People's Democratic Republic of Algeria

Ministry of Higher Education and Scientific Research

Mohamed seddik ben yahya University Jijel

Faculty of Natural and Life Sciences

Department of Earth and Universe Sciences

Course handout

1st Year Licence

Field: Earth sciences

Stream: Applied geology

Subject:

Geology 1

Presented by:

Dr : Djorfi Samir

Academic year 2023/2024

Geology 1 module program - 1st year - Applied geology.

Semester: 1

UEF11

Subject F111: Geology 1.

Teaching objectives

The aim of geology teaching is to acquire a basic knowledge of the major phenomena that govern the Earth, and to show that the Earth is an active planet characterized by dynamics whose functioning we must try to understand. The aim of this Geology 1 course handout is to enable 1st year students to understand the Earth's internal structure, the interactions between its various constituents and its dynamics. This document has been produced in compliance with the syllabus laid down by the Ministry of Higher teaching and Scientific Research.

Recommended prior knowledge

Notions of geology acquired at Lycée.

Semester: 1

UEF11

Subject F111: Geology 1.

Content of Subject: Course

Chapter 1: The Earth in the Universe

1.1 Introduction: objects of geology

1.2 Structure of the universe and birth of the solar system

1.3 Earth and the planets of the solar system.

Chapter 2: Internal geodynamics

2.1. Earth's internal structure

2.2. Structure of the terrestrial globe and notion of geoid

2.3 Current land and sea distribution

2.4. Earth's magnetic field

2.5. Continental drift and plate tectonics

2.6. Earthquakes

2.7. Volcanoes

Chapter 3: Tectonic

3.1 Tectonic concepts

3.2. Brittle deformation: faults

3.3. Soft tectonics: folds

3.4. Overlapping and thrust sheets

3.5. The formation of mountain ranges

Practical works:

Cartography:

Topographic maps: Presentation of a topographic map, notion of scale, coordinates networks, orientation, definition and characteristics of contour lines......

Production of topographic profiles.

Assessment methods: Exam(s), continuous assessment in practical works.

CHAPTER I: THE EARTH IN THE UNIVERSE

1.1 Introduction to geology:

1.1.1. Definition of geology:

Geology is a natural science concerned with the study of the earth from all points of view.

The word geology comes from two Greek roots:

ge : Earth

Logos: study, description, observation, discussion.

1.1.2. Aim and purpose of geology:

Traditional geology has evolved considerably in techniques and methods.

Geology is of vital importance both scientifically and economically, through the study and understanding of the complex history of the earth, with all the events that have taken place on its surface (tectonics, earthquakes, volcanoes), and through the search for and exploitation of raw materials (iron, copper, gold...), energy (oil, gas, coal...), water, the source of life, and construction materials (gravel, sand, gypsum...).

The main approaches to achieving these objectives are:

- The description of the composition and structure of the Earth's envelopes, its current appearance but also the reconstruction of its history. Geology describes the terrestrial materials, subsoil, soil and minerals that make up the superficial part of the Earth's crust.

- The study of the external and internal movements that occur at the surface and at depth, its various activities are grouped under the name of earth sciences.

- acquiring knowledge of the major phenomena that govern the planet (its dynamics, its history).

- introduction to fieldwork and information gathering (materials, resources, human concerns), for which the environment and its management have become a matter of survival.

The aim of geological studies may concern applications of geology, such as applied geology, which calls on other disciplines, whether in the field or in the laboratory.

Geological knowledge and research methods are applied in a wide range of economic and industrial fields, such as raw materials exploitation, civil engineering, water resource management, environmental management and natural hazard prevention.

There are many and varied careers in geology, for example: petroleum or mining geologist, hydrogeologist, volcanologist, seismologist, public works geologist, paleontologist, university researcher, etc.

1.1.3. Areas of study in geology:

Like all natural science specialties, geology is a science that draws on many disciplines (Biology, Physics, Chemistry, Maths, Climatology...).

Geology is divided into two main areas: Fundamental geology and applied geology.

The specialties of fundamental geology are, for example:

- Petrography = study of rocks,

- Mineralogy = study of minerals,

- Crystallography = study of the crystalline properties of matter,

- Volcanology = study of volcanoes,

- Seismology = study of earthquakes,

- Sedimentology = study of sediments,

- Geochemistry = study of the chemical behavior of elements,

- Stratigraphy = study of sediment succession,

- Paleontology = study of fossils,

- Geomorphology = study of the Earth's relief,

- Geophysics = application of various geophysical prospecting techniques,

- Geodynamics = study of the earth's internal and external movements, their causes and consequences.

- Geochronology = the dating and reconstruction of the earth's geological history.

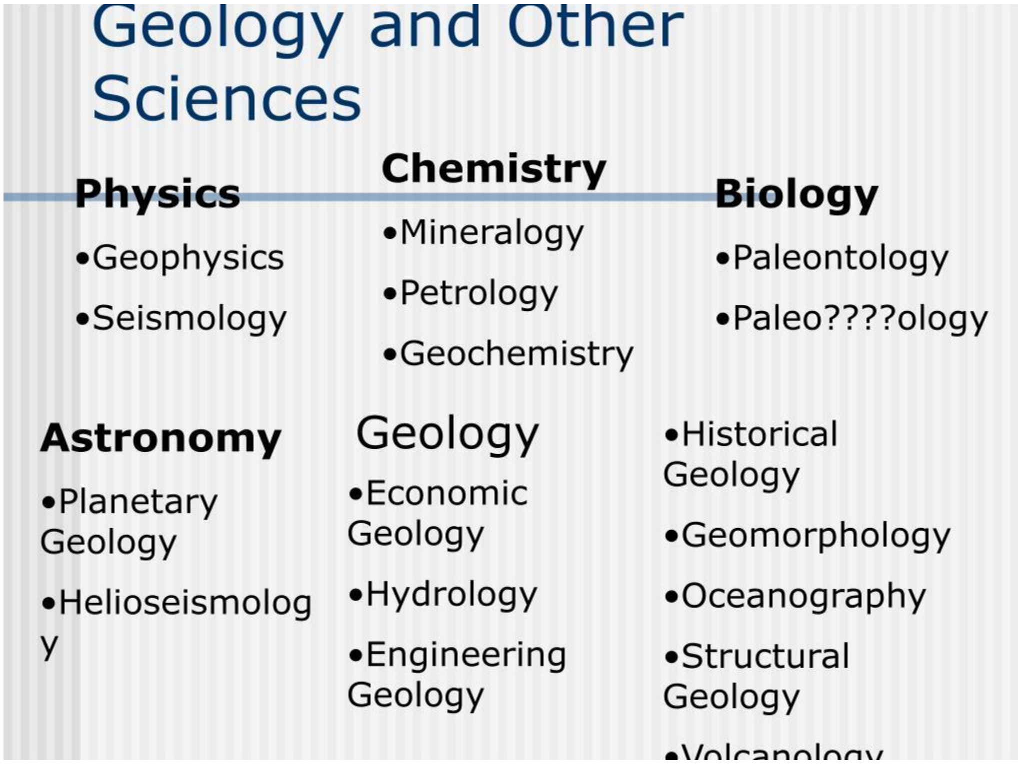


Figure 1: Relationship between some specialties of geology and several disciplines such as physics, chemistry, math and biology.

* Paleontology:

The study of ancient life on earth (animals and plants). It is the specialty that comes closest to biology. The science of fossils, it studies the beings that have lived on the globe over geological time, their evolution and their sequence from Precambrian times to the present day.

Paleontology is divided into :

Paleozoology: the study of fauna

Paleobotany: study of flora

Paleoecology: study of the environment

Paleogeography: uses all previous data to reconstruct ancient geographies, the evolution of continents and oceans, and the evolution of climates, fauna and flora.

Micropalaeontology: study of ancient micro-organisms.

The essential difference between biology and paleontology is the time factor: whereas biology works on present-day time (T = 0), paleontology works on life that may be billions of years old.

A stratigraphic scale has been established, based essentially on fossils. This scale is divided into 4 main parts:

Paleozoic = Primary Era = I aire

Mesozoic = Secondary era = II area

Cenozoic = Tertiary = III area

= Quaternary = VI area

This stratigraphic scale is still used by geologists today.

* Mineralogy: studies and classifies the minerals that make up rocks.

* Stratigraphy: a branch of earth sciences concerned with the study of the arrangement of geological layers in time and space.

The name is made up of two words:

Stratum: strata, envelopes, layers, beds ....

Graphaian: graphy, layout, description, study, ...

Stratigraphy is therefore concerned with all the physical and chemical conditions affecting geological strata and their evolution over time.

* Petrography: Branch of earth sciences concerned with the 'rocky' composition of the earth's crust.

Its essential aim is the macroscopic and microscopic study of the various rocks that make up the earth from all points of view: mineralogical composition, structure, texture, hardness...

There are three main groups of rocks:

* Sedimentary rocks

* Magmatic rocks

*Metamorphic rocks

*Sedimentology: Branch of geology concerned with the study of the characteristics, emplacement and disposition of loose particles (sediments).

- Either during displacement,

- or during deposition, with all the phenomena involved in their transformation (diagenesis).

* Tectonics: a branch of the earth sciences concerned with the natural movements and deformations that the globe undergoes.

These deformations can be of different types: Plate tectonics, diaclases, faults, folds, orogenesis, etc....

* Geochemistry: the science that studies the characteristics and behavior of different chemical elements in the earth's crust, their quantitative distribution, combinations and migrations.

*Geochronology: Chronometers the history of the earth from its origins to the present day, making it possible to establish a relative scale of geological time based on the succession of deposits.

Geochronology made enormous progress with the discovery of radioactivity, giving an absolute scale.

*Geophysics: Applies the laws of physics to the search for information about the earth's internal constitution.

*Dynamic geology: studies geological phenomena, their genesis, and the relationships between elementary tectonic forms and those of the terrain.

The specialties of applied geology are :

Mining geology, hydrogeology, engineering geology (geotechnics), petroleum geology, environmental geology.

1.1.4. The geological approach :

The approach has become multidisciplinary, integrating disciplines such as geophysics, geochemistry, etc. Knowledge of the terrestrial globe is obtained from direct observations; a field study (reconnaissance of the region, collecting samples, surveying maps, taking measurements, laboratory study), and indirectly through the study of physical phenomena affecting the earth; This is the field of geophysics, because the direct study of earth samples has to contend with the complexity of the earth's internal conditions. To get to the depths, it has been necessary to call on indirect methods such as seismic reflection or refraction for image acquisition, or by measuring physical properties (wave propagation speed) from the ground surface, gravimetry (measurement of the gravitational field), magnetometry (measurement of the magnetic field). These measurements enable us to characterize the terrain by its physical parameters, and we have to take into account the time factor, because time is an immense space, in which extremely slow physical and chemical phenomena end up having remarkable effects on the earth's crust.

1.2. Structure of the universe and birth of the solar system

1.2.1. The universe:

The Big Bang theory is a set of phenomena describing the formation of the universe. It proposes the existence of an infinitely dense and very hot phase, during which the infinitely small Universe grew exponentially and rapidly, forming elementary particles and then atoms and all the raw material that gave rise to nebulae, galaxies, stars, interstellar clouds and all the celestial bodies that surround us. The universe was born around 15 billion years ago.

A galaxy is an assembly of dark matter, gas (hydrogen, helium), dust and stars, held together by gravity. There are several billion galaxies in the Universe. Our own galaxy is called the Milky Way. It contains 200 billion stars. This large galaxy resembles a flattened disk and is home to our solar system.

1.2.1.1. Evolution and expansion of the universe:

Nebulae, clouds of gas and dust, form in the expanding Universe. In these clouds, which contain a high proportion of hydrogen, very dense and very hot zones appear, in which hydrogen atoms, subjected by gravitation to very high temperature and pressure, fuse together to form helium atoms, where the core of the first stars is formed.

When stars die, all the atomic elements formed are expelled into the interstellar clouds, where they recombine. Each star contributes to the enrichment of the Universe and the creation of new stars.

The currently observable universe is made up of billions of galaxies and nebulae, with a diameter of around one billion light-years (one light-year = 10 13 km).

The universe is expanding, i.e. galaxies are moving away from each other, causing distances between them to increase and all galaxies to flee from our own (the Milky Way).

The discovery of the expansion of the universe put an end to the idea of the invariability of the world. This discovery demonstrated that not only do cosmic bodies evolve, but so does the entire universe, and that in the end, contraction will return the universe to the state it was in at the moment of its birth.

A new Big Bang and everything will start again: expansion, then contraction and so on to infinity.

Figure 2: conceptual diagram of the Milky Way

1.2.1.2.The solar system:

1.2.1.2.1. The solar system is located in the Milky Way, a spiral galaxy around 100,000 light-years in diameter, containing 200 billion stars. The Sun resides in one of the galaxy's outer spiral arms, the Orion arm. Composed of a star, the Sun, and the celestial objects orbiting it: this ensemble includes eight planets and an infinite number of objects of varying sizes (meteorites, asteroids, comets, interplanetary dust, etc.). Our sun appeared nearly 4.5 billion years ago.

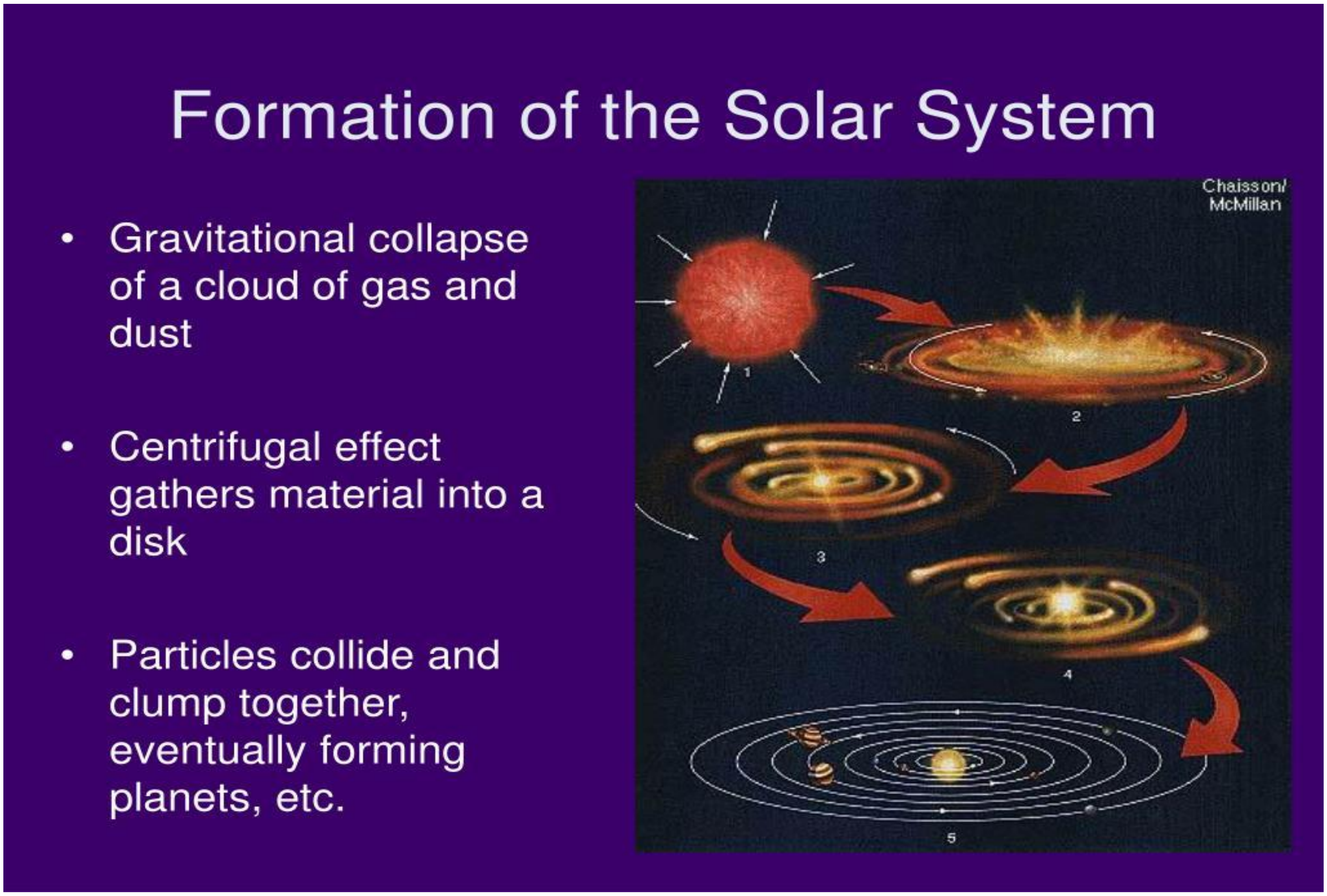
1.2.1.2.2. Birth and composition of the solar system: made up of the Sun, planets, satellites, asteroids, comets and a whole host of debris left over from its formation. It was formed by the rotation of a cloud of interstellar gas and dust - the solar nebula - the remains of two generations of stars. The Solar System is made up of the sun and its eight orbiting planets, in order of increasing distance from the sun: Mercury, Venus, Earth, Mars, Jupiter and Saturn, Uranus, Neptune.

Pluto: is a satellite detached from Neptune.

(The first four planets are called inner telluric planets, and four outer gas giant planets).

The sun is the gravitational center of all the planets, which orbit in the same direction and virtually in the same plane. Because of its mass (99.9% of the solar system's mass), the sun exerts a considerable force of attraction.

All the planets except Mercury and Venus have natural satellites orbiting them, e.g. the moon around the earth.



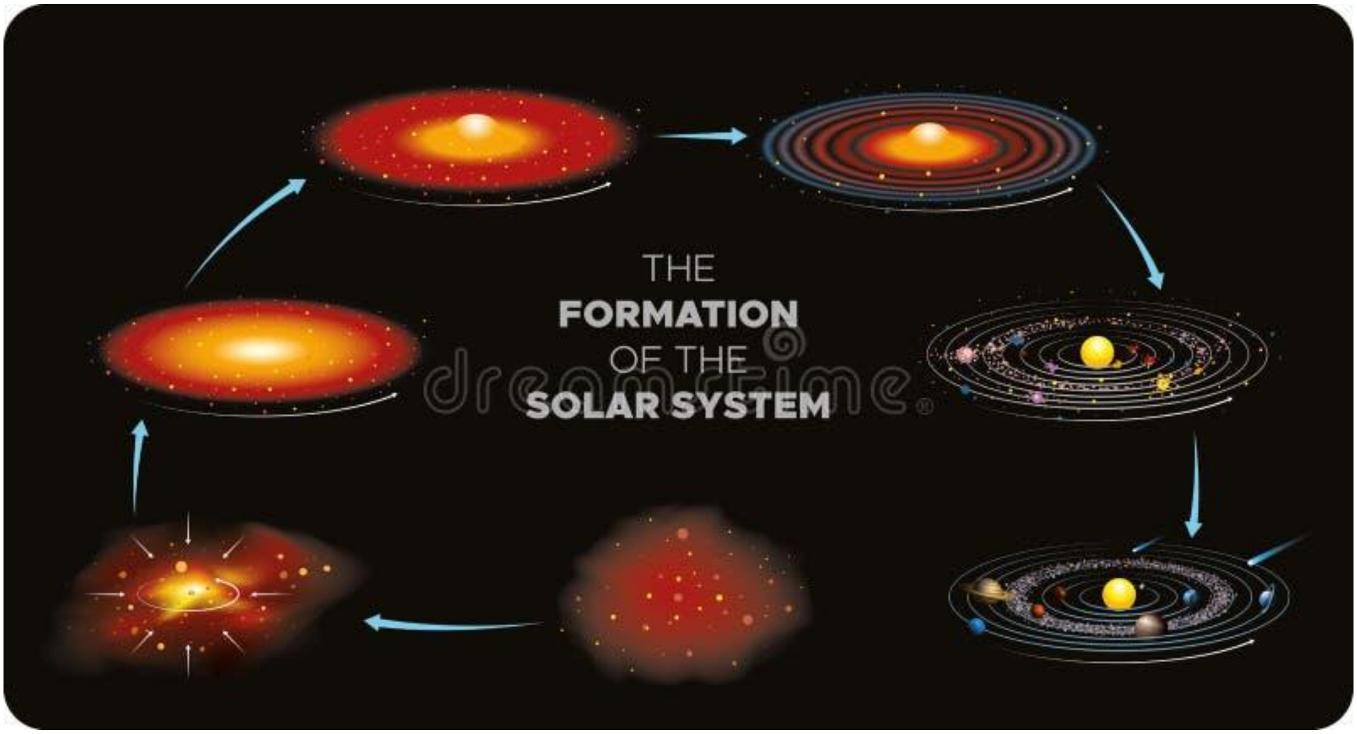


Figure 3: Stages in the formation of the solar system

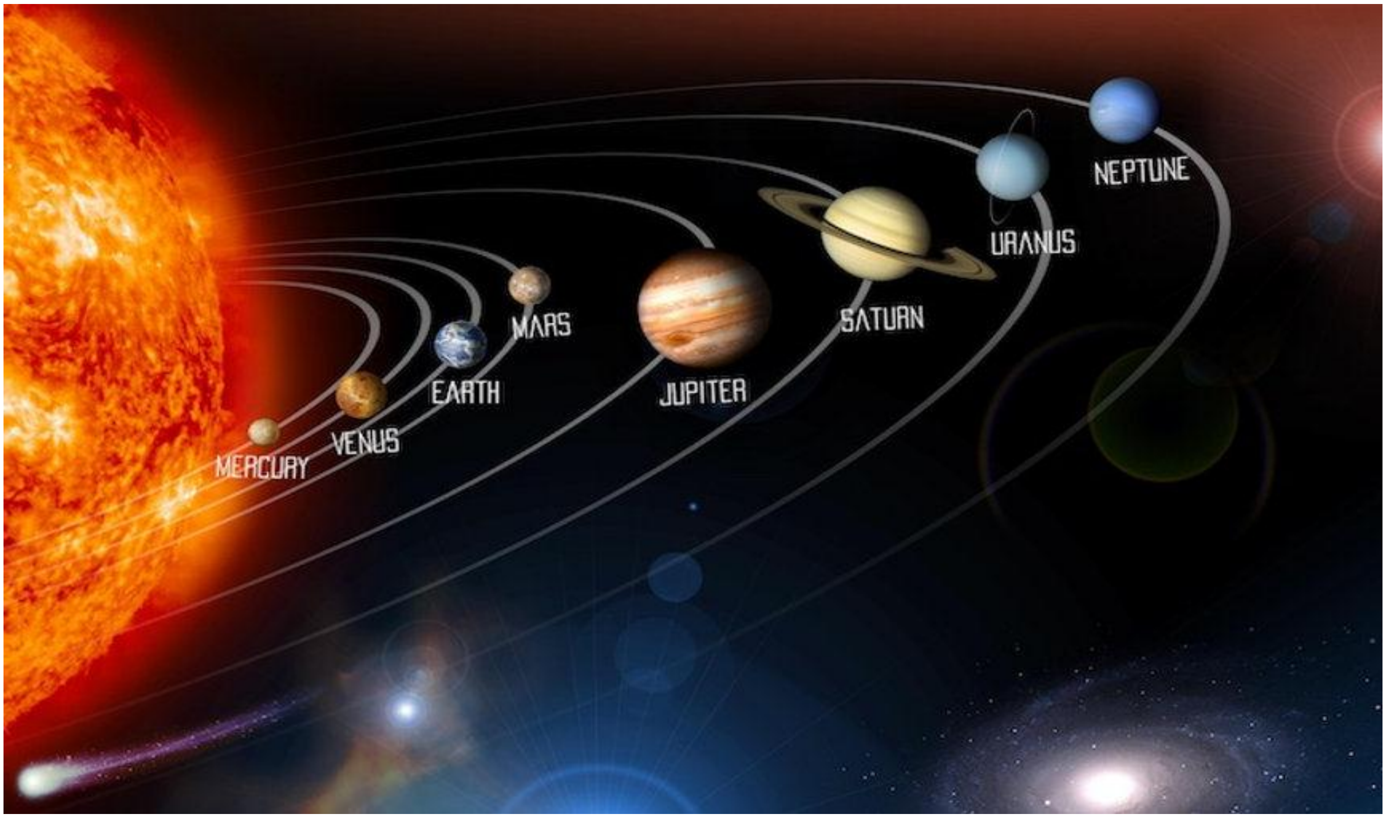


Figure 4: The Solar System: Sun, planets and orbits

1.3. The earth and the planets of the solar system

1.1. The planets of the solar system:

All the constituents of the solar system, which are : The Eight Planets, the Four Dwarf Planets, the Satellites, the Asteroids, and the Comets, can be defined as follows:

1.3.1.1. Planets:

These are bodies orbiting the Sun, differentiated from one another by their size and constituent materials. There are eight known planets.

- Telluric planets: The four inner planets have a dense, rocky composition. Modest in size, the largest of these planets being the Earth, they are composed largely of minerals such as silicates, which form their solid crust and semi-liquid, and metals such as iron and nickel, which make up there.

All have an atmosphere (gas envelope), except Mercury.

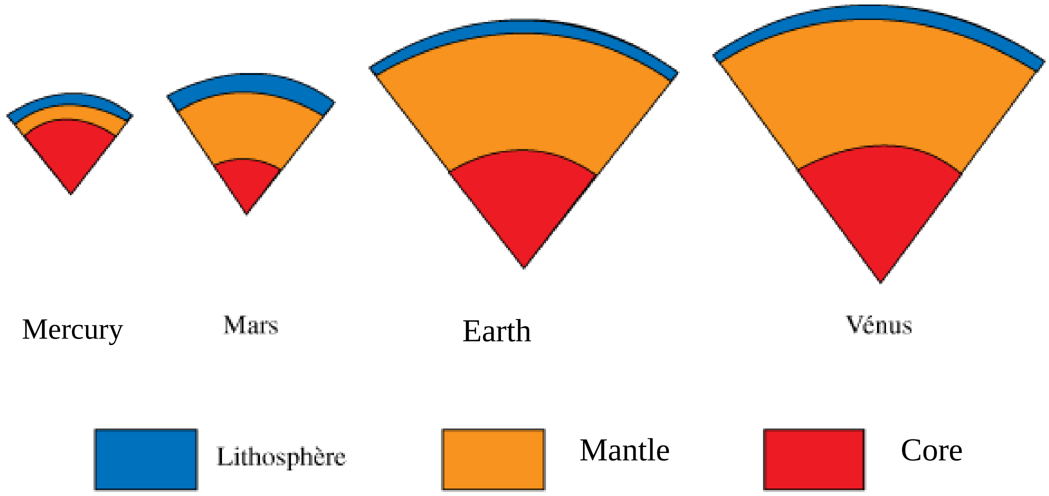


Figure 5: Envelopes of the terrestrial planets

- Giant planets: Jupiter, Saturn, Uranus and Neptune are much larger, low-density (gaseous) giant planets formed in regions far from the Sun, whose atmosphere, based on hydrogen and helium, has retained a composition very close to that of the nebula from which they originated.

Pluto is very poorly known, and is probably a satellite that has escaped from Neptune's orbit, and appears to be similar in size to the telluric planets and in density to the giant planets.

1.3.1.2. Four dwarf planets:

Charon,

Ceres,

Xena, and Pluto (Placed in this category since 2006 by some specialists).

1.3.1.3. Satellites: Some planets have satellites.

For example, the Moon is the satellite of the Earth.

Others, like Jupiter, have several.

1.3.1.4. Comets: are small celestial bodies in the Solar System, generally a few kilometers in diameter, composed mainly of volatile ice.

When a comet enters the inner Solar System, its proximity to the Sun causes sublimation and ionization of its surface, creating a tail: a long trail of gas and dust.

1.3.1.5. Meteorites: are extraterrestrial rocks that circulate in the solar system and are eventually captured by the Earth's gravitational pull. As they pass through the atmosphere, they heat up and volatilize on the surface. The inner part of the meteorite can be preserved and collected for examination.

There is a wide variety of meteorites, of which there are three main classes: chondrites, achondrites and metallic meteorites.

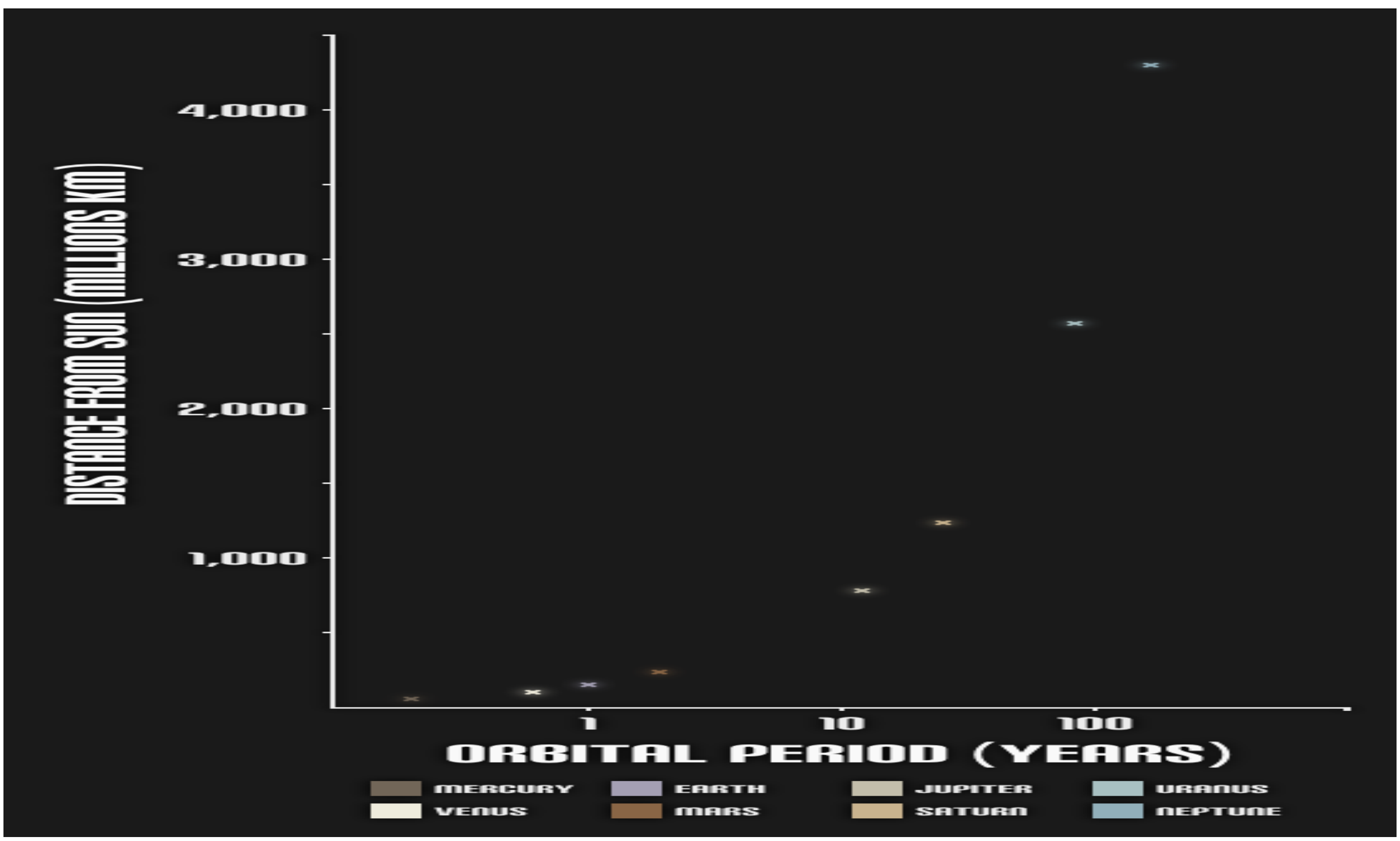
Ex: In Arizona, over 1200 m in diameter and 175 m deep, these meteorites are the result of collisions between larger celestial objects. The age of the meteorites, determined by various isotopic methods, is remarkably consistent across all types: 4.55 Ga (1 Ga = 1 billion years).

1.3.1.6. Asteroids: are mainly small solar system bodies composed of non-volatile rocks and metallic minerals, orbiting the sun and ranging in size from several hundred kilometers to microscopic dust.

Table 1: Characteristics of the different planets

Planètes	**Planets Distance from sun million Km**	**Radius Km**	**Mass of earth = 1**	**Average density**	**Average external temperature °C**	**Chemical composition**	**Atmosphere**	**Nbr of satellites**
Mercury	**57,9**	**2439**	**0,055**	**5,45**	**167**	**Iron + Silicates**	**--**	**0**
Vénus	**108,2**	**6100**	**0,81**	**5,25**	**465**		**CO_2, N_2 H_2O, Ar**	**0**
Earth	**149,5**	**6400**	**1**	**5,52**	**+ 15**		**N_2, O_2, Ar, CO_2, H_2O**	**1**

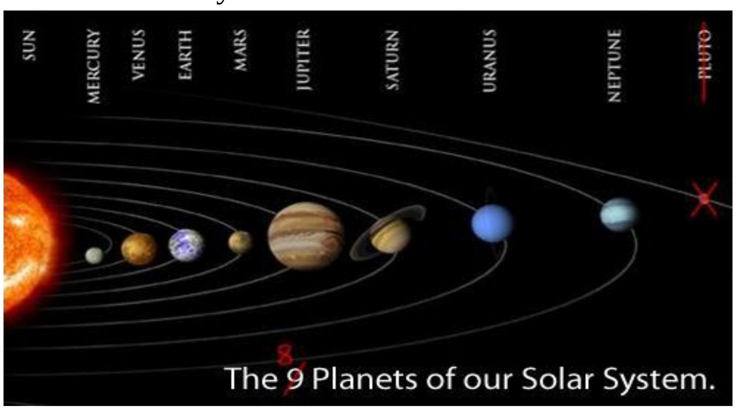
Mars	**227,9**	**3400**	**0,11**	**3,94**	**- 65**		**CO_2, N_2, Ar, H_2O**	**2**
Jupiter	**778,0**	**71490**	**318**	**1,33**	**- 110**	**He**	**H_2, He, CH_4, NH_3**	**63**
Saturn	**1427,0**	**60268**	**95,2**	**0,69**	**- 140**	**+**	**H_2, He, CH_4, NH_3**	**47**
Uranus	**2871,0**	**25560**	**14,6**	**1,27**	**- 210**	**H_2**	**H_2, He, CH_4**	**27**
Neptune	**4499,0**	**24760**	**17,3**	**1,64**	**- 220**			**13**



Name	Diameter	Distance from Sun	Length of Year:
Mercury	4,879 km	57,909,227 km	88 Earth days
Venus	12,104 km	108,209,475 km	225 Earth days

Name	Diameter	Distance from Sun	Length of Year:
Earth	12,742 km	149,598,262 km	365.24 days
Mars	6,779 km	227,943,824 km	1.9 Earth years
Jupiter	139,822 km	778,340,821 km	11.9 Earth years
Saturn	116,464 km	1,426,666,422 km	29.5 Earth years
Uranus	50,724 km	2,870,658,186 km	84.0 Earth years
Neptune	49,244 km	4,498,396,441 km	164.8 Earth years

Figure 6: Distances and periods of sidereal revolution of the planets in the solar system

<table>
<tr>
<td>Our Solar System

</td>
<td>There are 8 planets in the solar system.
Pluto is no longer considered a planet.

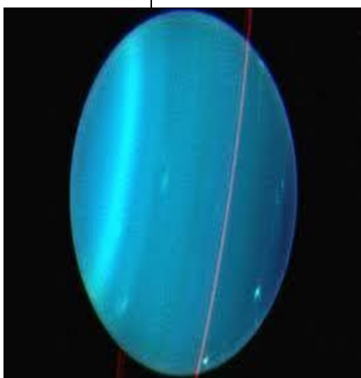
From the sun the order of the planets is: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune</td>
</tr>
<tr>
<td>Jupiter
</td>
<td>Jupiter is the largestplanet.

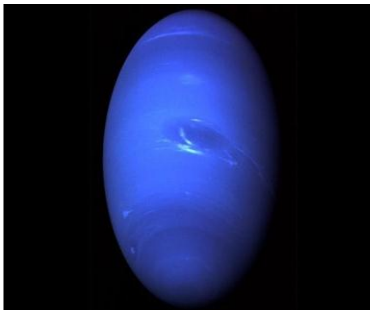
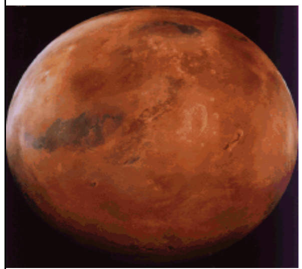
It is 5th from the sun.

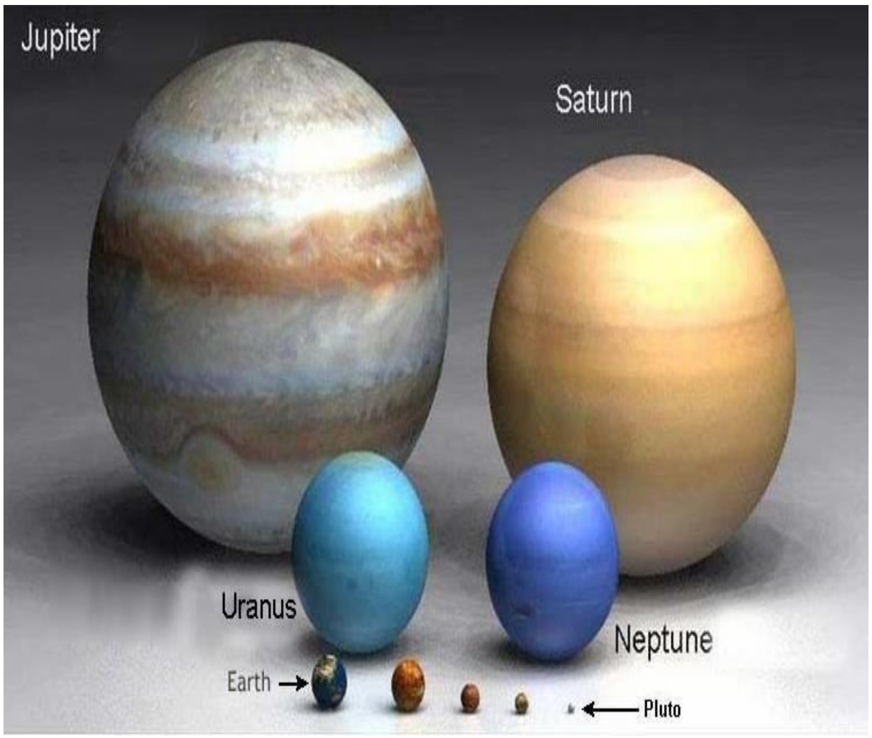
It is considered a gasgiant. It has no solid surface.</td>
</tr>
<tr>
<td>Saturn
</td>
<td>Saturn is 6th from thesun.

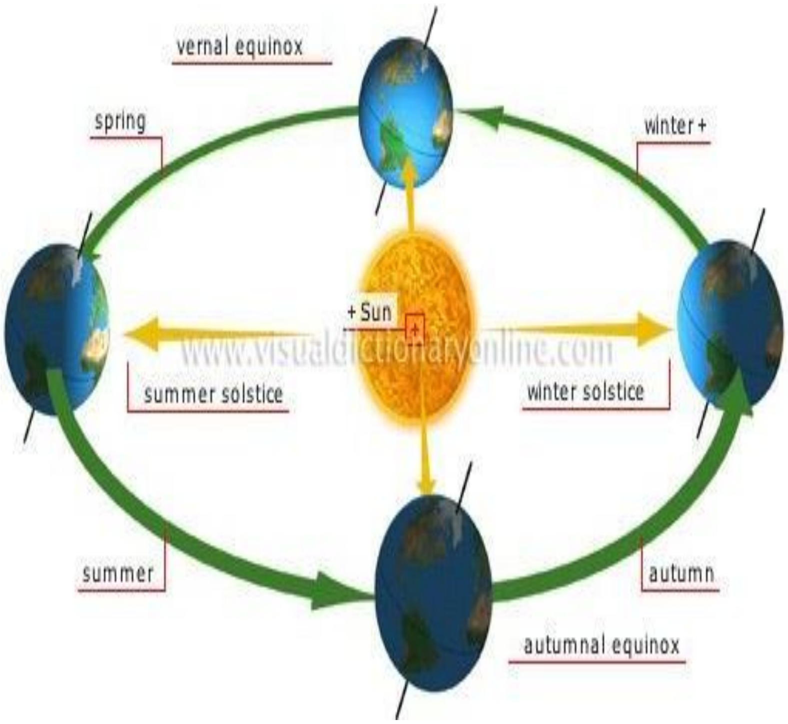
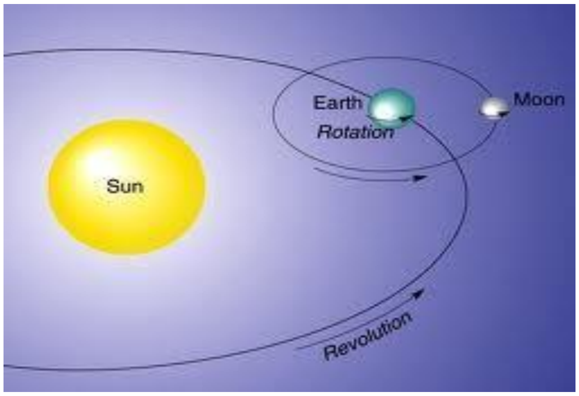
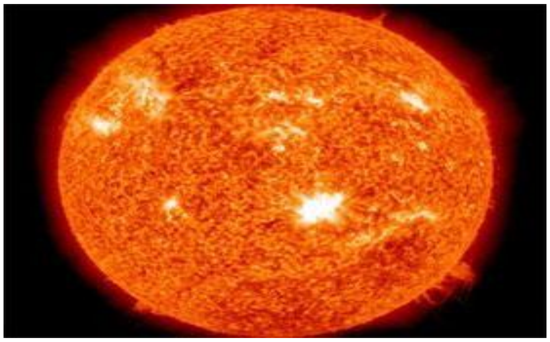
It is considered a gasgiant. It has no solidsurface.

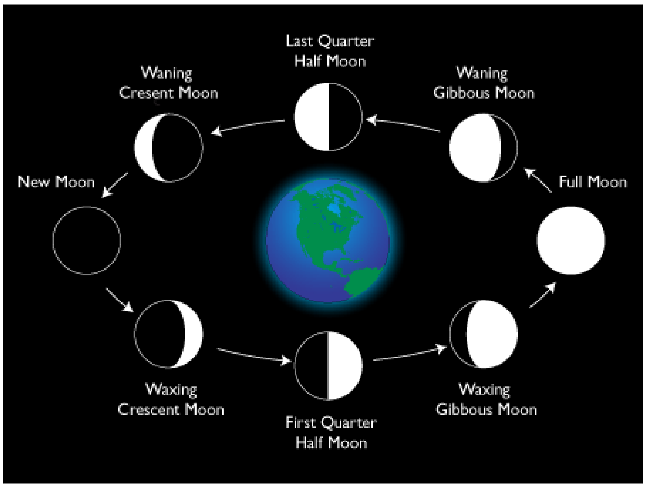
It has rings around it.</td>
</tr>
</table>

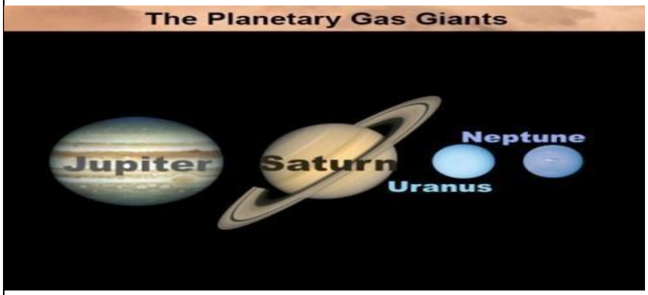
 Uranus	Uranus the 7th planet from the sun. It is considered a gas giant. It has no solid surface. It has rings around it.	 Venus	Venus is second from the sun. It is similar to the size of earth. It is a very hot planet. It is a terrestrial planet (rocky)

 Neptune	Neptune is the 8^{th} planet from the sun. It appears blue from telescopes and is a gasgiant. It has no solid surface. It has rings around it.	 Mars	Mars is 4^{th} from thesun. It is a terrestrial planet (rocky) The atmosphere is thinand it has canyons andriverbeds.
 Earth	Earth is the 3^{rd} planetfrom the sun. It is a terrestrial planet (rocky) It can support life because it has an atmosphere, liquid water and is close enough to the sun for light and warmth.	 Mercury	Mercury is the closet to the sun and is the smallest. It is a terrestrial planet (rocky) It has lots of craters and looks like our moon.

Planets According to Size 	Planets sorted in order of size from largest to smallest are: **1- J**upiter **2- S**aturn **3-U**ranus **4-N**eptune **5-E**arth **6-V**enus **7-M**ars **8-M**ercury

Seasons  	Due to the tilt on its axis, the Earth experiences seasons during its revolution around the sun. When the tilt is closer to the sun it is spring and summer. Farther we experience fall and winter.
Sun-Earth-Moon relationship  	The Sun is a stationary star. Earth rotates on its axis and revolves around the sun. The moon rotates on its axis and revolves around Earth.
Sun 	An average sized star. It is 4.6 billion years old. It is about 110 times bigger than the Earth.

The Moon 	The moon is a small rocky satellite. It rotates on its axis and revolves around the Earth about once every 30 days. It is ¼ the size of Earth. It has no atmosphere or life, has very little water, and extreme temperatures.
Phases of the Moon 	There are 8 phases of the moon and are based on the moons position to Earth and the sun. 1. New moon 2. Waxing crescent 3. First quarter (half) 4. Waxing gibbous 5. Full 6. Waning gibbous 7. Last quarter (half) 8. Waning crescent

Gas Giants 	the 4 largest planets, made mostly of gas: Saturn, Jupiter, Uranus, Neptune

Terrestrial Planets 	rocky inner planets: Mercury, Earth, Venus, Neptune

Figure 7: Some characteristics of the planets in the solar system

1.3.2. The Earth:

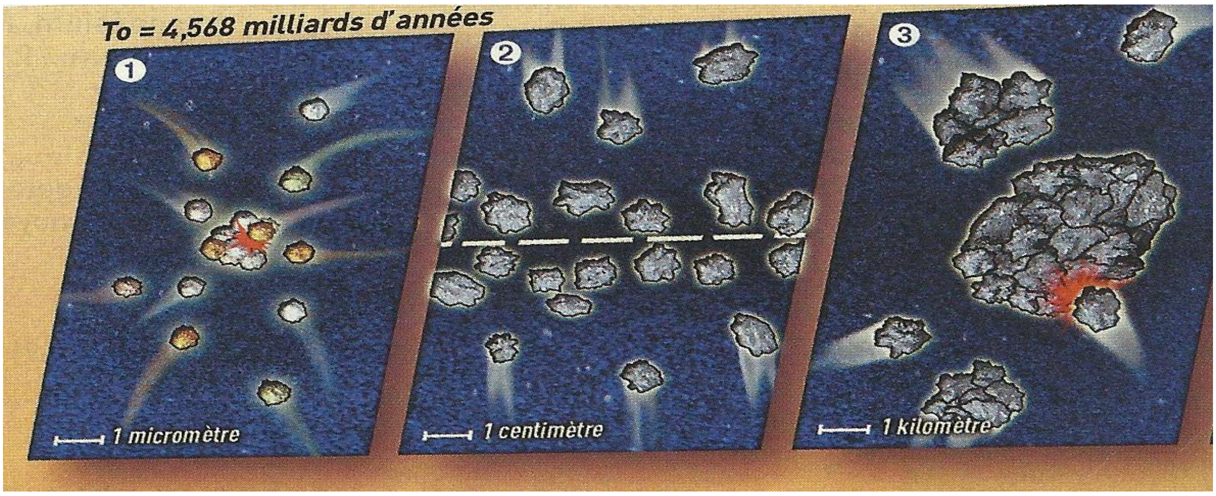
1.3.2.1. Its formation:

It is a rocky planet in the solar system.

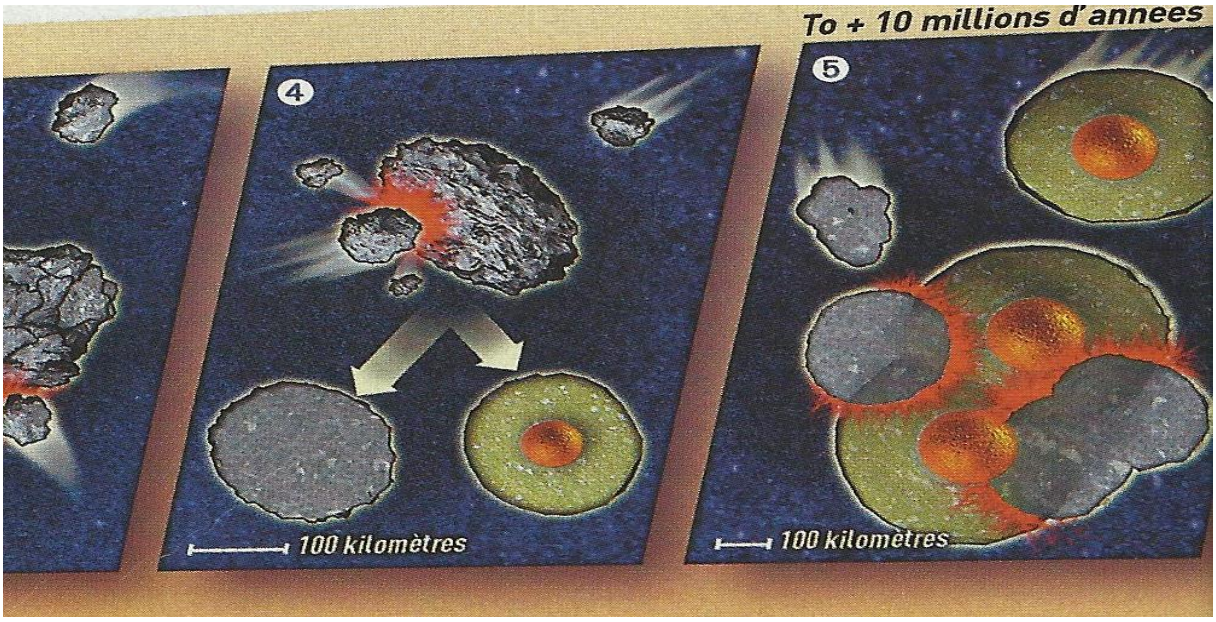
Its distance from the sun and its mass allow it to have an atmosphere.

1.3.2.1.1. Stages in the formation of the Earth:

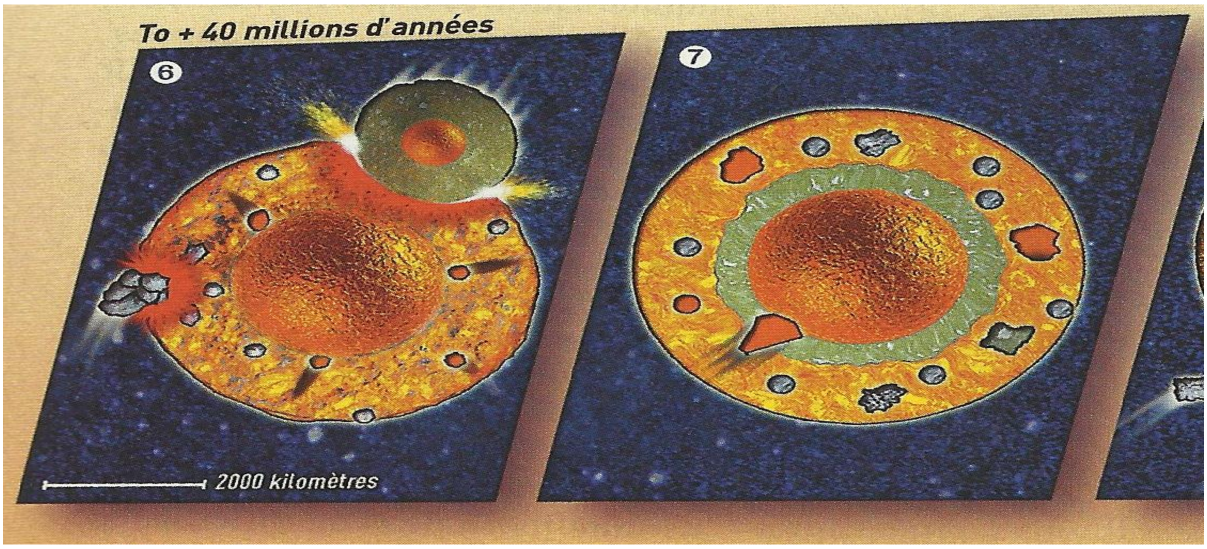
- From dust to planets: Planet Earth was formed around 4.5 billion years ago, by the agglomeration of cosmic matter (rocky fragments, dust and gas) in fusion. Gradually, the Earth cooled, the lighter elements rising to the surface and the heavier ones (iron) sinking to form the core, and the current high temperature inside the Earth comes from the radiogenic heat of nuclear reactions, It is therefore natural to think that the earth was formed from molten matter, but it must then have passed in whole or in part through the liquid state, and a differentiation by gravity took place, as we know from the superimposition in the globe of increasingly dense layers as we go deeper into the earth.



Around 4.568 billion years ago, tiny solid grains condensed and stuck together.1 when they reached centimetric size, these grains sedimented in the median plane of the disk.2 They collided and agglomerated.



Planetesimals are formed3 and then planetary embryos.4 Under the effect of shocks and the disintegration of radioactive elements, large embryos heat up sufficiently to differentiate into a metallic core (orange), a mantle (green) and a basaltic crust. Smaller embryos remain as aggregates of undifferentiated material (grey).



The Earth is born from the collisions between a dozen or so planetary embryos 5. The energy imparted by the collisions is such that the Earth, having finally reached the point of growth, melts6. An ocean of silicate magma appears (orange-yellow), with iron concentrated in the central core. Subsequent collisions bring new materials: Metallics migrate to the core; silicates remain in the mantle, which crystallizes from the magma ocean (green) 7.

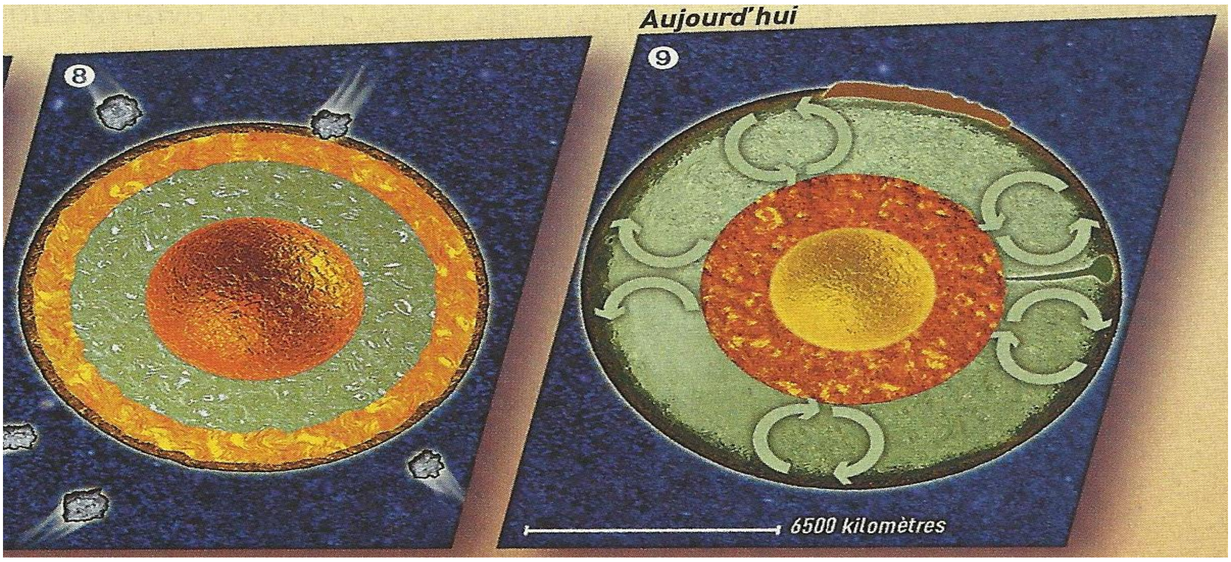


Figure 8: Stages in the formation of the Earth

Objects formed in the outer parts of the solar system probably contributed a significant proportion of the water present on Earth8. Our planet acquired a structure close to the one we know today (with a central metallic core, solid at the core and liquid on the outside, a solid silicate mantle, an outer envelope bearing the first continents and oceans, and a gaseous envelope) after a few hundred million years9.

2.1.8.1. The particularities of the Earth:

1.3.2.2.1. The terrestrial globe:

- The Earth is a planet in the solar system. It has the shape of an ellipsoid of revolution, slightly flattened at the poles, with the following dimensions: Maximum diameter 12758 km and minimum diameter 12714 km. Its radius is 6370 km, its mass is 5.9x1024Kg and its average density is 5.51g/cm.

The Earth is located around 150 million km from the Sun (1 Astronomical Unit) and is the 3rd inner planet of the solar system, orbiting the Sun and turning on itself. The planet Earth is highly complex, with most of its structure inaccessible to direct observation, an average temperature of +15°C, the presence of life (oxygen in its atmosphere) and abundant water, making it ideal for carbon chemistry, and therefore for living beings.

The earth is characterized by the presence of the atmosphere and the hydrosphere.

1.3.2.2.2. The atmosphere:

The atmosphere is the earth's outer envelope. It plays a key role in the emergence and evolution of life, and determines the intensity of geological processes at the earth's surface. The earth's gaseous envelope, the environment in which life exists, is the most dynamic and unstable sphere on the planet. The medium controls the distribution of energy at the earth's surface, and many chemical transformations, particularly of photochemical origin, take place at this level. It is also where matter (and energy) is exchanged with the rest of the solar system and space in general. It is therefore in very close contact with the oceans, the terrestrial biosphere and the lithosphere, and functions as a medium for the transfer of matter from one sphere to another. Nitrogen, oxygen and argon make up the bulk of these gases. In percentage terms, the volume of these gases remains constant in the atmosphere up to a height of around 100 km. However, over geological time, the quantity of oxygen has not remained constant, as this gas is involved in the processes of the living world and others in chemical interactions. Among the less abundant gases, the noble gases Ne, He, Kr and Xe also appear in definite quantities. Other minor gases, including carbon dioxide, water vapour, methane, nitrous oxide and hydrogen, show variable concentrations in space and time. Water vapour is the extreme example, with a range of up to three orders of magnitude. For one constituent, the variability indicates a short residence time in the atmosphere, resulting from the predominance of source (and discharge) terms over accumulated quantities and transport and mixing rates (Junge, 1963). The different atmospheric envelopes are: troposphere, stratosphere, mesosphere and thermosphere (Fig. 9).

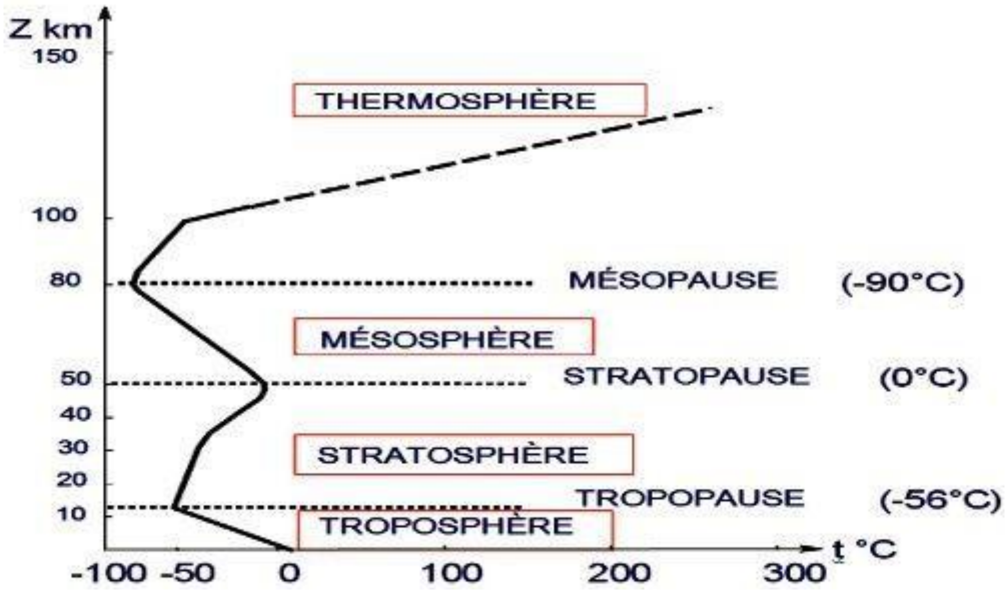


Figure 9: Atmospheric envelopes (Météo France éducation)

1.3.2.2.3. The Biosphere:

The biosphere is the totality of living organisms and their living environments, in all the ecosystems present, whether in the lithosphere, the hydrosphere or the atmosphere. The biosphere's reaction capabilities, under the effect of solar energy, enable it to alter other spheres. Infinite and unplanned, these transformations and interactions help to maintain conditions favorable to life. The biosphere is thus an open, complex; self-regulating system in which positive and negative feedbacks play an important role. The biosphere exchanges energy and matter with other systems (Fig. 10).

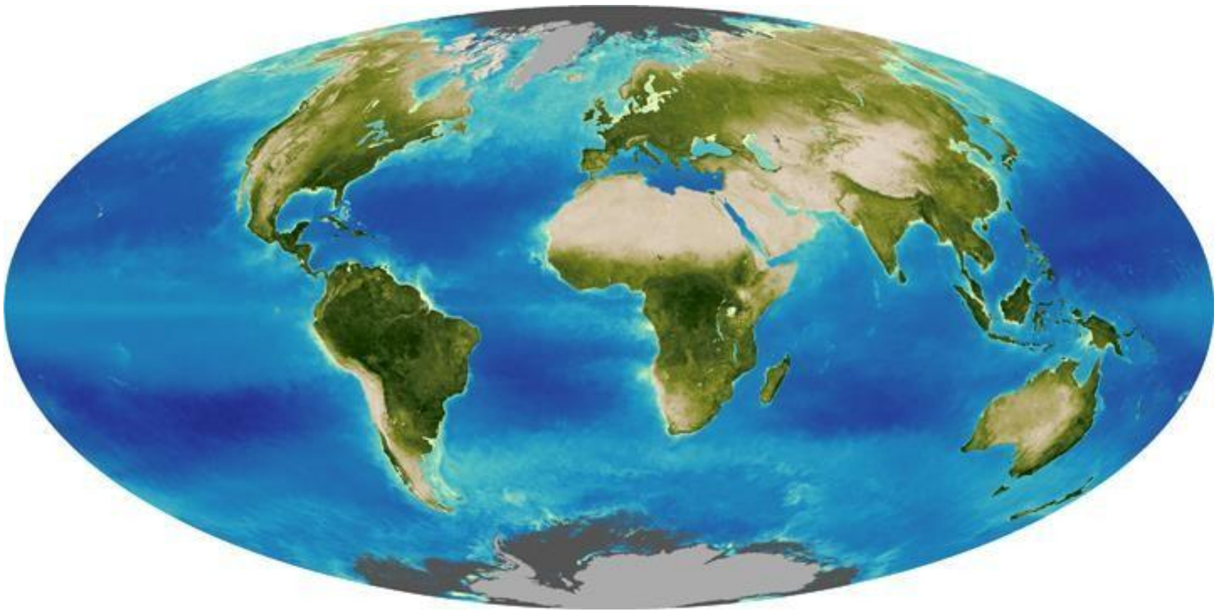


Figure 10: biosphere (earthobservatory.nasa.gov)

2.1.8.2. Hydrosphere:

Hydrosphere: all the earth's water reserves. Water covers 71% of the earth's surface. All the earth's water reserves are called the hydrosphere. The hydrosphere is made up of seas and oceans, watercourses (rivers, streams, torrents), underground reserves, ice (glaciers, ice floes, icebergs, snow) and the various forms of water present in the air (clouds, water vapor).

There are two types of water.

Salt water (97%) is found in seas and oceans, while fresh water (3%) is found in lakes, rivers, groundwater, ice and the atmosphere.

The following diagram shows the different states of water:

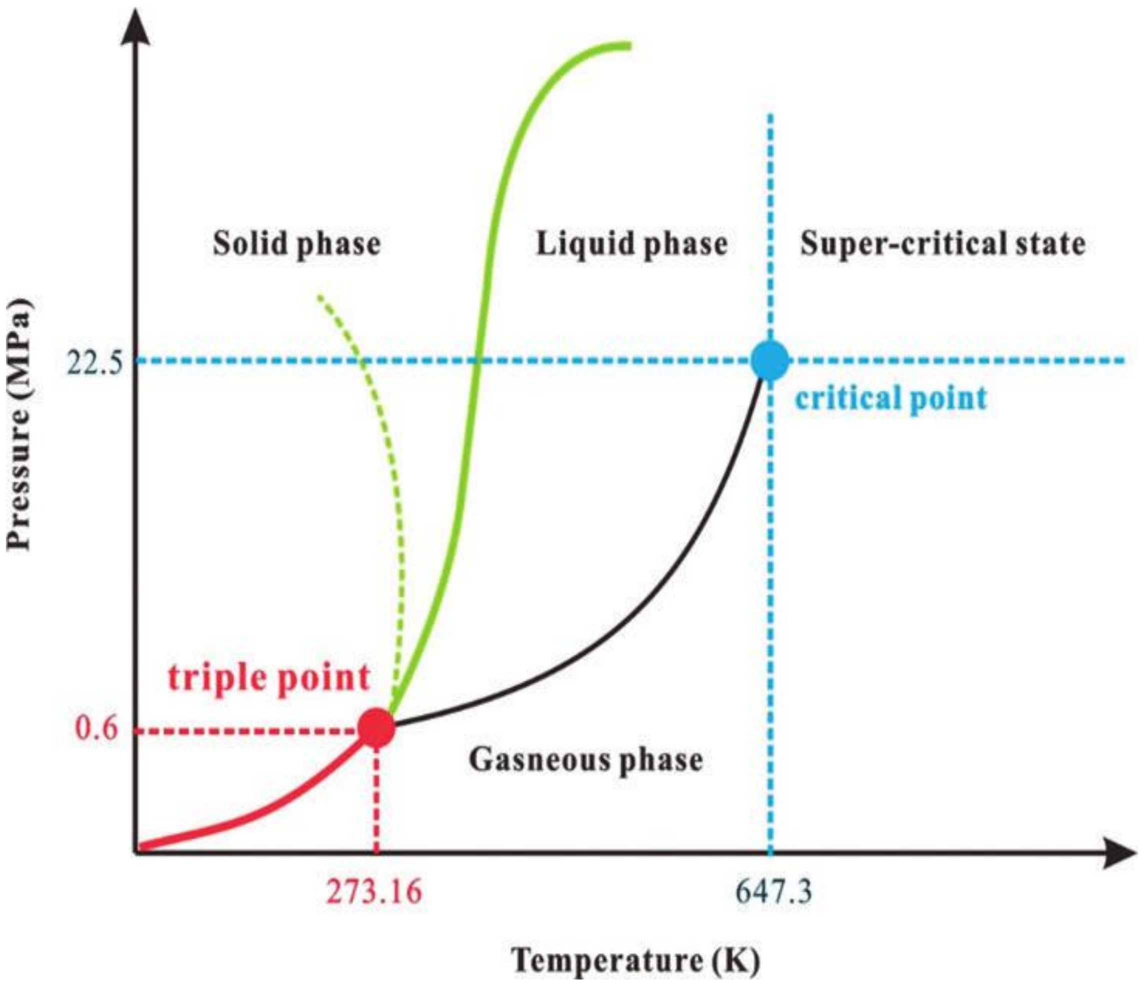


Figure 11: Different states of water

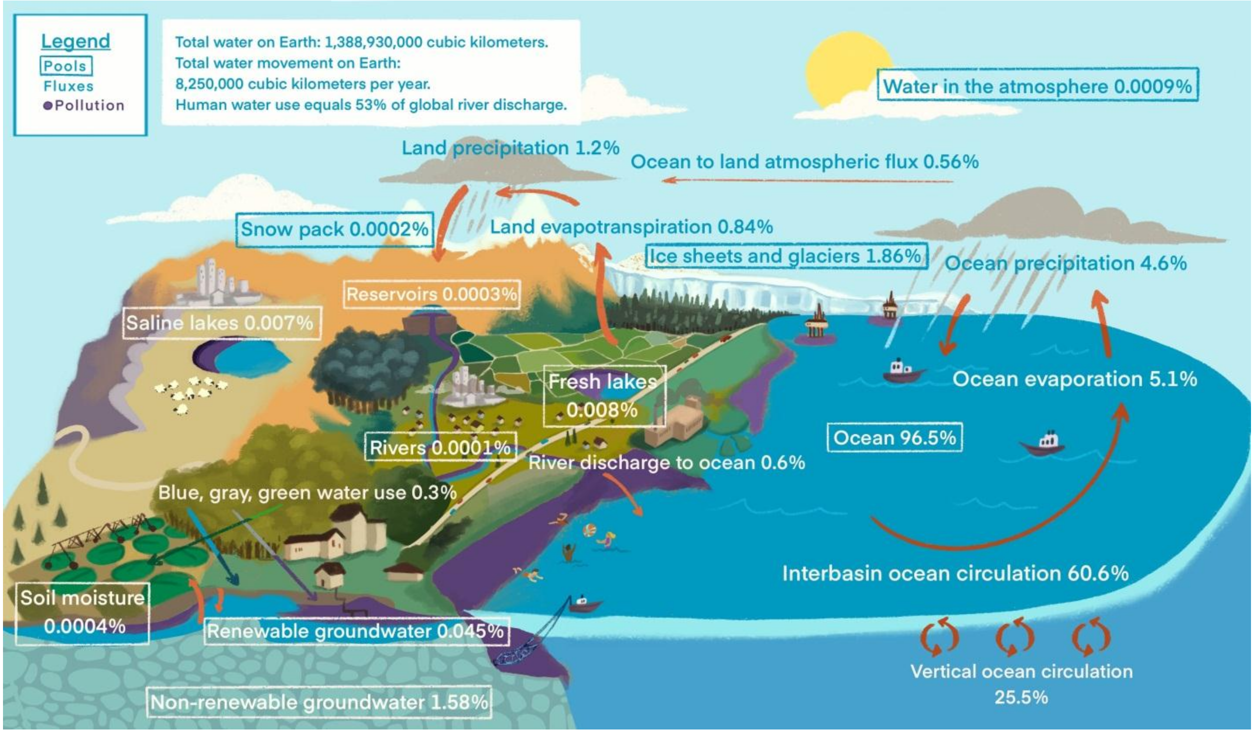


Figure 12: The water cycle (US. Department of the interior, US. Geological Survey)

CHAPTER 2: INTERNAL GEODYNAMICS

2.1. Internal structure of the globe and the geoid:

2.1.1 Introduction:

The terrestrial globe is not homogeneous; it is made up of a succession of concentric layers of varying composition and thickness. There are layers separated by discontinuities highlighted by seismology:

1 Earth's crust

2 Mantle

3 Core

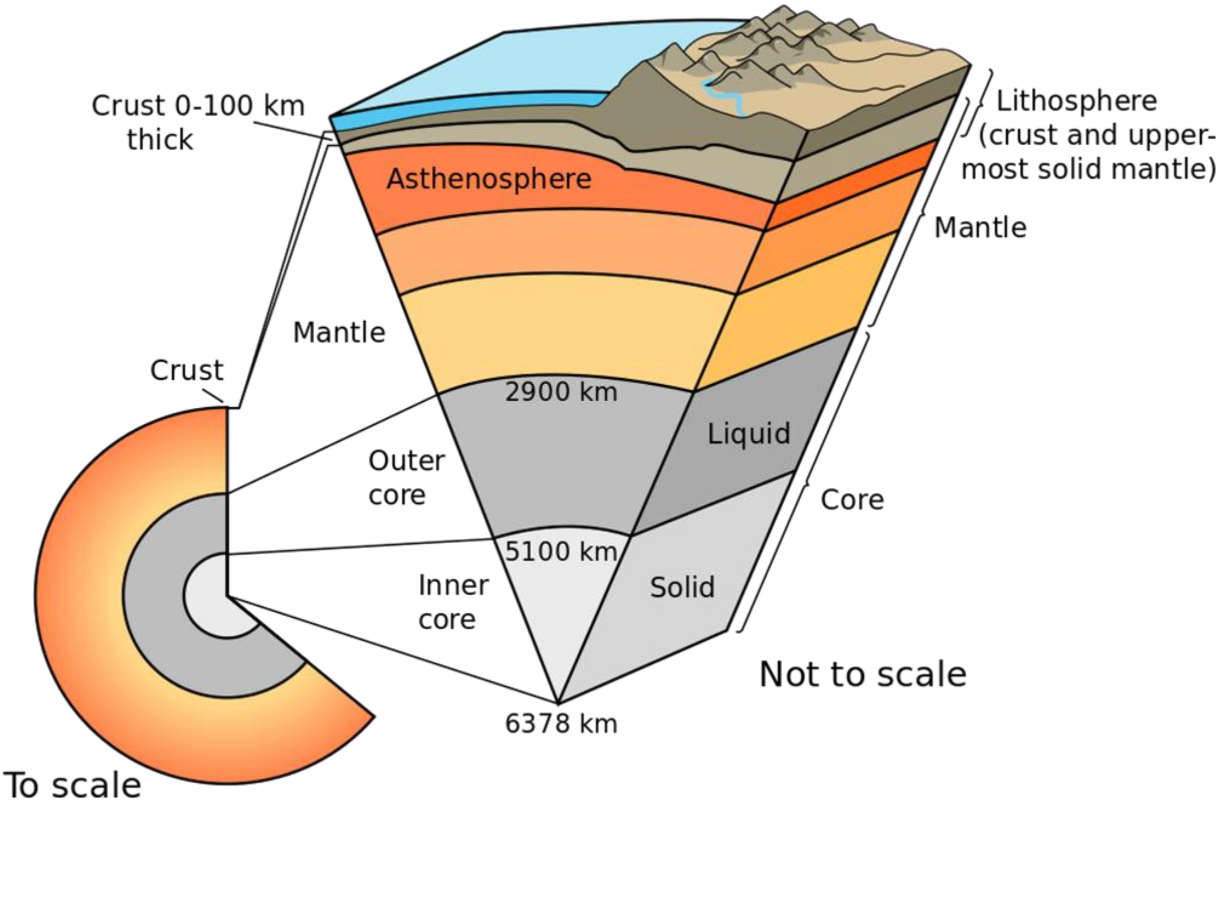


Figure13: The internal structure of the globe

The Earth's interior is thus made up of a number of superimposed layers, distinguished by their solid, liquid or plastic state, as well as by their density.

How do we know this? A kind of echography of the Earth's interior, based on the behavior of seismic waves during earthquakes. Seismologists Mohorovicic, Gutenberg and Lehmann were able to determine the state and density of the layers by studying the behavior of these seismic waves. The speed at which seismic waves propagate depends on the state and density of the material.

Some types of wave propagate equally well in liquids, solids and gases, while others propagate only in solids. When an earthquake occurs on the surface of the globe, waves are emitted in all directions.

There are two main areas of wave propagation: surface waves, which propagate on the earth's surface, in the earth's crust, and cause all the damage associated with earthquakes, and volume waves, which propagate inside the earth and can be recorded at several points around the globe.

Volume waves are of two main types: shear waves or S-waves, and compressional waves or P-waves.

2.1.2. Volume seismic waves :

The P-wave moves along creating successive zones of expansion and compression. Particles move back and forth in the direction of wave propagation, like a "slinky". This type of wave can be likened to a sound wave. In the case of S waves, the particles oscillate in a vertical plane, at right angles to the direction of wave propagation (Fig. 9).

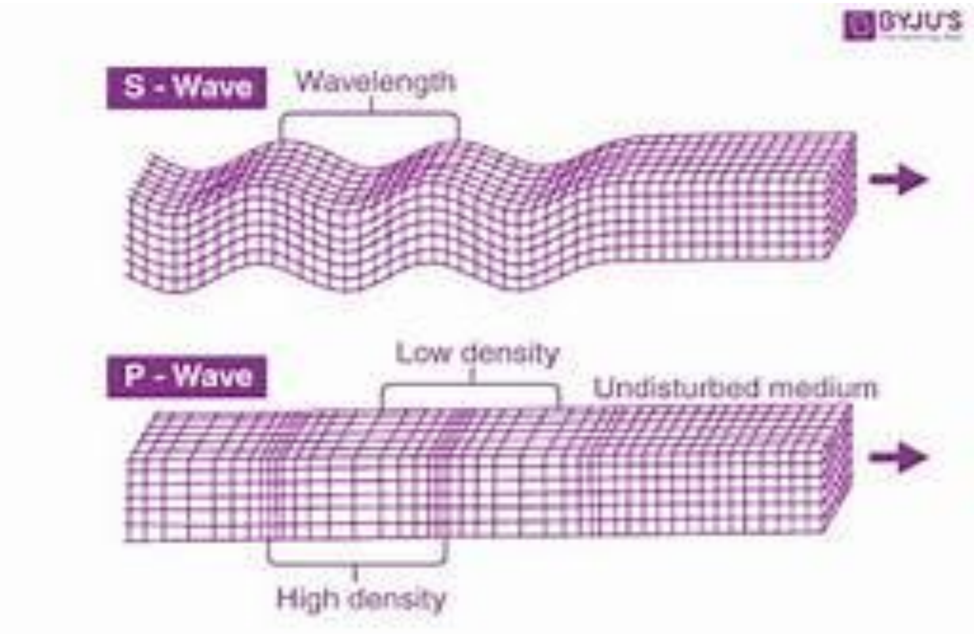


Figure 14: Volume waves

The Earth's internal structure, as well as the state and density of matter, have been deduced from analysis of the behavior of seismic waves. P waves propagate in solids, liquids and gases, while S waves propagate only in solids. We also know that the propagation speed of seismic waves is proportional to the density of the material in which they propagate (Fig. 10).

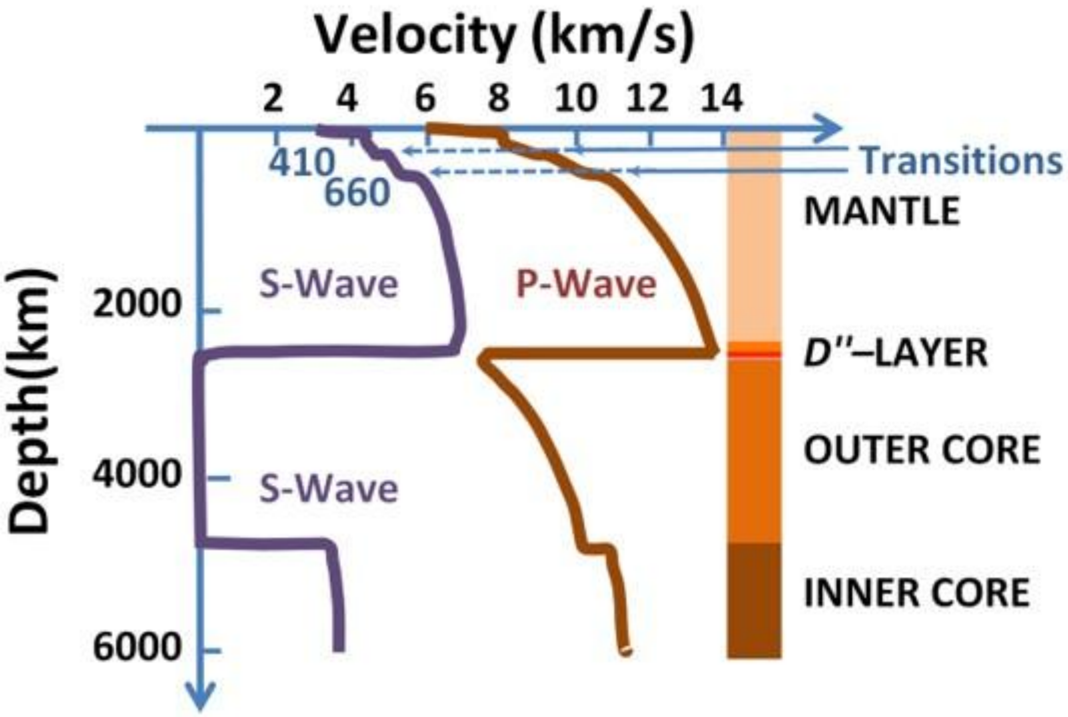


Figure 15: Seismic wave propagation

The abrupt interruption in S-wave propagation at the boundary between mantle and core indicates a transition from solid (lower mantle) to liquid (outer core). The gradual increase in P- and S-wave velocity in the mantle indicates an increase in material density as we move deeper into the mantle. The sudden drop in P-wave velocity at the mantle-core contact is linked to the change in material state (from solid to liquid), but relative velocities continue to rise, indicating an increase in densities. In more detail, at the lithosphere-core contact

asthenosphere, there is a slight drop in P and S wave propagation speeds, corresponding to the transition from solid material (lithosphere) to plastic material (asthenosphere).

The composition of the Earth's crust is fairly well known from the study of the rocks that make up the Earth's surface, and also from numerous boreholes. Our knowledge of the mantle and core is, however, more limited. Despite our best efforts, no borehole has yet penetrated the MOHO.

2.1.3. The crust:

The crust, the surface part of the earth, is made up of :

- Oceanic crust

- Continental crust

1.1.3.1 Oceanic crust:

From top to bottom, under a layer of water averaging 4.5 km in depth (Fig.), the following layers can be distinguished

Layer 1: Composed of sediments, it is thickest near the ridges and a few kilometers thicker near the continents. It averages 300 m; velocity VP is 2 km/s; density varies between 1.93 and 2.3.

Layer 2: Basaltic bedrock, 1.7± 0.8 km thick, VP speed between 4 and 6 km/s, density 2.55

Layer 3: Oceanic layer, formed by gabbros, 4.8 km thick, VP speed 6.7 km/s, density 2.95

1.1.3.2.Continental crust :

The continental crust extends over 30 to 70 km (maximum thickness is reached beneath mountainous regions) and has near-surface average granite composition. The continental crust is characterized by the presence of sedimentary and metamorphic rocks and the Conrad discontinuity. Density is 2.7 (Fig.16).

The Mohorovicic discontinuity marks the boundary between crust and mantle.

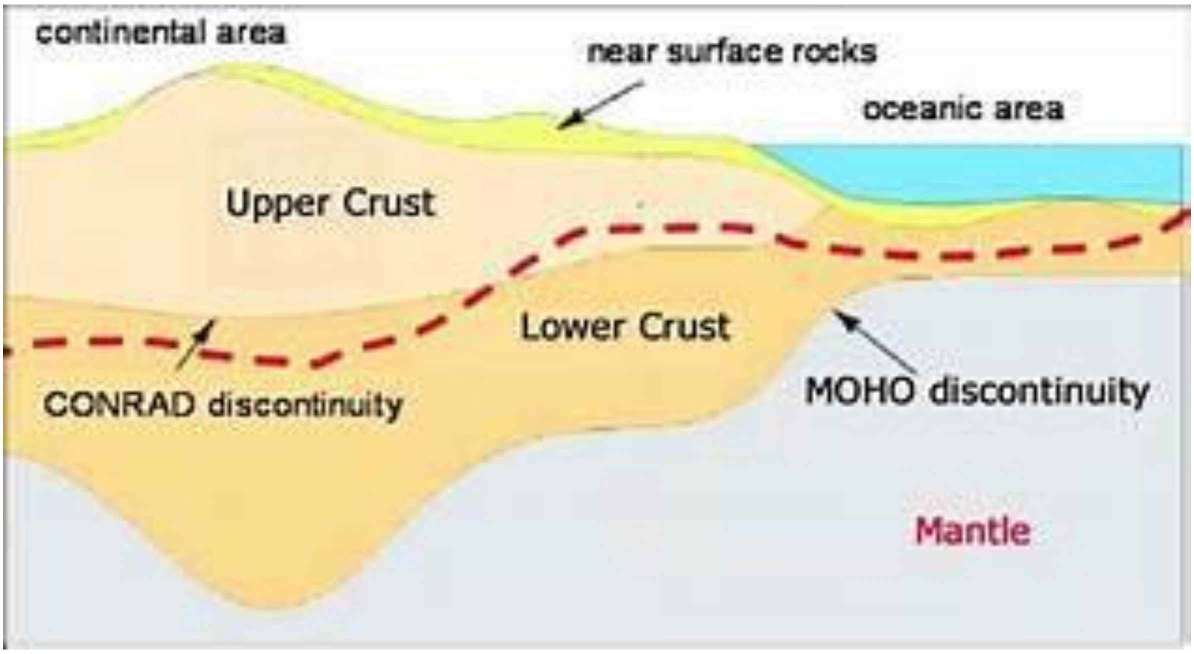


Figure 16: Earth's crust

2.1.4. The lithosphere:

This is the earth's most superficial envelope, with an average thickness of 100 km. It comprises the crust and the upper part of the upper mantle up to a very special zone known as the LVZ (low velocity zone). This zone divides the upper mantle into two parts, is located around 100 km below the surface and extends to a depth of 230 km. The speed of seismic waves is greatly reduced here, hence its name. In this zone of lower velocity, materials are more ductile, giving the lithospheric plates mobility over a more rigid zone: the asthenosphere (Fig. 6).

- The mantle: this is a large rocky envelope extending to depths of between 50 and 2,900 km, representing 2/3 of the earth's mass. It is basic in nature (peridotite, ophiolite). In the upper mantle, between 100 and 400 km, there is a viscous, plastic zone, animated by convection movements, which explains the mobility of lithospheric plates: the asthenosphere.

The mantle is subdivided into two parts: the upper mantle, density 3 - 4, and the lower mantle or mesosphere, density 4 - 5.

The mantle rises to the surface at mid-ocean ridges, in the form of basaltic lava, which cools and forms the oceanic crust.

2.1.5. Asthenosphere :

Between 100 km and 670 km deep. This is the lower part of the upper mantle. Materials here are once again more rigid, and wave velocities are higher. These two zones are also separated by a 1300° C isotherm, which marks the lower limit of the lithosphere (Fig.17).

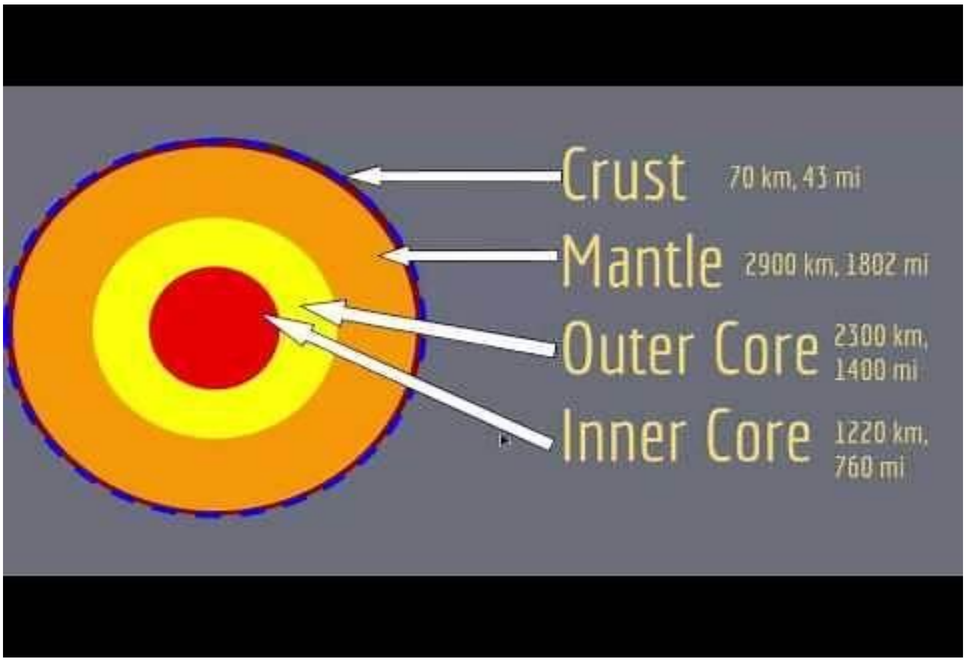


Figure 17: Lithosphere and Asthenosphere (www.aquaportail.com)

2.1.6. The mesosphere:

This refers to the lower mantle, with its high density and very high temperature.

2.1.7. The core:

The core is divided into an outer core and an inner core. They account for 15% of the Earth's volume.

2.1.7.1. Outer core:

The outer core (8) is liquid. It is essentially composed of 80-85% iron, around 10-12% of a light element not yet determined from among sulfur, oxygen, silicon and carbon (or a mixture of all four)1,2, and around 5% nickel. Its viscosity is estimated at between 1 and 100 times that of water, its average temperature reaches 4,000 degrees Celsius and its density 10. The Gutenberg discontinuity (13) marks the transition between the mantle and the core.

This enormous quantity of molten metal is stirred up by convection, mainly thermal (secular cooling of the planet), and to a lesser extent compositional (phase separation, demixing). These movements interact with the planet's movements, mainly daily rotation and, on a longer time scale, precession of the globe. The conductive nature of iron allows the development of variable electric currents that give rise to magnetic fields, which in turn reinforce these currents, creating a dynamo effect by sustaining each other. This explains why the liquid core is the source of the Earth's magnetic field. The source of energy needed to maintain this dynamo most likely lies in the latent heat of crystallization of the seed.

2.1.8.1. Inner core: Earth's seed.

The solid inner core (9) (also known as the "seed") is essentially metallic (mainly iron and nickel alloys, in proportions of around 80%-20%) and is formed by progressive crystallization of the outer core. The pressure of 3.5 million bars (350 gigapascals) maintains it in a solid state, despite a temperature in excess of 6,000°C3 and a density of around 13. The Lehmann discontinuity (not shown) marks the transition between the outer and inner core.

The inner core is still an active subject of geological research. Various observations suggest that the inner core is in motion. The exact nature of the inner core remains a matter of debate. Others suggest a liquid core, or even a two-part core.

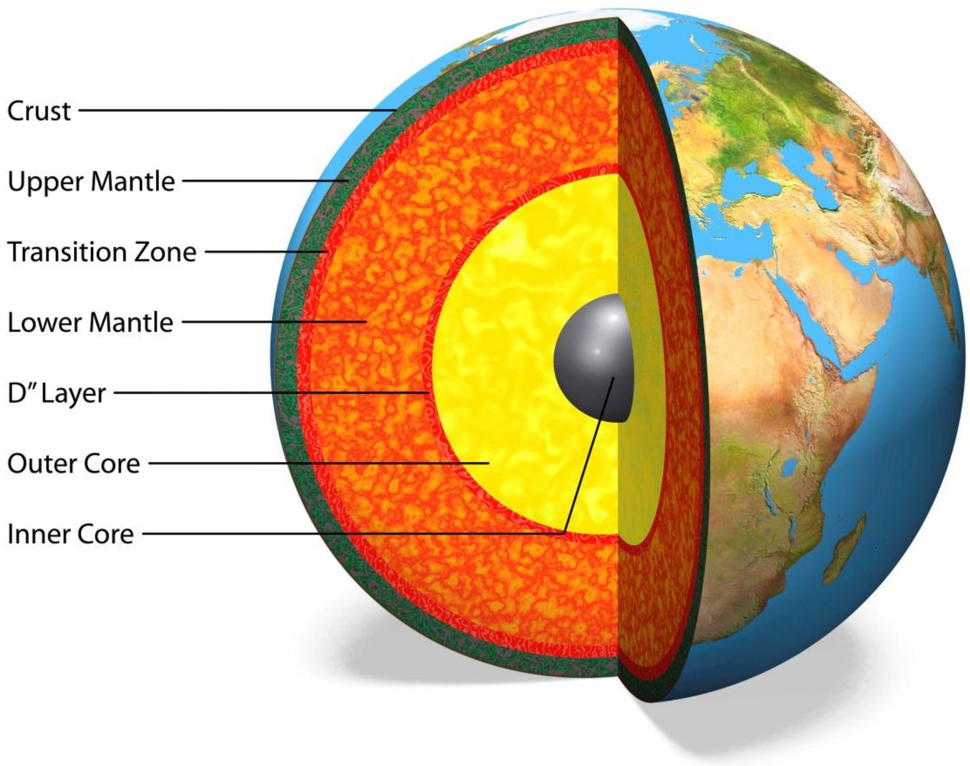


Figure 18: Earth's internal structure (u.laval.can).

Two major discontinuities separate crust, mantle and core: the Mohorovicic discontinuity (MOHO), which marks a density contrast between the Earth's crust and mantle, and the Gutenberg discontinuity, which also marks a significant density contrast between mantle and core. A third discontinuity separates the inner and outer cores, the Lehmann discontinuity (Fig.19).

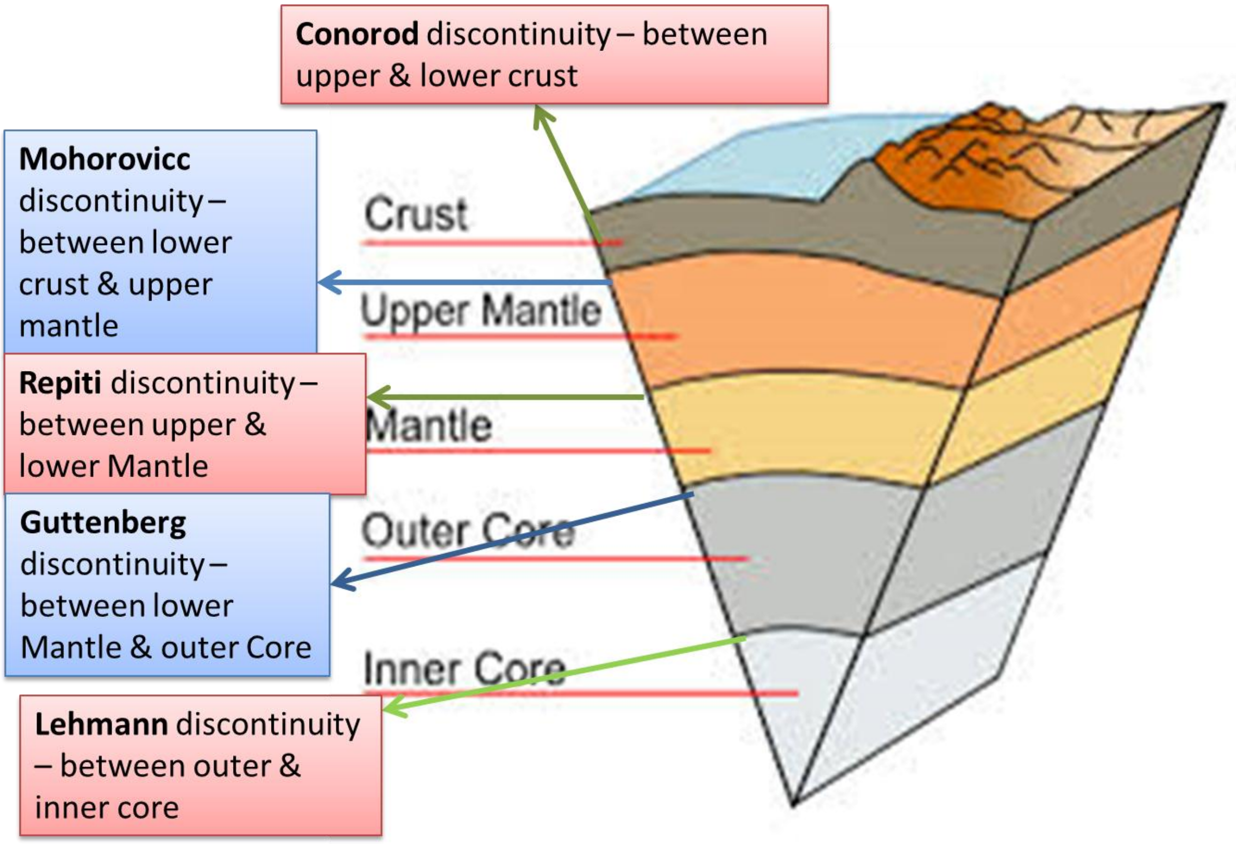
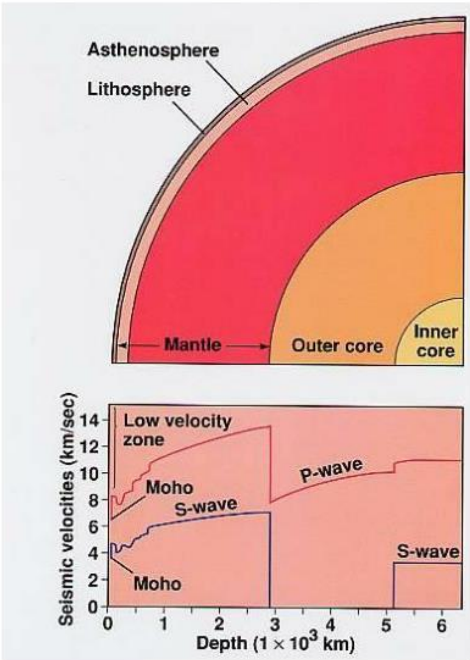


Figure 19: The Earth's various discontinuities (univ.laval.can).

Table 2: Summary of the earth's internal structure

Seismic Discontinuities



Discontinuities	Depth (km)	Composition
Lehman	5144	Fe solid against FeO, FeS fluid (inner/outer core boundary)
Gutenberg	2885	fluid FeO, FeS against (Mg, Fe) silicates, velocity decrease, density increase (outer core-mantle boundary)
D''	2870	thin, mixing of mantle and core material? (D"=D double-prime)
670 km	670	worldwide, no earthquakes deeper, debates over whether a composition, phase, or viscosity change
400 km	400	worldwide
LVZ	50-200	regionally variable depth
Moho	4-55	(abbreviation of Mo-ho-RHO-vi-chik) - sharp compositional change
Conrad	? 5-30	mafic to felsic crust, often absent

2.1.8. Secondary structures:

2.1.8.1. Subduction zone:

A subduction zone (3) shows a plate sinking into the mantle, sometimes up to several hundred kilometers.

2.1.8.2. Lithosphere and asthenosphere:

The lithosphere (11) consists of the crust (tectonic plates) and part of the upper mantle. The lower limit of the lithosphere lies at a depth of between 100 and 200 kilometers, where the peridotites approach their melting point. It includes the Mohorovicic discontinuity (14).

Sometimes found at the base of the lithosphere (some geologists include it here, but most place it in the asthenosphere) is a zone known as the LVZ (for "Low Velocity Zone"), where there is a marked decrease in the velocity and attenuation of P and S seismic waves. This phenomenon is due to the partial melting of peridotites, which results in greater fluidity. The LVZ is generally not present beneath the roots of mountain massifs in the continental crust.

The asthenosphere (12) is the zone beneath the lithosphere.

2.1.8.3. Volcanism:

Two types of active volcanism are represented here, the deeper of the two (5) is said to be "hot-spot". These are volcanoes whose magma originates deep in the mantle, close to the boundary with the liquid core. These volcanoes are therefore not linked to tectonic plates and, as they do not follow the movements of the Earth's crust, they are virtually immobile on the surface of the globe, forming island archipelagos such as Tahiti. Hot-spot volcanism is produced by a plume of hotter material (7) which, starting at the boundary with the core, partially melts as it approaches the Earth's surface.

2.1.8.4. Characteristics:

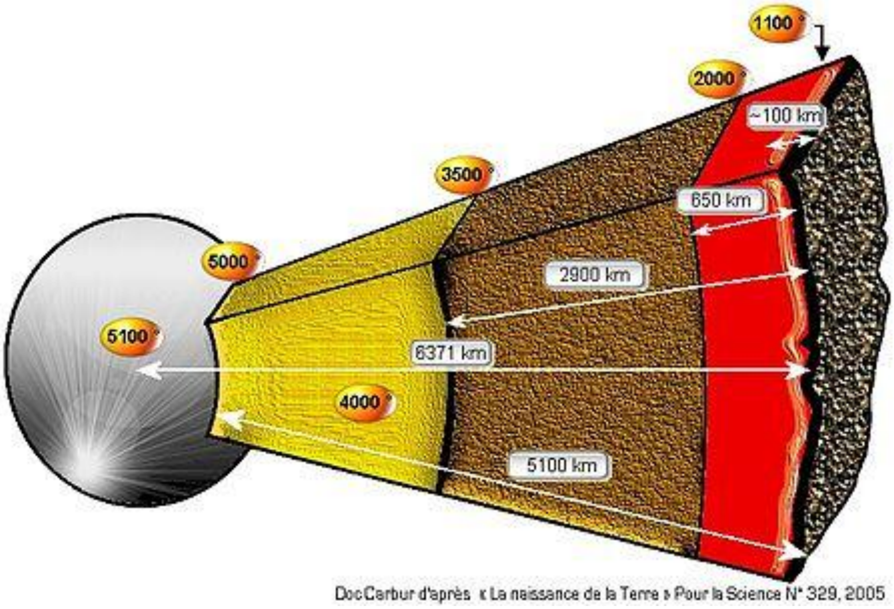


Figure 20: Dimensions of the various layers and approximate temperatures https://commons.wikimedia.org/wiki/File:Dimensionsglobe.jpg?uselang=fr

2.1.8.4.1. Dimensions of the different layers and approximate temperatures:

Recent calculations have revised core temperatures upwards, to between 3800°C and 5500°C depending on depth.

2.1.8.4.2. Internal heat:

In the figure opposite, temperatures are given in degrees Celsius for guidance only. As they cannot be measured directly but can only be deduced, they are approximate (the deeper you go, the greater the margin of error). The Earth's internal heat is produced by the natural radioactivity of rocks through the decay of uranium, thorium and potassium.

2.1.**9. Geoid concept:**

2.1.9.1. Definition:

The shape of the earth appears very irregular in detail. The orographic features of the earth's surface are of minimal importance compared to the size of the earth.

2.1.9.2 Variable radius:

The globe is not perfectly spherical, and the actual equatorial radius is some twenty kilometers greater than the polar radius.

This has the astonishing effect of causing the Mississippi, whose source is near the Great Lakes, to flow into the Gulf of Mexico at a higher level (distance from the center of the globe) than its source. If altitude were measured in relation to the center of the Earth, water would flow from the lowest point to the highest. In reality, sea level is always taken as the reference for altitude, so the reasoning in terms of mechanical energy is valid.

The equatorial radius of this ellipsoid is a = 6378 km

The polar radius b = 6357 km the difference is 21 km

The average radius of the Earth is 6400 km.

The degree of flattening of the Earth is (a - b) / a = 1/ 297.

The Earth's mass is estimated at 5.977 × 1024 kg and its average density is 5.517.

The Earth can be considered as a solid surrounded by a discontinuous liquid envelope, the hydrosphere, and a gaseous envelope, the atmosphere.

The Earth is not spherical; its equatorial radius is 21 km greater than its polar radius. The globe is like a fluid that is subject to two forces: the force of gravity, which tends to transform it into a sphere, and the centrifugal force, which tends to flatten it.

Variations in the value of gravity are linked to; the heterogeneous distribution of masses in the earth's crust, topographical irregularities of the surface, as well as the presence of other masses such as the moon and sun in the earth's vicinity.

A geoid is defined by an equipotential surface of the Earth's gravity field, i.e. a surface where gravity is constant. This surface corresponds to the mean level of the oceans and seas (assumed to be at rest, in the absence of tides and currents) and extends beneath the continents. This surface is called the geoid, and represents the actual shape of the globe.

However, the surface of the geoid is irregular, with peaks and valleys due to heterogeneities in the density of the Earth's crust. It is believed, however, that the geoid remains close to a surface called the ellipsoid of revolution, flattened at the poles.

Note: If the Earth were stationary and mass distribution perfectly homogeneous, this geoid would be a sphere.

2.2. Current distribution of land and sea:

2.2.1. Introduction:

71% of the earth's surface is covered by vast expanses of water (seas, oceans, rivers) and 29% by continents, islands and archipelagos, which is why the earth is called the Blue Planet.

The emerged parts of the globe, the continents, present multiple irregularities, differences in shape and altitude that make up the relief. Mountain ranges, plains and plateaus are all the result of the Earth's geological phenomena.

- The layout of oceans and continents is constantly (but slowly) evolving.

The earth's surface is divided between oceans with negative relief, dominated by sedimentation, and emerged lands with positive relief, dominated by erosion. The average depth is around 4,000 m, with a record of 11,000 m in the Mariana Trench. On the continents, the average altitude is 840 m, culminating in Mount Everest at 8848 m. 75% of the globe's surface is less than 100 m high. 70% of the seabed is between -3000 and -6000 m.

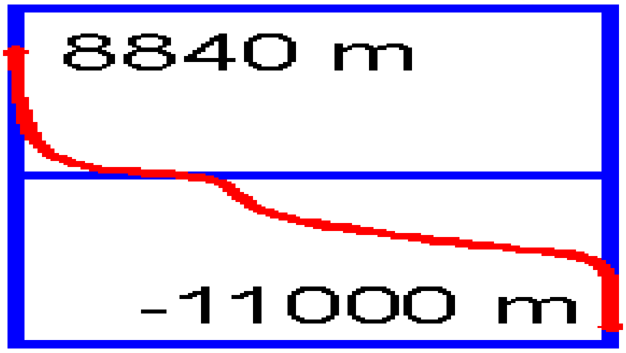


Figure 21: Maximum depth of oceans and highest points of continents

Land mass is largely concentrated in the northern hemisphere.

- Northern Hemisphere: 61% sea,

- Southern Hemisphere: 81% sea.

Figure 22: Maritime hemisphere

Figure23: Continental hemisphere

Figure 24: Current distribution of land and sea

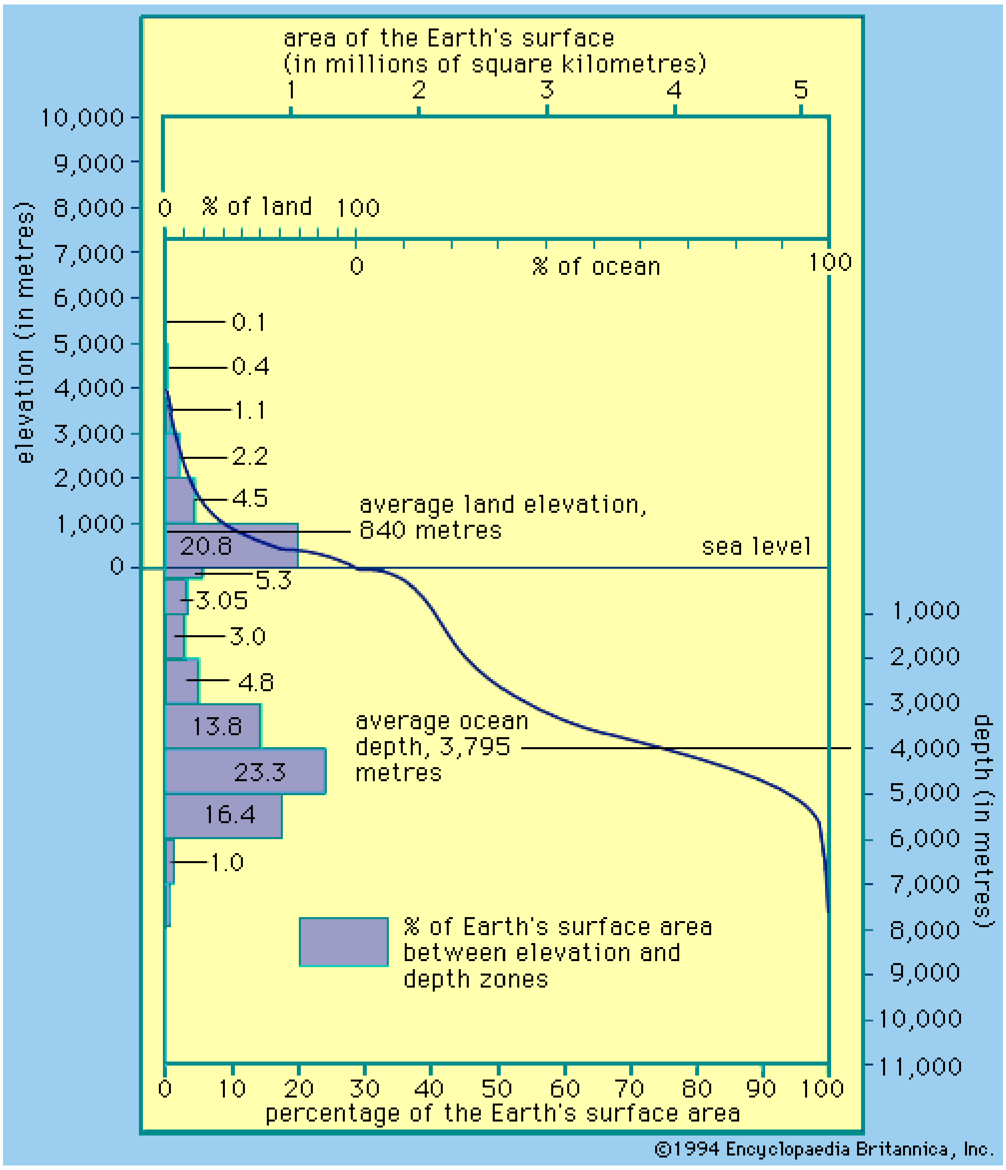


Figure 25: The hypsometric curve (positive and negative relief)

2.2.2. Oceans:

2.2.2.1. The different oceans :

Figure 26: The world's oceans

a. The Pacific Ocean is the world's largest ocean (1/3 of the Earth's surface).

The Pacific ocean floor is marked by numerous volcanic activities, including the Pacific Ring of Fire.

b. The Atlantic Ocean is the second largest ocean in terms of surface area.

It is much younger than the Pacific Ocean and its level of volcanic activity is very low.

c. The Indian Ocean lies between Africa and Oceania, south of Asia.

d. The Arctic Ocean lies to the north of the Northern Hemisphere continents. It is covered by ice (polar cap).

e. The Antarctic Ocean lies on the shores of the Antarctic continent and to the south of the other oceans.

2.2.2.2. Ocean morphology

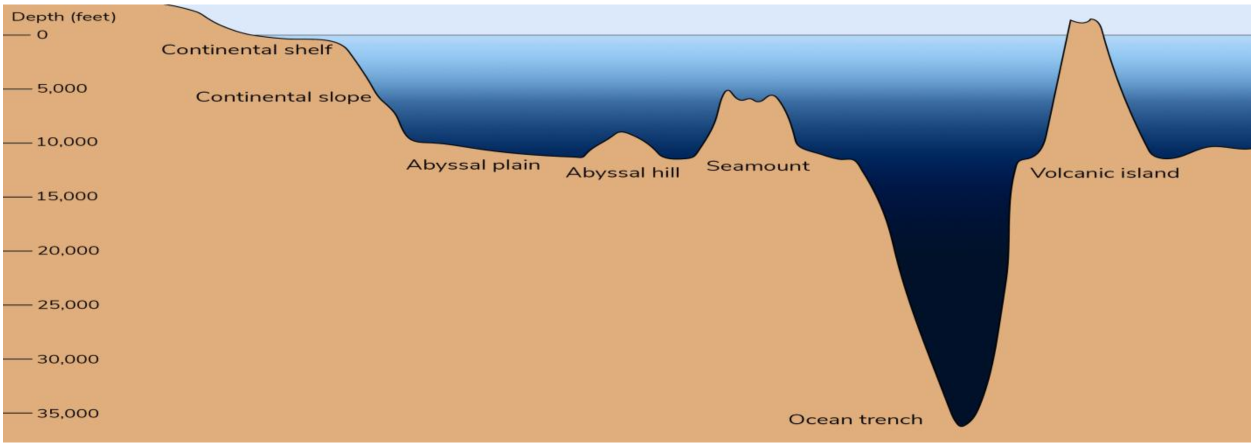


Figure 27: Morphology of the ocean floor

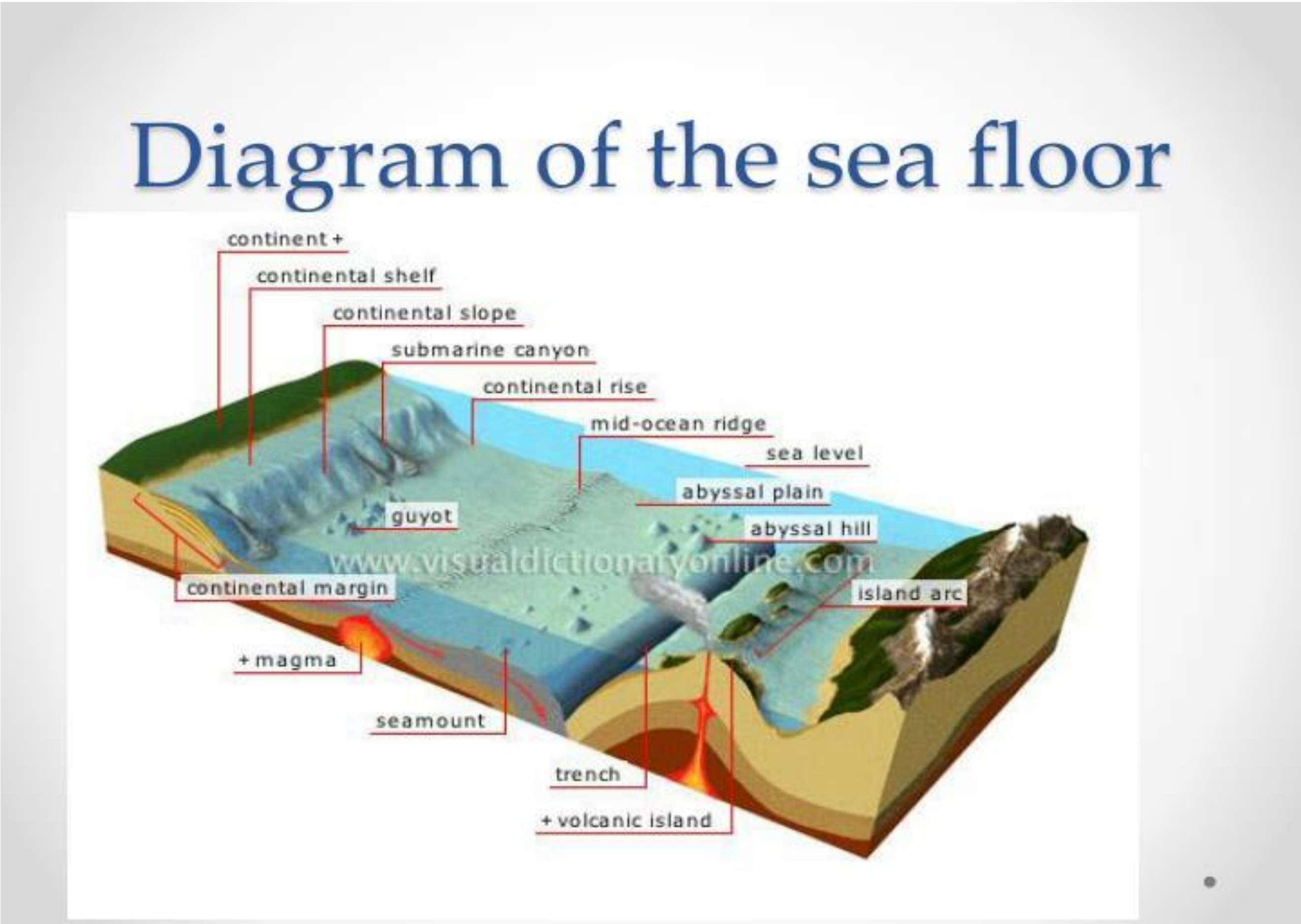


Figure 28: Structure of the ocean floor

2.2.3. Today's seas:

Seas (as opposed to oceans) are bounded by or enclosed by continents.

They are much smaller than oceans, and can vary greatly in surface area.

Seas may be in contact with oceans. They can be distinguished from them by the continental land masses that surround them. For example, the Mediterranean Sea is connected to the Atlantic

Ocean, but is separated from it by the Strait of Gibraltar and the countries that surround it. The climate between the ocean and the seas will also vary.
The sea can also be completely surrounded by the continental shelf, with no contact with the ocean; this is known as a closed sea.

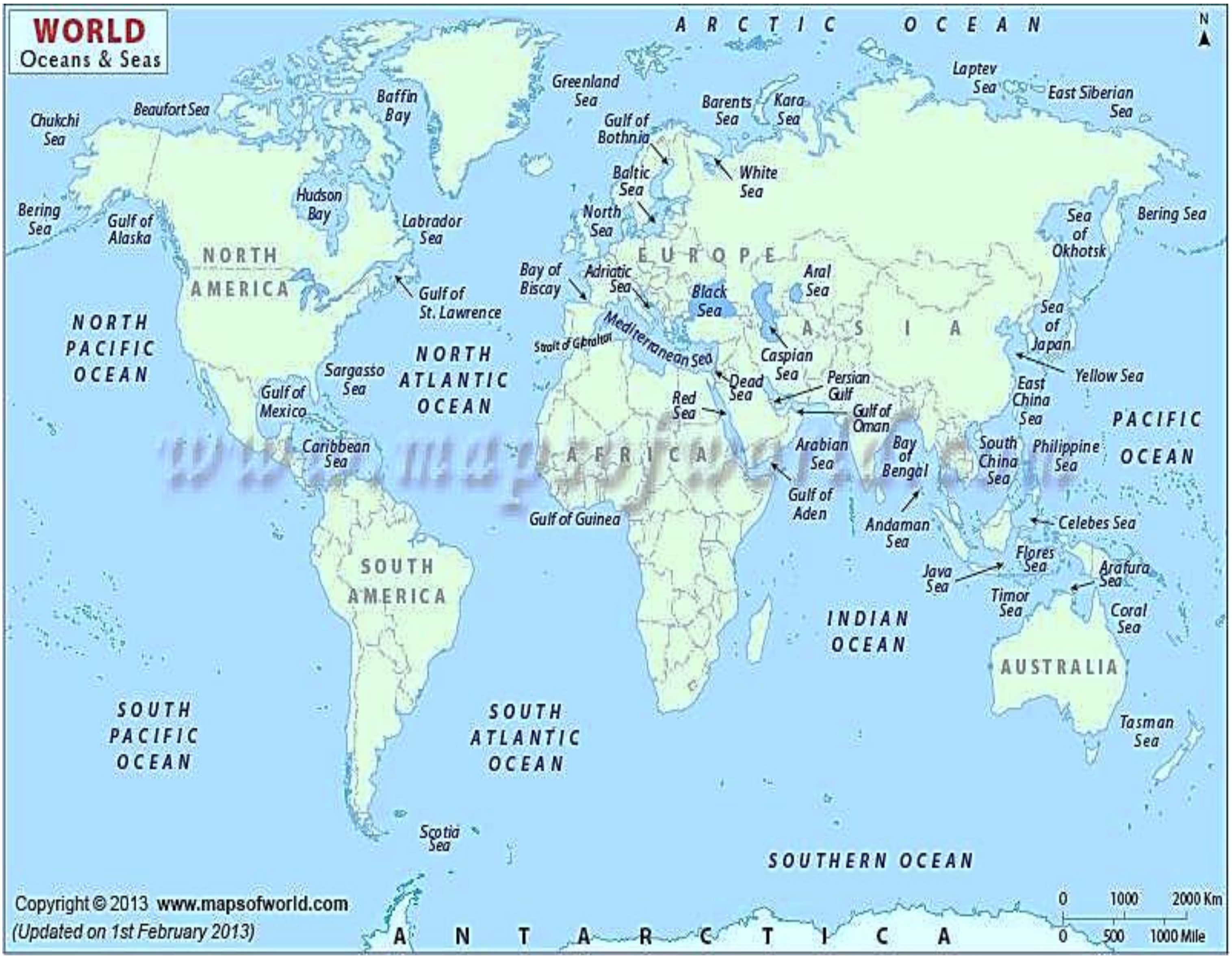


Figure 29: Current distribution of seas

* In contact with the ocean: Mediterranean /

O. Atlantic.

* Continental sea: Black Sea (closed sea)

Other examples of seas connected to oceans

- Atlantic Ocean / Mediterranean Sea; Baltic Sea and English Channel;

- Pacific Ocean / China Sea; Yellow Sea and Bering Sea;

- Indian Ocean / Red Sea; Persian Gulf and Arabian Sea.

2.2.4. The continents:

Seas and oceans isolate large land masses called continents. The smallest land masses are called islands.

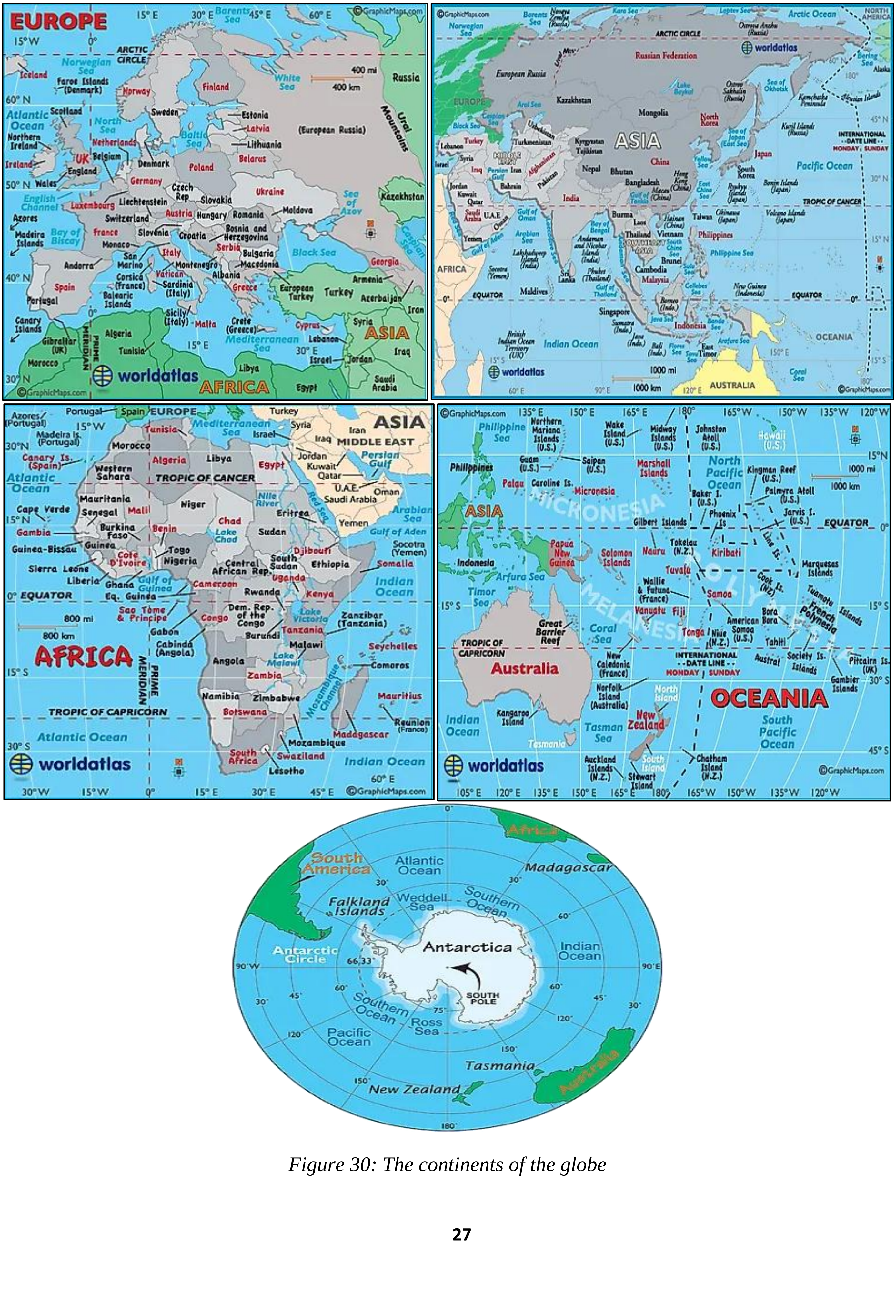


Figure 30: The continents of the globe

We distinguish:

*** 5 continents:**

Africa, America, Europe and Asia (Eurasia) . Oceania (Australia and the Pacific Islands). Antarctica, which is covered in ice.

*** Islands:** There are many of them. They are small strips of land surrounded by water.

For example: Madagascar, Reunion, Hawaii...

*** Archipelagos:**

A group of several small islands in the form of a chain.

For example: Philippines, Indonesia, Greece...

2.3. The earth's magnetic field:

2.3.1 Introduction:

The Earth's magnetic field, also known as the Earth's shield, is a huge, non-uniform magnetic field that surrounds the Earth.

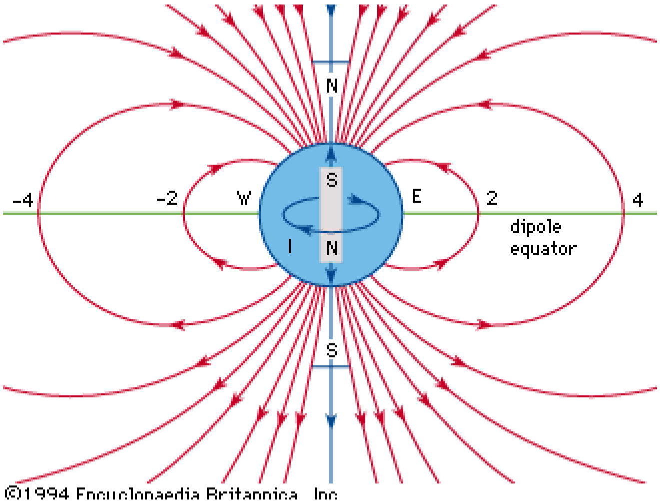


Figure 31: Earth's magnetic field

The magnetic field is shaped like a "pseudo" sphere enveloping the Earth, known as the "magnetosphere".

It is spherical in shape, but squashed at the poles and thicker at the equator.

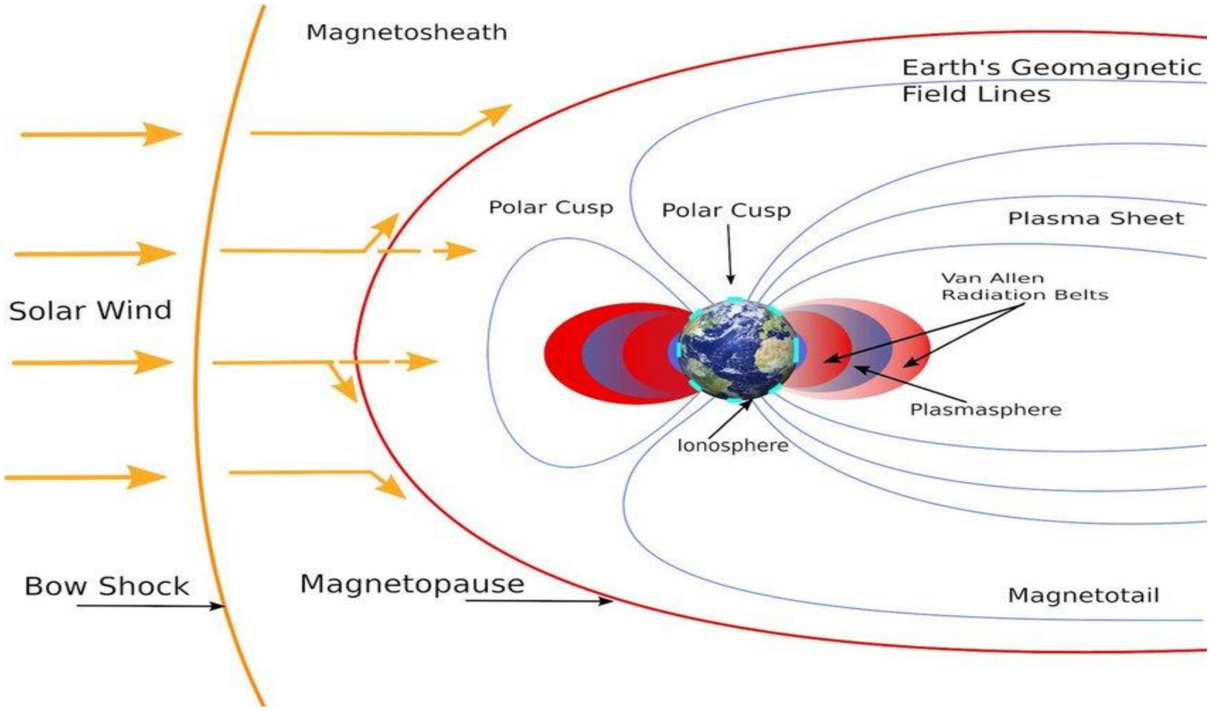


Figure 32: Structure of the Earth's magnetic field

2. 3.2 Origin of the Earth's magnetic field:

The earth is made up of a series of interlocking layers with different physico-chemical properties, which do not behave uniformly (displacement, speed) as the earth rotates.

These differences in behavior give rise to currents of electrons in the core - the natural dynamo responsible for the magnetic field.

The Earth's magnetic field is therefore generated by the movements of the liquid metallic core in the Earth's deepest layers.

External variations in the field are due to currents circulating in the upper atmosphere. These layers are highly ionized, and this phenomenon is essentially due to the sun's electromagnetic radiation.

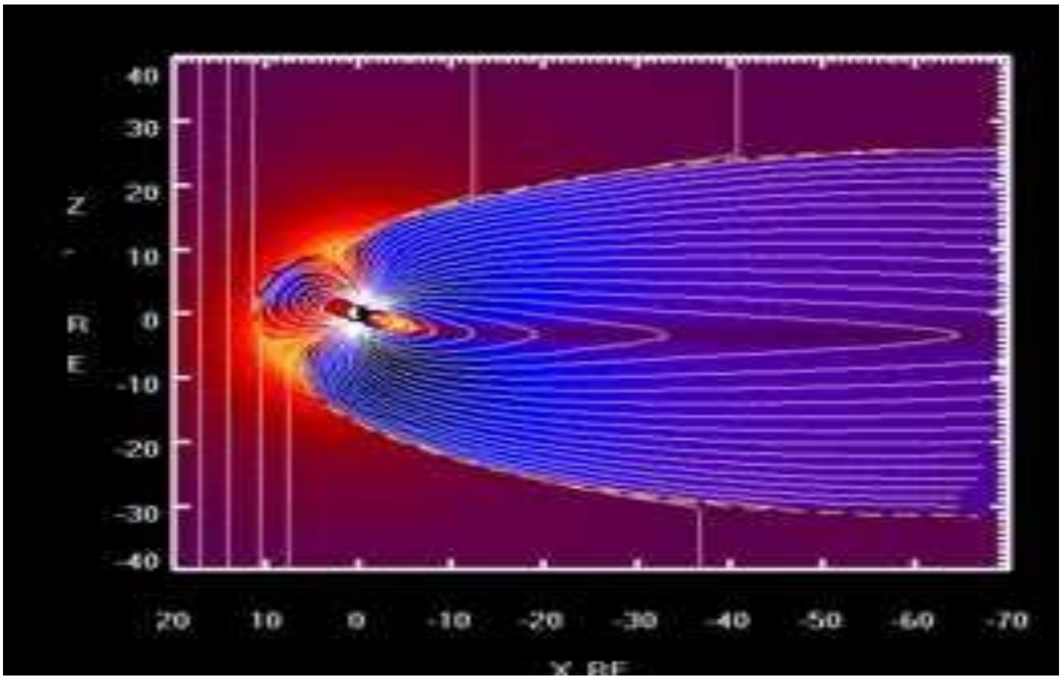


Figure 33: Model variation of the Earth's magnetic field in the face of a solar wind storm

2.3.3. History of the Earth's magnetic field:

According to studies by John Tarduno (USA), the Earth already possessed a magnetic field 3.45 billion years ago.

Understanding the Earth's magnetism was an important step in formulating the theory of plate tectonics. Two aspects of magnetism: paleomagnetism and inversions of terrestrial magnetism. The discovery of bands of magnetic anomalies on ocean floors parallel to ridges has reinforced the theory of the expansion of the ocean floor.

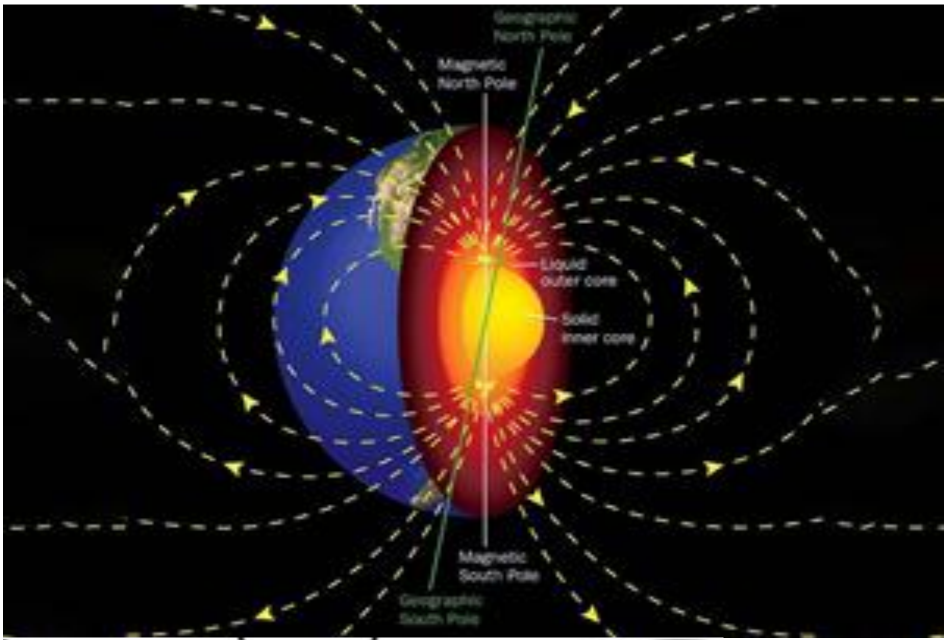
The study of the magnetic field over geological time is called paleomagnetism. Some rocks contain ferromagnesian minerals that become magnetized in a magnetic field and retain a memory of this.

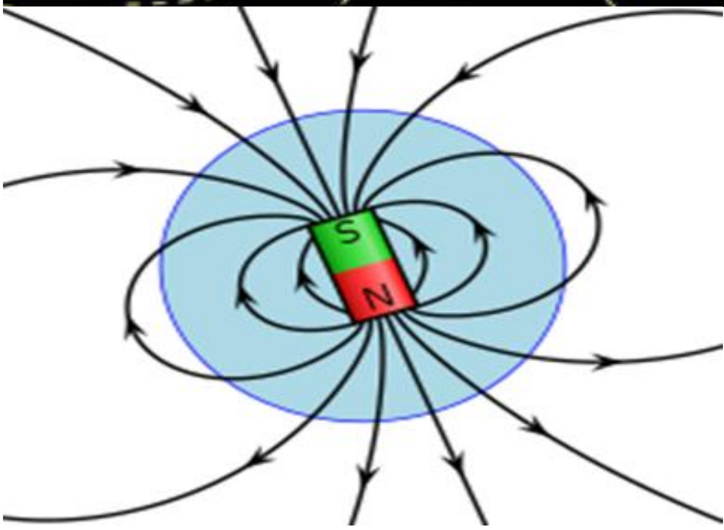
Volcanic rocks are subjected to the Earth's magnetic field as they cool, acquiring a stable thermo-remanent magnetization that follows the direction of the field and then remains at ordinary temperature.

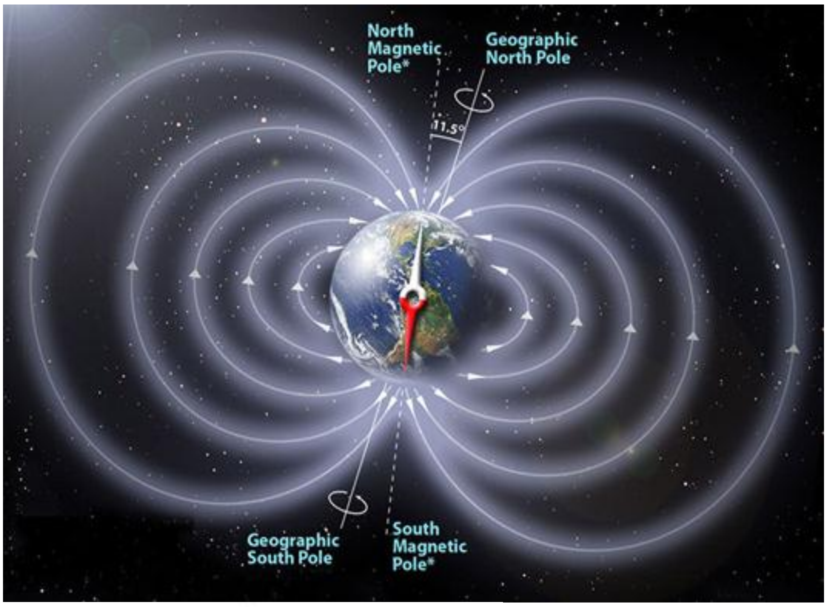
Ancient rocks can therefore be traced back to the Earth's magnetic field at the time they were laid down, while certain sedimentary rocks contain magnetic minerals whose orientation was acquired during sedimentation or crystal growth.

The method consists in measuring the remanent magnetism of rocks, previously oriented in their current position at the time of sampling, and from this study we have been able to highlight the variation in the position of the magnetic poles over geological time: these are pole reversals that have occurred many times over geological time.

The paleomagnetism and reversals of the Earth's magnetism etched into the rocks of the ocean floor support the theory of the expansion of the ocean floor.







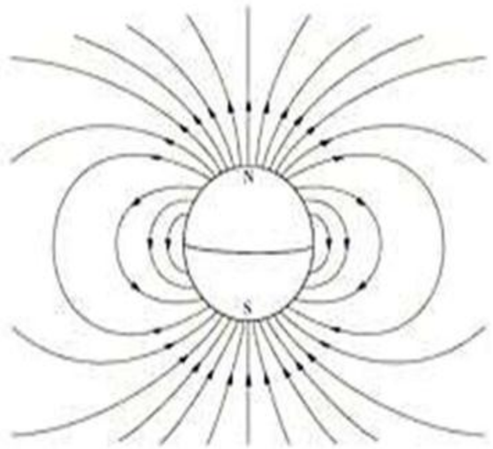


Figure 34: Magnetic poles

2. 3.4 Magnetic prospecting:

Many ores and rocks rich in magnetic minerals have high magnetization intensity. Magnetic anomalies, and subsequently veins and layers of magnetic rock, can be detected directly in the field.

Another method uses natural electrical currents in the ground, comparing variations in the earth's magnetic field at the surface with those of the surface telluric field.

2.3.5. Description:

The earth's magnetic field can be compared, as a first approximation, to that of a straight magnet (or a magnetic dipole, or a flat coil through which a current flows).

The center point of this magnet is not exactly at the center of the Earth, but a few hundred kilometers away.

Other planets in the solar system have magnetic fields: Mercury, Saturn, Uranus, Neptune and above all Jupiter. The Sun itself has one.

Although magnets have been known since antiquity, it was the Chinese who, around 1000- 1100, used them to orient themselves using the compass. The relationship between magnets and the Earth's magnetic field was discovered in 1600 by William Gilbert, an English physicist and physician to Queen Elizabeth I, who published Magno Magnete Tellure (On the Great Magnet of the Earth). This theory was the first to describe the Earth's global characteristics, before Isaac Newton's theory of gravity. He demonstrated how a compass placed on the surface of a magnetized ball always indicates the same point, just as it does on Earth.

2.3.5. Notion of pole:

The Earth's North Magnetic Pole is in fact a misnomer, since it corresponds to the magnetic "south" of the Earth's right-hand magnet.

Thus, the Earth's North Magnetic Pole (which is in fact a misnomer, as it corresponds to the magnetic "south" of the Earth's right-hand magnet) is located some 1000 km from the geographic North Pole towards Canada, at 81°N 110°W; while the Earth's South Magnetic Pole (and thus the magnet's magnetic north) is at 65°S 138°E. It should be noted, however, that these positions are not fixed, as they vary over the course of the day, and that the North Magnetic Pole, for example, moves closer to the North Geographic Pole by around 40km/year.

2.3.6. The terrestrial dipole:

The Earth's North Magnetic Pole is actually a pole of "south" magnetism.
This is purely a convention, due to the choice of calling the tip of the Earth's surface "North".
"North" the point of the compass needle, which points approximately to the geographic North Pole.
The magnetic South Pole lies off the coast of Terre Adélie, in the Urville Sea, at 65°S and 138°E.

2.3.7. Applications:

2.3.7.1. The compass: The compass points in the direction of the Magnetic North Pole (not the Geographic North Pole).

The relative angular difference is called the magnetic declination, and its value depends on the location.

2.3.7.2. Mining exploration:

Mining exploration is one of the major fields of application for the study of geomagnetism.
As different rocks have different magnetizations, the value of the Earth's magnetic field intensity is altered.
This makes it possible to map structures at depth, according to variations in rock magnetization.
2.3.7.3. A protective shield for life :

The Earth's magnetic field plays an essential role in the development of life on Earth, deflecting the deadly particles of the solar wind to form the aurora borealis and aurora australis.

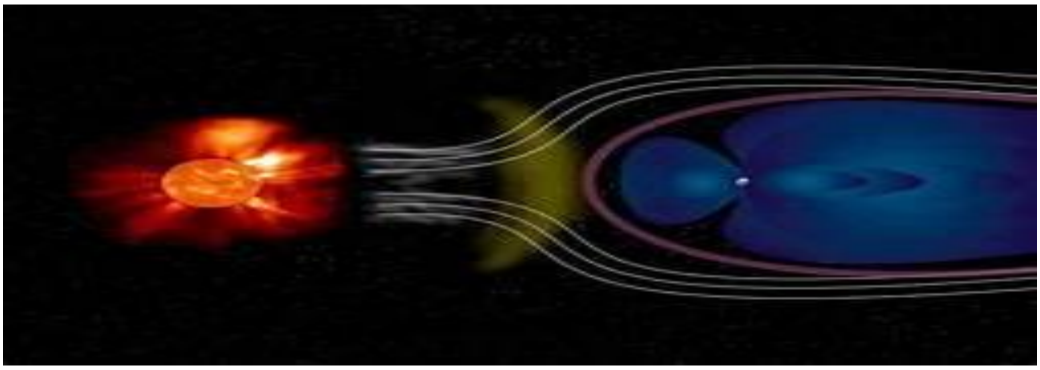


Figure 35: Opposition of the Earth's magnetic field to the solar wind

The electrically-charged particles thrown up by the sun during the frequent eruptions that take place on its surface crash violently into the earth's magnetic field, so violently that some of them manage to break through this natural "shield" and enter the earth's atmosphere, where they give rise to the splendid aurora borealis we all know.

Figure 36: Aurora borealis and australis

However, scientists have observed a decrease in the Earth's magnetic field.

2.3.8. Future developments:

Once the core has cooled and solidified (in a few billion years) and the magnetic field has disappeared, it is likely that existing life forms will no longer be able to survive.

These are the conditions that prevail today on the Moon and Mars.

2.4 Continental drift and plate tectonics:

2.4.1. Introduction:

The theory of plate tectonics, developed in 1960, revolutionized the earth sciences. It is a comprehensive theory that explains many structural and geophysical phenomena, from mountain building to earthquakes and continental drift through plate movement.

According to this theory, the earth's outer envelope is made up of large lithospheric plates, which drift on the deeper, partially melted mantle. Early observations revealed the horizontal movement of continents, or continental drift, while oceanographic studies revealed the expansion and renewal of the ocean floor. Today, all these movements form part of plate tectonics.

2.4.2. The theory of continental drift:

Figure 37: Alfred WEGENER (1890-1930)

The idea of a single original continent was put forward by A. Wegener, who was struck by the similarity in shape of certain continents, and formulated the hypothesis of a relative displacement of continents. This similarity in shape was superimposed by geological, paleontological and paleoclimatic coincidences, and on the basis of these various arguments he proposed a mobilist model: continental drift.

The continental drift theory assumes that all present-day landmasses were originally a single continent called Pangea, 200 million years ago. The 1st separation formed two continental blocks 180 million years ago, Laurasia to the north and Gondwana to the south.

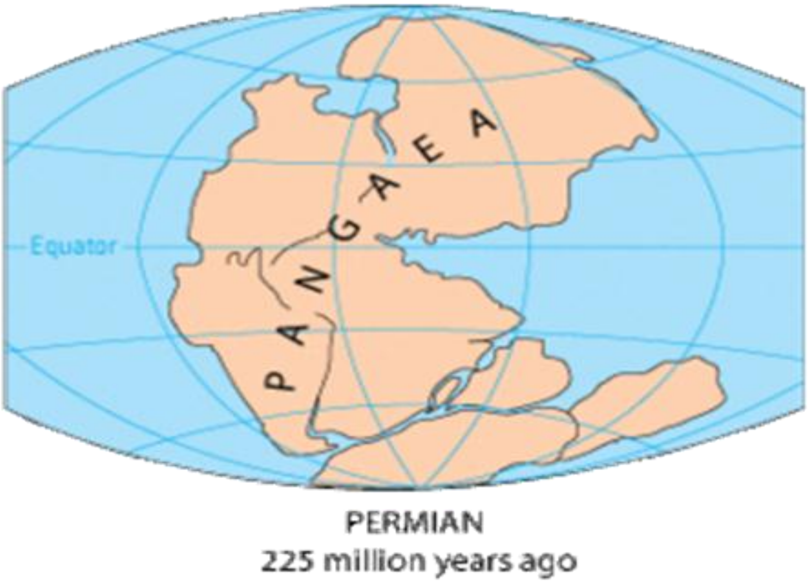


Figure 38: Aspect of the globe during the Triassic period

2.4.2.1. Geographical arguments:

The possible interlocking of certain continental coasts now separated by marine domains, e.g. the coasts of Africa and South America.

Figure 39: Geographic complementarity of tectonic plates

2.4.2.2. Geological arguments:

Wegener also highlights similarities in stratigraphy, geological structures and petrography on either side of the Atlantic. Certain geological structures, such as mountain ranges, are connected from one block to the other, e.g. the close links between the geology of West Africa and that of Brazil.

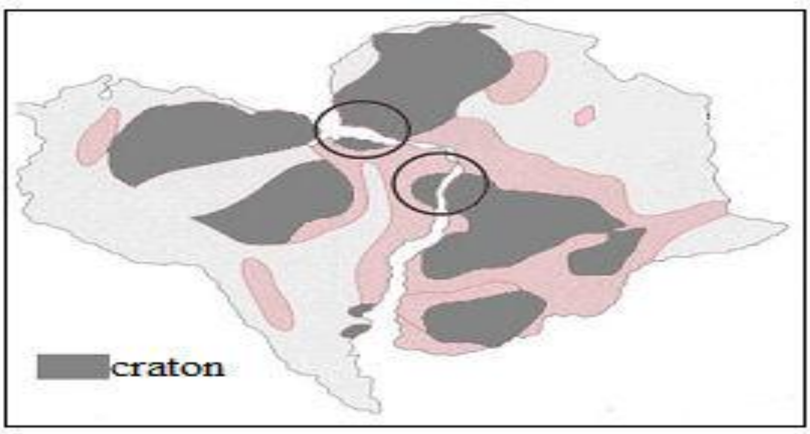
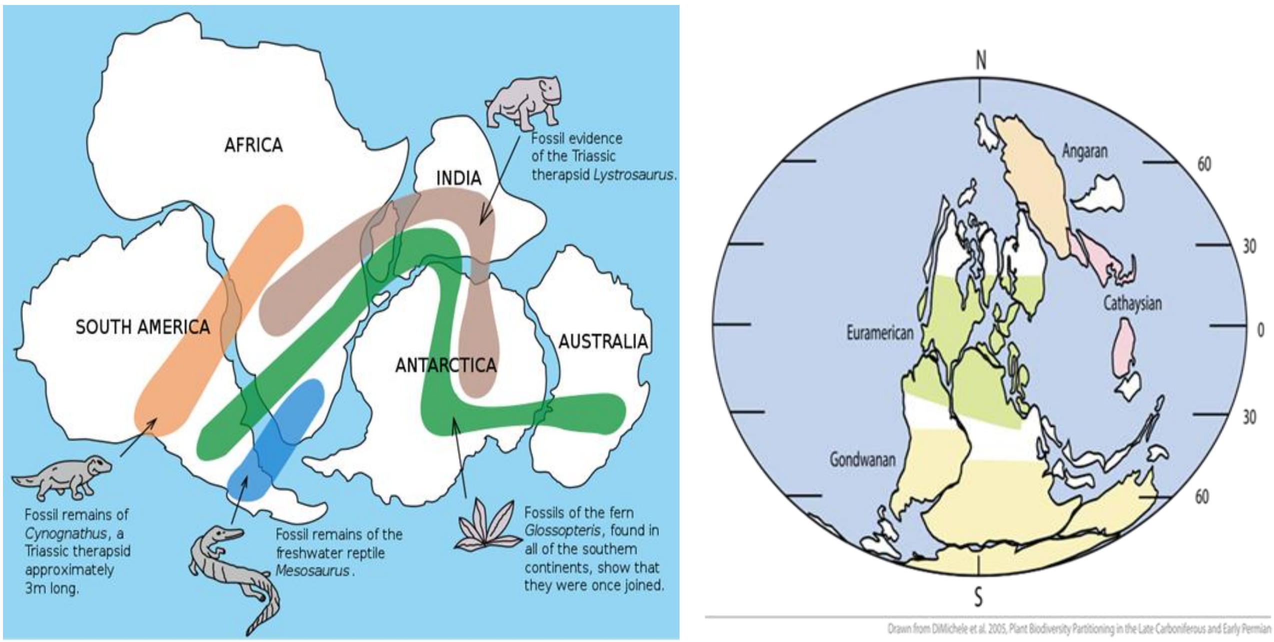


Figure 40: Intercontinental geological links

2.4.2.3. Paleontological arguments:

Similar fossils of plants, ferns and terrestrial animals are found on both sides of the Atlantic on today continents



Ex: Dinosaur remains.

Figure 41: Intercontinental paleontological links paleoclimatic continuity.

2.4.2.4. Paleoclimatic arguments:

At present, glacial deposits formed during the Permo-Carboniferous glaciation (around -300 Ma) are distributed across Antarctica, Africa, South America, India and Australia. The study of climate change and ice ages confirms the theory.

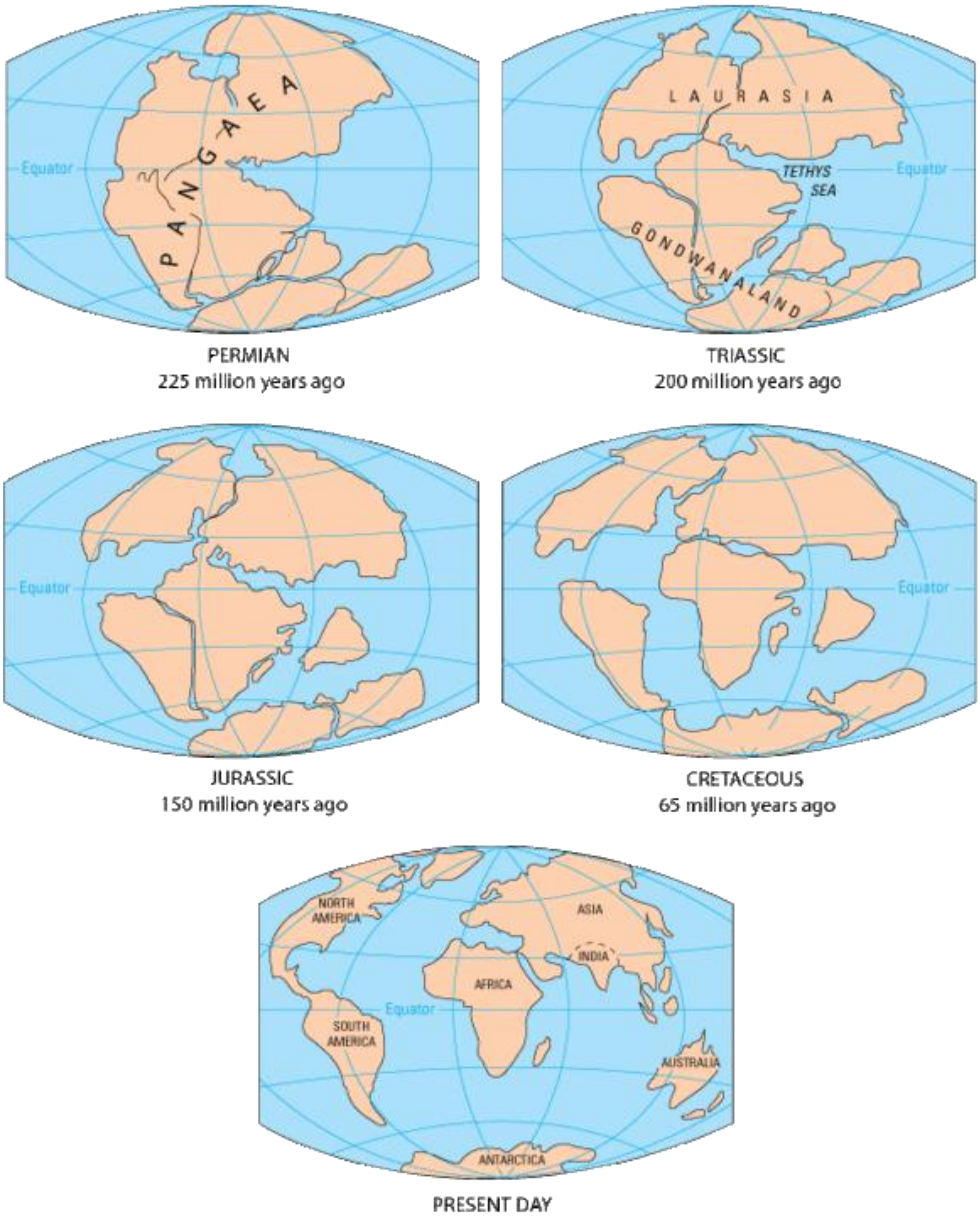


Figure 42: Geographical reconstruction of continents

2.4.2.5. Structural arguments: The evidence of the continuity of various major structural sequences on either side of the Atlantic.

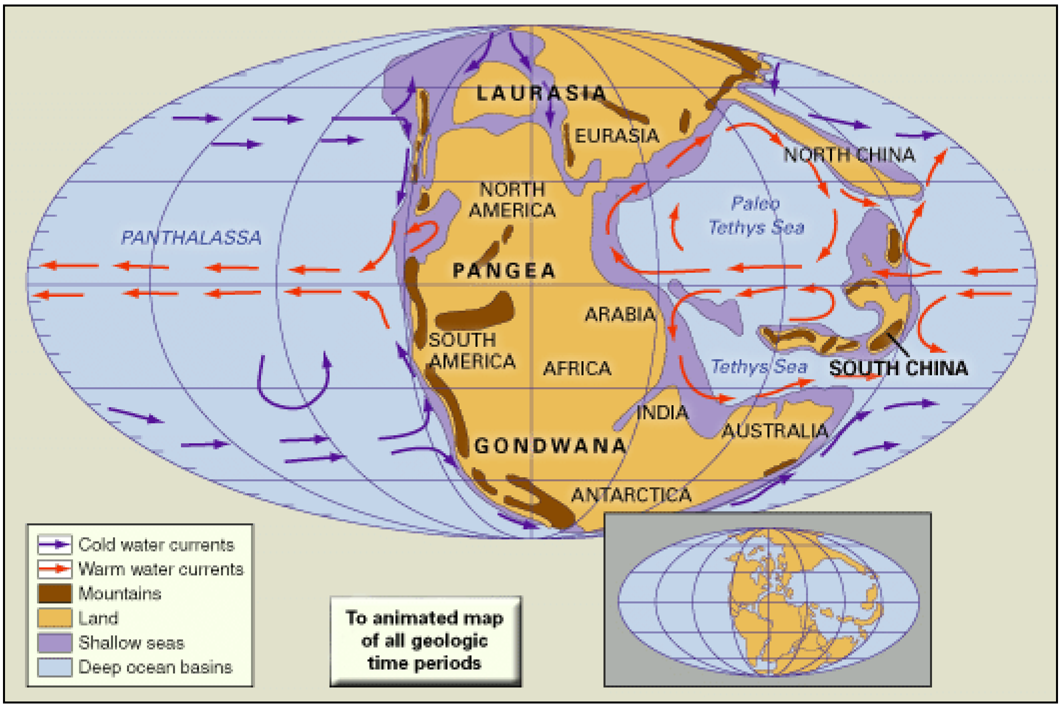


Figure 43: Intercontinental structural connection

Main structural directions with the main African-American shields.

2.4.2.6. Magnetic arguments: Some rocks contain ferromagnesian minerals that magnetize in a magnetic field and retain its memory.

Volcanic rocks are subjected to the Earth's magnetic field as they cool, acquiring a stable, thermo-remanent magnetization that follows the direction of the field and then remains at ordinary temperature.

Ancient rocks can therefore be traced back to the Earth's magnetic field at the time of their emplacement, while certain sedimentary rocks contain magnetic minerals whose orientation was acquired during sedimentation or crystal growth.

It was on the basis of this study that we were able to demonstrate the variation in magnetic pole positions over geological time.

All these arguments led Wegener to suggest the presence of a supercontinent, Pangaea, whose southern part, called Gondwana, would have begun to fragment into various continental blocks, resulting in the current layout of the southern continents.

The theory of continental drift was rejected by many geologists, especially geophysicists, as Wegener was unable to propose a mechanism to explain the drift.

2.4.3. The theory of plate tectonics:

Plate tectonics is a scientific model explaining the global dynamics of the Earth's lithosphere. The lithosphere, the Earth's rigid outer layer consisting of the crust and part of the upper mantle, is subdivided into so-called tectonic or lithospheric plates. The theory of plate tectonics assumes that the lithosphere is divided into several rigid plates that float on the viscous asthenosphere and move relative to each other. Plate boundaries include ocean ridges, trenches and transform faults.

A plate is a rigid unit made up of crust (continental + oceanic) and upper mantle down to the asthenosphere. Plate movement is attributed to convection currents, due to density differences in the asthenosphere.

2.4.3.1. Definition of a plate:

- It's a large, rigid cap: not very deformable.

- About 100 km thick.

- It forms the earth's surface envelope: the lithosphere (hence the name Lithospheric Plate).

- The plate can carry an ocean: e.g. the "Pacific" plate.

- It may carry a piece of ocean and a continent, e.g. the "African" or "South American" plate...

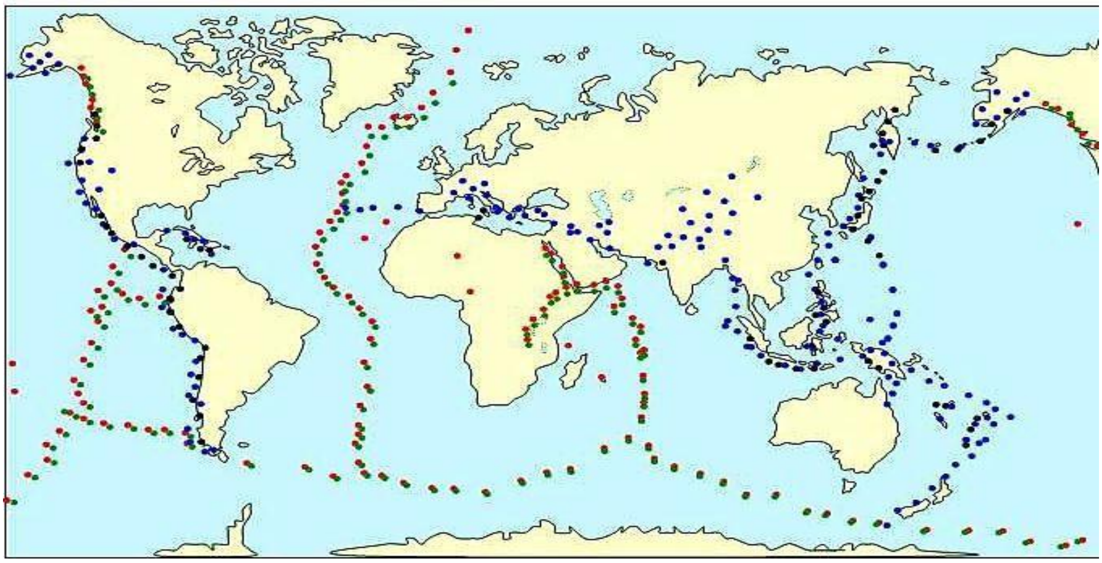


Figure 44: Tectonic plate boundaries

- Lithospheric plate: Portion of rigid lithosphere delimited by boundaries with significant seismic and volcanic activity.

- It may be totally oceanic or comprise both a continental and an oceanic part.

2.4.3.2. Distribution of earthquakes and volcanoes:

The distribution of the main earthquakes and, to a lesser extent, volcanoes, has enabled us to identify the outline of a dozen major plates.

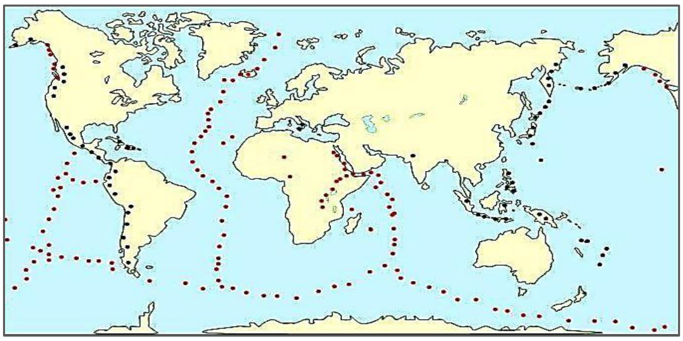


Figure 45: Distribution of volcanoes

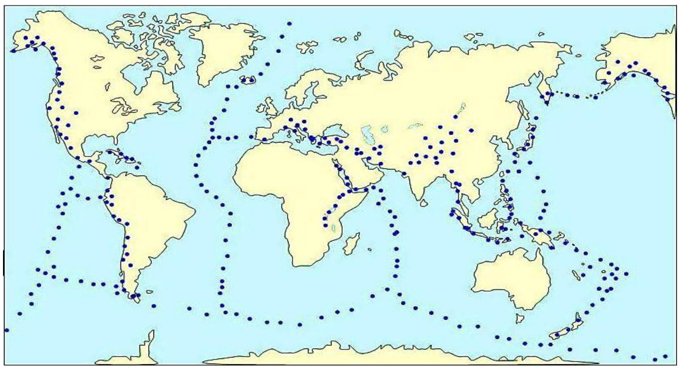


Figure 46: Distribution of earthquakes

2.4.3.3. Main tectonic plates:

These are in descending order of size:

1. Pacific,
2. Eurasia,
3. Africa,
4. Antarctica,
5. India-Australia,
6. North America,
7. South America,
8. Nazca,
9. Philippines,
10. Arabia,

11. Coco

12. Caribbean

Some of these plates can be divided into several smaller plates (units)

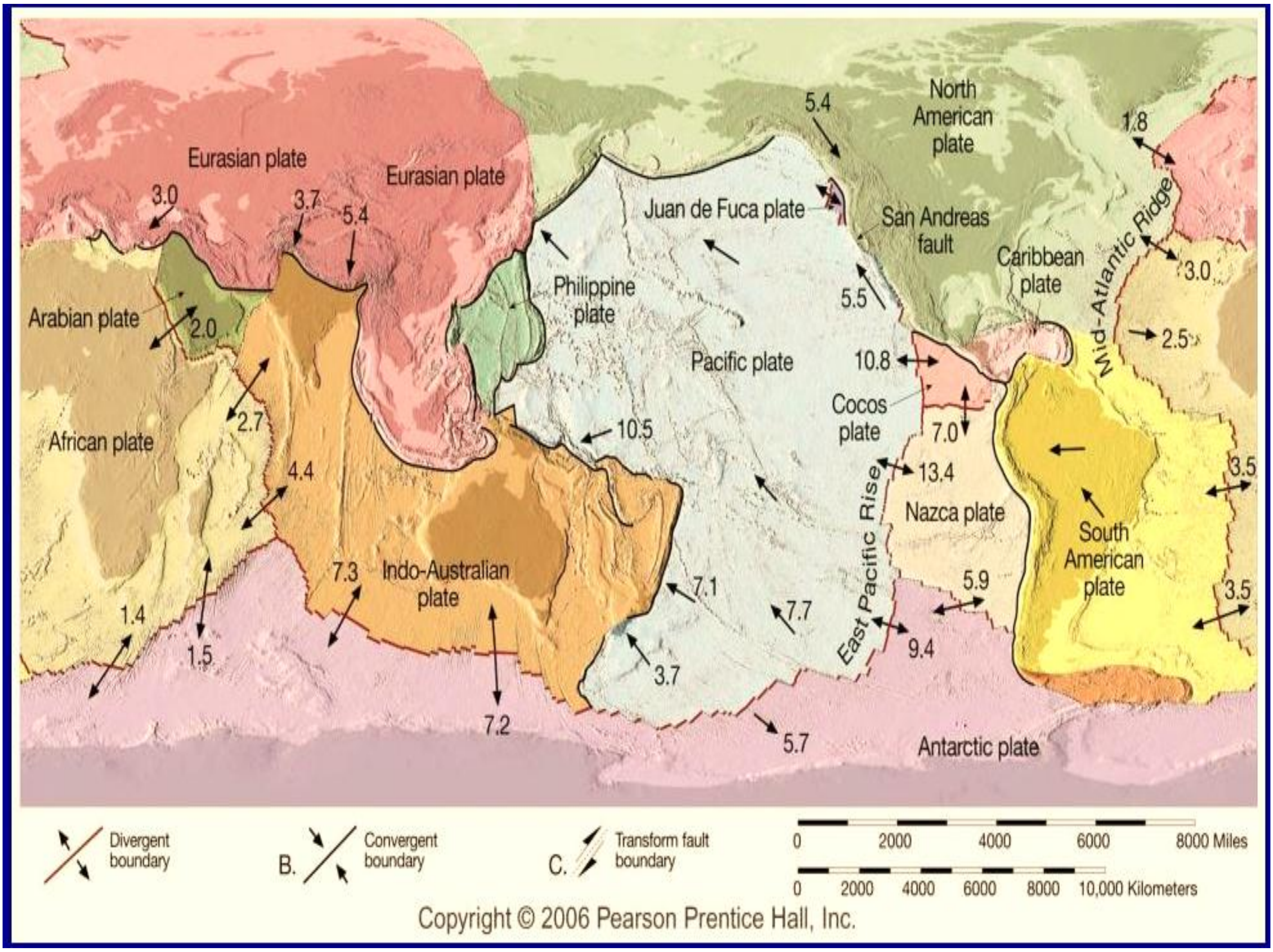


Figure 47: Distribution and relative motion of lithospheric plates.

2.4.3.4. Plate formation:

Oceanic lithosphere forms at the axis of ridges:

Mantle material rises and partly melts, the magma produced rushes into the fractures and spills out onto the ocean floor. The new floor cools and is gradually covered with sediment.

The discovery of an accentuated relief, with veritable submarine mountain ranges, the oceanic ridges, and deep depressions, the oceanic trenches, revealed the existence of three major types of lithospheric activity at plate boundaries: divergence, convergence and slip.

2.4.3.4.1. Divergence or oceanic expansion:

The ocean floor is made up of basalts that magnetize when they are formed, and thus retain the memory of the Earth's magnetic field at the time of their emplacement. Some rocks contain ferromagnesian minerals that magnetize in a magnetic field and retain its memory.

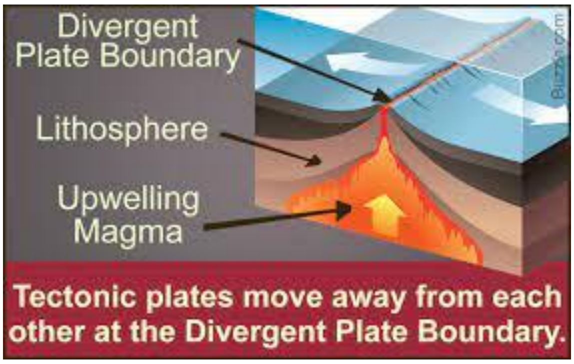


Figure 48: Divergence or ocean expansion

At rifts, basaltic lava flows out and, as it cools, pushes the older rocks to either side of the ridge, the oceanic ridges, the boundaries along which two plates diverge. Basalt contains an iron oxide whose particles, in their liquid state, are oriented towards the Earth's magnetic field. It so happens that, in the Earth's past, its magnetic field has reversed many times.

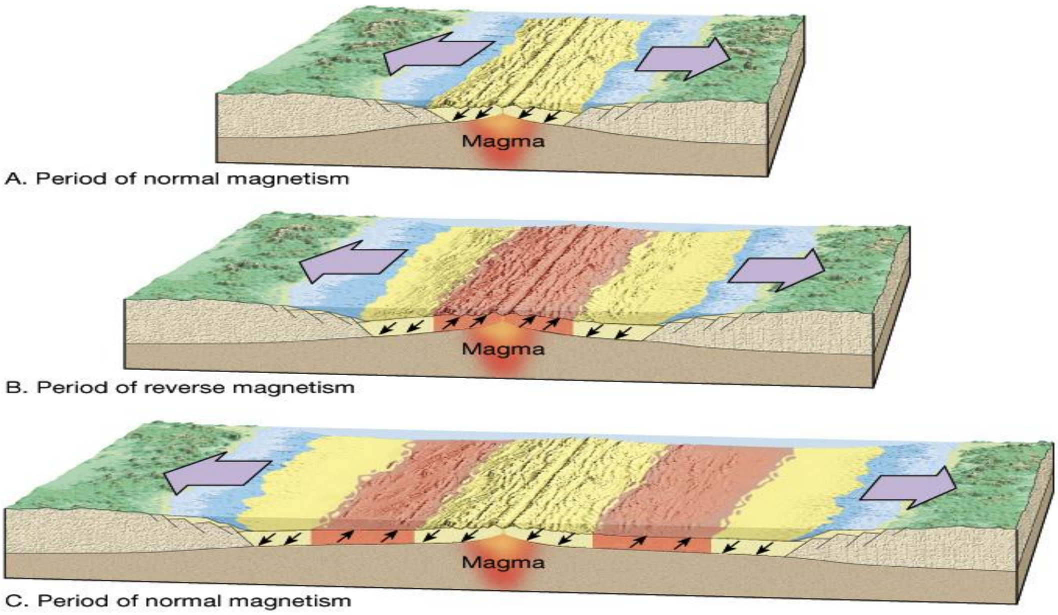


Figure 49: Stages in the formation of an oceanic ridge

These inversions remain inscribed in cooled rocks in the form of alternating bands, and the polarity of the paleomagnetic bands makes it possible to determine their age, which translates into the fact that the ocean floor becomes increasingly older as it moves away from the rift and is constantly renewed at the rift: this is the expansion of the ocean floor, a phenomenon which, although slow, is not negligible.

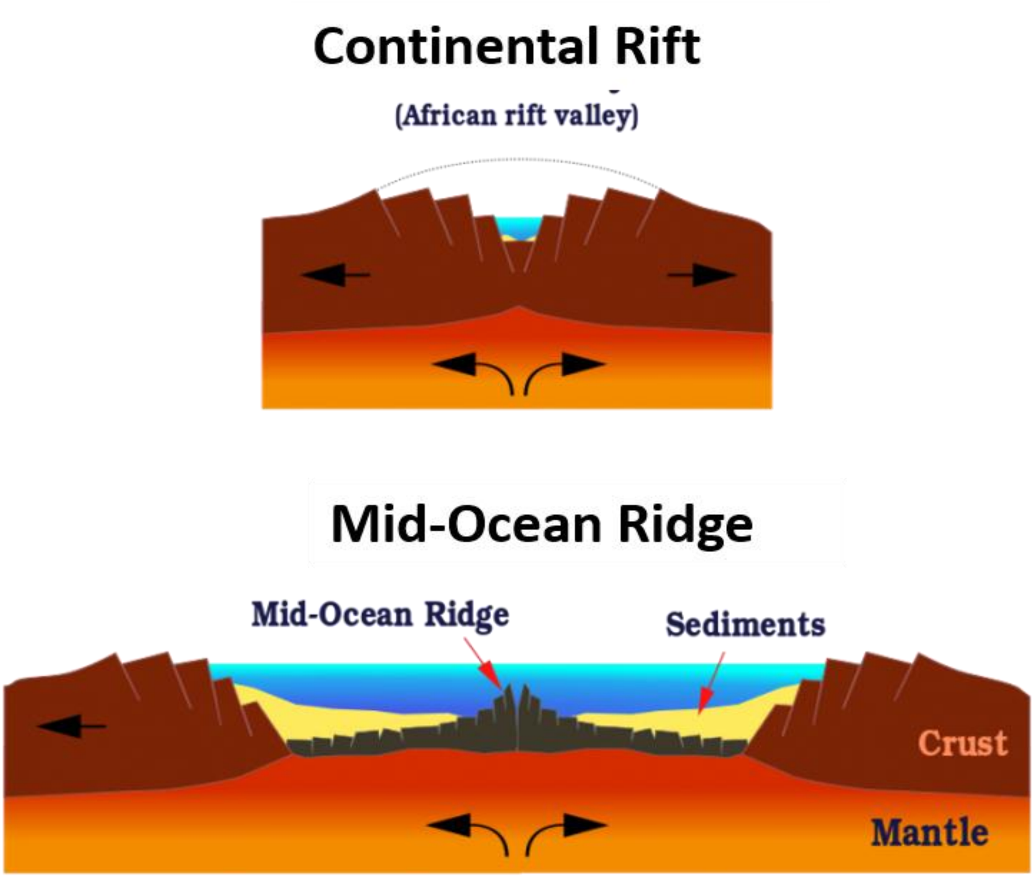


Figure 50: Principle of ocean ridge formation

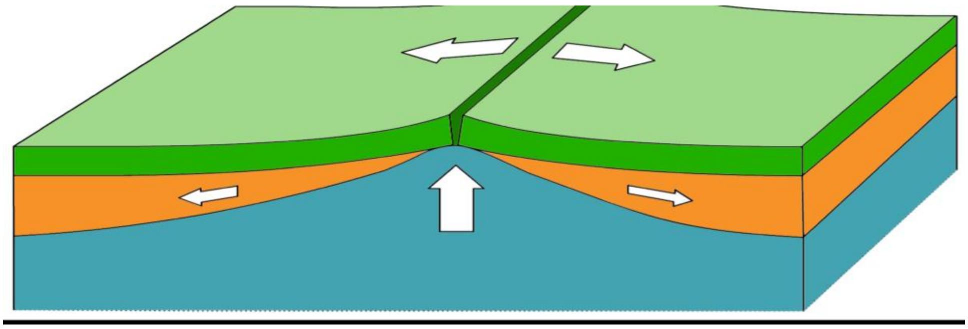


Figure 51: Plate tectonic divergence

2.4.3.4.2. Convergence:

Convergence zones are the main source of orogenesis. The formation of continental mountains Trenches form where two plates converge, with one plate sliding beneath the other and sinking into the mantle. Trenches are zones of destruction (or subduction zones) at plate boundaries. Convergence sometimes leads to the clash or collision of continental blocks that cannot sink by subduction. These convergence boundaries are zones where mountain ranges can form. For example, the Andes or Himalayas.

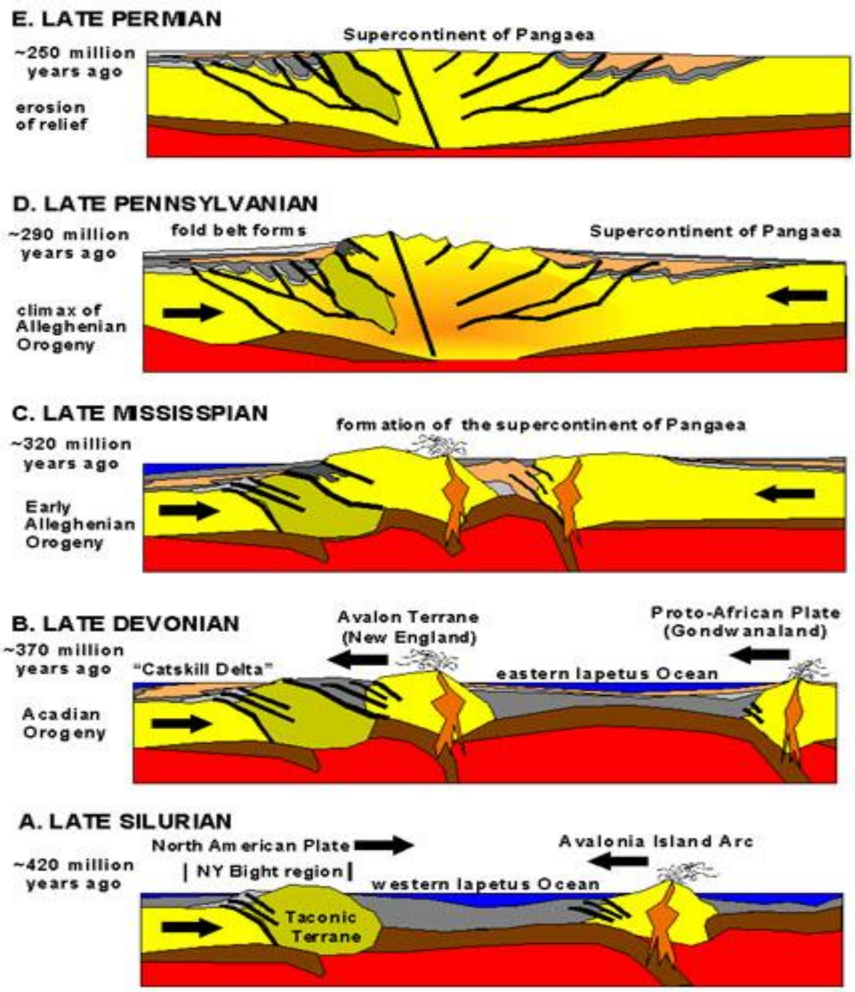


Figure 52: Subduction principle

Figure 53: Convergence of two continental plates

Figure 54: Volcanoes in subduction zones

2.4.3.4.3. Sliding: is created by transform faults, where two plates slide over each other. Transform faults cut the ridges transversely. These boundaries are neither the place where lithosphere is created nor where it disappears. They are simply sliding zones.

Sliding" refers to the horizontal sliding of two plates. It involves the lateral displacement of one plate against another.

Ex: The San Andreas fault, which runs from the Gulf of California to San Francisco.

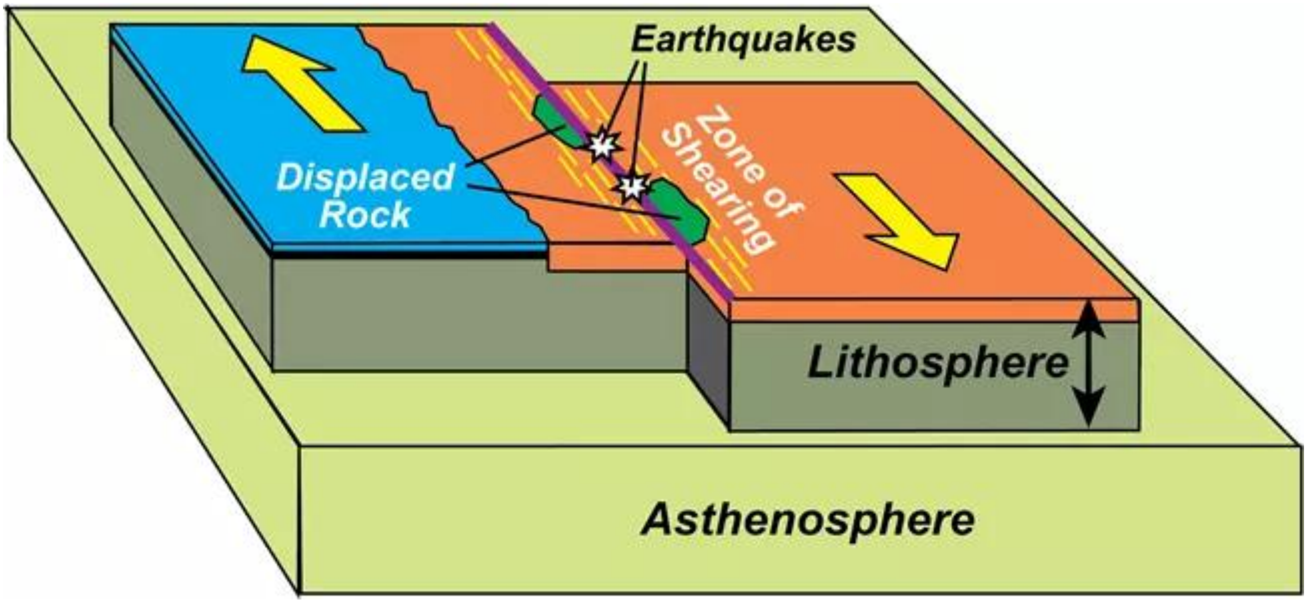


Figure 55: Lithospheric plate sliding principle

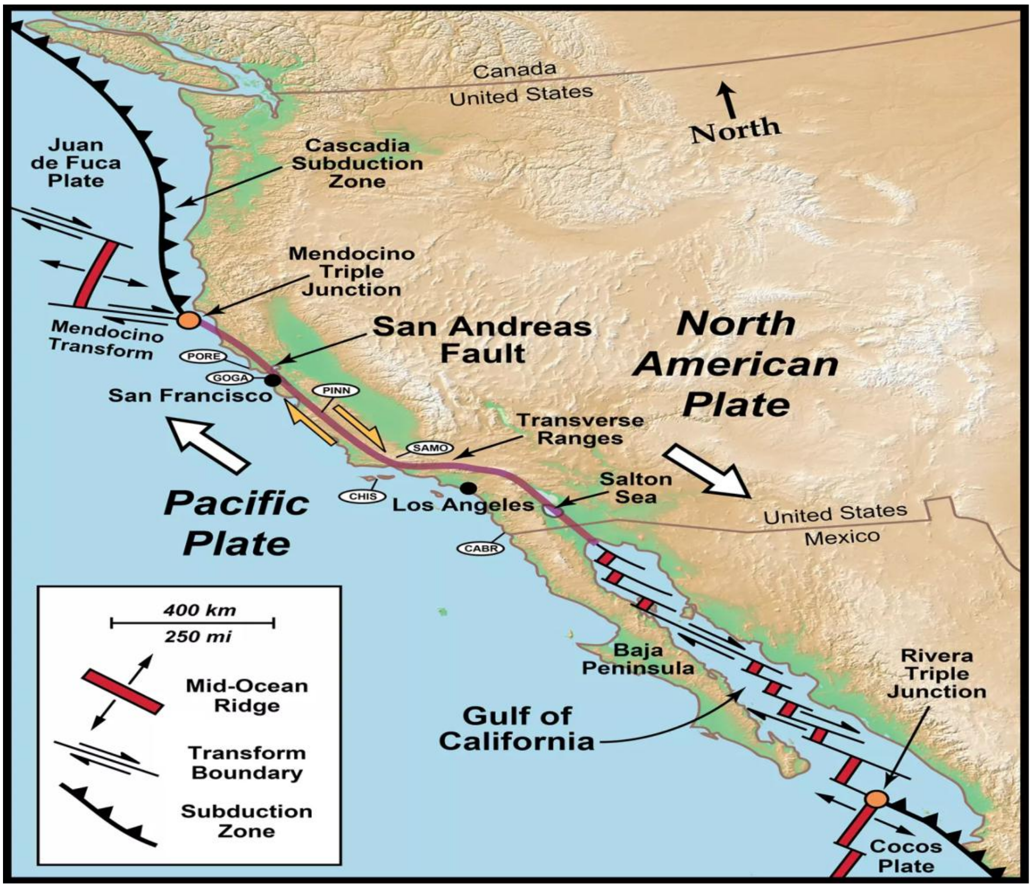


Figure 56: Evolution of the San Andreas fault

Figure 57: Aerial photo of the San Andreas fault

. Conclusion:

Continental lithosphere + Continental lithosphere = COLLISION + formation of mountain ranges (Orogenesis)

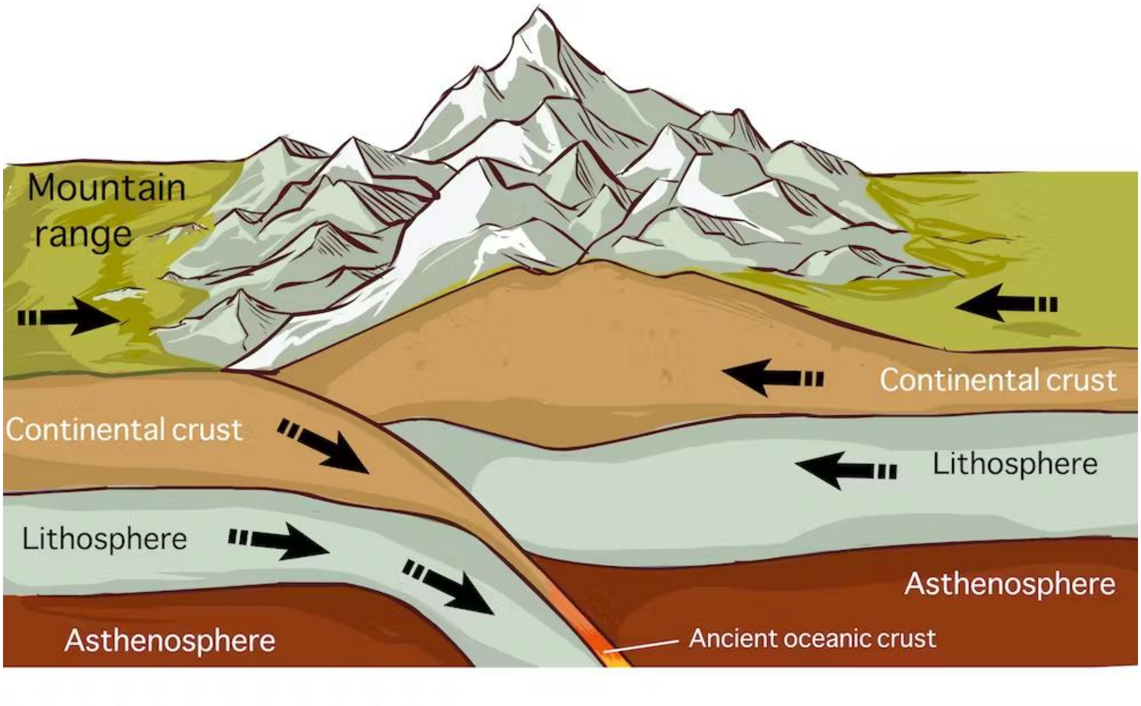


Figure 58: Process of mountain range formation

- Oceanic lithosphere + continental lithosphere = SUBDUCTION and disappearance of the oceanic lithosphere

2.4.5. Map of tectonic activity highlighting plate boundaries:

Yellow arrows indicate convergence, red arrows divergence and black arrows sliding.

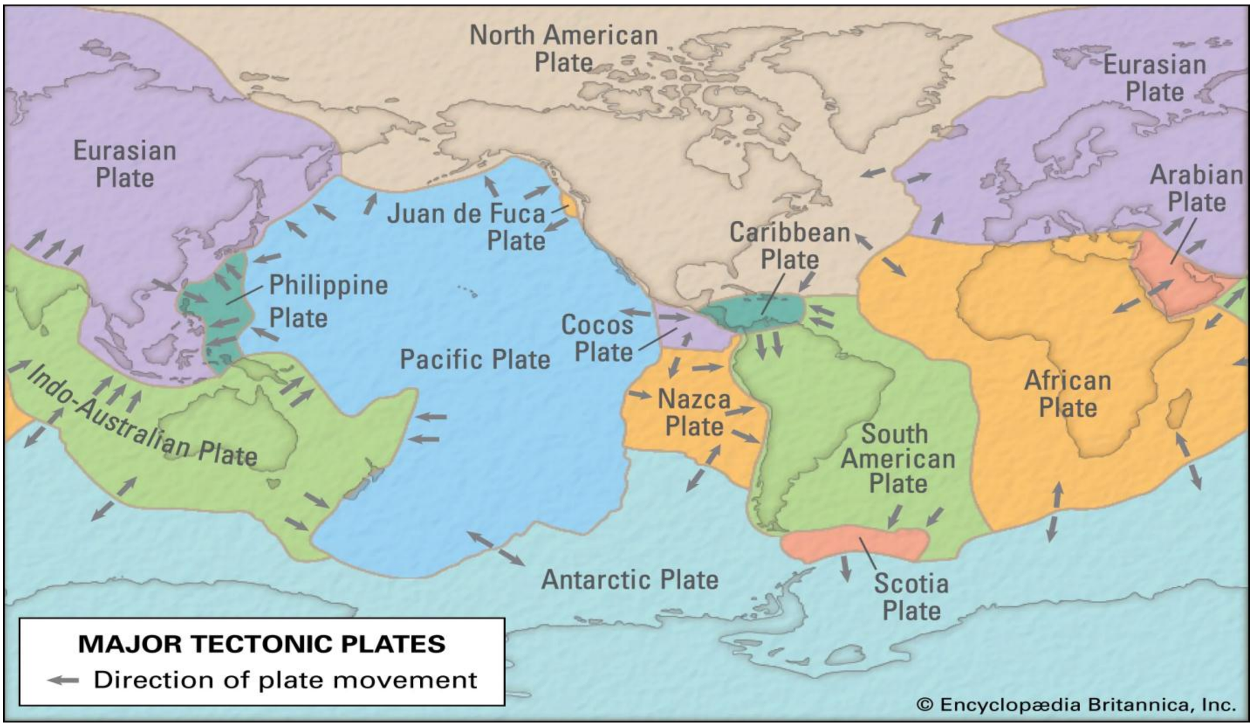


Figure 59: Lithospheric plate displacement map

Blue arrow Spreading movement

Red arrow Closing movement

NOTE: When 2 plates move towards each other, continents collide and mountain ranges are formed (e.g. the Himalayas).

During collision, rocks are subjected to high pressure, causing deformation (e.g. folds and faults).

- Dorsal: A long submarine mountain chain that stretches over 60,000 km across the world's oceans. It is 1,000 km wide and 2,000 m high.

- Rift: fissured collapse trough, located in the axis of ridges and up to ten kilometers wide.

- Pillow-lava: lava emitted along the axis of ridges, which cools to form pillows.

- Collapse trough: collapse of a portion of lithosphere between 2 fault systems.

Plate tectonics terms:

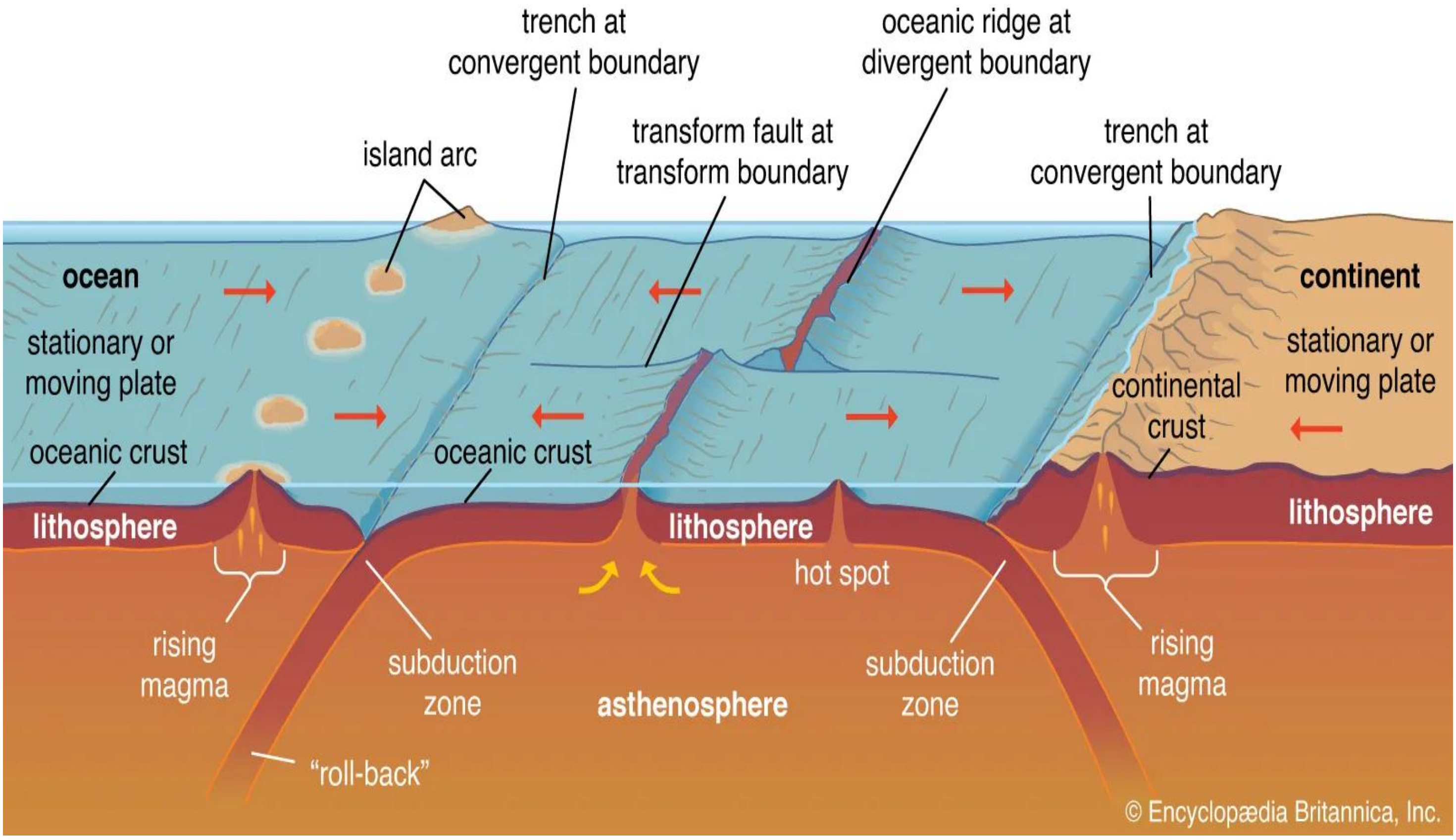


Figure 60: Plate tectonic terms

2.4.6. Frequently asked questions:

- How is tectonic plate movement measured?

Today, the movement of a given plate can be determined with a relative accuracy of a few millimeters, thanks to geodetic positioning techniques, in particular GOS *(Geodetic observation system)*. To trace the path of plates through geological time, geologists generally study the past magnetic field: certain minerals (such as magnetite or hematite) acquire, at the time of their formation, a feed whose direction and sense are those of the magnetic field.

This field varies with latitude, being almost horizontal at the equator and vertical at the poles. By measuring the magnetic field of ancient rocks, we can determine the latitude at which they were formed, and thus reconstruct the successive positions of continents.

- Has their geometry always been constant?

No. The position and size of the plates have constantly changed, shaping the face of today's Earth. We know, for example, that around 300 million years ago, all the land masses formed a single block (Pangea) into which an arm of the sea (Tethys) penetrated. Around 200 million years ago, Pangea split in two: to the north, Laurasia (Eurasia, Scandinavia, Greenland and North America); to the south, Gondwana (South America, Africa, Australia, India, Madagascar and Antarctica). In turn, these two masses broke apart, the Tethys closed, while the Atlantic and Indian oceans opened up. And plates collided once again: Africa's push against Eurasia forged the Alps, while India pushed Asia, causing the Himalayas and Tibet to rise. And before Pangea?

Megacontinents have formed on several occasions. Rodinia, for example, appeared about a billion years ago, and broke up 300 million years later. In fact, it seems that continental masses come together to form a megacontinent in a more or less cyclical fashion. the rhythm of the opening and closing of the oceans and collisions would explain, in part. the periodicity of mountain chain formation episodes, orogenies, by prolonging the current movement of plates, we can see that the Mediterranean will close and Australia will collide with Indochina. an enormous continental mass consisting roughly of Eurasia, India, Africa and Australia could therefore form. In 30 to 50 million years.

- What are the most dangerous plate boundaries?

Because of their location, convergent plate boundaries (subduction and collision zones) are the most dangerous for mankind.

This is particularly true of those where the speed of movement is fastest. Some belts are particularly active, both seismically and volcanically. One borders the Pacific, the other stretches from southern Europe to China, via the Middle East and southern Asia. All these areas are likely to be hit by a major earthquake in the decades to come. In all likelihood, the Sumatra region will shake again in the near future. So will the west coast of the United States. Geophysicists are also expecting a strong tremor near Istanbul, on the northern Anatolian fault, which runs 1500 km through Turkey, at the boundary between the Eurasian and African plates and along the Himalayan chain, the suture between India and Asia. The subduction zones bordering the Pacific are also home to the vast majority of the world's most fearsome active volcanoes: Mount St. Hellens, Pinatubo.

2.5. Earthquakes:

2.5.1. Definition of an earthquake:

Earthquakes are one of the manifestations of plate tectonics. Seismic activity is concentrated along faults (rupture zones in the lithosphere). Near the boundaries between tectonic plates, friction is high, and movement between the two crustal blocks is blocked. Energy is then stored along the fault. When the limit of rock resistance is reached, there is an abrupt rupture and sudden displacement along the fault, releasing all the slowly accumulated energy.

An earthquake is therefore the sudden displacement across a fault as a result of the build-up of stress along the fault over time.

After the main tremor, there are aftershocks, sometimes deadly, which correspond to the readjustment of blocks in the vicinity of the fault.

2.5.2. Different types of fault:

- Normal faults:

When tectonic forces stretch two compartments of rock, they move apart horizontally, and one sinks in relation to the other, sliding along a more or less inclined plane. This type of fault is found in stretching zones of the earth's crust.

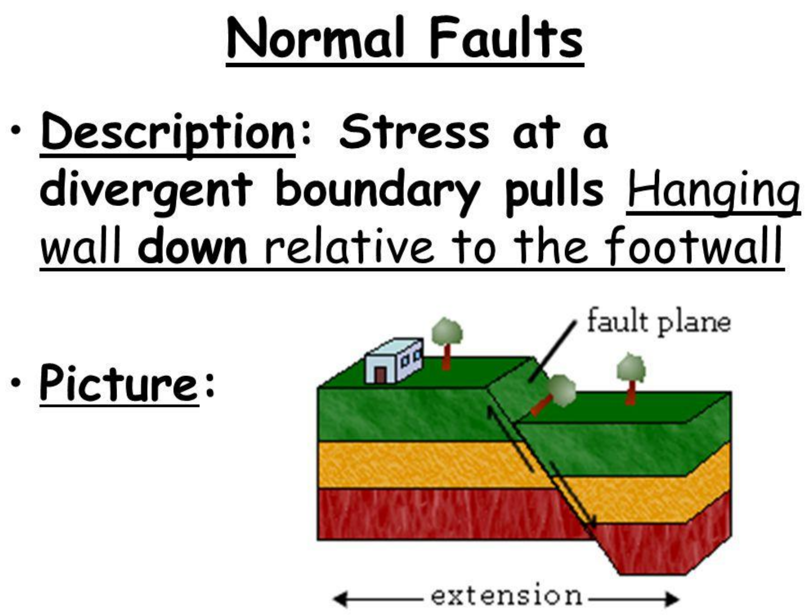


Figure 61: Normal fault

- Reverse faults:

Plate movements push the two blocks towards each other: they overlap, resulting in horizontal shortening and relief formation.

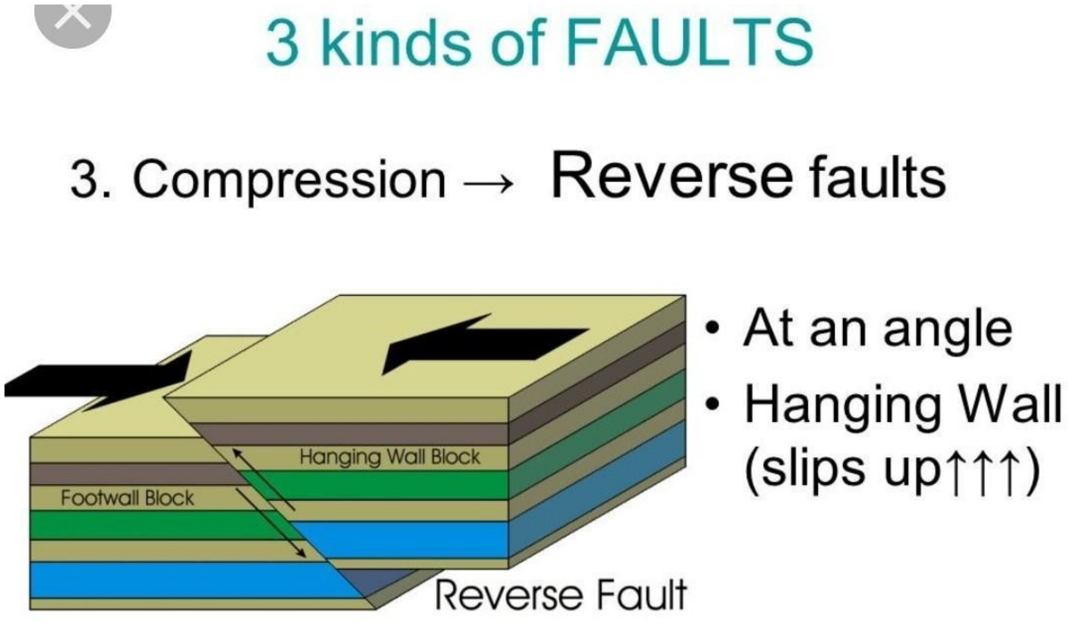


Figure 62: Reverse fault

- Strike - slip fault:

The blocks slide against each other, shifting the landscape. The Kunlun fault in China (Tibet) is one of the largest active strike-slip faults in Central Asia. Two major earthquakes occurred here in 1997 and 2001.

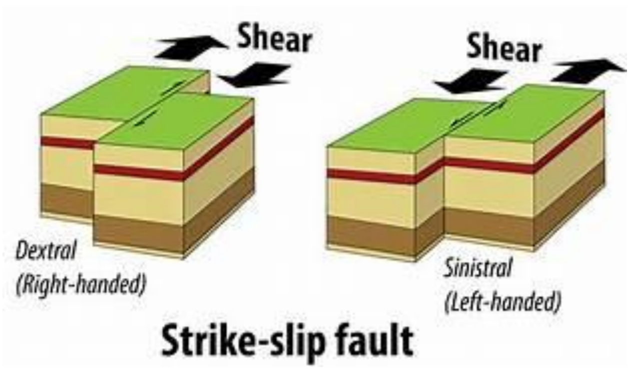


Figure 63: Strike - slip fault

2.5.3. Characteristics of an earthquake:

2.5.3.1. Recording earthquakes: seismographs, or seismometers. They measure ground movements.

These instruments are highly sensitive to ground vibrations, which are recorded by the stylus on the cylinder, producing a seismogram.

Nowadays, most seismometers are electromagnetic and can record the speed of ground movement, making earthquake detection quicker and more accurate.

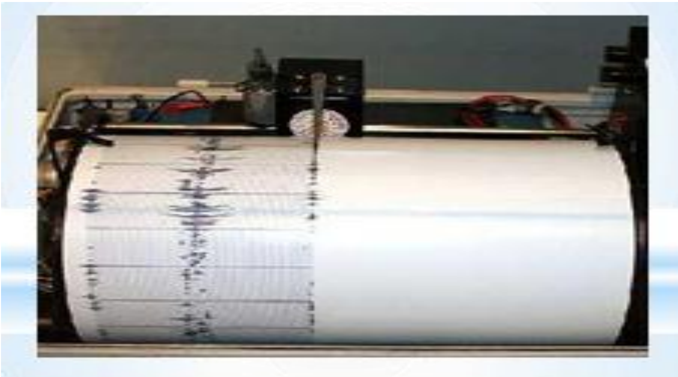


Figure 64: Seismograph

2.5.3.2. The focus (or hypocenter): is the point where the rupture occurs, where movement begins and energy is released.

Focal points are located in the lithosphere (between 0 m and 700 Km).

The location of the focus is expressed by its longitude, latitude (G.P.S. coordinates) and depth.

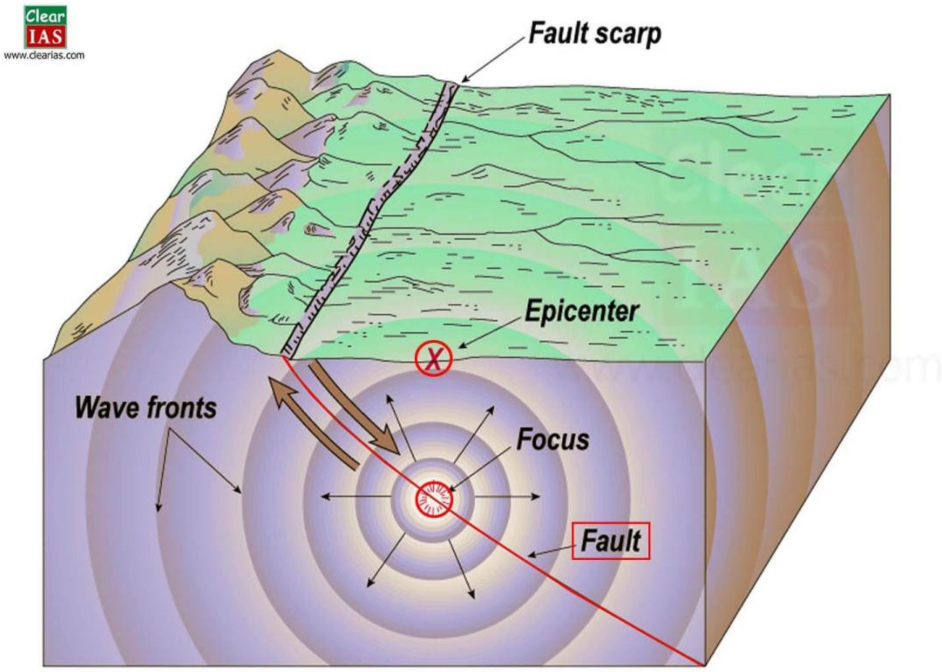


Figure 65: Earthquake hypocenter and epicenter

2.5.3.3. The epicenter: is the point located on the surface vertically above the focus. This is where the tremor is strongest.

2.5.4. Earthquake categories:

2.5.4. 1. Tectonic earthquakes:

The most frequent and dangerous, located at the level of tectonic plates. They are known to be deep.

2.5.4.2. Volcanic earthquakes:

Result from the accumulation of magma in a volcano and its eruption.

2.5.4.3. Artificial earthquakes:

Are generated by deep pumping, mining, nuclear testing...

2.5.5. Earthquake depth:

Depending on their depth, there are 3 types of earthquake:

2.5.5.1. Superficial earthquakes:

The most frequent, the focus is at a depth of between 0 and 60 km.

2.5.5.2. Intermediate earthquakes:

Focus between 60km and 300 km

2.5.5.3. Deep earthquakes:

Focus beyond 300 km

2.5.6. Measuring an earthquake:

Earthquakes are measured on two scales:

2.5.6.1. Intensity scale: The intensity of an earthquake is not a scientific measurement; it is determined by two things we observe:

-the extent of the damage caused by an earthquake, and the population's perception of the earthquake.

On a scale of degrees of intensity (Mercalli scale, 12 degrees); intensity is a function of distance from the epicenter, since the tremor is felt most strongly at the epicenter, and decreases with distance from it.

2.5.6.2. Magnitude scale (or Richter scale):

This expresses the magnitude of the earthquake (the amount of energy released by the quake).

It is based on measurements made by seismometers.

It is an instrumental datum, obtained from a seismograph recording, and provides information on .the energy developed at the focus

Table 3: Comparative table between Mercalli and Richter scales

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

Richter magnitude is defined as the decimal log of the maximum amplitude measured in microns by a seismograph located 100 km from the epicenter.

Experience shows that magnitudes are always below 9. Major destructive earthquakes have magnitudes in excess of 7, and damage below 4 is insignificant.

M = log A/T where A: Amplitude in microns

T: Time in seconds

The magnitude is related to the energy released, and increases with the latter (the magnitude value obtained increases with the energy released by the earthquake.

Table 4: Magnitude scale (or Richter scale)

Richter Magnitude	Description	Earthquake Effect
0-2.0	Micro	Never felt by people
2.0-2.9	Minor	Felt but not recorded
3.0-3.9	Minor	Felt but no damaged caused
4.0-4.9	Light	Ceiling Lights swing but no damaged
5.0-5.9	Moderate	Affects weak construction and cause wall crack
6.0-6.9	Strong	Affects area up to 160 km from the epicenter
7.0-7.9	Major	Affect area up to further area and cause several damaged
8.0-8.9	Great	Affect area beyond 100 miles and cause severe damaged
9.0-9.9	Great	Affect area beyond 1000 miles with disastrous effects

2.5.7 .The different types of waves .

Seismic waves are elastic waves that propagate in all directions. A distinction is made between

* Volume waves: travel through the earth

* Surface waves: propagate parallel to the earth's surface.

These two types of waves follow one another and are superimposed on seismometer recordings.

2.5.7.1. Volume waves:

These propagate inside the globe. Their propagation speed depends on the material they pass through. We observe:

2.5.7.1.1. P waves: (Main) (Primary waves = Compression waves = Longitudinal waves)

They propagate in all media.

The ground displacement that accompanies their passage takes the form of successive dilations and compressions.

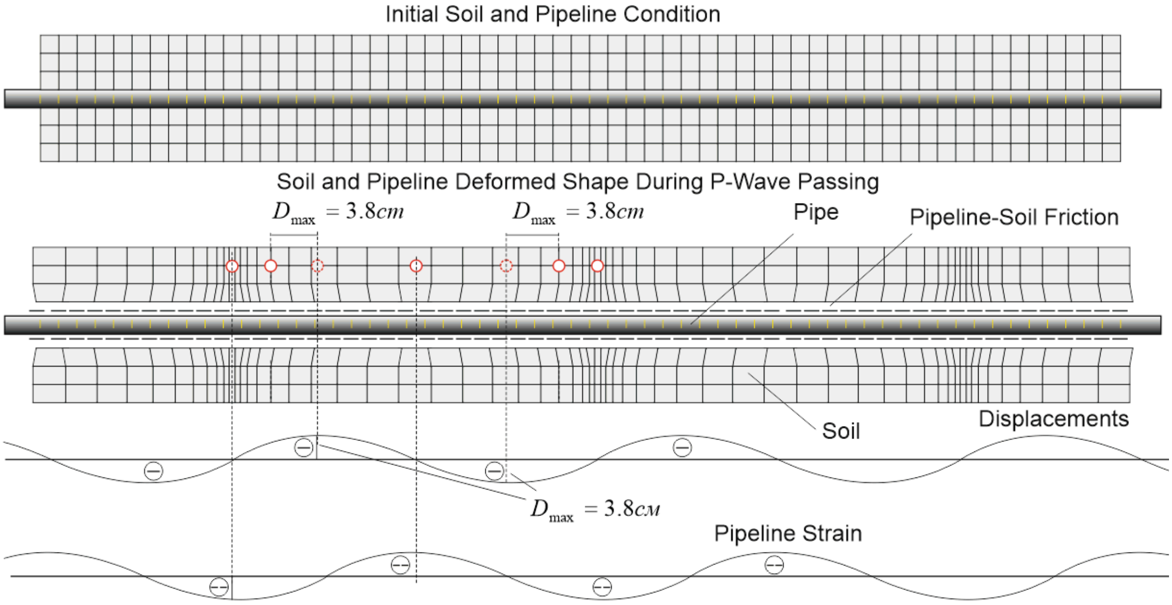


Figure 66: Conceptual diagram of soil behavior during the passage of a primary wave.

- These are the fastest (6 Km/s near the surface).

- They are the first to be recorded on seismometers.

2.5.7.1.2. S: (Secondary) waves (shear or transverse waves)

- They propagate only in solids.

As they pass, the ground moves: perpendicular to the direction of wave propagation.

- Not as fast as

A P wave, their speed is 4.06 Km/s.

Travel in all directions from the hypocenter, and are capable of crossing the Earth from one end to the other.

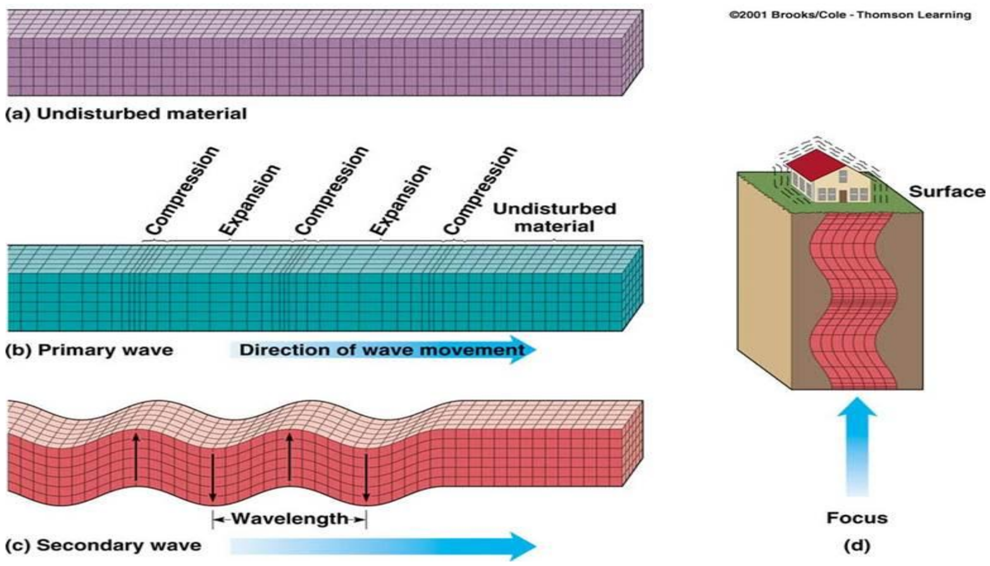


Figure 67: Conceptual diagram of ground behavior during the passage of the primary and secondary wave.

2.5.7.2. Surface waves:

Surface waves are :

- slower than volume waves,

- their amplitude is often greater.

They are guided by the Earth's surface.

They are observed:

2.5.7.2.1. Love waves:

Love waves cause horizontal shaking, which is the cause of much damage to building foundations. Their propagation speed is around 4 Km/s.

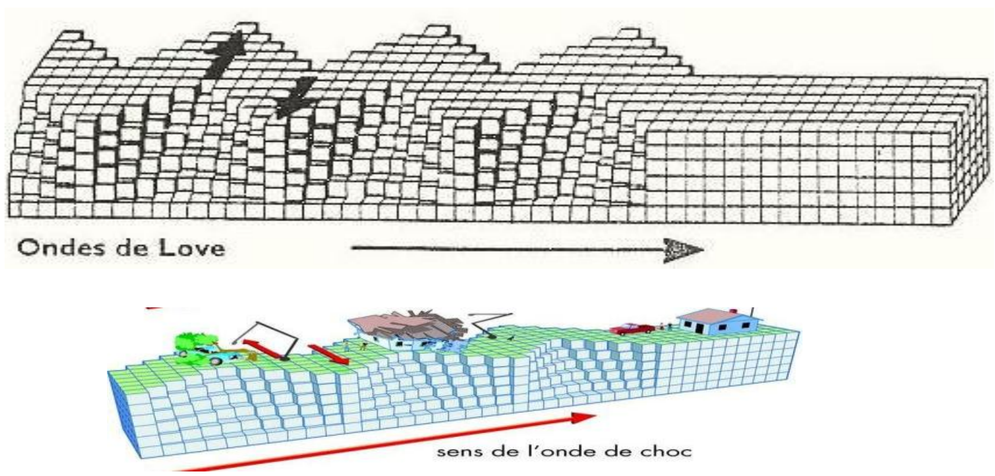


Figure 68: Conceptual diagram of soil behavior during the passage of a Love wave

2.5.7.2.2. Rayleigh waves:

These are the slowest waves. Their displacement is complex, both horizontal and vertical, or more precisely, elliptical.

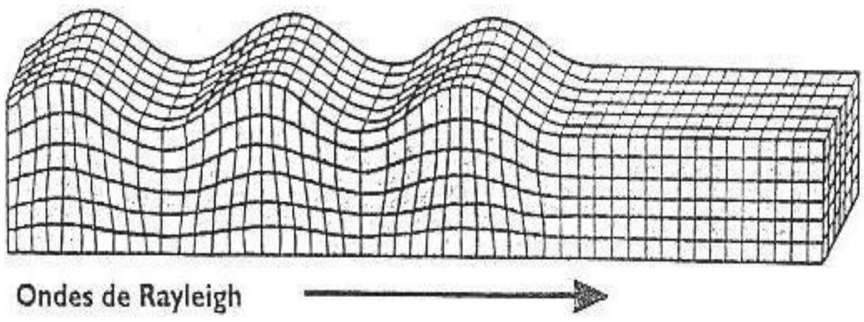


Figure 69: Soil behavior during the passage of a Rayleigh wave

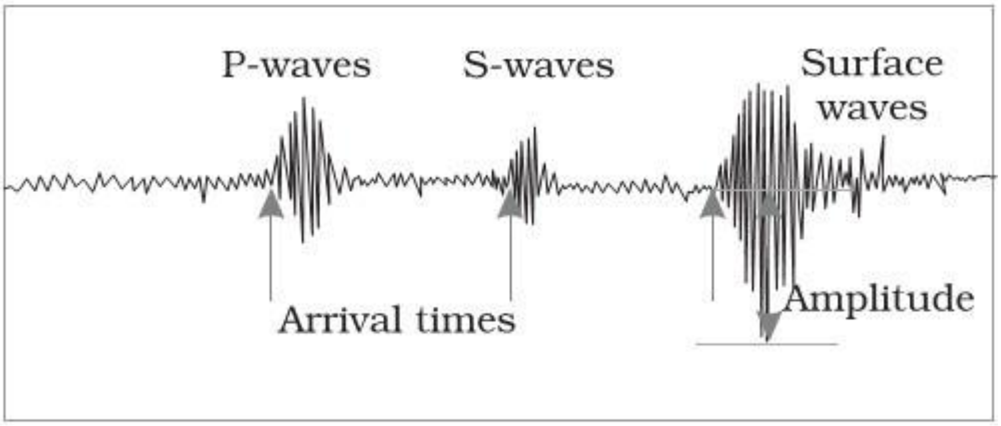


Figure 70: Order of appearance of seismic waves on a seismogram

2.5.8. Possible origins of earthquakes:

The lithosphere is divided into a number of large plates separated by mid-ocean rifts. These plates "float" on the asthenosphere, which is the seat of very slow convection movements. These movements bring deep-sea material to the surface in the oceanic rifts, which in turn causes the plates to move relative to each other.

At the other end, in the ocean trenches, the plates sink and disappear into the asthenosphere, where two plates collide and overlap to form mountain chains. It is in these areas that sudden earthquakes occur, resolving slowly accumulated stresses as soon as they exceed the resistance limit of the materials that make up the earth's crust.

Some earthquakes are also triggered by volcanic activity:

- Volcanic explosion

- Cracking of the crust

- Slumping of central parts of volcanoes into the vent.

Superficial earthquakes are related to faults: lateral or vertical displacement along faults causes earthquakes.
2.5.8. Global seismicity :

Global seismic activity is characterized by seismicity indices that vary from region to region, and the geographical distribution of seismic zones is not random.

2.5.8.1. Seismicity index:

The seismicity index reflects the total annual number of earthquakes, irrespective of their intensity, for a standard surface area of 100,000 km2.

Generally speaking, geologically ancient regions such as Scandinavia, the African, Canadian and Russian shields are less exposed to earthquakes than recent orogenic zones such as Japan, the Alpine chain and plate boundaries.

2.5.8.2. Earthquake distribution:

Some regions of the globe are more seismic than others. Earthquakes are not randomly distributed.

If you look at their distribution on a planisphere, you can see that they are located in very specific zones:

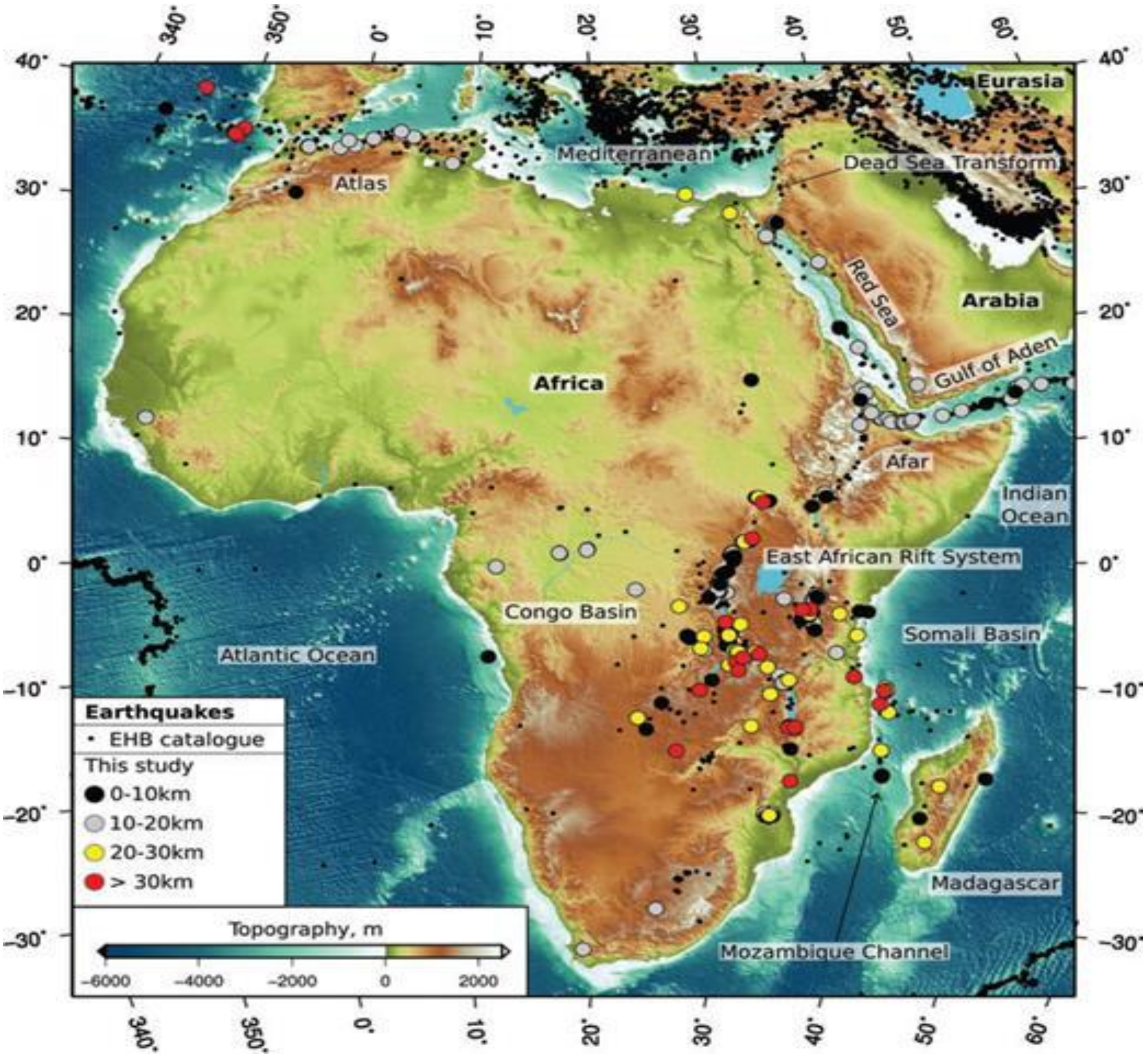


Figure 71: Distribution and types of earthquakes (depth) at the Euro-African tectonic boundary

. - In the middle of the ocean:

They are aligned, often in the middle of the ocean, along a submarine mountain chain, characteristic of oceanic ridges.

Earthquakes are fairly shallow (average depth of focus: 20 km). Very frequent.

- On the edges of continents:

This is the case around the Pacific Ocean. Earthquakes are localized in abyssal trenches and in mountain ranges bordering continents (Andes, Rockies). Focal points are increasingly deep (up to 700 km).

- In intracontinental positions:

most often in major mountain ranges (Alps, Himalayas). The average depth of these foci is 70 km.

2.5.9. Seismicity in Algeria: Algeria is exposed to seismic risk in its most densely populated part, the Tellian zone, which is the most affected by earthquakes, due to recent orogeny linked to the Alpine cycle, forming part of the Mesogean zone. In terms of plate tectonics, this zone corresponds to the line where the two tectonic plates meet.

The northern part of Algeria lies on the northern edge of the African tectonic plate, which is colliding with the Eurasian plate, causing earthquakes.

2.5.10. Geographical distribution of earthquakes:

In fact, only a hundred or so earthquakes are classified as high intensity, and only 10 as catastrophic. The geographical distribution of earthquake epicenters across the globe is not random, and three main zones can be distinguished:

2.5.10.1 Peripacific zone: this is the largest zone, accounting for 68% of all earthquakes and 80% of global seismic energy. It begins with Japan, New Zealand, Chile, South America, Mexico and Alaska.

2.5.10.2 Mesogean zone: Concentrates 21% of earthquakes and 15% of seismic energy. It encompasses all regions of the Alpine fold, from Portugal to the Pacific, via the Maghreb and Central Asia. (Caucasus, Himalayas, Indonesia) Earthquakes are caused by the convergence of the Eurasian and African plates.

2.5.10.3 Mid-Atlantic zone: These are submarine mountain ridges, especially those in the middle of the oceans. It starts in Iceland, passes through the Azores islands, skirts Africa, crosses the Indian Ocean and ends in the Red Sea.

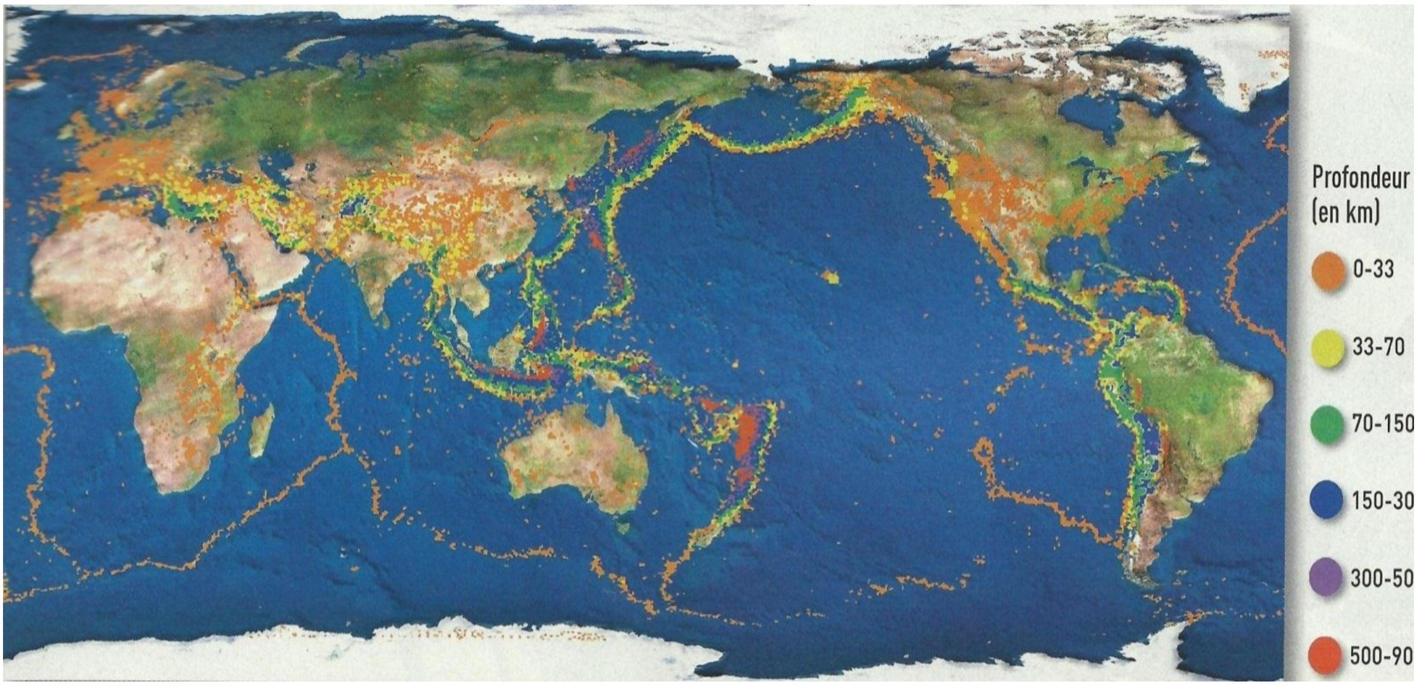


Figure 72: Distribution of earthquakes around the globe

It is remarkable that, with a few exceptions, the earthquake centers are located in recent orogenic zones, along faults, and that these seismic fault sets correspond to tectonics.

2.5.11. Effects of earthquakes:

Major earthquakes often have remarkable geological effects:

2.5.11.1. Creation and play of faults:

The San Francisco earthquake (1960) shifted the San Andréa fault over a length of 470 km, levelling the two lips by a few cm to one meter, and unhooking the two neighboring compartments by 25 cm to 7 m.

2.5.11.2. Uplift and subsidence:

During the Yokohama earthquake (1923), the bay was uplifted by 2 m and subsided towards the center by 100 to 200 m.

2.5.11.3 ground heave and subsidence:

Earthquakes sometimes trigger landslides, which caused a dam in the Chélif valley to topple over (Asnam 1954).

2.5.11. Disturbance in the origin of springs:

Disturbances reflect upheavals in the subsoil that lead to changes in the path of groundwater, and some springs gush out of certain fissures.

2.5.11.4. Marine manifestations of earthquakes:

Submarine earthquakes are often accompanied by tidal waves or tsunamis, when the sea rises and invades the shoreline, causing waves to reach great heights (up to 30 m in the Chile earthquake), tearing away dykes, destroying harbours and sweeping away houses, with several hundred victims recorded in Japan.

2.5.12. Prevention and protection:

Earthquakes are still very difficult to predict, even with sophisticated equipment. However, the regions at risk are fairly well known.

Earthquakes occur in regions where the crust is brittle, i.e. essentially at the point of contact between two plates and on their periphery. Faulty regions are also affected. Prevention is the most effective way of protecting life and property.

Seismic-resistant buildings are more resistant to earthquakes. In some countries, such as Japan, which is very frequently hit by earthquakes, regular evacuation drills and safety instructions learnt at a very early age at school help to reduce the loss of human life. This is because the greatest number of casualties are caused by collapsing buildings and ruptured gas, electricity and water pipes, leading to fire and flooding.

2.5.13. Some frequently asked questions:

- Is it possible to predict earthquakes?

Man has always tried to predict earthquakes.

Numerous attempts using different parameters have been tested in research institutions, but without success.

The complexity of rupture explains the difficulty of prediction.

The spatial tool has been used for a possible prediction. The results are not very encouraging.

However, seismologists are continuing their efforts to anticipate the occurrence of an earthquake.

- Is there a link between climate and earthquakes?

Many members of the public have often asked whether heat waves, especially in winter, are a sign that an earthquake is imminent ?

Since earthquakes are more closely linked to variations in the globe's internal stresses, there is no link between seismicity and climate.

Earthquakes can occur in cold, hot or temperate regions.

They also occur on the seabed, with no link to climate variations.

- Do earthquakes occur at a particular time of year?

No. Earthquakes occur all year round, with no preferred month.

This is because crustal deformation is assessed on a geological time scale, not a human one.

- What secondary phenomena are associated with earthquakes?

When an earthquake occurs, the following secondary effects can be observed:

- Rumbling:

These indicate the deformation of the earth's crust as seismic waves pass over it.

- The drying up of springs (of water) and the appearance of new ones:

The displacement of crustal blocks means that groundwater flow routes can be altered.

- Gas emissions:

The magnitude of the tremor can lead to the release of various gases due to the high pressures inside the earth's crust.

- The occasional flash of light:

These brief flashes sometimes appear at the moment of the main shock, due to friction between the edges of the fault and the electrification of the surrounding air.

2.6. Volcanoes and volcanism:

2.6.1 Introduction and definitions:

* Volcanism is the set of phenomena associated with volcanoes and the presence of magma.

* Volcanology is the science of studying, observing and preventing the risks associated with volcanoes.

- **Definition:** Volcanoes are natural devices

through which magmatic products from internal

zones reach the surface of the earth's crust, either in the open air or under water.

A volcano is a land, submarine or extraterrestrial feature.

It is formed by the ejection and piling up of materials resulting from the rise of magma in the form of lava and ash.

This magma comes from the partial melting of the mantle and, exceptionally, of the earth's crust (lithosphere).

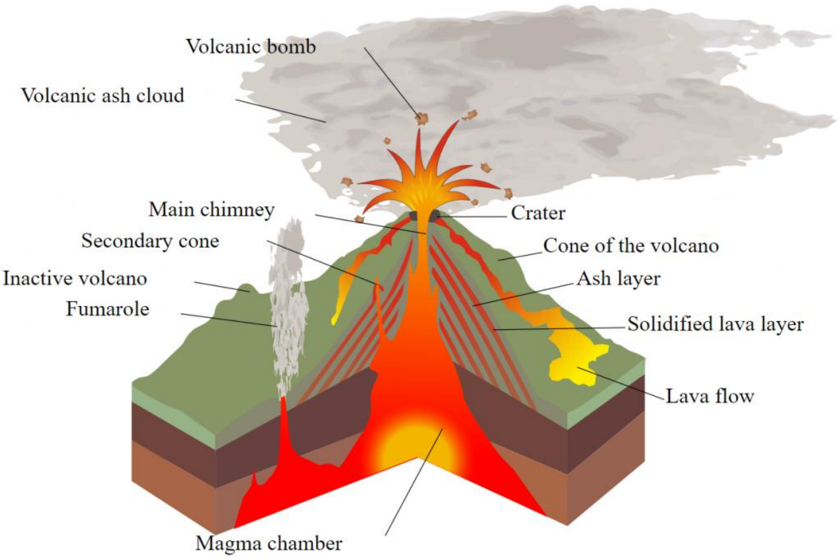


Figure 73: General structure of a volcano

Accumulation can reach thousands of meters in thickness, forming mountains or islands.

2.6.2. Volcano structure:

According to the nature of materials, the type of eruption, their frequency and the Orogenesis, volcanoes take varied forms but in general they have the aspect of a mountain conical, on top of a crater.

A volcano is made up of different structures, which are generally found in each of them:

Figure 74: Aerial photo of ETNA crater

2.6.2.1. The magma chamber:

Fed by magma from the mantle (acting as a reservoir).

(Magma chambers are found at depths of between 10 and 50 km in the lithosphere).

2.6.2.2. The main chimney:

This is the main transit point for magma from the magma chamber to the surface.

2.6.2. 3 the summit crater:

The opening where the main vent emerges (exits);

2.6.2.4. One or more secondary chimneys:

Originating from the magma chamber or the main chimney, these usually emerge on the flanks of the volcano, sometimes at its base.

They can give rise to small secondary cones;

2.6.2.5 Lateral fissures:

These are longitudinal fractures in the volcano's flank caused by its swelling or deflation.

They may allow lava to be emitted in the form of a fissural eruption.

2.6.3. Main manifestations of volcanic activity:

Generally speaking, any volcanic eruption is heralded by precursory signs, and the eruption itself is characterized by the emission of various products.

2.6.3.1. Eruption precursors:

The eruption is preceded by underground noises, by seismic tremors that often modify the origin of aquifers or lead to the formation of cracks, by heat surges and by the release of smoke.

2.6.3.2. Eruption proper:

This often begins with a violent explosion and the emission of a column of gas, followed by solid and liquid materials.

2.6.3.3. Products released by volcanoes:

2.6.3.3.1. Gases:

Volcanic devices emit gaseous products known as fumaroles, at temperatures between 50 and 600°C. Fumaroles release water vapor, chlorides, sulfur vapor, sulfurous gases, hydrogen sulfide and carbon dioxide.

2.6.3.3.2. Solid products: (Pyroclastic materials)

These volcanic projections come in all sizes, from bombs (ø > 32 mm) to dust (ø < 0.35 mm), volcanic ash (ø between 0.35 and 4 mm) and lapillis (ø between 4 and 32 mm). Consolidated bombs and lapillis produce volcanic breccia, while small lapillis, ash and dust produce volcanic tuff.

Lapillis: meaning small stones. These are round, hazelnut-sized fragments of lava. When lapilli contains a lot of gas bubbles, it's called slag.

Volcanic bombs: These are blocks of lava, thrown into the air, which partially solidify. Round or spindle-shaped, they can weigh several tons

2.6.3.3.3. Liquid products:

These are lavas, flowing from the crater and fissures at temperatures between 600 and 1200°C. Lava can appear in flows or in extensive sheets, and is distinguished according to its degree of fluidity:

- Basic lavas are generally hotter and more fluid, with a low silica content, e.g. basalt.

- Acidic lavas are viscous, silica-rich lavas, e.g. andesite, trachyte.

If the lava contains less than 50% glass, it is very fluid at high temperatures. It is then called basalt, a heavy, black, iron-rich rock.

If lava is low in silica, it is said to be basic.

If it contains around 60% glass, it is already more difficult to flow. It is then called andesite, and is gray in color.

2.6.3.4. Paravolcanic phenomena:

Paravolcanic phenomena (fumaroles, solfataras, geysers, crater lakes, etc.) are among the most spectacular and frequently visited objects. Volcanic and geothermal geotourism is booming

2.6.3.4.1. Fumarolean emissions:

These are often hot water vapors (100 to 300°C), rich in carbon dioxide and hydrogen sulfide, the oxidation of which by atmospheric oxygen results in a deposit of free sulfur.

Solfatara, which means "sulfur mine", today, designates volcanic areas rich in sulfur. Sulfur is used in the manufacture of sulfuric acid.

2.6.3.4.2. Geysers:

These are very hot springs that gush out intermittently, with water either coming from deep underground (as in the case of volcanoes) or from the surface, which has infiltrated, heated up at depth and risen to the surface. The water generally contains a high proportion of mineral salts acquired at depth, which precipitate to form siliceous or calcareous deposits. These hot springs constitute a source of thermal energy that can be exploited. Iceland takes advantage of the steam emitted by its volcanoes to heat homes and generate electricity.

2.6.4. Different types of volcano:

There are three types of volcano:

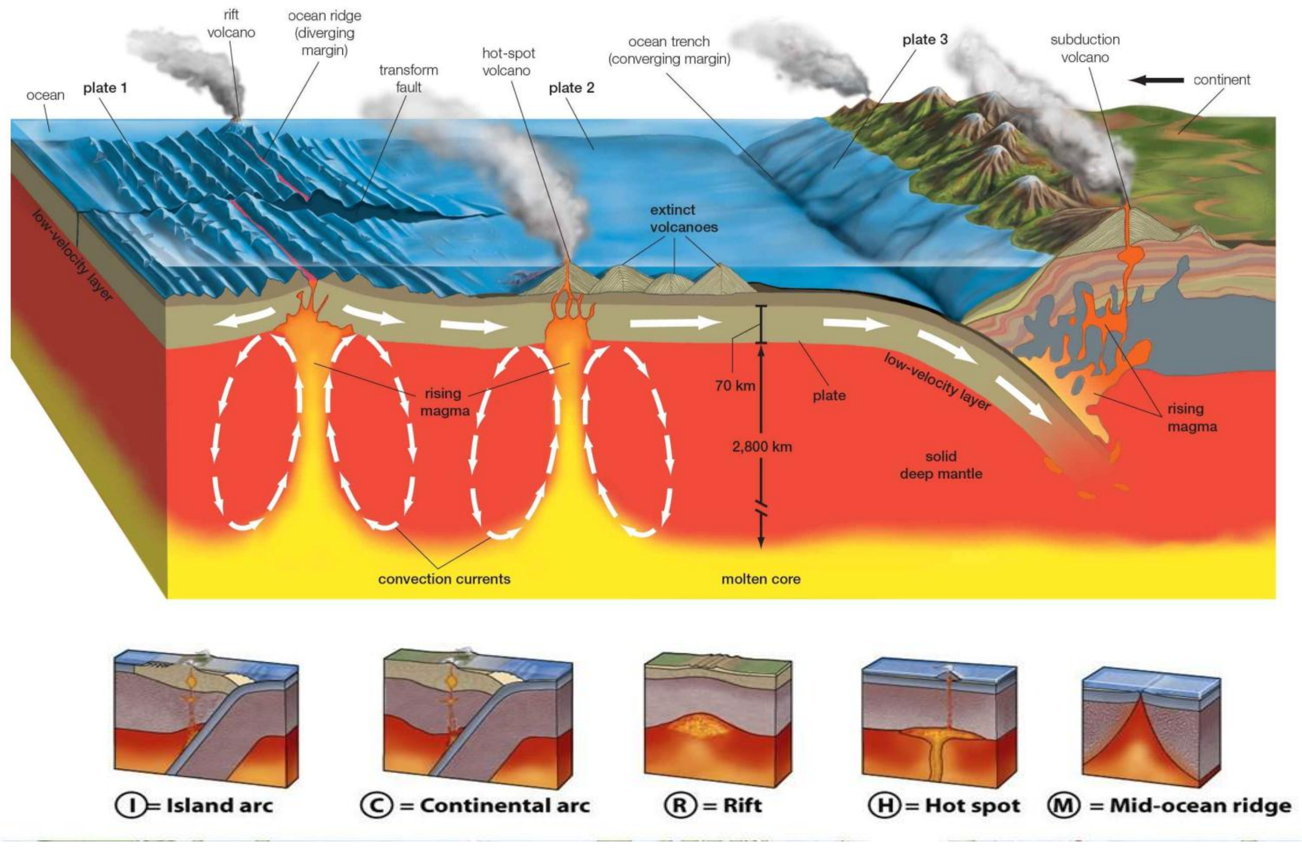


Figure 75: different types of volcanoes

2.6.4.1. Volcanoes of subduction chains:

- Continental: Pacific Ring of Fire

- Oceanic: island arcs

2.6.4.2. Rift volcanoes:

- Mid-ocean ridges (mid-Atlantic ridge)

- Continental rifts (Africa)

2.6.4.3. Volcanoes isolated from hotspots: intra-plate and hotspot volcanism

Volcanoes sometimes arise far from any lithospheric plate boundary (there may be over 100,000 undersea mountains over 1,000 meters2). These are generally interpreted as hot-spot volcanoes. Hotspots are plumes of magma from deep in the mantle that pierce lithospheric plates. Since hotspots are fixed, as the lithospheric plate moves over the mantle, successive volcanoes are created and aligned, the most recent being the most active because it lies directly under the hotspot. When the hotspot emerges beneath an ocean, it gives rise to a string of aligned islands, as in the case of the Hawaiian archipelago (a volcanic island in the Pacific Ocean, one of the eight main islands that make up the US state of Hawaii) or the Mascarene Islands (an archipelago in the Indian Ocean made up of three main islands). If the hot spot emerges beneath a continent, it will give rise to a series of aligned volcanoes. This is the case of Mount Cameroon and its neighbors. In exceptional cases, a hotspot may emerge beneath a lithospheric plate boundary. In the case of Iceland, the effect of a hot spot combines with that of the mid-Atlantic ridge, giving rise to an immense lava pile that allows the ridge to emerge. The Azores (a group of Portuguese islands in the North Atlantic) and the Galapagos (a volcanic archipelago in the Pacific Ocean) are other examples of hotspots emerging beneath a lithospheric plate boundary, in this case a ridge

2.6.5. The different types of eruptions:

There are two main types of volcanic eruption:

2.6.5. 1. Red or effusive volcanoes with lava flows (fluid magma):

Figure 76: Effusive eruption

2.6.5.2. Grey or explosive volcanoes with glowing cloud projections:

The lava plug is expelled by a sudden outgassing of the magma.

Note:

* Volcanoes in subduction chains are responsible for explosive volcanism.

 - Rift volcanoes and isolated Hot Spot volcanoes are responsible for effusive volcanism.

Figure 77: Explosive eruption

Three types of eruption are observed in explosive volcanoes

2.6.5.2.1. Strombolian eruptions:

- Stromboli.

- Not very dangerous, as these eruptions produce little tephra (e.g. volcanic bombs, slag, etc.).

- Only within a radius of a few hundred metres or a few kilometers from the crater.

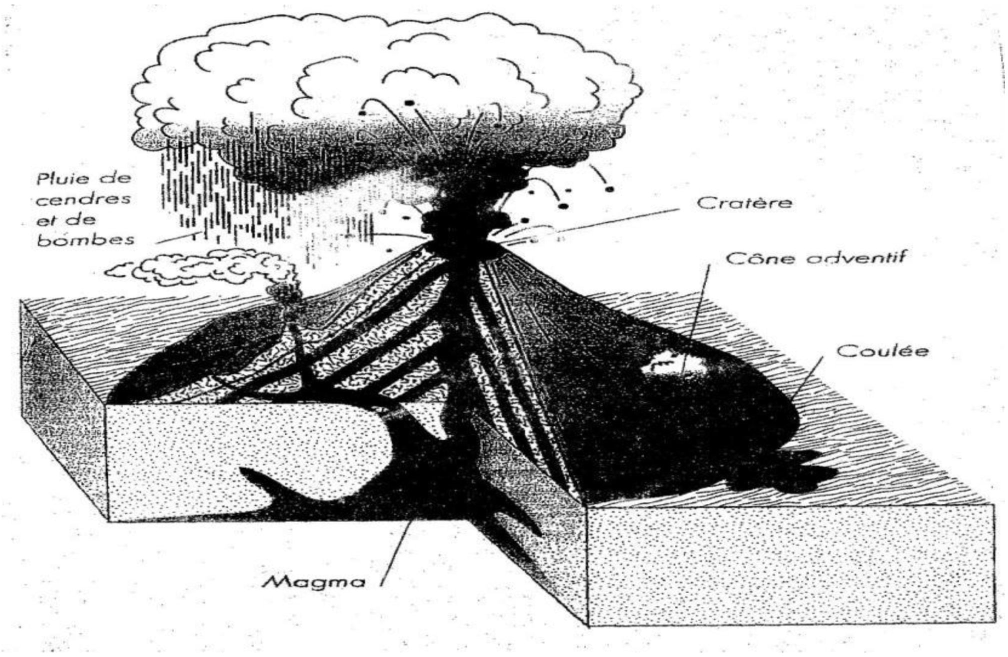
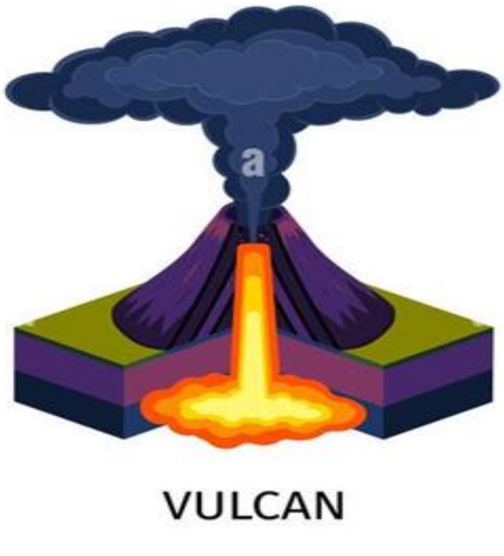


Figure 78: Strombolian activity (strato-volcano)

2.6.5.2.2. Vulcanic eruptions: These are dangerous because they are brief (explosions) lasting from a few seconds to a few minutes, and can be very intense.



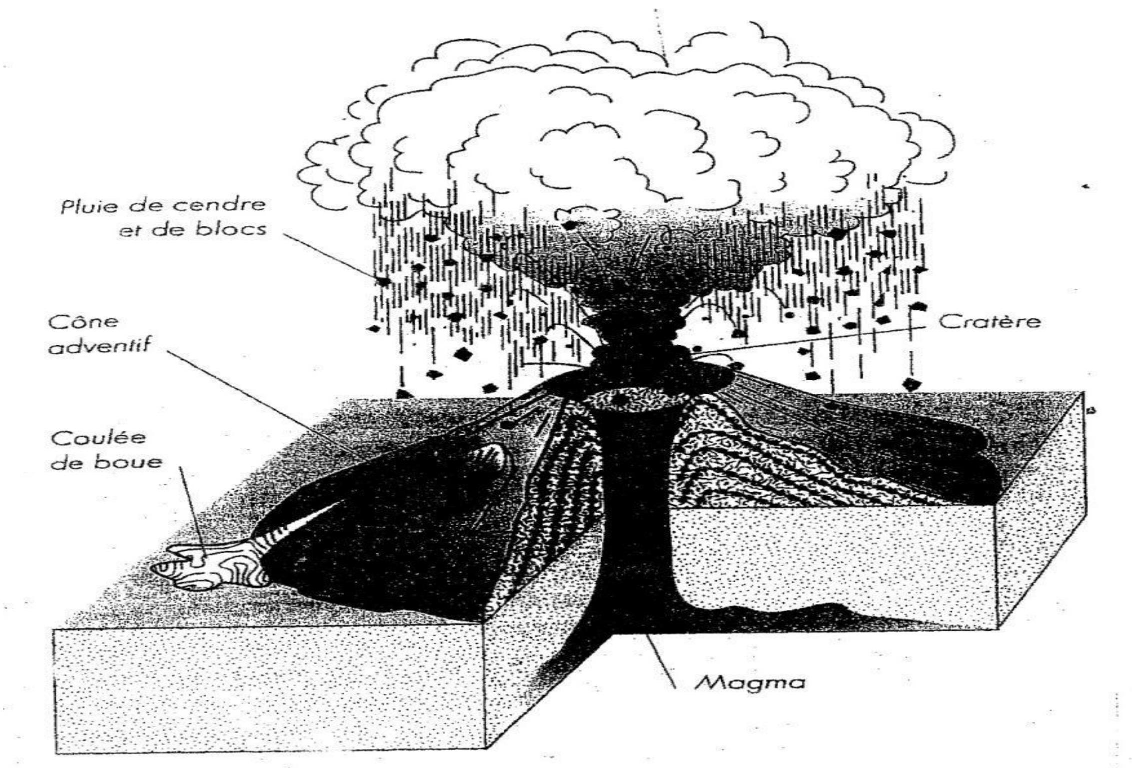


Figure 79: Vulcanian activity

If these eruptions are repeated regularly in an eruptive crisis lasting days, months or years, they are similar to strombolian eruptions.

2.6.5.2.3. Peeling eruptions:

- These are the most dangerous. They continue for several hours or days.

- They form eruptive columns several tens of kilometers high.

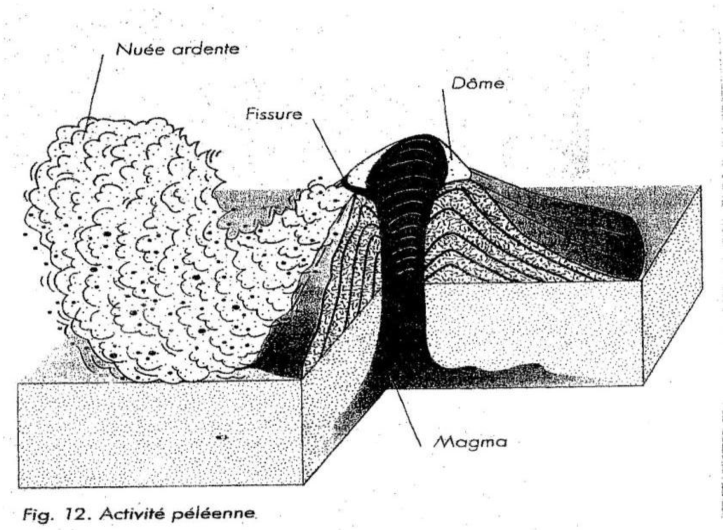


Figure 80: Pelean activity

2.6.6. Other volcano classifications:

- Depending on the nature of the underlying magma, its fluidity and the amount of pressure generated by the gases, two major types of eruption can be distinguished:

a) Fissurale eruption:

1) Non-explosive: cracks in the earth's crust, releasing very fluid lava and a very large volume of material, usually hidden from view on the ocean floor (e.g. basalt). Fissural volcanism, which is more or less explosive, is at the origin of oceanic crust, and results in the expansion of the ocean floor.

2) With explosion: so-called explosive eruptions occur when the magma is rich in gas, or when its high viscosity slows down degassing; this is known as the Icelandic type.

b) **Punctiform eruption:** These are the "real" volcanoes of popular imagination, with a chimney, crater and cone. In this type of eruption, there is either a single, violent explosion that volatilizes a large volume of material, or there are repeated eruptions.

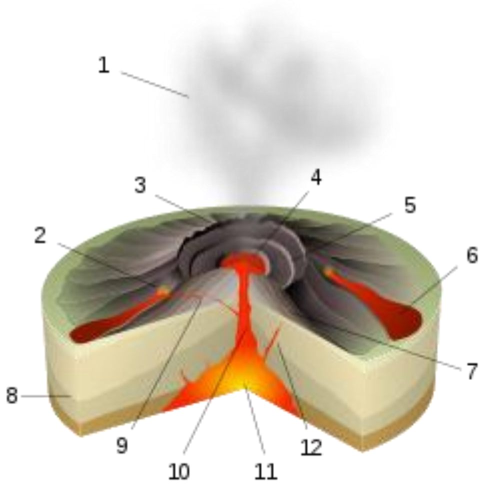
Note: ash is extremely fertile, as it is rich in potassium minerals. Because of this fertility, volcanic regions are among the most densely populated in the world. In Indonesia, up to 3 rice harvests a year are obtained, as the ash released by volcanoes is rich in fertilizing elements.

- Volcanic eruptions - according to the different volcanic edifices:

The distinction between different eruptive edifices was recognized by Mercali in 1907. Depending on the viscosity of the lava and the extent of explosive phenomena, volcanoes can be classified according to their behavior. There are 4 main types:

1) Hawaiian type (Hawaiian Islands - Pacific Ocean)

These volcanoes have craters whose diameter is greater than their height, and produce very fluid lavas that build low-slope cones (4 to 6°). Explosions and projections are minimal.



1, ash plume; 2, lava fountain; 3, crater; 4, lava lake; 5, fumarole; 6, lava flow; 7, layers of lava and ash; 8, stratum; 9, sill; 10, magma conduit; 11, magma chamber; 12, dike

Figure 81: Hawaiian eruption

1). Strombolian type: (Lipari Island - Italy)

Lava flows are less fluid, and eruptions are explosive. Characterized by a regular cone, where less fluid lava flows alternate with layers of projections (pyroclastic blocks, lapillis and ash).

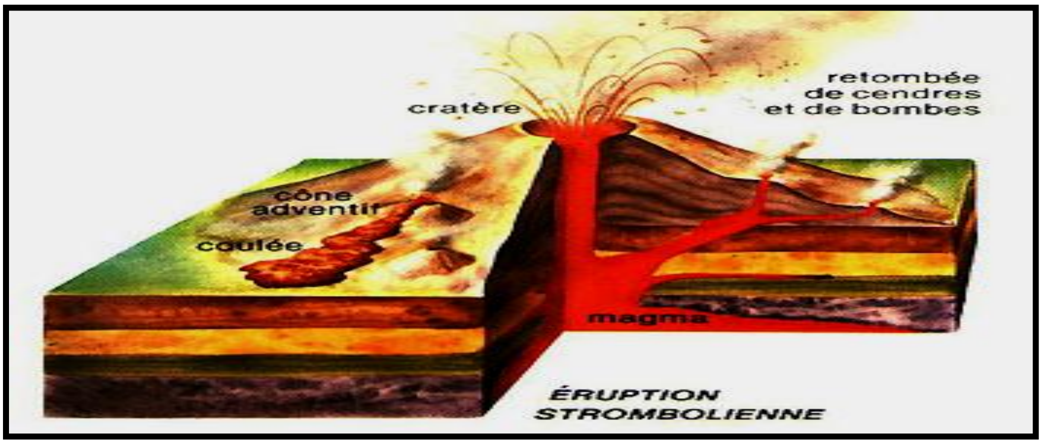


Figure 82: Strombolian eruption

2) Vulcanian type (Lipari island - Italy)

These eruptions are explosive and very violent.

The lava, acidic and highly viscous, tends to clog the chimney with a plug that is constantly fragmented by violent explosions, and the cone is almost entirely made up of projections.

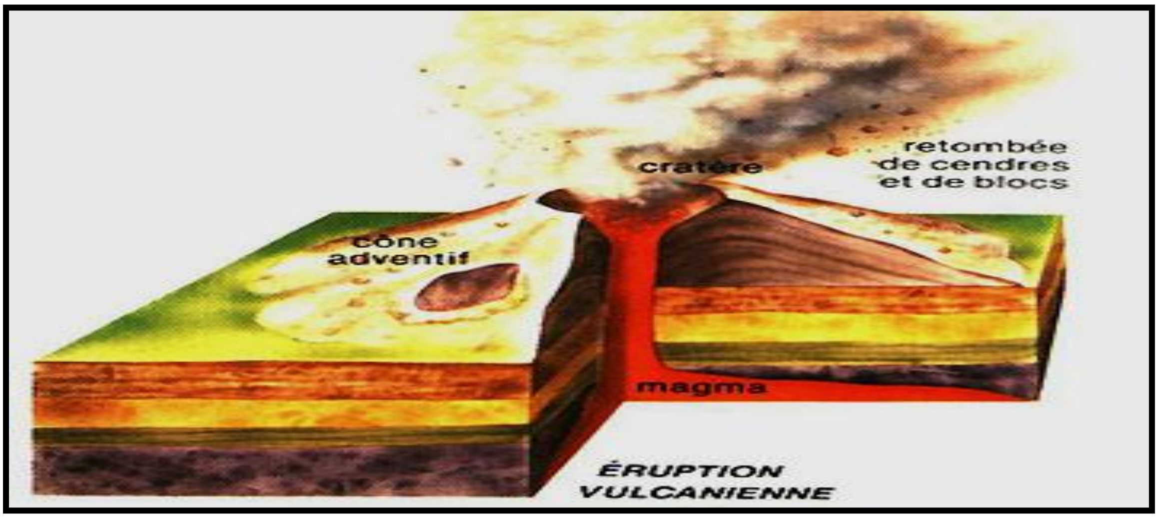


Figure 83: Vulcanian eruption

3) .Pelean type: (Mountain Pelée - Martinique)

The magma is so viscous that it ends up forming an enormous plug: domes and extrusion needles, which can be accompanied by explosions. The pressurized gases then seek to escape by lateral routes, resulting in fiery clouds (huge clouds of gas, water vapor and ash).

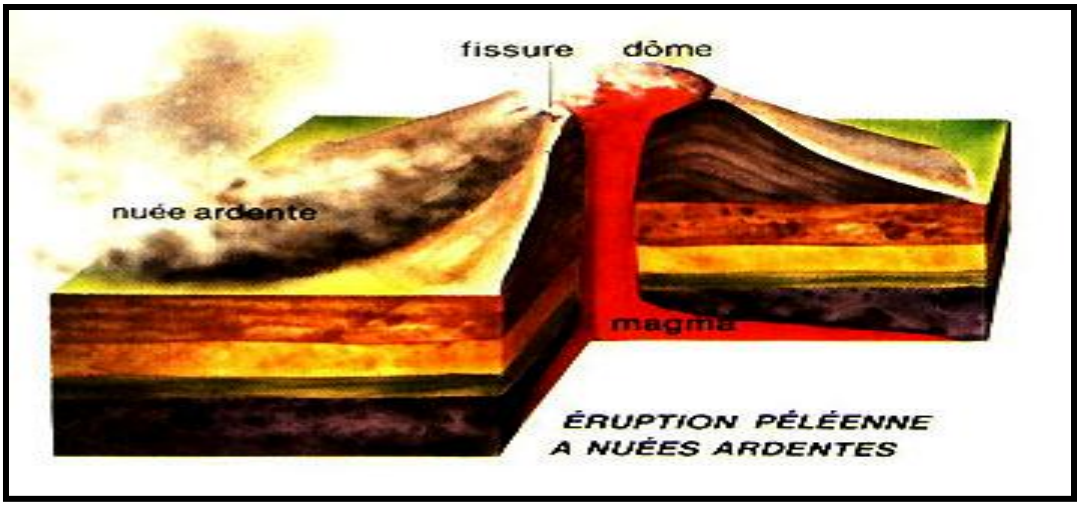


Figure 84: Peeling eruption with glowing clouds.

- According to their activity:

A volcano is said to be active when its last eruption was a few decades ago at most, dormant when it has not erupted for several hundred years, and extinct when its last eruption was at least 50,000 years ago and it is subject to erosion.

2.6.7. Geographical distribution of volcanoes:

There are over 1,000 active volcanoes in the world today. These volcanoes are not randomly distributed across the globe.

Their main domain is the oceans and oceanic islands, and they are particularly abundant in the Pacific (1,000 volcanoes). Volcanoes are distributed as follows:

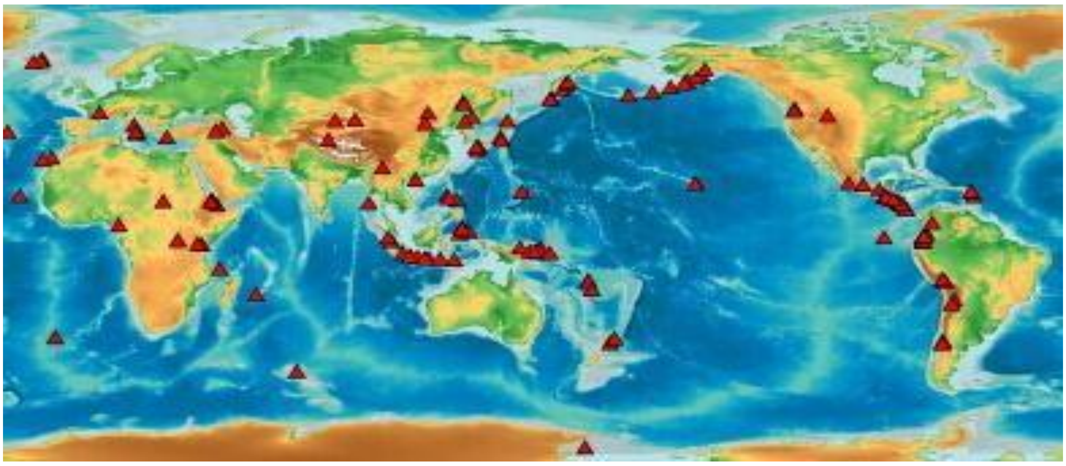


Figure 85: Geographical distribution of volcanoes

2.**6.7.1. The Pacific "belt of fire»:**

More than half of all volcanoes (around 62%) are located around the Pacific Ocean. These include volcanoes in Japan, the Philippines, Indonesia, the Andes Cordillera, the Rocky Mountains, etc.

2/3 of the world's volcanoes are grouped around the Pacific Ocean, distributed along the coasts and islands of the Pacific (Hawaii, Kuril Islands, Japan, and Philippines). This distribution of volcanoes coincides perfectly with that of earthquakes in the same area, proving the relationship between volcanism, earthquakes and plate tectonics.

2.6.7.2. The Mesogean zone: (Mediterranean)

Corresponds to young mountain regions (Mediterranean, Caucasus, Asian mountains e.g. Etna, Vesuvius, Lipari Islands, Ararat).

2.6.7.3. The Atlantic zone:

There are numerous volcanoes in Iceland, the Azores, Cape Verde, the Canaries and a few underwater volcanoes in the equatorial region.

2.6.7.4. The intercontinental zone:

These are volcanoes located on Africa's eastern divide, marked by large lakes (Kilimanjaro, Africa's highest peak, 6010 m). Finally, some recent volcanic massifs are located within the continents themselves, e.g. the Hoggar and eastern Siberia.

2.6.8. Relationship between volcanoes, crustal deformation and earthquakes:

Volcanoes are also located on fractures in the earth's crust, so how can volcanoes, crustal deformation and earthquakes all affect the same regions? When a zone breaks up, the earth shakes through the fractures in the crust, and lava can rise and erupt. Volcanoes and earthquakes are both linked to the deformation of the globe, and today's earthquakes are convincing proof that our planet has not finished deforming.

2.6.9. Protection against volcanic hazards:

Volcanic eruptions can be catastrophic, devastating entire regions. The slopes of volcanoes attract people because they are ideal for farming (very fertile soils). The energy released during an eruption cannot be controlled. Prevention is therefore essential, by monitoring dangerous volcanoes and organizing evacuations when necessary.

Eruptions are fairly predictable, and most volcanoes are well known for their dangerous eruptive mode.

Many signs that magma is rising in the vent can be detected by measuring devices: seismographs, inclinometers and laser distance meters measure variations in distance between two points, a further sign that magma is rising.

Finally, there are the warning signs of an eruption: gas emissions, ash and mini-explosions.

2.6.10. The benefits of volcanoes:

- Volcanoes are a source of destruction, but also of fertility: - volcanic ash, which contains potassium, phosphorus and calcium, is highly nutritious (fertilizer for agriculture).

- Precious stones sometimes emerge: once cooled, magma conceals rubies, gold, garnets, diamonds, etc.).

- Sulfur can also be found, which is now used to make rubber stronger.

CHAPTER 3: Tectonics:

3.1 Concept of tectonics (soft and brittle)

3.1.1 Introduction:

Tectonics is the discipline devoted to the study of the structures acquired by rocks after their formation. It is therefore the science of the deformations of the Earth's crust, and is also known as Structural Geology.

Depending on their intensity and the nature of the rocks, tectonic forces (responsible for modifying the original layout of the layers) can produce folds or breaks, known as faults.

3.1.2. Geometric marking:

For a given layer, we define the direction, which is given by the intersection of the stratification plane of the layer with a horizontal plane, and the dip, which is expressed by the maximum angle made by the layer with the horizontal.

The dip therefore lies in the plane perpendicular to the direction; it is zero for a horizontal layer, and 90° for a vertical layer.

3.1.3. Description of tectonic faults:

The formation of mountain ranges or orogenesis (oro: mountain, relief) is the result of horizontal and vertical movements of the crust. The stresses to which the rocks are subjected result in two types of deformation:

- Some are continuous and flexible, the domain of folds,

- others are discontinuous and brittle, manifested by faults.

- There are other intermediate deformations, such as flexures and fissures, and others accompanied by subhorizontal displacement, such as thrust sheets.

3.2. Brittle deformation : Faults

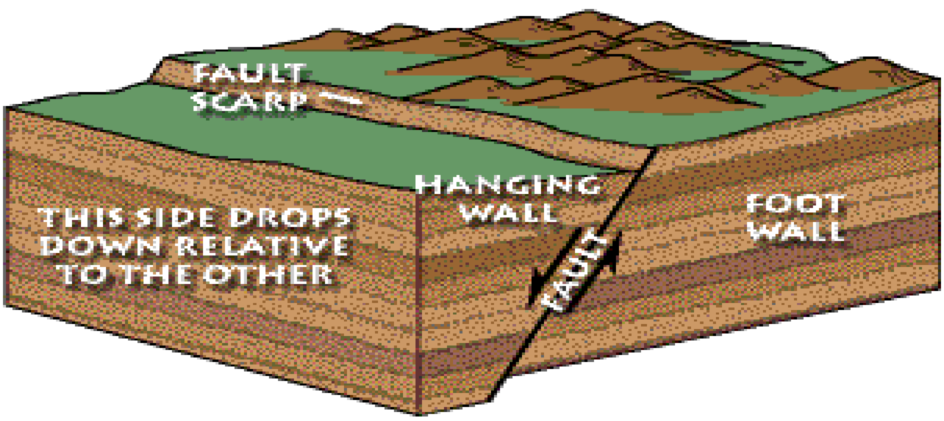


Figure 87: General appearance of breakable deformation

3.2.1. Definitions:

- A fault is a plane of rupture along which the two blocks of rock resulting from the fracture move relative to each other.

- This is due to the polishing of the rock by friction, which also leaves its mark in the form of parallel friction striations. The direction of relative movement of the blocks is known from the "little steps" of recrystallization that form during the play of the fault.

- The surface of rupture or slip is called the fault plane.

- Fault dimensions range from a few millimeters (microscopic) to hundreds of kilometers (tectonic plates).

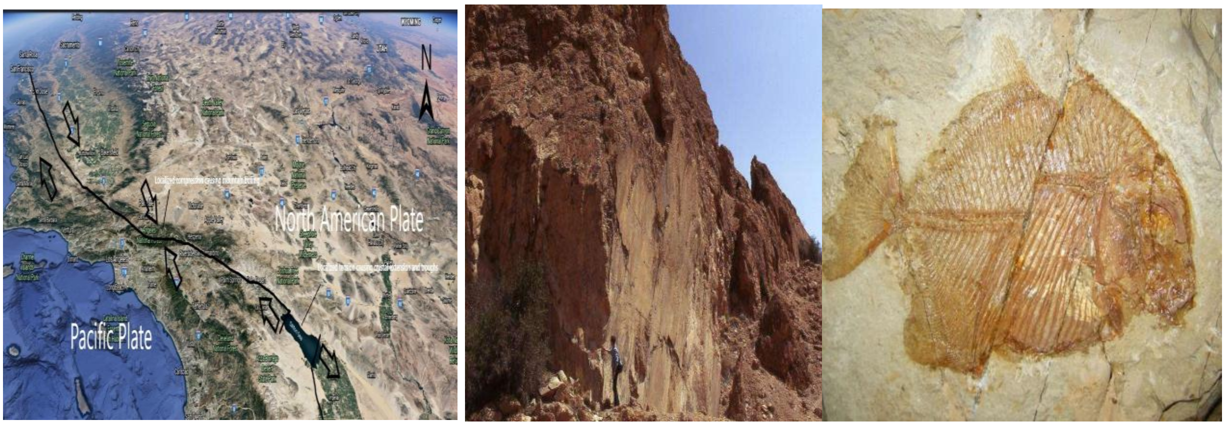


Figure 88: Different fault dimensions.

- Rock failure is due to the action of stresses. When the rock's capacity for resistance reaches its limit, it fractures.

- This is the result of "shearing", the effects of which are localized on a surface.

Note:

- Active faults are responsible for the majority of earthquakes.

- They can be distinguished as follows:

- Diaclases, which are breaks with no visible displacement.

- Flexures are abrupt changes in dip along a given surface, but without fracture.

- Depending on the orientation of the stresses, the resulting rock fractures reveal three types of fracture:

Normal fault,

Reverse fault

Striking fault

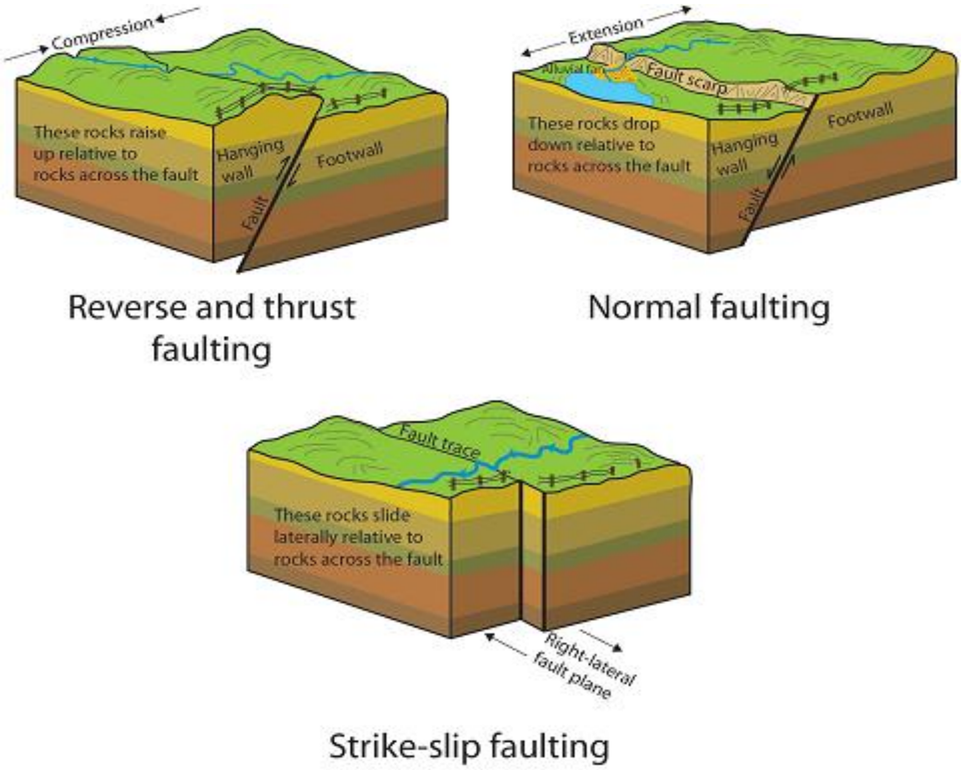


Figure 89: Three types of fault (Wikipedia).

3.2.2. Fault characteristics:

- Fault plane: surface along which displacement has taken place. It is also known as the fault mirror, which undergoes mechanical polishing, sometimes striated, depending on the direction of relative movement.

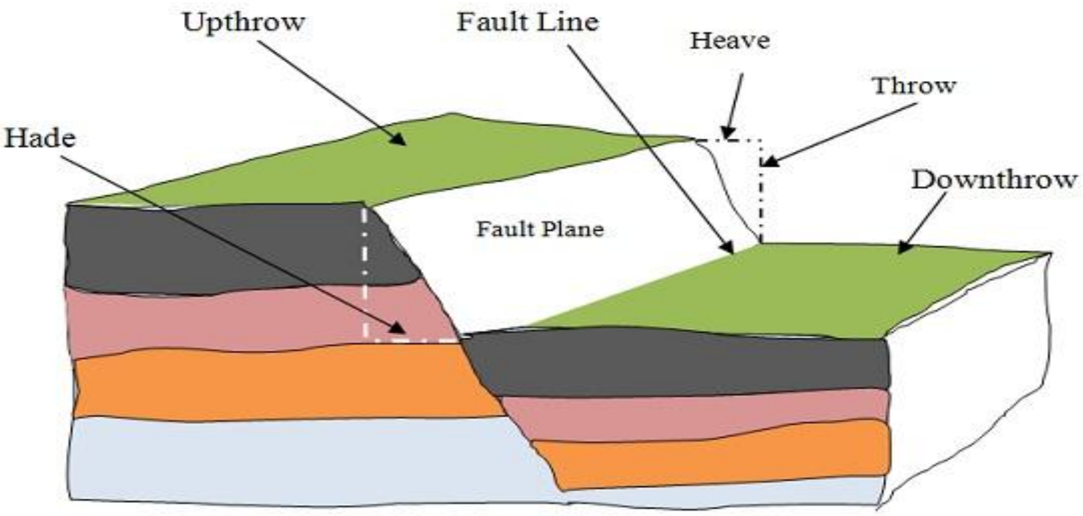


Figure 90: Fault structure.

It corresponds to an anomalous contact plane, which is represented by a thick line on a geological map. This plane is defined by its direction and dip, which are measured with a compass.

- Fault top: compartment above the fault plane.

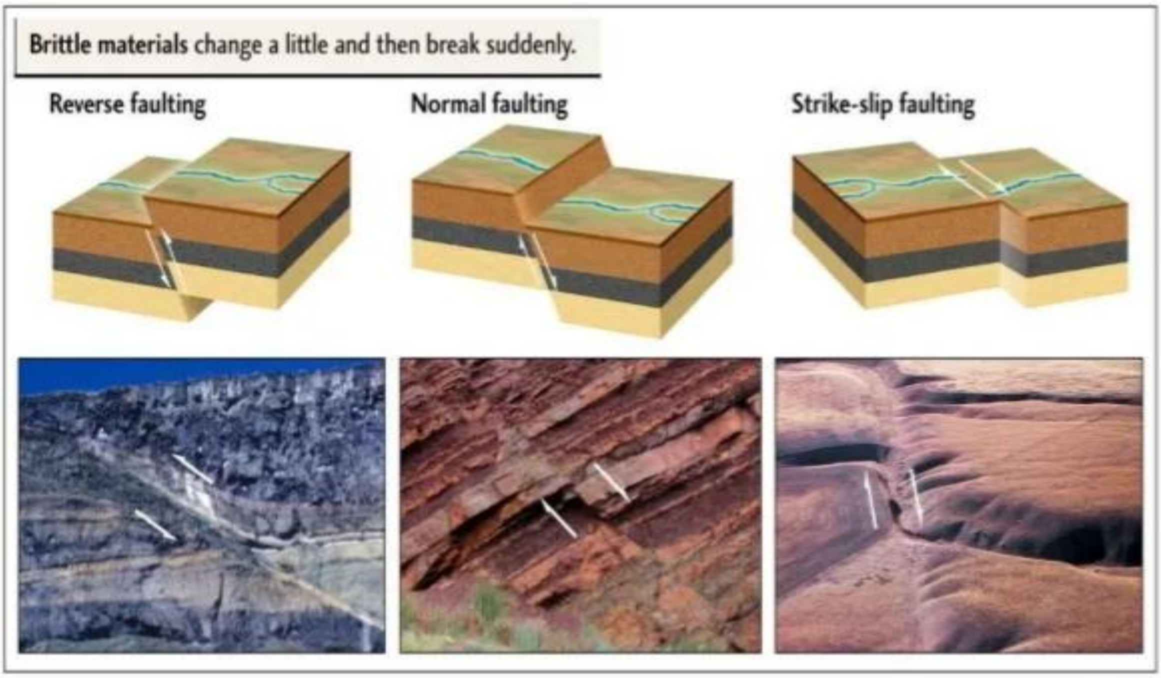


Figure 91: Photo of a fault

- Fault wall: compartment below the fault plane.

- Rejection: The fault rejection measures the offset of the blocks in relation to each other. It is the distance separating two points on either side of the fault plane that were previously in contact.

Rejection is the relative displacement of a given reference layer in the vertical or horizontal direction.

- Dip: the angle between the fault plane and the horizontal.

- The lips of a fault: represent the extremities of each of the two blocks separated by the fault:

3.2.3. Different types of fault:

Depending on the type of relative movement, three types of fault are defined: from

Normal fault

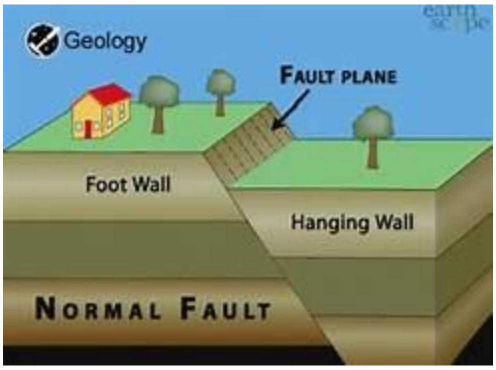
Reverse fault

Stripping fault (sliding fault)

3.2.3.1. Normal (or extensional) faults:

A normal fault accompanies an extension; the compartment above the fault ("roof") descends relative to the compartment below the fault ("wall"). The fault plane is inclined towards the lowered compartment.

A set of normal faults can form structures called horsts and grabens.



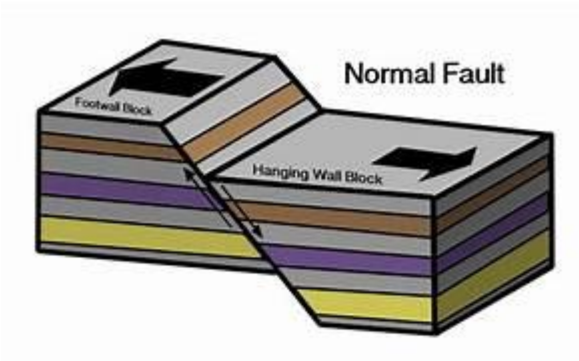
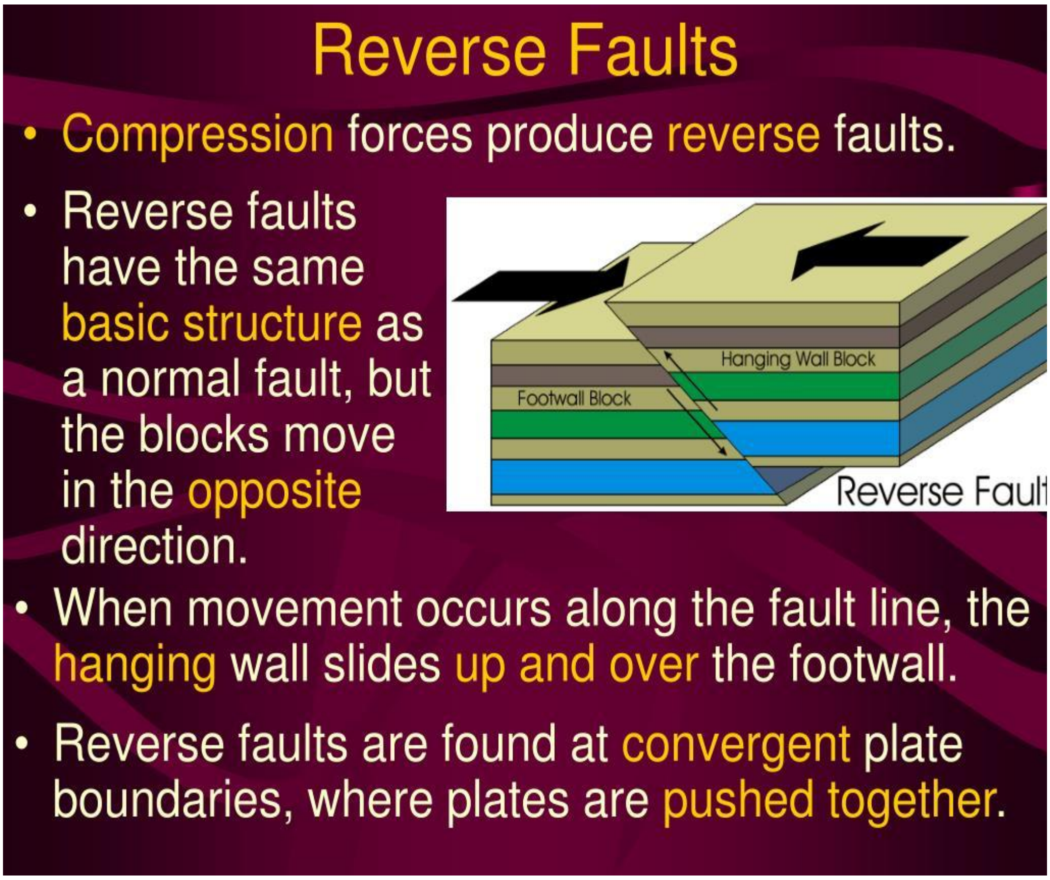


Figure 92: Normal fault

3.2.3.2. Reverse faults:

A reverse fault, or thrust fault, accompanies compression; the compartment above the fault ("roof") rises relative to the compartment below the fault ("wall"). The fault plane is then inclined towards the raised compartment and appears to dip below.



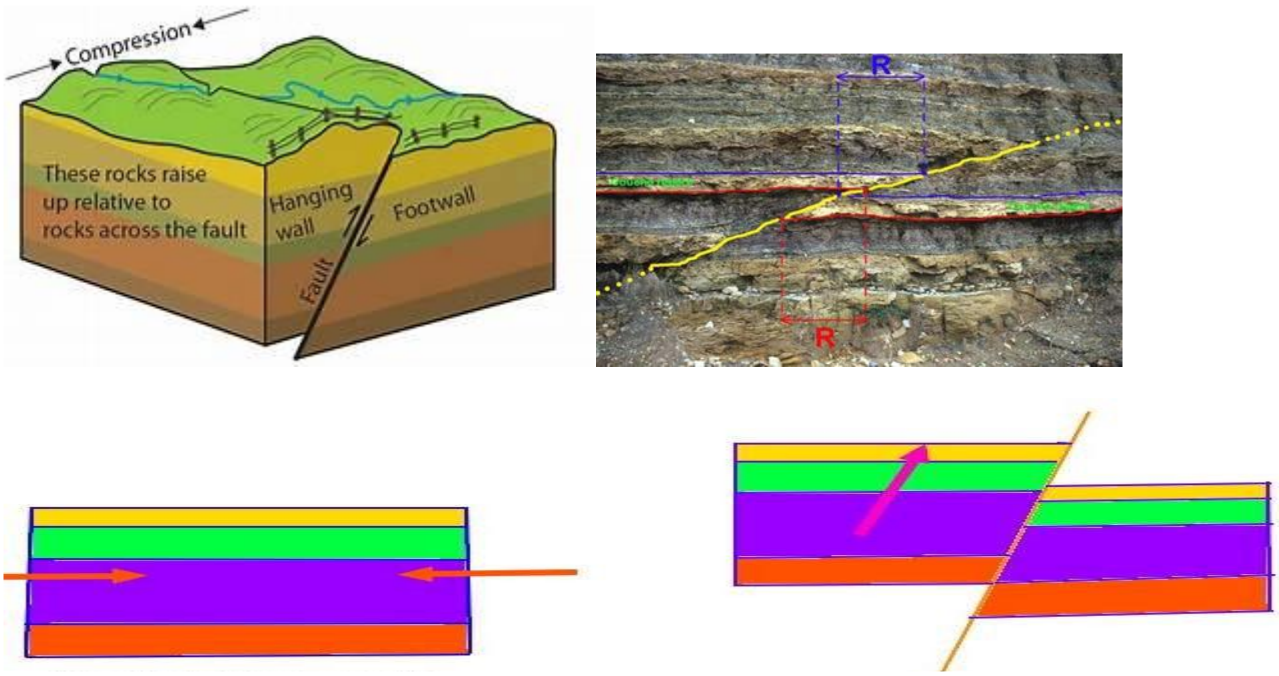


Figure 93: Reverse fault

One of the compartments will rise relative to the other, reducing the space created by compression.

3.2.3.3. Decrochement fault:

An offset accompanies an essentially horizontal sliding movement. They can be dextral or senestial, depending on whether the compartment opposite the observer is moving to the right or left (respectively).

The fracture surfaces of strike-slip faults are almost vertical and invisible.

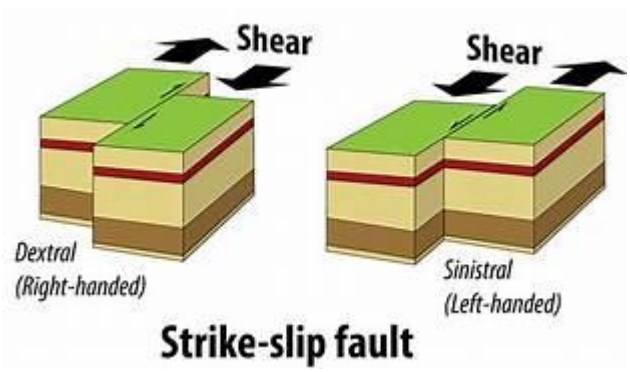


Figure 94: Strike - slip fault:

Other types of fault:

- The fault is vertical: if the horizontal rejection is zero.

- Conformal faults: their plane is inclined in the direction of the dip of the layers.

- Contrary (non-conforming) faults: if their plane is inclined in the opposite direction to the dip of the layers.

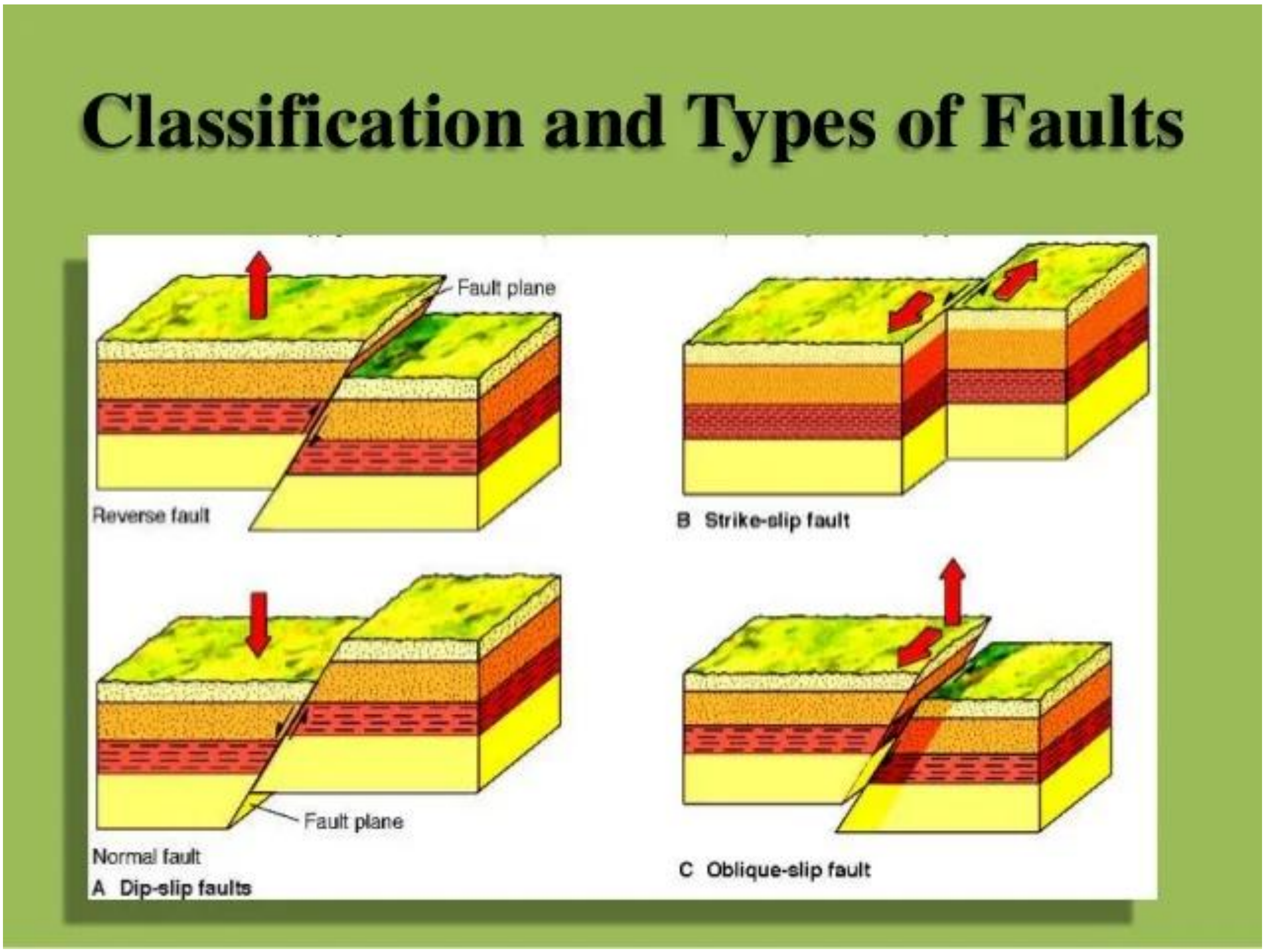


Figure 95: Different types of fault

3.2.4. Fault grouping:

Faults can be grouped together to form a fault field. The raised compartment between two lowered compartments is called a Horst or Mole, and the lowered compartment between two moles is called a Graben.

A graben is a collapse trough bounded by normal faults.

The term rift is used for grabens.

A horst comprises a series of fault-bounded, elevated compartments.

3.2.4.1. Graben structure:

Graben: tectonic structure formed by normal faults running in the same direction.

These faults delimit compartments that become lower and lower towards the middle of the structure.

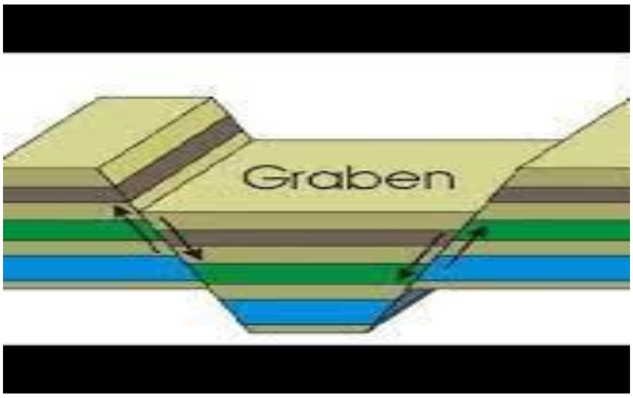


Figure 96: Graben structure

3.2.4.2. Horst structure:

Horst: tectonic structure formed by faults of the same direction.

These faults delimit compartments that become lower and lower as they move away from the middle of the structure.

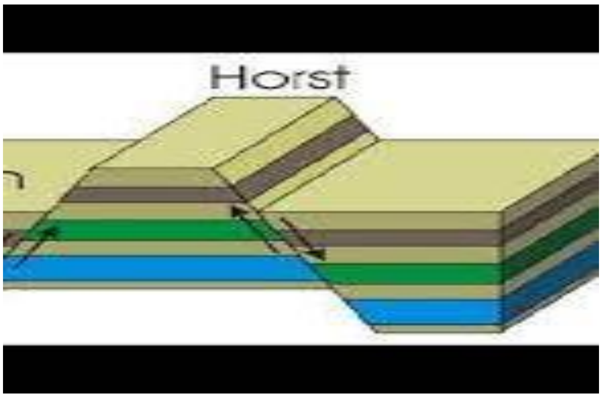


Figure 97: Horst structure

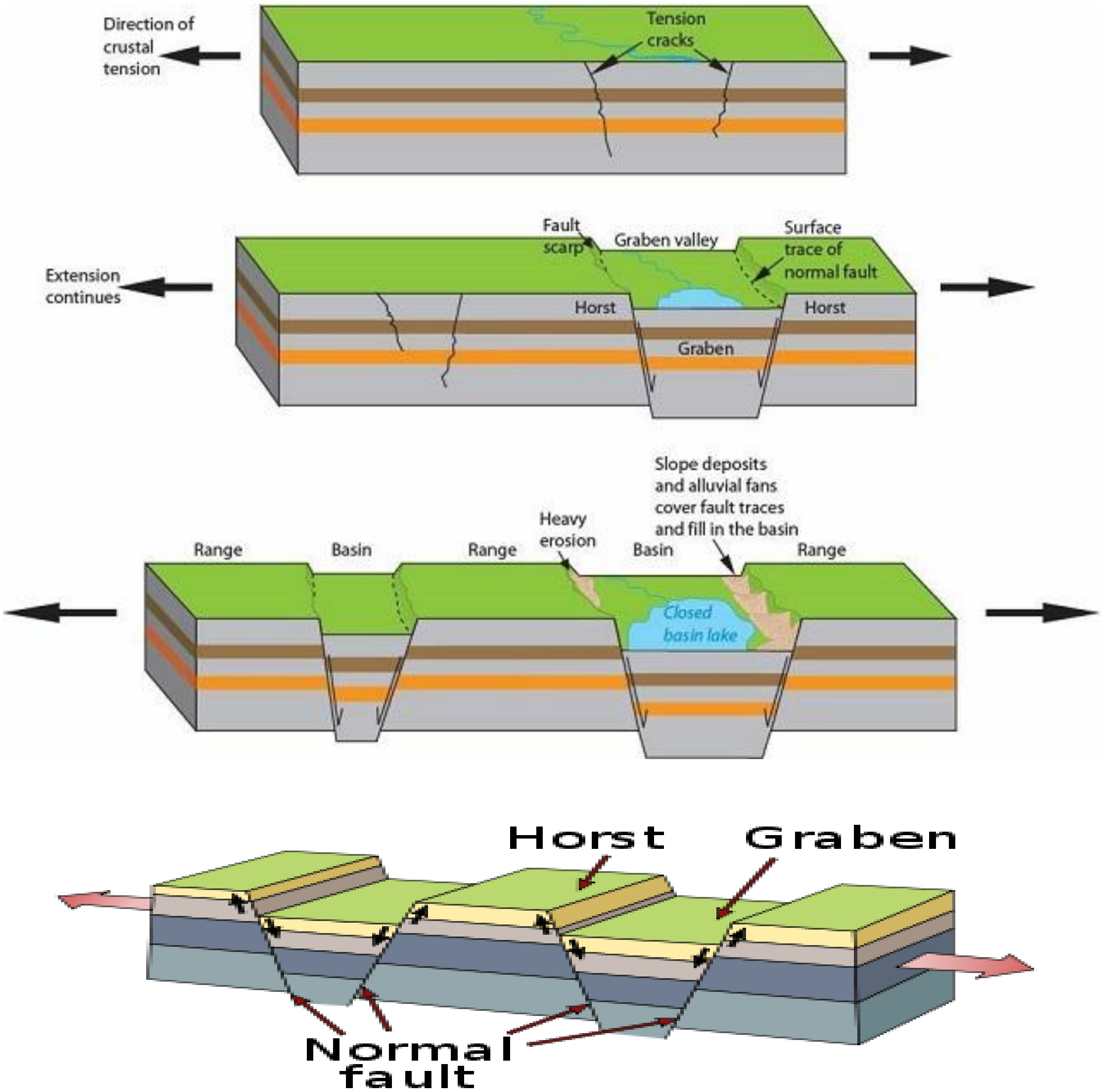


Figure 98: Diagram of a horst / graben structure (Wikipedia).

In geology, a graben (a term of German origin meaning "ditch") is a tectonic collapse ditch between normal faults. The compartment raised above the graben is called a "horst". A long graben or a series of grabens can produce a Rift Valley.

3.2.5. Relationship of faults to earthquakes and volcanoes:

The relationship between earthquakes and volcanoes is obvious: the internal fault fields of orogenic belts are the most seismic.

Volcanoes are closely linked to extensional fault fields in the crust of fissures, which bring the ground surface into contact with the superficial part of the mantle.

3.3. Soft tectonics: folds

3.3.1. Definitions:

- Folds are more or less accentuated undulations in the layers. They form in the event of ductile or plastic deformation, and are referred to as soft tectonics.

- Folds are continuous deformations formed by +/- tight undulations. They are the manifestation of brittle rock behavior, and the simplest means of absorbing horizontal compressive stress.

- A fold is a deformation of rock under the effect of stress.

- A fold is a deformation of the rock into a curvature (hump or hollow) resulting from the bending of strata (lateral tectonic compression).

- Under the effect of tectonic forces, the rock has not broken but bent. This "plastic" behavior can be seen in very rigid, usually brittle rocks.

In fact, the application of low-intensity forces over a long period of time enables the rock to be gradually modified (folded) rather than fractured.

3.3.2. Fold characteristics:

3.3.2.1. The hinge:

Is the location of the points of maximum curvature of the layer affected by the fold (right).

It is the zone of maximum curvature of the fold.

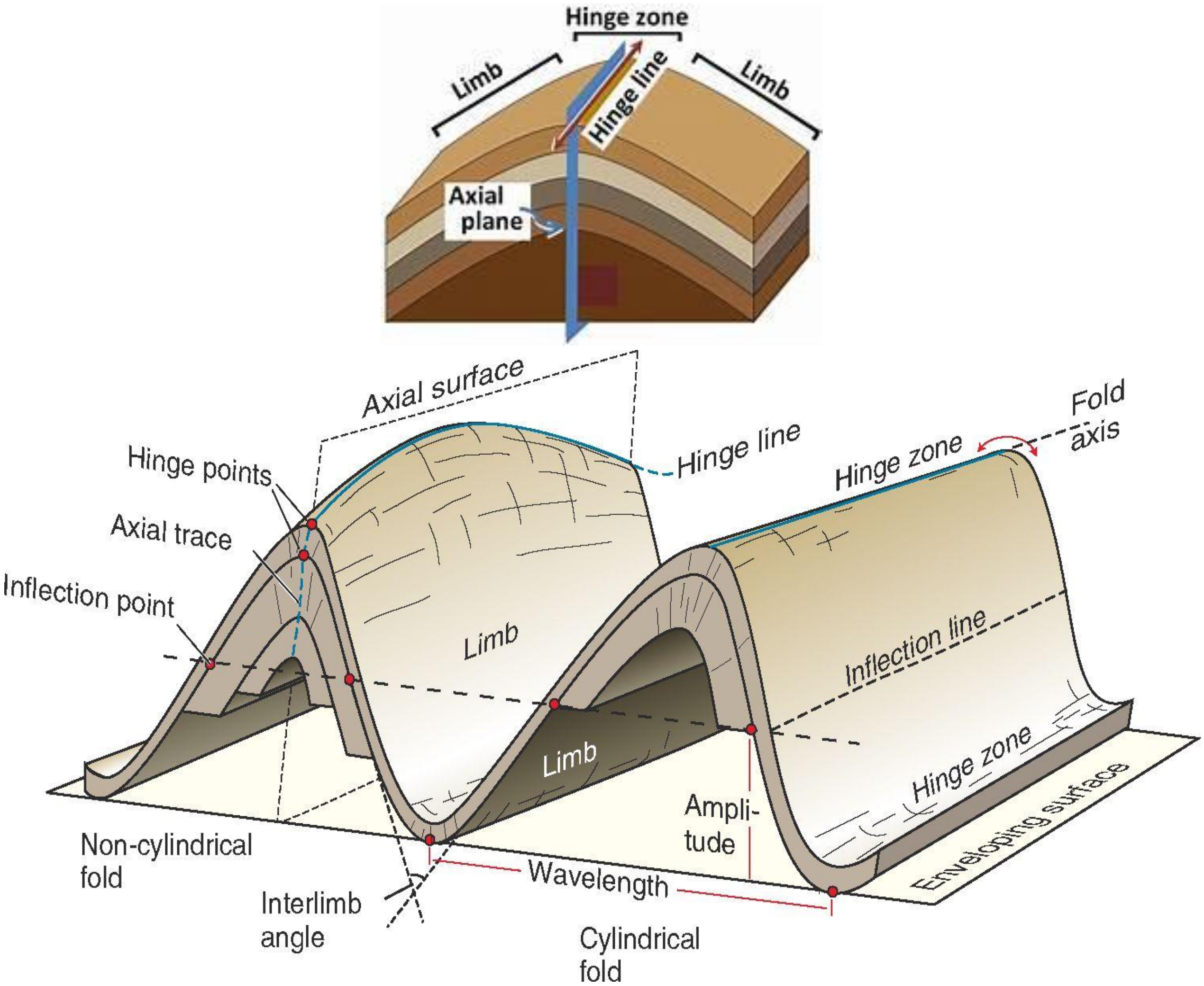


Figure 99: Main components of a fold (geocaching.com).

3.3.2.2. Flanks: are the surfaces connecting two successive hinges. These are the areas of minimum curvature,

3.3.2.3. The fold axis: is the line passing through the middle of the hinge. The direction of a fold is that of the fold axis.

3.3.2.4. The axial surface: is the flat surface passing through the hinges of all the layers affected by the fold.

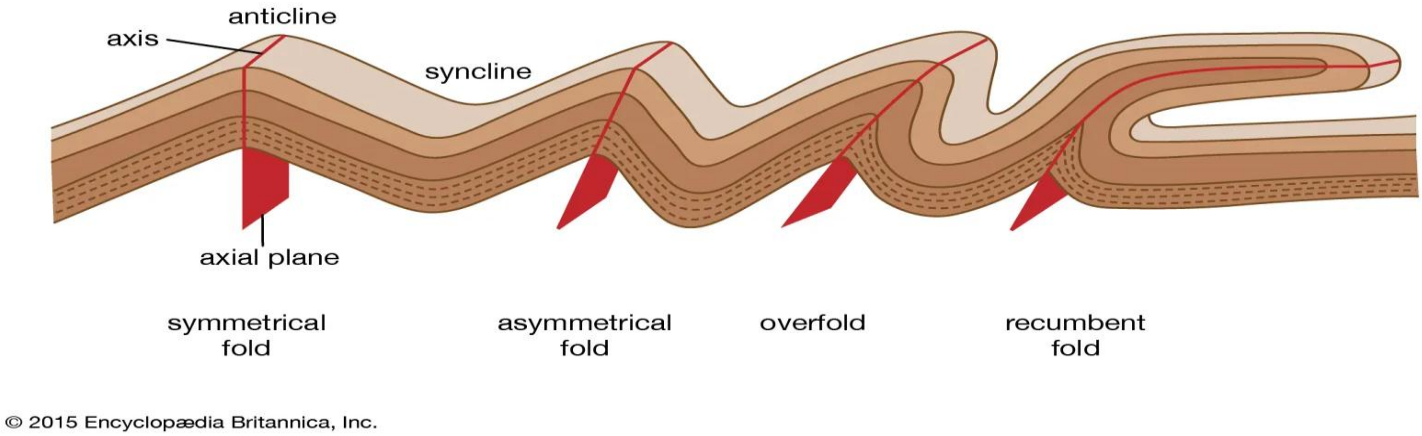
3.3.2.5. The spill of a fold: is the deviation of its axial surface from the vertical or horizontal.

3.3.2.6. The direction of a bend (or elongation): is that of the axial surface of the bend; in principle, it is perpendicular to compression.

3.3.2.7. The crest: this is the highest topographic point of the fold (passing through the summit),

3.3.3. The main types of fold:

There are different types of fold, depending on the inclination of the flanks and axial surface, shape, type of deformation, mode of formation, etc.



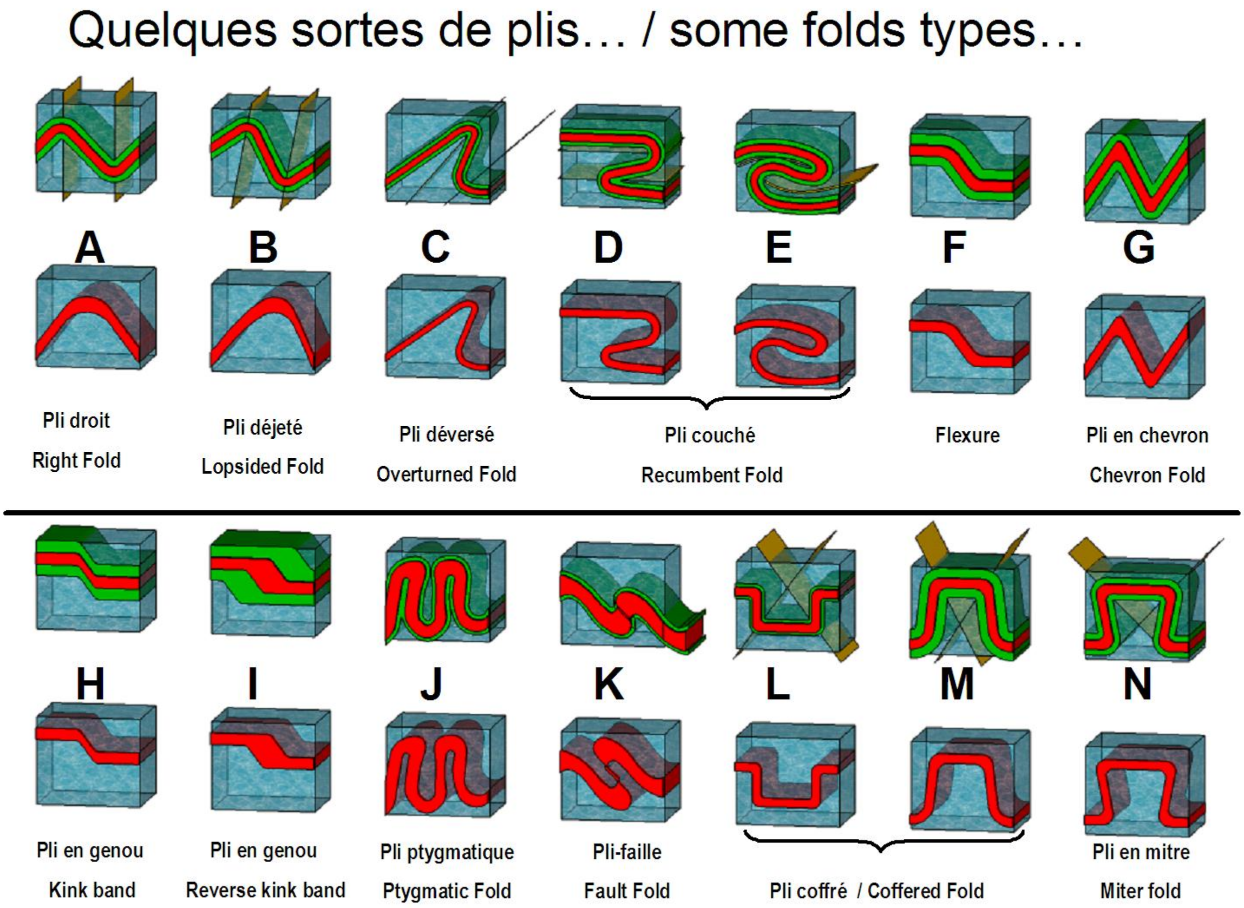


Figure 100: Fold types (larousse.fr).

3.3.3.1. According to the inclination of their flanks and their axial surface: we can distinguish:

3.3.3.1.1. Straight folds: the two flanks are equally and oppositely dipping, and the axial plane is vertical,

3.3.3.1.2. Ejected folds: one of the flanks is straightened without reaching the vertical, so that the two flanks have different dips.

3.3.3.1.3. Tilted folds: one of the flanks has risen above the vertical, the reverse flank.

3.3.3.1.4. Knee folds: one flank is above the vertical and the other flank is vertical

3.3.3.1.5. Inverted folds and recumbent folds: both flanks are approaching the horizontal.

3.3.3.2. Depending on the orientation of the concavity and the succession of layers:

We can distinguish:

3.3.3.2.1. Anticline: An anticline is a hump-shaped fold.

In an anticline, the concavity of the layers is oriented downwards (in the shape of a tunnel) and the oldest layers are found at the heart of the fold.

3.3.3.2.2. The syncline: a trough-shaped fold.

In a syncline, the concavity of the layers is oriented upwards (gutter-shaped) and the core is formed by the most recent layers.

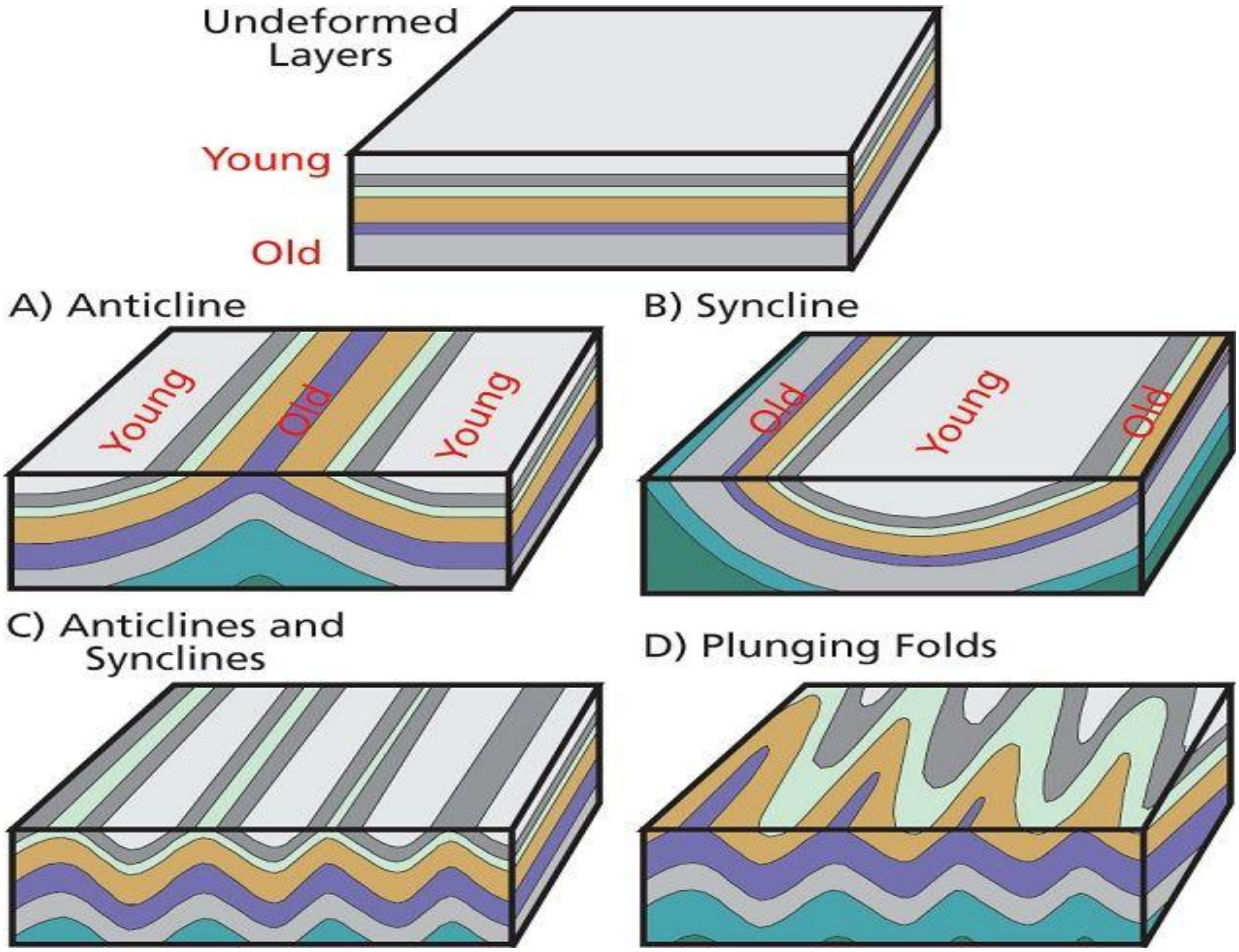


Figure 101: Syncline and anticline

3.3.3.3. Depending on the type of deformation of the thickness of the flank layers, a distinction can be made between:

3.3.3.3.1. Isopaque folds: Folds whose layers maintain a constant thickness are referred to as "isopaque folds".

3.3.3.3.2. Anisopaic folds: in contrast to isopaic folds, the flanks are stretched, laminated or fractured.

3.3.3.3.2.1. Fault folds: are the result of intense deformation of the fold, with rupture and faulting. When the geological layers on either side of the rolling zone are separated (with rejection).

3.3.3.3.2.2. Stretched fold: when the thickness of the layers on one flank decreases.

3.3.3.3.2.3. Laminated fold: when the thickness of the layers on a sidewall becomes zero.

3.3.3.3.2.4. Overlapping fold: superimposition of old layers on recent layers with horizontal rejection at the curvature.

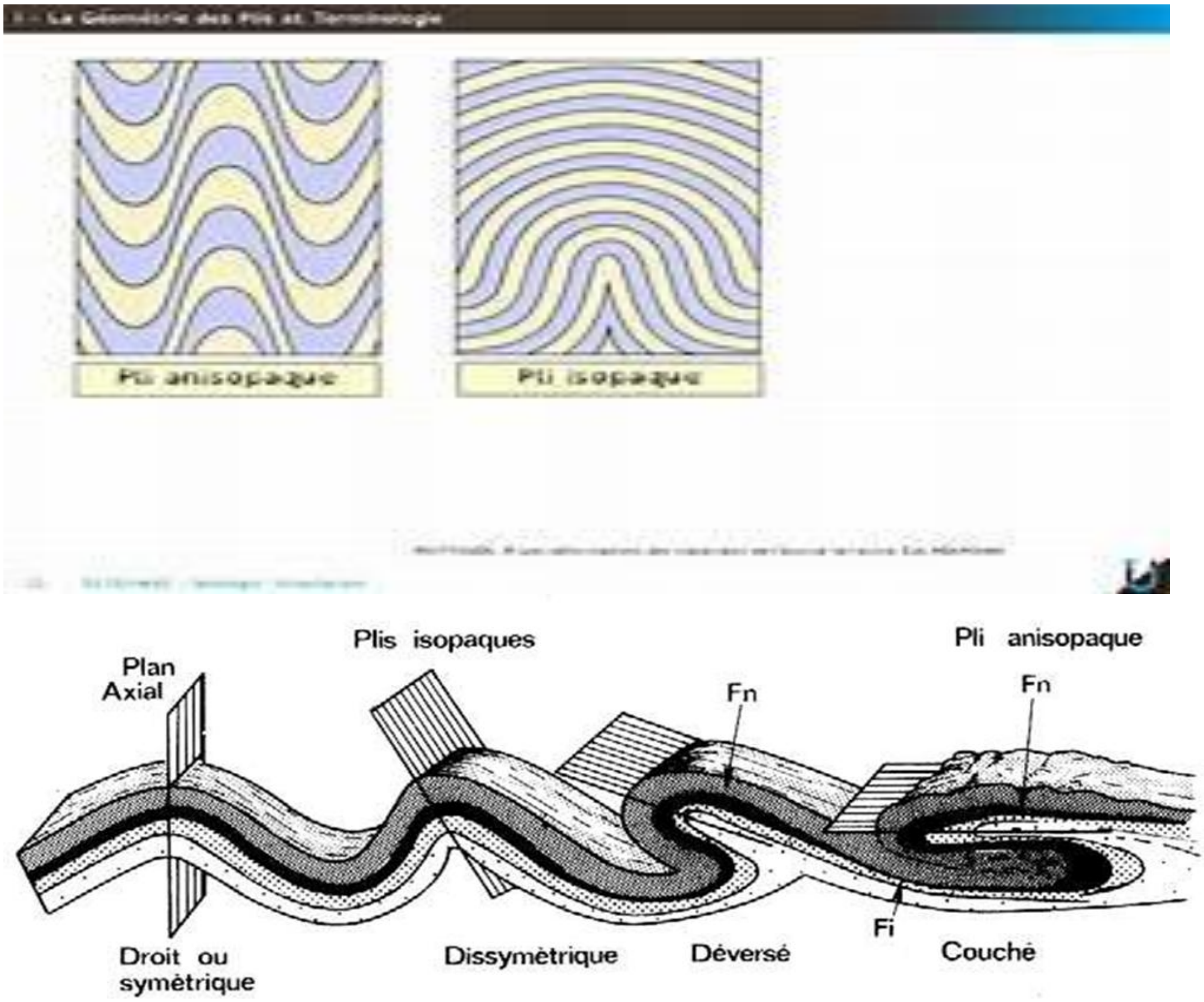


Figure 102: Isopaque and anisopaque folds

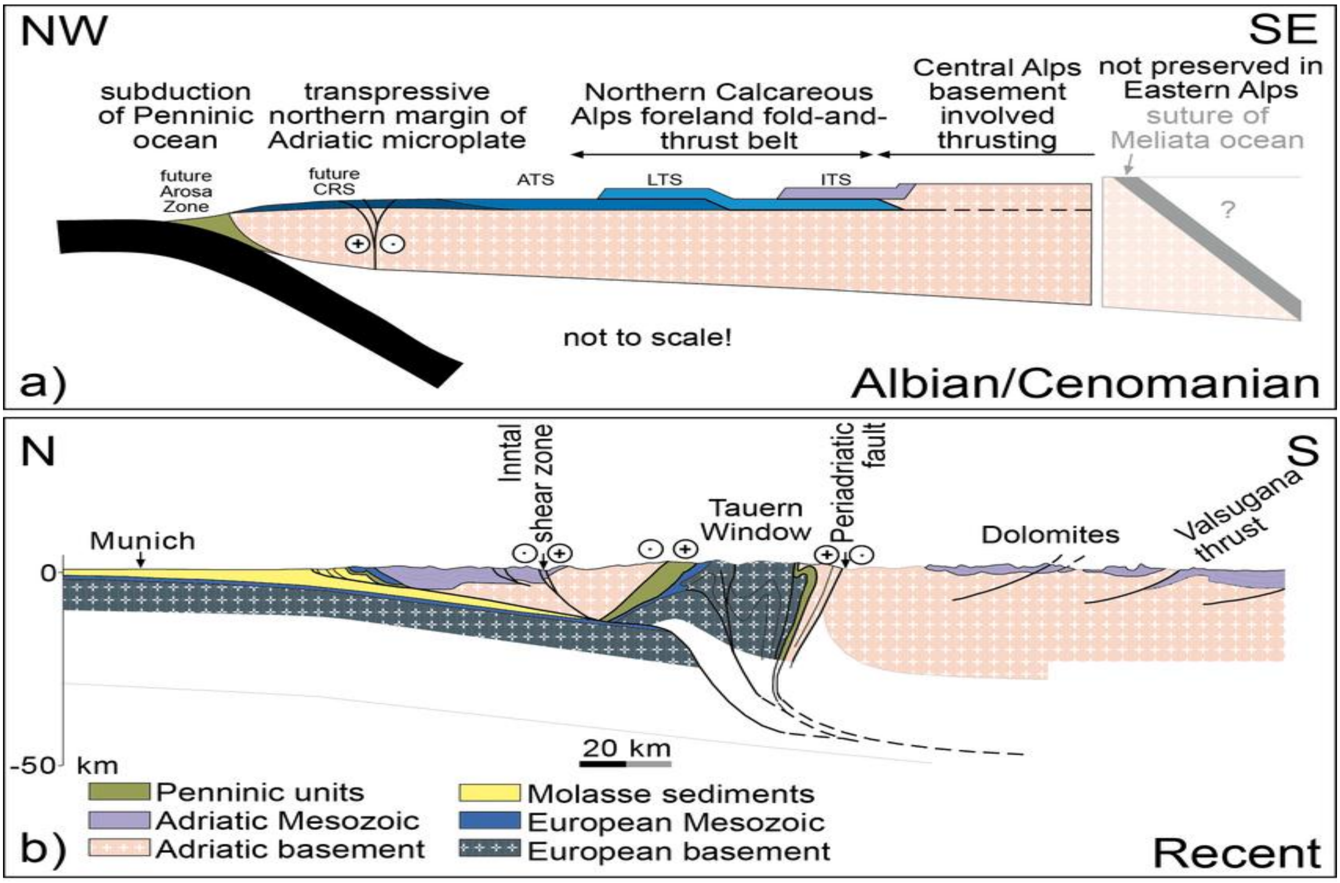


Figure 103: Evolution of soft deformation towards a thrust sheet.

3.3.4. Characteristic relief :

From a morphological point of view, folds can give rise in the landscape to a succession of shapes characteristic of the relief of folded zones: mountain, valley, cluse, combe...

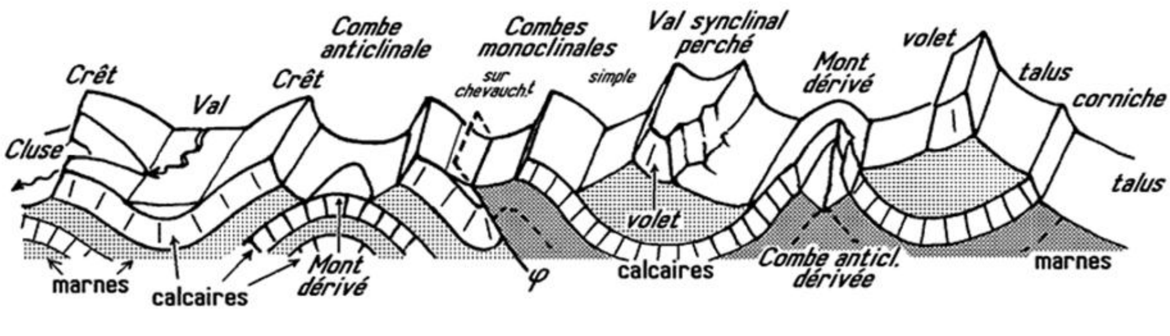


Figure 104: Names used to describe the relief of folded chains (geol-alp.com).

3.3.5. Fold grouping:

Folds are rarely isolated and group together to form anticlinoriums (set of folds that outline an anticline on a larger scale, the synclinorium set of folds that outline a syncline).

Others Types of Folds

. Layered rocks folded into arches are called anticlines whereas troughs are referred to as synclines.

The two sides of a fold are referred to as limbs. The two limbs come together to form an imaginary line called the fold axis. The direction in which the fold axis points indicates the strike of the fold.

A dome is an anticlinal structure where the flanking beds encircle a central point and dip radially away from it.

. A basin is a synclinal structure appearing as a bowl-shaped depression where rock layers dip radially towards a central point.

The eroded surface of a fold appears as a series of bands of different rocks. Rock bands appearing on one side of the fold axis are duplicated on the other side. For basins and domes, strata exposed at the surface form concentric circles around a central point.

For anticlines, the surface rock exposures become progressively older towards the fold axis.

Synclines show the opposite trend. Rock exposures become progressively younger towards the axis of synclines.

. Rock layers dip away from the fold axis in anticlines, but dip toward the fold axis in synclines.

- Plunging Folds

.A fold can be divided by an imaginary surface called the axial plane. The axial plane divides a fold as symmetrically as possible. The line formed by the intersection of the axial plane with the beds defines the fold axis.

.The axis of a fold can be horizontal. If the axis is not horizontal, the structure is said to be a plunging fold.

. The plunge of a fold can be described as the angle a fold axis makes with a horizontal surface. The axis of a plunging fold can therefore be described as having a certain strike (e.g. N 10o W) and plunge (e.g. 20o NW). Unlike dipping beds, the plunge of a fold axis is in the same direction as the strike of the axial plane.

Folds can be classified by their geometry with respect to their axial plane.

(a) Symmetrical Folds: Axial plane is vertical an beds dip at approximately the same angle, but in opposite directions, on either side of the plane.

(b) Asymmetrical Folds: Axial planes are inclined and one limb of the fold dips more steeply than the opposite limb, but still in opposite directions.

(c) Overturned Folds: Axial plane is inclined and both limbs of the fold dip in the same direction.

In general, the greater asymmetry in the fold, the more intense the deformation.

When folds plunge into the earth, they essentially disappear from the surface. The curved strata comprising a plunging fold form a horseshoe or hairpin pattern on the surface where they plunge into the earth.

For anticlines, the horseshoe or hairpin shape closes in the direction that the anticline plunges.

For synclines, the horseshoe or hairpin-shape opens in the direction that the syncline plunges.

In the field, a geologist can reconstruct the geometry of folds by:

(a) Measuring the strike and dip of various strata exposed in outcrops

(b) Noting which direction the beds become younger

(c) Measuring any structural deformations within the rocks.

(d) Once this information is obtained, the geologist can employ the principles of geometry and trigonometry to determine the orientation of the axial plane and also whether the fold plunges. If the fold plunges, then the plunge of the fold axis can also be determined using geometry, trigonometry and field measurements.

3.4. Overlap and nappes:

3.4.1. Introduction:

Fault and fold deformation can occur in mountain ranges:

Rocks previously folded at depth are uplifted by complex tectonic phenomena. These folded rocks can then be faulted: this is known as fold-faulting.

The next stage is the creation of an overlap: as compression continues, the displacement of one block on top of the other becomes greater.

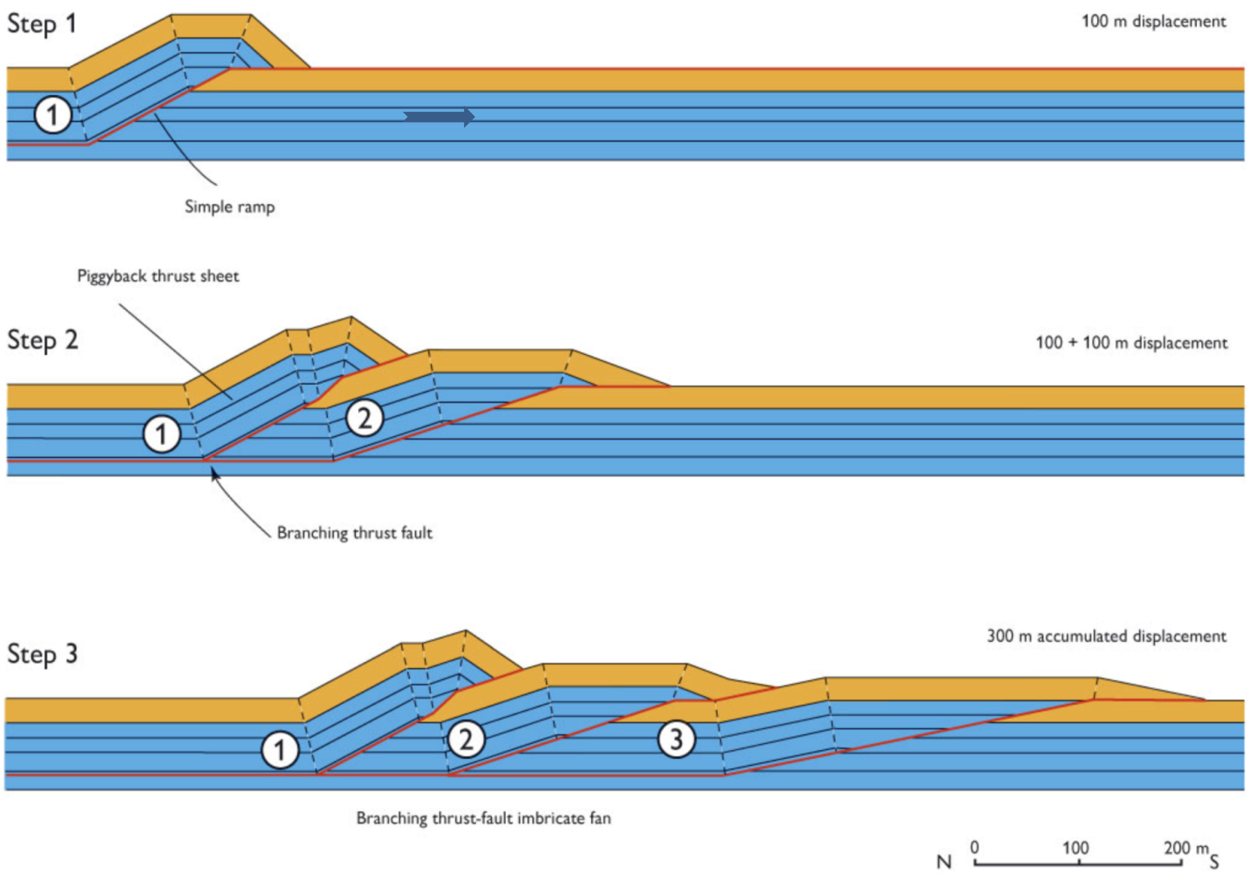


Figure 105: Evolution of a reverse fault to a thrust fault

3.4.2. Definition:

A thrust is a tectonic movement that causes one series of terrains to overlie another by means of an anomalous reverse fault contact.

In geology, a nappe or thrust sheet is a large sheetlike body of rock that has been moved more than 2 km (1.2 mi) or 5 km (3.1 mi) above a thrust fault from its original position. Nappes form in compressional tectonic settings like continental collision zones or on the overriding plate in active subduction zones. Nappes form when a mass of rock is forced (or "thrust") over another rock mass, typically on a low angle fault plane. The resulting structure may include large-scale recumbent folds, shearing along the fault plane, imbricate thrust stacks, fensters and klippes.

The term stems from the French word for tablecloth in allusion to a rumpled tablecloth being pushed across a table.

Overthrusts are tectonic faults that cause geological units (of different ages) to overlap abnormally.

The lower part deforms the upper part as it moves (new folding), while the upper part overlies younger terrain.

Note:

When movements take place over long distances (several kilometers) and involve large areas, we speak of a thrust sheet.

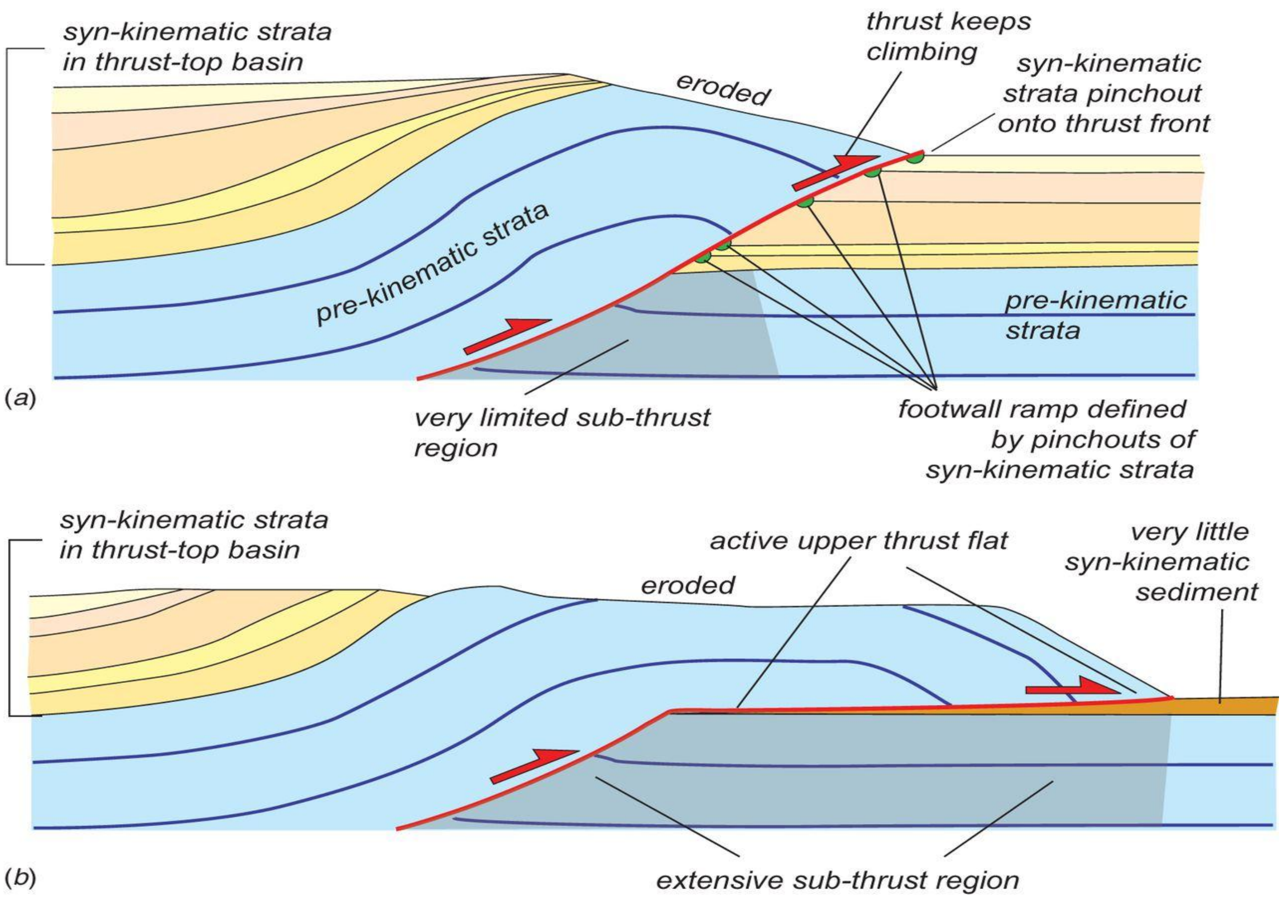


Figure 106: Stages in the formation of a thrust sheet

3.4.3. Characteristics:

* Overriding" and "thrusting" are tectonic concepts that correspond to two facts, the second of which explains the first.

Explanation: What we observe:

The first fact is the vertical superposition of two sets of terrains whose succession is not normal.

* This superposition is referred to as "abnormal contact" and "overlap".

* The second fact is the horizontal movement of one of the two series, explaining the superposition observed, and hence the abnormal contact and overlap;

This corresponds to the very notion of "overlapping" or "thrusting".

We say that:

The upper unit is thrust: allochthonous; this is the thrust sheet;

the lower unit is considered autochthonous: it has not moved.

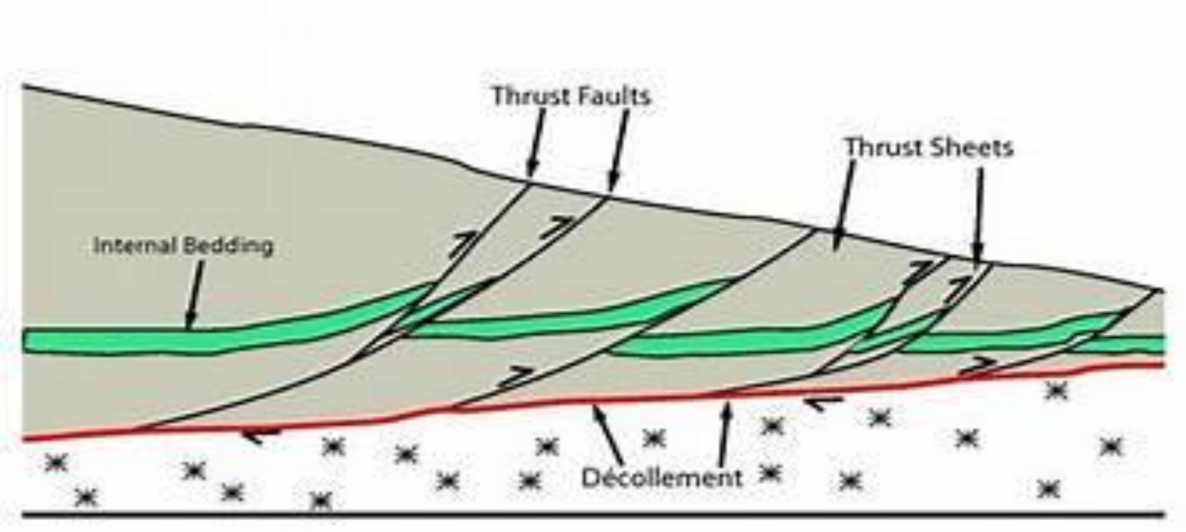


Figure 107: Units of a thrust sheet

3.4.4. Allochthonous and autochthonous units:

The nappes are a collection of allochthonous, uprooted terrains, which rest on an autochthonous bedrock via an anomalous contact:

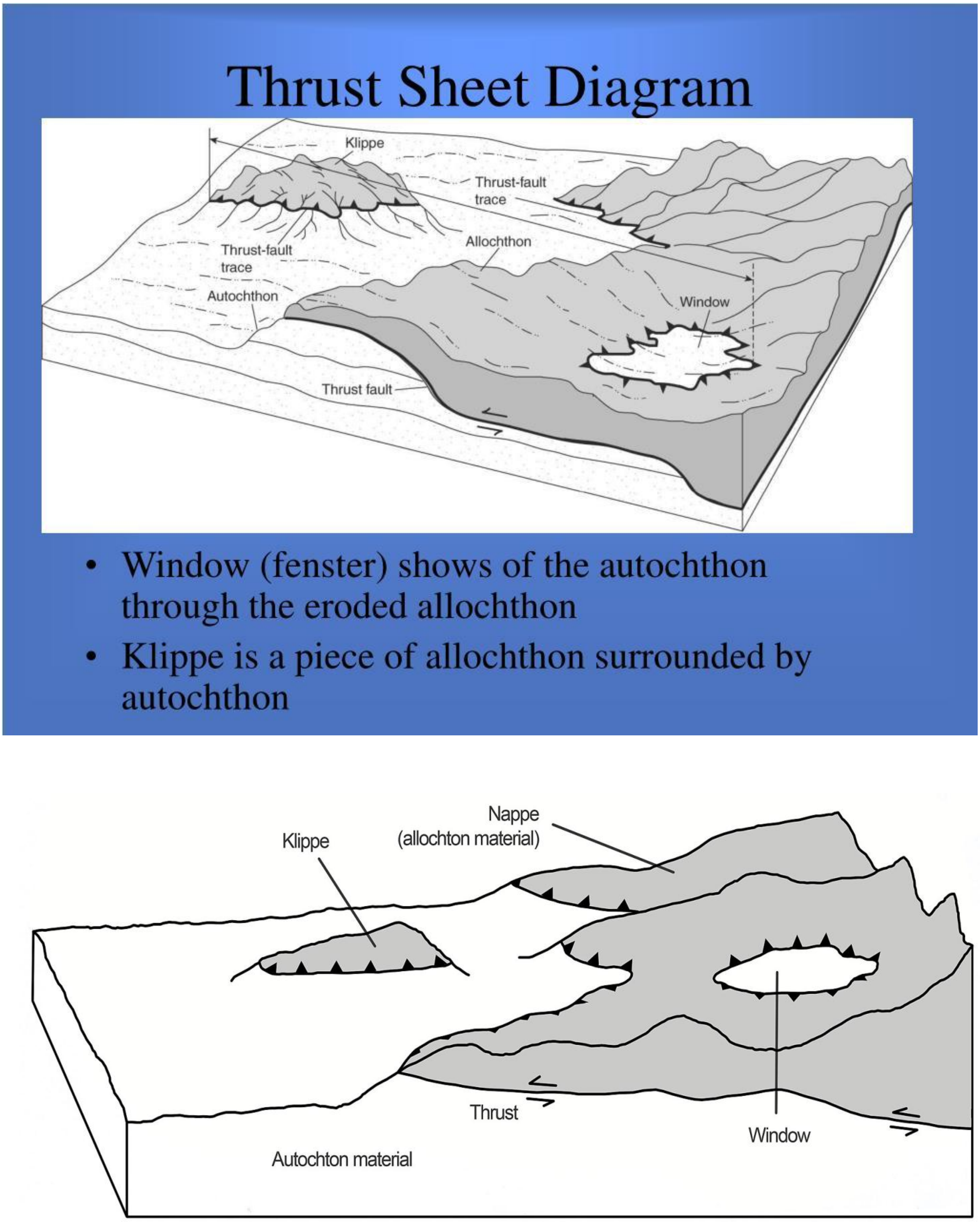


Figure 108: General structure of a thrust sheet

- Klippes: This is the result of clearing the erosion of the front part, the klippe is part of the overlapping unit.

- Windows: this is the result of clearing the erosion of part of the overlapping unit, giving a window onto the overlapped unit.

3.4.5. Different types of nappes :

*** Depending on the nature of the dominant rocks,** there are essentially 3 families:

- Cover nappes:

These are formed solely of sedimentary material detached from its original bedrock.

The rocks may have undergone varying degrees of metamorphism and may be schistose.

- Basement nappes:

- These are formed of metamorphic rocks and may overlie other basement units or sedimentary units.

- Ophiolitic nappes:

- These are composed of oceanic lithosphere (crust and mantle) and associated oceanic sediments.

- Their presence in chains (orogens) materializes the suture of an ancient oceanic domain.

* Depending on the driving force behind nappe displacement:

In addition to compressional forces, which cause thrusting and thrusting?

Gravity also plays a major role in the movement of sediments. This is referred to as a "gravity" sheet.

Note: this phenomenon occurs outside any tectonic context.

Ex. Slip of the sedimentary cover of continental margins.

There are two types of nappe:

- tectonic nappes.

- Gravitational nappes.

3.5. The formation of mountain ranges "orogenesis":

3.5.1 Introduction and definitions:

Mountain formation refers to the geological processes that underlie the formation of mountains. These processes are associated with large-scale movements of the Earth's crust (tectonic plates). Folding, faulting, volcanic activity, igneous intrusion and metamorphism can all be parts of the orogenic process of mountain building. The formation of mountains is not necessarily related to the geological structures found on it.

The understanding of specific landscape features in terms of the underlying tectonic processes is called tectonic geomorphology, and the study of geologically young or ongoing processes is called neotectonics.

See also: List of mountain types

There are five main types of mountains: volcanic, fold, plateau, fault-block and dome. A more detailed classification useful on a local scale predates plate tectonics and adds to these categories.

A mountain chain, or more precisely a folded chain, is a structurally complicated relief whose materials have been subjected to lateral pressure, giving rise to folds of varying complexity.

Chains correspond to compressed and shortened portions of crust, trapped between two plates that are approaching each other, superimposed on a zone of weakness in the crust. This zone generally corresponds to a geosyncline.

Orogenesis or tectogenesis, the birth of a folded chain, e.g. a chain like the Alps may have been folded before being uplifted, or at the same time.

* Orogenesis is the set of phenomena leading to the formation of a mountain chain.

Orogenesis, or orogeny, characterizes the set of geodynamic processes that depend on plate tectonics and lead to the formation of a mountain system in the broadest sense of the term.

An orogen results from the collision of two continental lithospheric plates of different nature and density.

2.5.2. The formation of mountain ranges:

Any model explaining the formation of a mountain range must explain and integrate the following main characteristics (of mountain ranges):

- Sedimentary rocks are very abundant in mountain ranges, and contain fossils of marine organisms:

This implies that the sediments from which they are derived were deposited in a marine environment; furthermore, their composition shows that a large proportion of these sediments were deposited in an ocean basin. First conclusion: before ending up in a mountain range, all the sedimentary material was in an ocean.

- There are also metamorphic rocks in mountain ranges.

These metamorphic rocks occupy a well-defined portion of the mountain range. Second conclusion: metamorphic rocks result from the transformation of sedimentary and igneous rocks of the mountain range, deep in the earth's crust.

- Mountain ranges often contain shreds of oceanic crust (basalts) trapped in faults.

Third conclusion: not only were the sediments that form the mountain range deposited in a marine basin, they were also deposited on basaltic oceanic crust.

- Another important feature (common to all major mountain ranges) is that the rocks are deformed to varying degrees.

Before the theory of plate tectonics, there was a superb debate between the "horizontalists", who believed that mountain ranges were formed by the action of lateral compression forces, and the "verticalists", who of course invoked great vertical forces.

At the time, plate movement was unknown, which left plenty of room for the imagination!

The theory of plate tectonics reconciles horizontalists and verticalists by proposing a model that takes into account lateral compression and uplift of an enormous mass of material, and by identifying the engine responsible for the forces required to form a deformed mountain range.

3.5.3. The main stages in the formation of a mountain range:

3.5.3.1. Obduction case:

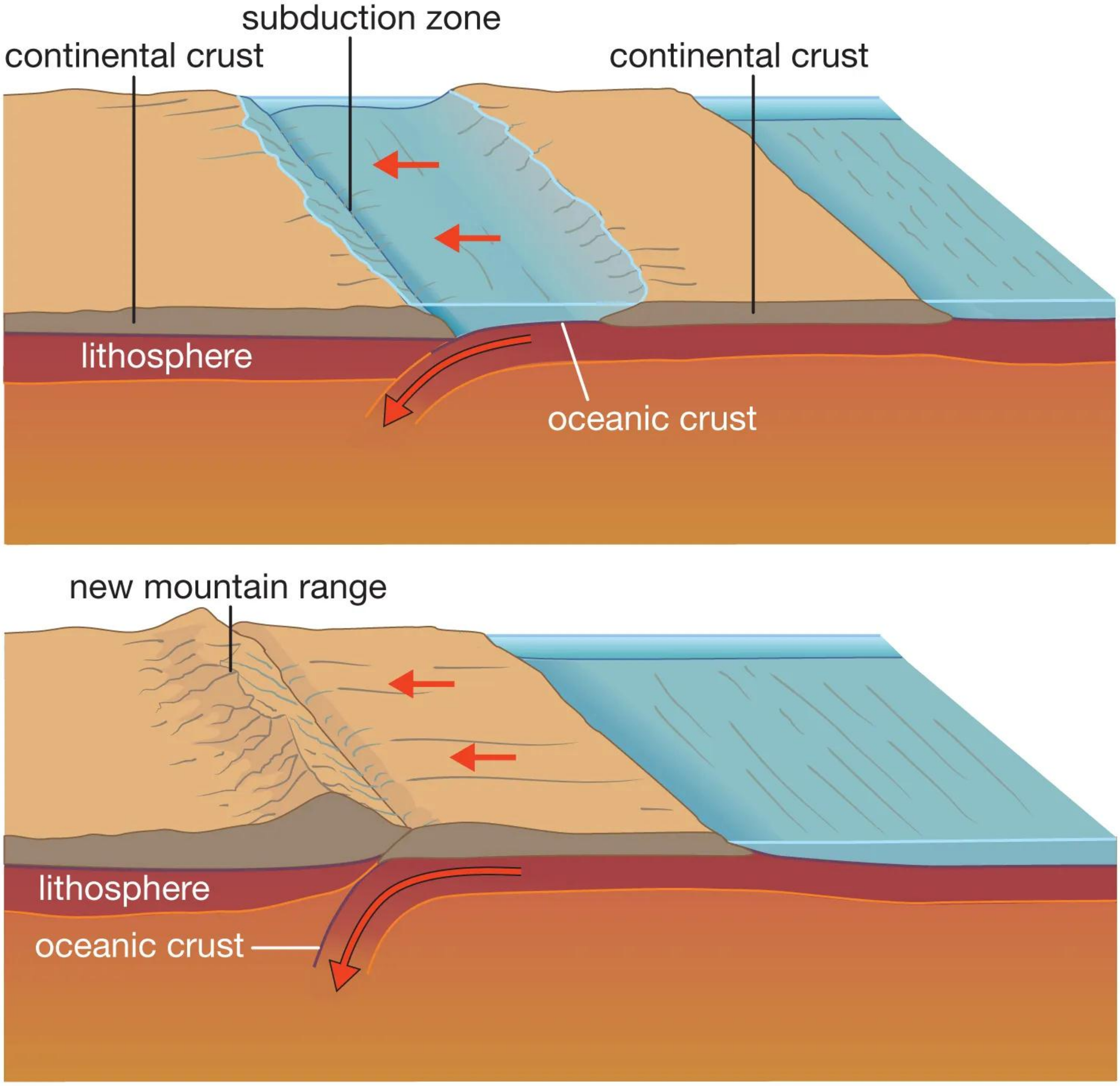
Let's start with a **passive continental margin:**

* A margin where there are no significant tectonic movements.

* Where there is no subduction zone.

* Where a prism of sediments from continental erosion accumulates on the continental shelf and margin.

Continental collision



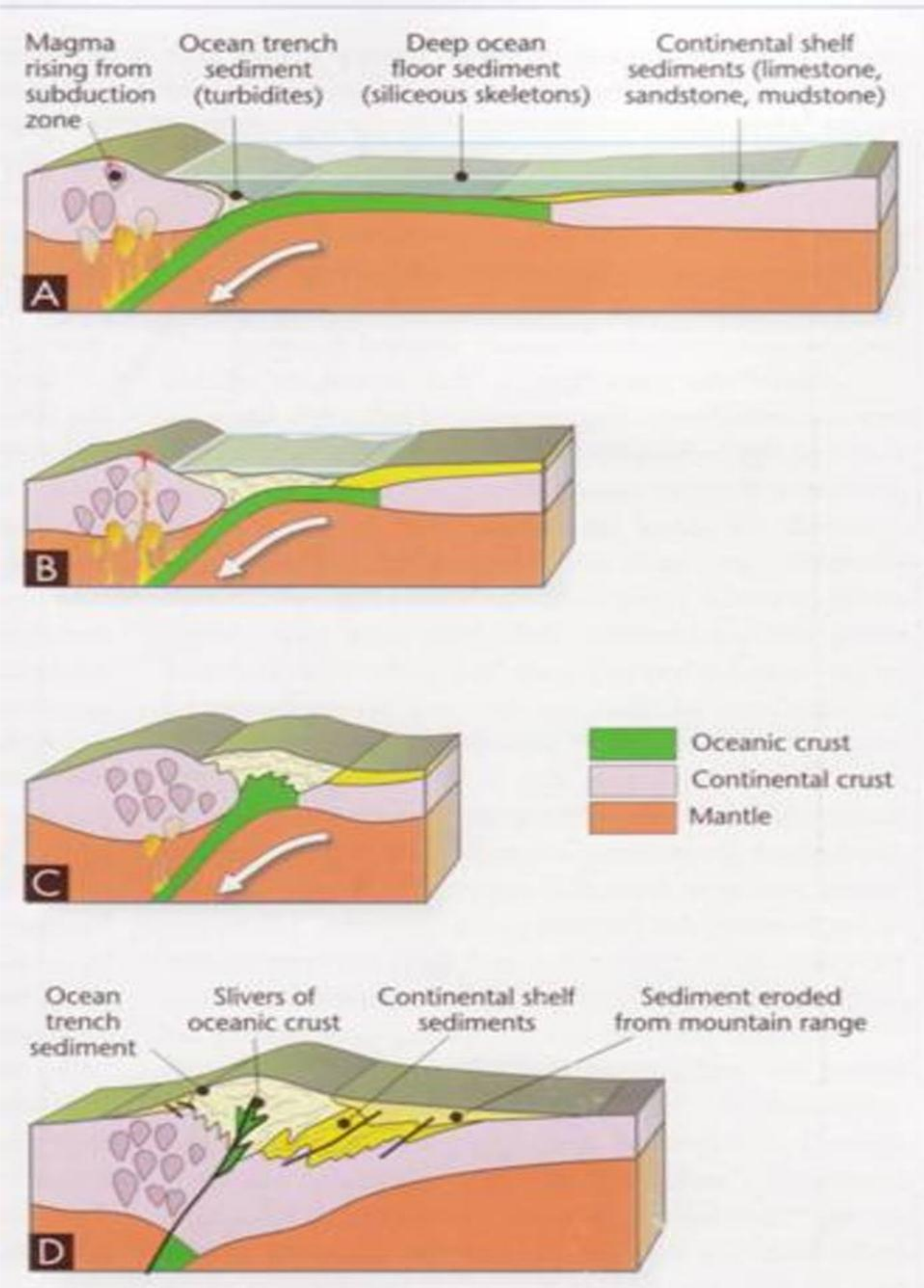


Figure 109: The main stages in the formation of a mountain range

At some point, this lithosphere fractures and one lip sinks beneath the other, creating a subduction zone.

The movement is then transformed into a system of collision between two plates:

We have moved from a passive to an active continental margin.

3.5.3.2. Subduction chains:

These form on active continental margins when an oceanic plate sinks beneath a continental plate. As it travels, the plunging plate rubs hard against the adjacent rocks, generating earthquakes and releasing intense heat, resulting in the formation of magma pockets that feed volcanoes.The continental plate accumulates at the plate boundaries, contributing to the formation of mountain ranges, e.g. the Andes.

The subduction zone becomes an obduction zone:

The collision between the volcanic arc and the continent creates a large overlap of all the material from the accretionary prism onto the continental margin.

Igneous activity ceases, and large masses of igneous rock (in red) can become trapped in the lithosphere.

With the collision of the two plates and the cessation of movement, the chain has reached its maximum height and acquired its characteristics.

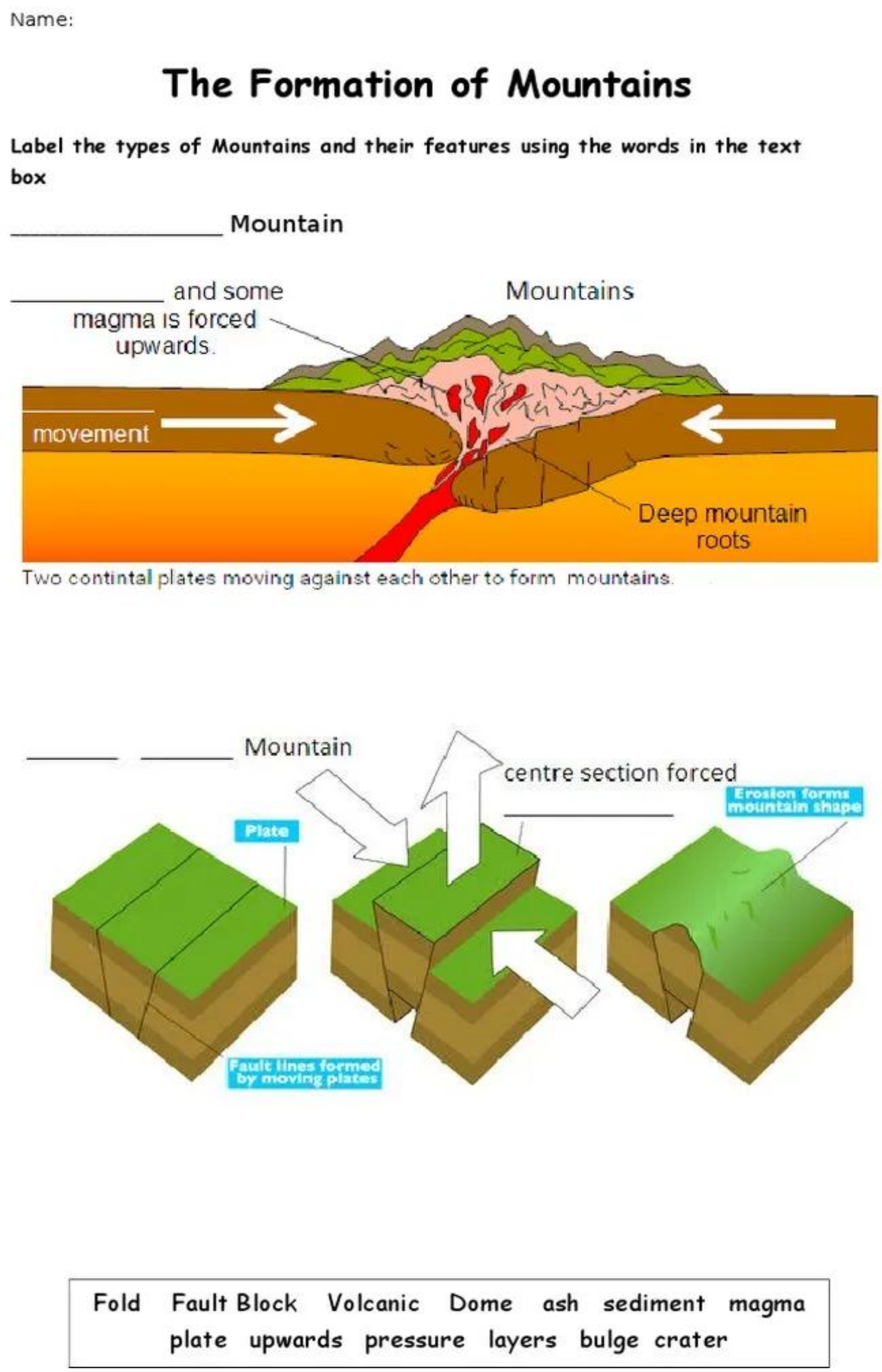


Figure.110: General structure of a mountain chain

Accretionary prism: *superimposition of scales on the front of a plate in certain subduction zones. It results from the planing of sediments (oceanic or eroded from continents) and fragments of* *oceanic crust belonging to the plunging plate, which are stopped by the rigid buffer formed by the overriding plate.*

B. Other cases:

Mountain formation (orogenesis) by continental collision:

1. **A mountain range is born in an area of the globe where two tectonic plates converge:**

When two continental lithospheres collide ("collision range", such as the Himalayas or the Alps).

When two continental plates of the same type and density collide, the engine of the mechanism stalls.

Because of their low density, it is not powerful enough to push one of the plates into the asthenosphere.

The two plates weld together to form a single plate.

- Obduction chains:

Part of the oceanic crust does not sink beneath the continent, but instead covers it. Obduction results from the blocking of subduction by the sinking of a continent beneath the mantle. C-a - d they form when a continent is drawn into a subduction zone, with the oceanic crust overlapping the continent through a series of thrust sheets. When subduction ceases, these light zones are lifted by isostatic readjustment, e.g. obduction chains in New Guinea.

- Collision chains:

These are the end result of the evolution of subduction and obduction chains. When the two continental blocks brought together by oceanic subduction come into contact, the shock produces the formation of a so-called collision chain, much wider than the initial subduction chain. If plate convergence continues, an intracontinental chain is formed, with a very wide fan-shaped structure. Ex: Himalayas, Tibet.

During collision, sedimentary material is transported upwards to form mountain ranges. At the contact between the two continental lithospheres, compression causes horizontal shortening, and hence vertical thickening, resulting in mountain ranges. Examples include the Himalayas, at the boundary between the Indian and Eurasian plates, and the Alps and Atlas ranges.

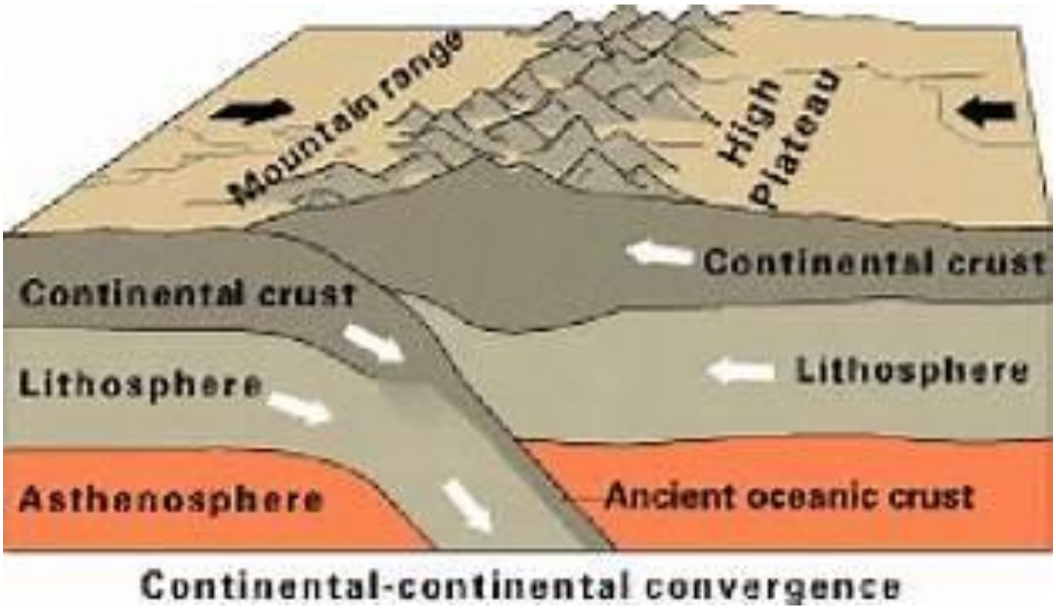


Figure 111: *Stages in the formation of a mountain chain by collision*

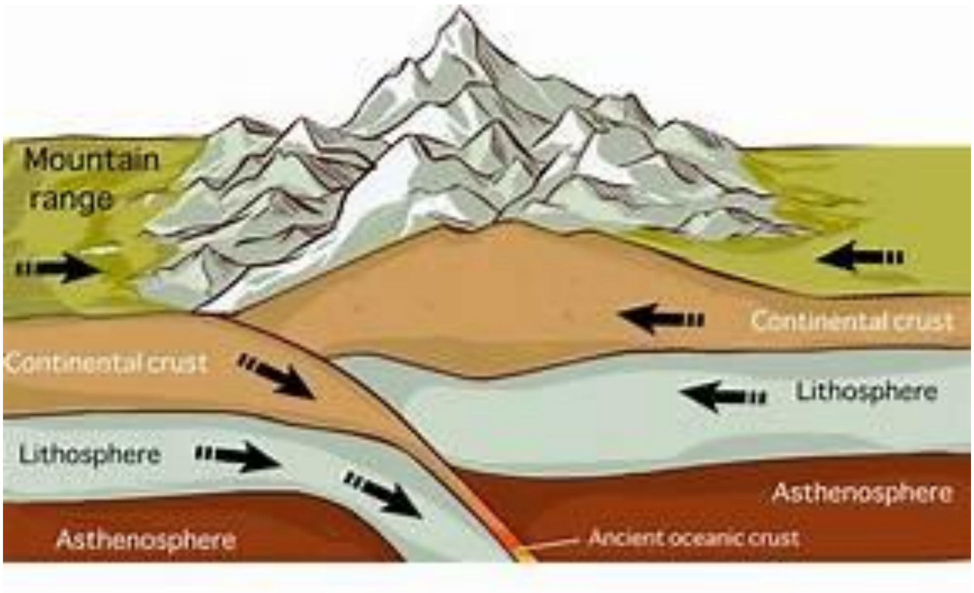


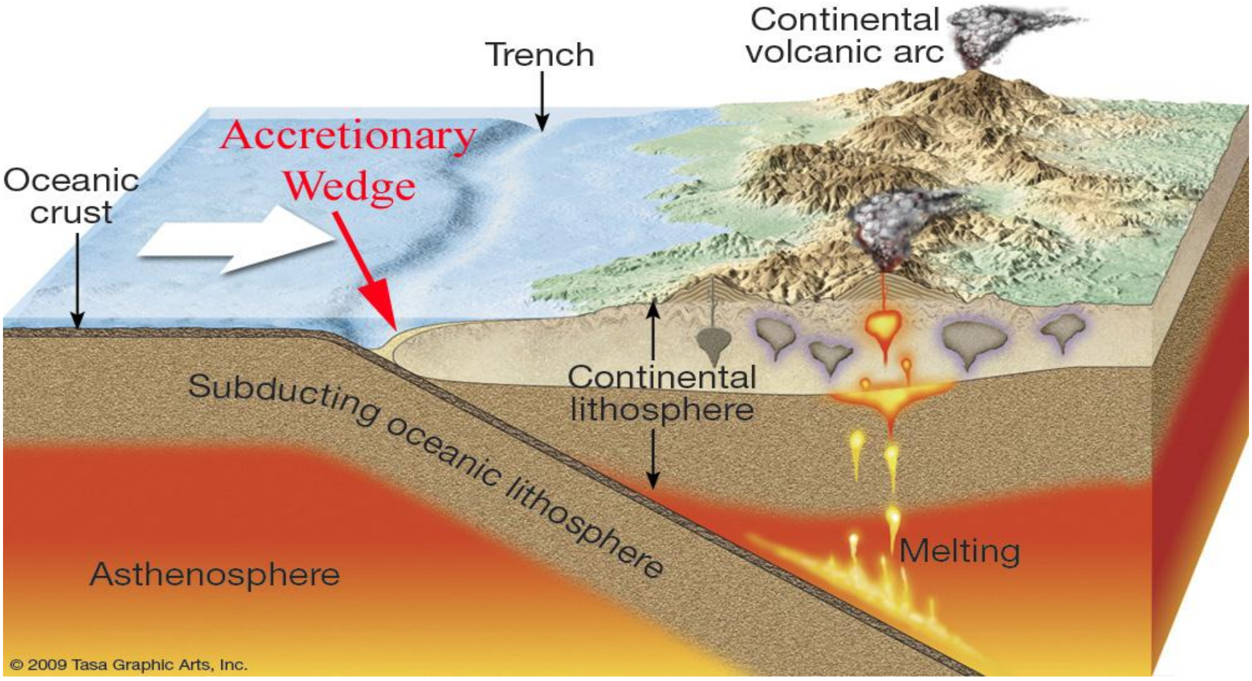
Figure 112: Continental crust thickening

RESULTS:

- Thickening of the crust with presence of a crustal root,

- Presence of ophiolite and partial melting of continental crust rocks.

There will be a zone of undeformed rocks adjoining the deformed rocks of the chain, sometimes symmetrically on either side of the chain. There will also be highly deformed metamorphic rocks at the roots of the chain, as these are formed under very high temperatures and pressures. There will also be shreds of basaltic oceanic crust trapped in faults.



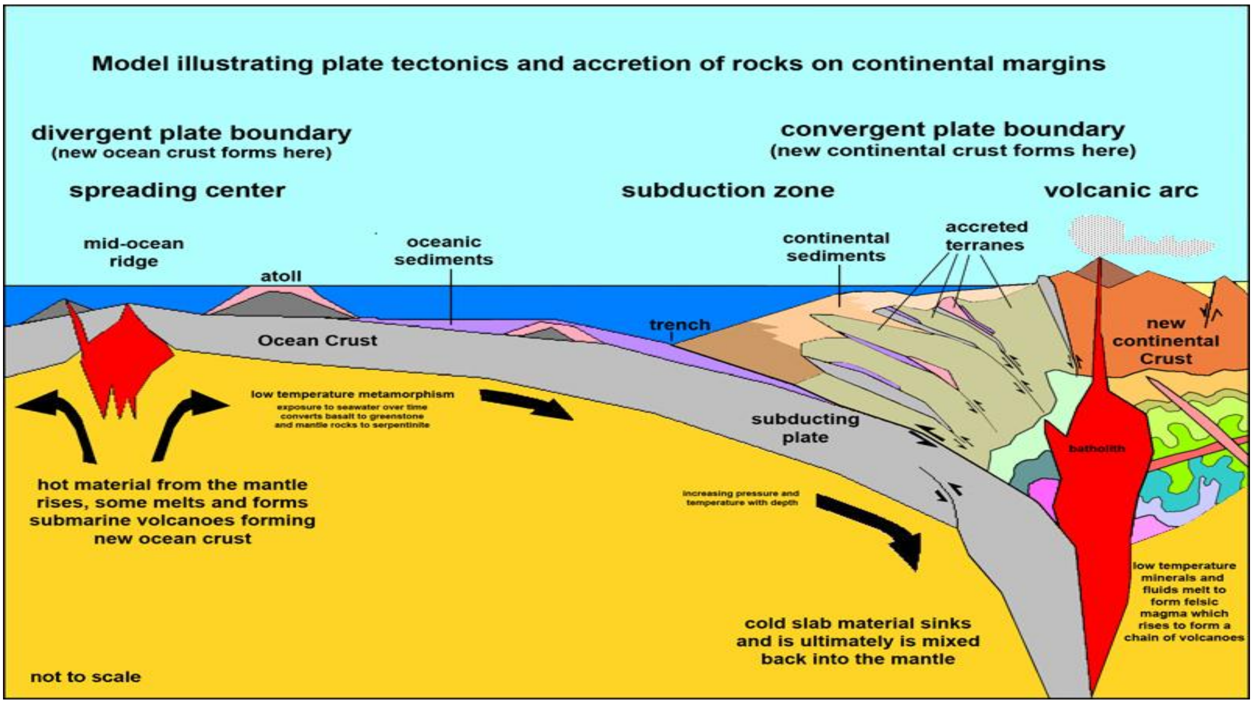


Figure 113: The formation of an accretionary prism

When they collide with a large continental plate, these terrains are torn away from the plate that carries them and stuck to the margin of the large continental plate, as their density is too low for them to be embedded in the asthenosphere. Several of these "exotic" pieces can accumulate in this way.