REPUBLIC DEMOCRATIC AND PEOPLE'S OF ALGERIA
وزارة التعليم العالي والبحث العلمي
MINISTRY OF HIGHER EDUCATION AND SCIENTIFIC RESEARCH
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DEPARTMENT OF BIOLOGY

Courses and Corrected Exercises of the *Geomorphology Module.*

3rd Year Ecology and Environment

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Academic Year 2024-2025.

TABLE OF CONTENTS

Chapter I : Generalities

Chapter II : The Structure

Chapter III : Deformations Tectonics

Chapter VI : Ecological Preponderances of the Geomorphology Factor

Chapter V : Zonal Climatic Geomorphology

Chapter IV : External Factors of Morphology

LIST OF FIGURES

Chapter I: Generalities.

I - Introduction to Geomorphology:

Geomorphology appeared in the second half of the nineteenth century as a branch of geology. With the contribution of William Morris Davis, it has become a geographical discipline based on a model of the evolution of relief of universal value. (Roger Coque 1993; Louis-Edmond Hamelin, 1964).

William Morris Davis (February 12, 1850 – February 5, 1934) was an American geographer. He is often considered the father of American geography and is also recognized as the father of geomorphology.

I-1- Definitions:

Geomorphology is the science that describes and explains the different forms of the Earth's relief as well as their genesis. It analyses the shapes of the Earth's surface (relief) and explains how they are formed and changed by tectonics and erosion.

The term geomorphology, derived from the Greek (geo = Earth, morph = shape, and logos = discourse, study, science), refers to the science that has as its object the description and explanation of the earth's relief, whether continental or underwater.

As a discipline of physical geography and geosciences, geomorphology focuses on the genesis and evolution of landforms. Increasingly quantitative, it tends to be classified among the physical sciences of the Earth, thus being halfway between geology and geography.

Physical geography is the study of the morphology of the landscape, describing it and then explaining the processes that led to its shape. It focuses on defining the factors that govern the genesis and evolution of the landscape. **Physical geography**, or **environmental geography**, is the branch of geography that describes the Earth's surface and is not directly concerned with human activities. It is therefore, by definition, a science of nature.

Geomorphologists analyze landscapes, seek to understand their history and evolution, and predict future changes through a combination of field observations, laboratory experiments, and numerical modeling.

Like any science, geomorphology has **one object** : **relief**: it describes the shapes of the Earth's surface and explains their formation and evolution.
Methods: Mapping, modelling.
There are several branches of geomorphology: structural, climatic (zonal), dynamic, glacial, littoral, fluvial, and volcanic.

I-2- Geomorphology - Ecology Relations:

The relationships between geomorphology and ecology are fundamental to understanding the dynamics of landscapes and ecosystems.

I-1-1- Influence of Geomorphology on Ecology:

a. Topography and Hydrology:

The shape of the landform influences drainage patterns and water availability in a region, directly affecting the distribution of habitats and species. For example, talwegs (valleys) often concentrate water flows, creating humid conditions favourable to certain plants and animals (Montgomery, D.R, 2001).

b. Types of Soils:

Geomorphology determines soil formation, which varies according to mineral composition, topography, and erosive processes. These soils influence vegetation, which in turn affects animal communities (Brady, N.C., & Weil, R.R., 2008).

c. Microclimates:

Landforms create microclimates by altering exposure to sun, wind and precipitation. South-facing slopes, for example, are generally drier and warmer than north-facing slopes, affecting local vegetation and wildlife (Barry, R.G., & Chorley, R.J., 2009).

I-1-2- Influence of Ecology on Geomorphology:

a. Vegetation and Erosion:

Ground cover protects the soil from erosion by reducing the impact of rainfall and stabilizing the soil through plant roots. Bare areas are more susceptible to erosion and landslides (Vanacker, V et al., 2003).

b. Bioturbation:

The activities of organisms, such as earthworms and plant roots, alter soil structure and influence geomorphological processes by promoting soil aeration and mixing (Wilkinson, M.T et al. 2009).

I-1-3- Dynamic interactions:

a. Evolution of the Landscapes:

Interactions between geomorphological and ecological processes contribute to the evolution of landscapes over time. Ecosystems adapt to geomorphological changes such as volcanic eruptions, glaciations, and tectonic movements, and in turn influence these processes through their presence and activities (Huggett, R.J. 2007).

b. Transition Areas:

Transition zones, such as riparian forests (riparian forests), wetlands and coastal dunes, are examples of systems where interactions between geomorphology and ecology are particularly visible and important for biodiversity and ecosystem stability (Mitsch, W.J., & Gosselink, J.G, 2015)

In summary, geomorphology and ecology are closely related and interact in complex ways to shape landscapes and ecosystems. These relationships are crucial for the sustainable management of natural resources and the conservation of ecosystems.

I-1-4- Geomorphology and ecology of the landscape:

Geomorphology is an important field for landscape ecology. The forms and structures of the landscape are decisive for flora and fauna and their functions within ecosystems, in particular concerning biological corridors and certain points such as islands, lakes, rivers, passes, straits, hollows, etc. which naturally control the flow of genes, species and populations.

What is a biological corridor?

The corridor (or "biocorridor") is "a passage of free movement for fauna and flora", it is the path made up of natural spaces that fauna uses to go from one massif to another or simply to go from the area where it usually lives to the area where it reproduces.
For example, an amphibian usually lives in a dry area but needs to reach a pond to reproduce. If a road prevents it, the entire survival of the population is at stake

I-3-Talwegs and Interfluves:

A talweg, or thalweg, is the line formed by the points with the lowest altitude, either in a valley (Max Derruau, 1969, 2001) or in the bed of a river (fig.I.1).

Etymology:

Talweg (taːlveːk) is a German term, formed from the two nouns Tal, meaning "valley", and Weg, meaning "path": it literally means "valley path". In French, it looks more like a water collection line. The talwegs are mostly shaped by river erosion and frequently occupied by the hydrographic network.

The talweg is opposed to the ridge line, ridge line or watershed. The space between two talwegs is called an interfluve.

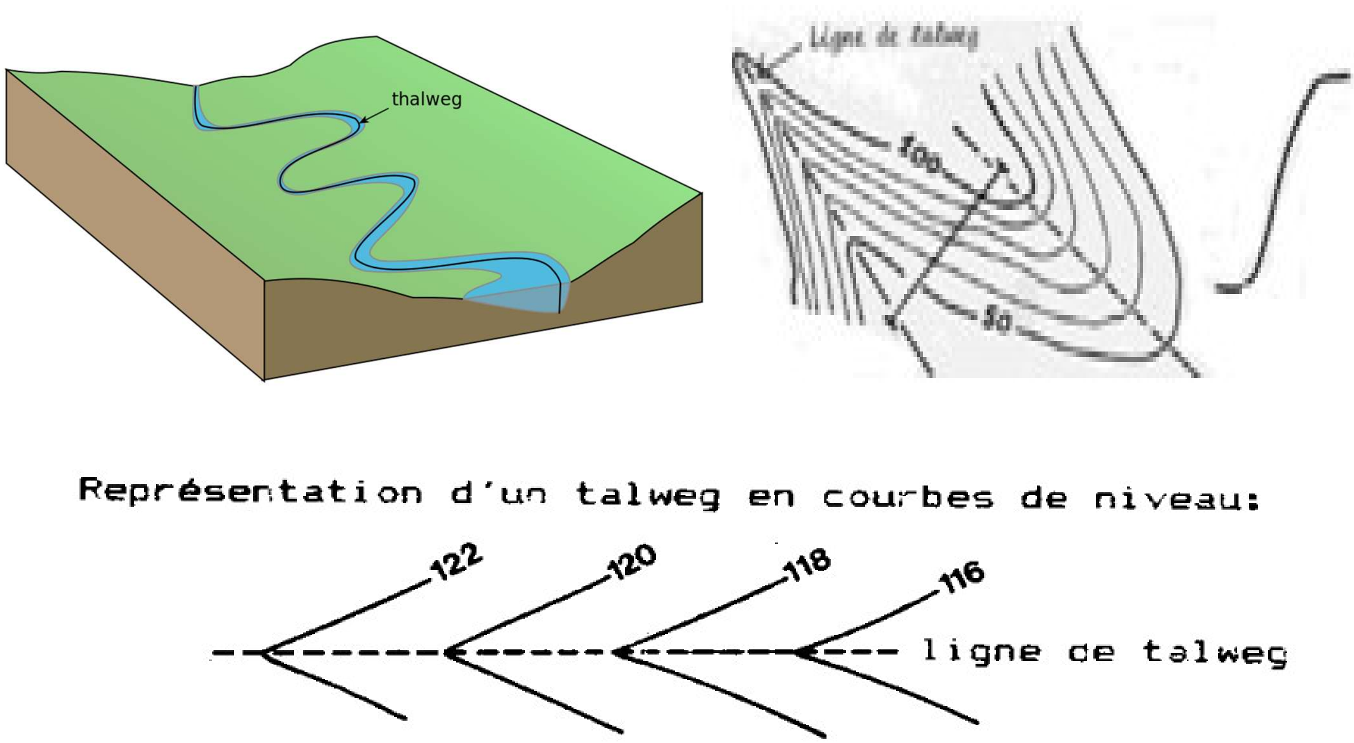


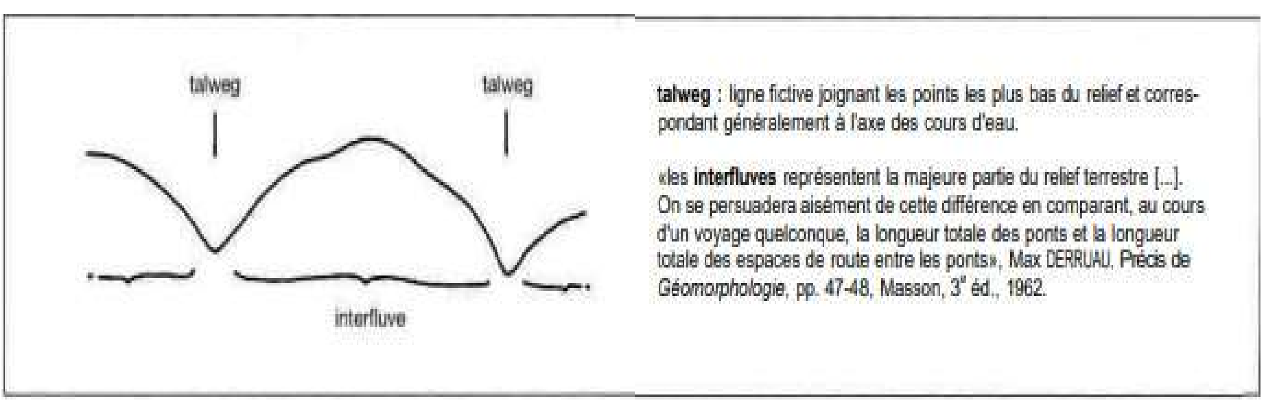
Figure.I.1 : Diagram of a Thalweg

An interfluve (fig.I.2) is a relief between two talwegs (Max Derruau, 1969). It is made up of slopes, separated or not by a flat surface. The interfluve ridge (Roger Brunet, 1993) refers to the line where rainwater is divided.

The interfluves represent most of the Earth's relief, since:

- Talwegs are relatively narrow: the bed of a watercourse is part of a talweg; The term "interfluve" is any part of the Earth's relief that is not a talweg.

Figure.I.2: Diagram of a Thalweg and interfluve.



I-4- Erosion, lithology, structure:

I-4-1-Erosion:

Erosion is the process by which materials on the earth's surface are worn, moved, and transported by natural agents such as water, wind, ice, and gravity. It plays a crucial role in shaping landscapes by breaking down rocks and redistributing sediments. For example, rivers can carve out valleys, and wind can form sand dunes. Erosion can be chemical, where minerals are dissolved by chemical reactions, or mechanical, where materials are physically broken (Montgomery, 2007).

I-4-2-Lithology:

Lithology is the study of the physical and chemical characteristics of rocks, including their mineral composition, texture, and structure. It is essential for understanding the properties of rocks and their behaviour under various geological conditions. Rock lithologies strongly influence geomorphological processes and erosion (Blatt, Tracy, & Owens, 2006).

I-4-3-Structure:

In geology, structure refers to the arrangement and organization of rocks in the earth's crust. This includes geological formations such as folds, faults, and joints. The geological structure determines how the rocks react to tectonic forces and influences the development of landforms. For example, faults can create mountains and valleys by displacing blocks of the Earth's crust (Fossen, 2010).

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TD Part:

Tutorials and Questions on the Introduction to Geomorphology

Exercise 1: Understanding the Basic Concepts:

Question 1 : Define geomorphology and explain its importance in the study of earth sciences.

Solution : Geomorphology is the science that describes and explains the different forms of the Earth's landform and their genesis. It analyses the shapes of the Earth's surface (relief) and explains how they are formed and changed by tectonics and erosion. Geomorphology is essential because it allows us to understand the processes of landscape formation, their evolution, and their impact on ecosystems and human activities.

Question 2 : Who is William Morris Davis and what is his contribution to geomorphology?

Solution : William Morris Davis (February 12, 1850 – February 5, 1934) was an American geographer often considered the father of American geography and geomorphology. Its major contribution is the cyclic erosion model, which describes the evolution of terrestrial landforms through different stages of development.

Exercise 2 : Relations between Geomorphology and Ecology:

Question 1 : Explain how topography and hydrology influence ecosystems.

Solution : The shape of the landform influences drainage patterns and water availability in a region, directly affecting the distribution of habitats and species. For example, talwegs often concentrate water flows, creating humid conditions that are favourable to certain plants and animals.

Question 2 : How does vegetation affect soil erosion?

Solution : Ground cover protects the soil from erosion by reducing the impact of rainfall and stabilizing the soil through plant roots. Bare areas are more susceptible to erosion and landslides.

Exercise 3 : Erosion, Lithology and Structure:

Question 1 : Describe the erosion processes and their impacts on the landform.

Solution : Erosion is the process by which materials on the earth's surface are worn, moved, and transported by natural agents such as water, wind, ice, and gravity. It plays a crucial role in shaping landscapes by breaking down rocks and redistributing sediments. For example, rivers can carve out valleys, and wind can form sand dunes. Erosion can be chemical, where minerals are dissolved by chemical reactions, or mechanical, where materials are physically broken.

Question 2 : What is lithology and why is it important in geomorphology?

Solution : Lithology is the study of the physical and chemical characteristics of rocks, including their mineral composition, texture, and structure. It is essential for understanding the properties of rocks and their behaviour under various geological conditions. Rock lithologies strongly influence geomorphological processes and erosion.

Question 3 : Explain how the geological structure influences the development of landforms.

Solution : In geology, structure refers to the arrangement and organization of rocks in the earth's crust. This includes geological formations such as folds, faults, and joints. The geological structure determines how the rocks react to tectonic forces and influences the development of landforms. For example, faults can create mountains and valleys by displacing blocks of the earth's crust.

Exercise 4 : Talwegs and Interfluves:

Question 1 : What is a talweg and how is it formed?

Solution : A talweg is the line formed by the lowest elevation points in a valley or riverbed. The talwegs are mostly shaped by river erosion and frequently occupied by the hydrographic network. The term is derived from the German "Tal" (valley) and "Weg" (path).

Question 2 : Compare and contrast talwegs and interfluves.

Solution : A talweg is the lowest line in a valley, usually shaped by river erosion and occupied by a stream. An interfluve is the relief between two talwegs, made up of slopes, separated or not by a flat surface. The interfluves represent most of the terrestrial relief because the talwegs are relatively narrow.

Exercise 5 : Dynamic interactions:

Question 1 : Describe how ecosystems can influence geomorphological processes.

Solution : Ecosystems influence geomorphological processes through several mechanisms, such as vegetation that protects the soil from erosion and the activities of organisms such as earthworms and plant roots that modify soil structure. These interactions promote soil aeration and mixing, thus influencing erosion and slope stability.

Question 2 : Give an example of a transition zone and explain its importance for biodiversity.

Solution : Riparian forests (riparian forests) are an example of a transition zone where the interactions between geomorphology and ecology are particularly visible. They are crucial for biodiversity because they provide varied habitats and biological corridors for wildlife, facilitating the movement of species and the survival of populations (Mitsch, W.J., & Gosselink, J.G., 2015).

These exercises and questions will allow students to better understand the basic concepts of geomorphology and its relationship with ecology, while applying their knowledge to concrete examples relevant to the Algerian context.

Chapter II: The Structure

II.1 – Influence of the Lithological Nature of the Formation:

II.1.1 - Definition:

Lithology: (from ancient Greek "collection of stones", composed of (lithos) "stone" and (logos) "speech, narrative, word"

- Nature of the rocks forming a geological layer
- Lithology is the branch of geology that studies the nature of the rocks in a formation. It is essential for understanding patterns and erosion.
- Earth science, study of rock formation. Refers to the different rock formations: magmatic, sedimentary, etc. We need to identify the nature of the rocks, and therefore their resistance to erosion.

II.1.2 - Influence of the lithological nature of the formation:

Its chemical, mineralogical and geotectonic characteristics are often predominant in erosion resistance.

Examples:

- Quartzites (compacted siliceous rocks) are resistant to erosion agents because these rocks are composed largely of quartz, which is a very stable mineral. For this reason, the landforms of geological formations made up of resistant rocks have convex shapes and steep slopes accompanied by high altitudes. (Example: Limestone-Djurdjura mountain range, Hoggar).

- On the other hand, marls, which are sedimentary rocks (a mixture of limestone and clay), are less resistant to atmospheric agents. This is why the reliefs of geological formations made up of such rocks have rounded concave shapes, with altitudes that are often very low because they are easily reduced by erosion.

Generally speaking, this is referred to as differential hardness.

II.1.3 – Influence of structure and tectonics:

Structure is the essential driving force behind the shaping of relief. Structural forms are all aspects that define the geometric structure and possible tectonic accidents of a given formation. Structural and tectonic forms are very important in erosion resistance.

Example:

- The greater the dip of the formation, the less resistant it will be to erosion because the dip increases, for example, the gradient of the water and therefore its erosion force.
- The presence of faults or cracks will also tend to weaken the geological formation because it exposes it even more, in its internal parts, to atmospheric agents.

II.1.4 – Influence of climate:

Whatever the climatic conditions, if the lithological and structural conditions allow it, there will always be the formation of tabular reliefs or cuesta. But in areas that have remained arid for a long time, where rainfall is low, the morphological forms are very different from those found in temperate zones.

II.2 - General structure of the globe:

The Earth is the third planet in order of distance from the Sun and the fifth largest in the Solar System both by mass and diameter. In addition, it is the only celestial object known to harbor life.

- It orbits the Sun in 365.256 solar days — a sidereal year — and rotates relative to the Sun in a sidereal day (about 23:56:04), slightly less than its 24-hour solar day due to this displacement around the Sun a. The Earth's axis of rotation has an inclination of 23°, which causes the appearance of the seasons.
- According to radiometric dating, the Earth was formed 4.54 billion years ago. It has a single natural satellite, the Moon, which formed shortly afterwards.

The Earth is a terrestrial planet, i.e. an essentially rocky planet with a metallic core, unlike gas giants such as Jupiter, which are essentially made up of light gases (hydrogen and helium) (NathalieMayer, 2020). It is the largest of the four terrestrial planets in the Solar System, either in size or mass (David P. Stern,2020). Of these four planets, Earth also has the highest global density, the strongest surface gravity, the strongest global magnetic field, the highest rotational speed (Paul J. Tackley,2002) and is probably the only one with active plate tectonics (Paul J. Tackley,2002).

Our earth is made up of a series of envelopes:

- The outer envelopes – Atmosphere
  - –Magnetosphere.
  - –Hydrosphere.
  - –Biosphere.

- The internal envelopes -Earth's crust
  - -Coat
  - -Kernel

II.2.1-External structure of the Earth: External envelopes of the Earth:

1 - Magnetosphere:

Our planet generates its own magnetic field, much like a gigantic dynamo. It is the difference in speed between the rotation of the planet and its liquid core that, by friction, generates this magnetic field (Jault D., et al., 2010).

The Earth's magnetosphere (fig.II.2) is the set of Earth's magnetic field lines located beyond the ionosphere, above 800 to 1000 km altitude.

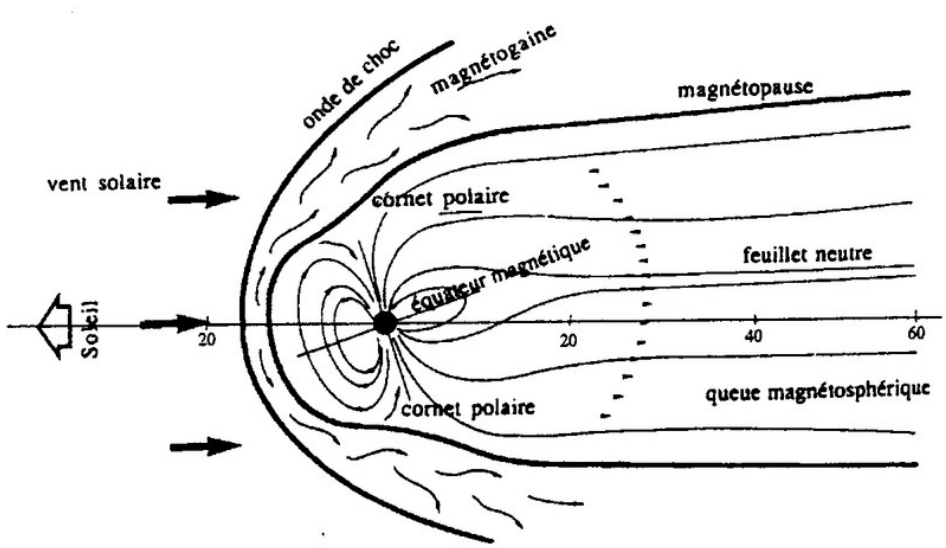


Figure.II.1: Diagram of the Earth's Magnetosphere.

The magnetosphere is immersed in the solar wind, and deformed by it: its very elongated shape, compressed on the side of the sun (day side) and stretched on the night side, a bit like the tail of a comet. *In reality, the magnetosphere acts as a screen and protects the Earth's surface from the excesses of the solar wind (bombardment by ionized particles constituting this flow from the Sun), harmful to life.*

The Earth is a planet surrounded by two fluid envelopes: The atmosphere, a gaseous envelope that exists on all planets except Mercury, and the hydrosphere, a discontinuous liquid envelope, essentially made up of water, and which is one of the originalities of the "Blue Planet" Earth.

2 - Atmosphere:

(From the Greek. atmos = steam and sphaira = sphere). The Earth's atmosphere refers to the gaseous envelope surrounding the solid Earth. The gaseous envelope of the earth, the environment in which life subsists, corresponds to the most dynamic and unstable "sphere" of this planet. This medium controls the distribution of energy on the surface of the globe, and many chemical transformations, especially of photochemical origin, occur at this level.

In addition, it is where the exchange of matter (and energy) with the rest of the solar system and space in general takes place.

On the other hand, it is in very close contact with the oceans, the terrestrial biosphere and the lithosphere, and functions as a medium for the transfer of materials from one sphere to another.

Dry air consists of 78.084% dinitrogen (N2), 20.95% oxygen (O2), 0.93% argon (Ar), < 0.5% to ~5% water vapor (H2O) -highly variable-, 0.039% carbon dioxide (CO2) and traces of other gases such as: Neon (Ne), Helium (He), Methane (CH4), Krypton (Kr), Dihydrogen (H2), Xenon (Xe).

3 - Hydrosphere:

(from the Greek. hudor = water and sphaira = sphere). - Is a term designating all the areas of a planet where water is present. It concerns water in liquid form (oceans, rivers, lakes, rivers, groundwater.........), solid form (glaciers, ice floes, etc.) or in gaseous form (water vapour). https://fr.wikipedia.org/wiki/Hydrosph%C3%A8re - It is the totality of the Earth's water (oceans, rivers, lakes, rivers, groundwater.........).

II.2.2 - Internal Structure of the Globe:

The Earth's interior is made up of a succession of layers with different physical properties: in the centre, the core, which forms 17% of the Earth's volume and is divided into the solid inner core and the liquid outer core; then, the mantle, which constitutes the bulk of the Earth's volume, 81%, and which is divided into the solid lower mantle and the upper mantle, which is mainly plastic, but whose very upper part is solid; finally, the crust (or bark), which accounts for less than 2% by volume and is solid.

Knowledge of the internal structure of the earth has often remained very difficult, because it is inaccessible unlike the outer layers of the earth (Atmosphere, Hydrosphere, Biosphere), for a start direct methods have been used to recognize the internal structure of the earth. https://www.youtube.com/watch?v=Ni32IzL34bA

a. Direct investigation methods

1. Comparison between rocks on the surface of the earth and those of meteorites.
2. Realization of the first drilling: the idea was to dig and see as we went along what was inside, the more we dug, the more we discovered the structure of the first layers, but a problem arose: the more they dug, the more the temperature increased, the drilling reached a record depth of 10,000m=10Km, and could not dig more because the sinking equipment started to melt because of the very high temperatures.

Direct methods have made it possible to know the internal structure of the earth up to a depth of 10 km.

b. Indirect investigation methods (geophysics):

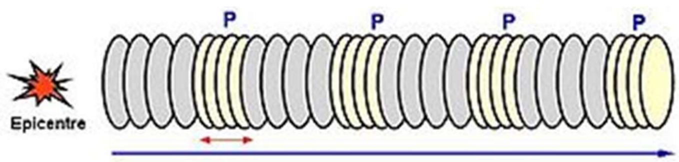
It was the analysis of seismic recordings obtained from seismographs that made it possible to completely renew the model of the Earth during the twentieth (20) century.

The principle is relatively simple: following an earthquake, the position of its epicenter is determined as precisely as possible. Then we record the vibrations that propagate throughout the globe. These wave phenomena are subject to physical laws such as reflection or refraction.

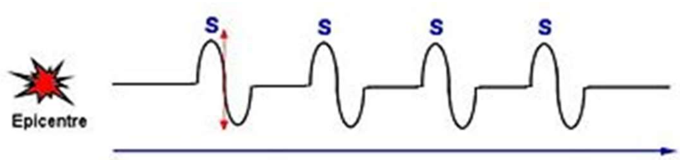
In addition, seismic waves do not all travel at the same speed depending on the medium they pass through, which makes it possible to evaluate the content of the Earth by carefully examining the time/distance curves travelled.

Some waves arrive quickly: these are the P waves (as in First); others are delayed and are recorded later: these are the S waves (as in Seconds).

P waves are vibrations that act in compression: particles move in the direction of propagation of the wave, a bit like in a spring. These compression waves propagate through solids, liquids, and gases.



S-waves are shear waves: particles move perpendicular to the direction of propagation of the wave, a bit like an oscillation on a string. These shear waves propagate in solids but not in liquid or gaseous media.



The speed of both types of P and S waves varies according to the density of the material being passed. The softer the layer crossed, the slower the waves propagate.

In addition, when a P wave arrives non-perpendicularly on a transition zone (mantle-core interface for example) a small part of its energy is converted into another waveform (a fraction of P then becomes S).

It is thanks to the study and recording of seismic waves that the internal structure of the globe has been precisely known, and the main internal discontinuities of the globe have been discovered (major discontinuities).

II.2.3 - Inner layers of the globe:

The internal structure of the Earth is divided into several successive envelopes (fig.II.2), the main ones being the Earth's crust, the mantle and the core.

This representation is very simplified since these envelopes can themselves be decomposed. To locate these layers, seismologists use seismic waves, and a law: **As soon as the speed of a seismic wave changes suddenly and significantly, there is a change of medium, and therefore of layer.**

This method has made it possible, for example, to determine the state of matter at depths that man cannot reach. (Deep mantle - core). These layers are delimited by the **major discontinuities** which are:

1/**Mohorovicic discontinuity**, (between 70 and 100Km deep) separates the Earth's crust from the Mantle
2/**Gutenberg discontinuity**, (2800Km), separates the Inner Mantle from the Outer Core
3/**Lehmann discontinuity,** (5100Km). Separates the liquid outer core from the solid inner core.

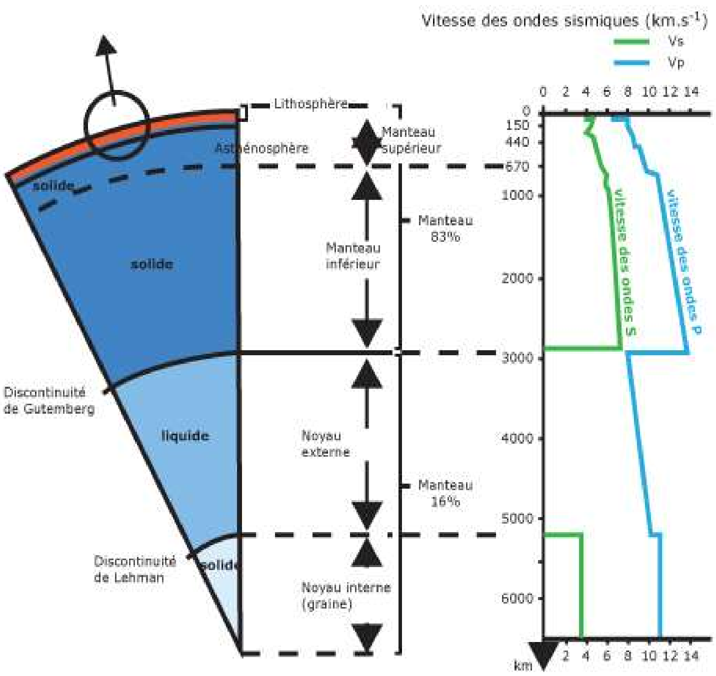
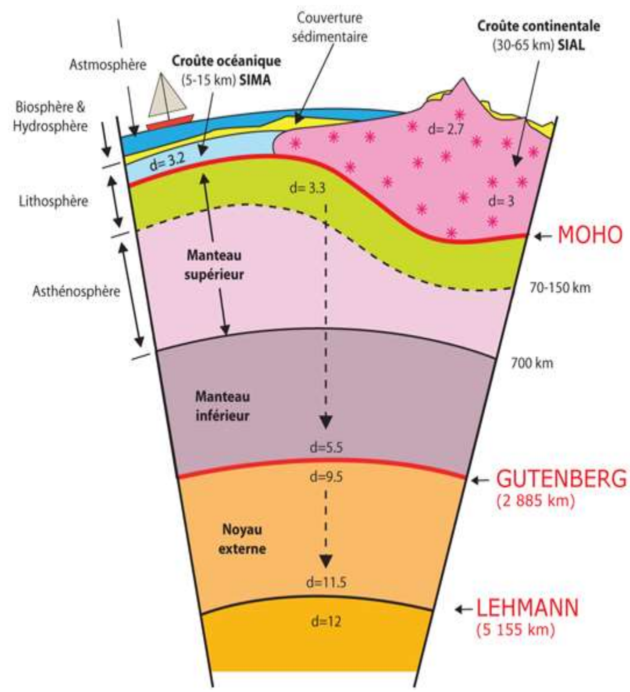


Figure.II.2: Major discontinuities of the earth, and internal structure of the globe**.**



1 - The Earth's Crust:

a. Composition of the Earth's crust:

The majority of the rocks that make up the Earth's crust are oxides.
Chlorine, sulfur, fluorine are the only important exceptions and their total amount in any rock rarely exceeds 1%.

F. W. Clarke has calculated that 47% of the earth's crust is made up of oxygen, which is mainly present (Table 1918). II.1) in the form of oxides, the main ones being silicon, aluminium, iron, calcium, magnesium, potassium and sodium oxides.

Silica is the major constituent of the crust. After a synthesis based on the analysis of 1672 rock types, Clarke obtained the following percentages of mass composition:

Table.II.1: Mean chemical composition of the earth's crust according to Clarke, 1924.

Oxide	**Sio2**	**Al2o3**	**Cad**	**MgO**	**Na2O**	**FeO**	**K2O**	**Fe2o3**	**H2o**	**Tio2**	**P2o5**	**Total**
Percentage	59.71	15.41	4.90	4.36	3.55	3.52	2.80	2.63	1.52	0.60	0.22	99.22

All other constituents are present in very small quantities (total < 1%).

b. Structure of the Earth's Crust:

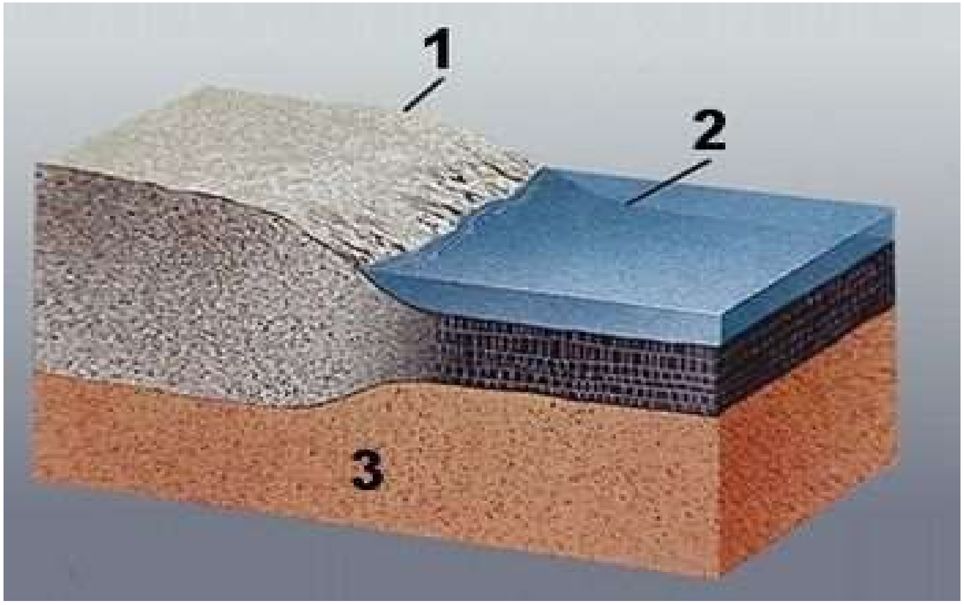
A distinction is made between the Continental Crust (30% of the Earth's surface) and the Oceanic Crust (70% of the Earth's surface) (fig.II.3):

Continental **crust** also called **SIAL** (silicon + aluminum). Essentially forms the **continents**. However, some parts may be submerged under seas or oceans, such as the continental shelf. The continental crust is **15 to 100 km thick**, with an average of **30 km**. **Mainly granitic**, with a density of 2.7 to 2.8.

The **oceanic *crust*** also called **SIMA** (silicon + magnesium). Essentially forms the **bottom of the oceans**. It is much thinner from **5 to 15 km in general**. Formed of **basaltic rocks**, it is also denser (3g/cm³).

c. Origin of the Earth's crust:

Whether continental or oceanic, the crust is always the result of the partial melting of the peridotites of the mantle which gives rise to magma. This magma crystallizes more or less quickly to form or regenerate a crust.



1 : Continental crust.
2 : oceanic crust.
3: Coat.

Figure.II.3: Simplified diagram of Continental Crust and Oceanic Crust.

The Subduction Zone: where a **plate sometimes sinks** up to several hundred kilometers into the mantle.

2 – Coat:

The mantle represents 84% of the Earth's volume. It is divided into two parts: the upper mantle and the lower mantle. Beneath the Moho lies the mantle, which occupies 83% of the Earth's volume and accounts for 67% of its mass. The characteristics of the two parts of the mantle are as follows:

- **The upper mantle** is less viscous (more ductile) than the lower mantle, which gives it plastic characteristics.
- **The lower mantle** has the properties of an elastic solid.

The Earth's mantle, although less rigid than the other layers of the Earth, is not liquid and extends to a depth of about 2900 km.

Its average composition is that of peridotite, an ultrabasic rock rich in magnesium and iron silicates, mainly consisting of olivine, pyroxene and garnet. Although the chemical composition of the mantle remains virtually constant, its mineralogy varies with depth. The top of the mantle (up to 400 km deep) is mainly composed of olivine-like peridotite.

Between 400 and 2900 km, the increase in pressure leads to an increasingly dense crystalline structure of the minerals, first changing to a spinel form (up to 650-700 km, marking the boundary between the upper and lower mantle) and then to a perovskite form at the base of the mantle. At a depth of 2900 km, the Gutenberg discontinuity separates the lower mantle from the core, marked by an increase in density from 5.5 g/cm³ to 10 g/cm³.

The low velocity zone: **the LVZ** is the area of the Earth's upper mantle through which seismic waves propagate at low speed.

The Earth's crust plus the upper part of the upper mantle up to the LVZ is called **the Lithosphere** or **Lithospheric Mantle** (because of its brittle behavior).

The lower part of the upper mantle is called the **Asthenosphere**, or also **the Asthenospheric Mantle.**

Peridotite *: Ultrabasic granular magmatic rock consisting of dominant olivine accompanied by pyroxene and spinel (picotite, chromite).*
Olivine *: Is a mineral of the silicate group, subgroup of nesosilicates, with the formula (Mg, Fe)2[SiO4]. It crystallizes in the orthorhombic crystal system.*
Spinel *: Is a mineral species of the oxide family (magnesium aluminum oxide) with the formula MgAl2O4 (magnesium aluminum oxide).*
Perovskite *: Originally refers to the mineral CaTiO3 (calcium titanate).*

3 - Core:

Constitutes the central part of the Earth and which forms 17% of the Earth's volume and which is divided into two layers, **Liquid Outer Core**, **Solid Inner Core** (fig.II.4).

Outer core (the abrupt interruption of S-wave propagation at the boundary between the mantle and the core indicates that the outer core is liquid), mainly composed of iron (about 80%) and nickel plus some lighter elements. **Its viscosity is close to that of water**, its average temperature reaches **4000 °C** and its density 10.

The transition to the inner core is accompanied by the crystallization of iron and nickel, expelling the light elements towards the outer core.

This enormous quantity of molten metal is certainly agitated (by convection, but also as a result of the various rotational and precession movements of the terrestrial globe).

Flows of liquid iron can generate electric currents that give **rise to magnetic fields** that strengthen the currents, thus creating a dynamo effect by maintaining each other. **The liquid core is therefore at the origin of the Earth's magnetic field**.

Solid inner core (or seed), a ball of solid iron located 6380 km from the earth's surface, essentially metallic formed by the progressive crystallization of the outer core. **The pressure**

keeps it in a solid state despite a temperature above **5000 °C** and a density of about 13. The inner and outer cores represent 15% of the Earth's volume.

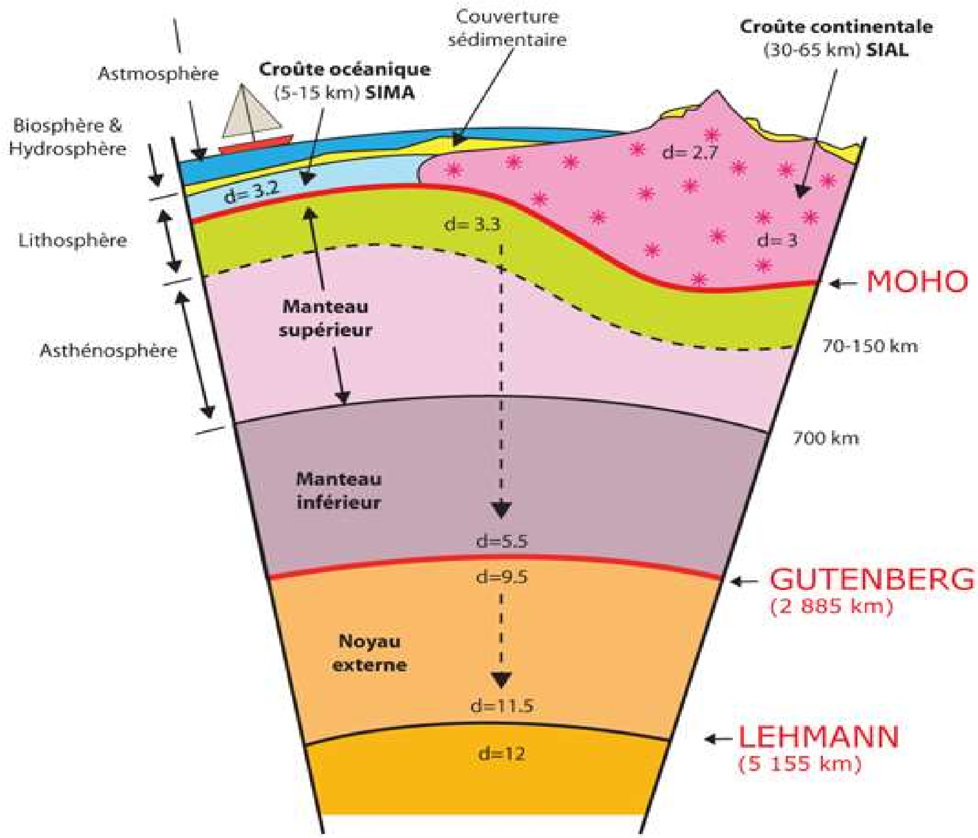


Figure.II.4: Internal structure of the Earth.

II.3 - Classification of Rocks:

Rock : a material generally formed of an assembly of minerals and presenting a certain static homogeneity.

Mineral: A naturally occurring chemical species most often in the form of a crystalline solid. The classification is based on their chemical and crystallographic characteristics.

A rock = an assemblage of minerals
A mineral = an ordered assembly (crystal) of atoms.

There are three main families of rocks that are differentiated by their mode of formation:

a. **Depending on the mineral composition:**

- Monomineral rocks, or monomineral rocks: composed of a majority mineral, e.g. pure limestone.
- Multi-mineral rocks, or multi-mineral rocks: aggregate of several minerals, e.g. Granite.

b. Depending on the homogeneity:

- Hard and coherent rocks: "stone";
- Plastic rocks: "clays";
- Loose rocks: "arenas", "sands";
- Fluid rocks = liquid: "oils", petroleum;
- Fluid rocks = gaseous: "gas".

c. Depending on their training methods and settings:

- **Exogenous rocks** (formed on the surface of the Earth's crust):

II.3.1- Sedimentary rocks:

These are **exogenous rocks** , i.e. rocks formed on the surface of the earth, and which form **5 cubic** lengths by volume of the earth's crust and **75 cubic lengths of the surface of the continents**. They are very varied because their genesis depends on many factors:

a- The Initial Nature of Disintegrated and Weathered Materials
b- The type of alteration
c- The mode of transport;
d- From the deposit area; modalities of diagenesis.

Sedimentary rocks are formed by the deposition of elements from the disintegration of rocks or the biosphere (plants, animals), either directly (bacterial secretions) or indirectly (corpses - > oil, coal).

They generally form in very calm environments (rivers, lakes, basins, deserts, seabeds) or in very violent conditions (storms).

These rocks are the result of the compaction and cementation of mud, sand, gravel or fossils. Depending on how they are formed, different types of sedimentary rocks are distinguished.

- **Detrital sedimentary rocks** : Rocks that come from the erosion of pre-existing continental rocks (plutonic rocks, volcanic rocks, metamorphic rocks). E.g. argillite, sandstone, conglomerate.
- **Chemical and biochemical sedimentary rocks** : Rocks that result from the precipitation of a chemical solution or the accumulation of organism skeletal debris (fossils) and the transformation of plant matter. E.g. Limestone, dolomite, gypsum, coal.

II.3.2 - Endogenous rocks:

(formed, at least partly at depth, at pressures and temperatures higher than those of the Earth's crust surface):

- **Magmatic rocks** / igneous rocks / fire rocks / eruptive rocks (formed by the crystallization / solidification of magma):
- **Plutonic** rocks [intrusive]: They have crystallized within the lithosphere. Are formed from magma that cools slowly to great depths (30 to 35 km) beneath the Earth's crust As a result, crystals have time to form well and the rock has a grainy texture. E.g. Granite, Gabbro;
- Volcanic rocks [extrusive/effusive]: They have spilled on the surface. Are the result of magma that cools rapidly on the surface of the Earth's crust. As a result, the crystals do not have time to form well and the rock is very fine-grained. E.g. Basalt, rhyolite, andesite; o Hydrothermal rocks: Formed from gases or solutions at high temperature, in relation to magmas;

II.3.3 - Metamorphic rocks:

Transformed rocks (recrystallization of existing rocks, as a result of increases in pressure and temperature most often linked to burial), metamorphism

http://www.luneceleste.com/pages/repertoires-des-termes-en-mineralogie/lettre-r/roche.html

A metamorphic rock is a rock formed by the recrystallization (and usually deformation) of sedimentary rocks or magmatic rocks under the effect of temperature and pressure that increase with depth in the Earth's crust. Metamorphic rocks can also form in contact with plutonic rocks and sedimentary rocks. E.g. Gneiss, paragneiss (Togola N., 2013)

These three major families of rocks are linked together on the Earth's surface by the rock cycle. The magmatic rocks formed by the crystallization of magma undergo erosion processes on the Earth's surface that lead to the formation and deposition of sediments.

Magma is at the origin of the formation of the Earth's crust, first at the level of oceanic ridges, then, by addition to the crust already present, at the levels of hot spots and subduction/obduction zones.

Conclusion:

Classifying rocks is essential to understanding the geological processes and history of the Earth. Using criteria such as origin, composition, and texture, geologists can categorize rocks in a systematic and scientific way. The bibliographic references provided offer additional resources for an in-depth study of the different types of rocks and their characteristics.

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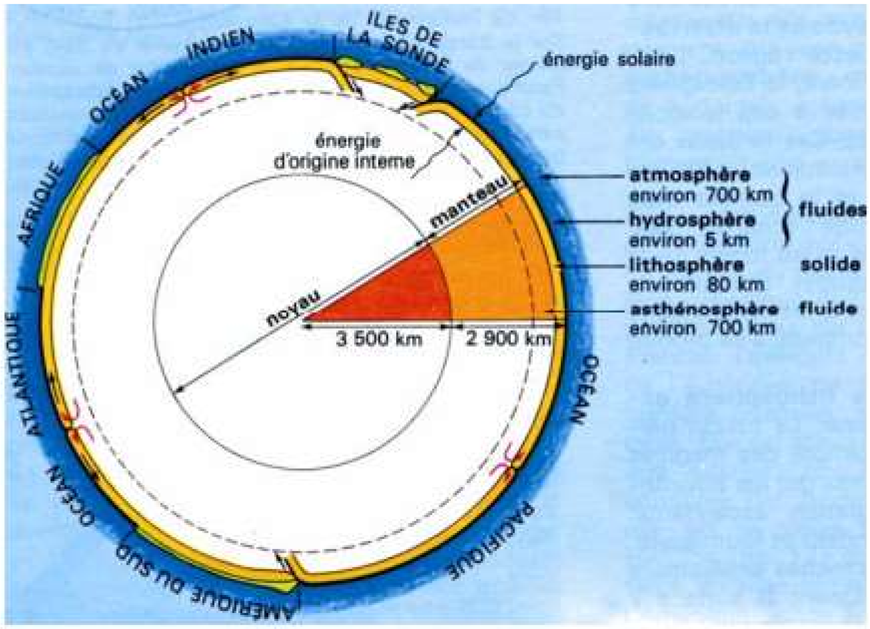
TD Part:

Exercise N°1:



Document 1: A globe made up of concentric envelopes

1. Name the three concentric envelopes that make up the globe. Specify the thickness of each one.
2. Determine the position of the asthenosphere. How deep is it?
3. What does the lithosphere include?

Exercises and Questions on the Classification of Rocks

Exercise 1: Igneous Rock Identification

Question: Classify the following rock samples as intrusive or extrusive and name them correctly:

1. A sample with large visible crystals.
2. A sample with a fine texture and no visible crystals.
3. A light-colored sample with visible crystals of feldspar and quartz.
4. A dark sample with a glassy texture and some gas bubbles.

Solutions:

1. Intrusive rock - Granite.
2. Extrusive rock - Basalt.
3. Intrusive rock - Granite.
4. Extrusive Rock - Obsidian.

Exercise 2: Classification of Sedimentary Rocks

Question: Determine the type of sedimentary rock (clastic, chemical, or organic) for the following samples:

1. A rock composed of cemented grains of sand.
2. A rock formed by the precipitation of calcite.
3. A rock formed from compacted plant remains.
4. A rock made up of shell fragments cemented together.

Solutions:

1. Clastic rock - Sandstone.
2. Chemical rock - Limestone.
3. Organic rock - Coal.
4. Organic rock - Shell limestone.

Exercise 3: Identification of Metamorphic Rocks

Question: Identify the following metamorphic rocks and determine whether they are foliated or non-foliated:

1. A rock with alternating mineral bands of light and dark colors.
2. A rock with an intergranular crystalline texture with no visible bands.
3. A rock formed by the transformation of limestone under pressure.
4. A rock with a thin-layered structure.

Solutions:

1. Foliated rock - Gneiss.
2. Non-foliated rock - Quartzite.
3. Unfoliated rock - Marble.
4. Foliated rock - Schist.

Exercise 4: Correspondence between Rock Types and Formation Processes

Question: Associate the following processes with the type of rock formed:

1. Rapid cooling of lava.
2. Compaction and cementation of sediments.
3. Metamorphism under high pressure.
4. Precipitation of minerals from aqueous solutions.

Solutions:

1. Rapid Lava Cooling - Extrusive igneous rock.
2. Sediment compaction and cementation - Clastic sedimentary rock.
3. Metamorphism under high pressure - Foliated metamorphic rock.
4. Precipitation of minerals from aqueous solutions - Chemical sedimentary rock.

Exercise 5: Reflection Questions

Question 1: Why do intrusive igneous rocks have larger crystals than extrusive igneous rocks?

Solution: Intrusive igneous rocks slowly cool below the Earth's surface, allowing the crystals to grow longer and become larger. In contrast, extrusive igneous rocks cool rapidly on the surface, resulting in the formation of small crystals.

Question 2: Explain why limestone can turn into marble.

Solution: Limestone can turn into marble through the process of metamorphism, which involves exposure to high temperatures and high pressures. This process recrystallizes the calcite minerals in the limestone, forming a denser, interlocuted crystalline texture typical of marble.

These exercises and questions are used to assess students' understanding of rock classification and formation processes. They also encourage critical thinking about the relationships between different categories of rocks and the geological processes that create them.

Chapter III: Tectonic Deformations

III. Tectonic deformations:

III.1. Isostatic equilibrium:

The term "isostasy" (from the Greek isos, equal, and stasis, stop) reflects the state of equilibrium of the rocks of the Earth's crust in relation to the underlying mantle. This phenomenon implies that, above a certain depth, called the compensation level, the mass of superficial crustal rocks is the same everywhere regardless of the altitude of the relief. Below the compensation level, there are no significant variations in density (Cazenave, 2020).

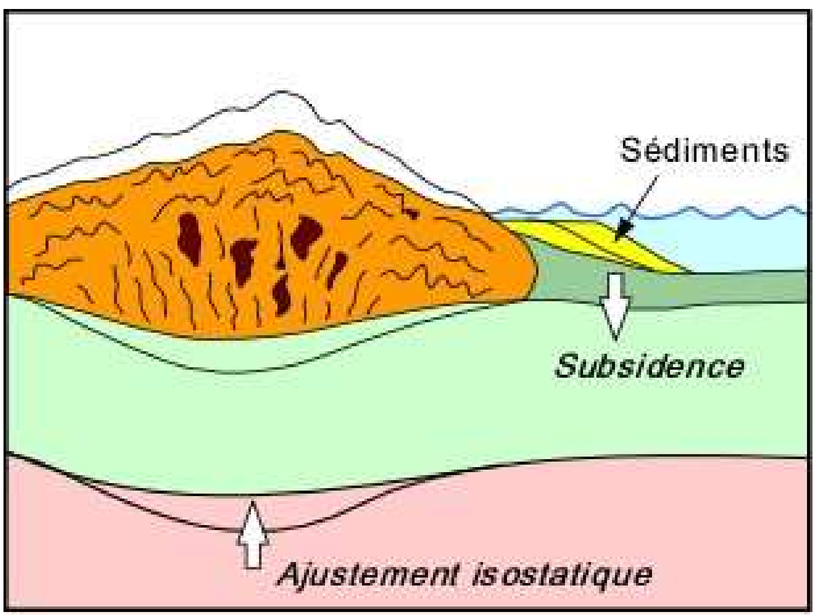
In geology, isostasy, also called isostatic equilibrium, is a phenomenon by which elements of the Earth's crust or, more generally, of the lithosphere that are buried at shallow depths are subjected to the same pressure regardless of topographical irregularities on the surface (Wikipedia).

The rigid lithosphere, cut into plates, rests in equilibrium on the denser, less rigid and therefore more deformable (=ductile) asthenosphere. This state of equilibrium of the masses of the lithosphere/asthenosphere is called isostasy.

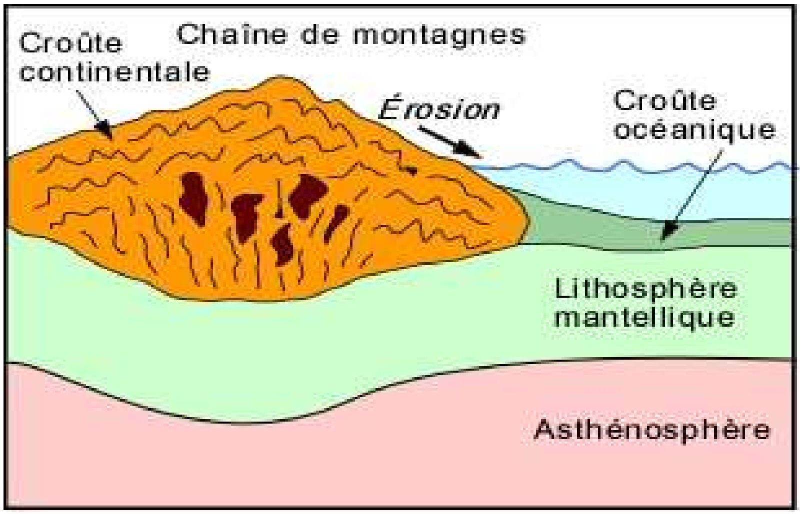
Animation: http://www.geo.cornell.edu/hawaii/220/PRI/isostasy.html

III.1.1- Erosion and isostasy:

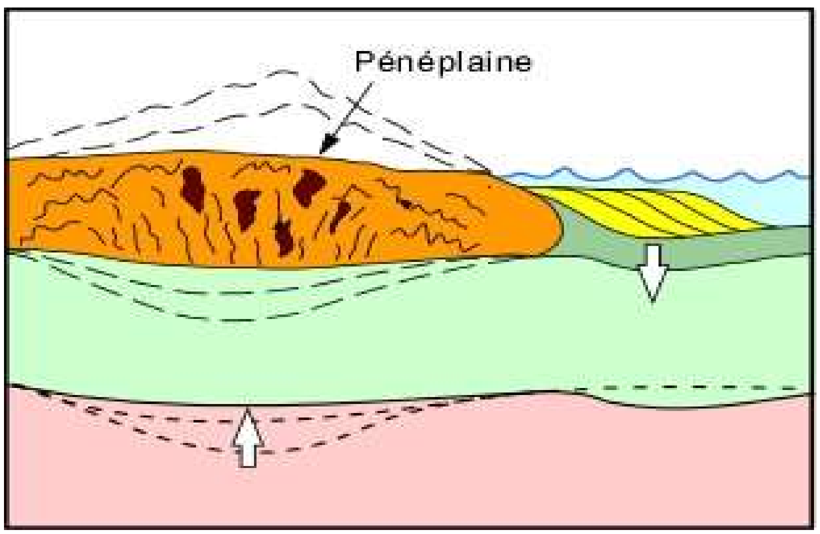
On a continental scale, erosion by runoff, ice and wind tends to flatten the reliefs towards a basic profile which is sea level.



According to the principle of isostasy (remember that the lithosphere "floats" on the asthenosphere), the ablation of a slice of material on the surface of a continent leads to a rebalancing of the masses; there is an upwelling of the entire continental lithosphere.



In this way, the continental crust gradually thins; We tend towards the peneplain and towards a thickness of continental crust that is compatible with the thickness of the oceanic crust, in accordance with the respective densities of the two crusts.



On the other hand, the overload due to the addition of sediments to the oceanic lithosphere creates a sinking called subsidence.

III.1.2- The principle of isostasy:

Archimedes' thrust applied to the earth's envelopes. In physics, Archimedes' principle states that any solid body immersed in a fluid will be subjected to a force directed from bottom to top: Archimedes' thrust, which is not enough to make an object float: this object must also be less dense than the fluid. Otherwise, the solid sinks, which occurs in some subduction zones where the subducted plate, denser than the mantle, flows spontaneously.

But in all other cases, the upper mantle is significantly denser than the crust, just as the lithosphere is denser than the asthenosphere. Under these conditions, the Archimedean thrust opposes the weight of the lithosphere in such a way that it "floats" on the asthenospheric mantle. According to the laws of hydrostatics, the Archimedes' thrust has an intensity proportional to the volume submerged.

III.1.3- Models of isostasy:

This concept explains the phenomenon by which the buried elements of the lithosphere are subjected to the same underground pressure, regardless of the reliefs visible on the surface. Isostatic compensating forces counteract surface erosion and create new landforms. Among the many models of isostasy, two models can be distinguished:

Principle of isostatic compensation:

a. Pratt's model:

Pratt's model (Fig. III.1) assumes that, above a compensation surface at a depth of more than 100 km, elevation variations are due to lateral variations in density:
Unlike Pratt's model,

b. Airy's model:

Assume that the rocks in the crust all have the same density and that they rest on rocks of higher density. Variations in altitude would be compensated by variations in the sinking of the base of the crust at depth.

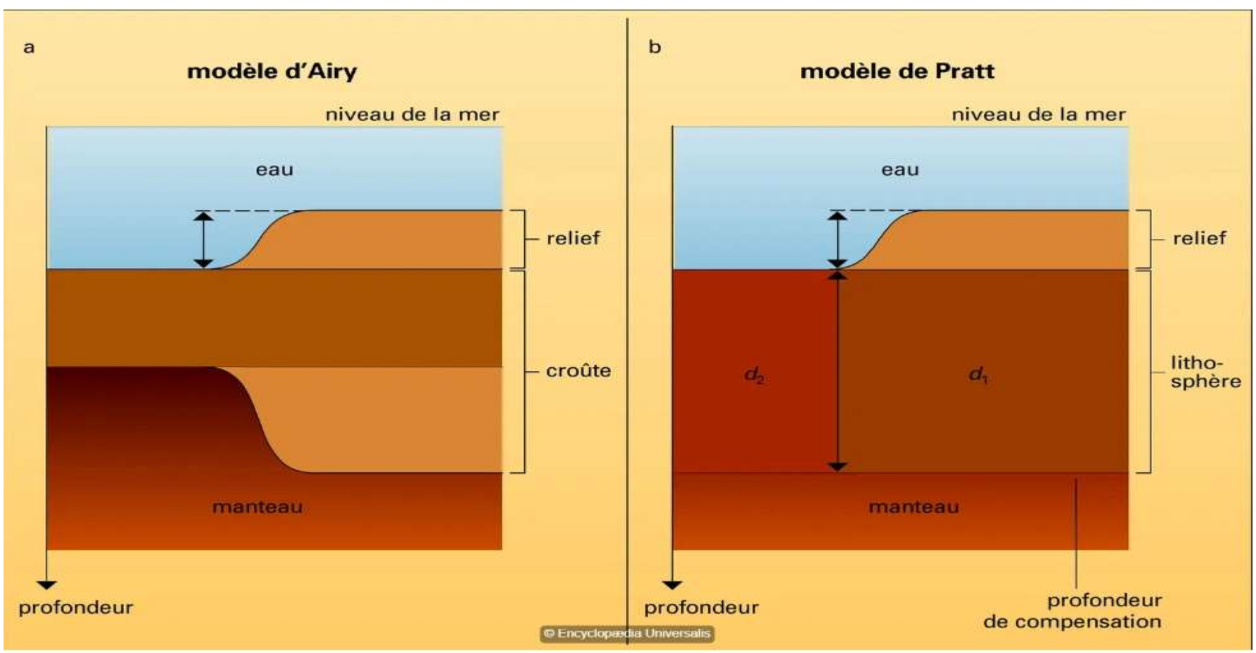
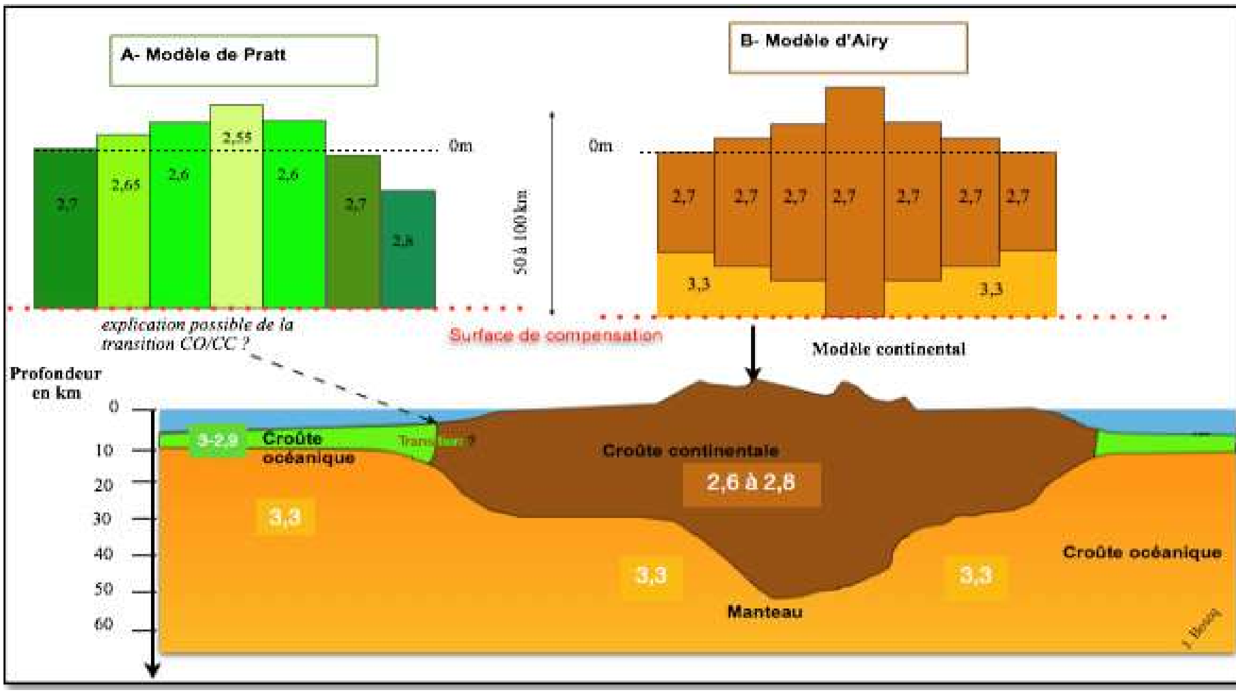
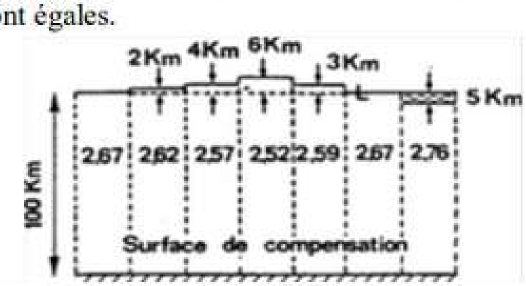


Figure.III.1: Principle of isostatic compensation. In **a**, Airy's model, In **b**, Pratt's model.



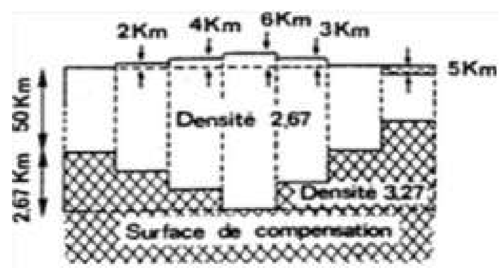
**** Modèle de Pratt***

Ce modèle est basé sur l'hypothèse que les densités varient latéralement dans des colonnes en fonction de leur élévation par rapport au géoïde. Plus la colonne est élevée, moins elle est dense et inversement, de telle sorte qu'à une certaine profondeur, appelée "*la profondeur de compensation*", les pressions seront égales.



**** Modèle d'Airy***

Airy suggère que des morceaux de croûte terrestre plus ou moins épaisse flottent sur une substance de forte densité selon le principe d'Archimède.



The higher the mountains, the more important their roots. In this model and at a certain depth, there is a so-called compensation surface, where the hydrostatic pressures equal. The reliefs will therefore be compensated by a crustal root and the depressions by an anti-root

III.2- Continental drift and plate tectonics:

Definition: The theory of continental drift was published in 1915 by the German geophysicist Alfred Wegener. This theory explains why the current continents have not always occupied the same place. These were united in a primitive supercontinent, Pangea, 250 million years ago.

III.2.1- Continental drift:

The set of horizontal displacements of the continents (or continental blocks) in relation to each other. These are tectonic forces induced by the slow convective movements of the mantle and the consequent displacements of the Earth's crust (displacements of rigid plates by the play of tectonic accidents).

The movement of rigid plates by the play of tectonics which promotes the circulation of heat with the displacement of matter. Thermal energy is transformed into mechanical energy by convection currents, there are two indicators that can be used to measure the loss of energy at the surface:

* Geothermal flux: measures the amount of heat dissipated through the rocks, the fact that the temperature with depth demonstrates that there are exchanges of thermal energy between the center and the surface of the earth (volcanic zone).

* The thermal gradient: measures the increase in temperature as a function of depth with the earthquake or longitudinal and vertical displacement of the earth's blocks. There are two categories of seismic waves: P wave: or first since they are the fastest, these are the compression waves where the displacement of particles is parallel (longitudinal) to the direction of propagation of the wave in the deep regions. S-wave: or secondary, these are vertical waves where the displacement of particles is transverse to the direction of propagation of the wave on the surface.

has. The arguments (evidence) for continental drift are:

- The parallelism of the coasts (the similarity of the shape of the continental shores);
- The distribution of certain fossils (similar fossil fauna and flora before the Mesozoic on continents);
- Traces of ancient glaciations [There are carboniferous sediments (glacial and coal) currently found on continents whose position is inconsistent with the associated environments;
- The correspondence of geological structures (Bourque P.A., 2004).

That is to say, there are arguments:

- **Paleoclimatic:** Traces of Permo-Carboniferous ice in the southern hemisphere → Direction of flow of ice, which comes from the Indian and Pacific Ocean basins → Continents of the southern hemisphere = **Gondwana.**
- **Paleontology:** Fossils of plants and animals in South America and Africa, need for fresh water
- **Pangea:** All the continents were grouped together in the Triassic.

- **Geological:** The rocks and their ages are similar in southern A and Africa: The Guinean and Brazilian coasts fit together perfectly.

- **Geodesic:** The USA is moving away from Europe by 2.5 cm/year
- **Structural:** Faults of the same lithological units on both sides of the Atlantic.

b. The conditions for continental drift are:

- The existence of a rigid lithosphere resting on the ductile asthenosphere allowing mechanical decoupling with the deep mantle.
- The lithosphere is composed of a finite number of plates whose boundaries (subduction zones, transform faults and ridges) correspond to seismic zones.
- The horizontal displacements of the plates are due to convective movements in the mantle.

c. The main stages of continental drift are:

Towards the boundary between the Paleozoic (PZ) and the Mesozoic (MZ) [about 250 million years ago], there is a single landmass, Pangea surrounded by an ocean, the **Panthalassa.** Then this landmass explodes to form two sub-groups, Laurasia and Gondwana, bordered to the west by a new ocean, the **Tethys**.

These continental blocks continue to fragment (and eventually converge) to gradually give rise to the current plates and oceans.

C1. Ocean expansion: (expansion of the ocean floor): Mechanism of opening up the oceans. The oceanic crust is constantly formed by the addition of magma at the level of the ridges and widens symmetrically with respect to them.

C2. A ridge : The area where the lithosphere is created, very wide, very deep [60,000 km long] for the Atlantic]. It is composed of a central rift (valley bounded by faults) and surrounded by volcanoes (shallow earthquakes). The depth of the ocean increases from the ridges - > ocean basins (6000m for the Atlantic);

C3. Ocean expansion : Vast convective movements dragging the lithosphere like a conveyor belt of ridges (partial melting) -> to the point of disappearance. The lithospheric plate thickens by cooling, causing an increase in its density;

C4. New Ocean : Cracking of the continent into 2 plates separated by oceanic lithosphere that infiltrates it.

III.2.2- Plate tectonics:

" ***Everything moves in depth, everything changes on the surface*** ."

a) - Tectonics : This is the part of geology that studies the nature and causes of the deformations of rock formations, more specifically in this case, the large-scale deformations of the Earth's lithosphere.

b) - Plate : Is a rigid volume, not very thick in relation to its surface.

Plate Tectonics **:** Is a unifying planetary scientific theory that proposes that the deformations of the lithosphere are related to the internal forces of the earth and that these deformations result in the division of the lithosphere into a certain number of rigid plates (14) that move relative to each other by sliding on the asthenosphere. Each of these plates may contain both oceanic and continental lithosphere.

Only three plates are entirely oceanic: the Pacific Plate, Nazca and Cocos. The movement of the plates takes place in response to the release of internal heat from the earth. As it dissipates, this heat sets its inner and outer layers in motion. This heat comes from two sources:

- The first source is inherited from the time of its formation by accretion 4.55 billion years ago;
- The second source comes from the decay of radioactive elements (U, Th, K.).

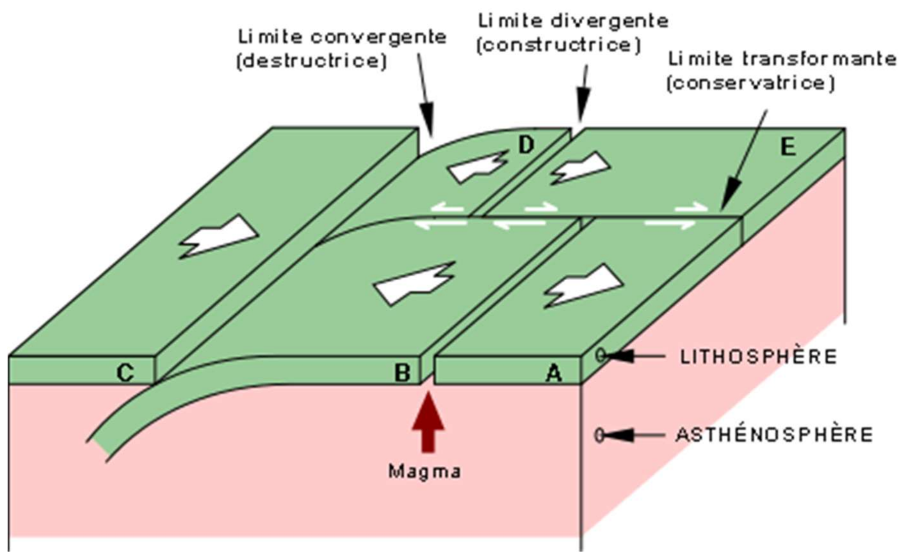
Heat spreads through different conduction and convection mechanisms. In solid layers, it is transmitted by conduction, while in liquid masses convection currents develop. In the outer zone of the core, they are responsible for the Earth's magnetic field, and in the mantle, they are responsible for the processes related to plate tectonics. These movements define three types of plate boundaries (Bourque P.A., 2004):

- **The divergent boundaries**, where the plates are moving away from each other and where new oceanic crust is produced; here, between plates A and B, and D and E;

- **The converging boundaries**, where the plates collide, as a result of divergence; here, between plates B and C and D and C;

Transform boundaries, when plates slide sideways against each other along faults; this type of boundary makes it possible to accommodate differences in the velocities of the displacement of plates relative to each other, as here between A and E, and between B and D, or even reversals of the direction of displacement, as here between plates B and E.

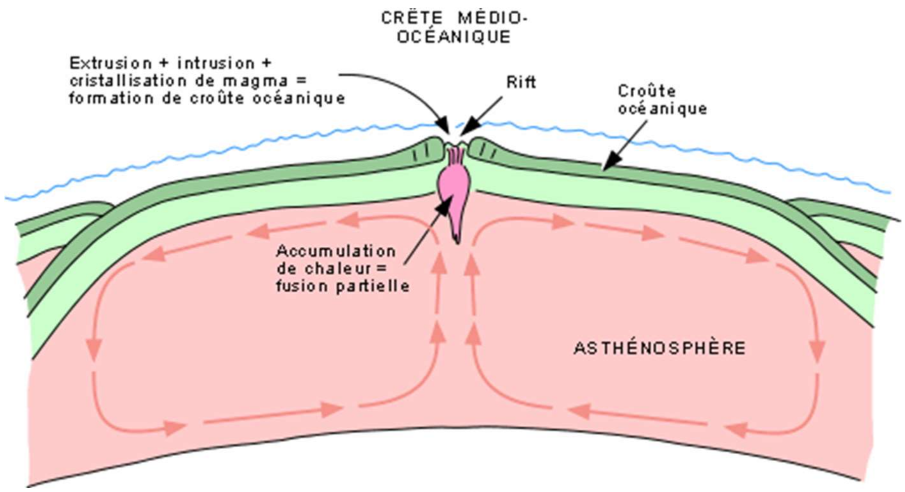
The movement of tectonic plates is provided by the large convection cells in the mantle, which are the result of the flow of heat from the center to the outside of the earth.



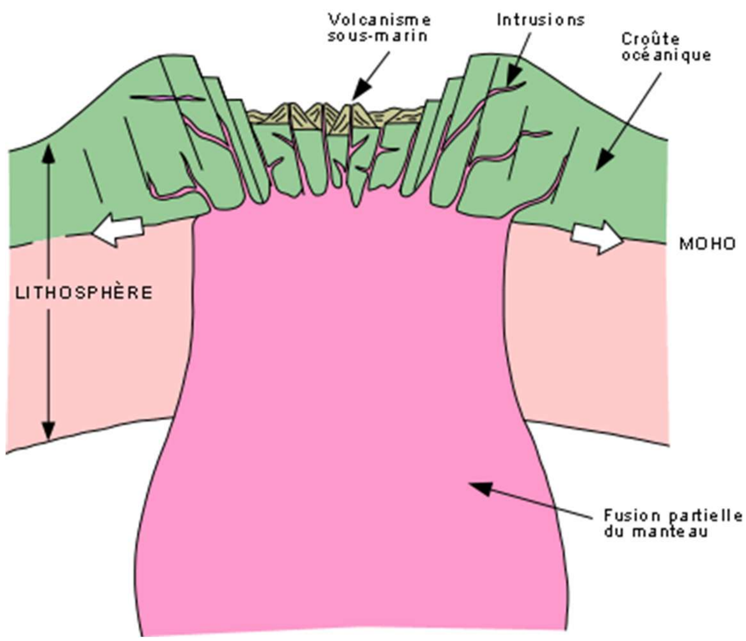
III.2.2.1 - The three types of borders:

a) - Divergent boundaries: A flow of heat that goes from the center to the outside of the earth, a flow caused by the radioactive decay of certain chemical elements in the mantle and which generates convection cells in the plastic mantle (asthenosphere).

Because of this convection, there is a concentration of heat in an area where the heated material expands, which explains the uplift corresponding to the oceanic ridge. The concentration of heat leads to a partial melting of the mantle which produces magma. Convection produces, in the rigid part of the earth's envelope (lithosphere), tensile forces that cause two plates to diverge; it is the driving force behind the conveyor belt, driving the oceanic lithosphere on either side of the ridge. Between these two divergent plates, the arrival of magma creates new oceanic crust (Bourque P.A., 2004).



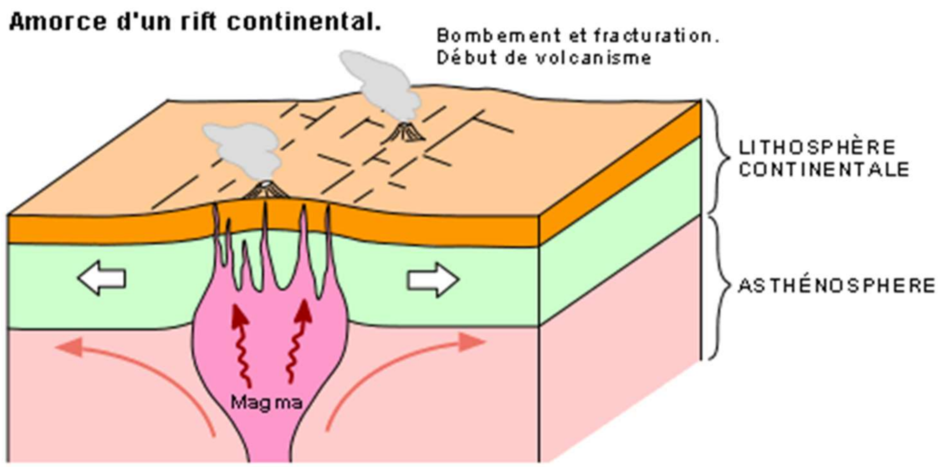
The following diagram is a close-up of the divergence area:



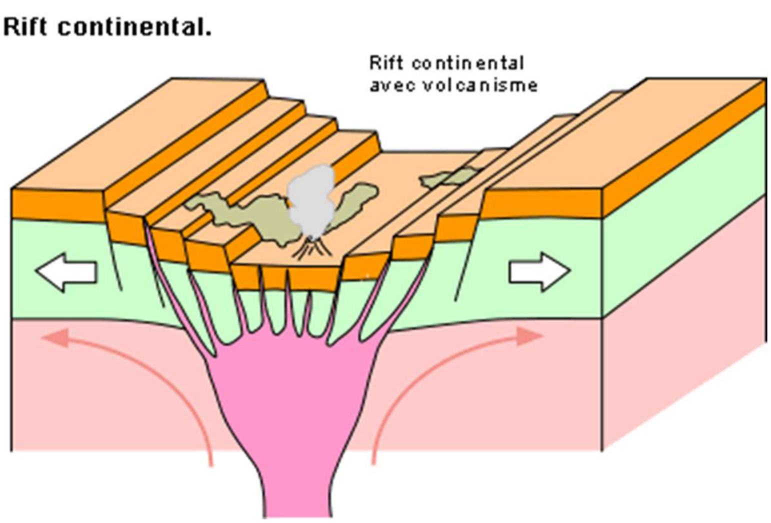
The spreading of the ocean floor creates tensions in the ridge area that result in collapse faults and open fractures, which forms a collapse gap in the middle of the ridge called an oceanic rift.

The magma produced by the partial melting of the mantle is introduced into rift faults and fractures. Some of this magma crystallizes in the lithosphere, while some is expelled onto the ocean floor in the form of lava and forms submarine volcanoes. It is this crystallized magma that forms new oceanic crust as the bottom spreads.

The following diagrams illustrate the four stages of ocean formation

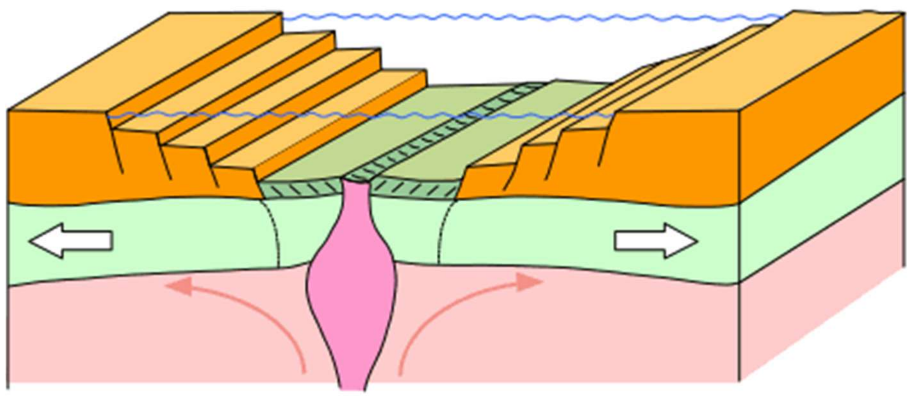


The accumulation of heat under a continental plate causes an expansion of the material that leads to a bulge of the lithosphere. This results in tension forces that fracture the lithosphere and initiate the divergence movement driven by the combined action of mantle convection and gravity. Magma will infiltrate the fissures, which will cause continental volcanism in places; The lavas will form volcanoes or flow along the fissures. An example of this early precursor stage of ocean formation is the Rio Grande Valley in the United States.



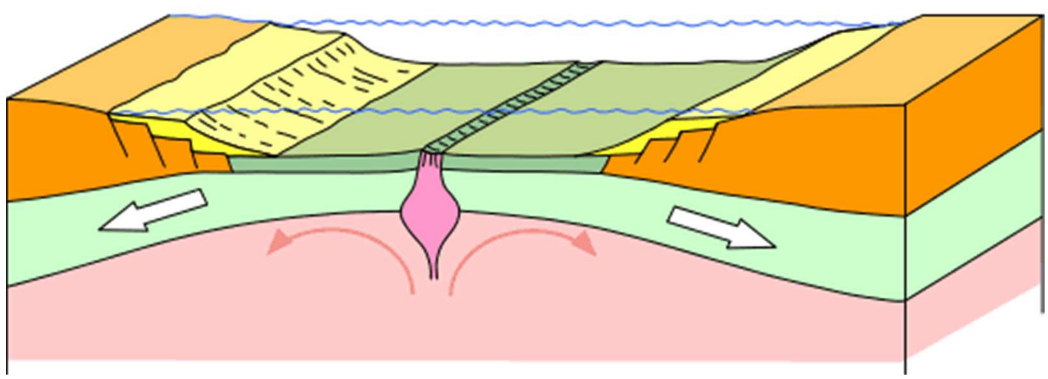
Continued tensions produce a stretching of the lithosphere; there will then be a stairway collapse, which produces a valley called a continental rift. There will be volcanoes and lava effusions along the fractures. The Great African Rift in East Africa is a good example.

Premier plancher océanique - Mer linéaire.



As the stretch continues, the rift sinks below sea level and marine waters flood into the valley. Two pieces of continental lithosphere separate and gradually move away from each other. Submarine volcanism forms a first basaltic ocean floor (oceanic crust) on either side of an embryonic ridge; this is the linear sea stage, as for example theRed Sea.

Océan de type Atlantique



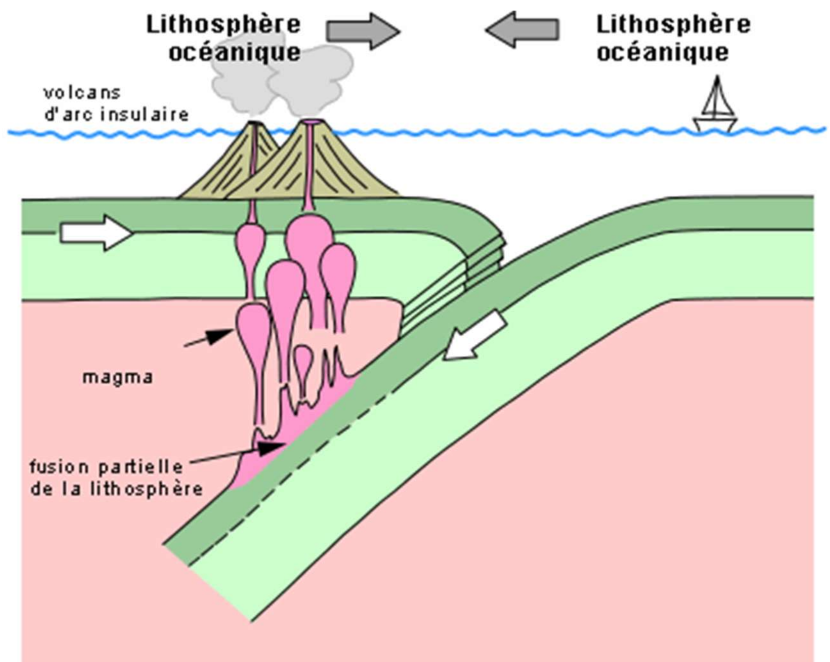
The widening of the linear sea by the spreading of the ocean floor leads to the formation of an Atlantic-type ocean, with its well-individualized ridge, its abyssal plains and its continental shelves corresponding to the margin of the continental crust.

Ocean ridges are important areas of internal heat dissipation from the Earth.

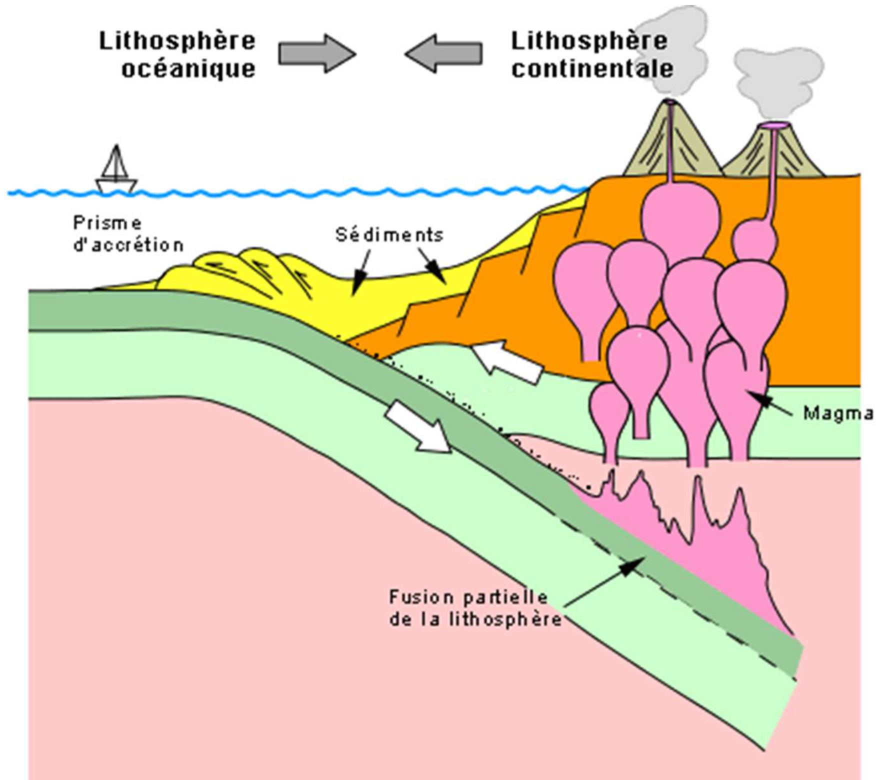
b. Converging borders:

The earth's surface is a finite space, the fact that the plates grow at divergent boundaries implies that lithosphere will have to be destroyed elsewhere to keep the earth's surface constant. This destruction takes place at the converging boundaries which, as the name suggests, mark the contact between two lithospheric plates that converge towards each other. The destruction of plaque is done by sinking a plate into the asthenosphere under the other plate, and by digesting the portion of plate embedded in the asthenosphere. (Bourque P.A., 2004).

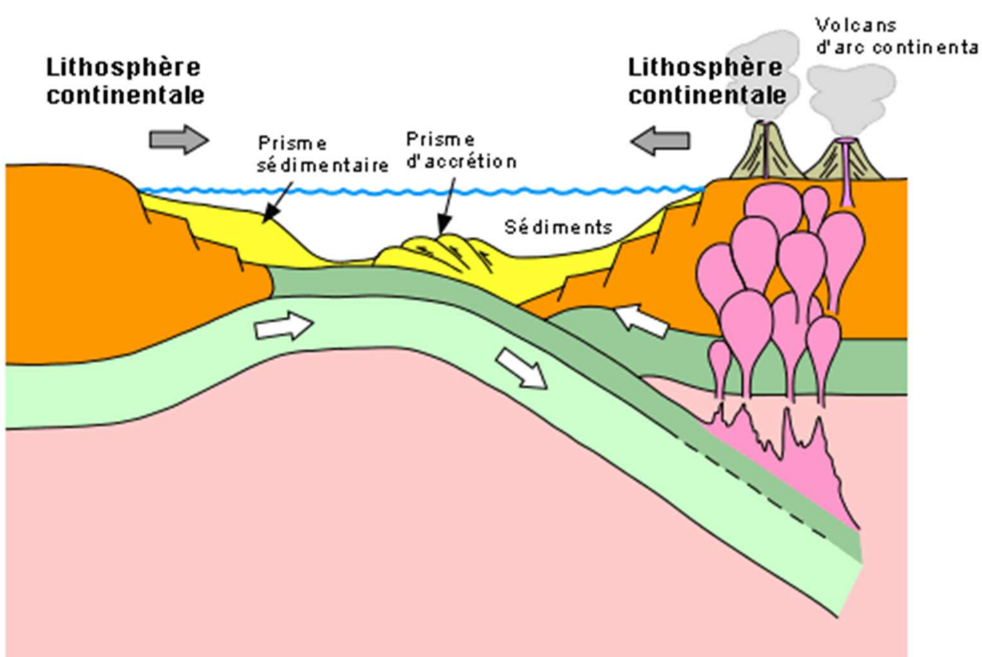
b.1. A first type of collision results from the convergence between two oceanic plates. In this kind of collision, one of the two plates (the denser, usually the oldest) sinks under the other to form a subduction zone.



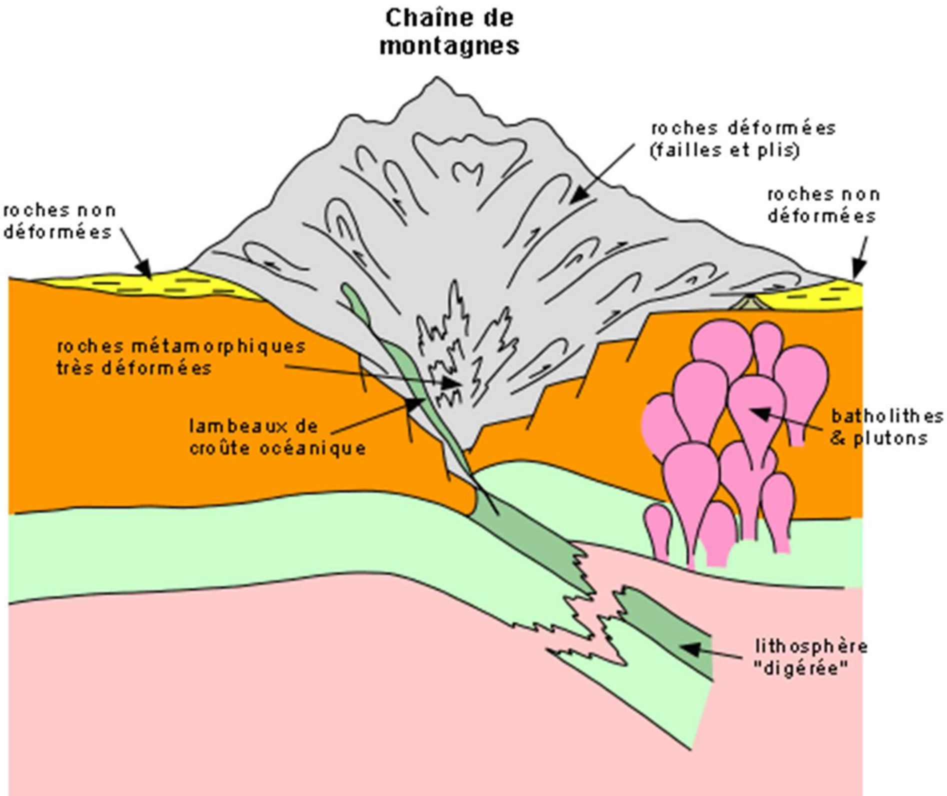
b.2 A second type of collision is the result of the convergence between an oceanic plate and a continental plate. In this type of collision, the denser oceanic plate sinks beneath the continental plate.



b.3 A third type of collision involves the convergence of two continental plates. As the oceanic space closes as two continental plates come together, the sedimentary material of the ocean floor, which is more abundant near the continents, and that of the accretion prism become more and more concentrated; the prism grows.



When the two plates collide, the mechanism coincides: the motor of displacement (convection in the upper mantle and gravity) is not strong enough to push one of the two plates into the asthenosphere because the density of the continental lithosphere is too low compared to that of the asthenosphere. All sedimentary material is compressed and lifts to form a mountain range where rocks are folded and faulted. Shreds of oceanic crust can even get stuck in faults. It is the welding between two continental plates to form a single one.



All the great folded mountain ranges were formed by this mechanism. A good recent example of this situation is the welding of India to the Asian continent, just a few million years ago, with the formation of the Himalayas.

c. Transforming borders:

Transform boundaries correspond to large fractures that affect the entire thickness of the lithosphere; the term transform faults is more often used. They are most often, but not exclusively, found in the oceanic lithosphere. These faults make it possible to accommodate differences in displacement velocities or even opposite movements between plates, or to act as a relay between divergent and convergent boundaries (Bourque P.A., 2004).

The famous San Andreas Fault in California is a good example of this situation: it relays the movement between the divergent boundary of the East Pacific Ridge, the convergent boundary of the Juan de Fuca-North America plates and the divergent boundary of the Juan de Fuca Ridge.

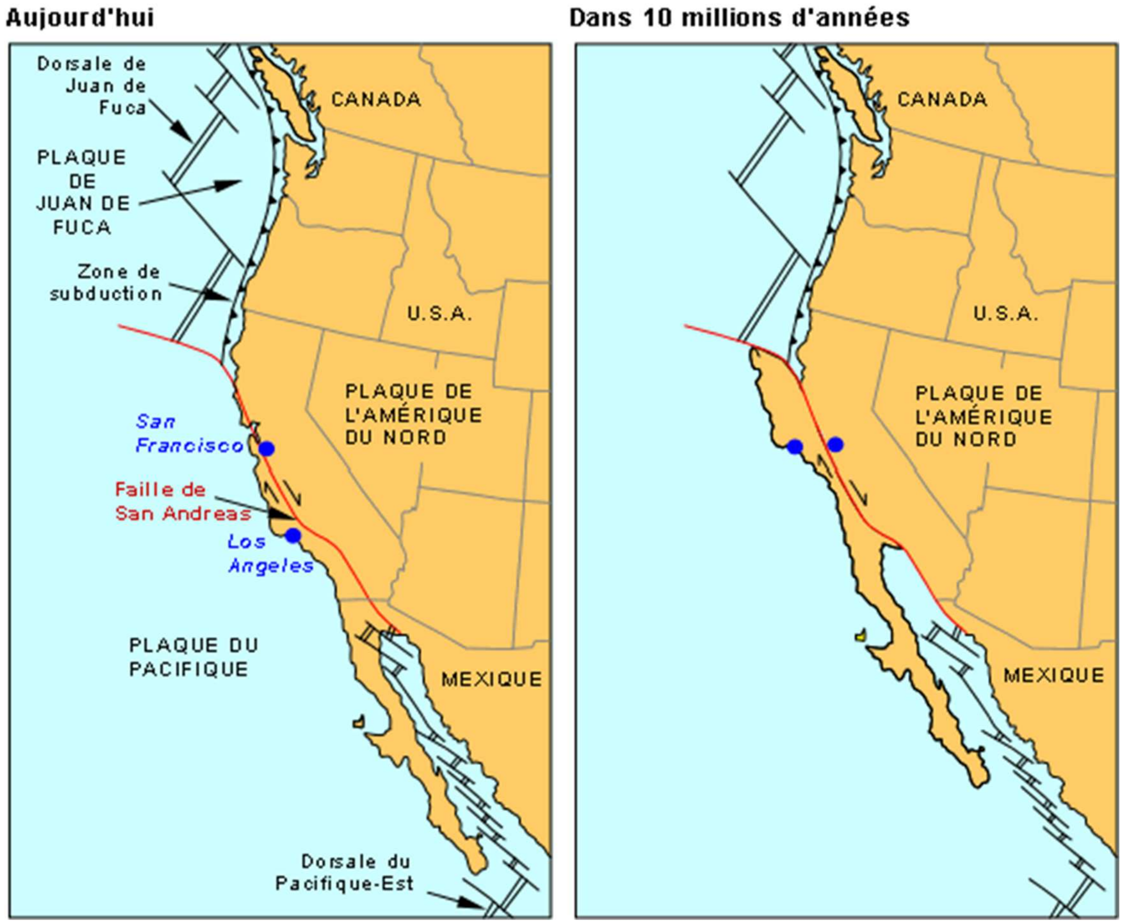


Figure.III.2: San Andreas fault in California.

d. At what rate are these movements of divergence and convergence taking place?

The rates of divergence and convergence are not the same everywhere. The divergence varies from 1.8 to 4.1 cm/year in the Atlantic and from 7.7 to more than 18 cm/year in the Pacific. Convergence is occurring at a rate of 3.7 to 5.5 cm/year in the Pacific. Note the rate of relative lateral displacement along the San Andreas Fault in California (~5.5 cm/year).

III.2.2.2 - Plate displacements:

On the sphere In fact, things are a little more complicated than that: any displacement on the surface of a sphere (in this case the Earth) is comparable to a rotation around a vertical axis passing through a point located somewhere on the surface of this same sphere.

The velocity V of any point on a given plate therefore simply depends on its distance R from the pole of rotation of the plate, and the speed of rotation of this plate around this pole of rotation. The following table gives the positions of the rotation poles, as well as the rotational velocities around these poles in degrees per million years, determined for the 12 major plates.

III.2.2.3-Displacements of the 12 plates:

These plates move, driven by convection in the mantle (fig.III.3). The speeds of these movements range from almost nothing to several centimeters per year, up to 20 cm/year in certain regions of Southeast Asia (Papua New Guinea) and the Pacific (Tonga-Kermadec). It has been observed that a certain number of volcanoes (generally marine, the famous hot spots) move only very slightly in relation to each other: by and large, they are stable and the plates "parade" over them.

Table.III.2: 12 large tectonic plates on the Earth's surface (in order of size):

Plaque		Pole de rotation		
		Latitude	Longitude	vitesse (°/Ma)
1	PACIFIQUE	-63.0	107.4	0.64
2	EURASIE	50.6	-112.4	0.23
3	AFRIQUE	50.6	-74.0	0.29
4	ANTARCTIQUE	63.0	-115.9	0.24
5	INDE-AUSTRALIE	45.5	0.4	0.54
6	AMERIQUE DU NORD	-2.5	-86.0	0.21
7	AMERIQUE DU SUD	-25.4	-124.6	0.11
8	NAZCA	47.8	-100.2	0.74
9	PHILIPPINE	-39.0	-36.7	0.90
10	ARABIE	45.2	-4.4	0.54
11	COCO	24.5	-115.8	1.50
12	CARAIBE	25.0	-93.1	0.21

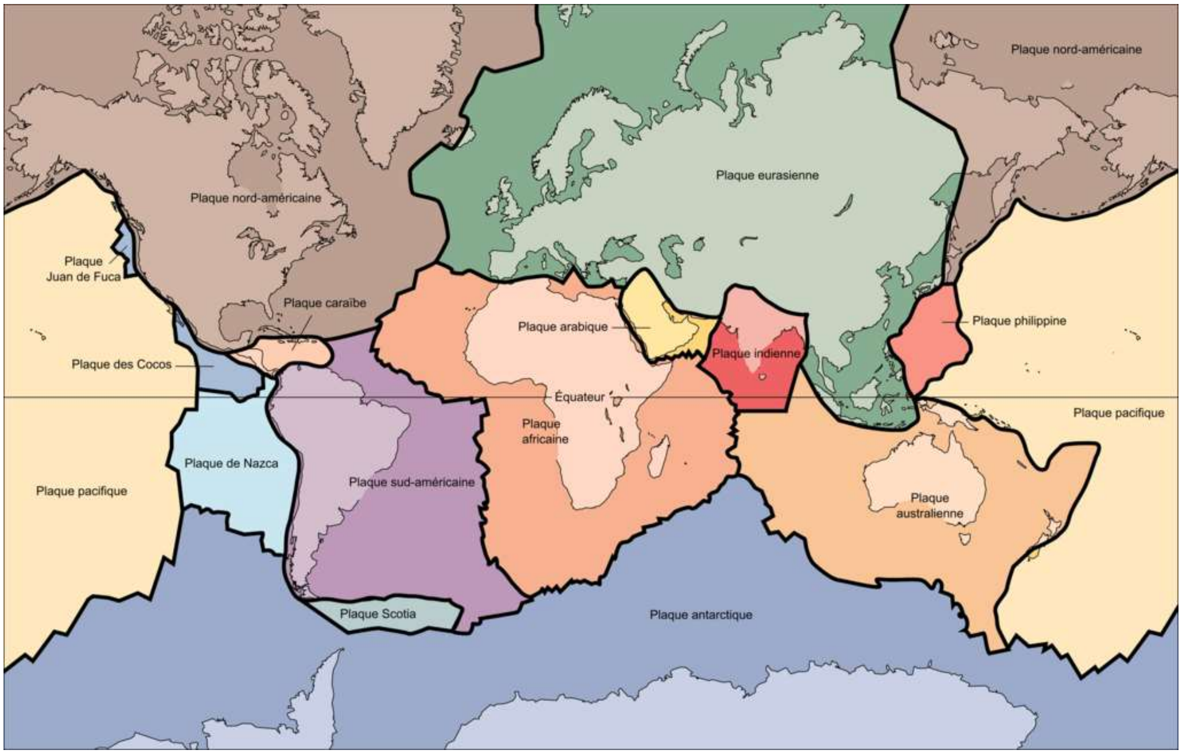


Figure.III.3 : The main lithospheric plates and their boundaries. (Source: Dictionary of History and Philosophy of Science, 1999).

III.2.2. 4 - Seismicity and plate tectonics:

Because of their movements, the plates "rub" against each other or "dabbe" against each other. The "shocks" of the plates against each other are the origin of earthquakes (or earthquakes). One of the very important consequences of the above is that these earthquakes do not occur just anywhere, but only along the boundaries between the plates.

III.2.2.5 - Subduction and Backbone:

A. Subduction:

When two plates converge (fig. III.4), one sinks under the other, into the mantle: this is subduction. This phenomenon generates earthquakes, volcanism, and the formation of mountain ranges. This term was coined by A. Amstrutz in 1951 for the Alps. It refers to the process during which one lithosphere sinks under another (in its time, the theory of plate tectonics was not yet developed). Subduction zones are also called convergent margins or active margins.

B. Back protector:

The (mid-) oceanic ridges, also called (mid-) oceanic ridges, form elongated reliefs on the bottom of the oceans. 1000 to 2000 km wide, they are more than 60,000 km long and more than 2000 m high from the ocean floor. At some points, the summit can reach the surface (Iceland, Azores, etc.). At the level of the ridges, the oceanic crust is constantly formed by the addition of magma.

The axis of the ridges is often marked by a lower zone, this is the rift, not to be confused with the first stage of continental extension, also called the rift.

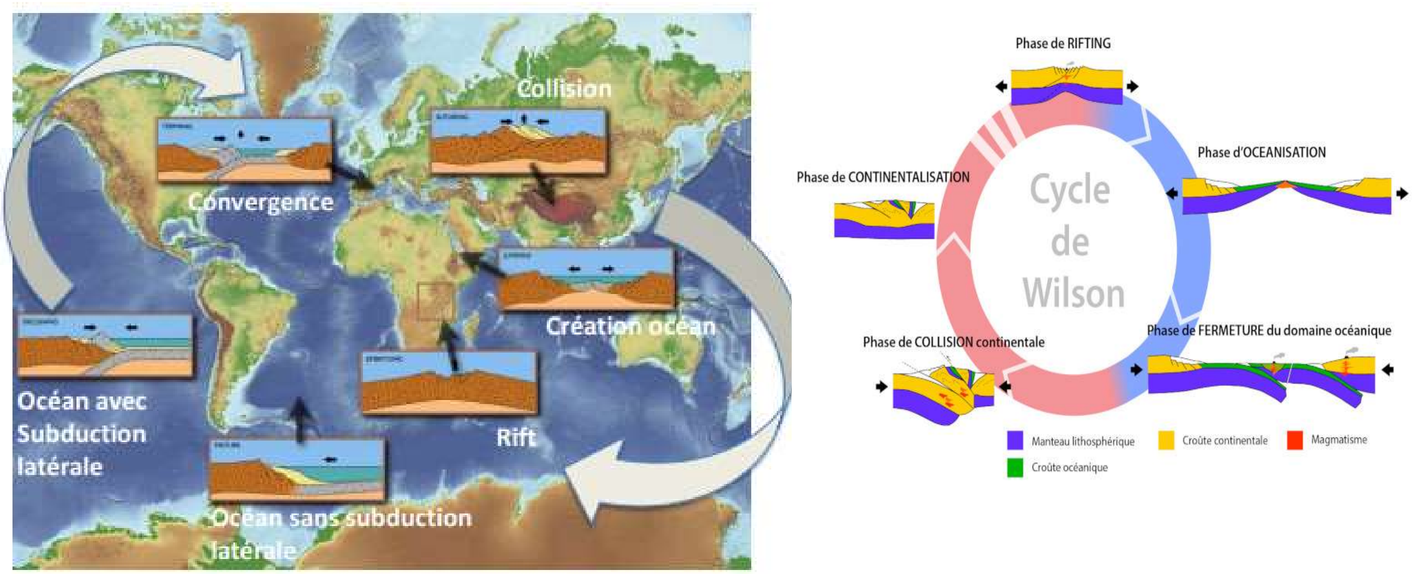


Figure.III.4: Simplified conceptual diagram of the Wilson cycle, and simplified lithospheric sections of the different corresponding tectonic phases.

The blue arrows in the cycle show the phases dominated by divergence, and the red arrows show the convergent phases.

In conclusion:

The earth is a system where all the parts, all the elements, form a great machine driven by thermodynamics. Thus, there is a continuous formation of new oceanic lithosphere at the level of the ridge and a progressive enlargement of the ocean.

On the other hand, since the terrestrial globe is not expanding, it is necessary to destroy the lithosphere, which is done by sinking the oceanic lithosphere into the subduction zones that correspond to deep oceanic trenches that can reach 11 km (Mariana Trench).

Ridges are dissected by so-called transform faults to accommodate differences in divergence rates.

TD Bet

Exercises and Questions on Plate Tectonics and Continental Drift

Exercise 1: Mapping Tectonic Plates

Question: On a blank map of the Earth, identify and name the major tectonic plates. Also indicate the limits of these plates.

Solution:

- Pacific Plate
- North American Plate
- South American Plate
- African Plate
- Eurasian Plate
- Indo-Australian Plate
- Antarctic Plate
- Nazca Plate
- Scotia Plate
- Caribbean Plate
- Convergent, divergent, and transform boundaries marked between plates

Exercise 2: Movement of the Plates

Question: Explain the three main types of tectonic plate boundaries and give an example of each type.

Solution:

1. **Convergent Boundary:** The plates are getting closer. Example: Indo-Australian Plate and Eurasian Plate (Himalayas).
2. **Divergent Boundary:** The plates move apart. Example: Mid-Atlantic Ridge between the North American Plate and the Eurasian Plate.
3. **Transforming Limit:** The plates slide horizontally against each other. Example: San Andreas Fault between the Pacific Plate and the North American Plate.

Exercise 3: Evidence of Continental Drift

Question: List and describe three pieces of evidence supporting the theory of continental drift proposed by Alfred Wegener.

Solution:

1. **Coastal correspondence:** The coasts of South America and Africa seem to fit together perfectly.
2. **Similar fossils: Fossils** of Mesosaurus, an aquatic reptile, have been found in both Africa and South America.
3. **Geological similarities:** Mountain ranges and rock formations on different continents correspond, for example, to the Appalachian Mountains in North America and the Caledonian Mountains in Scotland and Scandinavia.

Exercise 4: Impact of Plate Tectonics

Question: Discuss the impact of tectonic plate movements on natural phenomena such as earthquakes and volcanic eruptions.

Solution:

- **Earthquakes:** Occur mainly along the boundaries of transform plates (e.g. San Andreas Fault).
- **Volcanic Eruptions:** Volcanoes often form along convergent (e.g., Pacific Ring of Fire) and divergent (e.g., Mid-Atlantic Ridge) boundaries.
- **Mountain Formation:** Mountains form at converging boundaries where plates come together and rise (e.g. Himalayas).

These exercises and questions offer a variety of methods to explore and understand the concepts of plate tectonics and continental drift.

III.3- Formation of reliefs:

A landform is a variation of the earth's surface characterized by elevations and depressions from a reference level, often sea level (**zero**). It includes various geographical forms such as mountains, valleys, plateaus, hills, and plains, and is shaped by geological processes such as erosion, sedimentation, and tectonic movements.

Figure.III.5: Relief in Arizona, United States.

Geomorphology traditionally distinguishes three main types of relief:

- the Plain;
- the plateau;
- the Mountain.

Other landforms include valley, hill, fjord, gorge and, submerged, shoal, seamount, ridge and ocean trench.

The difference in altitude is the difference in altitude between two points on the ground. The slope and the position in relation to sea level also characterize the relief.

Topography measures aerial reliefs while bathymetry measures underwater reliefs.

III.1- Physical characteristics of a relief:

A relief is defined by:

a. **Its altitude** : There are low and high altitude areas. Low-lying areas are the most common on Earth:

- 0 to 200 meters ≡ 31% of the land area.
- 200 to 500 metres ≡ 29% of the land area.
- 500 to 1000 metres ≡ 20% of the land area.
- More than 1000 meters ≡ 20% of the land area.

b. **The distribution** of upland and lowland varies from continent to continent:

- Regions between 0 and 500 meters cover 85% of Europe, but only 44% of Asia.

- Regions above 1000 meters represent only 6% of Europe, 29% of Asia and 22% of Africa.

c. **Its slope:** It is never zero, even though some forms of relief seem flat to us.

A relief form is therefore an assembly of slopes whose dimensions, orientations and gradients are very variable;

- Its age: Reliefs have a life: we are talking about young, mature, old, etc. On a human scale, however, the changes remain very little visible.

III.2- Factors influencing the development of the relief:

The development of landforms is influenced by a variety of factors, including geological, tectonic, climatic and erosional processes. Here are some of the key factors that shape landforms:

1-Tectonic activity:

Landforms are significantly influenced by tectonic forces, which result from the movement and interaction of the Earth's tectonic plates. Tectonic processes such as plate collisions, subduction zones, and faults can give rise to landforms such as mountains, rift valleys, and volcanic features.

2-Geological composition:

The underlying geological composition of an area plays a crucial role in the development of landform. Different types of rocks and minerals have varying resistance to erosion, which can lead to the formation of distinct landforms. For example, tough rocks like granite can form a robust mountain range structure , while softer rocks like sandstone are more prone to erosion and can create unique formations such as arches or hoodoos.

3-Erosion:

Erosion and weathering processes shape landforms over time. Water, wind, ice and gravity contribute to the erosion and transport of rocks and sediments. Rivers carve valleys and canyons, glaciers carve mountains and valleys, wind can shape sand dunes, and coastal erosion creates cliffs and beaches. Weathering, degrading rocks and minerals, also contributes to the formation of specific reliefs.

4-Climate and weather:

Influence landforms by affecting erosion rates, sediment transport and deposition. Heavy rainfall increases erosion and forms deep river valleys, while arid regions see the accumulation of sand dunes. Freeze-thaw cycles in cold climates contribute to the formation of features such as freeze timing and talus slopes.

5-Stroke:

The reliefs develop and evolve over long periods. The processes of erosion, deposition, and tectonic activity are causing significant changes to the Earth's surface. Landforms can persist for millions of years or change rapidly in response to geological events such as earthquakes or volcanic eruptions.

6- Human influence:

Human activities can also have an impact on the relief. Human-induced factors such as mining, deforestation, urbanization and the construction of dams can alter the natural landscape, leading to the creation of artificial landforms or the modification of existing ones.

III.3- Types of relief:

Landforms can be classified into different types based on their characteristics, the geological processes involved in their formation, and their location. Here are some of the main types of landforms:

1/Mountains:

The mountains are of great relief, characterized by a high elevation and steep slopes. They are usually formed by tectonic processes such as the collision of tectonic plates or volcanic activity. Examples include the Himalayas, the Andes, and the Alps.

2/Trays:

Plateaus are raised flat areas with steep sides. They can be formed by volcanic activity, tectonic uplift, or erosion. Plateaus are often the result of remnants of ancient mountain ranges or may be associated with tectonic processes. The Colorado Plateau in the United States and the Deccan Plateau in India are notable examples.

3/Plains:

The plains are large, low-lying areas characterized by relatively flat or gently undulating landscapes. They are usually formed by the deposition of sediment by rivers, wind or glaciers over long periods of time. Plains are common in river valleys, coastal regions, and glaciation areas. The Great Plains of North America and the Indo-Gangetic Plain of South Asia are well-known examples.

4/Valleys:

Valleys are low-lying areas between mountains or hills, often carved out by rivers or glaciers. They can vary in size, shape, and depth. Valleys are usually characterized by a U-shaped or V-shape, depending on whether they are formed by glacial or fluvial processes. The Grand Canyon in the United States and the Nile Valley in Egypt are striking examples.

5/Deserts:

Deserts are arid regions characterized by sparse vegetation and low rainfall. They can be sandy (like the Sahara Desert), rocky (like the Atacama Desert), or a combination of both. Deserts often feature sand dunes, rock formations, and large tracts of arid land.

6/Coastal reliefs:

Coastal landforms are shaped by the interaction of land and sea. They include beaches, cliffs, bays, estuaries, and deltas. Coastal landforms are influenced by processes such as erosion, sediment deposition, wave action and changes in sea level. Examples include the Great Barrier Reef in Australia and the Cliffs of Moher in Ireland.

7/Difference between the plateau and the plain:

- **The plateau** is a flat surface incised by watercourses (rivers and streams) = the watercourses are enclosed.
- **The plain** is a flat surface on which the streams (rivers and streams) flow without any incision = the streams are on the surface.

Orogenies: Orogeny: (from Gr. Oros = mountain, genesis = origin):

III.4- Formation of mountain ranges.

The formation of mountains resulting from the movements of the earth's crust:

- Tectonic deformations linked to compression phenomena => Formation of a mountain range accompanied by fractures, folds, faults.
- All the phases of construction that lead to the formation of mountain ranges, in the broad sense.

Orogenic cycle: The orogenic cycle or tectonic cycle is the sequence of events corresponding to the formation and destruction of a mountain range. Such a cycle generally consists of three phases:

- Sedimentation in a sedimentary basin formerly called a "geosyncline", which often corresponds to a continental margin;
- Orogeny, i.e. folding of sediments accumulated in the sedimentary basin and uplift of a mountain range;
- Peneplanation of the mountain range.

There are three successive cycles since the Paleozoic: the Caledonian cycle, the Hercynian cycle and the Alpine cycle which is not finished.

Ancient ensembles: Between the Paleozoic and the Mesozoic (250 Ma)

a- Panthalassa: Unique ocean.
b- Pangea: Continental grouping.

c- Pangaea → Laurassia: 1st continental part.
→ Gondwana: 2nd continental part.

d- Two continental parts.

Part TD: Formation of Reliefs.

Question 1: What are reliefs?

Landforms are natural features that make up the Earth's surface. They include mountains, valleys, plains, plateaus, deserts, rivers, lakes, and coastlines.

Various geological processes, including erosion, deposition, tectonic activity, volcanic activity, weathering, and the actions of water, wind, and ice.

Question 2: How are reliefs formed?
The reliefs are formed p

Question 3: What is the difference between a mountain and a hill?

Mountains are higher and steeper landforms than hills. They often have rugged terrain, higher altitudes, and are formed by tectonic forces or volcanic activity. Hills, on the other hand, are smaller and have gentler slopes.

Question 4: What is the difference between the plateau and the plain?

The plateau is a flat surface incised by watercourses (rivers and streams) = the watercourses are enclosed.

The plain is a flat surface on which the streams (rivers and streams) flow without any incision = the streams are on the surface.

Question 5: **What are the three successive cycles since the Paleozoic?**

-The Caledonian cycle, the Hercynian cycle and the Alpine cycle which is not over.

-The ancient ensembles: Between the Paleozoic and the Mesozoic (250 Ma)

a- Panthalassa: Unique ocean.
b- Pangea: Continental grouping.

c- Pangaea → Laurassia: 1st continental part.
→ Gondwana: 2nd continental part.

d- Two continental parts.

Question 6: How are trays formed?

The plateaus are flat or slightly undulating reliefs. They can be formed by processes such as uplift, volcanic activity, or erosion, where the surrounding areas erode more quickly, leaving behind a relatively flat raised surface.

Question 7: What are the coastal features?

Coastal features refer to the various landforms found along coastlines, such as cliffs, beaches, sea piles, sand dunes, estuaries, and coral reefs. These features are shaped by the interaction of land, sea and geological processes.

Question 8: How are caves formed?

Caves are formed by the dissolution of soluble rocks (such as limestone) by water over long periods of time. Water seeps into cracks and joints, slowly widening them to create underground cavities.

Question 9: What is karst topography?

Karst topography refers to landscapes formed by the dissolution of soluble rocks, such as limestone or dolomite. It is characterized by features such as sinkholes, caves, endangered streams, and subsurface drainage systems.

Question 10: How are deserts formed?

Deserts form in regions with limited rainfall and high evaporation rates, resulting in arid conditions. They can be classified as hot deserts (such as the Sahara) or cold deserts (such as the Gobi), depending on their geographical location.

Question 11: What are the main types of plains?

The main types of plains include coastal plains (formed by the deposition of sediment along the coasts), alluvial plains (formed by rivers and floodplains), and glacial plains (formed by glacial action and sediment deposition).

III.4 - Tectonic accidents:

III.4.1- Definition of Tectonic Accidents

Tectonic accidents refer to discontinuities and deformations in the Earth's crust caused by tectonic movements. These geological structures mainly include faults, folds, thrusts and bedload sheets. Tectonic accidents result from the internal forces of the Earth, such as compression, tension, and shear, which cause fractures and displacements of rocks.

III.4.2- The different types of tectonic deformations:

There are two types of deformations:

- Brittle deformations (faults and fractures);
- Soft deformations (folds).

These two categories of deformations depend mainly on the physical conditions (mainly pressure) that are exerted during the deformation, and on the properties of the rocks (ductility, i.e. the ability to deform without breaking).

1 - The folds:

Definition : When ductile rocks are subjected to tectonic stresses, these rocks will generally deform in a flexible (non-brittle) manner. We then obtain undulations called folds (fig.III.6). Types of folds include anticlines (upward convex folds) and synclines (upward concave folds). Boggs (2006) describes folds as curvatures of rock layers under the effect of tectonic compression.

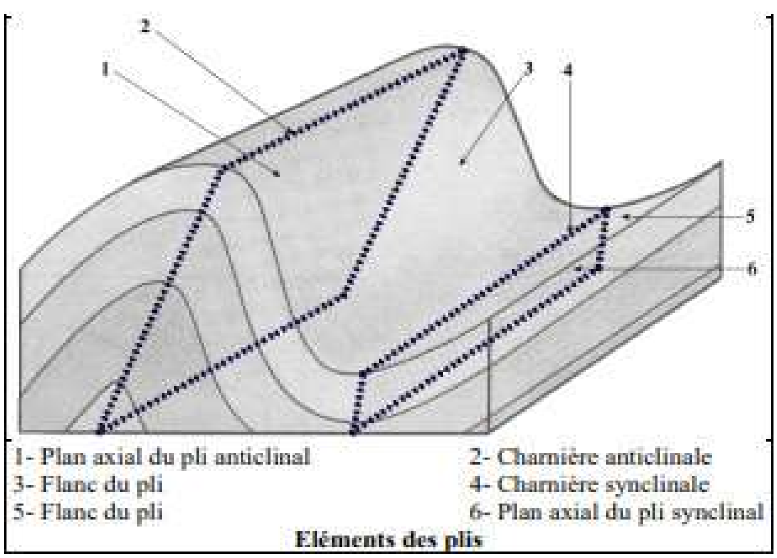


Figure.III.6: Elements of a fold.

1.1- The different types of folds:

a-Syncline:

A **syncline** is a geological structure consisting of a concave fold whose core is occupied by the most recent geological layers (fig.III.7).

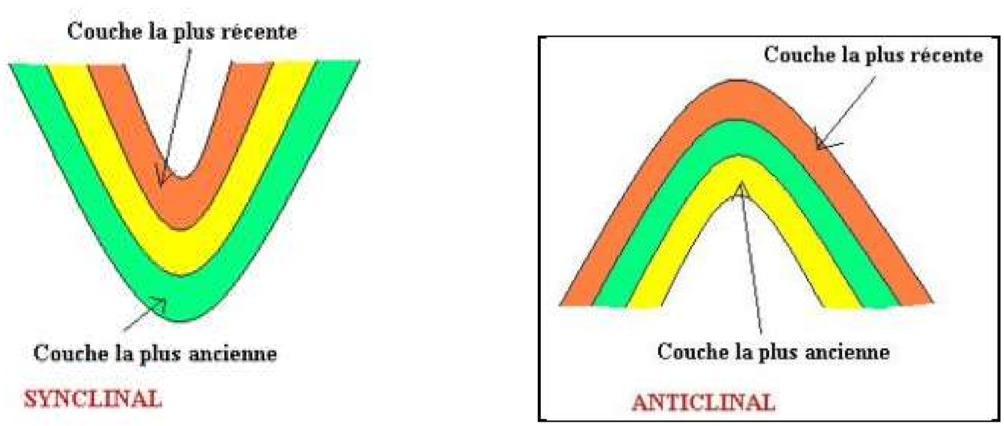


Figure.III.7: Diagram of a syncline and an anticline.

b- Anticline:

An anticline is a geological structure consisting of a convex fold whose core is occupied by the oldest geological layers and is overlain by more recent strata.
According to Press and Siever (2001), an anticline is formed when compressive tectonic forces act on layers of rock, causing them to bend upward into an arc-like structure. The characteristic shape of the anticline is easily identifiable in geological profiles and on topographic maps, where the contours of the rock layers show an upward curvature.

Figure.III.8: Anticline in the Halifax Formation (Cambrian). (Nova Scotia, Canada).

2. Fault:

A fault is a fracture in the Earth's crust (Fig. III.9) along which there has been a relative displacement on both sides. Faults can be classified according to the direction of displacement (normal, inverse, strike-slip). (Press and Siever, 2001),

2.1. Overlap:

In geology, a **thrust** is a tectonic movement leading one set of terrains to cover another through an anomalous contact (such as a recumbent fold, reverse fault), generally of low inclination, called an overthrust surface. This horizontal movement thus leads to the vertical superposition of two sets of land whose succession is not normal.

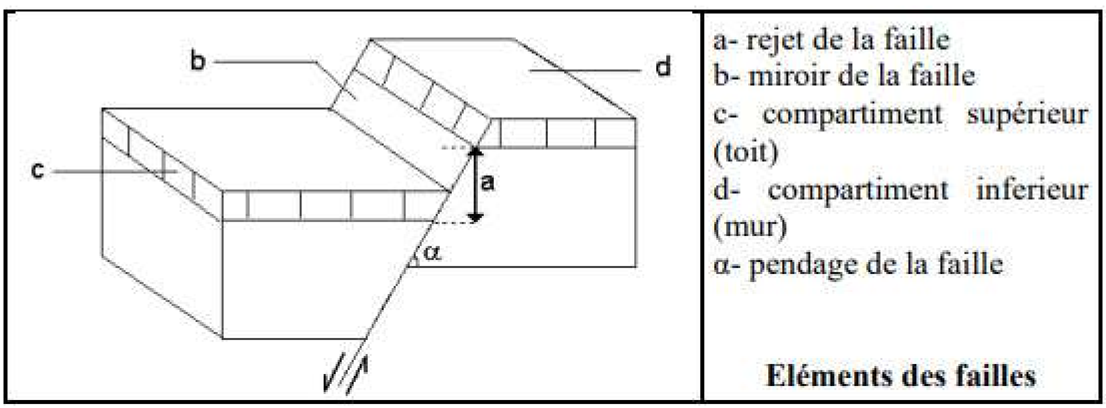


Figure.III.9: Main elements of a fault.

The higher unit is said to be carried or, again, **allochthonous**. The lower unit is considered to be **autochthonous** (Fig.III.10), i.e. not to have moved. (Alain Foucault and Jean-François Raoult, 2010)

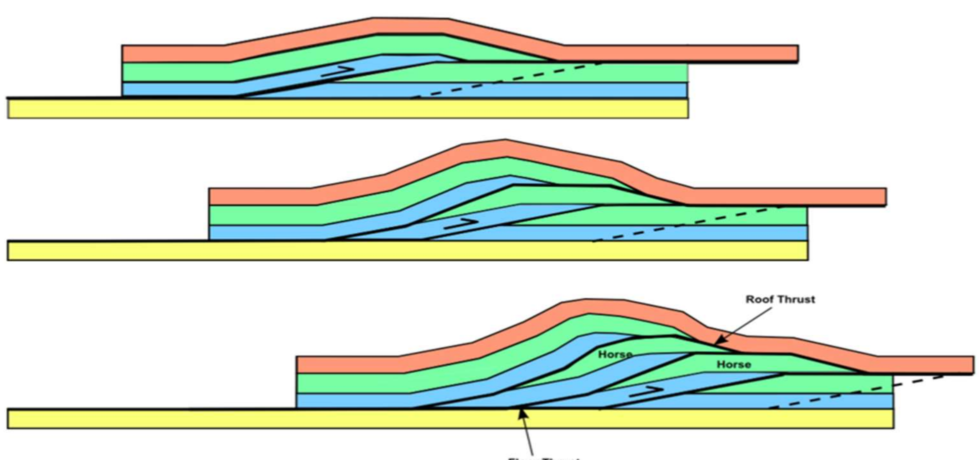


Figure III.10: Diagram on the sequences of an overlap leading to a stack of scales carried.

2.2 - Bedload table:

A **bedload sheet** is an important set of geological layers which, during an orogeny, have detached from the basement and moved horizontally over great distances, often tens of kilometres, over younger layers (Fig.III.11). This is referred to as non-native land as opposed to indigenous land. Davis and Reynolds (1996) describe bedload sheets as "rock masses displaced horizontally over large distances by tectonic forces (Fig.III.12).

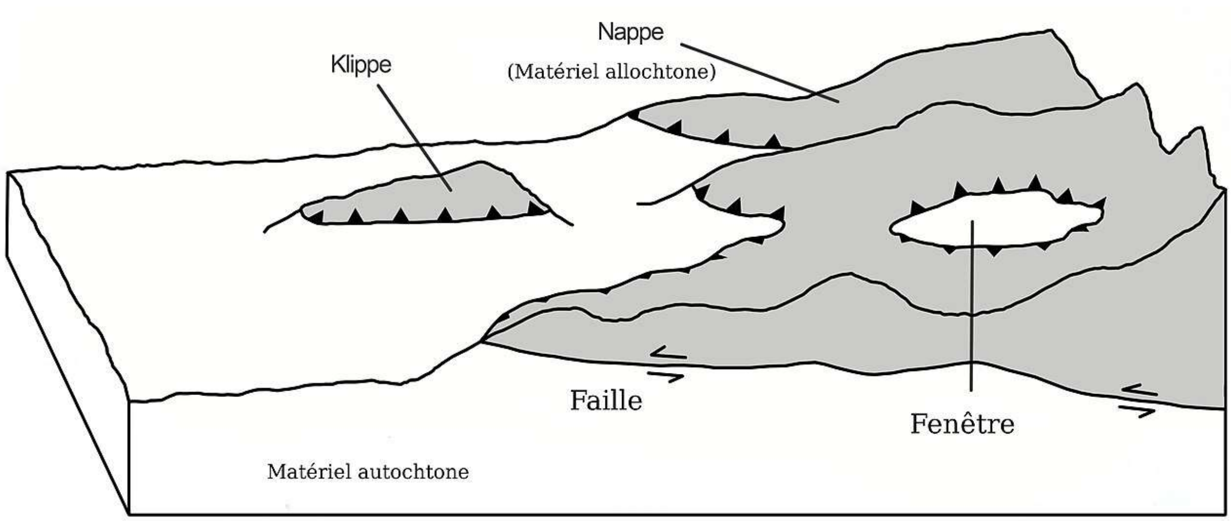


Figure.III.11: Main elements in a bedload sheet.

In grey, the remains of a bedload after the beginning of erosion.
A klippe (German for "pit") is a part of a bedload sheet that is isolated from the rest of it by the effect of erosion.
A window.and An area of the eroded water table allowing you to see the underlying indigenous terrains.

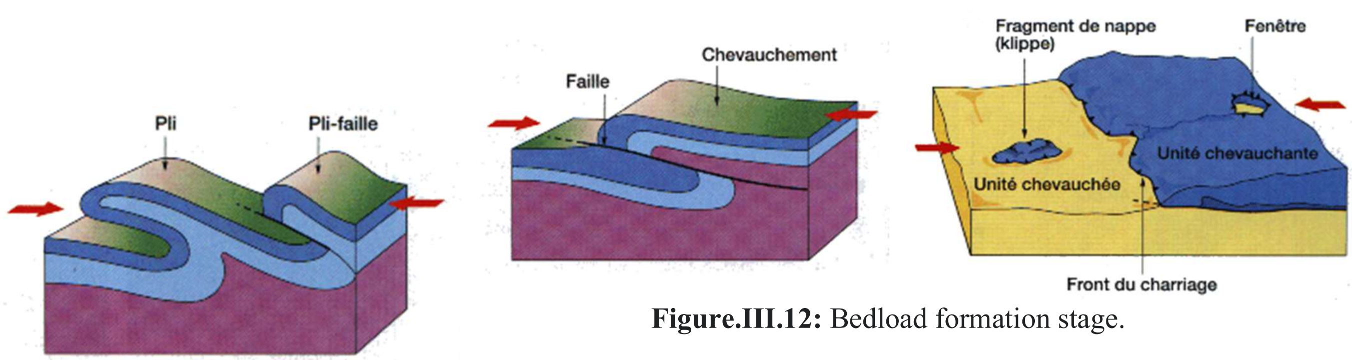


Figure.III.12: Bedload formation stage.

III.4 - Reliefs and simple structures: Cuestas

The **cuesta** is an asymmetrical landform (fig.III.13) consisting on one side of a steeply sloping bank with a concave profile (the front) and, on the other, of a gently inclined plateau in the opposite direction (the reverse). The cuestas are found at the edges of sedimentary basins that are not very deformed. The corresponding relief can also be called a **coast**.

Of Spanish origin, the word *cuesta* has passed into the lexicon of geomorphology and has the advantage of avoiding any confusion with the coasts, in the sense of coastline (Alain Foucault and Jean-François Raoult, 2010). It is also international, since it is used in the same technical sense in different languages, for example in English, Italian, Turkish (kuesta) or Romanian.

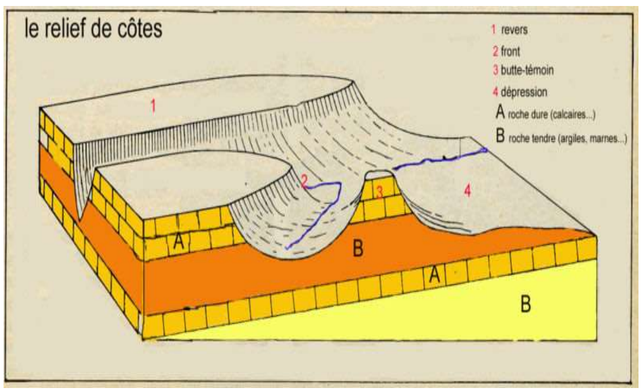


Figure.III.13: Main elements of a Cuestas and the cuesta of the South Downs in the London Basin.

III.4.1 – Training:

The conditions for the development of a cuesta relief are as follows:

- Existence of a monocline device (the layers have the same dip);
- Alternation of rocks of different hardness (hard rock at the top, soft rock below);
- Attack by an agent of erosion (hydrographic network that forms a cuesta by erosion. The latter also plays an important role in the evolution of the cuesta, depending on the thickness of the hard and soft layers it contains, also according to the direction of flow of this same network: anaclinal or not);
- concordant rocks.

Anaclinal network: a watercourse flowing in the opposite direction of the dip of the layers of the cuesta. Thus, over time, the anaclinal streams cut into the cuesta.

TD Part:

Questions and Answers on Tectonic, Anticline and Syncline Accidents

Questions:

1. What is a tectonic accident and what are its main types?
2. Describe an anticline. How is it formed?
3. What is a syncline and how does it differ from an anticline?
4. What are the differences between a normal fault, a reverse fault and a strike-slip fault?
5. What are the geological factors that influence the formation of anticlines and synclines?
6. How can tectonic accidents influence seismic hazards in a region?
7. Explain how anticlines and synclines can affect the exploration and exploitation of natural resources.
8. Give an example of a tectonic accident in Algeria and describe its characteristics.
9. What is the difference between an overlap and a bedload sheet?

Answers:

1. **What is a tectonic accident and what are its main types?**
   - **Answer:** A tectonic accident is a deformation of the earth's crust resulting from tectonic forces. The main types include faults (normal, reverse, strike-slip faults), folds (anticlines and synclines), thrusts and bedload sheets.
2. **Describe an anticline. How is it formed?**
   - **Answer:** An anticline is a geological structure formed by the folding of rock layers upwards, creating a convex shape. It usually forms under tectonic compressive forces, where layers of rock are pushed together.
3. **What is a syncline and how does it differ from an anticline?**
   - **Answer:** A syncline is a geological structure formed by the folding of rock layers downwards, creating a concave shape. It differs from an anticline, which is bent upwards. Synclines also form under tectonic compressive forces, but the layers are bent in the opposite direction.
4. **What are the differences between a normal fault, a reverse fault and a strike-slip fault?**
   - **Answer:**
     - **Normal fault:** The rock above the fault plane moves downward relative to the rock below. This is usually due to tensile forces.
     - **Reverse fault:** The rock above the fault plane moves upward relative to the rock below. This is usually due to compressive forces.
     - **Strike-slip fault:** Rocks move horizontally relative to each other, along the fault plane, under shear forces.
5. **What are the geological factors that influence the formation of anticlines and synclines?**
   - **Answer:** Geological factors include tectonic forces (compression, tension, shear), rock composition and structure, the presence of faults or other discontinuities, and pressure and temperature conditions.

6. **How can tectonic accidents influence seismic hazards in a region?**
   - **Answer:** Tectonic accidents, such as faults, are areas of weakness where earthquakes can occur. Sudden movement along a fault releases energy in the form of earthquakes, increasing seismic hazards in the region.
7. **Explain how anticlines and synclines can affect the exploration and exploitation of natural resources.**
   - **Answer:** Anticlines can form structural traps for oil and gas, making these areas suitable for exploration and development. Synclines can also contain mineral resources. Knowledge of these structures helps to locate and extract natural resources efficiently.
8. **Give an example of a tectonic accident in Algeria and describe its characteristics.**
   - **Answer:** The Beni Ourtilane fault is an example of a tectonic accident in Algeria. It is a dextral strike-slip fault that crosses the Tell Atlas Mountains. It is associated with frequent seismic activity and has a significant impact on the landscape and geological hazards in the region.

9- We speak of overlap if the movement remains restricted. When the relative displacement of a water table over another geological area becomes very important, it is then referred to as bedloading.

Exercise 1: Identification of Tectonic Accidents on a Geological Map of Algeria

1. **Instructions:**
   - Use a geological map of Algeria.
   - Identify and mark the different faults (normal, inverse, strike-slips).
   - Identify and mark the main folding structures (anticlines, synclines).
   - Look for areas of overlaps and bedload sheets and mark them.
2. **Questions:**
   - What types of faults predominate in Algeria?
   - Where are the main folding areas?
   - What are the examples of thrusts or bedload aquifers in Algeria?

Exercise 2: Case Study - The Beni Ourtilane Fault

1. **Instructions:**
   - Study the Beni Ourtilane fault, an important fault in Algeria.
   - Describe its geological features and its impact on the surrounding area.
   - Analyze the tectonic mechanisms responsible for this fault.
2. **Questions:**
   - What type of fault is the Beni Ourtilane fault?
   - What are the seismic risks associated with this fault?
   - How has the Beni Ourtilane fault influenced the local landscape?

Solutions for Tutorials

Exercise 1: Identification of Tectonic Accidents on a Geological Map of Algeria

1. **Identification of flaws**:
   - Normal Rifts: Mark them in blue on the map.
   - Reverse Faults: Mark them in red on the map.
   - Strike-slip faults: Mark them in green on the map.
2. **Folding**:
   - Anticlines: Mark them in black on the map.
   - Synclines: Mark them in purple on the map.
3. **Overlaps and bedload sheets** :
   - Mark them in orange on the map.
4. **Answers to questions**:
   - Strike-slip and reverse faults predominate in Algeria, particularly in seismically active regions such as northern Algeria.
   - The main folding areas are in the Atlas mountain ranges.
   - Examples of overlaps include the overlaps in the Tellian Atlas Mountains.

Exercise 2: Case Study - The Beni Ourtilane Fault

1. **Geological features**:
   - The Beni Ourtilane fault is a dextral strike-slip fault.
   - It crosses the Tell Atlas Mountains in Algeria.
   - The fault is associated with frequent earthquakes in the region.
2. **Regional Impact**:
   - The fault influences the hydrographic network and the surrounding valleys.
   - It creates significant seismic risks for local populations.
3. **Answers to questions**:
   - The Beni Ourtilane fault is a strike-slip fault.
   - Associated seismic hazards include frequent and potentially destructive earthquakes.
   - The fault influenced the local landscape by creating linear valleys and ground deformations.

TD Bet: Cuestas Questions and Answers

Questions

1. What is a cuesta?
2. What are the main character-defining elements of a cuesta?
3. How is a cuesta formed?
4. What is the difference between the reverse and the forehead of a cuesta?
5. What type of rock do cuestas usually form in?
6. Why are cuestas often asymmetrical?

7. Give an example of an area where cuestas are present.
8. How do sloping geological layers influence the formation of cuestas?
9. What role does differential erosion play in cuesta formation?
10. What are the impacts of cuestas on the landscape and land use?

Answers

1. **What is a cuesta?**
    - A cuesta is a type of asymmetrical relief resulting from the differential erosion of sloping geological layers, characterized by a gentle slope (reverse) and a steep slope (front).
2. **What are the main character-defining elements of a cuesta?**
    - The main elements of a cuesta are the reverse (gentle slope), the front (steep slope), and the sloping geological layers that make up the formation.
3. **How is a cuesta formed?**
    - A cuesta is formed by the differential erosion of layers of resistant and less resistant rocks. Sloping layers are eroded at different rates, creating a gentle slope on less resistant rocks and a steep slope on more resistant rocks.
4. **What is the difference between the reverse and the forehead of a cuesta?**
    - The reverse is the gentle slope of the cuesta, inclined according to the angle of the geological layer, while the front is the steep slope formed by the erosion of the resistant layer.
5. **What type of rock do cuestas usually form in?**
    - Cuestas usually form in sedimentary rocks such as limestone, sandstone, clay and marl.
6. **Why are cuestas often asymmetrical?**
    - Cuestas are asymmetrical due to differential erosion of sloping geological layers, where stronger rocks form steep slopes and less resistant rocks form gentle slopes.
7. **Give an example of an area where cuestas are present.**
    - One example is the Champagne region of France, where cuestas are characteristic of the landscape.
8. **How do sloping geological layers influence the formation of cuestas?**
    - The sloping geological layers determine the angle of the gentle slopes (reverse) and influence the way in which erosion acts on the individual layers, thus forming cuestas.
9. **What role does differential erosion play in cuesta formation?**
    - Differential erosion is crucial in the formation of cuestas, as it erodes less resistant rocks faster than resistant rocks, creating asymmetrical slopes.
10. **What are the impacts of cuestas on the landscape and land use?**
    - Cuestas influence drainage, agriculture, and construction due to their distinct slopes. Steep fronts can form natural barriers, while soft fronts can be used for agriculture.

These questions and answers provide an in-depth understanding of cuestas, their formation, and their impact on the landscape.

Questions and Answers Related to Cuestas:

Question 1: Define a cuesta and explain its formation:

Answer:
A cuesta is an asymmetrical landform characterized by a gentle slope (the front of the cuesta) and a steep slope (the reverse side of the cuesta). It usually forms in regions where layers of sloping sedimentary rocks are more resistant to erosion. The gentle slope corresponds to the more resistant rock layer, while the steep slope is eroded more quickly.

Question 2: What are the main factors that influence the formation of cuestas?

Answer:
The main factors that influence the formation of cuestas include the nature of the sedimentary rocks (their resistance to erosion), the inclination of the rock layers, erosional processes (such as water and wind), and local climatic conditions. Differences in erosion resistance between rock layers play a crucial role in the formation of the gentle and steep slopes characteristic of cuestas.

Exercise 1: Identifying Cuestas

Question: On a topographic map, identify and describe the characteristics of a cuesta. Explain how you can distinguish it from other landforms.

Solution:
To identify a cuesta on a topographic map, look for a series of hills or mountains with asymmetrical slopes: a gentle slope and a steep slope. The gentle slope represents the layer of rock that is more resistant to erosion, while the steep slope corresponds to the softer layer of rock. The contour lines on the map will be more spaced out on the gentle slope and closer together on the steep slope, indicating a variation in gradient.

Exercise 2: Analysis of Cuestas

Question: Explain how cuestas can influence land use and human activities in a given area.

Solution:
Cuestas can influence land use and human activities in several ways. Gentle slopes can be used for agriculture, pasture, or human settlements due to their accessibility and stable terrain. Steep slopes, on the other hand, may be less suitable for agriculture and settlement due to instability and erosion. Cuestas can also affect roads and infrastructure, requiring earthworks to create safe and stable passages.

III.5 - Evolution of the Jura Forms:

The **Jurassic** is a geological period that extends from −201.4 ± 0.2 to −145.0 million years (Ma).

The Jurassic is the period, or intermediate system, of the Mesozoic Era, which is also known as the Reptile Era.

The Jurassic system is subdivided into three geological series, the Lower Jurassic, the Middle Jurassic and the Upper Jurassic, formerly known as Lias, Dogger and Malm, respectively.

In 1795, the German naturalist Alexander von Humboldt proposed the term "limestone or Jura terrain" to refer to the predominantly limestone series of the Jura mountains, corresponding to the fossil-rich sediments deposited on the seabed of the Secondary era.

Its stratigraphic position within the Secondary period, between the Triassic and Cretaceous periods, was established by the geologist Ami Boué in 1829. In the same year, the French geologist and naturalist Alexandre Brongniart erected this lithological ensemble as a system, under the name of Jurassic after the limestones found in the Jura massif (Encyclopædia *universalis*, 1992).

This geological period is marked by intense tectonic and sedimentary activity, leading to the formation of various geological structures such as mountains, plateaus, valleys and sedimentary basins.

III.5.1 - Formation and Evolution Process:

1. **Plate Tectonics:** The Jurassic period was characterized by the fragmentation of the supercontinent Pangea and the opening of the Atlantic Ocean. This active tectonics has caused the formation of mountain ranges and faults, thus shaping the Jura reliefs (Ziegler, 1988).
2. **Sedimentation:** The epicontinental seas that covered large areas deposited sedimentary layers rich in marine fossils. These sediments, mainly limestone, sandstone and clay, accumulated in the sedimentary basins, forming strata characteristic of the Jurassic period (Selley, 2000).
3. **Erosion:** Erosion processes, such as the action of rivers, wind and ice, have sculpted the Jura reliefs, creating valleys, gorges and plateaus. Differential erosion has also led to the formation of typical landforms such as cuestas (Guiraud & Bosworth, 1997).
4. **Climate:** The Jura climate, which is generally hot and humid, has favoured the development of vast forests and the formation of soils rich in organic matter. Climatic variations have also influenced sedimentation and erosion processes (Ziegler, 1988).

III.5.2-Evolution of the Jura Forms in Algeria:

The Jurassian forms refer to the geological structures and landscapes formed during the Jurassic period (about 201 to 145 million years ago). This period is marked by marine and continental sedimentary deposits, mainly limestone, which gave rise to various reliefs. The evolution of the Jura forms is the result of complex tectonic, sedimentary and erosive processes, influenced by the climatic conditions of the time. These forms are well represented in Algeria, where they offer striking examples of the geological history of the Jurassic.

1. **Origin and Formation**

During the Jurassic, part of Algeria was submerged by shallow seas, favouring the formation of vast limestone deposits. These deposits stratified and formed limestone plateaus and mountain ranges (Ait Brahim & Choubert, 1972).

2. **Tectonics and Uplift**

Tectonic movements, especially those associated with the Alpine orogeny, caused these sedimentary layers to rise and fold. This created geological structures such as synclines (concave folds downwards) and anticlines (convex folds upwards) (Belkebir & Boudda, 2001).

3. **Erosion and Morphology**

Erosion processes, caused by water, wind and climatic variations, have shaped these structures into distinct shapes. Differential erosion, where the more resistant limestone layers remain raised while the softer layers are eroded, has created characteristic landscapes such as cuestas (asymmetrical hills or ridges), plateaus and gorges (Zighmi & Djaballah, 1995).

4. **Current landscapes**

The mountainous regions of the **Tell Atlas** and the **Highlands** in Algeria have many Jura formations. Structures such as **the Tighennif Gorge** and the **Tlemcen Plateaus** illustrate these geomorphological processes.

Karst forms, resulting from the dissolution of limestone, are also present, with caves and underground drainage systems (Tabel, 2014).

The Jurassic: it begins with a marine transgression; the calcareo-dolomitic facies with ooliths of the Rhaetian, resting on the Keuper, give way to marls in the Upper Lias.

In the **Hodna** and **Boussaâda**, carbonates fill the Atlas trench. In the western Tell and the Saharan platform, the deposits are carbonate (200 m).

Cretaceous: detrital and siliceous, it outcrops in the Saharan Atlas, where it reaches 1,200 m in depth. In the Aptian, a carbonate transgression with reefs marks sedimentation in the Hodna and the Aurès; sandstones dominate in the south and west (fluvio-deltaic).

In the Albian, sandstone and then flysch were deposited in the Saharan Atlas, while in the Tell, clay-sandstone facies dominated. In the SE of Constantine, an Upper Cretaceous transgression begins with carbonate deposits.

In the Cenomanian, the sea is present, shallow in the south (evaporites) or frankly marine in the Tell (1,000 m of pelagic marl). The Cenomanian is neritic (300 to 400 m thick) at Telagh and Tiaret, carbonate in the Hodna. The Turonian marl with lamellibranchs and echinoderms covers all of northern Algeria with the exception of the Highlands and the Constantinois.

In the Senonian, marl-limestone sedimentation continued, marked by a deepening of the sea.

5. Human Impact

The exploitation of limestone resources for construction and industry has also modified these reliefs. Quarries and excavations contribute to the modern evolution of the Jurassic landscapes in Algeria. These activities have sometimes revealed buried geological structures and important fossils, enriching the understanding of the geological history of the region (Belkebir & Boudda, 2001).

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1. http://www2.ggl.ulaval.ca/personnel/bourque/s1/plan.section.1.html
The internal dynamics of the earth.

2. http://www.geowiki.fr/index.php?title=Roche
Participatory encyclopedia dedicated to geology and Earth sciences.

3. http://planet-terre.ens-lyon.fr/article/histoire-tectonique-plaques.xml
History of the theory of plate tectonics.

4. http://aemq.org/FR/NOTIONS_GEOLOGIE / Basic notions in geology.

Chapter IV:
External Factors of Morphology.

IV-Introduction:

In geomorphology, erosion is the process of degradation and transformation of relief, and therefore of soils, rocks, banks and coastlines, which is caused by any external agent (i.e. other than tectonics).

A relief whose shape is mainly explained by erosion is called "erosional relief". The erosion factors are:

- The climate;
- The relief;
- The physics (hardness) and chemistry (solubility, for example) of rock;
- Ecological and pedological factors (presence/absence of fauna, vegetation cover, etc.) and their nature;
- Tectonic history (fracturing for example);
- Human action (agricultural practices such as ploughing, overgrazing, soil mineralization, slope crops, etc.), deforestation, waterproofing, artificialization, urbanization, which is taking on a growing and worrying importance in the world. Erosion acts at different rates and can, over several tens of millions of years, level mountains, dig valleys, and make cliffs recede.

IV.1- Erosion methods:

Erosion wears out the rock material and shapes a wide variety of shapes.

1. Recessed shapes:

Erosion can hollow out the rock and give rise to dissecting patterns (Pech et al, 1992)

- Gorge, canyon;
- Valley and glacial cirque;
- Chasm, cave, grotto;
- Ravine; etc.

The gully affects the landscapes called badlands. Precipitation, by flowing on slopes made up of loose materials (clay, sediments), digs channels and furrows.

2. Other forms:

Erosion can give rise to accumulation patterns:

- Turreted karst;
- Inselberg;
- Pinnacles;
- Chaos of granite balls (Brittany, Massif Central) or sandstone blocks (Fontainebleau Forest);
- Sugarloaf Rio de Janeiro; •
- Fireplace: fairy chimneys (Hautes-Alpes), Demoiselles coiffées (Turkey).

3. Littoral:

The retreat and transformation of coastlines depend on many factors:

- The configuration of the coast;
- The nature of the rock;
- The strength and direction of currents, waves, coastal drift and swell;
- The presence of pebbles;
- Anthropization. There are therefore several scenarios:
- Coastline with cliff different depending on the rocks;
- The creeks belong to the karst relief;
- The rias, abers and fjords;
- Marshes, deltas, estuaries;
- The dunes.

4. Erosion of agricultural soils:

- The erosion of agricultural soils produces crusts (gypsum or limestone), ferruginous and lateritic armour. This erosion (fig.IV.1) is largely due to human action: •
- Land clearing;
- Intensive agricultural methods, monoculture, cultivation in spaced rows, mechanization, ploughing, bare soil in winter, land clearing, furrows in the direction of the slope, etc.;
- Road and urban developments increase runoff areas;
- Overgrazing: in the Sahel countries, desertification is the consequence of overgrazing;
- Areas destroyed by fires are particularly vulnerable to erosion.
-

Figure.IV.1: Wadi in flood in cultivation area Soil erosion

IV.2- Erosion Process

Rocks exposed to air are decomposed under the influence of various agents, the action of which is especially important when there is no vegetation cover and in extreme climates. These atmospheric agents prepare the work of erosion, but also give rise to certain characteristic forms of relief.

Erosion is the set of external phenomena which, on the surface of the ground or at shallow depths, remove all or part of the existing land; and thus modify the relief. There are two types of phenomena; the effects of which most often add up.

1. **Chemical processes:**

   With alteration (surface modification of a rock) and dissolution by water more or less laden with carbon dioxide.

2. **Physical or mechanical processes:**

   With the disintegration of rocks and the removal of debris; hence the distinction between aeolian erosions; glacial fluvial; navy.

The water, contained in the fractures of the rocks, can freeze and increase in volume (10% more volume). This can cause the fractures to widen and the rock to burst. Water therefore participates in the physical alteration.

In the erosion process, there are generally three distinct phases:

- Destruction of rock material;
- Transport;
- Accumulation of debris.

Erosion involves a superficial disintegration of rock or soil called weathering (Weathering is the weathering of rocks by meteoric agents, i.e. mainly by water and temperature). It occurs on the spot, and produces debris. The degree of erosion depends on the characteristics of the rock:

- Hardness, for example: the most resistant rocks and minerals are diamond and corundum; the least resistant are talc, gypsum and calcite, the presence of quartz makes granite more resistant: erosion will therefore be slower;
- The expansion capacity of the rock;
- Of its chemistry.

IV.2.1 - Factors of physical or mechanical alteration of rocks:

A- Disintegration due to temperature variations:

a) Lightning action: Lightning can burst a rock. It is due to it that the star bursts observed in the mountains on the rocks of the summits are due.

b) Daytime and nighttime sunstroke and temperature variation:

Physical weathering also occurs in hot and dry climates. Under the effect of daytime and night-time temperature variations (from 50 to 60° in the desert), the rocks become brittle and cracks appear (fig.IV.2). Under the effect of temperature changes, internal tensions develop that cause the destruction of rocks.

Figure IV.2: Diagram illustrating the freeze/thaw phenomenon at the origin of the physical weathering of rocks.

c) Variations in temperature and water in physical weathering:

Temperature variations in cold and dry climates (freeze/thaw) can affect the physical structure of the rock (Fig.IV.3).

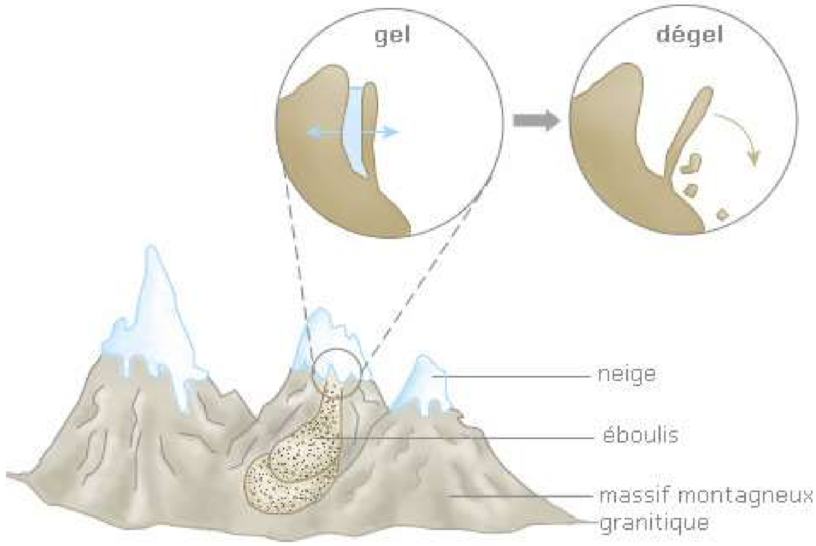

Figure IV.3: Cracked clay soil in hot and dry climates.

d) The role of plants in the physical alteration of rocks:

The roots of plants allow them to draw water and mineral salts essential to their development. As they grow, they are able to crack the rocks of the subsoil. Their growth causes these cracks to enlarge and the rock to gradually disintegrate (Fig.IV.4).

Figure.IV.4: Granite block partly eroded by plants.

Note: acidic molecules secreted by plants also contribute to the alteration of rocks.

B - The role of wind in the physical alteration of rocks:

Strong winds can also cause rocks to fracture and disintegrate.

Physical weathering, also known as mechanical weathering, causes the fragmentation and disintegration of the rock. Physical weathering facilitates chemical weathering, by increasing the contact surface between rock and rainwater.

Rather dry climates are more conducive to physical weathering.

IV.2.2 - Chemical alteration of rocks:

Chemical weathering affects the mineralogical and chemical composition of the rock. Rainwater is the main agent. This is enriched with carbon dioxide (which comes from the atmosphere).

It can be responsible for the dissolution of certain minerals in the rock by chemical phenomena such as hydrolysis, for example.

Depending on the mineralogical composition of the rock, it will be more or less affected by chemical weathering. In addition, depending on the initial rock, the weathering products formed are different.

a - Example of the chemical alteration of limestone:

Limestone is essentially made up of calcium carbonate with the chemical formula $CaCO_3$.
An experiment (Fig. IV.5) is used to verify the solubility of calcium carbonate in the presence of distilled water (without carbon dioxide) or in the presence of water enriched with carbon dioxide (which represents rainwater). **Chalk will be used to represent calcium carbonate.**

Chalk powder and distilled water or carbon dioxide-enriched water are placed in 2 test tubes. We are agitating. At the beginning of the experiment, in the 2 test tubes, the water has a whitish color.

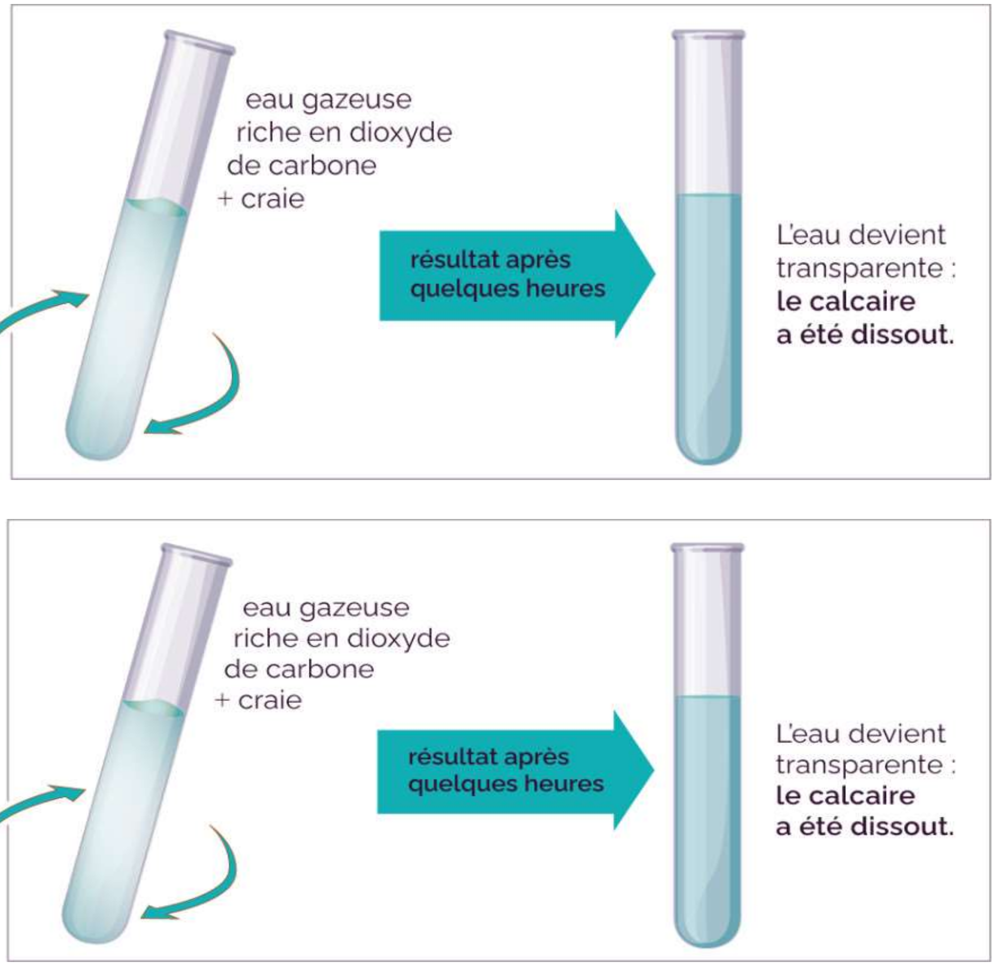

Figure IV.5: Results of the experiment after a few hours.

The carbon dioxide-enriched water dissolved the chalk powder.

The following chemical equation explains this phenomenon:

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

With: CO_2: carbon dioxide
H_2O: water
Ca^{2+}: calcium ion
HCO_3^- : hydrogen carbonate ion

Remark

In other cases, chemical weathering changes the structure of certain minerals, leads to the formation of new compounds, etc.

b. Example of physical and chemical weathering of a rock:

Granite Presentation of alteration at the rock scale (fig.IV.6)

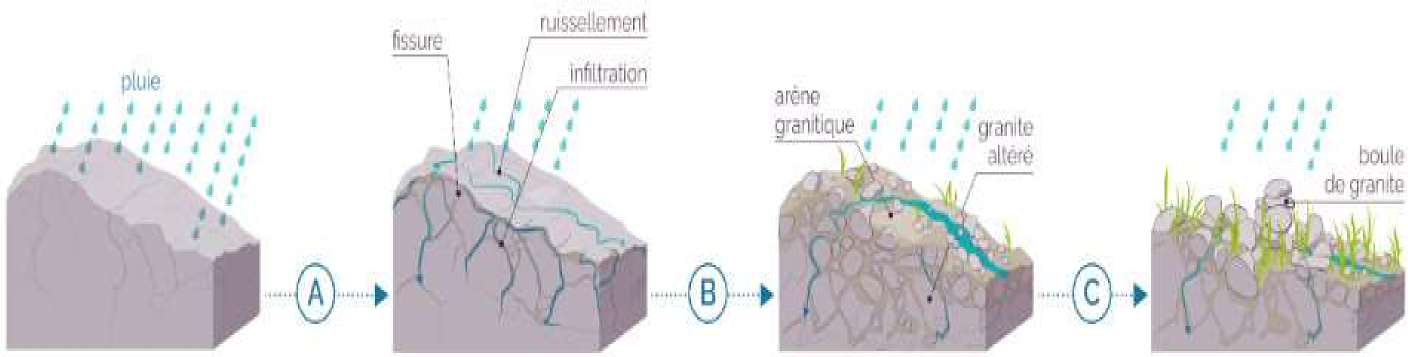

Figure.IV.6: Diagram showing the evolution of a healthy granite block under the effect of weathering Stage A: from healthy granite to cracked granite, Stage B: from cracked granite to weathered granite, Stage C: towards granite chaos

Physical and chemical alterations have therefore led to the disintegration of the granite massif over time.

Step A : from healthy to cracked granite
Healthy granite is a coherent rock. Under the effect of temperature variations, the phenomenon of freezing and thawing of water, wind and plants, the healthy granite massif undergoes physical alteration.
The healthy granite cracks: fractures appear. This fragmentation of the rock increases exposure to weathering factors. Under the action of rainwater, chemical alteration will then begin.

Stage B : from cracked granite to weathered granite
The presence of cracks promotes the circulation of rainwater in contact with the minerals of the granite. The chemical alteration is reinforced. A coarse sand called granite arena appears. Weathered granite becomes brittle.

Step C : towards granite chaos
The more the physical and chemical weathering (Fig. IV.7) continues, the more the granite disintegrates. Rounded blocks of granite are formed. The granite arena accumulates in the diaclases and at the foot of the granite massif. This structure is called a granite chaos.

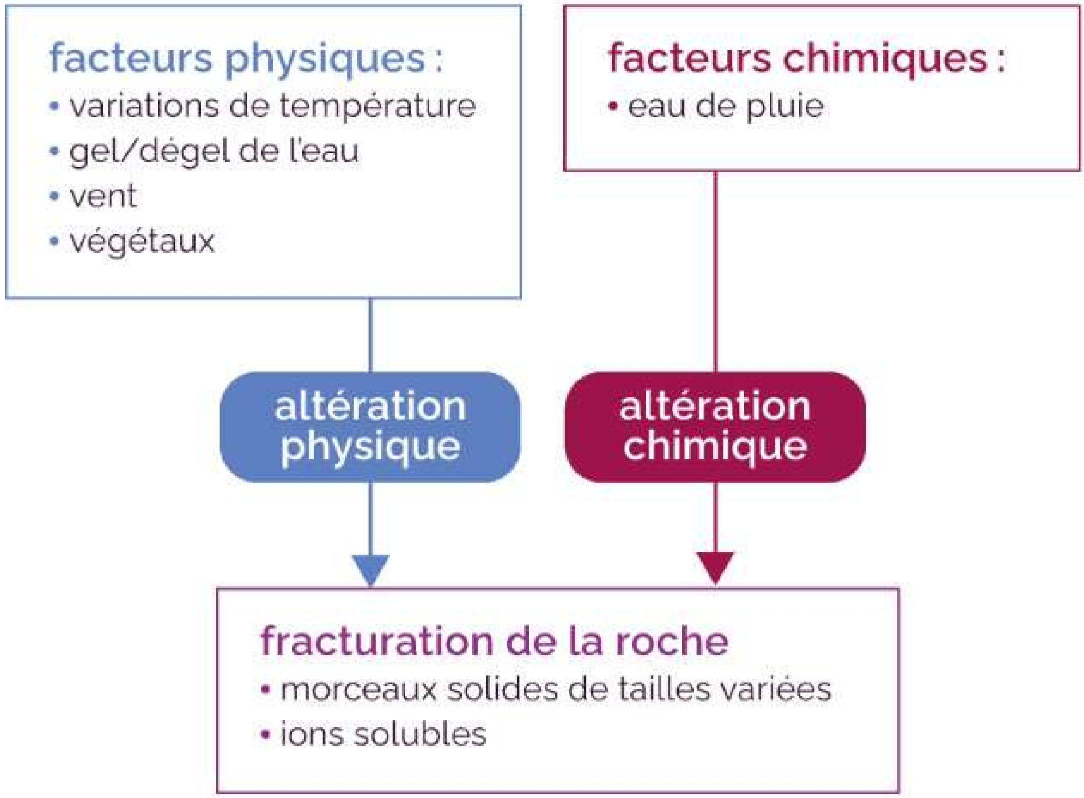

Figure.IV.7: Balance sheet showing the exogenous factors of rock weathering.

IV.2.3 - Types of erosion:

a) Water erosion: Caused by the action of water, it includes rainfall erosion (due to rainfall), river erosion (by rivers) and marine erosion (by waves and currents).

b) Rainfall erosion : The impact of raindrops loosens soil particles, which are then washed away by runoff. Poesen and Hooke (1997) explain that rainfall erosion is particularly problematic in Mediterranean environments where rainfall is intense.

c) River erosion : Rivers and streams carry sediments downstream, carving out riverbeds and forming valleys. Knighton (1998) describes how streams alter the landscape through erosion and sediment deposition.

(e) Marine erosion : Waves, tides and sea currents erode coastlines, creating cliffs, beaches and other coastal formations. Goudie (2004) provides a detailed description of marine erosion processes and their impacts on coastlines.

(f) Wind erosion : Caused by the action of the wind, it is particularly significant in arid and semi-arid regions where vegetation is scarce and the soil is dry and loose.

g) Deflation : Wind removes fine particles from the soil surface.

h) Corrasion : Wind-borne particles wear down rock surfaces and soils. Summerfield (1991) discusses the processes of deflation and corrasion and their importance in desert regions.

i) Glacial erosion : Resulting from the movement of glaciers that transport and abrade the underlying rocks and soils.

j) Striation: Rocks and debris carried by the glacier create linear marks on the rocks of the substrate.

k) Roche moutonnée: Formation of rocks polished and striated by the passage of glaciers. Summerfield (1991) also discusses the impact of glaciers on the shaping of landscapes.

l) Gravity erosion: Due to gravity, it includes mass movements such as landslides, landslides and avalanches.

m) Landslides: The rapid or slow movement of masses of earth or rock along slopes.

o) Rockfalls: Sudden fall of rocks or boulders from cliffs or steep slopes. (Goudie, 2004) provides a detailed analysis of gravity erosion processes and their effects on the landscape.

IV.3-Areolar erosion, or erosion on interfluves:

Erosion occurs through eroding agents, such as atmospheric and biological agents; Their modes of action are the very diverse erosion processes, classified into mechanical erosion processes on the one hand, and chemical erosion processes on the other.

The set of forms that results from erosion is modeling. If the processes of erosion contribute to reducing the high points of the relief, the modelling is called " **flattening** "; if, on the other hand, they tend to hollow them out, the modelling is said to be " **dissection** ". The dissection pattern is created by the erosion of running waters, or fluvial erosion, which has as its agent the concentrated flow of running water and which is exerted along the talwegs. The flattening pattern is created by areolar erosion, which has multiple agents and is exerted on the surface, on the interfluves.

The interfluve, made up of two slopes separated or not by a more or less flat surface, is subject to the alteration of the rocks of which it is composed. On-site weathering concerns all the phenomena of physical disintegration and chemical decomposition of minerals and rocks due to the action of water, temperature variations, the presence of oxygen and carbon dioxide, as well as the importance of organisms. Physical disintegration processes include, on the one hand, mechanical disintegration and, on the other hand, thermal disintegration.

IV.4-Slope profiles:

Slope profiles are graphical representations that show the variation in the elevation of a slope as a function of horizontal distance.

They are defined as cross-sections of the topography of a slope, illustrating the relationship between elevation and horizontal distance.

These profiles make it possible to visualize and analyze the shapes and slopes of the slopes, providing valuable information on the morphology, the stability of the slopes, and the geomorphological and geological processes active in the region.

IV.4.1-Importance of Slope Profiles:

Slope profiles are crucial for various geomorphological and environmental applications, such as landslide risk assessment, land use planning, and the study of erosion and sedimentation processes.

IV.4.2-Types of Slope Profiles:

1. **Convex profiles** : Convex profiles have a steep slope at the top that gradually becomes less steep towards the bottom of the slope. They are often associated with deposition processes and landslides (Goudie, 2013).
2. **Concave Profiles** : Concave profiles show a gentle slope at the top that becomes steeper towards the base. This type of profile is typical of areas of high erosion where runoff plays a major role (Summerfield, 1991).
3. **Linear profiles** : Linear profiles have a constant slope along the entire length of the slope. They are rare and often associated with specific geological formations or uniform erosive conditions (Selby 1993).

IV.5-Linear erosion: terraces:

Linear erosion refers to the erosion that occurs along watercourses, resulting in the formation of various river landforms. Among these reliefs, river terraces are geomorphological structures resulting from erosion and deposition along river valleys.

IV.5.1-Definition of River Terraces:

River terraces are flat platforms located on the edge of river valleys, formed by the processes of erosion and sediment deposition by rivers and streams. They are usually composed of alluvial deposits and can be observed at different heights above the current riverbed.

IV.5.2-Formation of River Terraces:

Terraces are formed by alternating periods of erosion and deposition caused by changes in stream flow, climate change, tectonic movements, and base level fluctuations (Vandenberghe 2008). When water levels drop or flows increase, the river makes incisions in its bed, leaving deposits on the sides that form terraces (Miall 1996).

IV.5.3-Types of River Terraces

1. **Erosion Terraces** : These terraces are mainly formed by the incision of the riverbed in the ancient alluvial deposits. They represent the former riverbed surfaces prior to a period of increased incision (Schumm 1977).
2. **Depositional Terraces** : These terraces are formed by the accumulation of sediment during a period of high water level or low flow. They are generally made up of more recent alluvial materials deposited by the river (Brierley & Fryirs 2005).

IV.5.4-Importance of River Terraces

River terraces are valuable natural archives of past environmental changes. They provide information on ancient river dynamics, climatic variations and tectonic movements in a given region (Bridgland & Westaway, 2008). In addition, they are often used in agriculture and urban planning because of their fertile soils and flat surfaces.

IV.6-Periglacial erosion:

Periglacial (etymologically "near glaciers") is a word that initially characterized the regions surrounding regions covered by glaciers, and therefore subject to a cold climate with long and heavy winter frost and summer thaw.

IV.6.1-Definition of Periglacial Erosion

Periglacial erosion is a set of geomorphological processes that modify the landscape under the influence of repeated freeze-thaw cycles, typical of regions located on the edge of glacial areas or in high-elevation and high-latitude environments (Washburn, 1973).

It refers to the erosion processes that occur in these periglacial environments, characterized by frequent freezing and thawing conditions but without permanent glaciers. These processes, dominated by the action of freeze-thaw on soil and rocks, lead to significant transformations of the landscape.

IV.6.2-Periglacial Erosion Processes:

1. **Cryoclastic:** The fragmentation of rocks under the effect of water freezing and thawing in the cracks of the rocks (fig.IV.8). This process is also known as gelifraction or gelifraction (French, 2007).
2. **Solifluxion** : The slow movement of water-saturated soils under the influence of gravity during periods of thaw. This leads to the formation of solifluxion lobes and terraces on the slopes (Matsuoka, 2001).
3. **Cryoturbation** : The mixing and movement of sediments and soils caused by freeze-thaw cycles. This process creates characteristic soil structures such as frost polygons (Harris and Murton 2005).

4. **Pingo Formation** : The formation of earth-covered ice hills that form when groundwater freezes and lifts the ground. Pingo are typical features of periglacial environments (Mackay 1998).

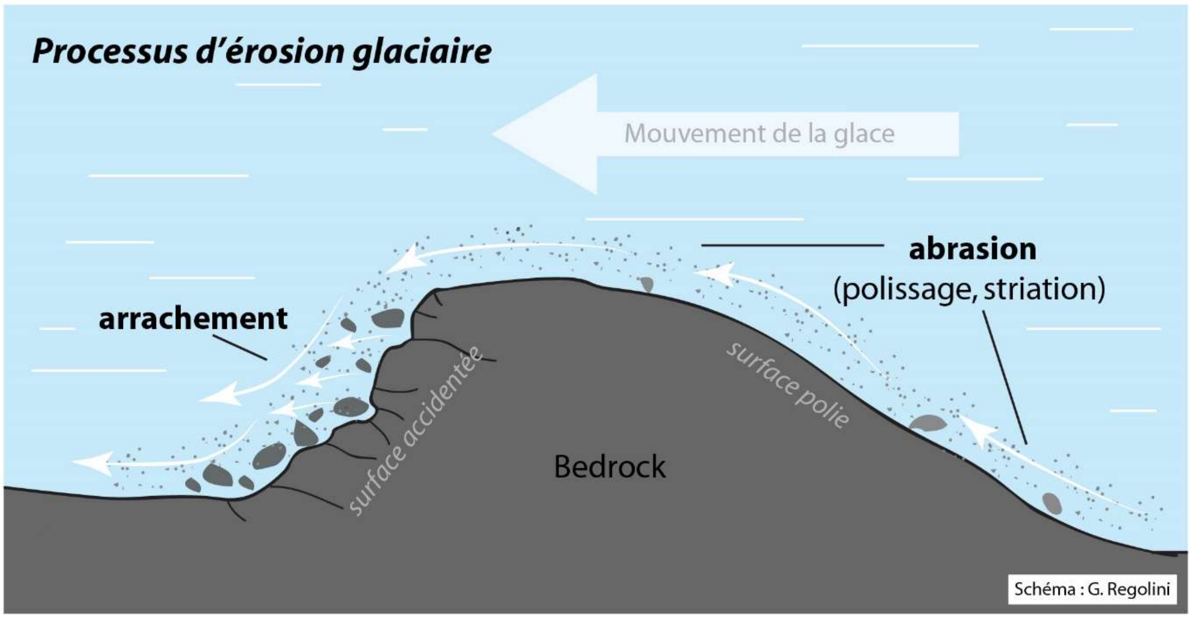

Figure.IV.8: Glacial erosion process.

IV.6.3-Impacts of Periglacial Erosion:

Periglacial erosion processes result in the formation of various distinctive geomorphological structures, such as scree, frost polygons, solifluxion terraces, and pingos. These landforms are valuable indicators of past and present climatic conditions in periglacial environments (Benedict, 1970).

Periglacial erosion processes play a crucial role in the formation and transformation of landscapes in regions subject to frequent freeze-thaw conditions. They also provide valuable clues about climate and environmental change in periglacial areas.

IV.6.4-Conclusion:

- **Causes / factors of erosion:**

- Climate is the cause and source of erosive energy. It is raindrops, runoff water on sloping land and strong winds that detach and carry away the earth particles:
- The topography of the land determines the severity of erosion. - The slope;
- The nature of soils and their vulnerability to erosion / The physicochemical properties of rocks (Hardness and solubility of the rock for example). The soils from soft rocks (marls, flyshes and laminated schists) are impermeable and very sensitive to erosion;
- Tectonic history (fracturing for example);
- Human action (agricultural practices, urbanization, etc.).
- The absence of plant cover which exposes the soil to the direct action of raindrops. – Biostasis.

Biostasis: Stable period in the constitution of the relief, where the absence of erosion results from the presence of a sustainable vegetation cover.

- The absence of erosion of the relief due to continuous vegetation cover.

- **How to fight erosion:**

• **Prevention first:** You must start taming water the moment the raindrop falls on the ground. The same must be done for wind erosion. It is therefore necessary to break the force of the raindrop: this is the essential role of plants, trees, their leaves and their roots. • **Then**, the water must be tamed as soon as it begins to flow, at the level of the farms by terraces on the sloping grounds, small dams (thresholds) made of dry stone, masonry, wire mesh or branch lines along ravines and small streams. At the level of a small watershed or a community, we must go as far as the construction of lakes and collinear dams.

• **Finally, it is necessary to complete with:**

- On sloping cropland: working along contour lines and arranging crops in alternating strips on the slopes, correct fertilisation and compliance with modern agronomic techniques are the basic rule of soil conservation;
- In pastures and sloping rangelands: the construction of level benches, terraces and ravine dams, the rotation of pastures and the fencing.

Resistance of geological formations to erosion:

The resistance of outcrops to the climatic factors of erosion is the basis of the morphological evolution of a region. This resistance is governed by three (03) main aspects which are:

- The lithological nature of the formation;
- Its structural and tectonic layout;
- Climate.

TD Part:

Exercises and Questions Relating to Periglacial Erosion

Exercise 1: Identify periglacial erosion processes

Question: Associate each periglacial erosion process with its appropriate description.

1. Cryoclastic
2. Solifluxion
3. Cryoturbation
4. Pingo's Education

a) Slow movement of water-saturated soils under the influence of gravity during thaw periods.b) Formation of earth-covered ice hills due to groundwater freezing.c) Mixing and displacement of sediments and soils caused by freeze-thaw cycles.d) Fragmentation of rocks by freezing and thawing water in rock cracks.

Solution:

1 - d) Fragmentation of rocks by water freezing and thawing in cracks in rocks.2 - a) Slow movement of water-saturated soils under the influence of gravity during thaw periods.3 - c) Mixing and displacement of sediments and soils caused by freeze-thaw cycles.4 - b) Formation of earth-covered ice hills due to groundwater freezing.

Exercise 2: Analyzing the impacts of periglacial erosion

Question: Explain how periglacial erosion processes influence landscape formation in periglacial regions. Give specific examples.

Solution:
Periglacial erosion processes, such as cryoclasty, solifluxion, cryoturbation, and pingo formation, alter landscapes by creating distinctive geomorphological structures. For example, cryoclastic results in the formation of scree and fragmented rock, while solifluxion forms solifluxion lobes and terraces. Cryoturbation creates freeze polygons, and the formation of pingos results in hills of ice covered with earth. These characteristics are indicators of the climatic and environmental conditions specific to periglacial regions.

Exercise 3: Case Study - Periglacial Erosion in Algeria:

Question: Research and describe a specific example of a periglacial erosion process in Algeria. What are the impacts observed on the local landscape?

Solution:

A specific example in Algeria can be found in the Tellian Atlas regions, where freezing and thawing processes influence mountainous landscapes. Cryoclastic is particularly visible, where rocks are fragmented due to repeated freeze and thaw cycles. This leads to the formation of scree slopes and boulder fields. Solifluxion can also be seen on slopes, where water-saturated soil slides slowly, forming solifluxion lobes and terraces. These erosion processes change the landscape by making slopes more unstable and creating distinct landforms.

Exercise 4: Comparison of periglacial processes:

Question: Compare and contrast the processes of solifluxion and cryoturbation in terms of mechanisms and geomorphological results.

Solution:

Solifluxion and cryoturbation are two distinct but related periglacial processes. Solifluxion involves the slow movement of water-saturated soils under the influence of gravity during periods of thaw, creating solifluxion lobes and terraces. In contrast, cryoturbation refers to the mixing and displacement of sediments and soils caused by freeze-thaw cycles, forming structures such as freeze polygons. While solifluxion is primarily a mass displacement process, cryoturbation is a process of mixing and redistributing materials. Both processes contribute to the formation of distinctive landforms in periglacial environments.

IV.7-Karst model

IV.7.1-Definition of a Karst:

A karst is a limestone massif characterized by numerous cavities dug by water. It is a geomorphological structure resulting from the hydrochemical and hydraulic erosion of soluble rocks, mainly carbonate rocks such as limestone, but also dolomite, gypsum and salt.

This process of chemical dissolution by water, often slightly acidic, creates a characteristic topography including geomorphological formations such as sinkholes, lapiaz, caves, chasms and underground rivers. The term "karst" comes from the name of a plateau located between Slovenia and Italy It is **in Kras**, where these formations are particularly well developed and studied.

IV.7.2-Formation of a Karst:

Karst relief is a form of landscape caused by water that infiltrates the earth and circulates underground, causing chemical erosion of the bedrock. This is why the formation of karst reliefs is restricted to regions made up of relatively soluble rocks, especially limestone. About 8% of the world's surface is made up of karsts.

(a) Chemical processes

Limestone, composed mainly of calcite or aragonite ($CaCO_3$), can be dissolved by carbonic acid (CO_2 dissolved in water). Rain absorbs CO_2 as it passes through the atmosphere and soil, forming a weak carbonic acid solution. This solution, by seeping into the cracks in the limestone, widens the openings and creates drainage systems and underground caves over thousands of years.

In the process of "karstification", carbonate rocks are shaped by solvation according to the following chemical reactions:

- Dissolution of carbon dioxide:

$CO_2 + H_2O \rightleftharpoons H_2CO_3$

- Aqueous dissociation of carbonic acid:

$H_2CO_3 + H_2O \rightarrow H_3O^+ + HCO_3^-$

- Acid attack of carbonates ("limestones"):

$H_3O^+ + CaCO_3 \rightleftharpoons Ca^{2+} + HCO_3^- + H_2O$

- Balance equation:

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

Karst geomorphology is therefore favoured by:

- Water:
    - its abundance;
    - Its CO_2 content (increasing with pressure);
    - Its low temperature (the colder the water, the more it is loaded with gas and therefore CO_2);
- Living beings (which release CO_2 into the soil through respiration, which considerably increases its content);
- The nature of the rock formations (fracturing, carbonate compositions, etc.)
- The water-rock contact time.

A cold, humid and calcareous geographical area is thus strongly predisposed to the formation of karsts (Fig.IV.9), which are however also found in extreme climatic regions.

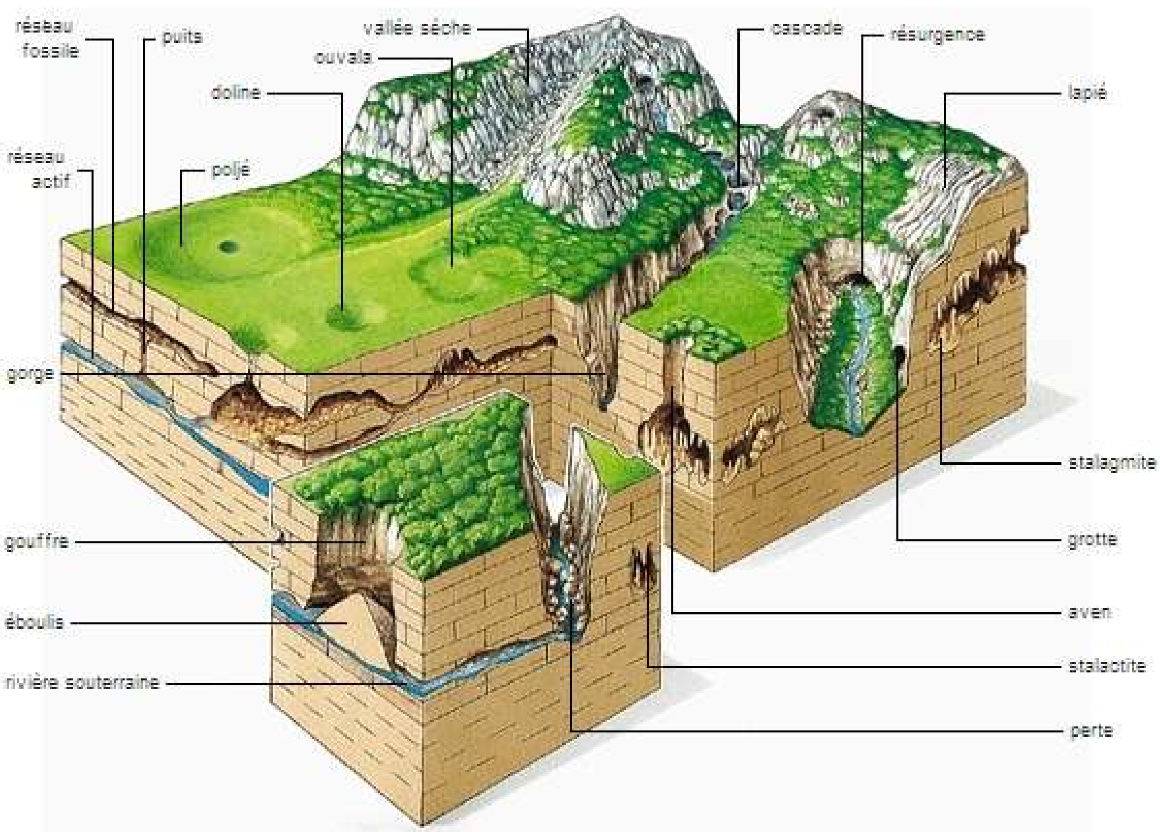

Figure IV.9: Main elements of a Karst.

IV.7.2- Constituent elements of a Karst:

a) The Lapiaz:

Lapiaz, also known as karren, are geological formations characteristic of karst landscapes. They are formed by the chemical dissolution of carbonate rocks, mainly limestone, under the action of slightly acidic rainwater. This dissolution creates grooves, cracks and grooves on the surface of the rocks, resulting in highly jagged and often spectacular landscapes.

a-1-Formation of the Lapiaz:

Lapiaz are mainly formed in regions where limestone is present on the surface and where rainwater, as it infiltrates, gradually dissolves the rock. Carbonic acid, formed by the dissolution of carbon dioxide in water, plays a crucial role in this process. Water seeps into the cracks and fractures of the limestone, gradually widening these openings by chemical dissolution.

a-2-Types of Lapiaz:

Lapiaz can come in different forms depending on the nature of the limestone, the amount of water available, and the climatic conditions. The main distinctions are:

1. **Surface lapiaz** : These are visible grooves and grooves on the surface of the limestone.
2. **Subcutaneous lapiaz** : They form under a cover of soil or vegetation and are not immediately visible on the surface.
3. **Fluted lapiaz**: Characterized by narrow and deep grooves.
4. **Pit lapiaz**: Have wider and often deeper depressions.

a-3-Importance of the Lapiaz:

Lapiaz play an important role in the hydrology of karst regions, as they facilitate the infiltration of surface water into groundwater. They are also important for biodiversity, providing micro-habitats for various species of plants and animals.

b) Definition of sinkholes:

Sinkholes are circular or elliptical depressions found in karst landscapes. They are mainly formed by dissolution and collapse processes in limestone soils and other soluble rocks. Sinkholes are important geomorphological features in karst regions, contributing to the hydrological and ecological dynamics of these areas.

b-1-Formation of the sinkholes

There are two main processes for sinkhole formation:

1. **Dissolution** : Rainwater, slightly acidic due to the presence of dissolved carbon dioxide, percolates through cracks and fractures in the limestone rock. This water gradually dissolves the limestone, creating underground cavities that can widen and cause sinkholes to form on the surface.
2. **Collapse** : When the underground cavities become large enough and the roof of these cavities can no longer support the weight of the upper layers, a collapse occurs, creating a sinkhole. This process is often accelerated by factors such as heavy rainfall or human activity.

b-2-Types of sinkholes

Sinkholes can be classified into several types according to their formation process and morphology:

1. **Sinkholes** : Formed mainly by the dissolution of limestone without collapse. They are usually shallow and have gently sloping edges.
2. **Collapse sinkholes** : Result from the sudden collapse of the roof of an underground cavity. They are often deeper and have steep edges.
3. **Subsidence sinkholes** : Formed when the soil settles slowly due to the underlying dissolution of limestone. They have irregular contours and less defined edges.
4. **Infiltration sinkholes** : Created by the infiltration of water into cracks and fractures, often accompanied by the removal of surface materials through erosive processes.

b-3-Importance of sinkholes:

Sinkholes play a crucial role in water management in karst regions. They allow the rapid infiltration of surface water into underground aquifers, contributing to groundwater recharge. Sinkholes can also serve as collection points for sediment and organic matter, influencing groundwater quality.

c) Dry valleys and poljés:

Among the largest karst landforms are dry valleys and canyons, carved out by ancient rivers that now flow underground, and poljés, which are large flat-bottomed, steep-sided sinkholes.

TD Part:

Exercises and Questions Relating to Karst, Dolines and Lapiaz:

Training

1. **Mapping of a Karst Region:**
   - Download a topographic map of a karst region.
   - Identify sinkholes, lapiaz and other karst formations.
   - Describe the geological processes that led to the formation of these features.
2. **Case Study:**
   - Choose a famous karst region (e.g. the Vercors plateau in France).
   - Describe the main karst formations present in this region.
   - Explain the impact of these trainings on the local hydrology and ecology.
3. **Dissolution Experience:**
   - Take a piece of limestone and dip it in an acidic solution (e.g., vinegar).
   - Observe and note changes over time.
   - Explain the chemical process involved and compare it with the natural formation of sinkholes.
4. **Sinkhole Collapse Simulation:**
   - Use a sandbox to create a limestone terrain model.
   - Dig a cavity below the surface and cover it with sand.
   - Simulate a collapse by gradually removing the sand from the cavity and observe the sinkhole forming.
   - Record your observations and compare them to natural processes.

Questions

1. **Definitions:**
   - What is a karst and how is it formed?
   - Define sinkholes and lapiaz. Explain the training processes for each person.
2. **Erosion and Dissolution Process:**
   - Describe how slightly acidic rainwater contributes to sinkhole formation.
   - Explain the role of carbonic acid in the dissolution of limestone.
3. **Types of sinkholes:**
   - Compare and contrast sinkholes of dissolution, collapse, subsidence and infiltration.
   - Give an example of a region where each type of sinkhole can be found.
4. **Hydrological Significance:**
   - Discuss the importance of sinkholes in recharging karst aquifers.
   - How do lapiaz influence drainage and water flow in karst regions?
5. **Human Impact:**
   - What are the potential impacts of human activities (such as urbanization and agriculture) on karst landscapes?
   - Propose measures to protect karst formations from the negative impacts of human activity.

6. **Case Studies:**
   - Choose a known karst region and describe its main geomorphological formations.
   - Explain how karst processes influence the daily lives of the people in this region.

Solutions

1. **Mapping of a Karst Region:**
   - The answers will vary depending on the card chosen. Students must correctly identify karst formations and explain their formation based on theoretical knowledge.
2. **Case Study:**
   - Answers will vary depending on the region chosen. A good answer will include a detailed description of the karst formations, an explanation of the formation processes and the impact on the local hydrology.
3. **Dissolution Experience:**
   - The observation should show the formation of bubbles and the dissolution of the limestone. The chemical process is the reaction of calcium carbonate with acetic acid to form carbon dioxide, water, and calcium acetate.
4. **Sinkhole Collapse Simulation:**
   - The observation should show the formation of a depression on the surface of the sand when the cavity collapses. This simulates the formation of collapse sinkholes.
5. **Definitions:**
   - A karst is a landscape formed by the dissolution of soluble rocks, mainly limestone.
   - Dolines are circular or elliptical depressions formed by dissolution or collapse in calcareous soils. Lapiaz are surface formations with grooves and crevices created by the dissolution of limestone.
6. **Erosion and Dissolution Process:**
   - Slightly acidic rainwater dissolves the limestone, creating cavities that can become sinkholes.
   - Carbonic acid ($H2CO3$) dissolves calcium carbonate ($CaCO3$), forming calcium bicarbonate ($Ca(HCO3)_2$) in solution.
7. **Types of sinkholes:**
   - Sinkholes: formed by slow dissolution without collapse (e.g. Slovenia).
   - Collapse sinkholes: formed by sudden collapse (e.g. Florida, USA).
   - Subsidence sinkholes: formed by slow settlement (e.g. Spain).
   - Infiltration sinkholes: created by water infiltration (e.g. Norway).
   -
8. **Hydrological Significance:**
   - Sinkholes allow the rapid infiltration of surface water into underground aquifers, recharging groundwater.
   - Lapiaz increases soil permeability, aiding drainage and reducing runoff.

9. **Human Impact:**
    - Human activities can accelerate the erosion and pollution of karst aquifers.
    - Protection measures: regulation of urbanisation, sustainable management of agriculture, protection of sensitive karst areas.

10. **Case Studies:**
    - The answers will vary. A good answer will include a description of karst formations and their impact on daily life.

These exercises and questions will help students to better understand karst processes, sinkhole and lapiaz formations, as well as their ecological and hydrological importance.

IV.8 - Wind Erosion: Wind Formations:

Wind erosion is the process by which wind carries and deposits soil and rock particles, shaping the landscape. This type of erosion is particularly active in arid and semi-arid environments, where vegetation is scarce and soils are dry and loose.

IV.8.1-Types of Wind Turbine Formations:

The main aeolian formations resulting from wind erosion include sand dunes, loess, and yardangs.

1. **Sand Dunes:** Sand dunes are hills or mounds of sand formed by the wind. They can vary greatly in size and shape, ranging from small ripples to towering formations. Dunes form when the wind carries grains of sand and deposits them in areas where its speed decreases, allowing sand to accumulate. Types of dunes include crescent dunes (barkhanes), longitudinal dunes, and parabolic dunes (Tsoar, H, 2001).
2. **Loess:** Loess is a wind-transported fine silt deposit, often formed in large patches covering thousands of square kilometres. These deposits usually occur far from their original source, indicating the wind's ability to carry fine particles over long distances. Loess is fertile and often used for agriculture because of its ability to retain moisture (Pye K 1987).
3. **Yardangs: Yardangs** are elongated ridges formed by wind erosion in soft, consolidated rocks. The wind erodes the softer material, leaving ridges and furrows parallel to the prevailing wind direction. Yardangs are often found in deserts where constant winds and sandstorms are common (McCauley, et al., 1977).

TD Part:

Exercises and Questions on Wind Erosion and Wind Formations

Theoretical questions

1. **Definition and Concepts**
   - **Question:** What is wind erosion? Explain its basic mechanics.
   - **Solution:** Wind erosion is the process by which wind carries and deposits soil and rock particles, shaping the landscape. Basic mechanisms include deflation (removal of fine particles), transport (jumping, crawling and suspension of particles) and abrasion (erosion of surfaces by impact of wind-borne particles).
2. **Types of Wind Formations**
   - **Question:** Name and describe the main wind formations resulting from wind erosion.
   - **Solution:** The main wind formations include:
     - Sand dunes: hills or mounds of sand formed by the wind.
     - Loess: a deposit of fine silt carried by the wind.
     - Yardangs: elongated ridges formed by wind erosion in soft rocks.
3. **Dune Formation Process**
   - **Question:** How are sand dunes formed and what factors influence their shape and size?
   - **Solution:** Sand dunes form when the wind carries grains of sand and deposits them in areas where its speed decreases. Factors influencing their shape and size include wind speed and direction, the amount of sand available, and the vegetation present. Types of dunes include crescent dunes (barkhanes), longitudinal dunes, and parabolic dunes.

Application Questions

1. **Map Analysis**
   - **Question:** Using a topographic map of a desert region, identify and describe the different visible aeolian formations.
   - **Solution:** Students should identify sand dunes, yardangs, and possibly loess areas, describing their relative shapes and positions.
2. **Case Study**
   - **Question:** Study a specific case of wind erosion in a given region (e.g., the Gobi Desert or the Sahara). Describe the environmental and human impacts of wind erosion in this area.
   - **Solution:** Students should research and present information about wind erosion in the chosen area, highlighting the impacts on agriculture, infrastructure, air quality, and the management measures put in place to limit these effects.

Practice

1. **Demo Experience**
   - **Exercise:** Replicate a simple experiment to demonstrate the effect of wind on the movement of sand particles. Use a sand box and a fan to observe the formation of small dunes.
   - **Solution:** Students should describe their experimental setup, observations of sand movement, and the conditions that led to the formation of the dunes.
2. **Wind Speed Calculations**
   - **Exercise:** If a sand particle is carried by the wind a distance of 50 meters in 10 seconds, what is the wind speed?
   - **Solution:** Wind speed (v) can be calculated using the formula v = d/t, where d is the distance and t is the time. So, v = 50 m / 10 s = 5 m/s.

Reflection Questions

1. **Climate Impact**
   - **Question:** Discuss the impact of climate change on wind erosion processes and wind formations.
   - **Solution:** Students should discuss how changes such as increased temperatures and altered precipitation patterns can affect wind erosion processes, potentially increasing the intensity of sandstorms and altering areas of dune formation.
2. **Preservation and Management**
   - **Question:** What measures can be taken to limit the negative effects of wind erosion in the affected areas?
   - **Solution:** Solutions may include planting vegetation to stabilize soils, installing wind barriers, managing farming practices to minimize soil disturbance, and using irrigation techniques to maintain soil moisture.

These questions and exercises offer a variety of approaches to understanding wind erosion and wind formations, while providing detailed solutions to aid in learning.

IV.9-Definition of Hydrowind Turbine Basins: Daïa

Hydrowind basins, also known as daïa (fig.IV.9), are natural depressions formed by the interaction of hydrological and aeolian processes. These structures are typical of arid and semi-arid regions where the combined action of water and wind sculpts the landscape by carving shallow basins. These basins can temporarily store water after rainfall, but they are often dry due to rapid evaporation and infiltration into permeable soils.

Figure.IV.10: A daïa on the El Kheng-Laghouat road.

IV.9.1-Mode of formation and characteristics of the Daïas:

1. **Formation process:** Hydrowind turbine basins are formed mainly by erosion caused by rainwater, which leaches fine sediments and transports them to low-lying areas. Wind also plays a role in moving soil particles and contributing to erosion of the edges of the basins. Over time, these combined processes deepen and widen depressions.
2. **Climatic Conditions:** Hydrowind turbine basins are commonly found in arid environments where rainfall is scarce but can be intense, causing sudden runoff and erosion. Rapid evaporation in these climates promotes the accumulation of fine sediments carried by water and wind.

3. **Ecology and Human Use:** These basins can become focal points for local vegetation, due to the temporary accumulation of water and nutrient-rich sediments. They can also be used by local people for agriculture or grazing during wet periods.

IV.9.2-Example in Algeria: The Daïas

In Algeria, hydrowind turbine basins are particularly well represented in the Saharan regions. Daias are temporary depressions that fill with water after rare rainfall, playing a crucial role in the local ecosystem by providing water points for fauna and flora.

Case Study: The daïa of the Algerian desert, such as those observed in the Grand Erg Oriental, illustrate well the formation process and the ecological importance of these basins. They are formed by a combination of river and wind erosion, and despite their temporary nature, they are essential for the survival of local species and traditional agricultural practices.

These hydrowind basins, or daïa, testify to the complex dynamics between hydrological and aeolian processes in the formation of desert landscapes and their importance for ecosystems and human activities in these extreme regions.

TD Part:

Exercises and Questions Related to Wind Erosion: Daïa

Exercise 1: Identification of the Daïa Formation Processes

Question: Explain the combined processes of hydrological and wind erosion that lead to the formation of hydrowind basins (daia) in arid regions. Use specific examples from Algeria to illustrate your answer.

Solution: Hydrowind basins are formed in arid regions by a combination of hydrological and aeolian processes:

- **Hydrological erosion:** During rare rainfall, rainwater causes sudden runoff, leaching fine sediments and transporting them to low-lying areas where water temporarily accumulates, creating depressions.
- **Wind Erosion:** Wind moves soil particles, contributing to the erosion of the edges of the basins and their widening. The wind also carries fine sediments, promoting their accumulation in the basins.
- **Algerian example:** The daïa in the Grand Erg Oriental in Algeria illustrate this process well. These depressions fill with water after rains, becoming crucial temporary watering holes for local flora and fauna.

Exercise 2: Analysis of the Characteristics of the Daïa

Question: What are the climatic and geomorphological factors that influence the formation and persistence of daïa in the Algerian deserts?

Solution: Climatic and geomorphological factors influencing the formation and persistence of daïa include:

- **Arid climate:** Low but sometimes intense rainfall results in rapid runoff and significant hydrological erosion.
- **Rapid Evaporation:** Due to the high temperatures, the accumulated water evaporates quickly, making the daïa often temporary.
- **Geological Substrate:** The presence of permeable sedimentary rocks promotes water infiltration, while clay soils can retain water for longer.
- **Prevailing Winds:** Strong, constant winds move sediment and contribute to erosion and accumulation in the basins.
- **Algerian example:** In the Algerian Sahara, daïas form mainly in areas where winds carry fine sediments and where occasional rainfall causes concentrated runoff.

Exercise 3: Case Study of the Daias

Question: Analyze the ecological importance of daïas in the Algerian deserts and discuss the challenges related to their conservation.

Solution: The daïas play a crucial role in the Algerian deserts:

- **Temporary Water Points:** These provide essential temporary water sources for local flora and fauna, promoting biodiversity in arid environments.
- **Local Ecosystems:** Daias create micro-habitats that allow the survival of various plant and animal species adapted to temporary conditions of humidity.
- **Conservation Challenges:**
    - **Climate Change:** Climate variations can reduce the frequency of rainfall, affecting the formation of daïas.
    - **Human Activities:** Overgrazing, agriculture and water extraction can disrupt the ecosystems of the daia.
    - **Accelerated Erosion:** Wind erosion exacerbated by unsustainable practices can destroy daia.

Algerian example: Conservation efforts in the Algerian Sahara must focus on the sustainable management of water resources and the protection of daïa habitats to preserve biodiversity.

These exercises and questions provide a framework for understanding and analyzing the formation processes, characteristics, and ecological importance of daia, while highlighting the challenges of their conservation and appropriate mapping techniques.

Questions:

Propose a methodology for mapping daïas in a desert region using topographic maps.

Methodology for Mapping Daïas with Topographic Maps

1. **Topographic Map Collection:**
    - Get detailed topographic maps of the desert region of interest. These maps must be of an appropriate scale (for example, 1:50,000 or 1:25,000) to allow for accurate identification of landform features.
2. **Preliminary Analysis of the Maps:**
    - Study contour lines to identify topographic depressions. Daias often appear as areas where contour lines form closed patterns indicating depressions.
    - Look for indications of watersheds, dry riverbeds, or areas where streams converge, as these areas are conducive to daia formation.

3. **Identification of Depressions:**
   - Plot areas of potential depressions on topographic maps. Use contour lines to determine the elevations of the lowest and highest points of depressions.
   - Note associated features, such as indications of runoff and possible areas of sedimentary deposition.
4. **Field Validation:**
   - Conduct field surveys to verify the depressions identified on the maps. Use GPS to pinpoint these areas and confirm their nature as daia.
   - Take detailed notes on the size, depth, and characteristics of the daia, as well as the soil conditions and surrounding vegetation.
5. **Analysis and Interpretation:**
   - Analyze map data to understand the spatial distribution of daïas. Look for patterns or correlations with other geomorphological features, such as slopes and runoff directions.
   - Interpret the results to formulate hypotheses about the processes of daia formation in the region and their dynamics.
6. **Report and Documentation:**
   - Write a report detailing the methodology used, the results obtained, and the conclusions drawn from the study. Include maps, field photos, and detailed descriptions of the mapped daia.
   - Document recommendations for the conservation of daia, taking into account their ecological importance and potential challenges in their conservation.

Practical example in Algeria:

For a concrete case in Algeria, you can follow this methodology in regions such as the Grand Erg Oriental, where daïas are common. Use topographic maps available from the national geographic services and validate your observations with field visits.

In Algeria, the mapping of daïas can provide valuable information for the management of water resources and the conservation of arid ecosystems.

IV.10-Anthropogenic Action and Morphogenesis:

IV.10.1-Anthropogenic action: refers to all human activities that modify the natural environment, influencing geomorphological processes. These actions include agriculture, urbanization, dam construction, deforestation, and resource extraction. These activities can accelerate erosion, alter sedimentation regimes, and cause changes in river and coastal systems (Tucker & Slingerland 1997).

IV.10.2-Morphogenesis: refers to the formation and evolution of landforms under the influence of various geomorphological processes, including those induced by anthropogenic action. Changes in land use, for example, can lead to significant changes in landscape morphogenesis, resulting in the creation of new landforms or the transformation of existing ones (Summerfield 1991).

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Chapter V:
Zonal Climatic Geomorphology.

V-Definition of Azonal Geomorphology:

Azonal climate geomorphology refers to the study of terrestrial landforms that are not directly influenced by regular (zonal) climatic zones, but rather by climatic processes specific to local conditions or temporary variations. This includes the impacts of extreme weather events, such as tropical cyclones, torrential rain events, snowstorms, etc. These events can shape relief through erosive and depository processes that differ from typical processes observed in zonal climate zones (Hooke, R. L., 2000).

Here are some examples of these terrestrial landforms that are not directly influenced by regular (zonal) climate zones, but rather by climatic processes specific to local conditions or temporary variations :

1. **Badlands** : Highly eroded terrain formations, often made up of soft rocks such as clay and shale. They develop in arid or semi-arid regions where irregular rainfall causes rapid and localized erosion.
2. **Canyons and Gorges** : These formations are often found in areas with intense river erosion, but can also be influenced by local phenomena such as sudden downpours or rapid snowmelt.
3. **Landslides** : These can occur in a variety of climatic environments, but are often triggered by specific events such as torrential rains, earthquakes, or changes in land use.
4. **Karst Topography** : Formations such as sinkholes, sinkholes, and caves, which result from the dissolution of carbonate rocks by carbon-dioxide-rich waters. Karstification processes can occur independently of major climatic zones and are influenced by local rainfall and groundwater chemistry.
5. **Pingos** : Mounds of frozen earth that form in permafrost regions, where pressurized water freezes and lifts the ground. Their formation is more related to the specific conditions of the permafrost than to a general zonal climate.
6. **Sand Dunes** : Although sand dunes are common in deserts (arid areas), their formation and dynamics are strongly influenced by local winds and specific short-term climatic conditions.
7. **Moraines** : Glacial deposits that form as a result of the accumulation and movement of material by glaciers. The formation of moraines is related to glacial and interglacial cycles rather than to a stable zonal climate.
8. **Taponi** : Small cavities in granitic or sandstone rocks, formed by chemical and mechanical degradation processes, often in maritime or arid environments where moisture and salts play an important role.

These landforms show how local conditions, and specific climatic variations can create unique landscapes, independent of wider climatic zones.

V.1- Climatic variations: The Quaternary

Climate variations during the Quaternary are characterized by glacial-interglacial cycles that profoundly altered the land and seascapes. This geological period, which extends over the last two million years, has been marked by significant climatic oscillations, resulting from astronomical, geophysical and atmospheric factors (Imbrie, J., & Imbrie, K. P, 1979).

V.1. 1- Definition and Main Cycles:

The Quaternary is divided into two epochs: the Pleistocene (2.58 million to about 11,700 years ago) and the Holocene (11,700 years ago to the present). Climate variations during this period are mainly attributed to Milankovitch cycles, which include variations in the eccentricity of the Earth's orbit, the inclination of the Earth's axis, and the precession of the equinoxes (Berger, 1988). These variations caused alternations between ice ages, when ice sheets expanded, and interglacial periods, characterized by a warmer climate and the retreat of ice.

V.1. 2- Impacts on Landscapes and Ecosystems:

Ice ages have led to an expansion of ice sheets, covering large areas of the Northern Hemisphere, including North America, Europe, and Asia (Clark et al., 2009).

These glaciations sculpted landscapes through erosion and the deposition of glacial materials, forming U-shaped valleys, moraines and glacial lakes. Interglacial periods, such as the Holocene, saw the retreat of glaciers, the rise in sea levels, and the recolonization of land by forests and other vegetation (Ruddiman, 2008).

V.1. 3- Paleoclimatic evidence:

Paleoclimatic studies, based on ice cores, marine and lake sediments, as well as fossil pollens, have made it possible to reconstruct the climatic variations of the Quaternary (Petit et al., 1999). Ice cores from Antarctica and Greenland revealed detailed records of glacial-interglacial cycles, including greenhouse gas concentrations and oxygen isotopes, which are indicators of temperature.

V.1. 4- The interests of this study:

The study of climate variations in the Quaternary is of major importance for understanding the natural mechanisms of climate and long-term dynamics. This period, which spans about 2.58 million years, is marked by repeated cycles of glaciations and interglaciations, providing critical insights into Earth's responses to natural climate forces. In addition, this knowledge helps to contextualize current climate change and predict future impacts on ecosystems, landscapes, and human societies (Ruddiman, 2008).

V.2- Indices of climatic variations:

The indices of climate variations in the Quaternary are diverse and include geological and biological data:

- Ice cores extracted from Greenland and Antarctica contain air bubbles that reveal greenhouse gas concentrations and oxygen isotopes, which are indicators of past temperatures (Petit et al., 1999).
- Marine and lake sediments,
- As well as fossil pollens, provide additional records of climatic and vegetation conditions at different times (Berger, 1988).
- Glacial moraines and other geomorphological formations reflect glacier advances and retreats (Clark et al. 2009).

V.2-.1-The nature of climatic variations:

Climate variations in the Quaternary are mainly characterized by cycles of glacial and interglacial periods. Ice ages are marked by lower global temperatures and the expansion of ice sheets, while interglacial periods are warmer, with ice shrinking (Ruddiman, 2008). These cycles are influenced by variations in the Earth's orbital parameters, known as Milankovitch cycles (Imbrie et al., 1993).

V.2.2- The causes of climate variations:

The causes of climate variations in the Quaternary are complex and include astronomical, geological and atmospheric factors.

Milankovitch cycles, which include:

- Variations in the eccentricity of the Earth's orbit;
- The inclination of the Earth's axis and the precession of the equinoxes play a major role in modulating the amount of solar radiation received by the Earth (Imbrie et al., 1993).

In addition to these astronomical factors:

- Volcanic eruptions;
- Changes in ocean circulation;
- Changes in greenhouse gas concentrations also contributed to climate variations during the Quaternary period (Ruddiman, 2008).

a) The consequences on sea level:

Climate variations in the Quaternary had significant impacts on sea level. During the ice ages, the vast amounts of water trapped in the ice sheets caused sea levels to drop.

On the other hand, the interglacial periods, marked by the melting of the ice, led to a rise in sea level. For example, during the Last Glacial Maximum, about 20,000 years ago, sea level was about 120 metres lower than it is today (Lambeck and Chappell, 2001). These fluctuations have influenced coastal geography, marine ecosystems, and human migrations (Clark et al. 2009).

b) Origin of Quaternary climatic variations:

The Quaternary is characterized by rapid and large climatic cycles linked to Milankovitch parameters, with a very marked period of 100,000 years. These cycles are associated with a variation in the volume of polar ice and therefore with a variation in sea level.

b.1) An astronomical origin:

The astronomical theory of climate by astronomer Milankovitch assumes that Quaternary climate variations are the consequence of cyclical variations in different Earth orbital parameters. Milankovitch distinguishes three levels of periodicity:

- **The variation in the eccentricity of the Earth's orbit**

The Earth's orbit is an ellipse with the Sun occupying one of the foci. The eccentricity of the ellipse is a measure of the difference between this ellipse and the corresponding circle (fig.V.1). The shape of the Earth's orbit varies over time between a quasi-circular shape and a more elliptical shape. The main component of this variation fluctuates over a period of 413,000 years. The current eccentricity of the Earth's orbit is quite small. The eccentricity is zero when the orbit is perfectly circular (e=0 below).

Different eccentricities:

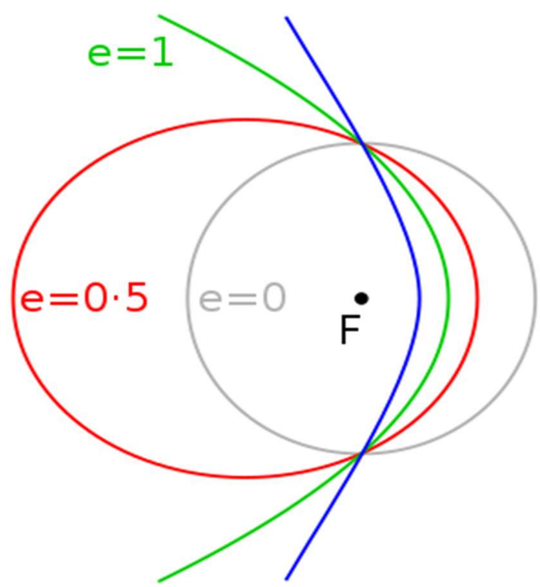

Figure.V.1: **Different eccentricities.**

OrbitalEccentricityDemo.svg, by ScottAlanHill via wikimedia commons, CC-BY-SA-3.0-migrated https://commons.wikimedia.org/wiki/File:OrbitalEccentricityDemo.svg

Eccentricity is one of the most important factors in natural climate change since, at its maximum, the Earth at perihelion (the point of the trajectory closest to the Sun) can receive up to 26% more energy from the Sun (fig.V.2) than at aphelion (the point of the trajectory farthest from the Sun).

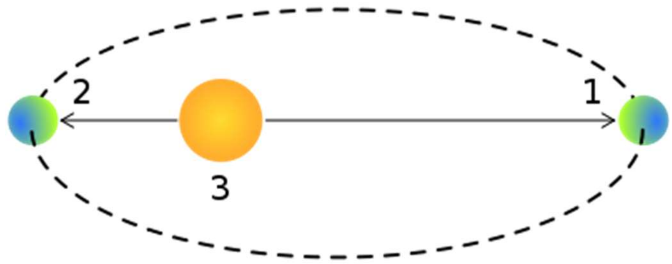

Figure.V.2: Perihelion (2) and aphelion (1) of the Earth in its orbit.

399px-Aphelion_(PSF).svg via wikimedia commons, public domain, https://commons.wikimedia.org/wiki/File:Aphelion_(PSF).svg

- **Variation in the obliquity of the Earth's axis of rotation**

The obliquity (or inclination of the axis of rotation) is a quantity that gives the angle between the planet's axis of rotation and the perpendicular to the plane of the Earth's orbit around the sun or plane of the ecliptic (fig.V.3).

The Earth's obliquity varies between 22.1° and 24.5° over a period of about 41,000 years. As obliquity increases, each hemisphere receives more radiation from the sun in summer and less in winter.

Thus, when the inclination is steeper (close to 24.5°), summers are warmer and winters colder, but when the inclination is lower (close to 22.1°), the seasons are less clear-cut in terms of temperatures: summers are less hot and winters milder.

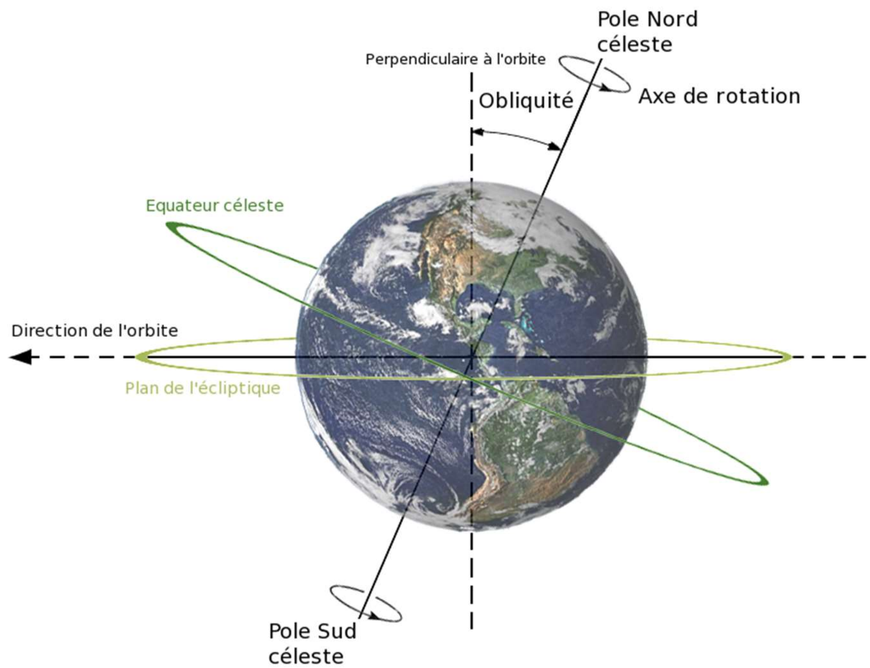

Figure V.3: Obliquity of the Earth with respect to the plane of the ecliptic.

Obliquite_plan_ecliptique via Wikimedia Commons, CC-BY-3.0, https://commons.wikimedia.org/wiki/File:Obliquite_plan_ecliptique.png

- **The precession of the equinoxes:**

The Earth does not rotate on its axis like a perfectly spherical balloon but rather like a spinning top because it is subject to precession (fig.V.4). Precession is the name given to the gradual change in the orientation of an object's axis of rotation. It is the displacement of the Earth's axis of rotation on itself, which describes a conic surface over a period of 19,000 to 23,000 years (average 21,000 years). The variation in the precession of the equinoxes is responsible for a shortening of a year by 20 minutes, modifying the position of the Earth at the solstices and equinoxes, thus modifying the seasons (Laskar, J, 1986).

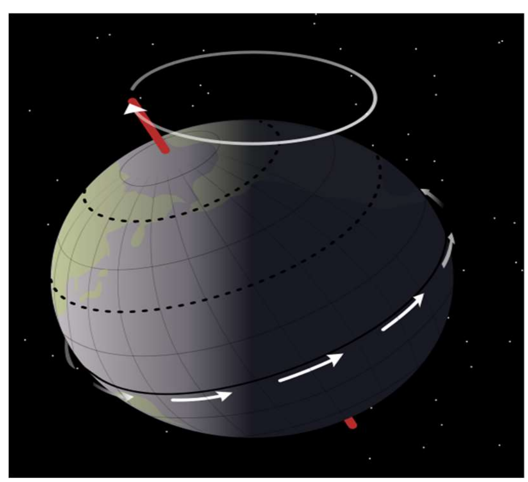

Figure V.4: Precession of the Earth's axis of rotation.

526px-Earth_precession.svg, by NASA, Mysid, via Wikimedia Commons, https://commons.wikimedia.org/wiki/File:Earth_precession.svg

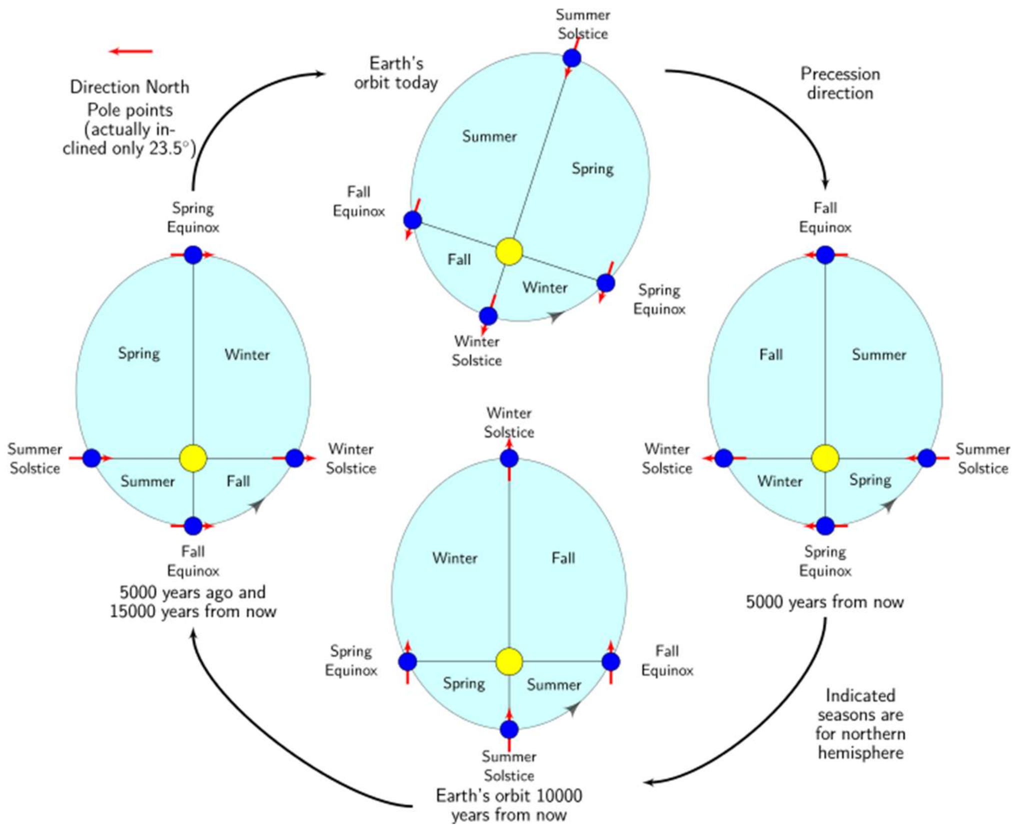

Figure V.6: Changes in the seasons due to the precession of the equinoxes.

Precession_and_seasons.svg, via wikimedia commons, CC-BY-SA-3.0, https://commons.wikimedia.org/wiki/File:Precession_and_seasons.svg

These three parameters have an influence on the amount of solar energy received by the Earth during the year and also on the contrast between the seasons. They are responsible for cyclical climatic variations called Milankovitch cycles (1941).

Milankovitch's astronomical hypothesis (Laskar, J, 1986) has been scientifically validated, particularly with regard to the 100,000-year periodicity found in the glacial and interglacial stages (fig.V.7) of the last 800,000 years. If we compile the data of the three preceding parameters with those of the variation in the power of solar energy and the δ 180 of ice, we obtain the following document:

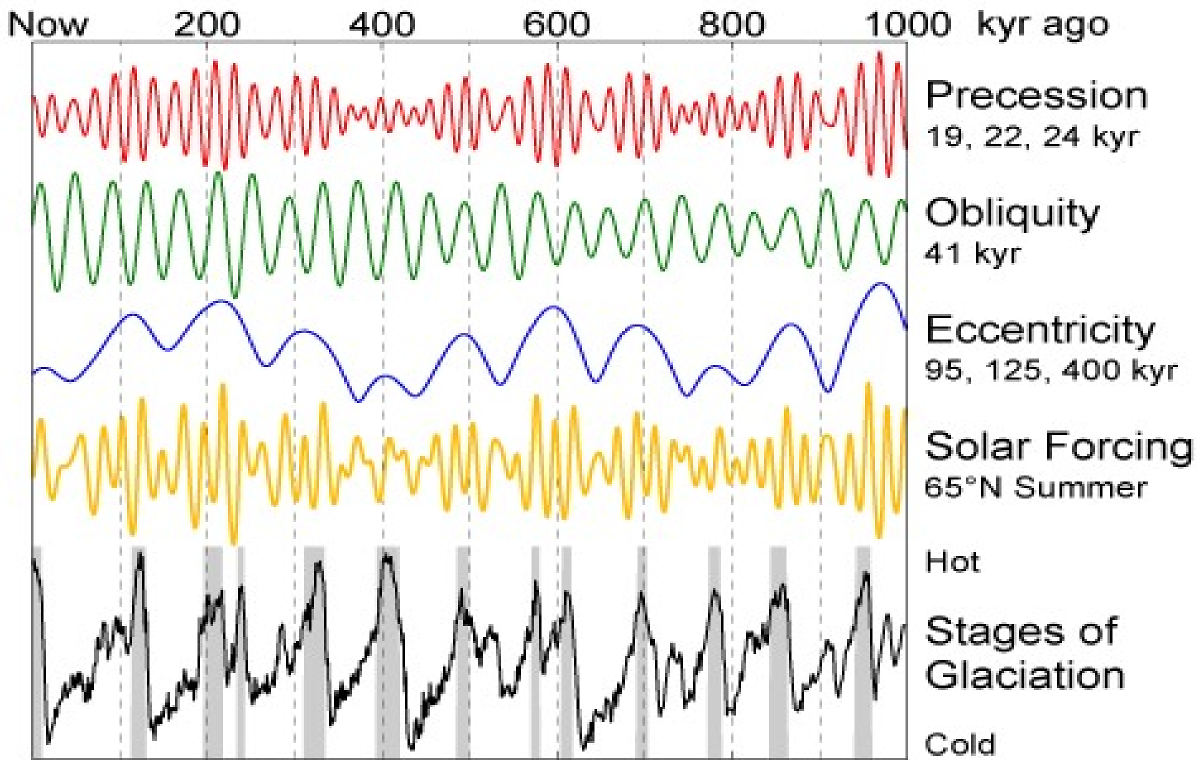

Figure.V.7: Combination of Milankovitch cycles.

Milankovitch_Variations, by Robert A. Rohde *vvia wikimedia commons,* CC-BY-SA-3.0-migré, https://commons.wikimedia.org/wiki/File:Milankovitch_Variations.png

Coupled with the Milankovitch cycles, there is a variation in the solar power received at 65° north latitude. This variation is a consequence of the variation in the Earth's orbital parameters.

To understand the origins of glacial-interglacial variations, two extreme cases, among many possible configurations, are represented:

- **For the Ice Age**, the Earth's orbit is almost circular (low eccentricity) and it was chosen to add a low inclination and a large Earth-Sun distance in summer. This results in a weak seasonal contrast and a configuration favourable to the appearance of an ice age.
- **For the appearance of an interglacial period**, an extreme orbital configuration is to consider a strong eccentricity (the Earth's orbit is an ellipse), a strong inclination and a short distance from the Earth to the Sun in summer. This would result in very contrasting seasons (fig.V.8).

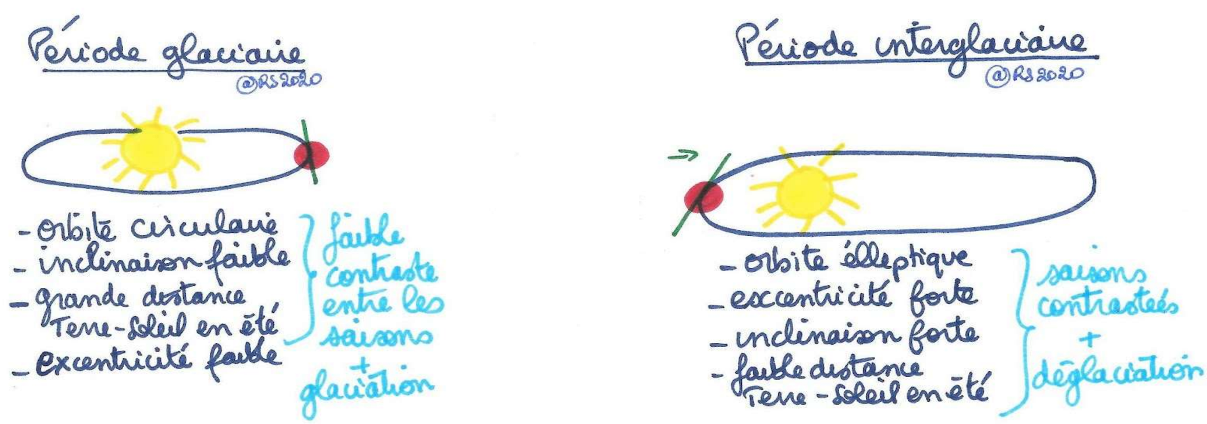

Figure.V.8: Representation of the three Milankovitch variables and consequences on the Earth's climate.

b-2) Amplifying mechanisms:

When we calculate the temperature variations that should be caused by previous astronomical variations, we find amplitudes much lower than those that are actually observed. It is therefore that there must be other parameters that influence the temperature and therefore the climates.

1) The Earth's Albedo

The radiation absorbed by the Earth consists, among other things, of infrared rays that warm the surfaces (fig.V.9). The more radiation absorbed, the greater the warming will be. The lower the reflected radiation, the greater the absorbed radiation.

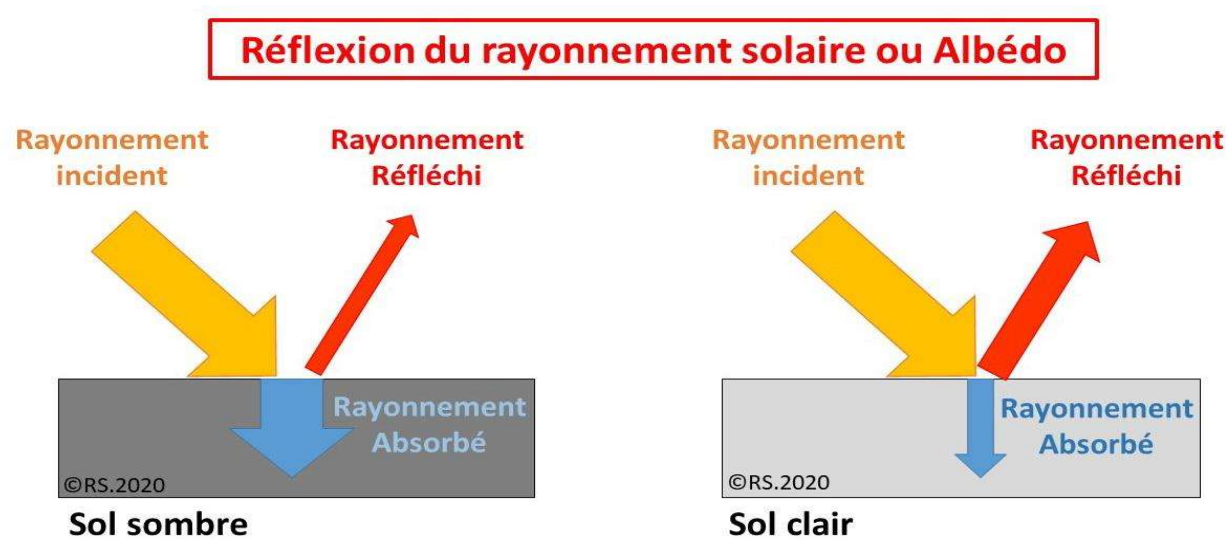

Figure.V.9: Principle of albedo.

Albedo is the ratio between solar energy reflected by a surface and incident energy (Tabl. V.1). Its value varies between 0 (for a black surface) and 1 (for a white surface). The albedo of a land surface can be measured using radiometers used in the field but also in the laboratory.

Table.V.1 : Value of the albedo for different surfaces.

Surface	**Ice**	**Snow**	**Ocean**	**Deciduous forest**	**Sand**
Albedo	0.6	0.75 to 0.9	0.05 to 0.15	0.15 to 0.2	0.25 to 0.45

Depending on the surface, the albedo is different. A low albedo such as that of the ocean means that the amount of reflected radiation is small, so that the amount of absorbed radiation is large. The surface concerned will therefore heat up more than in the opposite case of a high albedo surface.

During the ice age, very large snow or ice surfaces have a high albedo. This implies that a large part of the sun's radiation is reflected. As a result, the Earth's surface warms up less since it absorbs less radiation, which will therefore amplify the cooling.

Conversely, in times of global warming, high-albedo surfaces such as polar ice are less extensive and the opposite is therefore true. The incident radiation is absorbed more by the earth's surface (forests, sands, rocks, etc.), which will therefore warm up further.

- **The solubility of carbon dioxide:**

The solubility of CO_2 in seawater decreases when the temperature of the water and therefore of the atmosphere increases (Fig.V.10). Conversely, during a drop in temperature such as during a period of glaciation, the solubility of CO_2 will be greater than in a warmer climate, which will favor its dissolution.

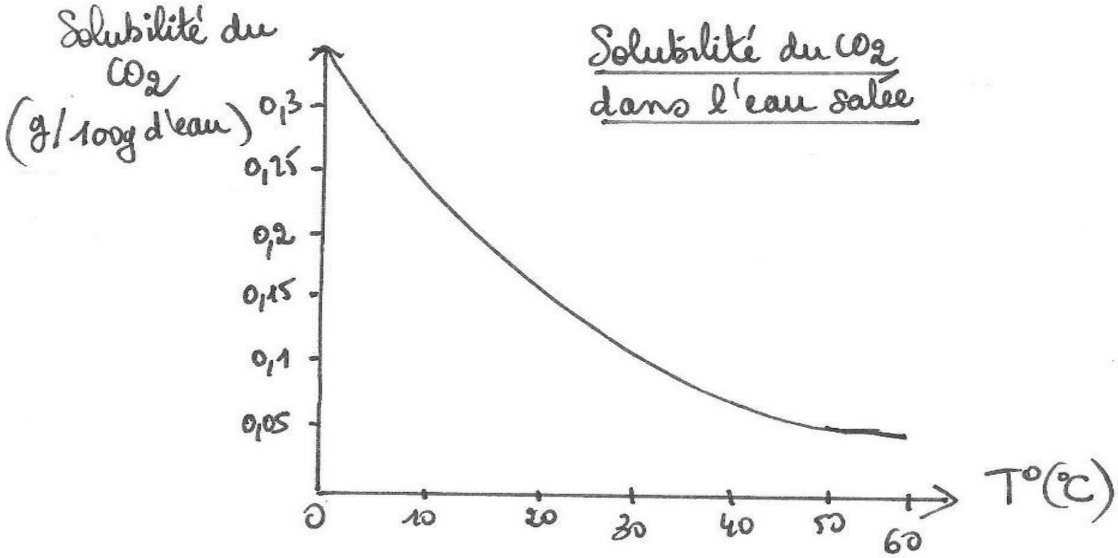

Figure.V.10: Solubility of CO2 in salt water (©SR.2020).

The warmer it is, the less CO2 will dissolve in seawater, which will increase its concentration in the atmosphere. As CO2 is a greenhouse gas, it will be accentuated by increasing the temperature of the atmosphere.

V.2- Morphological System of Algeria:

Algeria is in contact with two major geographical areas: the Mediterranean area and the Sahara. The compartmentalization of the relief into large strips roughly oriented from west to east accentuates the oppositions between the different natural environments that follow one another from north to south (fig.V.11).

To the south, the Sahara offers vast contrasts between the monotonous expanses of plateaus covered with stones (hamadas of the Draa), the basins hemmed in by dunes (Grand Erg occidental, Grand Erg oriental) and the imposing reliefs of the mountain ranges of the extreme south, centred on the Hoggar, which culminates at around 3,000 m.

To the north, in the Maghreb proper, two vigorously shaped mountain ridges frame the Interior High Plains, where a few isolated djebels (mountains) dominate vast basins, the bottom of which is often occupied by sebkhas (brackish water lakes, reduced in summer to a film of salt).

In the Tell, small coastal or sublittoral plains (Mitidja) alternate with relatively low mountain ranges, but with very steep reliefs, which juxtapose elements of ancient massifs (Greater Kabylia) and pieces of sedimentary cover (limestone, marl, sandstone, flysch) violently folded, faulted and straightened, in several phases, in the Tertiary era.

To the south of the High Plains and in contact with the Sahara, a second mountainous ridge, the Saharan Atlas, raises the heavier forms of more regular folds in a material based on limestone and marl.

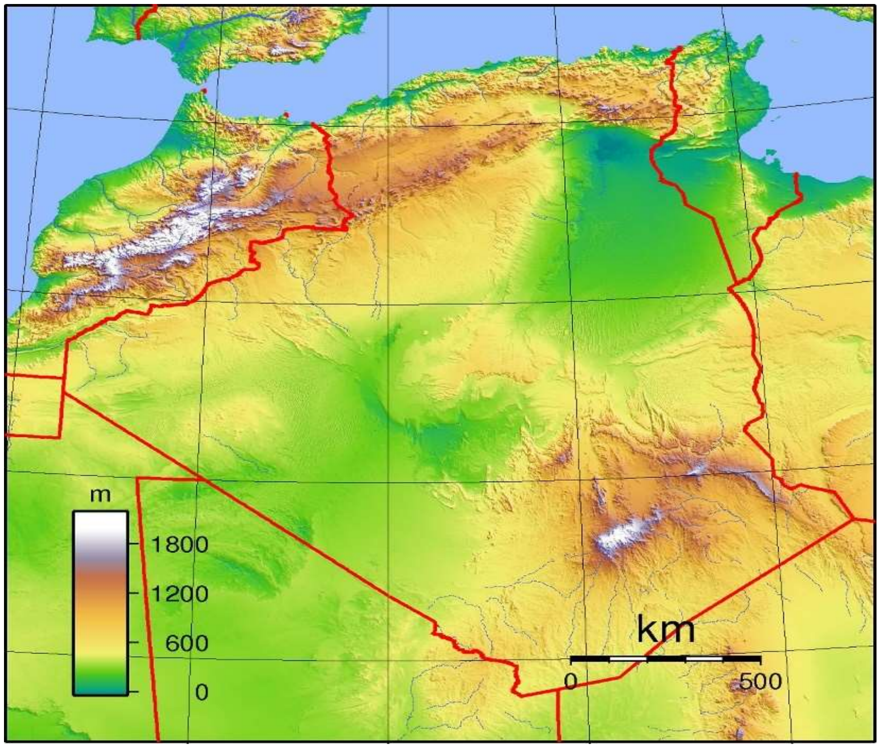

Figure.V.11: Geographical map of Algeria.

V.2.1- WETLAND:

a) - The Mediterranean Coast:

The Mediterranean coast, with its mild and humid climate, is bordered by the Tellian chains. It often has steep and picturesque reliefs, such as the corniche of Petite Kabylie, but also includes beautiful coastal and sublittoral plains where the main cities are located.

b) - The Tellian Border:

The Tellian border, located in immediate contact with the Mediterranean shores, is one of the most favoured areas. It is characterized by beautiful humid mountains that dominate narrow and marshy plains in their natural state, with Mediterranean vegetation including forests of holm oaks, cork oaks, Aleppo pines, as well as scrubland and scrubland. Violent erosion gullies the bare slopes during the winter. However, conditions vary from East to West.

b.1) - The Oriental Tell

The **eastern Tell**, stretching **from Algiers to Annaba**, is dominated by the mountains of **Grande** and **Petite Kabylie** and is distinguished by its very mountainous character.

This region includes small coastal plains (Bejaia, Djidjelli, Skikda, Annaba) and inland basins narrowed behind steep gorges (wadis Soummam, Rummel, el-Kebir, Seybouse).

Ancient massifs, straightened and dissected by erosion, form ledges on the sea (Grande Kabylie, Kabylie de Collo, Massif de l'Edough) and are surrounded to the south by the limestone "sierras" of Djurdjura, Bibans and the limestone chain of Babors, with peaks exceeding 2,000 m.

This region, the most densely mountainous in Algeria, is also the wettest, receiving 1 to 2 m of water annually, often in the form of snow.

The highest peaks are covered with cedar forests, while the humid and siliceous slopes of Grande Kabylie and the Collo and Edough peninsulas are covered with cork oak forests with scrubby undergrowth. This is the Algeria of the great djebels, humid and wooded.

b.2) - The Western Tell

The western Tell, relatively homogeneous as far as Algiers, was divided into small units:

- Of relief in the west, in the Oranais. The southern Tellian chain (Tessalas, Beni Chougrans, Ouarsenis massif) dominates a series of inland plains (Tlemcen, Sidi-Bel-Abbès, Mascara, Sersou), located below the Oran High Plains.
- To the west, the coastal Tellian chain is represented by the small massifs of Oran (Murdjajo) and Arzew,
- And by several coastal and sublittoral basins (Les Andalouses, Beni Saf, Oran, Mostaganem), separated by djebels (Tlemcen, Saïda) exceptionally reaching 1500 m. The limestone domes of the Traras massif are the last manifestations of the folds of the Middle Atlas.

The Oran region is drier than the Algiers or the Kabylies, as it is sheltered from the Atlantic air flows by the mountains of Morocco and southern Spain, while being exposed to Saharan influences, such as the chergui (or sirocco).

Annual rainfall exceeds 500 mm only on the summits of the djebels. Endoreism can be observed near the sea (Oran sebkha). The forests of Aleppo pine, cedar and kermes oak on the slopes of the djebels are often degraded to scrubby scrubland. The plains are home to sparse formations where the esparto grass, a steppe plant, coexists with mastic trees and wild olive trees.

c)-L'Algérois:

In the Algiers region, the relief is distinguished by well-defined compartments:

- Elongated and complex heights near the coast (such as the Dahra and the Sahel of Algiers);
- Plains close to the sea but often closed (such as the Mitidja and the middle Chlef valley);
- Mountain ranges in the background reaching nearly 2,000 m (such as the Ouarsenis and the Atlas of Blida).

The climate varies, with humid, forested mountains contrasting with a gentle coastline and plains that are dry in winter and warm in summer, once swampy but now rich in agriculture.

V.2.2- Arid Domain:

a) - The High Plains of the Interior:

The High Plains of the interior, located between the Tell and the pre-Saharan mountains, extend over 200 km in width and rise between 1,000 and 1,200 m above sea level.

Characterized by low and irregular rainfall (less than 500 mm per year, often less than 400 mm);

These plains experience significant temperature variations between day and night and between summer and winter.

The vegetation is mainly composed of low plants adapted to drought, typical of the steppes. The higher pre-Saharan mountains receive more rain, allowing the development of sparse forests of holm oaks, Aleppo pines and sometimes cedars.

The relief of the High Plains is less rugged than that of the Tell, with a thin and discontinuous sedimentary cover, dotted with a few isolated djebels. To the south, a mountain range forms almost continuous heights, more regular than those of the Tell.

Regional variations exist in the Interior High Plains, from Morocco to Tunisia. To the west, in the south of Algiers and Oran, the horizons are open with few djebels and an accentuated drought, dominated by steppe plains and large sebkhas.

To the east, in the Constantinois, the Tellian and pre-Saharan ridges come together, framing narrower and wetter plains, endorheic in the south. The cross-chain of the Hodna adds an additional complication.

b) - The Saharan atlas:

The Saharan Atlas closes the High Plains to the south, extending as far as Biskra. It consists of folded chains of limestone and marl:

- Including the **Ksour mountains** (2,230 m), the **Jebel Amour** (1,930 m), the **Ouled Naïl** (1,600 m) and **the Zibans**.
- To the east of **the Kantara breakthrough**, the altitudes increase with the **Aurès**, where the **Djebel Chelia** (2,328 m), the **highest point in Algeria, is located**. This massif with regular folds is flanked by **the Belezma to the west** and by **the Nemencha** and Tébessa mountains to the east. The Aurès dominates the Chotts depression by more than 2,000 m (chott Melrhir: –24 m).

The relief of the plains and djebels of the Saharan Atlas is strongly affected by erosion, characterized by endoreism (the wadis do not go to the sea except in the Constantinois) and rare but violent showers.

The relief is organized around endorheic basins, with humid and salty bottoms occupied by vast sebkhas (chott ech-Chergui, chott El-Hodna). These basins are surrounded by inclined planes, erosion glacis and steep slopes of a few djebels. The massifs, wetter than the neighbouring plains, bear forests of holm oaks and Aleppo pines above the scrubby low slopes.

V.2.3- Desert or Sahara Domain:

a) - The Sahara:

The Sahara, located south of the Saharan Atlas (fig.V.12), covers most of the Algerian territory. This environment is characterized by extreme dryness, monotonous and bare horizons (sandy ergs, stony hamadas), and grandiose reliefs in the extreme south, such as those of the Hoggar. Although hostile to the development of life, the Sahara has been home to human groups for centuries. In addition, its subsoil contains significant oil and natural gas resources, constituting a great wealth for contemporary Algeria.

Figure.V.12: Landscapes of the desert domain of the great south of Algeria.

V.2.4- LANDSCAPES and Characteristic Forms of Arid Zones:

From a geomorphological point of view, arid zones show a similarity of forms linked to the similarity of erosion factors which intervene according to 3 actions:

- Fragmentation
- Moving fragmented products;
- The deposit

A morphological model is considered to be characteristic of arid zones, and to form a relief, of a slightly inclined plane continuing by a flat formation called GLACIS and ending in a depression whose center is often salty.

A/ More or less flat formations:

They are classified in relation to their positions and reliefs and also in relation to the flow of water (presence or absence of wadis, talwegs, etc.).

1/ Cones of droppings:

An ejection cone or alluvial fan is a pile of debris carried by a torrent to the outlet of a valley or below a slope; it has a triangular shape.

In the mountains, the dejection cones are fed by floods. The top of a cone of dejection is called the apex.

The data used for the analysis of alluvial fan characteristics most often come from topographic maps or better still, aerial photographs.
From there, three characteristics are regularly highlighted that make it possible to discriminate the cones from each other:

- **The form**. It is fan-shaped, with an apex upstream and an arched boundary downstream.
- **The surface**. It has often been shown that the surface of a cone is in relation to that of the receiving basin. Precipitation (quantity and especially intensity),

2/ Glazes:

The term glacis comes from the Latin *glacies* (= ice) in the sense of: which slides. For the geomorphologists who used it to designate the inclined plane that connects the bottom of a slope to the surrounding plain, these are slopes with a gentle slope.

According to the Commission for the Vocabulary of Geomorphology (International Council of the French Language), a glacis is a **surface close to a plane, with a concave profile (1 to 12°), dominated by a system of steep slopes**.

There are two classifications according to the authors:

2.1-Classification of Tricart and Cailleux (1969) (Soil scientists):

These authors classify glazes according to the importance of the detrital material that covers them (fig.V.13), there are 3 types of glazes:

1- Denudation glacis or ablation glacis: which are assimilated to erosion glazes;
2- Spreading or covering glazes;

- **The flooding glazes.**

The bioclimatic conditions of morphogenesis can promote accumulation processes. In this respect, the case of arid environments is typical. This situation is the result of the rapid decrease downstream of the flow of wadis or diffuse flows, both by infiltration into their dry beds between floods, and by evaporation.

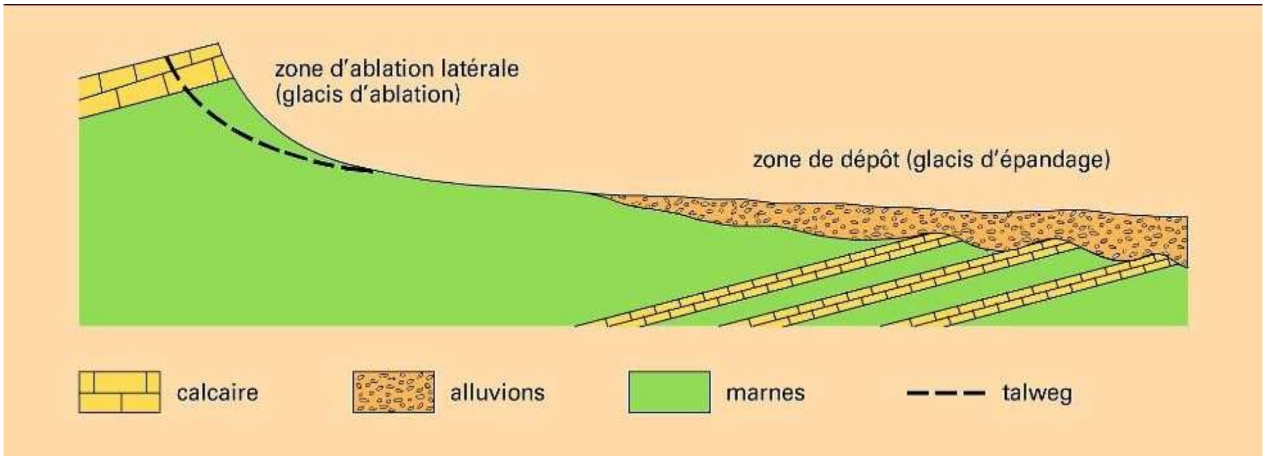

Figure.V.13: Diagram showing the positions of the ablation glacis to the spreading glacis.

Note: *the boundary between the different types of Glacis is not clear, even in the field differentiation is difficult to achieve.*

Table.V.2: Main types of glacis according to the Tricart and Cailleux Classification

Type	Genesis	Model
Glaze of Denudation	Formed by clearing the rock and moving the detrital elements removed.	Steeper incline
Glaze Spreading	Formed by alluvial accumulation combine with the denudation action.	Less steep slope
Flooding glaze	Significant alluvial accumulation by spreading	A surface angled accumulation

2.2-Pouget's classification (geomorphologist):

This classification is based on chronology, therefore based on the date of installation of the Glacis. We therefore distinguish:

- The Glacis of the Early Quaternary;
- The Glacis of the Middle Quaternary;
- Glacis of the Late or Present Quaternary.

1- Glacis of the Early Quaternary:

They correspond to the high surface of the Holocene and which were spared by the Villafranchian tectonic movement (tectonics that aims to change the relief) and which are formed by accumulation. These glacis show important calcareous crusts, and show a high position (altitude).

2- Middle Quaternary glaze:

They developed after the post-Villafranchian tectonic movement which caused a dislocation of the Old Glacis and clearing by erosion. They are characterized by a very thin limestone accumulation. The vegetation that develops is characterized by the dominant Esparto and White Sagebrush.

3- Late or current Quaternary glacis:

These are Glacis which show mainly alluvial material, the accumulation is much less, and it occurs and it presents itself in the form of limestone clusters or nodules and more rarely in the form of a continuous crust. Recent Glacis often show sandy accumulations.

B / Alluvial formations:

Among these training courses are:

1st formation: The terraces : are formations of the Late and current Quaternary, they are often located on either side of the wadis and are linked to the action of the digging of the wadis, they often show a coarse texture with a proportion of pebbles.

2nd formation: the alluvial wadi channels: they represent the flat surface of the wadis, the texture is medium to fine and the thickness of the alluvial accumulation forms decreases from upstream to downstream.

C/ The particular forms of the desert:

- **Ergs**:

  The ergs are the large dune massifs, they occupy about 20% of the surface of the Sahara.

- **The regs:**

  The regs, also called serir in the eastern parts of the desert, are flat, stony and gravelly expanses and constitute the most common landscape of the Sahara. The great regs are particularly inhospitable. We can mention the reg of Tanezrouft, the Libyan serir or the reg of Ténéré, which each occupies hundreds of thousands of km². They can also occupy the top of the plateaus.

- **The dayas:**

Dayas are basins of limited extent, generally with a clayey bottom, in which runoff water can accumulate. Alternating flooding and wind erosion can explain their formation. They are sometimes of karst origin on the plateaus. They constitute perennial vegetation areas. They are mainly found north of the Sahara.

- **Hamadas:**

Hamadas are tabular rocky plateaus bounded by cliffs. They are of sedimentary origin, most often limestone. When they are covered with sandstone, they are called tassilis (for example: Tassili des Ajjer in Algeria). In general, the surface shows bare rock, smoothed by wind erosion.

- **The Sebkha**:

Salt marsh, sometimes temporarily drained, which occupies the font of a depression. The terms of the vocabulary must be specified. It has been customary to call the great Sebkha "Chott", in reality, the term Sebkha corresponds well to the closed depression, and the Chott to the halo of vegetation which surrounds the closed depression.

- **The Garaa:**

These are closed depressions with little salt in the steppes. These depressions are very flat, and gradually connect with the neighboring plains. Their clay soil is very compact, and devoid of vegetation. The floods, coming from the peripheral reliefs, trigger periodic flooding of the **Garaa**, as well as a sedimentation of sand and clay. They are in fact forms of accumulation, corresponding to almost perfect horizontal surfaces.

- **The djebels:**

The term *djebel* refers to all other reliefs, whether they are hills or larger mountain ranges, The most important massifs are:

- The Hoggar is another imposing volcanic massif. It culminates at 2918 m.
- The Aïr is lower, the peaks are more tabular but still culminate at 2022m. The Adrar des Ifhoras to the south of the Hoggar is a crystalline and metamorphic extension which culminates at 890 m.

- **The Oasis:**

Saharan oases, a natural and anthropogenic environment, occupy only one thousandth of the surface of the Sahara. They are sometimes located on the bed of rivers that flow into the desert or at the foot of massifs producing springs or directly above outcropping or shallow water tables.

- **The Gueltas:**

This term refers to temporary or non-temporary bodies of water with no visible flow. These can be ponds in the beds of wadis, or natural cisterns in the rock.

- **The Fouggaras:**

Foggaras are long underground structures that allow the supply of water to certain oases, from plateaus or mountain ranges. This ancestral technique originated in what is now Iran, under the name of Qanât.

- **The Wadis:**

Wadis are watercourses with a temporary visible flow. Most of the time they are dry, Violent floods can sometimes occur, especially in the mountain ranges. The upstream part is formed by the collection of runoff channels, the middle part forms a wide bed whose limits are sometimes difficult to recognise on the plain.

V.3-Evolution of forms in the three domains:

The evolution of geomorphological forms in different types of climates (humid, arid desert or Saharan) is influenced by distinct geological processes, such as erosion, sedimentation, and climate change over long periods. Here is an overview of the evolution of forms in these three fields, accompanied by bibliographical references:

V.3.1-Wetland:

In humid climates, where rainfall is abundant and regular, geomorphological forms evolve mainly under the influence of water and vegetation.

- **River valleys and alluvial terraces** : Rivers and streams shape valleys by cutting through the landscape over time. Alluvial terraces form along streams as a result of sediment deposition during periods of overflow (Leopold and Wolman 1960).
- **Glaciation and glacial forms** : In areas where glaciers were present, U-shaped valleys and moraines are typical forms created by glacial activity. These forms are well studied in regions such as the Alps or the polar regions (Benn and Evans, 1998).
- **Karsts and karst formations** : Limestone rocks dissolve under the effect of acidic water, forming karst landforms such as caves, sinkholes and lapiaz. These formations are common in areas where limestone is abundant and groundwater is present (Ford and Williams 2007).

V.3.2-Arid desert domain:

Arid deserts are characterized by scarce and irregular rainfall, with high evapotranspiration, which influences geomorphological forms in a specific way.

- **Sand dunes** : Formed by the action of wind on sand particles, dunes can be barkhane-shaped, longitudinal dunes, or star-shaped dunes, depending on the direction and strength of the wind (Lancaster, 1995).
- **Reg and hamada** : Pebble and gravel covered areas (reg) and bare rock plains (hamada) result from wind erosion and differential accumulation of wind-displaced material (Thomas 2011).
- **Depressions and sebkhas** : Depressions can temporarily fill with water during rare rainfall, forming sebkhas, saline plains where salt deposits are formed by evaporation (Glennie, 1992).

V.3.3-Saharan domain

The Saharan climate is distinguished from other arid areas by specific geomorphological characteristics resulting from extremely arid conditions and marked temperature variations.

- **Ergs** : The vast expanses of mobile sand dunes are typical of the Sahara Desert, where significant deposits of sand have accumulated under the influence of the wind (McKee, 1979).
- **Rock Massifs and Inselbergs** : Erosion-resistant rock formations often emerge as isolated massifs (inselbergs) above the flat desert landscape, forming distinct features of the landform (Thomas, 2011).

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TD Part:

Exercises and questions relating to morphological forms in humid, arid and desert climates in Algeria, with their solutions:

Humid climate

Exercise 1: River valleys and alluvial terraces

1. Describe the processes responsible for the formation of river valleys in humid regions.
2. What are the characteristics of alluvial terraces and how are they formed?
3. Give examples of famous river valleys in Algeria and discuss their geomorphological significance.

Solution:

1. River valleys are formed by the hydraulic erosion action of streams that cut through the landscape over time, carrying sediment and eroding the riverbed and banks.
2. Alluvial terraces are flat formations located above the current bed of a river, formed by the deposition of sediments during periods of overflow. They bear witness to past variations in the level of the river.
3. Example: The Soummam Valley in Algeria, famous for its well-developed alluvial terraces, offers an example of the complex interplay between river processes and local geomorphological conditions.

Arid desert climate

Exercise 2: Sand dunes and ergs

1. What are the processes responsible for the formation of sand dunes?
2. Compare and contrast the different types of dunes (barkhanes, longitudinal dunes, star dunes).
3. Describe the requirements for the formation of an erg and give examples of ergs in Algeria.

Solution:

1. Sand dunes are formed by the accumulation of wind-blown sand, which deposits it when wind speed decreases in areas of low vegetation.
2. Barkhanes are crescent dunes formed by a dominant unidirectional wind. Longitudinal dunes form parallel to the direction of the prevailing wind. Star dunes are found in areas where several winds meet.
3. An erg is a vast expanse of mobile sand dunes. Example in Algeria: Erg Chèche in the middle of the Algerian Sahara, known for its spectacular dunes and extreme desert conditions.

Saharan climate

Exercise 3: Inselbergs and depressions

1. What is an inselberg and how is it formed?
2. Describe the process of formation of depressions and sebkhas in the Saharan desert.
3. What role do climatic conditions play in the formation of the specific geomorphological characteristics of the Saharan desert?

Solution:

1. An inselberg is an isolated landform that emerges above the flat desert landscape, often composed of erosion-resistant rocks. It is formed by differential erosion which leaves these reliefs isolated.
2. Depressions form in the Saharan desert due to wind erosion and the accumulation of fine materials, often filled with water during the rare rainfall to form sebkhas, saline plains.
3. Arid climatic conditions and prevailing winds strongly influence the morphology of the Saharan desert, shaping features such as ergs, inselbergs and sebkhas.

These exercises provide an opportunity to deepen the understanding of morphological forms specific to humid, arid and desert climates, focusing on examples and relevant geographical conditions in Algeria.

Chapter VI:

Ecological Preponderances of the Geomorphology Factor

VI- Ecological preponderances of the Geomorphology Factor:

VI.1-Definition:

The ecological preponderances of the geomorphology factor refer to the significant impact of landforms and geomorphological processes on ecosystems and biodiversity. Geomorphology influences environmental conditions, such as water availability, soil fertility, microclimate, and habitat, thereby determining the distribution and dynamics of biological communities (Huggett 2011).

VI.2-Influences of Geomorphology on Ecology

a. -Hydrology and Water Availability:

Landforms determine drainage regimes and water accumulation, influencing the availability of water for ecosystems. For example, river valleys can create biodiversity-rich wetlands, while steep slopes promote rapid runoff and reduce water infiltration (Knighton, 1998).

b. -Soil Fertility:

Geomorphological processes such as erosion, sedimentation and deposition of materials influence soil formation and composition. Alluvial plains, for example, tend to have more fertile soils due to regular sedimentation, favouring dense and diverse vegetation (Brady & Weil, 2008).

c. -Microclimate:

Geomorphological features such as elevation, slope orientation, and terrain configuration modify local microclimatic conditions, including temperature, humidity, and wind exposure. These microclimatic variations can create distinct ecological niches and influence species distribution (Forman 1995).

d. -Habitat and Fragmentation:

Landforms create diverse habitats and can act as natural barriers, fragmenting ecosystems and affecting the connectivity of species populations. Mountains, for example, can isolate populations, promoting speciation and genetic diversity (Lomolino et al., 2006).

e. -Disruption Process :

Geomorphological events such as landslides, volcanic eruptions, and floods can act as major ecological disturbances, reshaping landscapes and creating new opportunities for settlement and ecological succession (Walker & Willig, 1999).

VI.3-Importance for Ecological Management

Understanding the ecological preponderances of the geomorphology factor is crucial for the sustainable management of natural resources and the conservation of biodiversity. Watershed management plans, for example, need to incorporate geomorphological dynamics to maintain hydrological functions and aquatic habitats (Thorp et al. 2010).

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TD Part:

Exercises and Questions on the Ecological Preponderances of the Geomorphology Factor:

Training

1. **Topographic Map Analysis**
    - **Objective** : To identify and analyze the landforms present on a topographic map and their potential impact on local ecosystems.
    - **Instructions**:
        - Select a specific region on a topographic map.
        - Identify the different landforms (mountains, valleys, plains, etc.).
        - Describe how these landforms may influence the distribution of vegetation and animal habitats in this region.

2. **Case Study: River Valley**
    - **Objective** : To understand the impact of river valleys on biodiversity.
    - **Instructions**:
        - Choose a specific river valley (e.g., the valley of the M'ZI wadi).
        - Look for information about the biodiversity of this area.
        - Write a report explaining how the geomorphology of the river valley influences the diversity of plant and animal species.

3. **Erosion Modeling**
    - **Objective** : To simulate the effects of erosion on different types of landforms.
    - **Instructions**:
        - Use geomorphic simulation software (such as ArcGIS or QGIS).
        - Model erosion on a steep slope and on a plain.
        - Compare the results and discuss the ecological implications of each type of landform.

Questions

1. **Definition and Concepts**
    - What is geomorphology and how does it differ from other geoscience disciplines?
    - Explain the fundamental concepts of geomorphology and how they are applied in the study of landscapes.
2. **Influence of Landforms**
    - How do landforms influence the availability of water in a given region?
    - Describe how soil structure and lithological composition affect soil fertility and vegetation.

3. **Microclimate and Habitats**
    - How do geomorphological features such as elevation and slope orientation change local microclimatic conditions?
    - Explain the importance of the microclimates created by landforms for habitat diversity.

4. **Disruption Process**
    - What are the main geomorphological processes that act as ecological disturbances?
    - Give examples of major geomorphological disturbances and discuss their impact on ecosystems.

5. **Ecological Management and Conservation**
    - Why is it important to integrate geomorphology into watershed management and biodiversity conservation?
    - Propose sustainable management strategies that take into account the ecological preponderance of the geomorphological factor.

Proposed Solutions to the Exercises and Questions:

Training

1. **Topographic Map Analysis**
   - **Solution**:
     - **Selected Region** : Choose a mountainous region such as Milok.
     - **Identified Landforms** : Mountains, valleys, plains, hills.
     - **Impact on Vegetation and Habitats** :
       - **Mountains** : Presence of low-altitude, high-altitude forests, species adapted to cold and windy conditions.
       - **Valleys** : denser vegetation thanks to the accumulation of water, habitats for a diversity of animal and plant species.
       - **Plains** : Fertile soils suitable for agriculture, grassland ecosystems.

2. **Case Study: River Valley**
   - **Solution**:
     - **Valley of the Oued M'ZI**:
       - **Biodiversity** : Ecosystems rich in aquatic and terrestrial species, importance of wetlands.
       - **Geomorphological Influence** : Annual floods enrich soils, supporting thriving agriculture and habitat diversity.

3. **Erosion Modeling**
   - **Solution**:
     - **Steep Slope**:
       - **Results** : Faster erosion, soil loss, gully creation.
       - **Ecological Implications** : Soil degradation, negative impact on vegetation and habitats.
     - **Plain:**
       - **Results** : Slower erosion, sediment accumulation.
       - **Ecological implications** : More stable soils, habitats favourable to sustainable agriculture.

Questions

1. **Definition and Concepts**
   - **Solution**:
     - **Geomorphology** : The study of landforms and the processes that shape them (Huggett, 2011).
     - **Fundamental Concepts** : Erosion, plate tectonics, isostasy, etc.

2. **Influence of Landforms**
   - **Solution**:
     - **Water availability** : Mountains capture moisture, valleys promote water accumulation.
     - **Soil and Vegetation** : Fertile soils in the valleys, shallow soils on the slopes.

3. **Microclimate and Habitats**
   - **Solution**:
     - **Altitude and Orientation** : Altitude influences temperatures, slope orientation influences exposure to the sun and winds (Forman, 1995).
     - **Microclimates** : Creation of varied habitats, ecological niches for different species.

4. **Disruption Process**
   - **Solution**:
     - **Geomorphological disturbances** : Earthquakes, volcanic eruptions, landslides.
     - **Impact on Ecosystems** : Rapid changes in habitats, species adaptation (Walker & Willig, 1999).

5. **Ecological Management and Conservation**
   - **Solution**:
     - **Importance of Geomorphology** : Understanding natural processes for sustainable management.
     - **Management Strategies** : Protection of sensitive areas, restoration of degraded habitats, integration of geomorphological knowledge into planning (Brady & Weil, 2008).

Annexes

Biography

William Morris Davis is best known for his theory of the erosion cycle. He explains the creation and evolution of landforms in three successive stages: the stage of youth (raised relief), the stage of maturity (action of erosion)3, and the stage of old age. According to this theory, the orogeny is thus followed by a long phase of tectonic stability without rejuvenation of the relief, which is called the peneplain.

In 1928, he published his work on coral reefs, which reinforced Charles Darwin's theory on the subject.

W. M. Davis received his master's degree in 1870 from Harvard University. From 1870 to 1873 he held a position at the meteorological observatory of Córdoba (Argentina) and from 1876 to 1912, he taught at Harvard University and ended his career there as professor emeritus.

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