II. Seismology**
**III. Volcanology**
**VI. Plate Tectonics**

# I. Tectonics: Ductile and Brittle (Folds and Faults)

## I.1. Introduction

When subjected to stress, the Earth's crust deforms. Stress can be simply defined as a force applied to a certain unit of volume. Every solid has a force to resist stress. When stress exceeds the material's resistance, the object is deformed, resulting in a change in shape and/or volume.

## I.2. The Main Types of Deformation of the Earth's Crust (Figure 16)

Stresses can deform the Earth's crust. Deformation can be permanent or temporary. For example, the breaking of a vase dropped on the ground is permanent, while the deformation of a tennis ball due to impact on the racket is temporary. There are three main types of deformation that affect the Earth's crust: elastic, plastic, and brittle. The following diagram shows the general relationship between stress and deformation.

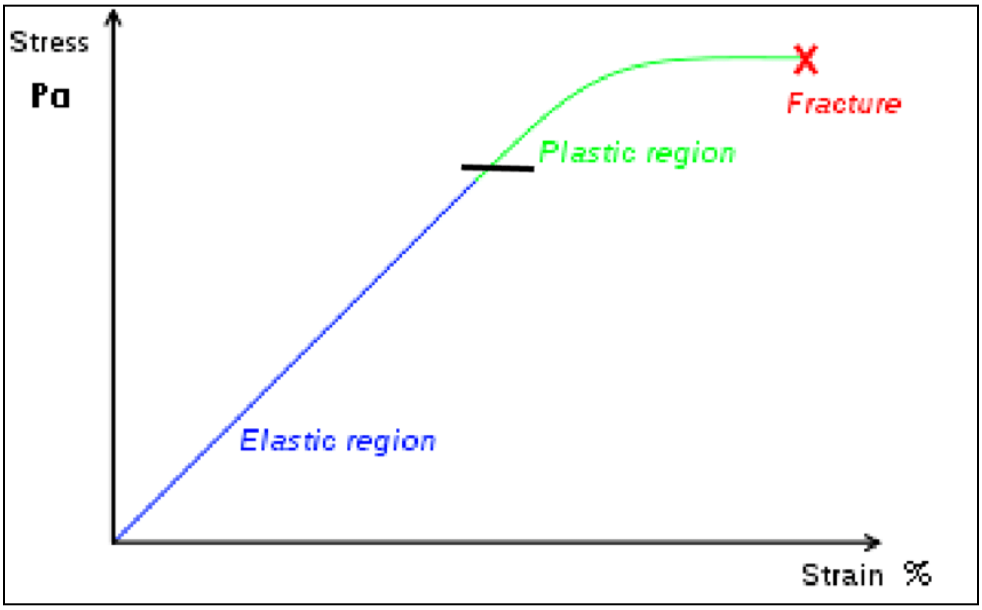


**Figure 16.** Graph showing the general relationship between stress and strain

The initial response of a material to stress is elastic deformation. When the stress is released, the material returns to its original shape and volume (e.g., a stretched rubber band or a tennis ball struck by a racket). The energy stored in the material during deformation is dissipated when the stress is released; this energy is transformed, for instance, into motion in the case of the tennis ball. In the diagram, the stress-deformation relationship is linear in the case of elastic deformation.

At a certain point during elastic deformation, the stress-deformation relationship becomes nonlinear: the material has reached its elastic limit. If the stress exceeds this limit, the material is permanently deformed; this results in plastic deformation (e.g., squashing a ball of modeling clay) or brittle deformation (e.g., glass breaking). In the case of plastic deformation, all the energy is used to deform the material. With an increase in stress, the material reaches a second threshold, its breaking point, and it fractures; this is brittle deformation. When a material is subjected to very rapid stress rates, plastic deformation is minimal or even nonexistent.

**I. 3. Types of Stress Deforming Rocks**

Sedimentary rocks are originally laid down in roughly horizontal layers as they result from the transformation of sediments deposited horizontally. However, they are often found tilted, deformed, affected by folds and faults.

The stresses responsible for deforming rocks in the Earth's crust have multiple sources. Deformations most often result from the movements of lithospheric plates, which translate into stresses that change the shape of rocks, their volume, and, in some cases, their chemical and mineralogical composition.

There are fundamentally two types of stresses that deform rocks: compressive stresses and tensile stresses.

**I.4. Concept of Tectonics**

Tectonics is a discipline of Earth Sciences that studies the structures, deformations, and movements affecting geological terrains after their formation, as well as the mechanisms and phenomena responsible for them. In general, rocks, or geological layers, can undergo two types of deformation:

They break. This is referred to as brittle tectonics, which gives rise to fractures.

They fold, forming folds. This is referred to as ductile tectonics.

**I.4.1. Ductile Tectonics (Folds)**

**I.4.1.1. Definition**

This type of tectonics gives rise to folding or folds. These correspond to undulations of geological layers under the influence of continuous compressive stress.

A fold is a flexible deformation of geological layers. It can be convex: this is an anticline, or concave: it is a syncline.

- ***An anticline:*** is a convex fold (bulge), with the oldest geological layers occupying the center. Generally, the term "anticline" considers the stratigraphic notion (superposition); the lowest layer, occupying the core of the anticline, is the oldest.
- ***A Syncline:*** A syncline is a concave fold with the youngest geological layers occupying the center. The oldest layer is found on the outside of the fold.

Fold generally possesses:

- **Hinge:** this is the region of maximum curvature. We speak of anticlinal hinge and synclinal hinge.
- **Fold Axis and Axial Surface:** the plane and line passing through the hinge.
- **Core or trough of a fold:** represented by the innermost layers of the fold.
- **Flanks:** parts of the fold on either side of the hinge.

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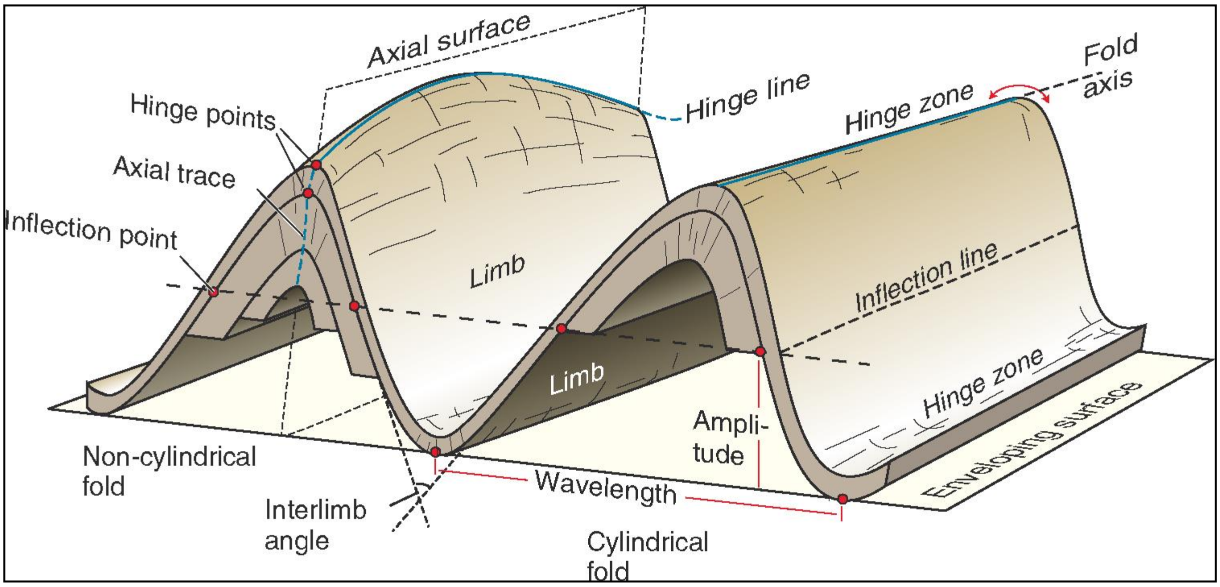


**Figure 17.** Summary diagram shows the main constituent elements of a fold

### I.4.1.2. Classification of Folds

The complexity of fold shapes leads to a descriptive classification referring to one or more elements of the observed fold, which may seem quite cumbersome. However, geologists have classified folds based on different criteria. The following classification is based on the position of the fold's axial plane: vertical, oblique, or nearly horizontal. Generally, the symmetry in the cross-section of the fold flanks allows for distinguishing between straight folds, overturned folds, inclined folds, recumbent folds, chevron folds, and fault-related folds, including:

***Symmetrical fold:*** vertical axial plane.

***Asymmetrical fold:*** slightly inclined axial plane.

***Over fold:*** strongly inclined axial plane.

***Laminated fold:*** strongly inclined axial plane and the thickness of the deformed layers varies.

***Fault fold:*** overturned or recumbent fold whose limb has been fractured.

***Recumbent folds:*** horizontal axial plane.

See Figure 18

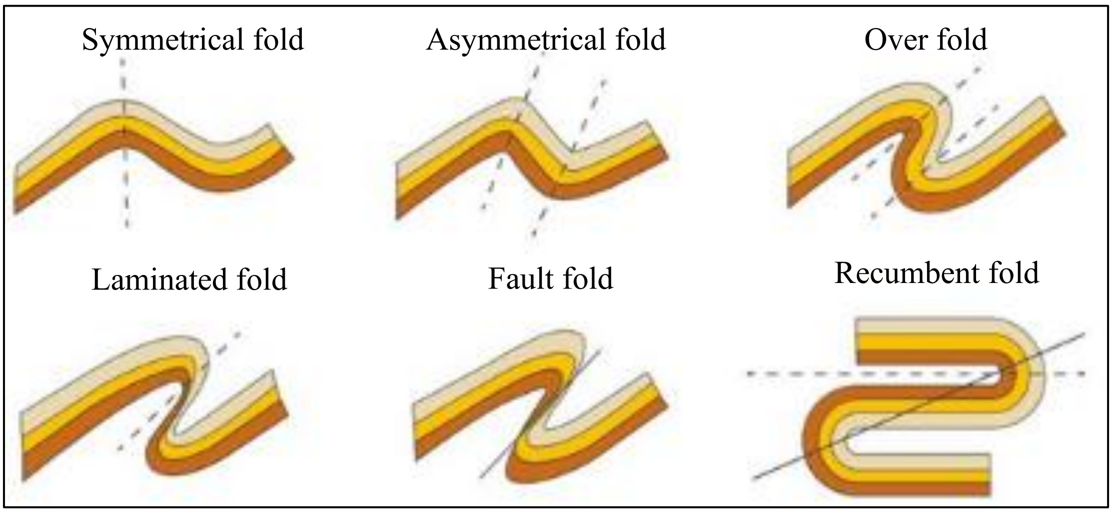


**Figure 18.** Types of Folds According to the Position of the Axial Plane

### I.4.2. Brittle Tectonics (Faults)

### I.4.2.1. Definition

This type of tectonics gives rise to fractures of several categories, we distinguish joints and faults.

- ***Joints:*** Joints occur when rocks break into two or more blocks without these blocks moving away from each other. There is no relative displacement.
- ***Faults:*** A fault is a fracture of rock layers with displacement between the two parts. The rocks are fragmented and displaced relative to each other.

A fault offsets two blocks relative to each other; the two parts separated by the fault are called compartments. Generally, there is a whole terminology around faults:

***a. Hanging wall and footwall:*** Typically, the compartment above the fault plane is called the hanging wall, and the one below is called the footwall.

***b. Fault plane:*** Surfaces generated by faults either obliquely or vertically.

***c. Fault gouge:*** Section of the fault plane that has been polished mechanically or affected by grooves, scratches, or striations oriented in the direction of movement. Morphologically, it is the visible part on the surface of the fault plane.

***d. Fault throw:*** Magnitude of the relative displacement of one compartment compared to the other along the fault plane. There are:

***d1. Vertical throw (Vt):*** It is the difference in altitude between the two blocks.

***d2. Horizontal lateral throw (HLT):*** Measures the sliding of the blocks against each other.

***d3. Horizontal transverse throw (HTT):*** Measures the separation between the blocks.

***e. Fault dip:*** The side towards which the raised compartment lip is turned.

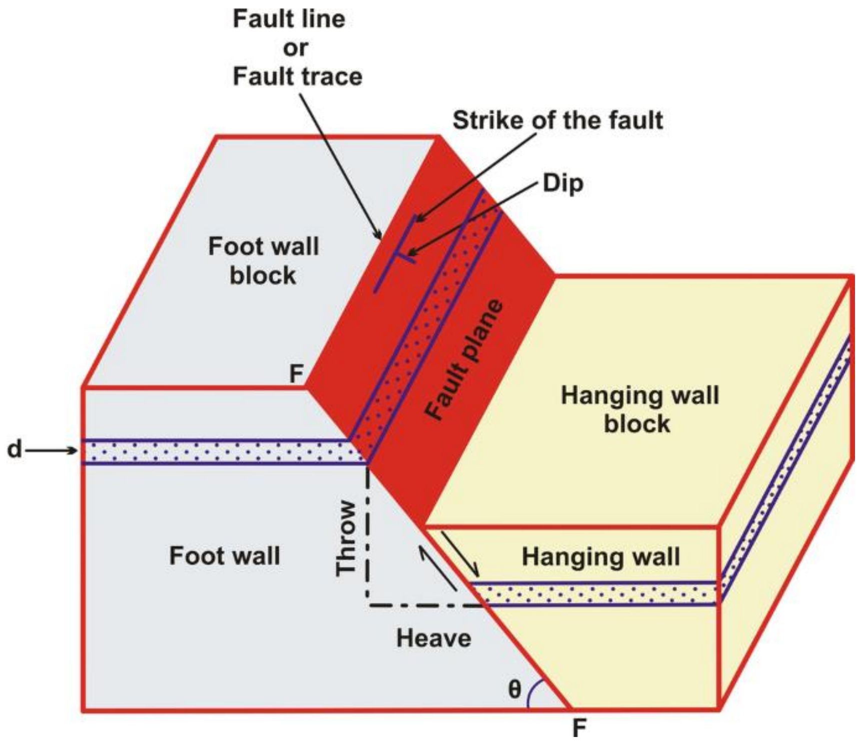


**Figure 19.** The main constituent elements of a fault

### I.4.2.2. Fault classification

***a. According to their dip:*** vertical or oblique faults.

***b. According to their displacement:*** we have

***b1. Normal fault:*** Tensional stresses produce normal faults; the hanging wall moves downward relative to the footwall, and the horizontal transverse displacement corresponds to extension. (Figure 20).

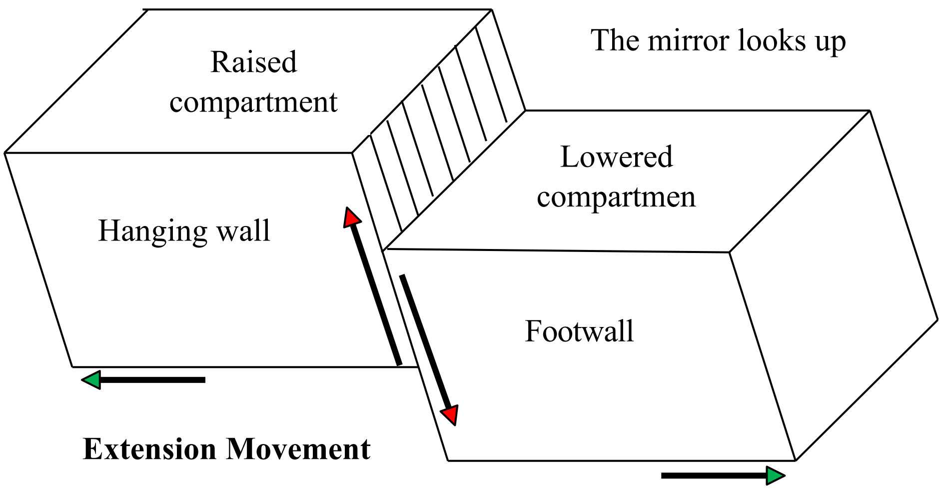


**Figure 20.** A normal fault.

***b2. Reverse fault:*** (compression fault = compressive fault), where the transverse horizontal rejection corresponds to a shortening (there is then an overlap of the compartment located above the fault plane on the other compartment; the roof rises relative to the wall ) (Figure 21).

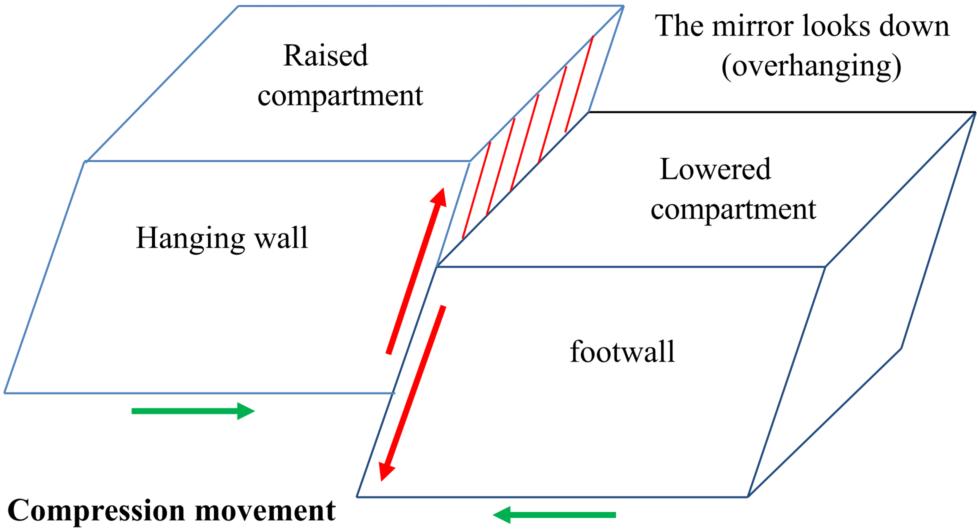


**Figure 21.** A reverse fault

***b3. Strike-slip faults (or shear faults):*** Strike-slip faults, also known as shear faults, represent a particular case where two compartments slide past each other horizontally within a horizontal plane. (Figure 22).

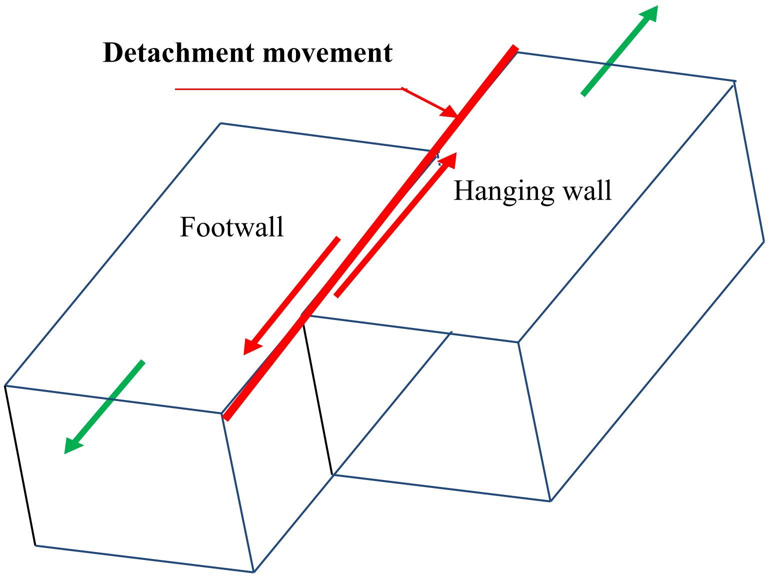


**Figure 22.** A strike-slip fault

# II. Seismology

## II.1. Earthquakes (General Overview)

### II.1.1 Definitions

Seismology is the science that deals with the study of earthquakes (seismic events). The word "seism" comes from the Greek word "seismos," meaning shake. Therefore, an earthquake is any more or less violent and brief (a few seconds) shaking or vibration of the ground, caused by the arrival of elastic waves transmitted through the lithosphere from a point called the focus or hypocenter. These waves result from a sudden release of energy accumulated by the movements of the Earth's tectonic plates.

The focus or hypocenter is the location where the initial shock occurs in depth (it is the place where rock rupture occurs in depth).

The epicenter is the point on the surface directly above the focus (Figure 23). Generally, at the epicenter, the force of an earthquake is maximal, and it decreases as one moves away from it.

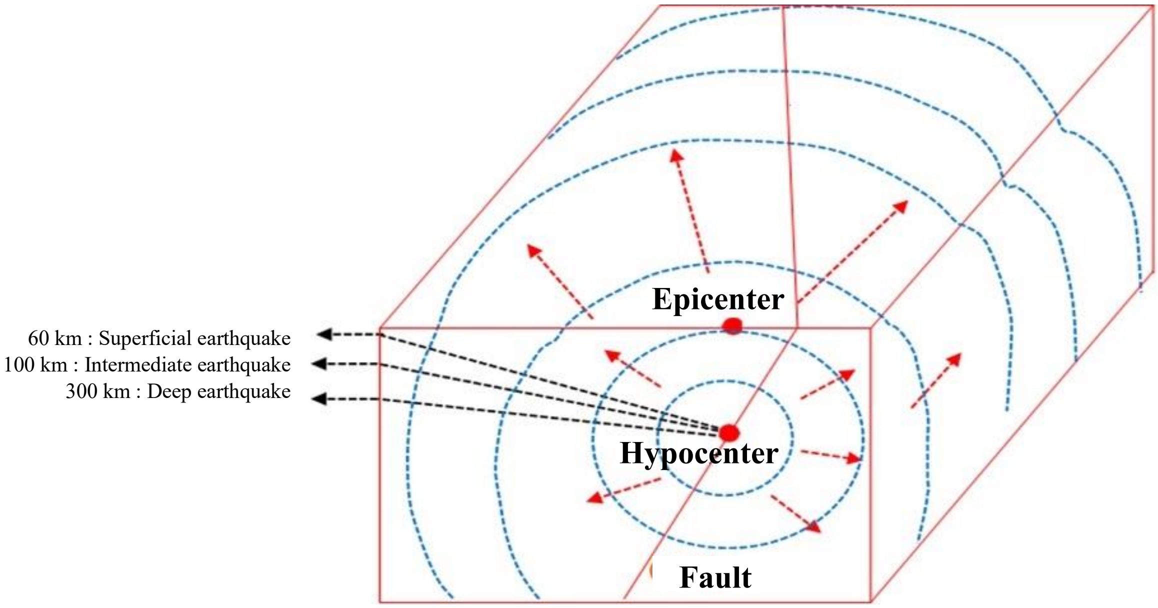


**Figure 23.** Earthquake

### II.1.2. Earthquake classification

The classification of earthquakes is based on several criteria, the most important of which are the depth of the focus and the origin of the earthquake.

**II.1.2.1. According to the depth of the hypocenter:** we distinguish

***a. Superficial earthquakes:*** the depth of the hypocenter is less than 60 km.

***b. Intermediate earthquakes:*** the hypocenter is located between 60 and 300 km deep.

***c. Deep earthquakes:*** the depth of the hypocenter exceeds 300 km.

**II.1.2.2. According to the origin of the earthquake,** we distinguish between tectonic and non-tectonic earthquakes.

***a. Tectonic Earthquakes:*** These earthquakes are directly linked to movements in the Earth's crust along faults. They are the most significant (accounting for 95% of recorded earthquakes), the most destructive, and can affect large areas.

***b. Non-tectonic Earthquakes:*** These earthquakes can be triggered by volcanic eruptions, the collapse of natural underground cavities, or large landslides. These earthquakes are generally of low intensity and affect limited areas.

### II.1.3. Study of Earthquakes

#### II.1.3.1. Origin of Earthquakes

The Earth's crust is formed by seven **(07)** large plates ***(Africa, North America, South America, Eurasian, Indo-Australian, Pacific, and Antarctic)*** and several smaller ones. These plates are known as tectonic plates. These plates are not stationary; they move at speeds ranging from 1-2 cm/year for the slowest plates to 6-7 cm/year for the fastest ones, and they do not all move in the same direction; instead, they can move in opposite directions.

Indeed, in certain regions, the movement of tectonic plates causes stress that accumulates in rocks. These rocks, which possess some elasticity, deform slowly. Elastic energy (potential energy, similar to that in a spring) is thus stored in the rocks. After a certain period, these rocks will reach their breaking point due to the accumulation of stress and will fracture, forming a fault.

The rupture of rocks begins at a point called the focus or hypocenter of the earthquake, from which it rapidly spreads. Simultaneously, the two compartments on either side of the rupture surface slide against each other. The fault created may or may not be visible on the surface; it is now a zone of weakness. There is a high likelihood that future earthquakes in the region will occur there.

The majority of the released energy dissipates as heat, potentially leading to rock melting near the focus. The remaining 20% to 30% of the released energy (seismic efficiency) is transported in the form of seismic waves that propagate in all directions, causing the medium to vibrate, hence the tremors that constitute the earthquake.

#### II.1.3.2. Characteristics of Seismic Waves

Two main types of waves are emitted by an earthquake:

***a. Body Waves:*** P-waves and S-waves originate from the earthquake's focus and propagate in all directions. They pass through the Earth's interior before reaching the surface. For this reason, P-waves and S-waves are referred to as body waves.

***a1. Primary waves (P- waves):*** These are the fastest waves (approximately 6000 meters per second near the surface) and are recorded first on a seismogram. They are longitudinal waves, vibrating particles of the medium along the direction of their propagation. They are also known as compression-dilatation waves because their propagation results in successive compressions

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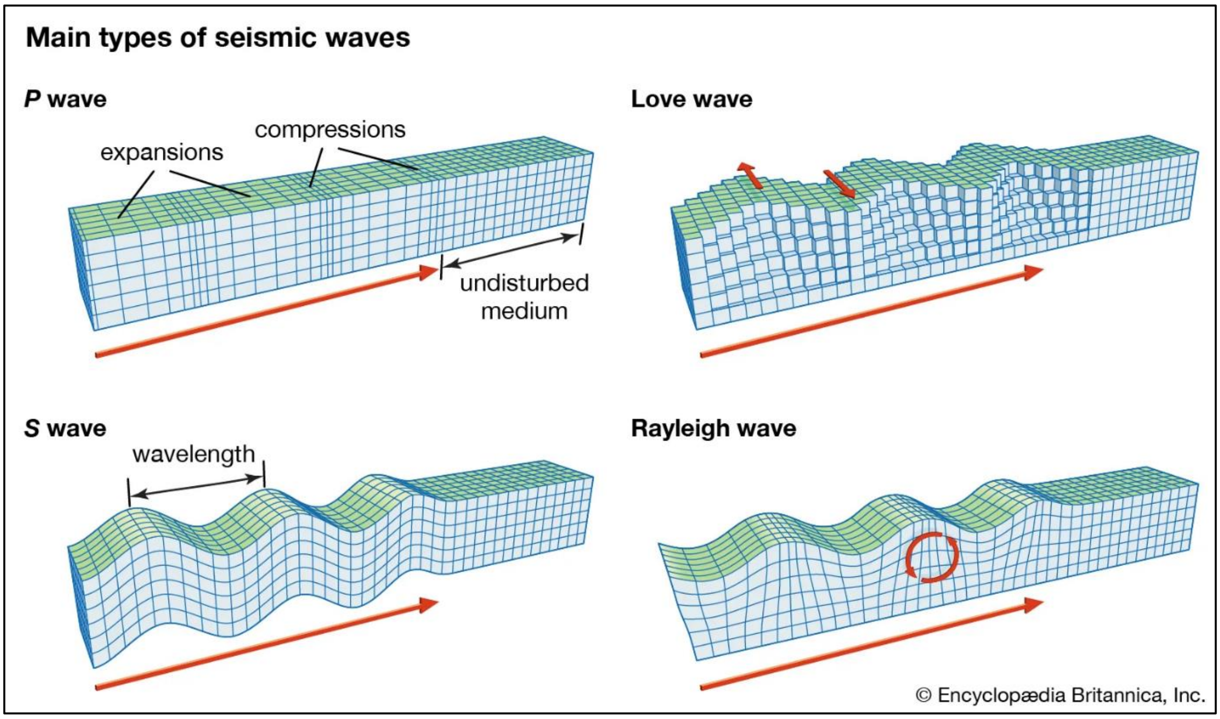
and dilations of the medium (thus variations in volume). P-waves can propagate through solids, fluids, and gases.

***a2. Secondary waves (S- waves):*** Their speed is slower than that of P-waves, and they appear second on seismograms (fig.12.b). They are transverse waves, where the particles of the medium vibrate perpendicular to the direction of propagation, thus transversely to this direction. Their propagation results in shear deformation of the medium (a movement resembling that of the branches of a pair of scissors), hence their other name shear waves. S-waves can only be transmitted through solids; they do not propagate in liquids or gases.

***b. Surface waves:*** (long-period waves) propagate at constant speeds; they come in two types depending on the order of arrival at the recording station after S, Love waves (L) and Rayleigh waves (R).

***b1. Love waves (L- waves):*** These are transverse waves like S-waves, but the vibrations of the particles of the medium occur only in the horizontal plane; they can only propagate in solids.

***b2. Rayleigh waves (R- waves):*** As they pass, the particles of the medium describe ellipses elongated vertically in retrograde fashion relative to the direction of propagation. R-waves propagate like waves on the surface of water (but in the case of the latter, the orbital motion of the particles is forward relative to the direction of propagation). Unlike Love waves, which have no vertical component but only a horizontal one, Rayleigh waves have both horizontal and vertical components, with the vertical one being more significant. R-waves can be transmitted through solids and liquids.




***Source.*** *https://www.britannica.com/science/seismic-wave*

**Figure 24.** Different Types of Seismic Waves

## II.1.3.3. Recording Earthquakes with Seismographs: (Seismograms)

A seismograph is a device used to record the shocks and vibrations caused by earthquakes. A seismograph must be attached to the Earth's vibrating surface and vibrates along with it.

To measure vertical movement, seismographs use a heavy mass supported by a spring. The spring is attached to a support that is itself connected to the ground. When the ground vibrates, the spring compresses and decompresses, but the mass remains almost stationary.

To measure horizontal movement, the heavy mass is suspended like a pendulum – one device measures east-west movements, and another measures north-south movements.

The curve drawn by the seismograph is called a **seismogram**, (Figure 25).

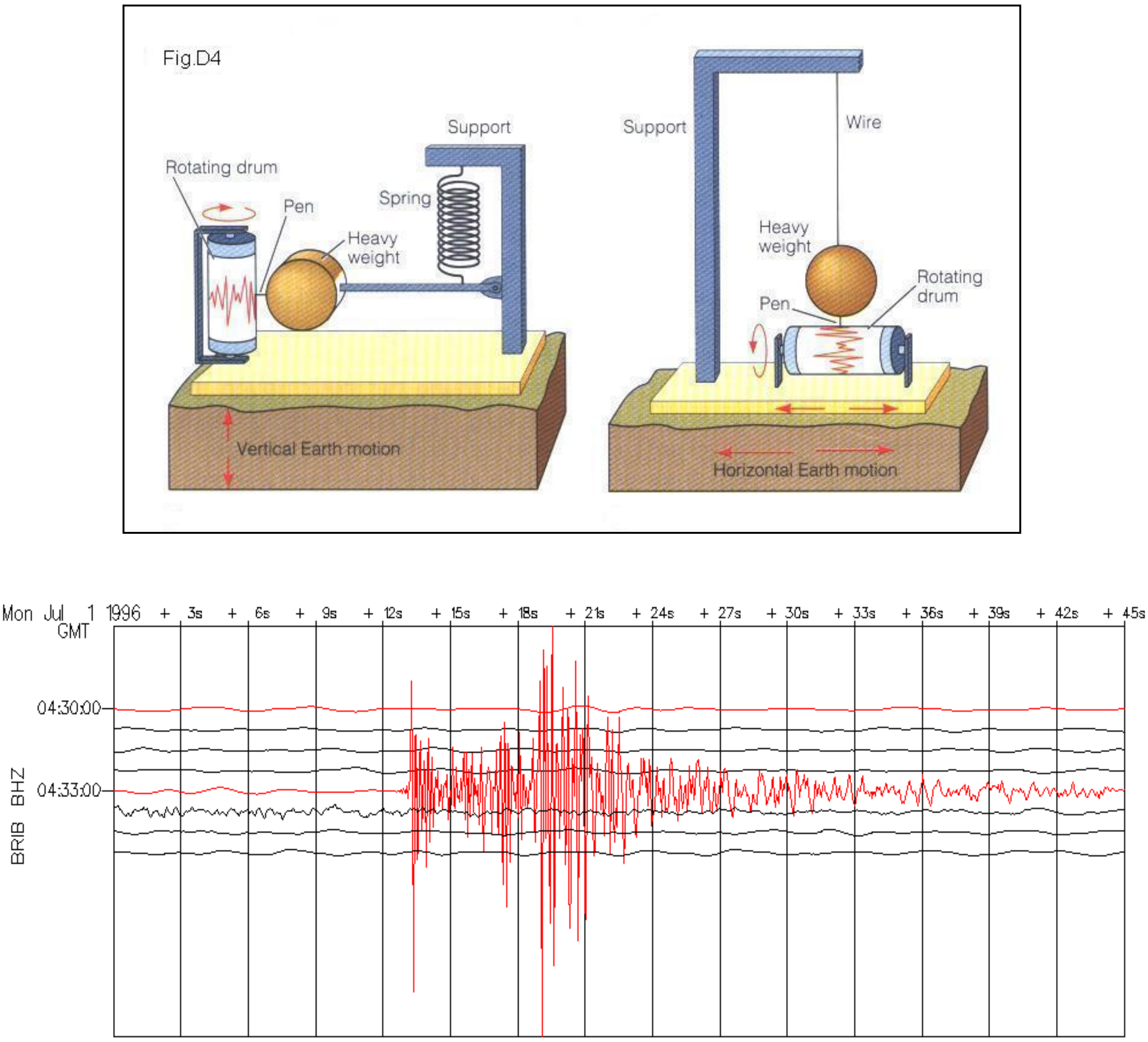



**Figure 25.** Seismograph and Seismogram

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## II.2. Measurement of an Earthquake

### II.2.1. Scales

There are two scales used to assess earthquakes: the Mercalli scale and the Richter scale. Nowadays, we primarily use the Richter scale, but earthquakes from the past can only be evaluated using the Mercalli scale.

#### II.2.1.1. The Mercalli scale

was developed in 1902 and modified in 1931. It indicates the intensity of an earthquake on a scale from I to XII (Table 1). This intensity is determined by two factors: the extent of damage caused by an earthquake and the perception of the earthquake by the population.

**Table 01. Mercalli scale (M.S.K)**

| Degree | The observed damage | Nomenclature |
|---|---|---|
| **I** | The earthquake is not felt by humans but is recorded by instruments. Animals may exhibit some uneasiness. | - |
| **II** | Shaking is perceived by a few people on upper floors of buildings. | **Very weak** |
| **III** | Fairly strong shaking, noted by several people on the ground. | **Weak** |
| **IV** | Dishes clink, floors creak. | **Mediocre** |
| **V** | The entire population perceives the earthquake (furniture shifting and suspended objects swinging). | **Fairly strong** |
| **VI** | Sleepers are awakened, beginning of panic, general ringing of bells. | **Strong** |
| **VII** | General fright but no damage to well-built structures; only a few cracks appear. | **Très fort** |
| **VIII** | Significant cracks (fissures in the walls) appear in buildings. | **Ruinous** |
| **IX** | Partial or total destruction of buildings. | **Disastrous** |
| **X** | Most buildings are destroyed. Cracks occur in the ground. | **Very disastrous** |
| **XI** | All buildings, bridges, and dams are destroyed. | **Catastrophic** |
| **XII** | No human-made structures remain. Significant changes in topography (watercourses diverted). This degree has not been reached. | **Cataclysmic** |

#### II.2.1.2. Richter Scale

The Richter scale allows for the comparison of energies released in different earthquakes. The goal was to define a quantity, called magnitude, linked to the energy developed at the earthquake's focus. Magnitude is calculated based on the measurement of ground motion amplitude determined from recordings obtained on a seismograph 100 kilometers from the epicenter. It was created in 1935 by Charles Francis Richter and Beno Gutenberg, two members of the California Institute of Technology. It is a logarithmic scale: the seismic waves of a magnitude 6 earthquake have ten times greater amplitude than those of a magnitude 5 earthquake, and the magnitude 6 earthquake releases approximately thirty-one times more energy. The scale is open-ended and without a known upper limit. In practice, earthquakes of magnitude 9 are exceptional, and the effects of higher magnitudes are no longer separately described. The strongest earthquake ever measured had a magnitude of 9.5, occurring on May 22, 1960, in Chile.

**Table 02. Richter Scale**

| **Degree** | **The observed damage** |
|---|---|
| **Less than 2** | Micro-earthquake, not felt. |
| **2 to 2.9** | Generally not felt, but detected by seismographs. |
| **3 to 3.9** | Often felt, but causing very little damage. |
| **4 to 4.9** | Objects shaken inside homes, noises of impacts, significant damage. |
| **5 to 5.9** | Major damage to poorly designed buildings in soft areas. Light damage to well-built structures. |
| **6 to 6.9** | Destructive in areas up to 180 kilometers from the epicenter. |
| **7 to 7.9** | Severe damage in broader areas. |
| **8 to 8.9** | Serious damage in areas hundreds of kilometers from the epicenter. |
| **More than 9** | Serious damage in areas hundreds of kilometers from the epicenter. |

### II.2.2. Locating an Earthquake on the Earth's Surface

In less than an hour after an earthquake, its epicenter is announced. How is it possible to locate an earthquake so quickly and with such precision?

P-waves propagate faster than S-waves; it is this property that allows the localization of an earthquake. Seismic waves are recorded at multiple locations around the globe by instruments called seismographs. We obtain a recording like the one shown in (Figure 26).

At a given location, since P-waves arrive first, there will be a time lag between the start of recording of the two types of waves on the seismograph; for example, in (fig.14.a), there is a 6-minute delay of S-waves compared to P-waves.

The propagation speeds of the two types of waves in the Earth's crust have been established, and therefore, we have calibrated curves, such as the one shown in (Figure 26).

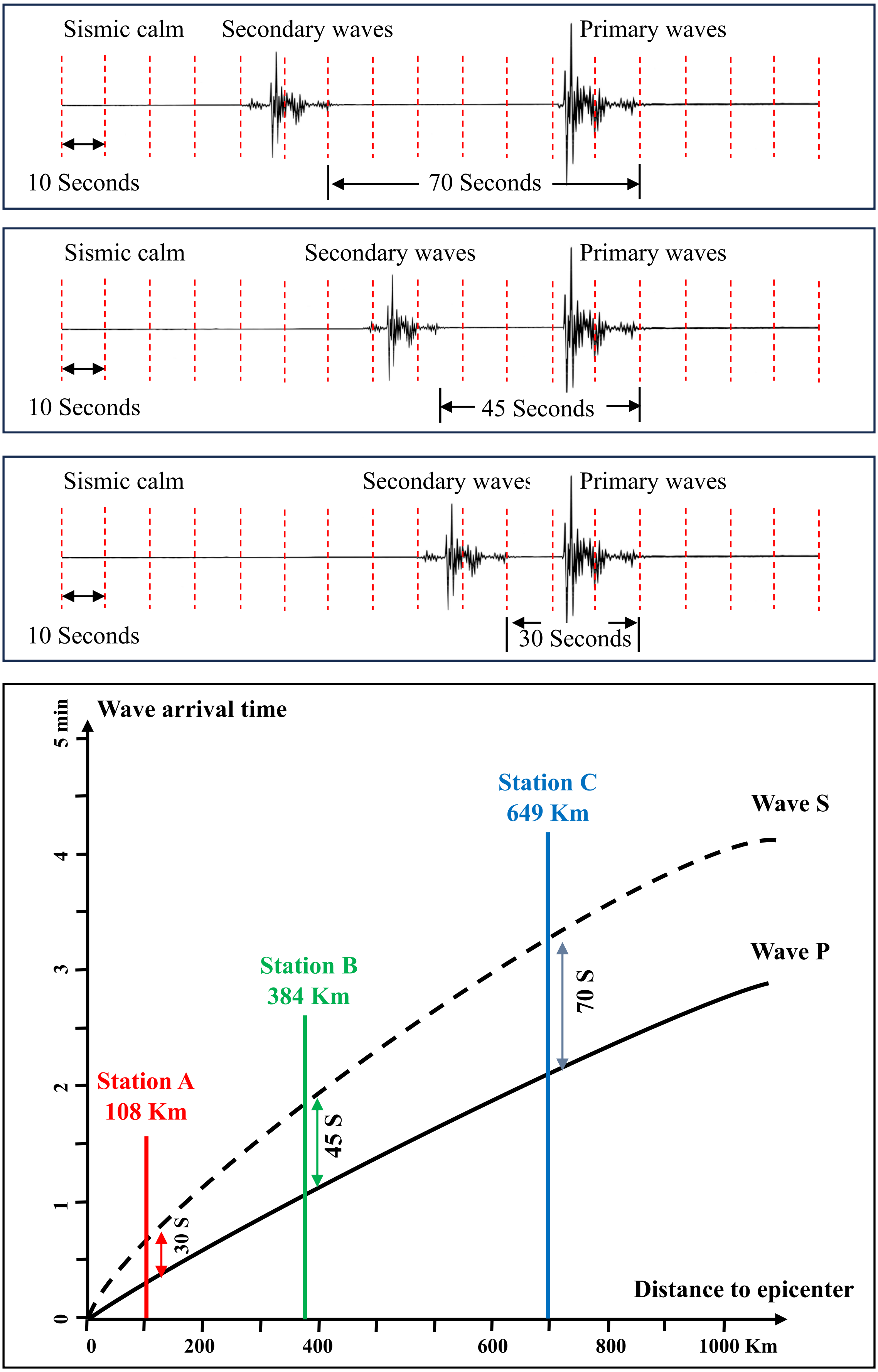


**Figure 26.** A graph showing the distance from the epicenter of a surface earthquake

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To determine the epicenter of an earthquake, it is essential to rely on seismic recordings from at least three stations.

Let's take the example of an earthquake that occurred in Algeria, recorded by three stations: station A in Djelfa, station B in Ouargla, and station C in Béchar, At the first station (Djelfa), it is observed that the secondary wave arrived 30 seconds after the primary wave, by consulting the velocity diagram of P and S waves as a function of the distance to the epicenter, it is found that this difference corresponds to a distance of 108 km. In other words, the epicenter is located 108 km from station A (Figure 26), we repeat this operation for stations B and C, and we find that the epicenter is 384 km from station B and 649 km from station C. (Figure 26).

Using a scale, we draw a circle around each station, with the radius equal to the distance between the station and the epicenter. (Figure 27).

The point of intersection of the three circles represents the epicenter of the earthquake.

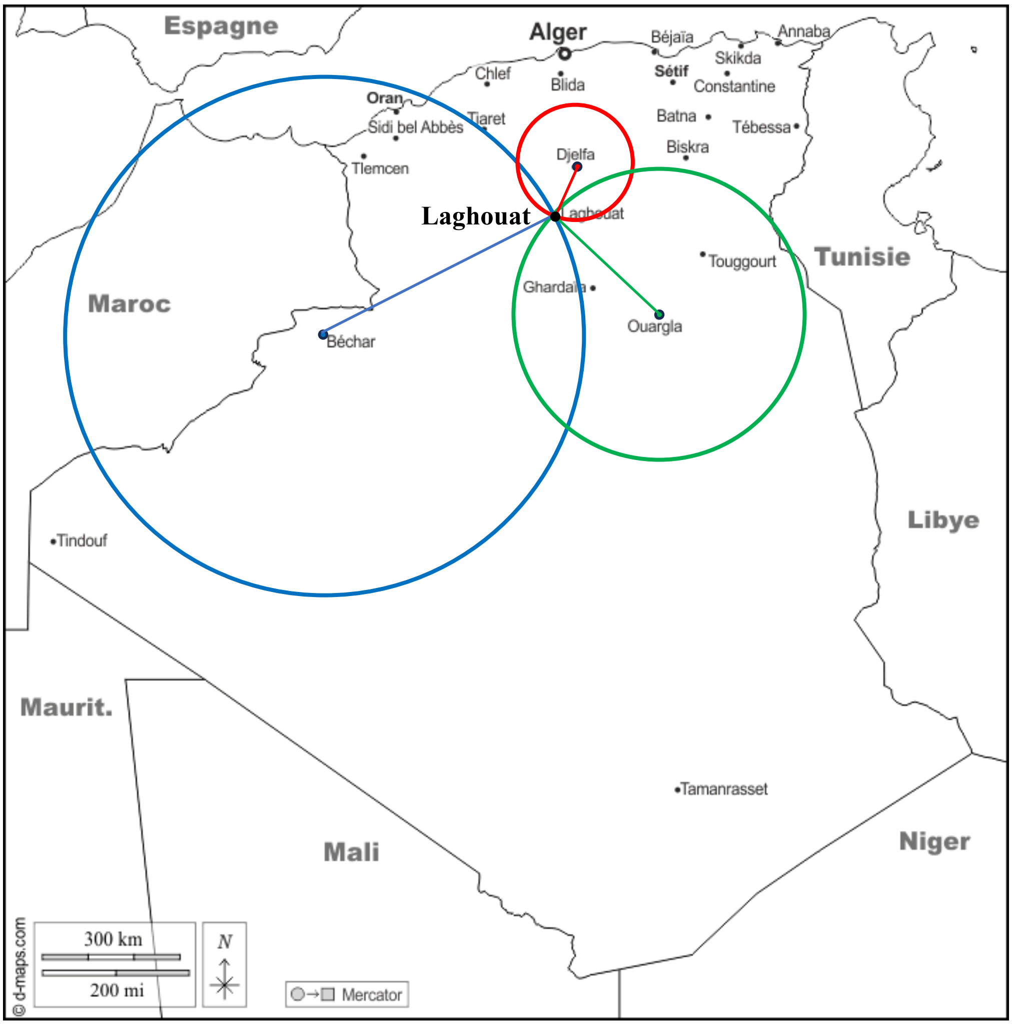


**Figure 27.** Location of an earthquake

# III. Volcanology

## III.1. Volcanoes

### III.1.1. Definition

The term "volcano" originates from Vulcano, an island named after Vulcan, the Roman god of fire. It is a geological structure resulting from the ascent and accumulation of molten magmatic materials (lava) on the surface. Their shape (more or less flattened – rounded) results from the varying viscosity of the involved lavas.

### III.1.2. Structure of a volcano. (Figure 28)

A volcano is formed of the following structures:

a) ***A magma chamber:*** Supplied by magma from the mantle, it acts as a reservoir for the magma (lava). When it empties due to an eruption, the volcano can collapse, giving rise to a caldera. Magma chambers are typically located between 10 to 50 km deep within the lithosphere.
b) ***A main volcanic vent:*** This is the primary pathway for magma to travel from the magma chamber to the surface.
c) ***A crater or caldera*****:** The summit where the main volcanic vent opens.
d) ***Secondary volcanic vents:*** These vents may originate from the magma chamber or the main volcanic vent and typically open on the flanks of the volcano, sometimes at its base. They can give rise to smaller secondary cones.
e) ***Lateral fissures:*** These are longitudinal fractures on the flank of the volcano caused by its swelling or deflation. They can allow the emission of lava in the form of a fissure eruption.

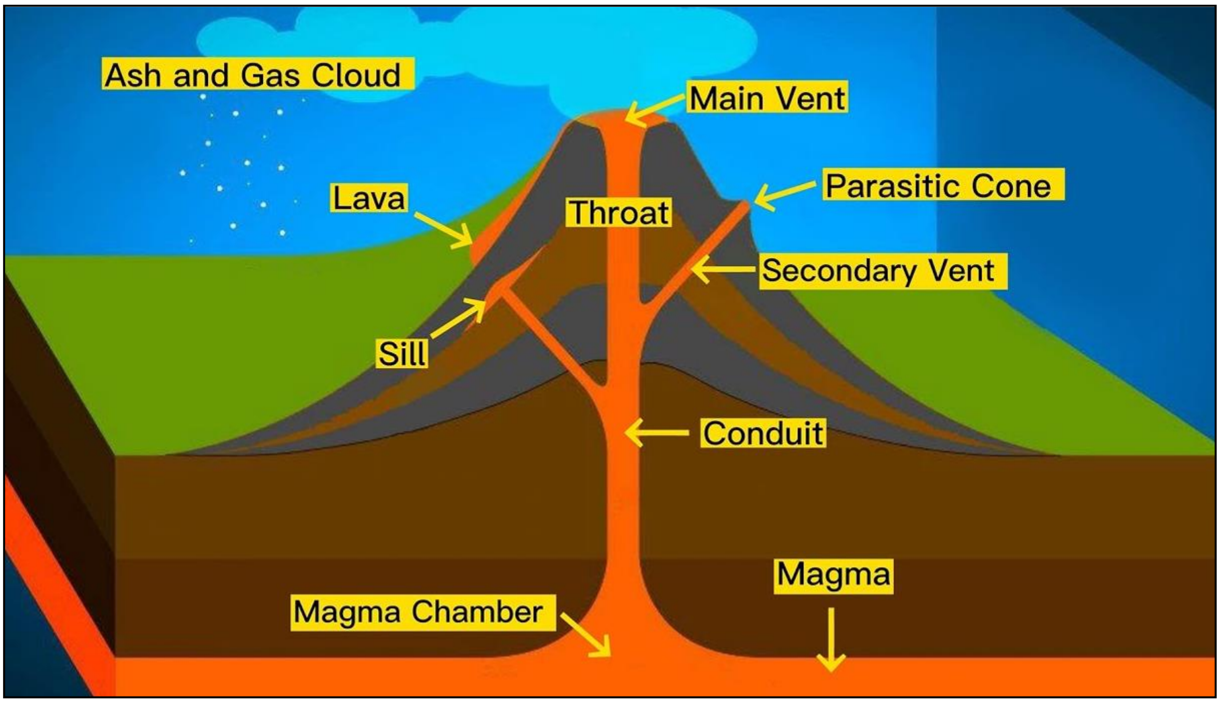


**Figure 28.** Volcano

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**III.1.3. Origin of Volcanism**

According to the theory of plate tectonics, volcanism is intimately linked to the movements of tectonic plates. Indeed, it is generally at the boundary between two plates that the conditions are met for the formation of volcanoes, thus distinguishing three types of volcanism:

**III.1.3.1. Divergent Volcanism**

In the rifts of mid-ocean ridges, the separation of two tectonic plates thins the lithosphere, causing rocks from the mantle to rise. These rocks, already very hot at around 1,200 °C, partially melt due to decompression. This results in magma that infiltrates through normal faults.

**III.1.3.4. Subduction Volcanism**

When two tectonic plates overlap, oceanic lithosphere, sliding beneath the other oceanic or continental lithosphere, descends into the mantle and undergoes mineralogical transformations. The water contained in the descending lithosphere escapes and hydrates the mantle, causing partial melting by lowering its melting point. This magma rises and traverses the overriding lithosphere, creating volcanoes.

If the overriding lithosphere is oceanic, an island volcanic arc will form, with volcanoes giving rise to islands. This is the case with Japan.

If the overriding lithosphere is continental, the volcanoes will be situated on the continent.

**III.1.3.3. Hotspot Volcanism**

It sometimes happens that volcanoes emerge far from any lithospheric plate boundary (there are over 100,000 seamounts over 1,000 meters tall underwater). They are generally interpreted as hotspots. Hotspots are plumes of molten magma from the depths of the mantle that penetrate the lithospheric plates. Since the hotspot remains fixed while the lithospheric plate moves over the mantle, volcanoes are successively created and aligned. When the hotspot emerges beneath an ocean, it gives rise to a chain of aligned islands, as seen in the case of the Hawaiian archipelago. If the hotspot emerges beneath a continent, it will then give rise to a series of aligned volcanoes. This is the case with Mount Cameroon.

**III.1.4. Materials Emitted by Volcanoes**

The most well-known materials emitted by volcanoes are:

**III.1.4.1. Volcanic Lavas**

Volcanoes emit lavas in the form of basaltic flows originating from mantle melting in the case of hotspot, ridge, or rift volcanism, or andesitic flows originating from lithosphere melting in the case of subduction volcanism. The temperature of the lava ranges between 700 and 1,200 °C, and the flows can extend for tens of kilometers, moving at speeds of fifty kilometers per hour and advancing through lava tubes.

**III.1.4.2. Volcanic Bombs (Tephra)**

These are magma and rock fragments torn from the volcano that are pulverized and sometimes projected up to tens of kilometers into the atmosphere. The smallest fragments, ashes, can even circumnavigate the Earth, carried by winds. Volcanic bombs, the largest ejecta, can be the size of a house and generally fall near the volcano.

**III.1.4.3. Volcanic Gases**

Degassing causes magma to rise along the volcanic vent, which can contribute to the explosive and violent nature of an eruption in the presence of viscous magma. Volcanic gases are primarily composed of:

- ***Water vapor with a content of 50 to 90%.***
- ***Carbon dioxide with a content of 5 to 25%.***
- ***Sulfur dioxide with a content of 3 to 25%.***

**III.1.5. Types of Volcanoes**

**III.1.5.1. Effusive Type**

Effusive type volcanoes are characterized by lava whose fluidity depends on its chemical composition. These volcanoes are mainly found along divergent plate boundaries as well as hotspots. This activity generally causes material damage but is rarely dangerous to humans.

The speed of lava flows is higher when their viscosity is low. The viscosity of the lava depends on its silica content. Generally, the most fluid magmas are those of basaltic origin. This rock mostly has a low silica content, allowing it to flow without accumulating in the magma chamber and thus without creating "explosions".

Furthermore, after the eruption, as the lava moves away from the volcano, the temperature drops rapidly. This cooling causes an increase in the viscosity of the lava and therefore a decrease in its speed.

**III.1.5.2. Explosive Type.**

Explosive type volcanoes are characterized by the ejection of ash and/or blocks over a radius of several kilometers. They are mainly located in plate convergence zones (subduction). The explosions are more impressive when the lava viscosity is high. Indeed, silica, present in large quantities in this type of magma, produces very viscous lava, which traps the gases present in the magma. Upon contact with the air, this leads to an explosion, which then becomes a pyroclastic flow.

This type of activity is the most dangerous due to the projection of blocks of different diameters over a large radius: it causes not only material damage but also significant loss of human lives.

## III.2. Igneous Rocks

### III.2.1. Introduction

Rock is a constituent material of the Earth's crust, generally formed from an assemblage of minerals exhibiting a certain statistical homogeneity.

Igneous rocks are the product of the cooling and solidification of silicate melts, called magmas. This cooling can occur either on the Earth's surface (resulting in volcanic rocks) or within the Earth's crust (resulting in plutonic rocks).

### III.2.2. Classification of Igneous Rocks

The classification of igneous rocks can be based on the level and dynamics of their emplacement, on their descriptive aspect of minerals (architecture and constituent elements), and on their chemical composition.

#### III.2.2.1. Classification according to the mode of emplacement. (Figure 29)

The level and dynamics of emplacement of igneous rocks allow for a more precise terminology:

***a. Plutonic rocks:*** (intrusive rocks strictly speaking) characterized by emplacement at great depth. (e.g., Gabbro).

***b. Volcanic rocks:*** (extrusive effusive rocks or explosive rocks) characterized by superficial, aerial, or underwater emplacement. (e.g., Basalt)

***c. Filonian rocks:*** fall into the category of rocks of shallow or medium depth. (e.g., Rhyolite, dacite,...).

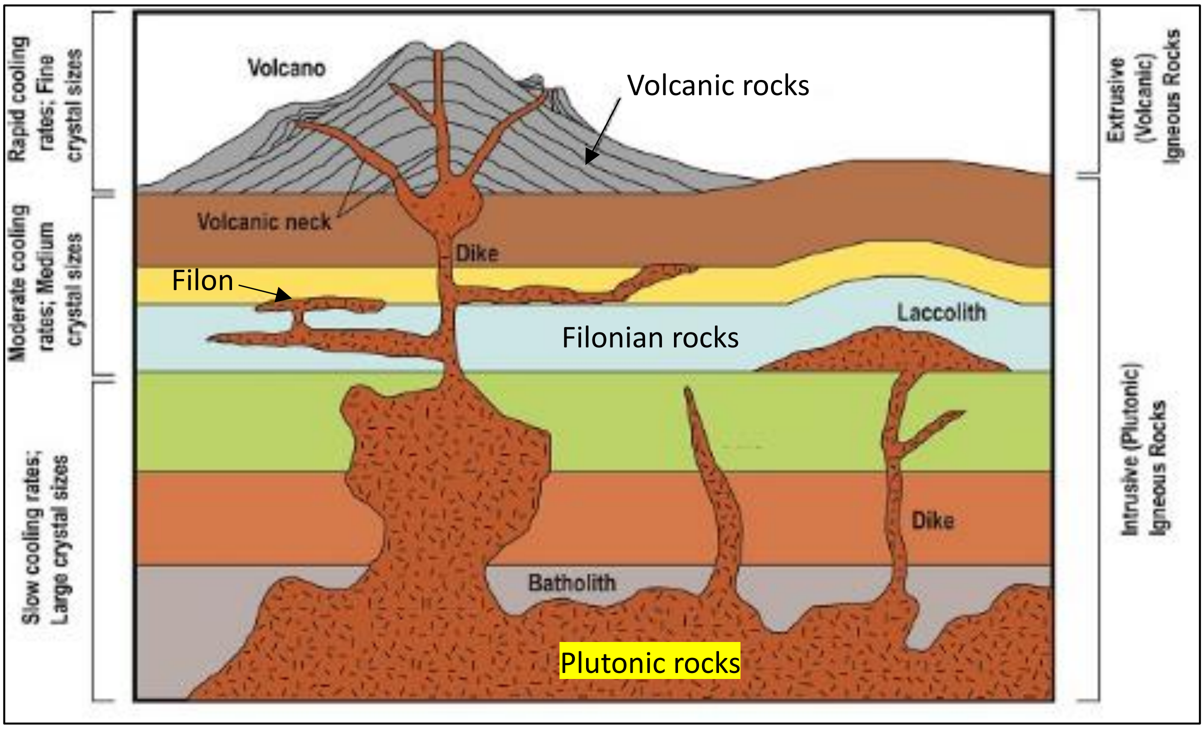


**Figure 29.** Classification of Igneous Rocks According to Mode of Emplacement

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### III.2.2.2. Mineralogical Classification

The descriptive aspect of rocks gives rise to a universally used classification; the mineralogical classification takes into account the arrangement and nature of the constituent minerals of the rock. Thus, we can distinguish:

***a. Fully crystallized rocks:*** called holocrystalline, subdivided into coarse-grained rocks (granite) and fine-grained rocks (microgranite) according to the size of the minerals.

***b. Partially crystallized rocks:*** called hypocrystalline or microlitic.

Non-crystallized rocks: called hyaline or vitreous because they are solely composed of glass.

### III.2.2.3. Chemical Classifications

For incompletely crystallized rocks, a mineralogical classification can be difficult or even erroneous. It is then simpler to carry out a chemical classification. The "content" of SiO2 gives an idea of the "acidic" or "basic" nature of an igneous rock, thus we can distinguish:

***a. Acidic rock:*** saturated in silica with 66% or more by weight of silica SiO2, hence generally containing quartz crystals and low levels of iron, magnesium, and calcium.

***b. Intermediate rock:*** containing between 52% and 66% by weight of silica (e.g., diorite).

***c. Basic rock:*** undersaturated in silica with a content between 45% and 52% by weight of SiO2, hence the absence of quartz crystals (e.g., basalt).

***d. Ultrabasic rock:*** or ultramafic contains less than 45% by weight of silica, therefore it is very rich in iron, magnesium, and calcium (e.g., gabbro).

### III.2.3. Study of Magmas

### III.2.3.1. Concepts of Magma

A magma is a natural molten silicate bath, which may contain crystals or rock fragments in suspension. Its crystallization leads to igneous rocks. A magma is characterized by its predominantly silicate composition, high temperature (1200°C to 1500°C), and variable viscosity.

### III.2.3.2. Different Types of Magmas

Generally, and in a simplified manner, we mainly distinguish two types of magmas based on their silica content:

***a) Hyper-siliceous magma:*** When the silica content is high (75%), the molten magma is very viscous and therefore flows slowly through the Earth's crust. This type of magma generates granitic rocks, which represent nearly 95% of intrusive rocks within pre-existing rocks.

***b) Hypo-siliceous magma:*** When the silica content is low (50%), the molten magma is fluid and quickly traverses the Earth's crust to flow to the surface. This type of magma generates basaltic rocks, which represent nearly 95% of effusive rocks on the Earth's surface.

### III.2.3.3. Crystallization of Magma (Fractional Crystallization)

During the progressive cooling of magma, there is a crystallization of mineral assemblages in a well-defined order: ultramafic, mafic, intermediate, and felsic. These four assemblages define four major types of igneous rocks (Figure 30).

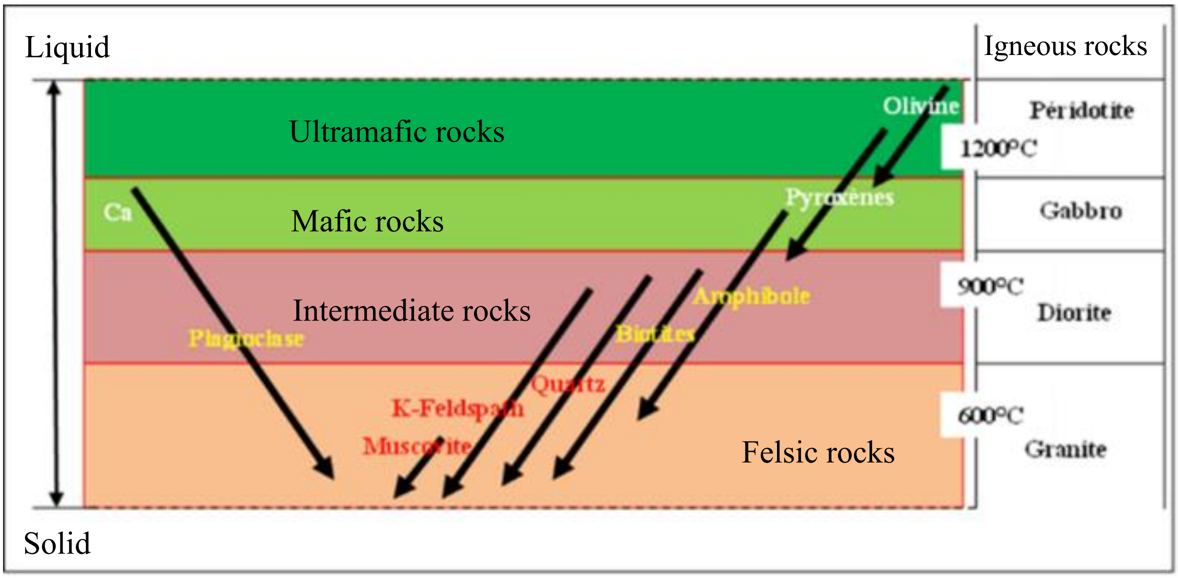


**Figure 30.** Crystallization of Magma (Fractional Crystallization)

**Example:** (Crystallization of magma cooling in a magma chamber) (Figure 31).

The first minerals to crystallize will obviously be the high-temperature minerals, first olivine, then pyroxenes and amphiboles. These crystals will form in the magma and settle towards the base of the magma chamber to form a rock rich in olivine, pyroxene, and amphibole, therefore giving rise to a mafic igneous rock (a gabbro) (igneous rock "A").

The residual liquid (remaining) will thus be depleted in these minerals; therefore, we will have a magma with a composition different from its initial composition. This magma will have an intermediate composition. If this magma is introduced into a secondary chamber and continues to cool, the first minerals to crystallize will be amphiboles, biotites, quartz, and certain plagioclase feldspars, resulting in an intermediate igneous rock (a diorite) (igneous rock "B").

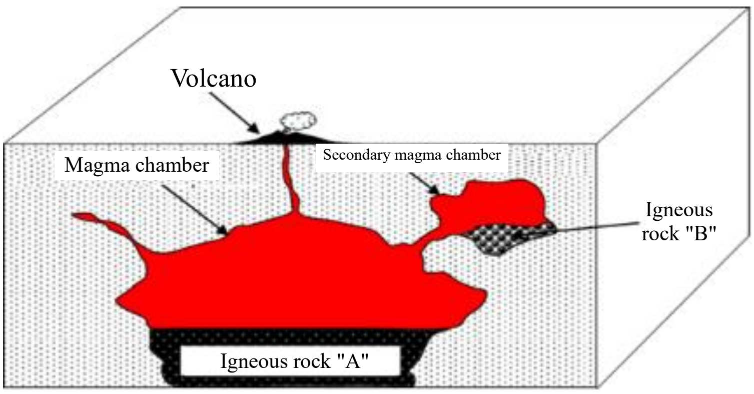


**Figure 31.** Crystallization of magma cooling in a magma chamber

### III.2.3.4. Partial Melting

Partial melting is the opposite process of fractional crystallization. If the temperature of a solid material composed of an assemblage of silicate minerals is gradually increased, this assemblage transitions entirely or partially from the solid phase to the liquid phase. Just as in the case of magma cooling where not all minerals crystallize simultaneously, they also do not all melt at the same time when heated.

The first minerals to melt are the low-temperature minerals: quartz, potassium and sodium feldspars, and muscovite.

The melting is then only partial, as a mixture of solid and liquid is obtained.

If this liquid is extracted from the mixture and remobilized (introduced along fractures or into another chamber, for example), this felsic magma will, upon crystallization, form rhyolites or granites.

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## IV. Plate Tectonics

### IV.1. Theory of Continental Drift

In 1912, the physicist-meteorologist Alfred Wegener proposed a revolutionary geological theory. He launched the first unifying theory of the different disciplines of geology. Wegener was struck by the similarity of the coasts of Africa and South America. He deduced that these two parts of the world were once a single block in ancient times. His theory, called the theory of continental drift, now recognized, starts from the hypothesis of the existence of a single original continent, Pangaea. According to this theory, the supercontinent "Pangaea" began to separate approximately 225-200 million years ago, eventually fragmenting into the continents as we know them today (Figure 32).

In general, this theory is based on the following three major observations:

**IV.1.1. Coastline parallelism:** If we examine the Earth's globe, we easily notice the complementarity of the coastlines between South America and West Africa, suggesting that these two continents are pieces of the same block.

**IV.1.2. Geographic distribution of certain fossils:** The fossil content of various regions strengthens the idea of a supercontinent. Indeed, the presence of similar fossilized animals and plants has been observed in regions currently separated by oceans. However, these oceans represent insurmountable barriers for the dispersion of species such as reptiles or plants. This distribution of fossils can only be explained by a past joining of continental masses.

**IV.1.3. Traces of ancient glaciations:** Several indicators show that 250 million years ago, certain portions of the current continents were covered by an ice cap. The flow direction of glaciers from that time period has even been identified. Various formations such as moraines, desert sands, or evaporitic rocks constitute climatic markers. The distribution of these formations, especially glacial moraines in India, can be explained by admitting a different arrangement of continents, grouped into a supercontinent, Pangaea.

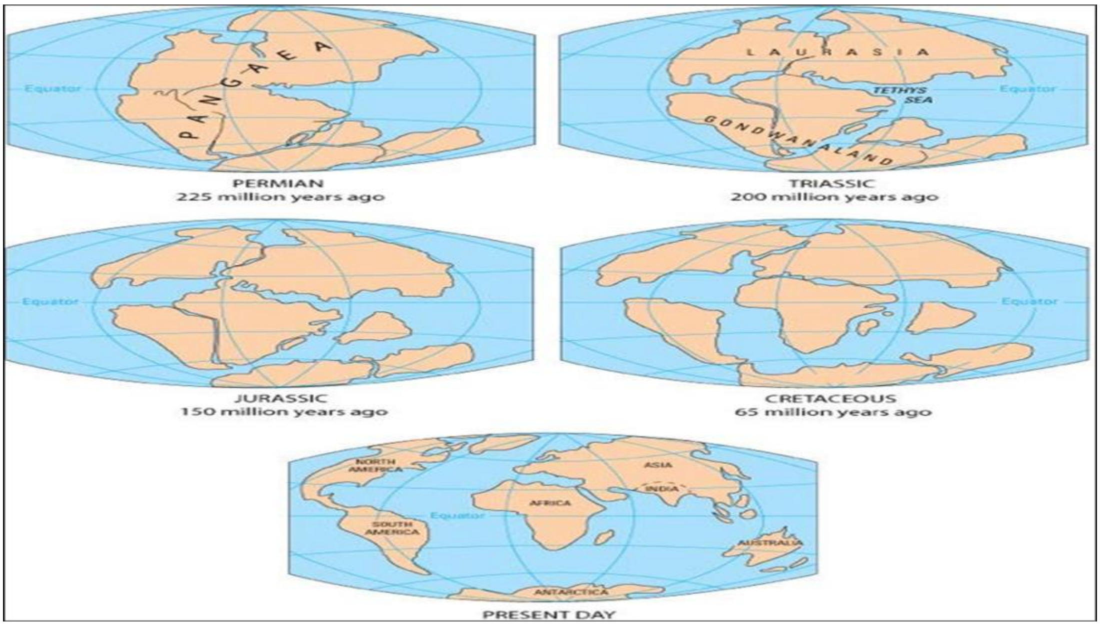


**Figure 32.** Breakup of Pangaea. (USGS.2012)

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### IV.2. Major Lithospheric Plates

If we study the location of the most active volcanoes and the most significant earthquakes, we realize that their distribution outlines the contour of the major lithospheric plates (fig. 28).

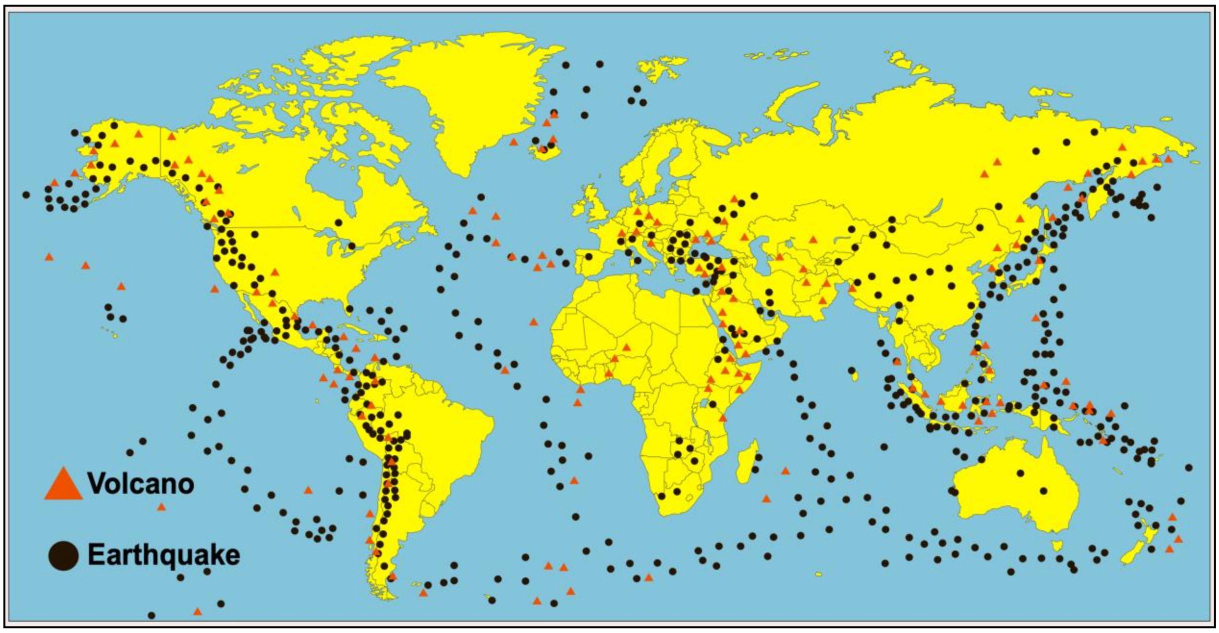


**Figure 33.** Map of the global distribution of earthquakes and volcanoes.

Thanks to these studies, we know that the lithosphere is today divided into 14 rigid plates (Figure 33). These plates move relative to each other by sliding on the asthenosphere. The largest plate is the "Pacific" plate and is made up entirely of oceanic crust. The other major plates include oceanic and continental crusts. There are mainly seven (07) major plates: Pacific, Eurasian, North America, South America, Africa, Australia and Antarctica. There are also at least seven (07) other smaller plates: Nazca, India, Juan de Fuca, Philippines, Arabia, Cocos, Caribbean.

Most often, the slowest plates include a lot of continental lithospheres: Eurasian, North American. The fastest plates are all predominantly oceanic: Pacific, Nazca. The speed of a plate is even faster if it has subduction type boundaries: Pacific and Nazca.

### IV.3. Causes of Plate Movement (Terrestrial Convection)

Several studies have shown that the driving force behind the movement of tectonic plates is the radioactive decay of certain chemical elements in the asthenosphere. The heat flux released by radioactive decay reactions produces convection cells in the mantle, which drag the lithospheric plates.

The Earth dissipates its heat primarily through convective processes, meaning through joint movements of hot material upward and cold material downward. The movements of cold material, on the scale of the mantle, are mainly represented by subductions and the sinking of cold lithospheric plates into the mantle. Movements of hot material are less evident to observe; in the upper part of the mantle, they are represented by upwellings beneath mid-ocean ridges; in the lower part, they are less well-localized and more difficult to observe.

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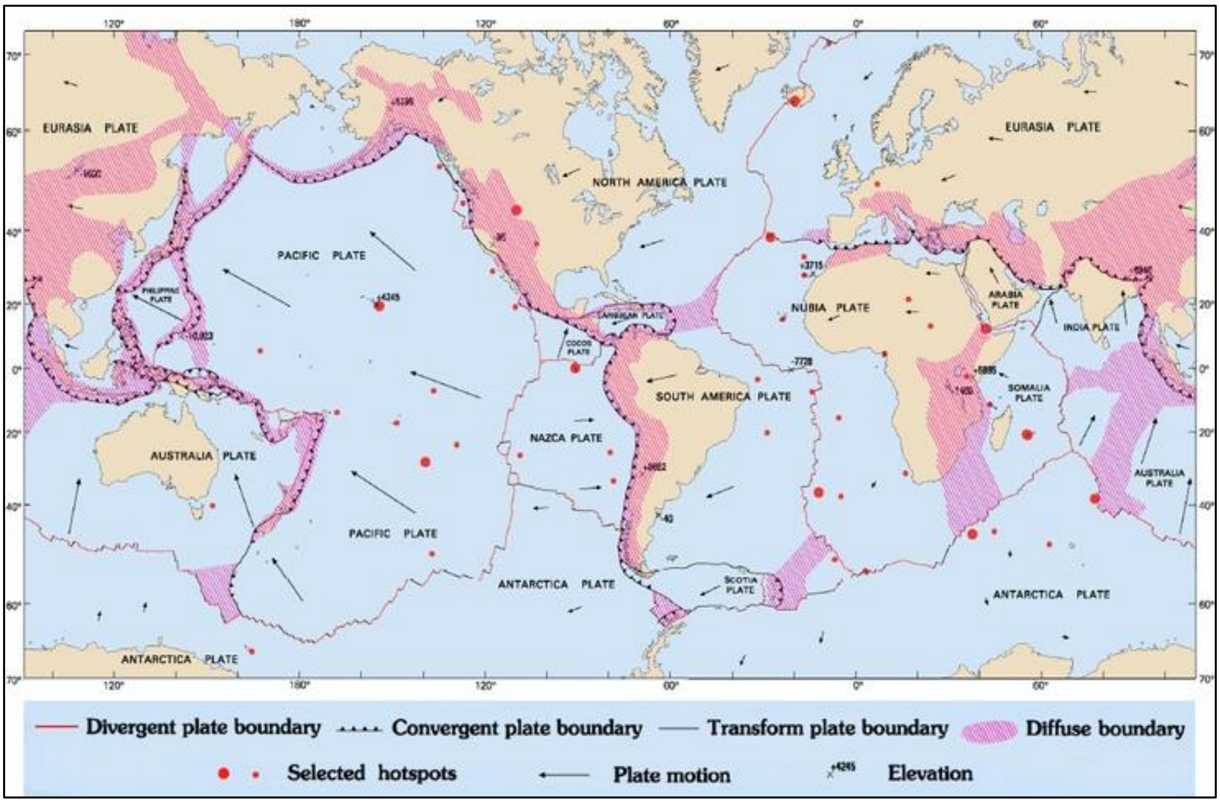


**Figure 34.** Major Lithospheric Plates

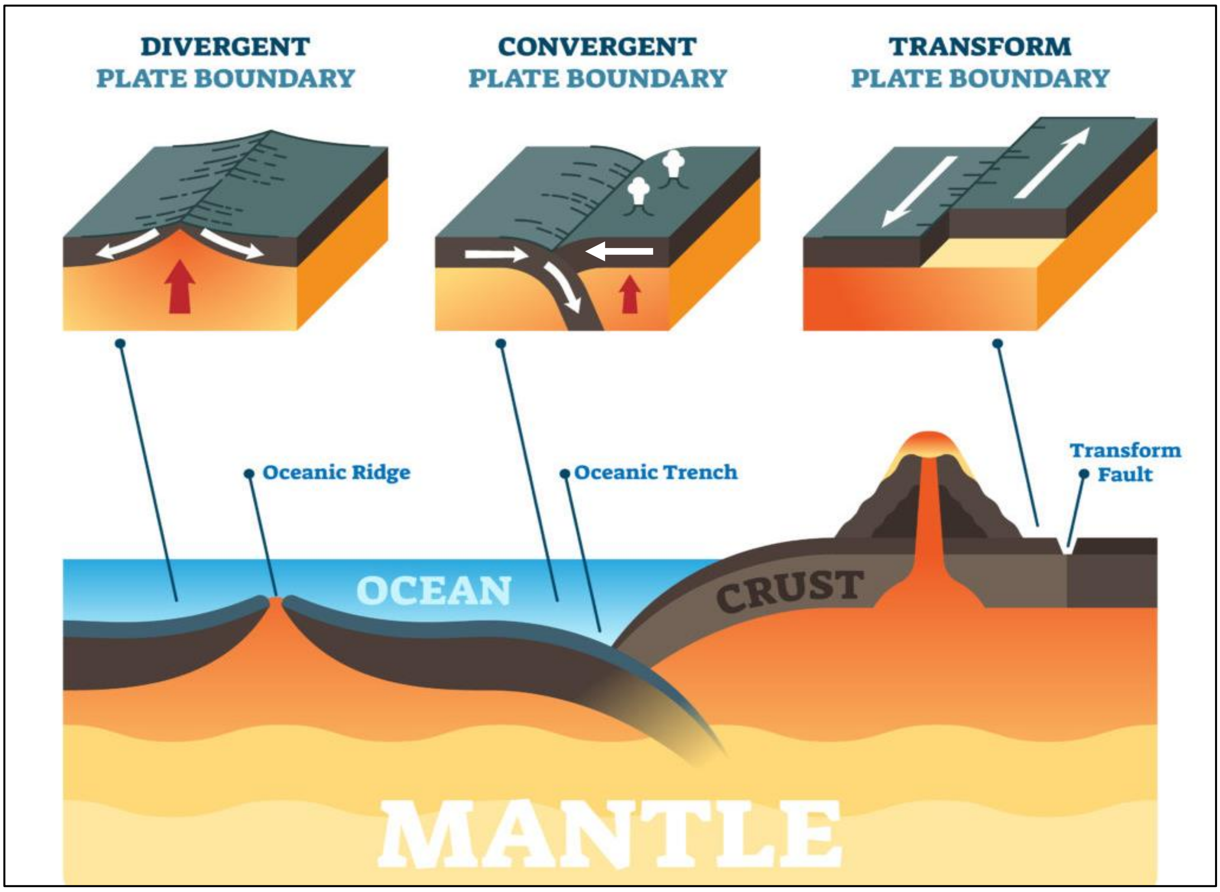


**Figure 35.** Different types of boundaries between tectonic plates

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It follows that any modification of the terrestrial convection regime will likely result in different styles of plate tectonics. In particular, if there is more heat to dissipate, one can expect a significantly different convection pattern.

Generally, these movements define three types of boundaries or limits between plates: (Figure 34).

**IV.3.1. Divergent boundaries:** where plates move away from each other (here, between plates A and B, and D and E).

**IV.3.2. Convergent boundaries:** a consequence of divergence (here, between plates B and C, and D and C).

**IV.3.3. Transform boundaries:** when two plates slide laterally past each other along faults. This type of boundary accommodates differences in the velocities of plate movement relative to each other, as seen here between A and E, and between B and D, or even reversals in the direction of movement, as seen here between plates B and E.

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