Geology for Engineers:

Fundamental Concepts and Applications

Dr. Zine el Abidine LAIDANI
Saad Dahlab University of Blida
Faculty of Technology
Department of Civil Engineering
E-mail: laidani_z@univ-blida.dz



October 2025

Table of Contents

I. Abbreviation 6

II. Glossary 6

III. Objectives 7

IV. Target Audience: 7

V. Course Description 8

Chapter I: Introduction to Geology 9

1. Introduction 9

2. Geology 9

3. The Earth 9

3.1. A Gaseous Envelope 9

3.2. A Discontinuous Liquid Envelope 9

3.3. The Crust 9

3.4.The Mantle 10

3.5. The Outer Core 11

3.6. The Inner Core 11

Definition (Summary) of Geology 13

4. Goals of Geology 13

4.1. Scientific Goal 13

4.2. Economic Goal 13

5. Fields of Geology 14

5.1. Petrography 14

5.2. Mineralogy and Crystallography 14

5.3. Petrology 14

5.4. Sedimentology 14

5.5. Stratigraphy 14

5.6. Paleontology 14

5.7. Tectonics or Structural Geology 15

5.8. Applied Geology 15

6. Conclusion 15

Chapter II: Minerals 16

1. Introduction 16
2. Definition of a Mineral 16
3. Crystals 16
4. Classification of Crystals 17
4.1. Polymorphs 18
4.2. Isomorphs 18
5. Criteria for Recognizing Minerals 19
5.1. Density 19
5.2. Color 19
5.3. Streak Color (Streak) 19
5.4. Luster 19
5.5. Transparency 20
5.6. The Shape of the Mineral 20
5.7. Cleavage 20
5.8. Hardness 20
6. Nomenclature of Minerals 21
7. Classification of Minerals 22
a. Chemical Composition of the Earth's Crust 22
b. Mineral Families: 23
8. Clay Minerals 25
8.1. Classes of Clay Minerals 27
i) Kaolinite Group 27
ii) Illite Group 27
iii) Montmorillonite Group 28
9. Rocks 28
a. Definition of a Rock 28
b. Igneous Rocks: Definitions 29
i. Plutonic Rocks: 29
ii. Volcanic Rocks: 29
iii. Magmatic Processes 29
a) Volcanic Structures 30
b) Fundamental Processes of Igneous Rock Formation 30

i. Formation of Magma (Silicate Melt) 30
ii. Magma Transfer 30
iii. Magma Ascent Rate 31
c) Different Types of Magmas 31
d) Classification and Naming of Igneous Rocks 31
i. Extrusive Igneous Rocks 31
ii. Intrusive Igneous Rocks (Plutonic Rocks) 32
a. Sedimentary Rocks 32
i. Sedimentation Process 33
a. Erosion: 33
b. Transport: 34
b. Deposition: 34
c. Diagenesis: 34
ii. Classification and Naming of Sedimentary Rocks 35
a. Detrital Rocks: 35
b. Chemical Rocks: 35
c. Organic Rocks: 35
b. Metamorphic Rocks: 36
i. Definitions 36
ii. Factors of Metamorphism 36
iii. Types of Metamorphism 37
iv. Conclusion 37
Chapter III: Action of various elements on rocks 38
1. Introduction 38
2. Action of Air on Rocks 38
a. Wind Erosion = Aeolian Erosion 38
b. Aeolian Sedimentation 40
3. Action of Water on Rocks 42
a. Runoff 43
b. Watercourses 45
4. Action of Glaciers on Rocks 47

5. Conclusion 50
Chapter IV: GEODYNAMICS 50
Introduction 50
I. Internal geodynamics: 51
1. Seismology : 51
1.1. Definition of an Earthquake 51
2. Seismic Waves 55
2.1 Seismographs and Seismograms 55
2.2. The Different Types of Waves 56
3. Concept of Tectonics (Soft and Brittle) 58
3.1. Brittle Tectonics (Faults) 58
3.2. Soft or Ductile Tectonics (Folds) 59
4. Volcanology : 61
4.1. Definition of a Volcano 61
II. Extenal geodynamics: 64
1. Surface Weathering 64
2. Types of Weathering Processes 64
5. Conclusion 67
Chapter V: Adaptation of Geological Techniques to the Needs of Civil Engineering 68
Introduction: 68
1. Geological Map 68
2. Types of Maps Useful to the Civil Engineer 68
3. Methods of Survey and Interpretation 71
4. Applications in Civil Engineering 72
4.1. Method for Drawing a Geological Cross-Section 72
4.2. Establishment of a Geological Cross-Section 73
Conclusion 76
General Conclusion 76
Bibliography 77

I. Abbreviation

EUS: Earth and Universe Sciences (Sciences de la Terre et de l'Univers)

GPS: Global Positioning System

BRGM: Bureau de Recherches Géologiques et Minières

SIAL: Silicium + Aluminium (continental crust composition)

SIMA : Silicium + Magnésium (oceanic crust composition)

II. Glossary

Geology: Science that studies the Earth—its composition, structure, history, and the processes that shape it.

Crust: The thin outermost layer of the Earth, divided into continental (granitic, SIAL) and oceanic (basaltic, SIMA) crust.

Mantle: The thick layer beneath the crust, composed mainly of peridotite; site of convection currents driving plate motion.

Core: Central part of the Earth composed largely of iron and nickel; divided into an outer liquid core and a solid inner core.

Moho (Discontinuity of Mohorovičić): Boundary between the Earth's crust and mantle, marked by a sudden increase in seismic wave velocity.

Isostasy: State of gravitational equilibrium between Earth's crust and mantle; explains why continents "float" at certain elevations.

Plate Tectonics: Theory describing the movement of rigid lithospheric plates over the asthenosphere.

Hydrogeology: Branch of geology dealing with the occurrence and movement of groundwater.

Engineering Geology: Application of geological knowledge to civil engineering and construction projects.

Erosion: Mechanical removal of rock materials by wind, water, or ice.

Weathering (Altération): Breakdown of rocks by physical, chemical, or biological processes.

Sediment: Particles produced by weathering and transported by natural agents.

Mineral: Naturally occurring, homogeneous solid with a defined chemical composition and ordered atomic structure.

Rock: Aggregate of one or more minerals forming the solid part of the Earth's crust.

Stratigraphy: Study of the sequence and relationships of rock layers (strata) to reconstruct geological history.

Tectonics: Study of large-scale movements and deformations of the Earth's crust.

III. Objectives

This course provides a scientific and methodological synthesis of Geology, covering all the disciplines of Earth Sciences (plate tectonics, structural geology, mineralogy, petrography, geochemistry, geomorphology, sedimentology, etc.).

The aim of this course is to equip students with the knowledge and skills required to better understand geological phenomena and geotechnical problems and to read and interpret a topographic map:

- To introduce students to the reconstruction of the Earth's history from its origins to the present day, focusing on the study of accessible constitutive materials.

- To categorize current geological processes and reconstruct the past history of the Earth based on the study of rocks, archives, and other geological markers.

- To understand the scientific and methodological synthesis of geology, based on the knowledge and skills acquired.

- Students will be able to examine and assess their acquisition of knowledge about the formation of the Earth, its internal structure, and all processes affecting its surface.

- Students will aim to acquire basic notions about rocks, minerals, and certain physical phenomena such as earthquakes and volcanoes.

-Students are encouraged to deepen their understanding of various concepts through consultation of a proposed bibliography at the end of the work.

IV. Target Audience:

This course is intended for second-year engineer students in civil engineering at Saad Dahlab University of Blida.

V. Course Description

The course is organized into five chapters:

In the first chapter, general concepts are presented, such as the definition of geology, the origin of the Earth, the divisions of geology, and the internal structure of the Earth.

The second chapter defines the basic concepts of mineralogy and presents the different types of rocks (igneous rocks, sedimentary rocks, metamorphic rocks, and unconsolidated rocks), as well as their cycles of formation.

The third chapter is dedicated to the action of various elements on rocks, namely: wind, water, and glaciers.

The fourth chapter briefly describes the theory of plate tectonics, defining divergent boundaries, convergent boundaries, and transform boundaries, as well as concepts of internal geodynamics (earthquakes, volcanoes).

Finally, in the fifth chapter, we address the adaptation of geological techniques to the needs of civil engineering, such as geological mapping, the use of graphic constructions, geological surveys of surfaces, geological cross-sections, and stereographic projection.

Chapter I: Introduction to Geology

1. Introduction

In the captivating world of geology, we explore the mysteries and history of the Earth, delving into the core of rocks, minerals, and geological phenomena that shape our planet. This course takes you on an exciting journey through geological time, revealing the hidden wonders of our environment through natural forces and complex processes.

2. Geology

Definition

The word geology comes from two roots (Greek):

- geo: the Earth
- logos: study, description, observation, discussion

Geology is a science of the Earth or the globe. Rocks and layers are the primary objects of study in geology[1].

3. The Earth

Celestial mechanics has allowed us to calculate the mass of the Earth (radius: 6371 km) and, from there, its density, which is 5.5. Moreover, the study of seismic wave propagation has shown the existence of discontinuity surfaces where the waves are reflected or refracted. It is currently considered that the Earth consists of different concentric envelopes characterized by different compositions and/or rheological behaviors:

3.1. A Gaseous Envelope

- The atmosphere.

3.2. A Discontinuous Liquid Envelope

- The hydrosphere.

3.3. The Crust

The crust can be:

- **Continental**: with a density of about 2.7 in its upper part and 2.8 in its lower part, its average composition is close to that of granite; its

thickness is about thirty kilometers but can reach 60 to 70 kilometers in orogenic (mountain) areas [2].

- **Oceanic**: with a density of about 3, of basaltic composition, and approximately 7 kilometers thick.

The continental crust forms a series of blocks that "float" on the denser mantle according to a hydrostatic mechanism. Any relief of the crust is consequently compensated by a "root" extending into the mantle, similar to an iceberg in the sea. This "hydrostatic" balance is called isostasy. The oceanic crust also rests on the mantle and is likewise in isostatic equilibrium with it. The differences in thickness and density between the continental and oceanic crust mean that the surface of the latter is usually at an average altitude about 5000 meters lower than that of the continents.

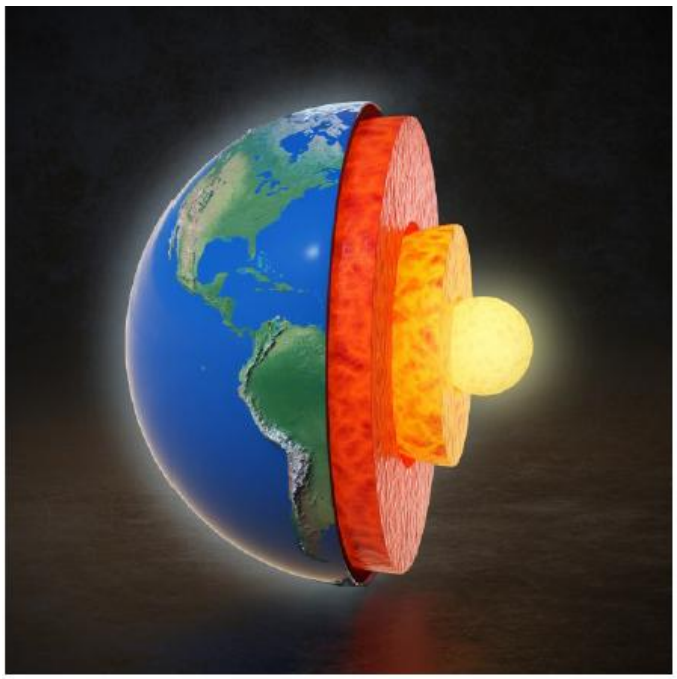


Figure1: Cross-section showing the internal structure of the Earth

3.4.The Mantle

The mantle is of peridotitic composition (rock primarily composed of olivine) and includes:

- An upper solid part (density= 3.4). The crust and the upper solid part of the mantle constitute the lithosphere, which has a total thickness of about 100 km beneath the oceans and 150 km beneath the continents. The Mohorovičić discontinuity, or Moho, separates the crust from the lithospheric part of the mantle. The lithosphere is divided into plates and can deform plastically at depth.

- A lower non-solid part (but not liquid), known as the asthenosphere, which is capable of flowing due to a very partial melting of the rock (1 to 2%), and whose density varies from 3.4 to 5.5 depending on depth. It extends down to about 2885 km [3].

Note : The increase in the density of the mantle at depth corresponds to a change in the crystalline structure (and thus mineralogical) of the peridotitic compounds that compose it, under the action of pressure [1].

3.5. The Outer Core

The outer core is liquid, primarily composed of iron, with a depth ranging from 2885 to 5155 km and a density of 9.5 to 11.5.

3.6. The Inner Core

The inner core is solid, formed of iron and nickel, extending from 5155 km to the center of the Earth and has an average density slightly greater than 12.

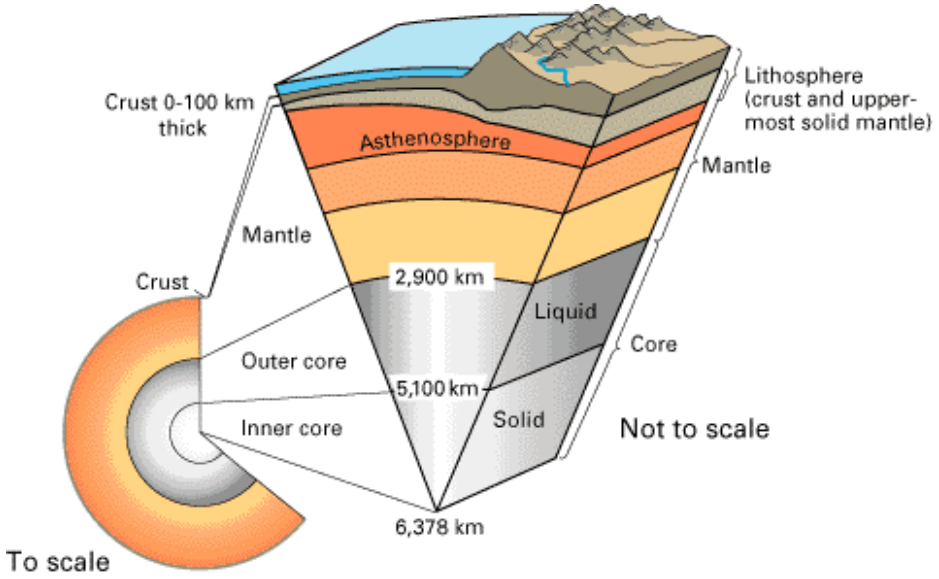


Figure 2: difference earth's layers

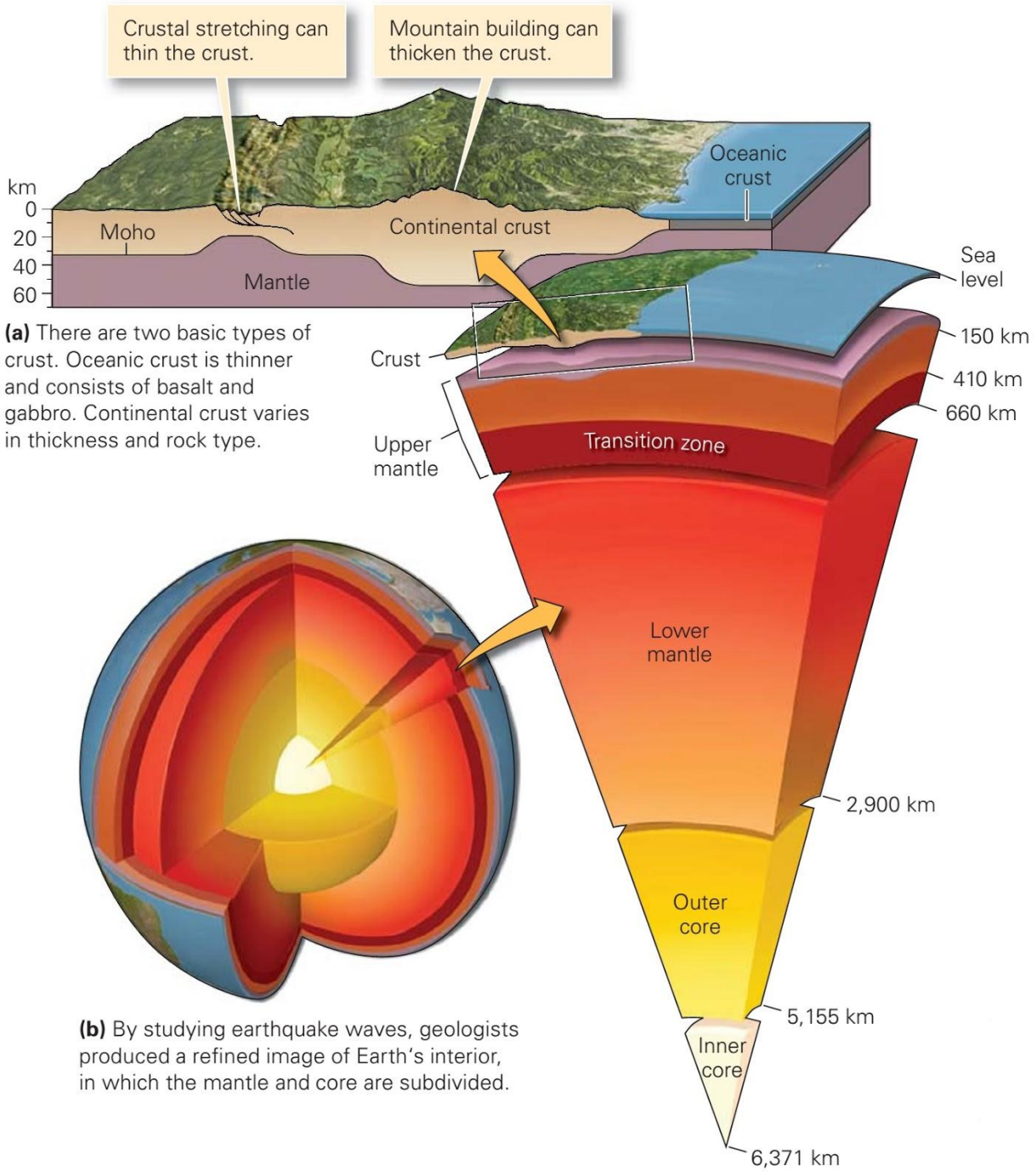


Figure 3: The Internal Structure of the Earth

Geology focuses on the outermost rigid (hard) envelope: the lithosphere, which is directly accessible for observation. Geology is a science of observation. This lithosphere is not immutable (invariable). It deforms, breaks, and folds. It is said to evolve and be in motion. Geology also studies this evolution over past and future times. Geology generates significant scientific interest. Today, it extends to the study

of the solar system, our galaxy (the Milky Way), and even the entire Universe or Cosmos. Thus, geology is linked to the Earth and Universe Sciences (EUS*). (Biology is a Science of Nature and Living Beings: SNL*). It focuses on the study of rocks, minerals, fossils, as well as natural resources (water, ores, coal, hydrocarbons, construction stones, etc.). Geology also investigates terrestrial activity illustrated by earthquakes, volcanic eruptions, and ground instabilities (landslides, slippages).

Definition (Summary) of Geology

Geology is a science of the Earth. It focuses on the study of rocks and the evolution of the Earth's outermost envelope: the lithosphere, particularly the crust, which is directly accessible for observation. It also encompasses the study of the solar system and the universe.

4. Goals of Geology

4.1. Scientific Goal

Geology aims to reconstruct the age and history of the Earth. Studies show that it formed about 4.6 billion years ago. Its surface was composed of magma (molten rocks + gases). Their temperature gradually decreased, allowing the formation of the first terrestrial crust. The degassing of the magma (carbon dioxide, oxygen, and others) contributed to the formation of the atmosphere[4,5] .

The discovery of the concept of plate tectonics, which shows that continents carried by lithospheric plates are in motion, is a major scientific result. It explains the positioning of geographic regions prone to earthquakes and volcanic eruptions. It allows for hypotheses about the future of the Earth, particularly regarding the arrangement of continents in 50 million years, for example.

From a biological perspective, plate tectonics is the main driver of the evolution of life. Explanation: As they move, continents come together or break apart. Coastal areas expand or disappear. These variations in marine areas compel organisms to adapt to new environmental conditions or, in some cases, to become extinct.

4.2. Economic Goal

Geology also has an economic purpose. Deep layers are explored and exploited to discover mineral resources (water, coal, ores, hydrocarbons, construction stones including limestone for concrete, certain rocks such as clays for medicine and cosmetics, metals, and precious stones: gold, silver, diamond, opal, etc.).

5. Fields of Geology

The objects of study in geology are varied. For this reason, there are different specialties.

5.1. Petrography

Petrography aims to describe and classify rocks (macroscopic study). It is complemented and refined by studying under a polarizing microscope. Volcanology is a specialty of petrography.

5.2. Mineralogy and Crystallography

Mineralogy focuses on minerals (their chemistry, e.g., quartz; SiO_2), while crystallography deals with the shape of crystals (hexagonal, as shown in the photo above).

5.3. Petrology

Petrology is not the study of oil (when this is the case, it is referred to as petroleum geology or petrology) but rather the study of rocks based on geochemistry (the chemistry of rocks).

Example : In the case of igneous or metamorphic rocks, chemical analyses (SiO_2, Al_2O_3, K_2O, Na_2O, MgO, FeO, etc.) allow us to determine their formation conditions (temperature, pressure, depth).

5.4. Sedimentology

Sedimentology aims to uncover the mechanisms of formation of sedimentary rocks. A sedimentary rock is formed by the accumulation of debris from other rocks.

5.5. Stratigraphy

Stratigraphy is the study of geological strata (or layers). It applies to determine the succession and age of different layers.

5.6. Paleontology

Paleontology is the science of fossils. A fossil is a remnant or trace of an extinct animal or plant, the traces of which are preserved within the rocks.

Note Paleontology is divided into:

- **Paleozoology**: the study of fauna
- **Paleobotany**: the study of flora

5.7. Tectonics or Structural Geology

Tectonics studies the deformation of layers or terrains. It shows that rocks (igneous, metamorphic, and sedimentary) break (brittle tectonics) and fold (ductile tectonics) during or after their formation.

5.8. Applied Geology

Applied geology encompasses the practical applications of certain branches of geology.

a) Petroleum Geology: is based on stratigraphy, micropaleontology, tectonics…

b) Metallogeny: (or ore geology or mining geology): focuses on the genesis of mineral deposits and the search for useful mineral substances.

c) Hydrogeology: is the study of groundwater. It focuses on water tables trapped in layers and cavities. The branches involved include the petrography of sedimentary rocks and stratigraphy [4,6].

d) Marine Geology: focuses on marine environments and the sediments of coastal areas. Along with paleontology, it is the branch that has the most affinity with biology.

6. Conclusion

In conclusion, geology is the science that reveals the structure, composition, and evolution of the Earth. By studying rocks, minerals, and geological processes, it allows us to reconstruct the history of our planet, understand natural phenomena such as earthquakes and volcanoes, and identify valuable natural resources. Geology serves both scientific and economic purposes, offering essential knowledge for environmental protection and civil engineering applications.

Chapter II: Minerals

1. Introduction

Minerals are the fundamental components of the Earth's crust and form the basis of all rocks. They are natural, solid substances with a definite chemical composition and an ordered atomic structure. The study of minerals, known as mineralogy, provides essential insight into the composition, properties, and behavior of the materials that make up our planet.

In this chapter, we will explore the nature and classification of minerals, their physical and chemical characteristics, and their role in rock formation. By understanding minerals their crystal structures, compositions, and variations we gain a deeper appreciation of the dynamic processes that shape the Earth's surface and interior.

2. Definition of a Mineral

Definition

A mineral is a natural, homogeneous solid with a defined chemical composition and an ordered atomic structure [1,3]. Minerals are the elemental materials of the rocks in the Earth's crust.

The ordered atomic structure means that all minerals are crystals, which are solids that possess a polyhedral shape limited by flat faces (in cases where crystal formation has not been disturbed by external agents).

The science that deals with the study of minerals is called **mineralogy**.

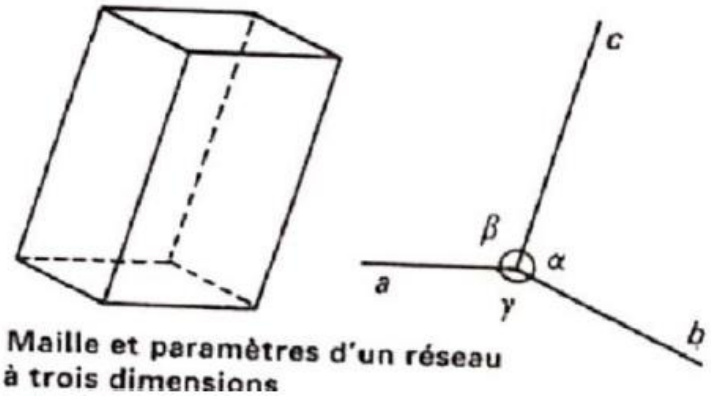
Example Liquid water is not a mineral, but ice, which is solid, natural, homogeneous, has a defined chemical composition (H_2O), and an ordered atomic structure (ice is crystallized), is a mineral.

3. Crystals

A crystal is defined as a homogeneous and natural mineral solid, characterized by flat surfaces and very precise angles, that is well-organized [1,7].

The science that studies crystals is called **crystallography**.

Crystals are classified according to the parameters of the crystal's unit cell (fundamental polyhedron), which represents the smallest parallelepiped that retains the geometric, physical, and chemical properties of a crystal. This includes the three sides a, b, and c of the parallelepiped and the three angles α, ß, and γ located between these three sides.



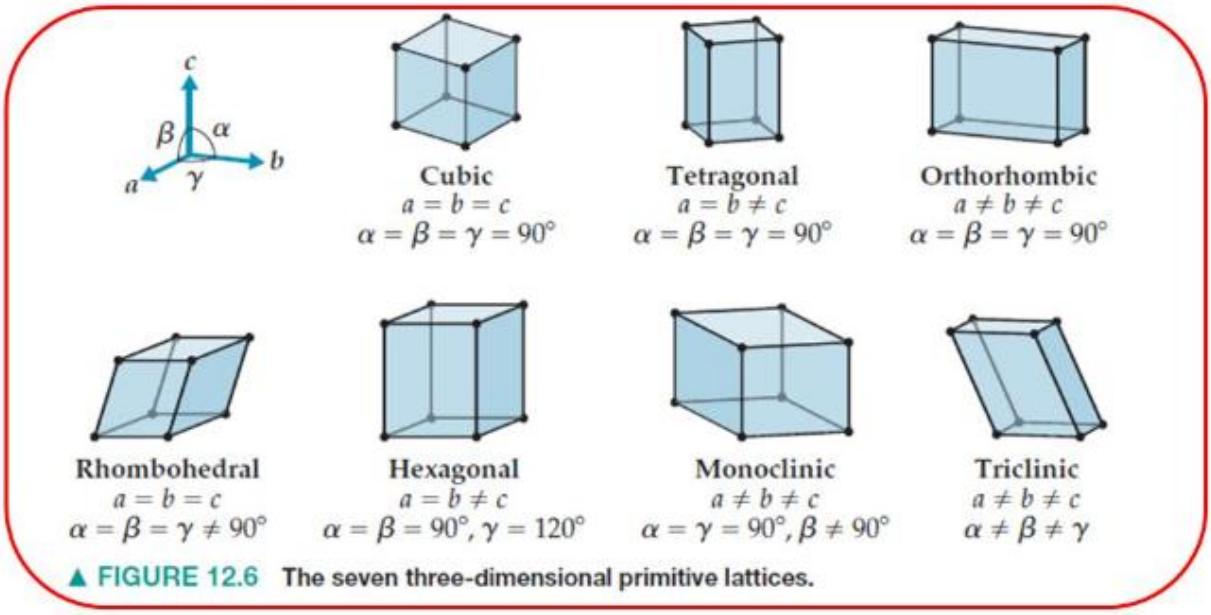
Maille et paramètres d'un réseau à trois dimensions

Figure 1

α : angle entre b et c.
β : angle entre a et c.
γ : angle entre a et b.

4. Classification of Crystals

Crystals are defined by their axes of symmetry, and this symmetry allows for the classification of crystals into a number of groups. There are **7 crystal systems** distinguished as follows:



▲ FIGURE 12.6 The seven three-dimensional primitive lattices.

1. Cubic System: a=b=c ; α= ß = γ = 90°
2. Tetragonal System: a = b ≠ c ; α= ß = γ = 90°
3. Orthorhombic System: a ≠ b ≠ c; α= ß = γ = 90°
4. Rhombohedral System: a=b=c ; α < 120° ; α= ß = γ ≠90°
5. Hexagonal System: a = b ≠ c ; α= ß = 90°, γ =120"
6. Monoclinic System: a ≠ b ≠ c ; α= γ = 90°≠ ß
7. Triclinic System: a ≠ b ≠ c ; α≠ ß ≠ γ

Example

Quartz is a mineral that belongs to the rhombohedral system.



Figure 5: Quartz

4.1. Polymorphs

Polymorphs are minerals that have the same chemical formula or composition but crystallize in different systems.

Example

Carbon (C) has two polymorphs: graphite, which crystallizes in the rhombohedral system and is a very soft mineral, and diamond, which crystallizes in the cubic system and is the hardest mineral in nature. Diamonds form at very high pressure and temperature at depths of more than 150 km and are brought to the surface by a volcanic rock called kimberlite.

4.2. Isomorphs

Isomorphs are minerals that have the same crystalline structure but different chemical compositions.

Example

Forsterite (Mg_2SiO_4) and fayalite (Fe_2SiO_4) are isomorphs; they belong to the olivine family, crystallizing in the orthorhombic system with a general chemical formula of (Mg, Fe)2SiO_4. The Mg^{2+} can be replaced by Fe^{2+} in the olivine formula and vice versa, as these two elements have similar chemical properties.

5. Criteria for Recognizing Minerals

5.1. Density

Density is an important criterion for determining a mineral [1]. Minerals are classified as follows:

- Light minerals: with a density of 1 to 2
- Medium-heavy minerals: with a density of 2 to 4
- Heavy minerals: with a density of 4 to 6
- Very heavy minerals: with a density greater than 6

The highest densities are found in metals, such as gold (15 to 16) or platinum (14 to 20). Most minerals have a density ranging from 2 to 4.

Example

Gold and phlogopite are two minerals that may appear similar. However, the density of gold is 15, while that of phlogopite is 2-3.

5.2. Color

For some minerals, color can be a determining criterion. However, many minerals exhibit various shades and even very different colors.

Example

Olivine has a characteristic green color (from olive, hence its name).

5.3. Streak Color (Streak)

The streak color (or powder color) of minerals is the color that is left as a mark or powder when a mineral is rubbed on a white surface. The powder color of minerals can differ from the color of the mineral itself.

Example

Pyrite (FeS_2), which is yellow, leaves a greenish-black streak.

5.4. Luster

Luster is the property of a mineral to reflect light. Several types of luster are distinguished, including:

- Metallic Luster: strong shine typical of metals (gold, copper, silver)
- Vitreous Luster: a luster reminiscent of glass (quartz)
- Greasy Luster: the surface of the mineral appears to be coated with oil
- Earthy Luster: minerals that have no luster (they have a earthy appearance). **Example**: certain clays.

5.5. Transparency

Transparency is the property of minerals to allow light to pass through. Based on the degree of transparency, minerals can be classified as:

- Transparent minerals: objects can be clearly seen through them, and writing can be read through the mineral.
- Translucent minerals: light passes through the mineral even under significant thickness, but objects cannot be distinguished through it.
- Opaque minerals: do not allow light to pass through.

5.6. The Shape of the Mineral

- Cubic: cubic shape.
- Octahedral: shape of an octahedron.
- Tabular: rectangular shape (see Fig. 9).
- Acicular: needle-like shape (see Fig. 10).
- Laminaire: in the form of lamellae or laths (flattened and elongated) (see Fig. 11).



fig 9



fig 10



fig 11

5.7. Cleavage

Cleavage is the property of a mineral to break along well-defined parallel planes. These planes are referred to as **cleavage planes**.

5.8. Hardness

Hardness is the resistance of a mineral to scratching. A mineral is said to be harder than another if it can scratch the latter. Hardness is classified in relation to that of 10 reference minerals (Mohs scale) [3,5] (see Table 1):

Table 1: menirals classification based on hardness

Mineral	Mohs Hardness	Hardness Classification
Talc	1	Weak
Gypsum	2	Weak
Calcite	3	Weak
Fluorite	4	Moderate
Apatite	5	Moderate
Orthoclase	6	Moderate
Quartz	7	Strong
Topaz	8	Strong
Corundum	9	Very Strong
Diamond	10	Very Strong

6. Nomenclature of Minerals

Approximately four thousand mineral species are known, of which only about thirty are significant. Each year, around ten new minerals are discovered [1,7].

With the exception of a few well-known mineral names that have existed since ancient times, all mineral names are feminine and end in **-ite**. Minerals are named after a person's name, a term that refers to their chemistry, some of their external properties (such as appearance, habit, color), or their original locality.

Examples:

- Albite ($NaAlSi_3O_8$): The name comes from the Latin word Albus (white), alluding to its color.

- Chromite ($FeCr_2O_4$): Named due to the presence of a high content of chromium in the mineral.

- Nadorite ($PbSbO_2Cl$): Named after Djebel Nador, Constantine, Algeria, where the mineral was discovered (see Table 2).

- Sillimanite (Al_2SiO_5): Dedicated to Professor Benjamin Silliman of Yale University (1779-1864).

Table 2: Minerals Discovered in Algeria

Minéral	Origine du nom du minéral	Localité	Date de la découverte
Nadorite	Inspiré du nom de sa localité	Jebel Nador, Constantine, Algérie.	1870
Sénarmontite	Dédié au minéralogiste français Hureau de SENARMONT (1808-1862)	Mine du Djebel Haminate, Ain Beida, Constantine, Algérie.	1851
Kulkeite	Dédié au Dr Holger Kulke, géologue allemande	Ksar el Boukhari, Derrag, Algérie.	1980
Dussertite	Dédié à D. Dussert, ingénieur des mines français	Jebel Debar, Constantine, Algérie.	1925

7. Classification of Minerals

a. Chemical Composition of the Earth's Crust

The Earth's crust is essentially composed (99%) of 8 chemical elements: O, Si, Al, Fe, Ca, Mg, Na, and K [2,3]. The weight percentages of these elements are as follows:

O: 46.60%

Si: 27.72%

Al: 8.13%

Fe: 5%

Ca: 3.63%

Na: 2.83%

K: 2.59%

Mg: 2.09%.

Oxygen is an anion (negative charge, O^{2-}), while all the other elements are cations (positive charge) and will tend to bond with oxygen. Since oxygen and silicon are the most abundant elements in the Earth's crust, most minerals that make up the crust are an assembly of silicon and oxygen, in addition to the other elements. This is the family of silicates.

b. Mineral Families:

Minerals are grouped into classes, labeled in Roman numerals.

Class I: Native Elements

A native element is a chemical substance that cannot be broken down into simpler components. It represents 3 to 4% of mineral species. Metals exist as native elements (pure constituents) or, more commonly, as alloys. They are divided into three subclasses:

Native metals: gold (Au), silver (Ag), copper (Cu), platinum (Pt), ...

Semi-metals: bismuth (Bi), antimony (Sb), arsenic (As), ...

Metalloids: carbon (C), sulfur (S), ...

Class II: Sulfides and Derivatives

These represent 15 to 20% of minerals. Many ores are sulfides. They are divided into two groups:

Sulfides, arsenides, antimonides, tellurides: the anionic group contains only sulfur, with the most common being pyrite (FeS_2) and galena (PbS_2).

Sulfosalts: the anionic group consists of sulfur and another metal.

Class III: Halides

The anionic group of halides consists of halogens. This class represents 5 to 6% of mineral species. The best-known example is halite (NaCl), or rock salt. Halides are brittle, light, and often soluble in water.

Class IV: Oxides and Hydroxides

This class groups minerals whose anionic group is composed of oxygen or hydroxyl ($[OH]^-$). Oxides make up 14% of minerals. They are divided into three subclasses:

Simple oxides: hematite (Fe_2O_3), an iron ore.

Multiple oxides: spinel ($MgAl_2O_4$), used in jewelry as a substitute for ruby.

Hydroxides.

Class V: Carbonates and Nitrates

These minerals are characterized by their fragility and low hardness. Two subclasses are distinguished:

Carbonates: the anionic group is the carbonate group $[CO_3]^{2-}$. They represent 9% of known species. Important examples include calcite ($CaCO_3$), the main component of limestone.

Nitrates: the anionic group is the nitrate ion $[NO_3]^-$.

Class VI: Borates

The anionic group is either the borate ion $[BO_3]^{3-}$ or the ion $[BO_4]^{5-}$. This small family represents 2% of minerals.

Class VII: Sulfates and Derivatives

This class represents 10% of minerals and is defined by the anionic group in the form $[XO_4]^{2-}$.

Sulfates: $[SO_4]^{2-}$. The most well-known sulfate is gypsum, or plaster stone ($CaSO_4 \cdot 2H_2O$).

Chromates: $[CrO_4]^{2-}$.

Tungstates: $[WO_4]^{2-}$.

Molybdates: $[MoO_4]^{2-}$.

Class VIII: Phosphates and Derivatives

This class represents 16% of minerals. The anionic group is in the form $[XO_4]^{3-}$.

Phosphates: $[PO_4]^{3-}$.

Arsenates: $[AsO_4]^{3-}$.

Vanadates: $[VO_4]^{3-}$.

Class IX: Silicates

The base unit of the mineral is the silicate ion $[SiO_4]^{4-}$. Silicates make up more than a quarter of the minerals on the Earth's surface. This abundance has led to a specific classification based on structural considerations, specifically the

arrangement of [SiO_4] tetrahedra. All silicates have a basic structure composed of Si^{4+} and O^{2-} ions.

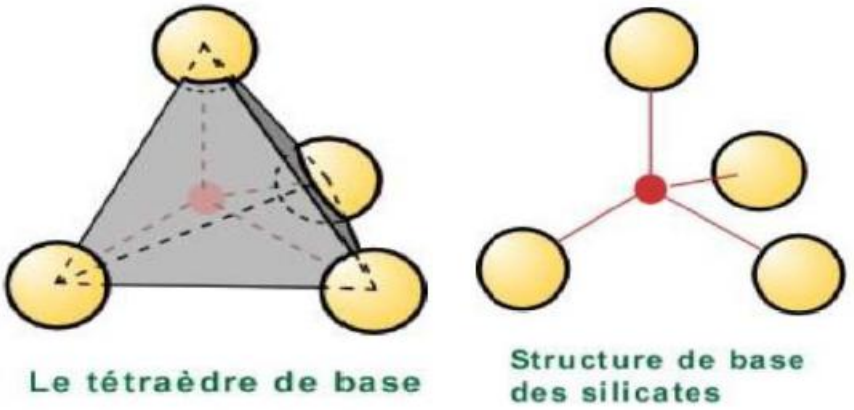


Figure 6: tetrahedral sheet

Silicates are divided into 6 subclasses:

Nesosilicates: These represent about 5% of mineral species. They include olivine ($(Mg, Fe)_2SiO_4$), garnets, and topazes.

Sorosilicates: These represent about 3% of mineral species. Among them is epidote.

Cyclosilicates: These represent only 2% of mineral species and are well-known as gemstones. They include all beryls such as aquamarine, emerald, and all tourmalines.

Inosilicates: These represent about 4.5% of mineral species. The two main families are pyroxenes and amphiboles.

Tectosilicates: The basic chemical formula is SiO_2, as in quartz. Tectosilicates represent 4% of minerals.

Phyllosilicates: Several families are distinguished within this group, including micas, **clays**, and serpentines. Phyllosilicates represent about 6.5% of mineral species.

8. Clay Minerals

Each clay mineral is formed by the stacking of microscopic crystals, which are commonly referred to as "layers" due to their appearance resembling an extremely thin sheet or plate. These layers are themselves composed of crystalline units called "fundamental structures." These structures align in a single plane, which is why the layers have a very large surface area compared to their thickness. The thickness of the layers and fundamental structures is estimated to be around 0.5 nm ($5x10^{-7}$ mm).

In reality, there are only two types of basic crystalline layers: tetrahedral or silica layers and octahedral or alumina layers. Their constitution differs depending on the stacking arrangement of these layers and the various binders and metal ions contained in the crystal lattice.

- **The Tetrahedral Layer (sheet)**
  This is a combination of six silica tetrahedral units composed of four oxygen (O) atoms at the vertices surrounding a single silicon (Si) atom. In figure 1.2 (a), we can see a silica tetrahedron. Figure 1.2 (b) shows the arrangement of oxygen atoms at the base of each tetrahedron, which are located on a plane, and the vertices that are not joined all point in the same direction.

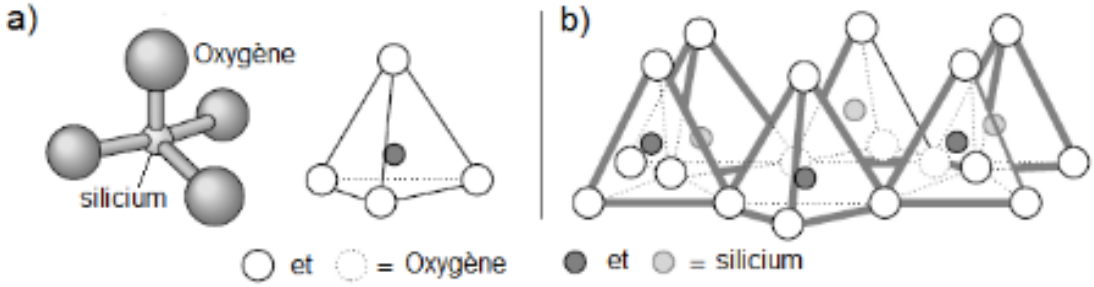


Figure 7: Basic Tetrahedral Structure

- **The Octahedral Layer**
  The octahedral layer is a combination of octahedral units composed of six oxygen (O) or hydroxyl (OH) atoms placed at the vertices of an octahedron, which encloses a metal atom, either aluminum (Al) or magnesium (Mg). Each of these atoms can be replaced by a metallic atom such as iron (Fe), titanium (Ti), nickel (Ni), chromium (Cr), or lithium (Li).
  Figure 1.2 (a) illustrates an octahedron, while figure 1.2 (b) shows the arrangement of octahedrons to form the sheet structure. The rows of oxygen or hydroxyl atoms in the sheet are found on two planes.

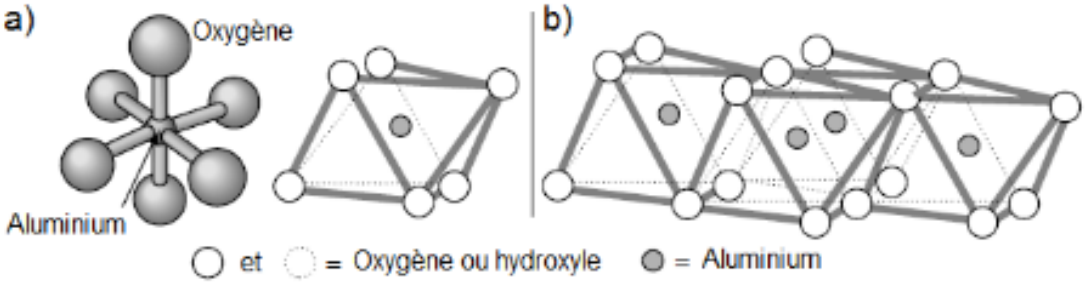


Figure 8 : Basic Octahedral Structure

8.1. Classes of Clay Minerals

The classification of clays is a complex subject due to the diversity of their properties. However, three main groups are commonly encountered: kaolinites, illites, and montmorillonites. These pure clays serve as benchmarks for classifying different types of clays.

i) Kaolinite Group

The name "kaolinite" comes from the word "Kauling," which refers to the summit of a hill near "Jaucha Fu" in China. This is where a whitish clay was discovered centuries ago.

Kaolinite is considered a 1:1 clay mineral, composed of alternating layers of tetrahedral and octahedral sheets (as shown in Figure 1.3). These two sheets are bonded in such a way that the vertices of the tetrahedral sheet align with those of one layer in the octahedral sheet, forming a single unified layer. The repetition of these basic layers is held together by hydrogen bonds from the tetrahedral sheet.

Kaolinites are highly stable with a solid structure and have low water absorption. They exhibit minimal swelling and shrinkage responses to changes in water content.

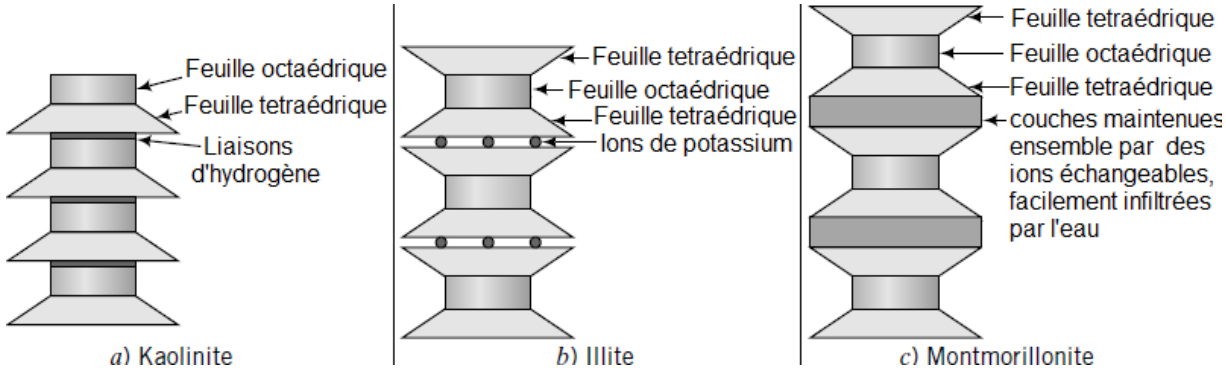


Figure 9: Structure of Kaolinite, Illite, and Montmorillonite

ii) Illite Group

Illite, another important component of clay soils, was discovered by Professor R.E. Grim from the University of Illinois. Like montmorillonite, it has a 2:1 structure. Illite is considered one of the most abundant clay minerals on Earth. Its structure resembles that of montmorillonite, with a single octahedral sheet sandwiched between two tetrahedral sheets, and the elemental layers have a thickness of about 1 nm.

However, the key difference lies in the bonds between these elemental layers: in illite, they are held together by potassium (K) ions. These bonds, while stronger than those in montmorillonite, are weaker than the hydrogen bonds found in kaolinite. The interlayer cations such as potassium (K), calcium (Ca), or magnesium (Mg) prevent water from entering the structure, keeping the basal spacing constant. As a result, illite group minerals cannot expand by absorbing water like halloysite, vermiculite, and smectite.

iii) Montmorillonite Group

Montmorillonite is a widely abundant clay mineral that was discovered in Montmorillon, France. It consists of basic layers composed of two tetrahedral sheets sandwiching an octahedral sheet that contains aluminum atoms (gibbsite). It is sometimes referred to as "smectite" and is classified as a 2:1 mineral.

The elemental layers of montmorillonite are approximately 0.96 nm thick and, like kaolinite, can spread out significantly in length and width. Water molecules are strongly attracted to the charged surfaces of the tetrahedral sheets, acting as a weak bond between the layers (as seen in Figure 1.3). However, these bonds are weak, and when water increases in the soil, water molecules can easily infiltrate between the layers, causing them to separate. As a result, montmorillonite exhibits extremely high swelling and shrinking properties. The particles of montmorillonite generally consist of one to a few elemental layers and have a thickness ranging from 1 to 10 nm.

9. Rocks

a. Definition of a Rock

A rock is a material that makes up part of the Earth's crust, regardless of its properties and physical appearance. A rock is an arrangement of minerals in relation to each other, organized according to the laws of crystallography. Each rock has a specific architecture, shape, dimensions, and unique arrangement. There are three major families of rocks.

- **Igneous Rocks**, formed by the crystallization of magma.
- **Sedimentary Rocks**, originating from the accumulation and consolidation of sediments.
- **Metamorphic Rocks**, resulting from transformations that rocks undergo when exposed to conditions of temperature and/or pressure different from those present during their initial formation.

These three main rock families are interconnected at the Earth's surface through the rock cycle. Igneous rocks, formed by the crystallization of magma, are subjected

to surface processes of erosion that lead to the formation and deposition of sediments. These sediments accumulate and undergo physical and chemical processes, resulting in the formation of sedimentary rocks. Both igneous and sedimentary rocks may experience temperature and/or pressure conditions different from those during their formation, transforming them into metamorphic rocks. Finally, these temperature and pressure conditions can lead to the melting of metamorphic rocks and the formation of magma.

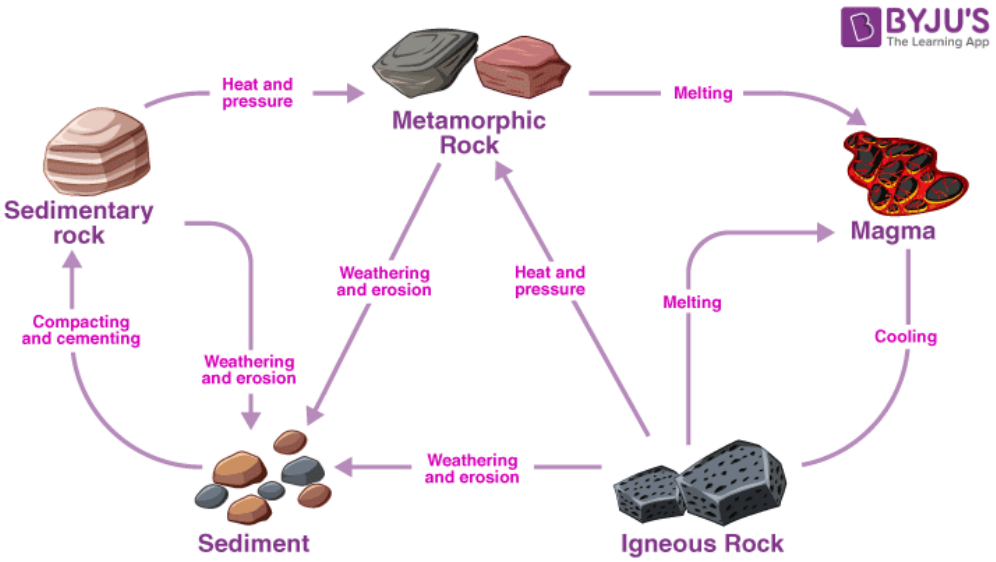


Figure 10: The Rock Cycle

b. Igneous Rocks: Definitions

Igneous rocks result from the solidification (crystallization and cooling) of magma. Magma is a molten silicate mixture, consisting of a liquid phase (the most substantial), a solid phase (crystals), and a gaseous phase (0.1–3%).

Based on the cooling process of magma, there are two types of igneous rocks:

i. Plutonic Rocks: These are formed by the slow cooling of magma at depth. The magma has sufficient time to fully crystallize, resulting in rocks with large minerals visible to the naked eye.

ii. Volcanic Rocks: Formed by the rapid cooling of magma at the surface, where minerals do not have enough time to crystallize completely. Volcanic rocks are thus characterized by minerals that are invisible to the naked eye.

iii. Magmatic Processes

Volcanism is a phenomenon largely responsible for the creation of oceanic openings.

a) Volcanic Structures

There are various types of volcanic structures.

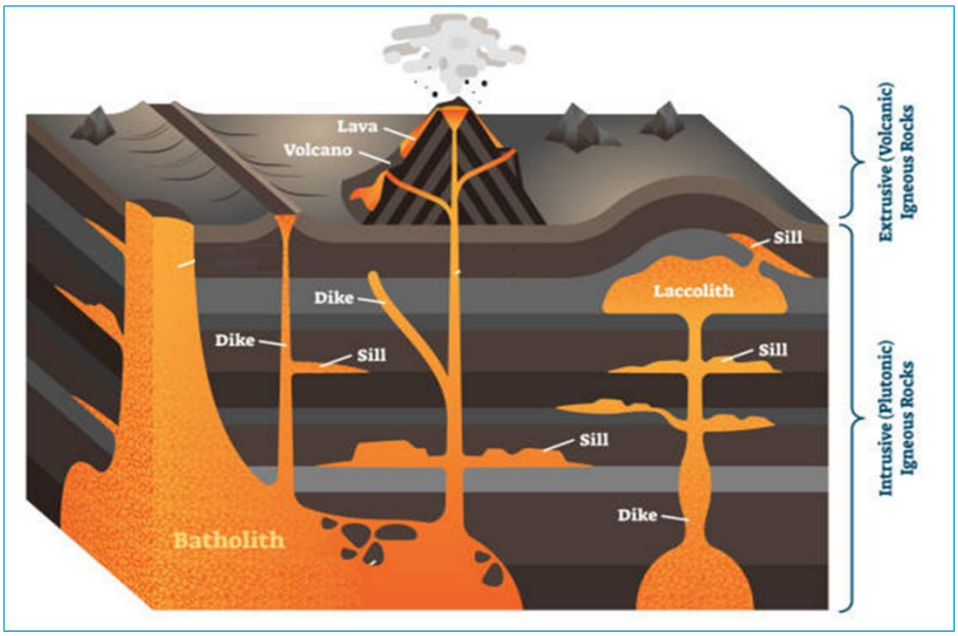


Figure 11: Volcanic Structures

Sill: A horizontal body of rock.

Dyke: A slightly vertical body of rock.

Batholith: A large body of rock with an unknown base.

Laccolith: A body trapped between surrounding rocks, with a known base.

b) Fundamental Processes of Igneous Rock Formation

i. Formation of Magma (Silicate Melt)

Temperature Increase: Leads to the melting of materials.

Pressure Decrease: Often associated with the melting temperature.

Magmas ascend due to their lower density compared to the surrounding rocks, a property related to their temperature. As they rise, they cool, increasing their viscosity, but as pressure decreases, their viscosity decreases. The primary cause of rock melting is decompression.

ii. Magma Transfer

The main forces driving magma upward are gravity and density. When liquids form by partial melting, they become lighter than the surrounding rocks. To reach the surface, magma moves along fractures of varying sizes. Gases play a crucial role in driving the ascent of magma.

iii. Magma Ascent Rate

- Rapid Ascent: Associated with volcanic activity.
- Slow Ascent: Associated with plutonic activity.

The ascent rate of magma is a critical factor, and during its ascent, magma may undergo chemical composition changes.

c) Different Types of Magmas

Types of magmas are determined by their chemical composition, temperature, gas content, and viscosity (resistance to flow). Three main types of magma are:

- Basic or Basaltic Magmas: Contain 45–55% SiO_2, rich in Fe, Mg, Ca, low in K, Na. Temperature: 1000–1200°C. Low gas content and low viscosity.

- Intermediate or Andesitic Magmas: Contain 55–65% SiO_2, intermediate levels of Fe, Mg, Ca, K, Na. Temperature: 800–1000°C. Intermediate gas content and viscosity.

- Acidic or Rhyolitic Magmas: Contain 65–75% SiO_2, low in Fe, Mg, Ca, high in K, Na. Temperature: 600–800°C. High gas content and very viscous.

Approximately 80% of magmas emitted by volcanoes are basaltic, while andesitic and rhyolitic magmas represent about 10% each of the total.

d) Classification and Naming of Igneous Rocks

The mode of emplacement largely determines the structure and texture of igneous rocks, making it crucial to understand. Due to pressure from surrounding materials and its density (which is always lower than its surroundings), magma rises to the surface. Two scenarios are considered:

i. Extrusive Igneous Rocks

When magma (around 1200°C) reaches the lithosphere's surface (approximately 20°C), it cools rapidly, preventing crystal formation and development. Crystals remain microscopic or are absent, giving the rock a glassy appearance.

This type of magma is termed Volcanic Magma, and rocks formed by this process are known as Effusive Igneous Rocks or Volcanic Rocks, also called Extrusive Rocks. They cool either in open air or underwater as lava flows. Examples of volcanic rocks

include basalt, rhyolite, and andesite, which are typically low in silica and dark in color.

ii. Intrusive Igneous Rocks (Plutonic Rocks)

These rocks cool very slowly before reaching the surface and are found in large masses called batholiths or in narrow veins like dykes and sills. These veins form when magma ascends toward the surface. Igneous intrusions can be either concordant or discordant. Concordant intrusions fill pre-existing cracks or fissures in the surrounding rock, while discordant intrusions are powerful enough to create new fractures.

A simplified classification of igneous rocks is presented in Table 3

Table 3: types of igneous rocks

Type de roches ignées (ou magmatiques)	**Intrusives**	**Extrusives**
Autres noms donnés	Plutoniques	Effusives Volcaniques
Vitesse de refroidissement	Lent	Rapide
Endroit du refroidissement	À l'intérieur de la Terre	À la surface de la Terre
Grosseur des cristaux formés	Gros	Petits

a. Sedimentary Rocks

In general, sedimentary rocks form through a complex process of weathering and erosion of other types of rocks within the Earth's crust. This complex process consists of four main stages (Fig12).

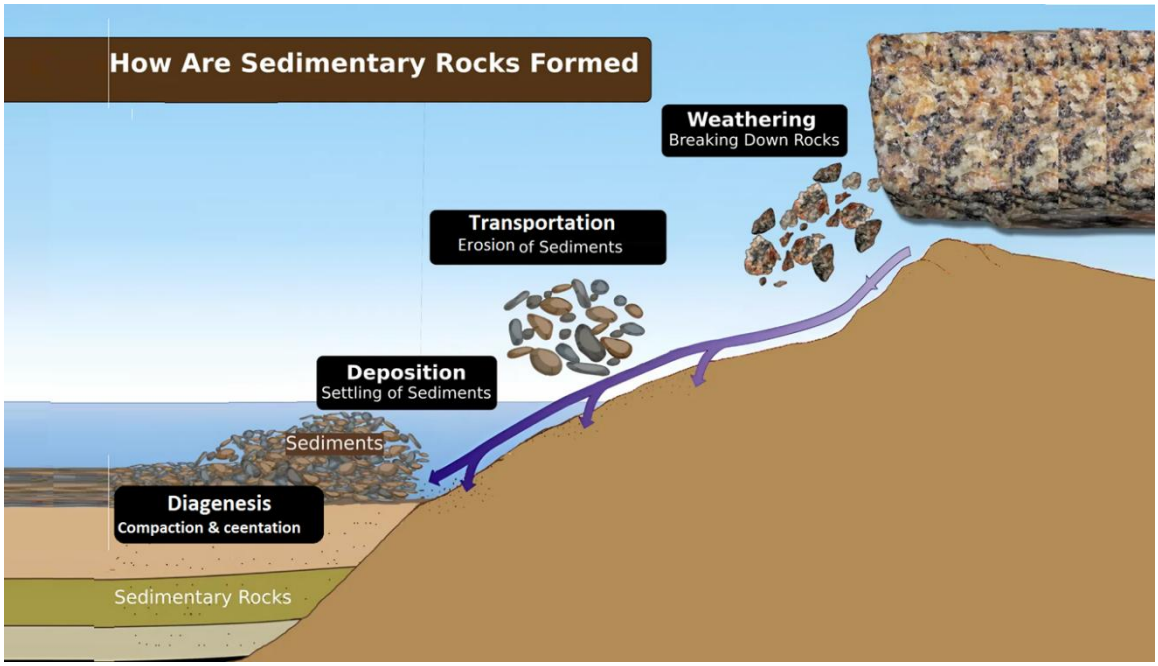


Figure 12: Main Phases of Sedimentary Rock Formation

- Particle Production: Through surface erosion and weathering of crustal rocks.
- Transport of Particles: Primarily by water, wind, or ice.
- Sedimentation and Deposition: In a suitable environment to form sediment.
- Diagenesis: Physical and chemical processes (compaction, chemical cementation, biochemical processes) that transform loose sediments into sedimentary rock.

i. Sedimentation Process

The formation of sedimentary rocks involves several stages:

a. Erosion:

This is the process of breaking down pre-existing rocks. There are two types of erosion:

Physical or Mechanical Erosion: The disintegration of rocks into smaller pieces through physical or mechanical processes.

Chemical Erosion: The dissolution of chemical elements by water, leading to the decomposition of rocks or minerals.

The agents of erosion include water, wind, freeze-thaw cycles, and temperature changes.

b. Transport:

Sediments resulting from erosion can be transported over long distances by wind or water in rivers, streams, or ocean currents.

b. Deposition:

When the transport agent's velocity decreases to the point where it can no longer carry the sediments, these sediments are deposited. Deposition occurs in sedimentary basins, most often at the bottom of seas. The sediments accumulate in successive layers, with variations in composition, particle size, color, etc., over time depending on the nature of the sediments being transported.

c. Diagenesis:

Diagenesis refers to the physical and chemical processes that transform loose sediment into consolidated rock. Diagenesis involves two main stages (figure 2):

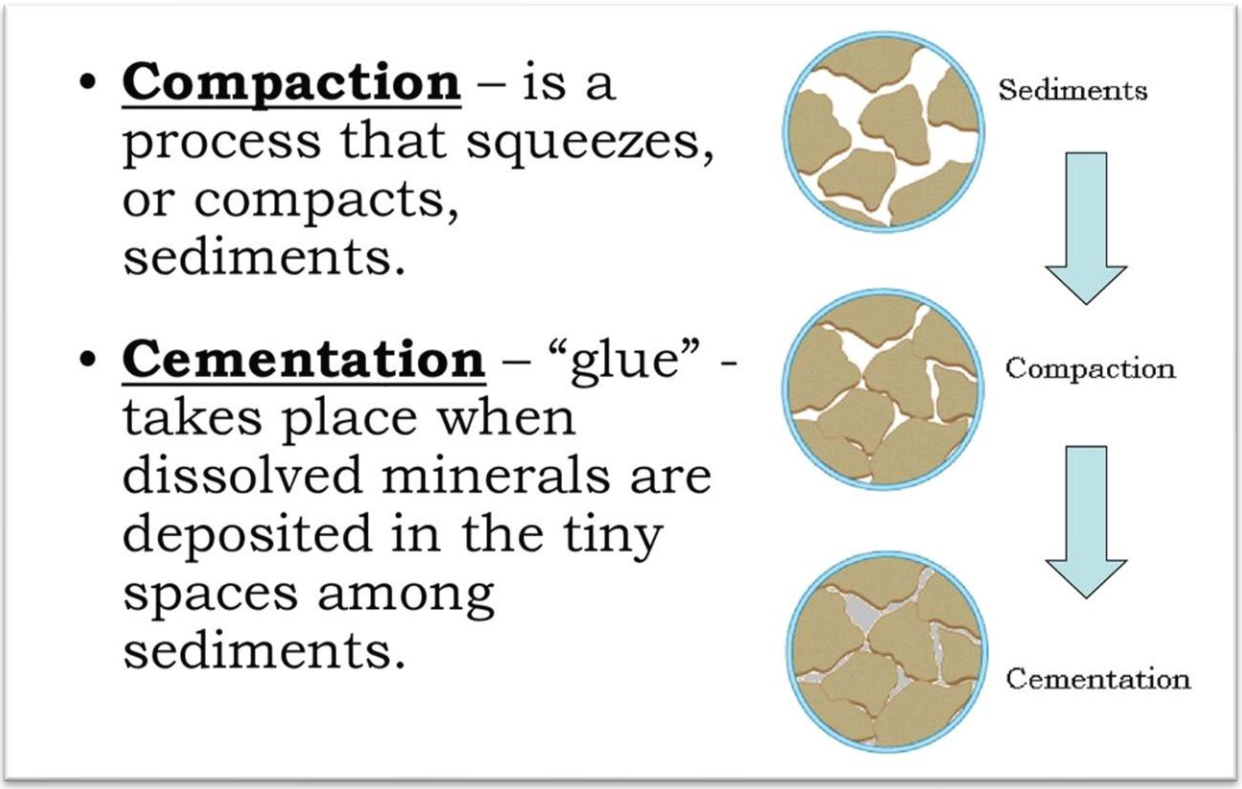


Figure 13 :Different Stages of Diagenesis

- Compaction: The sediments are squeezed closer together, reducing the voids or pores between particles and eliminating water contained in those pores.

- Cementation or Lithification: The sediments bond together through a chemical cement, transforming them into solid rock.

Diagenesis occurs at shallow depths and low temperatures, typically between 100 to 200°C, distinguishing it from metamorphism. The factors influencing diagenesis include:

- Living Organisms
- Water Action
- Physical Factors (pressure, temperature, tectonic movement)

ii. Classification and Naming of Sedimentary Rocks

Sedimentary rocks are classified into three main categories based on their origin and composition. These categories are:

a. Detrital Rocks: These rocks form from fragments of pre-existing rocks, minerals, and other organic materials that are transported, deposited, and cemented to create solid rocks. Common examples of detrital rocks include sandstone, shale (or clay), and conglomerate.

b. Chemical Rocks: These rocks form from chemical substances dissolved in water that precipitate and solidify. Common examples of chemical rocks include chalk (formed from the shells of marine microorganisms), saline rocks (such as halite, formed from the evaporation of saltwater), and certain varieties of limestone.

c. Organic Rocks: These rocks form from accumulated and consolidated organic material. A well-known example is coal, which forms from the decomposition of plant material under specific conditions of pressure and heat.

It is important to note that these categories are not strictly distinct, and many sedimentary rocks may contain elements from all three types, resulting from complex sedimentary processes.

b. Metamorphic Rocks:

i. Definitions

The term metamorphism (from the Greek meta = change and morph = form) refers to the transformation of a solid rock, resulting in the formation of new minerals and/or the acquisition of new textures and structures due to conditions of temperature and pressure that differ from those present during its original formation.

Metamorphism can affect:

- **Sedimentary Rocks:** In this case, they are referred to as parametamorphic rocks.
- **Igneous Rocks**: These are termed orthometamorphic rocks.
- **Metamorphic Rocks:** These are known as polymetamorphic rocks.

The lower limit of metamorphism corresponds to a temperature of 200°C and a pressure of 300 MPa (3000 atmospheres or 3 kb). Below this limit, the domain of diagenesis prevails.

The upper limit of metamorphism corresponds to the partial melting of the rock. When the rock melts, it enters the domain of magmatism.

ii. Factors of Metamorphism

The main factors of metamorphism are:

Temperature: It increases with depth (the geothermal gradient is approximately 30°C per kilometer) and/or with the emplacement of plutonic or volcanic rocks.

Pressure: This also increases with depth and is due to the weight of overlying layers. Rocks subjected to this pressure do not show a preferred orientation; this is known as lithostatic pressure (1 kbar at a depth of 4 km, 5 kb at 15 km, and 10 kb at 30 km for an average crust density of 2.5). Pressure can also increase due to constraints, particularly in regions with high tectonic activity, such as mountain ranges.

Fluids: The spaces between the grains in a rock are always filled with a fluid, typically water (H_2O) containing dissolved minerals. This fluid plays a crucial role in metamorphic processes because it can transport dissolved components (in solution) and heat, significantly increasing the rate of reactions between minerals. When a rock lacks fluid, metamorphism results in very few reactions.

Time: Most metamorphic reactions take millions of years to complete. Laboratory experiments have demonstrated that high temperatures and pressures, along with extended reaction times, yield larger grains. Therefore, metamorphic rocks with large grains are products of metamorphic conditions that have been maintained for a much longer duration, likely spanning several million years.

iii. Types of Metamorphism

i. Contact Metamorphism:

Contact metamorphism occurs in the surrounding rock at the interface with intrusive bodies. When hot magma is introduced into a sequence of cold rocks, there is a transfer of heat (see figure 2.24) and cooking of the surrounding rock at the edges.

ii. Regional Metamorphism:

Regional metamorphism affects large areas and is controlled by significant increases in pressure and temperature. It is the metamorphism associated with the roots of mountain ranges (related to the genesis of major mountain chains, typically at temperatures of 700°C to 800°C).

iii. Shock Metamorphism:

Shock metamorphism is produced by the impact of a meteorite on the planet's surface. The impact generates extremely high temperatures and pressures that transform the minerals of the impacted rock, with conditions that far exceed those encountered in regional metamorphism.

iv. Conclusion

To summarize, minerals are the fundamental building blocks of rocks and the Earth's crust. Understanding their properties—chemical composition, crystalline structure, and classification—helps identify and analyze different rock types and geological formations. Mineralogy and crystallography provide essential tools for engineers and geologists to interpret the physical behavior of rocks and their suitability for various applications.

Chapter III: Action of various elements on rocks

1. Introduction

The reliefs of landscapes undergo changes over time due to the action of various erosion agents. Continents gradually flatten to reach the base level, which corresponds to that of the oceans. The resulting landscapes reflect the characteristics, composition, and arrangement of geological formations. The erosive forces of water, ice, and wind contribute to shaping continental surfaces.

2. Action of Air on Rocks

The action of wind is most prominent in regions where vegetation is absent, as sediments can move easily. This is particularly the case in deserts (hot or cold) or along coastal areas (beaches). A climate becomes desertic when annual precipitation is less than 250 mm [2,7].

Note: Wind acts as both an agent of erosion and transportation.

a. Wind Erosion = Aeolian Erosion

a) Deflation

Depending on wind velocity, particles of varying sizes are transported a process known as aeolian deflation. The finest particles, typically dust, are carried in **suspension**. Sand grains move by **saltation**, while larger particles are transported by **creeping (rolling or sliding**) across the surface under the push of the wind. Wind acts to remove these materials from their original location. Wind removes the finest materials, leaving behind a rocky desert surface known as a **reg**. It can also lead to the formation of closed desert depressions, referred to as **chotts** or **sebkhas** in the Sahara.

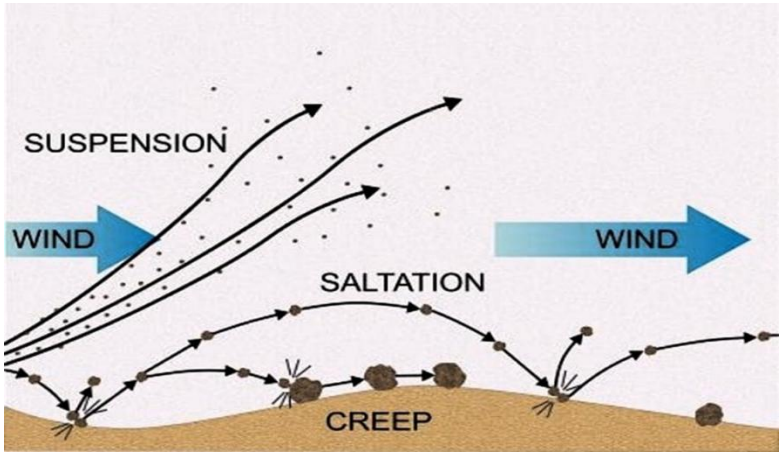


Figure 14 :Effect of wind on rocks



Figure 15 :Reg



Figure 16 :Sebkha

b) Corrasion

Sand grains transported by the wind can erode rocks upon impact, creating numerous abrasions. This process is responsible for shaping stones with geometric forms, such as tetrahedral-shaped stones or **dreikanters** (three-faced stones sculpted by wind erosion).

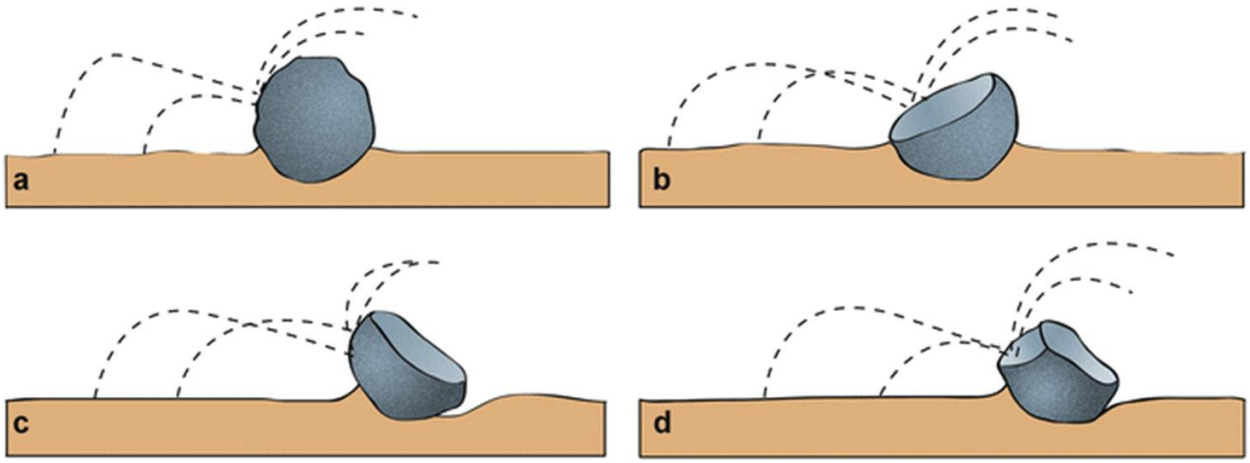


Figure 17 : Stages in the Formation of Geometrically Shaped Stones by Wind Action (Corrasion)



Figure 18 :Tetrahedral Stones or Dreikanters

b. Aeolian Sedimentation

When wind strength decreases, the particles it transports settle and form **aeolian deposits**:

a) dunes

are sand deposits ranging from a few meters to over 100 meters in height, typically composed of silica grains (quartz), and occasionally gypsum. There are several types of dunes (crescent-shaped dunes called **barkhanes**, transverse dunes, star-shaped dunes, etc.). Their shape depends on the wind's

direction and strength. Dunes are dynamic structures that can move several meters per year. Large sandy deserts rich in dunes are known as **ergs**, covering about 25% of the Earth's deserts. **Fossil dunes** can also be observed, which are evidence of different climatic conditions in the past (e.g., the El Kala region in Algeria).

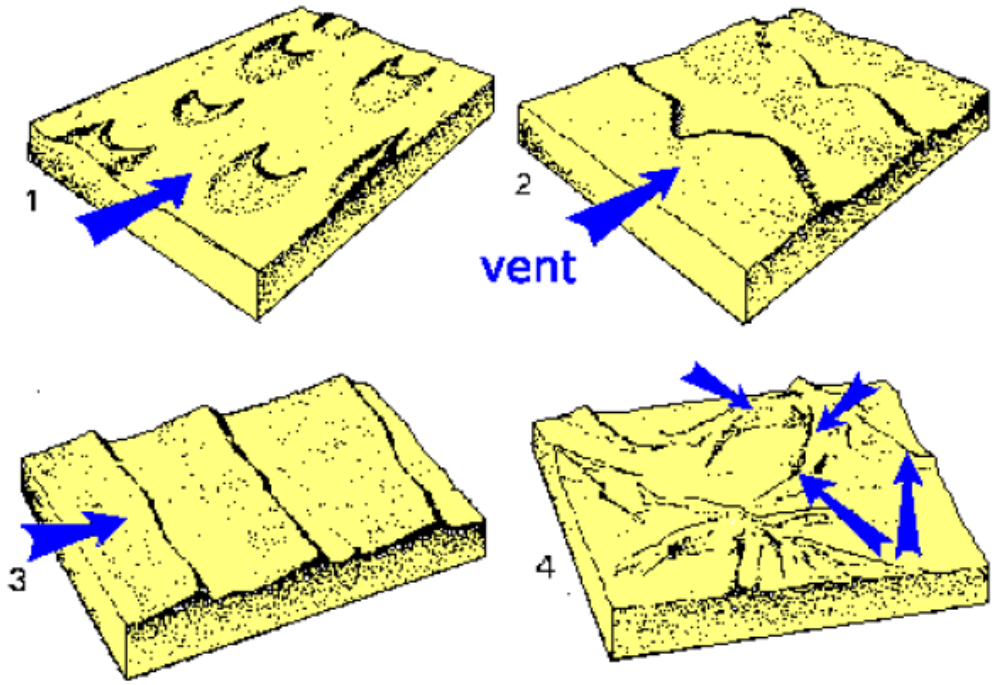


Figure 19 : Main Types of Aeolian Dunes. (1) Barkhanes; (2) Parabolic Dunes; (3) Transverse Dunes with Straight Ridges; (4) Interference Dunes.



Figure 20 :Fossil Dunes

b) *Dust* consists of very fine particles transported in suspension in the air, forming a dust cloud. Sahara dust (60 to 200 million tons per year) can be deposited far away, reaching as far as Europe, the Atlantic, or even America.

c) *Loess* refers to the accumulated deposits of dust, often several meters or tens of meters thick.



Figure 21 : Loess

In conclusion: The geological role of wind, once considered minor, is actually fundamental. Indeed, hundreds of millions of tons of dust are transported by the wind every year. These movements play a significant role in climate, sedimentology, and pedology.

3. Action of Water on Rocks

Water reaching the ground is divided into three components: one part infiltrates the soil, another flows across the surface as runoff, and the rest evaporates from open water surfaces or vegetation (this process is called evapotranspiration).

The erosive action of runoff water largely depends on the quantity of precipitation over a short period. Thunderstorm rains, in particular, are responsible for significant erosion of continental surfaces.

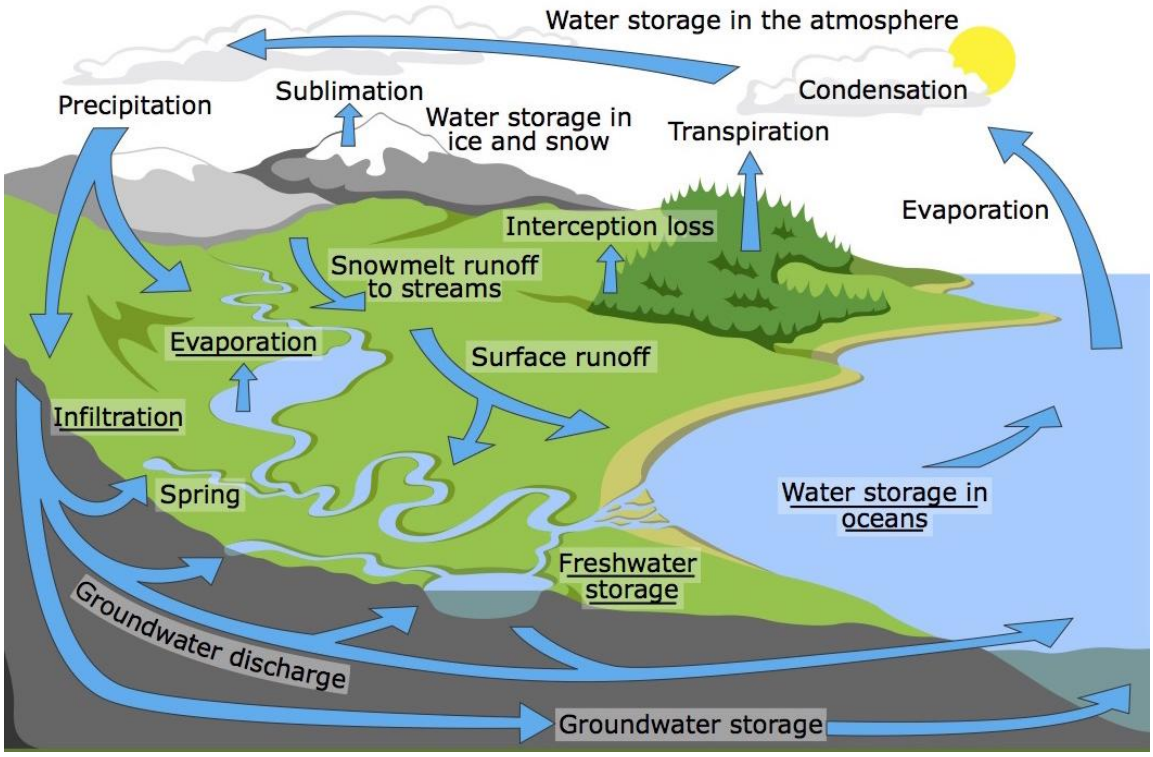


Figure 22 :The Water Cycle

a. Runoff

- If the terrain is homogeneous (composed of rocks of the same type), several phenomena can be observed[4,7]:

a) Ravinement :

Occurs in clayey, marly, or schistose terrains. After heavy rainfall, water flows through pre-existing fissures in the soil, gradually widening them. The effects of this erosion can sometimes be catastrophic, leading to landscapes like **badlands**.



Figure 23 :Ravinement

b) *Lapiaz Formation:*

Develops in limestone terrains. Runoff water erodes and dissolves the limestone, creating grooves or fissures known as **lapiez**.



Figure 24 : Lapiez

- If the terrain is heterogeneous (composed of rocks of different types), runoff water removes the finer, softer, or more soluble materials, leaving behind the more resistant or insoluble parts. This process leads to the formation of features such as **hoodoos (fairy chimneys)**, **granite chaos**, or ruiniform landscapes.



Figure 25 :hoodoos (fairy chimneys),

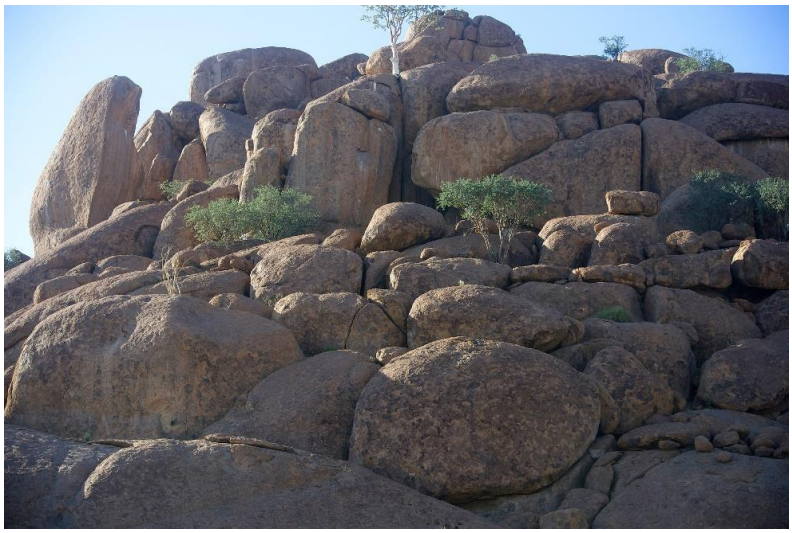


Figure 26 :granite chaos

b. Watercourses

After runoff, rainwater gathers in a well-defined channel and flows toward larger streams[5].

- When watercourses are temporary (water is absent during part of the year), they are called torrents or wadis (common in arid regions like Algeria).
- When they are permanent (water is always present), they are referred to as rivers or streams.

Note : Watercourses act as agents of **erosion, transport, and deposition**.

The Different Types of Watercourses:

a) Torrents:

These are fast-flowing watercourses in mountainous regions, consisting of three main parts:

- **Reception Basin:** This is where runoff water collects. Erosion is predominant here, including rill erosion and surface runoff effects.
- **Flow Channel:** A narrow, steeply sloping channel where the primary function is the transport of materials.
- **Alluvial Fan (Debris Cone):** The main area of deposition, where transported sediments accumulate, forming a fan-shaped deposit.

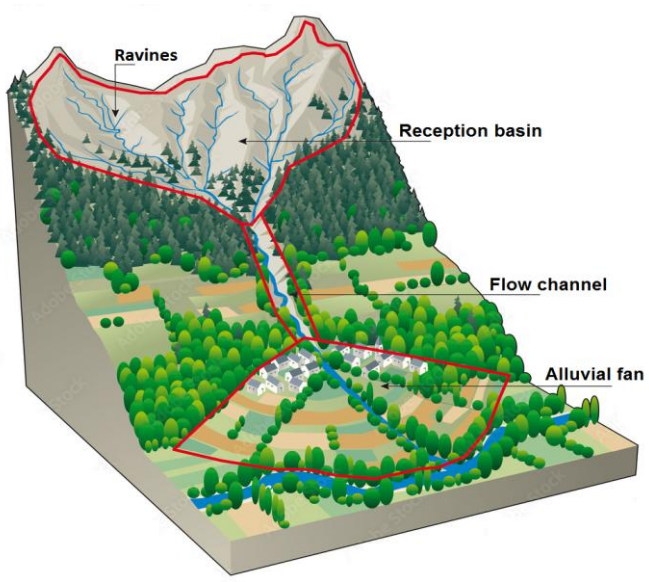


Figure 27 : Torrents

b) *Permanent Watercourses:*

These form a hierarchical network, with rivers converging into a larger river, or river system, which then flows either to the sea (exorheism) or to closed inland basins (endorheism).

- The world's largest watershed is the Amazon Basin in South America, covering nearly 6 million km².
- Rivers account for only 0.0001% of the Earth's total water reserves.

Over time, watercourses carve out their valleys, progressively deepening them. In homogeneous terrain, valleys tend to take on a **'V'-shaped profile** due to uniform erosion.

The point where the river meets the sea, known as the **mouth,** can take two forms:

- **Estuary:** Formed when the river's flow is relatively low, allowing tidal or marine influences to dominate.
- **Delta:** Formed when the river's flow is high, depositing sediments at the mouth, creating a fan-shaped feature (e.g., the Nile Delta or the Mississippi Delta).

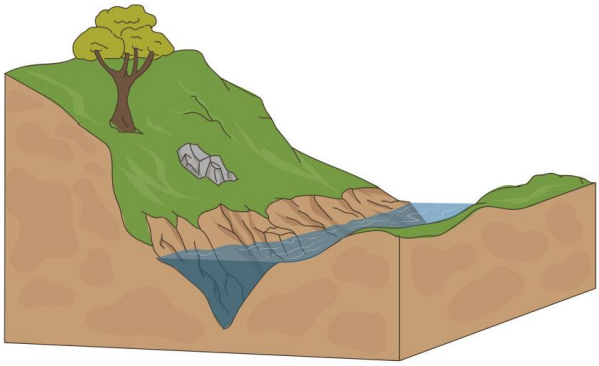


Figure 28 :V shaped profile



Figure 29 : Delta



Figure 30 :Estuary

4. Action of Glaciers on Rocks

a) *Mountain glaciers*, also known as alpine glaciers, are composed of several distinct zones[3]:

- **Glacial Cirque:** This circular-shaped area, located at the highest altitude, is where snow accumulates. Over time, the snow compacts and transforms into ice under its own weight, forming the glacier's reservoir.
- The **glacial tongue** has an elongated shape, and it is in this zone that the ice flows. It contains numerous **crevasses** caused by the glacier's movement. The surface is often covered with debris, which is especially abundant along the sides and at the front of the glacier. These debris deposits are called **moraines**.

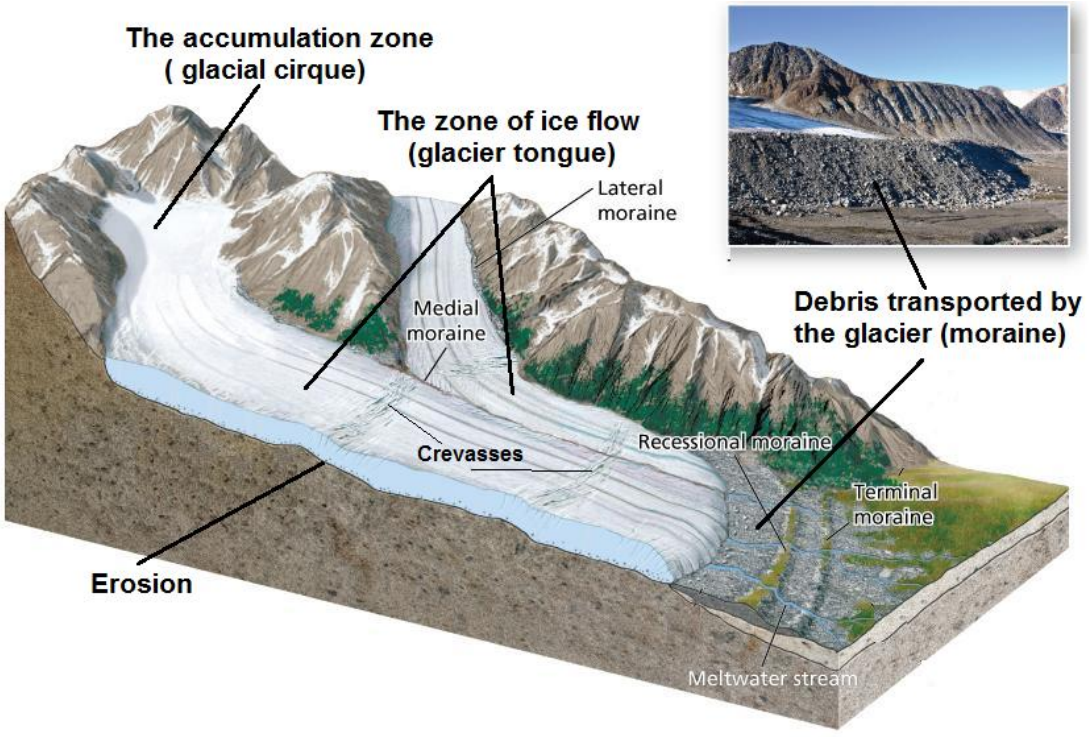


Figure 31 :morphology of a mountain glacier

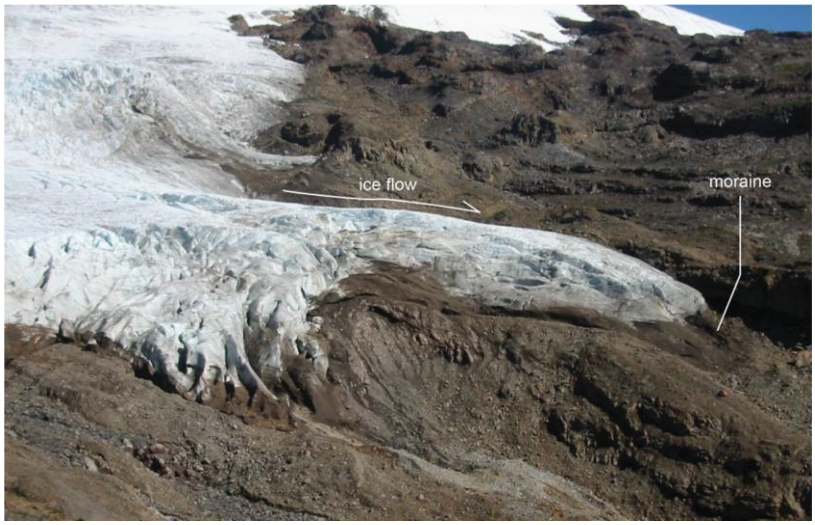


Figure 32 :Moraine

b) *Inlandsis*

Are large glaciers with significant thickness (several thousand meters in some areas). Currently, two major inlandsis exist: one in **Greenland** and the other in **Antarctica**. These glaciers are also in motion, and as they move, they fragment into **icebergs**, which then drift out to sea and melt.



Figure 33 : Inlandis

Note: Glaciers can be responsible for both **erosion** and **accumulation**:

- *Erosional Forms:*
  As a glacier moves, it erodes the rocks over which it flows. This process results in a **glacial valley** with a flat floor and a characteristic **U-shape** profile.

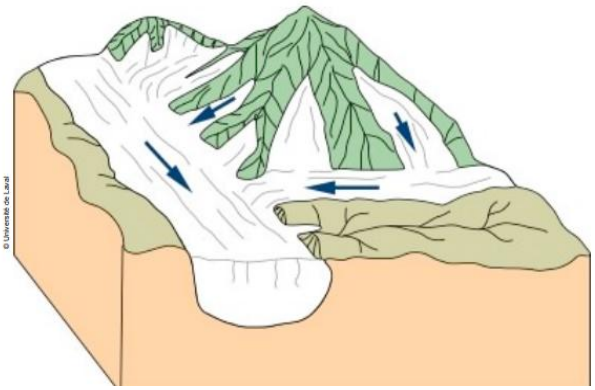


Figure 34 :U-shaped profile

- *Accumulation Forms:*
  As the glacier melts, it leaves behind blocks and debris of all sizes, forming **moraines** (such as **terminal**, **lateral**, and **ground** moraines). The glacier can also transport very large blocks, known as **erratic blocks,** which can weigh several tons.



Figure 35 : Erratic blocks

5. Conclusion

In conclusion, natural agents such as wind, water, and glaciers continuously transform the Earth's surface through erosion, transport, and sedimentation. These processes shape landscapes, modify rock structures, and contribute to the rock cycle. Understanding these actions is essential for predicting geological hazards, managing soil erosion, and planning sustainable civil engineering and environmental projects.

Chapter IV: GEODYNAMICS

Introduction

In this chapter, we will delve into the heart of geodynamics, exploring the forces

and processes that shape our planet both at depth and on the surface. Internal geodynamics will uncover the mysteries of subterranean phenomena that sculpt the landforms, while external geodynamics will guide us through the forces acting at the surface, shaping and sometimes altering these remarkable features.

I. Internal geodynamics:

Internal geodynamics concerns the dynamics of the Earth's solid globe, from its surface to its core. Therefore, we focus on the depths of the Earth [1,5].

1. Seismology :

Seismology is the science that studies earthquakes or seismic tremors (the term "seismology" comes from the Greek word 'seismos'). Numerous earthquakes occur every day, but most of them are not felt by humans. Around 100,000 earthquakes are recorded annually on the planet. The most powerful of them are among the most destructive natural disasters: the deadliest earthquake in recent history, which occurred in China in 1976, caused over 600,000 deaths. In Algeria, earthquakes have also claimed many lives, notably in El Asnam in 1980 (3,000 deaths) and in Boumerdès in 2003 (over 2,000 deaths).

1.1. Definition of an Earthquake

An earthquake is a sudden shaking of the ground caused by the arrival of waves generated deep within the Earth due to the rupture and abrupt movement of two lithospheric blocks. The result is an instantaneous release of energy. The earthquake's focus (**or hypocenter**) is the point where the movement originates, while the **epicenter** is the projection of this point onto the Earth's surface and corresponds to the location where the shaking is most intense.

An earthquake can be classified as **shallow** (focus at a depth of less than 60 km), **intermediate** (between 60 and 300 km), or **deep** (greater than 300 km). Shallow earthquakes are the most dangerous. The rupture typically occurs through **the formation of a fault** or the reactivation of an older fault.

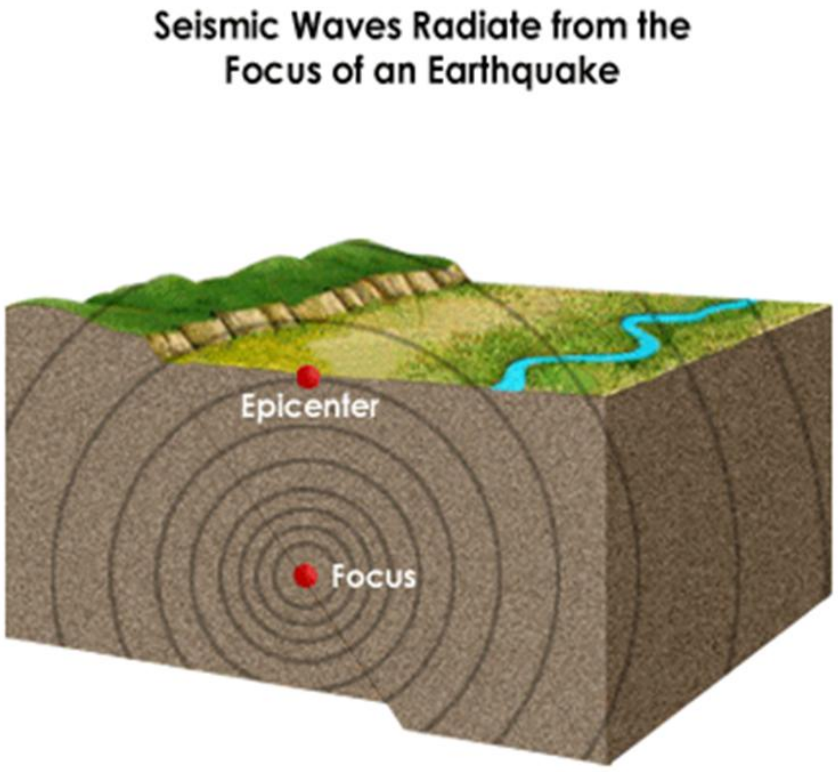


Figure 36 : Characteristics of an Earthquake

1.2. Causes of Earthquakes

An earthquake is a more or less violent shaking of the ground, which can have three main origins:

- **Tectonic Earthquakes:**

These are the most common and destructive earthquakes, occurring primarily at the boundaries of tectonic plates. They result from the sliding of two rock masses along faults. Between earthquakes, this sliding is temporarily blocked, causing energy to accumulate through the elastic deformation of rocks. When the energy is suddenly released during an earthquake, it generates seismic waves that can be highly destructive.

The release of accumulated energy does not typically occur in a single shock. Several adjustments may take place before a stable configuration is reached. After the main shock, aftershocks can occur, typically with decreasing intensity, lasting

from a few minutes to over a year. These secondary shocks can sometimes be more destructive than the initial earthquake because they may cause buildings that were only partially damaged during the main quake to collapse, often while rescue operations are underway.

- **Volcanic Earthquakes:**

These result from the accumulation of magma in a volcano's magma chamber. Seismographs then record numerous microseisms (tremors) due to fractures in the compressed rocks or the degassing of the magma. The gradual rise of the hypocenters (linked to the rising magma) is an indicator that the volcano is awakening and that an eruption may be imminent.

- **Artificial Earthquakes**

These are caused by human activities such as dam construction, deep groundwater pumping, mining extraction, underground explosions, or nuclear testing. These activities can trigger earthquakes of low to moderate magnitude, known as induced seismicity.

1.3. Measurement of an Earthquake:

For a long time, scientists have tried to classify earthquakes and have developed several scales to characterize them:

a) Intensity Scales:

These scales are based on the observation of the effects and consequences of an earthquake on common indicators in a given location (effects on people, objects, furniture, buildings, and the environment). The intensity of an earthquake is not a reliable measure, as it depends not only on the distance to the epicenter but also on factors such as soil type, building structures, and the time of the earthquake.

The most well-known intensity scales are Mercalli (developed in 1902, modified in 1931, and abandoned in 1964) and the MSK scale (from 1964 onward). Both scales consist of 12 degrees of intensity, from I (weakest) to XII (strongest).

b) Magnitude

The power of an earthquake can be quantified by its magnitude, a concept introduced in 1935 by seismologist Charles Francis Richter. Magnitude is calculated from the different types of seismic waves, considering various parameters such as the distance to the epicenter, the depth of the focus, and others.

Table 5: Comparison between the Mercalli Intensity Scale and the Richter Magnitude Scale

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

2. Seismic Waves

2.1 Seismographs and Seismograms

A seismograph is an instrument used to record earthquakes. The principle behind its operation is as follows: the base of the instrument and the recording cylinder (both fixed to the ground) vibrate when seismic waves pass through, while the suspended mass tends to remain stationary due to inertia. This difference in motion between the mass and the rest of the instrument allows the seismograph to measure and record seismic activity.

There are different types of seismographs designed to record all types of seismic waves. The recorded data from an earthquake is called a **seismogram.**

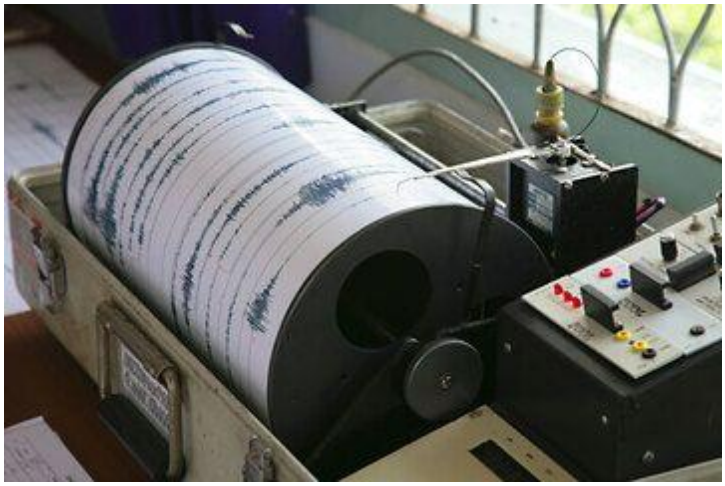


Figure 37 :seismograph

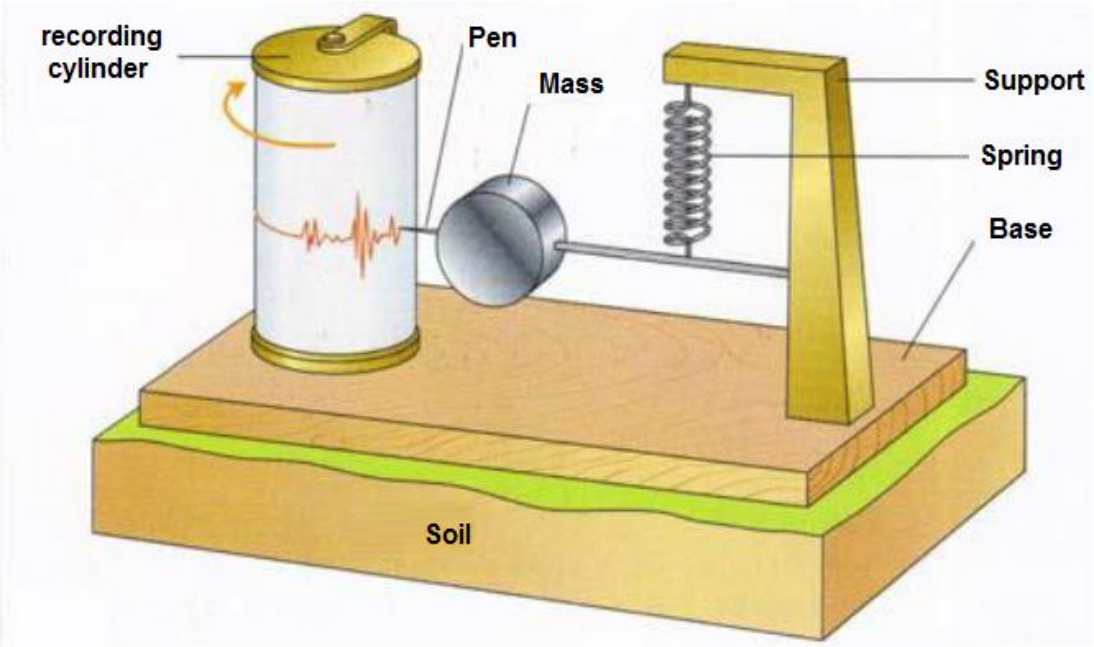


Figure 38 : Principle of the Seismograph

2.2. The Different Types of Waves

Earthquakes generate waves that propagate outward from the focus at varying speeds depending on the medium. There are two main types of waves: **body waves (P and S)** that propagate in all directions and travel through the planet, and **surface waves (L and R)** that move parallel to the Earth's surface (they only cause shaking down to a certain depth):

a. Body Waves:

- **P-Waves (Primary Waves):** P-waves are longitudinal or compressional waves. The particles move in the direction of propagation (the ground displacement accompanying their passage occurs through successive expansions and compressions). These waves can travel through all types of media (solids, liquids, and gases) and are the fastest seismic waves, traveling at speeds of about 6 km/s near the surface.

- **S-Waves (Secondary Waves) :** S-waves are transversal or shear waves. The particles move perpendicular to the direction of wave propagation. S-waves cannot travel through liquid media, and they are specifically stopped by the Earth's outer core. They are slower than P-waves and appear second on seismograms..

b. Surface Waves:

There are two types of surface waves: Love waves (L) and Rayleigh waves (R). Their effect is similar to the ripples formed on the surface of a lake..

- **Love Waves :** Love waves cause horizontal shaking, which is responsible for significant damage to building foundations. These waves travel at about 4 km/s.

- **Rayleigh Waves**: Rayleigh waves are characterized by a complex motion that is similar to the movement of dust carried by a wave, involving both horizontal and vertical displacements.

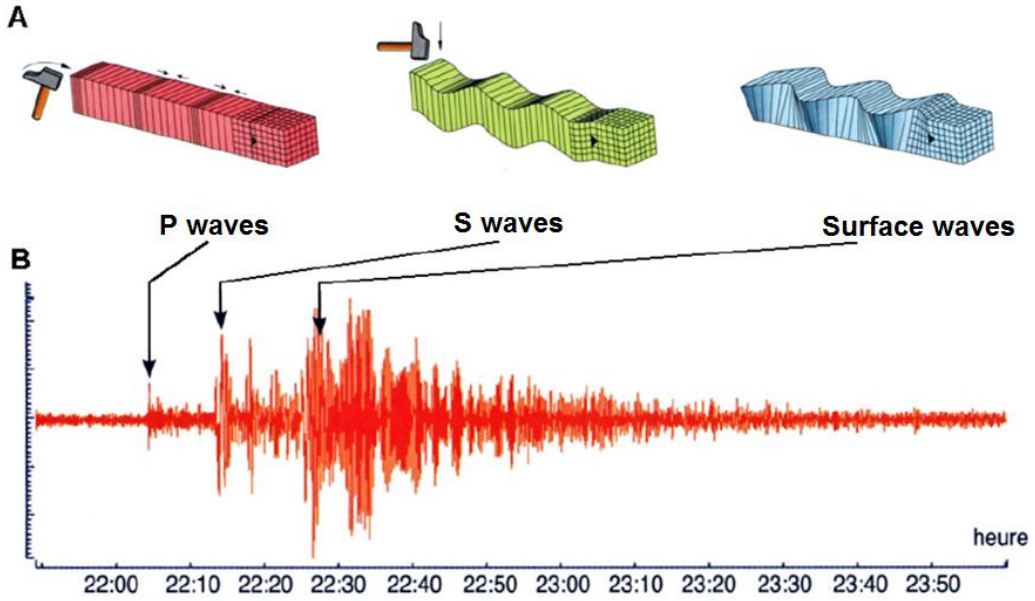


Figure 39 :Seismic Waves. (Recording made in Germany during the earthquake that occurred in Haiti on January 12, 2010, at 21:53 (GMT).

1.6- Geographical Distribution of Earthquakes

Earthquakes are not randomly distributed across the surface of the Earth. There are three main seismic zones (see the figure below):

- **Mid-Ocean Ridges:** These are found in the middle of the oceans and correspond to the zones of oceanic crust creation. Earthquakes in these regions are typically shallow (with foci at depths < 20 km) and generally have low magnitudes. They are associated with tensional movements and sliding along faults, due to the divergence of tectonic plates.
- **The Alpine Belt (Perialpine Belt)**, This belt encompasses the entire Alpine orogenic system, stretching from the north of Africa (including the Maghreb) to the mountain chains of Central Asia (Himalayas, Indonesia). Earthquakes in this zone can be deeper (reaching depths of up to 70 km) and reflect convergent tectonic movements, where plates are moving toward each other.
- **The Zone around the Pacific Ocean (The "Ring of Fire"):** Earthquakes in this region correspond to the major oceanic trenches, particularly around the Pacific Ocean. This is where approximately 80% of the total seismic energy is released. The depth of seismic foci in this zone varies significantly, from shallow to very deep, with foci reaching depths of 300 to 700 km. As we will see in the next chapter, the distribution of earthquakes in this zone closely mirrors the distribution of volcanism, highlighting the boundaries of tectonic plates.

These three zones are key to understanding the distribution of seismic activity, and they underscore the relationship between tectonic plate boundaries, seismicity, and volcanic activity.

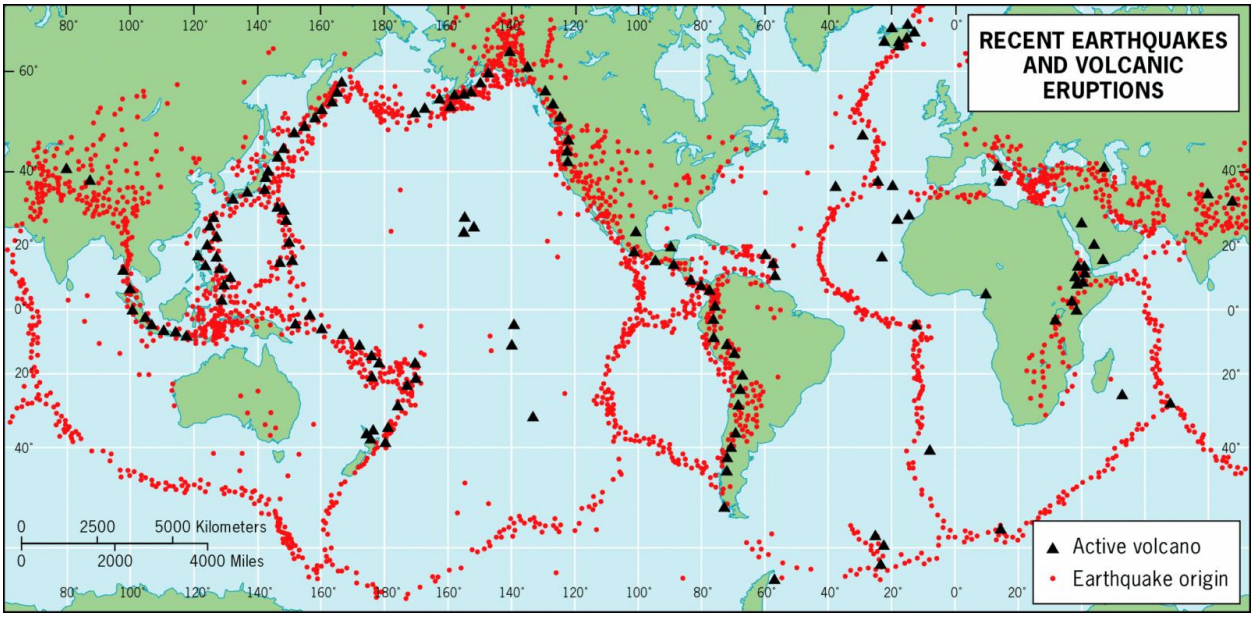


Figure 40 : Map of the Global Distribution of Earthquakes and Volcanoes

3. Concept of Tectonics (Soft and Brittle)

Tectonics is the study of the deformations that have affected geological formations after their deposition. Depending on their intensity and the nature of the rocks, tectonic forces (responsible for modifying the original arrangement of the layers) can produce folding or fractures, called faults.

3.1. Brittle Tectonics (Faults)

A fault is a geological feature that separates two parts of the same layer and displaces them relative to each other**.** It occurs when there **is brittle deformation** of the rock layers, which is referred to **as brittle tectonics.** Active faults are responsible for the majority of **earthquakes**.

a) Description of a Fault

A fault is characterized by several features:

- The separation surface is called the **fault surface or fault plane**.

- **The lips** represent the ends of the two blocks separated by the fault: on each side, one block is lowered (hanging wall) and the other is elevated (foot wall).

-**The displacement (or throw)** expresses the relative movement of the two blocks: it can be vertical or horizontal.

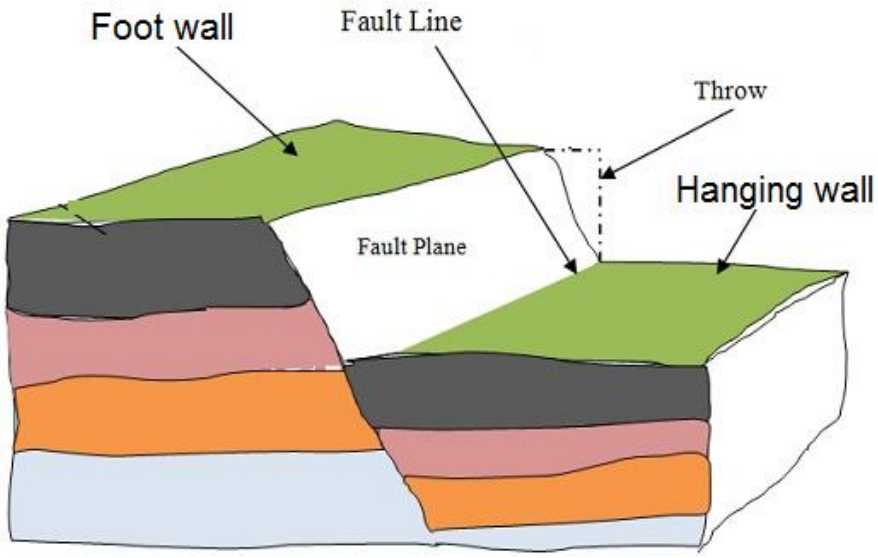


Figure 41 : Structure of a Fault

b) Types of Faults

Depending on the type of relative movement, three types of faults are defined: normal fault, reverse fault, and strike-slip fault.

- **Normal Faults**

A normal fault occurs in response to extension; the block above the fault ("hanging wall") moves downward relative to the block below the fault ("footwall"). The fault plane is inclined towards the lowered block.

- **Reverse Faults**

A reverse fault (or thrust fault) occurs in response to compression; the block above the fault ("hanging wall") moves upward relative to the block below the fault ("footwall"). The fault plane is inclined towards the elevated block and appears to dip beneath it.

- **Strike-Slip Faults**

A strike-slip fault involves a primarily horizontal sliding movement. These faults can be dextral (right-lateral) or sinistral (left-lateral), depending on whether the block opposite to the observer moves to the right or left, respectively.

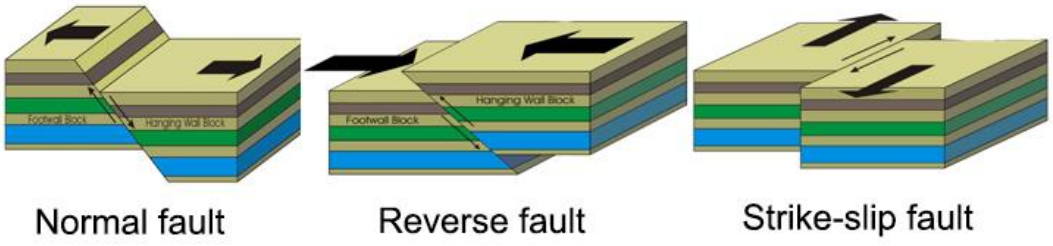


Figure 42 : The Three Types of Faults

3.2. Soft or Ductile Tectonics (Folds)

Folds are undulations or wave-like bends in rock layers. They form as a result of **ductile or plastic** deformation, which is referred to as **soft or ductile tectonics**.

An **anticline** is a fold shaped like an arch (anticline = 'A' shape), and a **syncline** is a fold shaped like a trough or basin..

a) Description of a Fold

The key components of a fold are:

- **hinge axis:** An imaginary plane that divides the fold symmetrically into two halves.
- **Crest:** The highest topographic point of the fold (the peak of the arch).
- **limb (Flanks):** refers to the sides of a fold.
- **Trough:** It refers to the lowest point or the concave part of a fold or structure.

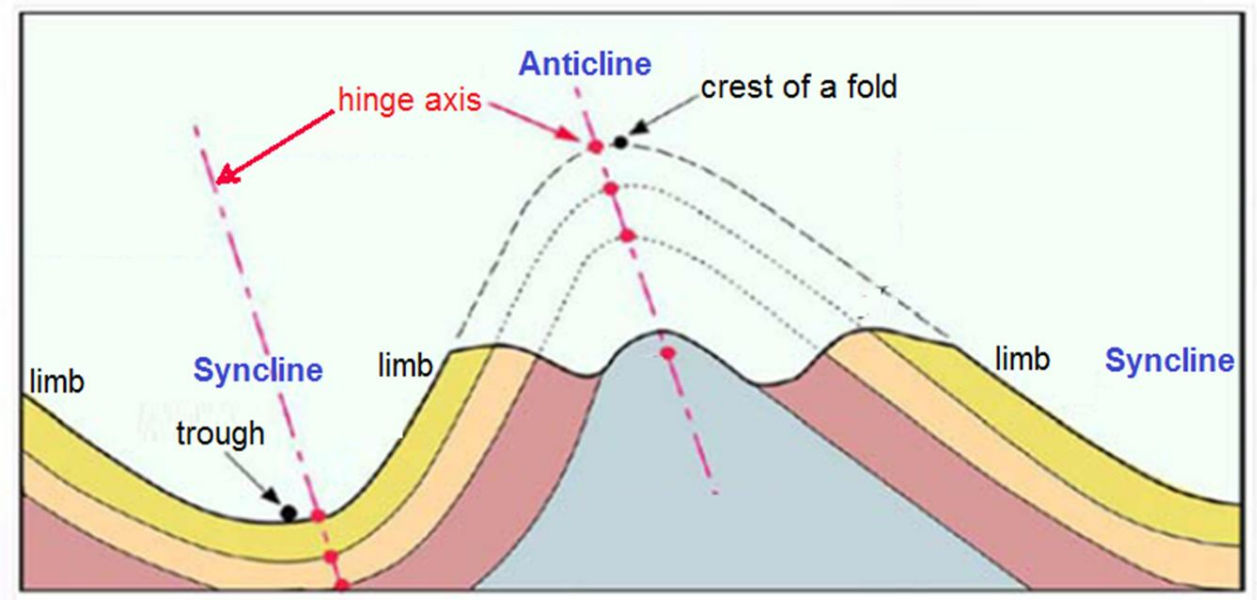


Figure 43 : Main Elements of a Fold

b) The Main Types of Folds

There are different types of folds, classified based on the inclination of their limbs, shape, type of deformation, and mode of formation. Based on the inclination of their limbs, the following types of folds can be distinguished:

- Symmetrical Folds (Right Folds): Both flanks have equal and opposite dip angles, and the axial plane is vertical.
- Asymmetrical Folds: One of the flanks is tilted but does not reach vertical.
- Overturned Folds: One of the flanks has exceeded the vertical, creating what is called the reverse flank. If one flank is vertical, this is referred to as a knee fold.
- Recumbent and Overturned Folds: Both flanks approach the horizontal position.

Les plis-faille sont le résultat d'une déformation intense du pli, avec rupture et apparition d'une faille.

Si l'épaisseur des couches restent constante, on parle de pli isopaque, dans le cas contraire, il s'agit d'un pli anisopaque (cas du pli laminé dans la figure suivante).

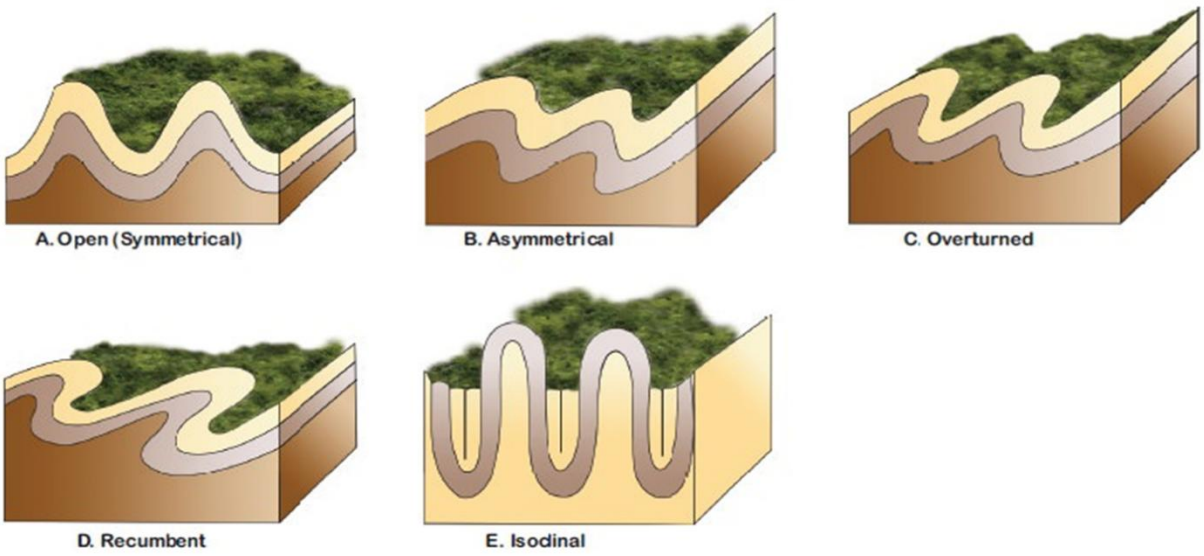


Figure 44 : Types of fold

4. Volcanology :

4.1. Definition of a Volcano

A volcano is a conical-shaped landform built up by lava and volcanic materials ejected from deep within the Earth. It has erupted, or may erupt, molten materials through a vent and a crater.

Alternatively, a volcano can be defined as a landform, either terrestrial or submarine, formed by the ejection and accumulation of materials from the ascent of magma in the form of lava (**effusive type**) and tephra (**explosive type**). This magma comes from the partial melting of the mantle, and in exceptional cases, from the Earth's crust.

The accumulation of volcanic materials can reach thousands of meters in thickness, forming mountains or islands. Depending on the nature of the materials, the type and frequency of eruptions, volcanoes take various forms, but generally appear as conical mountains topped by a crater or caldera. The primary location of material discharge during an eruption is usually at the summit of the volcano, where the volcanic vent opens; however, lateral openings may also appear on the flanks or base of the volcano.

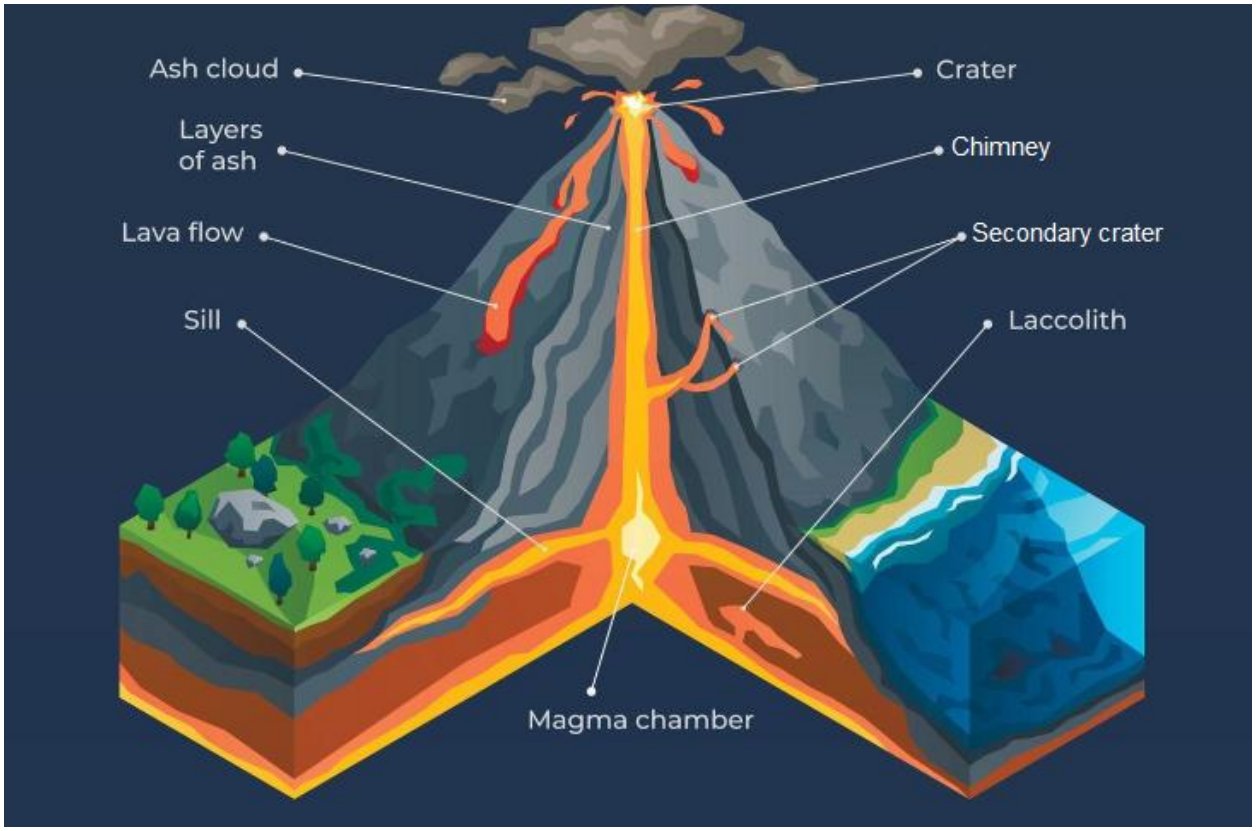


Figure 45 : Cross section of volcano

A volcanic eruption occurs when the magma chamber beneath the volcano is pressurized by the influx of magma from the mantle. Depending on the amount of magma in the chamber, it may eject varying amounts of gas. The pressurization is accompanied by swelling of the volcano and very shallow, localized earthquakes beneath the volcano, signaling that the magma chamber is deforming. The magma typically rises through the main vent, undergoing degassing, which causes a tremor :a constant, very slight vibration of the ground. Other phenomena may accompany the eruption, such as significant earthquakes, landslides, tsunamis, etc..

a) Gases

Gases are emitted from the crater and from vents distributed across the volcanic structure, known as fumaroles, which can reach temperatures of up to 900°C. These gases are composed of:

- **Water vapor** (90% by volume)
- **Carbon dioxide** (CO_2)
- **Sulfuric acid** (H_2S), which is relatively rare. Sulfur is common in the form of sulfur vapor or sulfur dioxide (SO_2) gas.

The presence of dissolved gases facilitates the flow of lava. Annual emissions of CO_2 are estimated at 60 million tons, and those of SO_2 at 4 million tons (a major

source of sulfur in the atmosphere). Some of these gases (as well as volcanic ash) absorb solar radiation and contribute to the greenhouse effect. As a result, volcanic eruptions can have a noticeable impact on the climate.

b) Lava Flows

Lava is molten rock emitted by volcanoes in a liquid or semi-solid state, with temperatures ranging from 700 to 1200°C. Lava flows can cover a wide range of areas, from a few hundred square meters to several thousand square kilometers. The appearance of lava flows depends on numerous factors, including the topographic slope, the presence of liquid water (such as oceans), flow velocity, and viscosity.

There are several types of lava, each with distinct characteristics:

- **Smooth lava**: Smooth, with a regular surface.
- **Ropey lava:** Characterized by a rough, jagged surface with overlapping ridges.
- **Prismatic or Columnar lava**: Lava that forms regular vertical prisms.
- **Pillow lava**: Lava that forms under water, creating pillow-like shapes.



a b



c d

Figure 46 : Types of lava flows

II. Extenal geodynamics:

1. Surface Weathering

Weathering refers to all the physical (mechanical) and chemical processes that break down solid rock into smaller particles or alter its composition. These processes lead to the formation of soils by transforming the parent rock in place. The products of weathering are then redistributed by dynamic agents such as gravity, wind, ice, rivers, and oceans.

2. Types of Weathering Processes

a) Physical (Mechanical) Disintegration

Rocks are never completely solid or uniform; they contain discontinuities caused by variations during sedimentation (sedimentary joints) or by tectonic stresses that deform the rock. These stresses create cracks (joints or fractures) and sometimes faults with displacement. Even small fractures can weaken rocks and make them more vulnerable to breakdown.

Causes of joint formation:

- During sediment consolidation
- During the cooling of volcanic rocks
- During relaxation after tectonic stress

Over time, these fractures expand due to freeze–thaw cycles and the presence of water, further fragmenting the rock mass.

b) Gravitational Action

Gravity plays a key role in the movement of weathered materials. Particles detached by disintegration on steep slopes are transported downhill by gravity until they accumulate at the base of the slope. This contributes to slope evolution and landscape reshaping.

c) Rockfalls (Mass Wasting)

A rockfall occurs when a large volume of rock suddenly detaches and collapses, often along a cliff or steep face. This process is common in fractured rock formations, where cracks and discontinuities make the structure unstable. Rockfalls are sudden and can be extremely destructive.



Figure 47 : Rockfalss

d) Runoff (Surface Water Erosion)

Runoff refers to the flow of rainwater on the surface. Its erosive effect becomes significant when it moves across impermeable layers (such as clay), concentrating the flow and forming small ravines or gullies.

Vegetation greatly reduces runoff, as plant roots increase soil permeability and stabilize slopes. The intensity of runoff depends on factors such as rainfall intensity, soil permeability, vegetation cover, and slope gradient.



Figure 48 : Runoff

e) Other Slope Movements

Other surface processes include:

- Dry landslides (soil or rock movement without water saturation)
- Mudflows, where water-saturated materials flow downslope
- Solifluction, a slow flow of waterlogged soil typical in cold climates

All these mechanisms shape the Earth's surface by breaking down, transporting, and depositing materials.



Figure 49 : Mudflows



Figure 50 : Solifluction

5. Conclusion

To conclude, geodynamics explains the internal and external forces that drive the evolution of our planet. From earthquakes and volcanic activity to tectonic movements, these processes shape the Earth's surface and create new geological structures. Understanding geodynamics is vital for assessing seismic risks, predicting volcanic eruptions, and ensuring the safety and sustainability of engineering projects in geologically active zones.

Chapter V: Adaptation of Geological Techniques to the Needs of Civil Engineering

Introduction:

Modern civil engineering relies heavily on a thorough understanding of soil and subsoil conditions, since the stability and durability of any structure depend directly on the geological characteristics of the ground on which it is built. Geological techniques, initially developed for scientific and mining exploration, have become fundamental tools in civil engineering. Their adaptation allows engineers to assess site conditions, anticipate natural hazards, and design safe and economically efficient structures.

Civil engineers must be able to read and interpret geological information in order to make informed design and construction decisions. Among the essential techniques, geological mapping provides an overview of the nature and distribution of formations; graphical constructions enable the visualization of the three-dimensional structure of the subsurface; discontinuity surveys supply critical data about the weakness planes in rock masses; and stereographic projection allows for a rigorous analysis of rock slope and excavation stability.

This chapter therefore aims to present the main geological methods adapted to the requirements of civil engineering, emphasizing their practical application, interpretation, and contribution to the safety and performance of engineering structures.

1. Geological Map

Geological mapping is the graphical representation, at a given scale, of the subsurface of a region, showing the nature, arrangement, and structural features of rock formations.

It is a fundamental tool in civil engineering because it allows engineers to:

- identify areas that are favorable or unfavorable for construction;
- anticipate geotechnical problems related to soil conditions (landslides, settlements, collapses);
- locate natural resources (aggregates, water, clays, etc.) required for engineering projects.

2. Types of Maps Useful to the Civil Engineer

Geological map: shows the nature and age of outcropping rocks as well as their structural features (folds, faults, fractures).

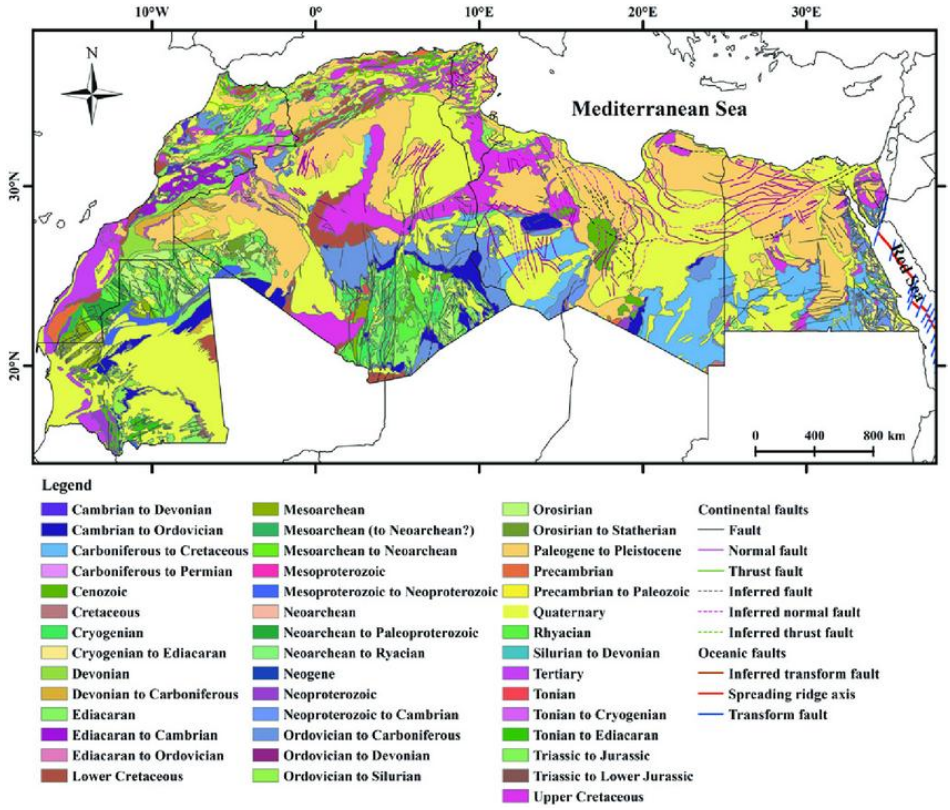


Figure 51 : example of geological map

Topographic map: represents the relief and serves as the base for geological mapping.

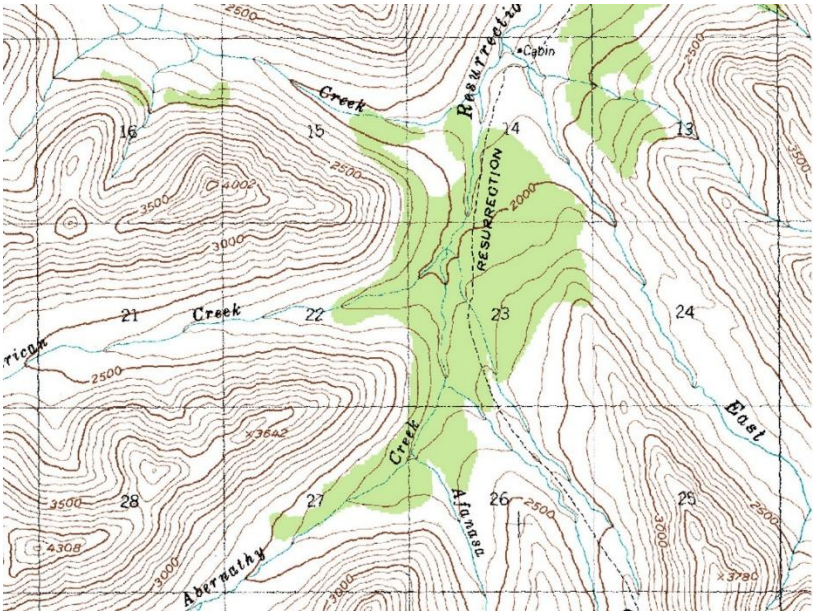


Figure 52 : example of topographic map

Geomorphological map: illustrates landforms and erosion processes.

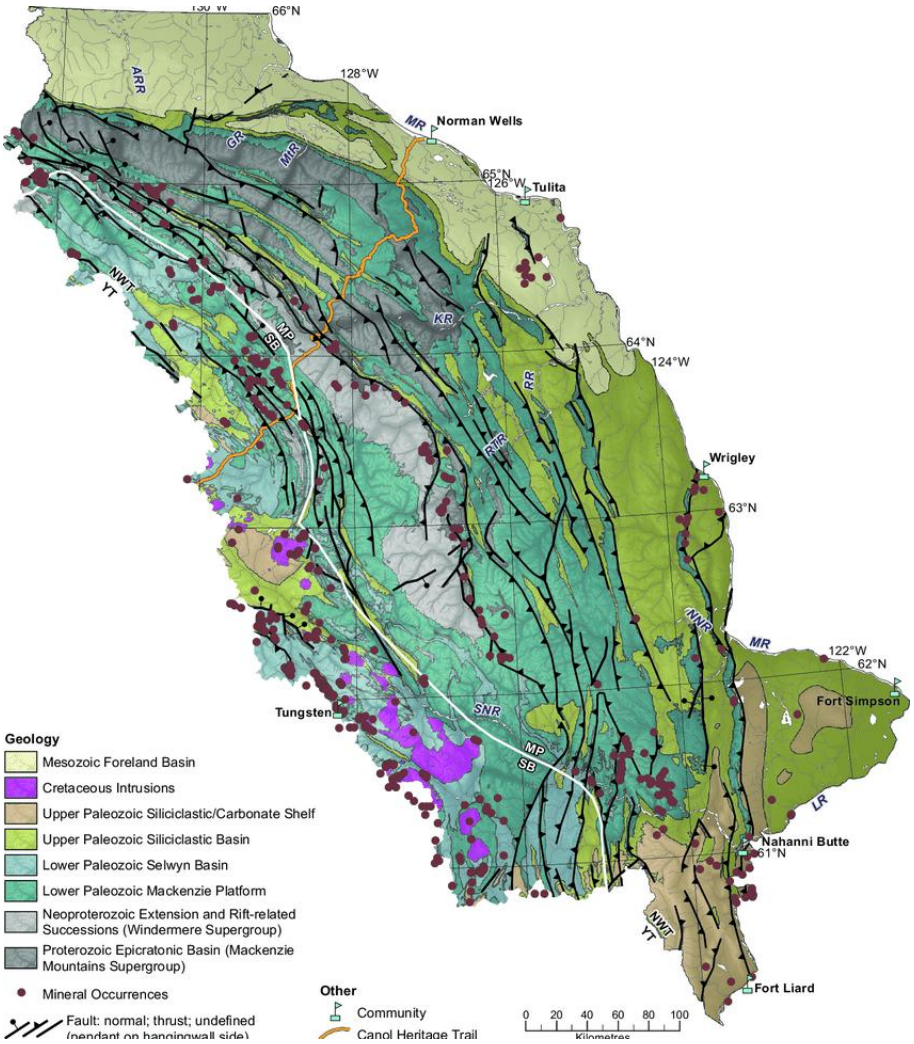


Figure 53: example of geomorphological map

Hydrogeological map: indicates groundwater tables, springs, and the permeability of formations.

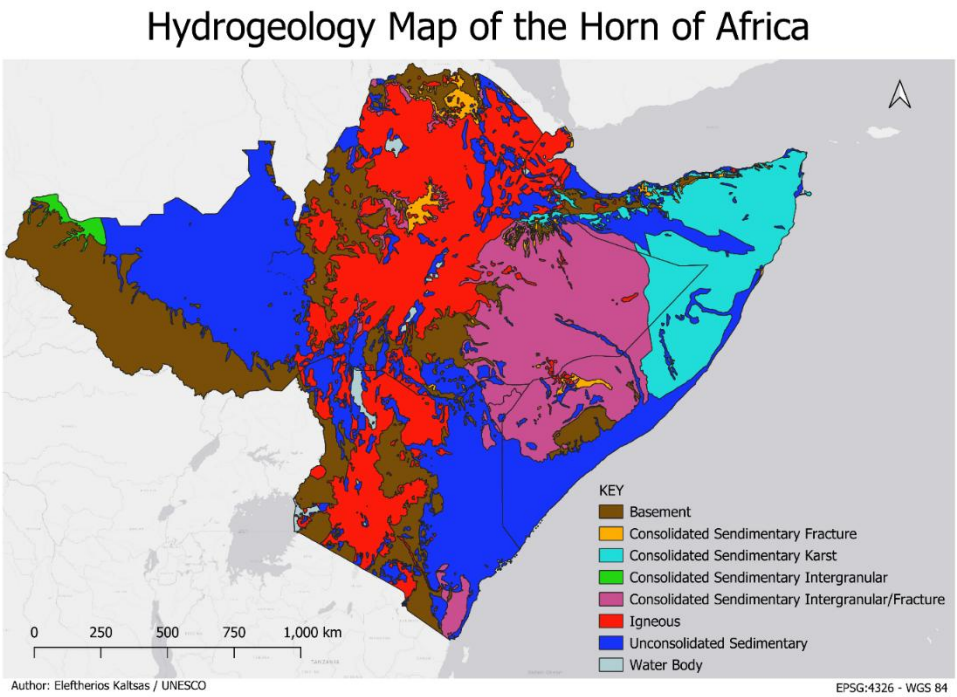


Figure 54: example of hydrgeological map

Geotechnical map: provides a synthesis of geological and mechanical data useful for construction.

3. Methods of Survey and Interpretation

The process of geological mapping involves two complementary phases: fieldwork and office work. Fieldwork consists of direct on-site reconnaissance to observe the terrain, measure the orientation of geological layers (dip and strike), and record lithological characteristics such as rock type, texture, and degree of alteration. These observations are carefully plotted on topographic maps to establish the spatial distribution of different formations and structural features such as faults or folds.

Once the field data are collected, office work begins. This phase involves compiling and interpreting the field observations to produce a coherent geological map. The geologist analyzes profiles, cross-sections, and contact relationships to reconstruct the subsurface structure of the area. The interpretation stage transforms raw measurements into a model that can be understood and used by engineers.

For civil engineering applications, map scale plays a crucial role. Large-scale maps, generally between 1:5 000 and 1:25 000, are preferred because they provide sufficient detail to represent local geological conditions relevant to construction projects.

4. Applications in Civil Engineering

Geological maps are essential for a wide range of engineering projects. They are used in site investigations for dams and bridge foundations, where understanding the distribution of bedrock and weak zones is critical for design safety. In the planning of roads and tunnels, geological mapping helps to identify fractured zones, fault lines, or unstable slopes that could present construction hazards. Furthermore, geological interpretation supports the analysis of unstable areas, such as landslides or zones of differential settlement, enabling engineers to adopt preventive measures or stabilization solutions before construction begins.

4.1. Method for Drawing a Geological Cross-Section

To construct a geological cross-section, the first step is to select an appropriate profile line on the topographic map, preferably perpendicular to the main structural direction of the area. The outcrops and geological contacts are then projected onto this line, taking into account their spatial positions and measured dips. Each layer is drawn with its true thickness, respecting the observed orientations. Finally, structural features such as faults, folds, and joints are added to complete the representation. The resulting section provides a vertical "slice" through the terrain, revealing the relationships between the different formations and structures below the surface.

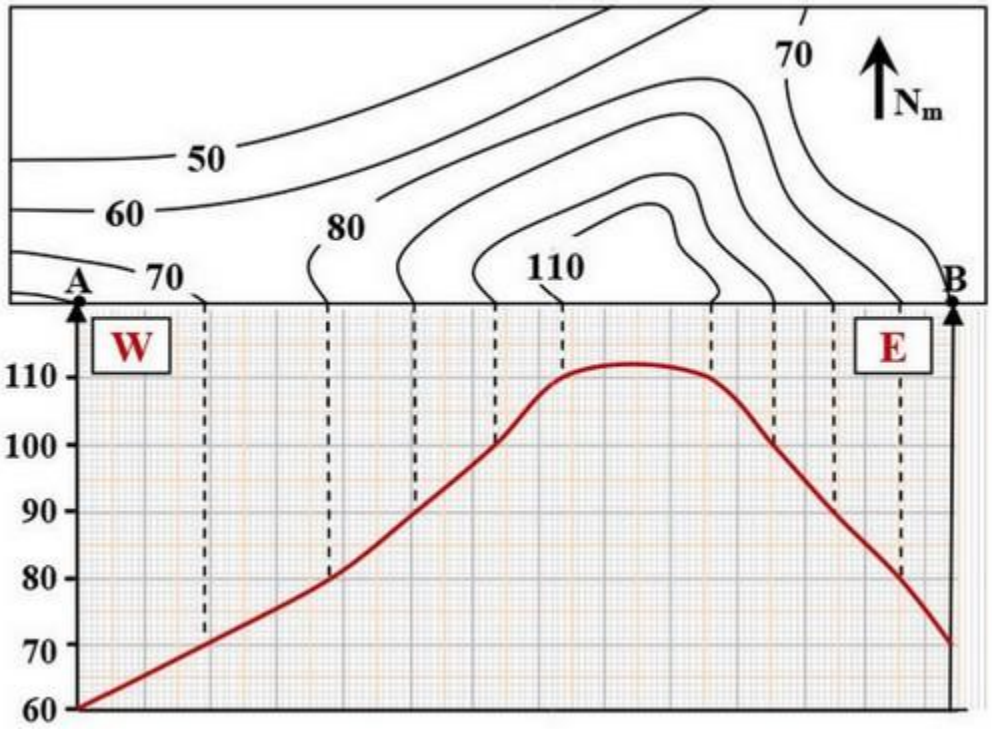


Figure 55: example 1 of topographic Cross-Section map

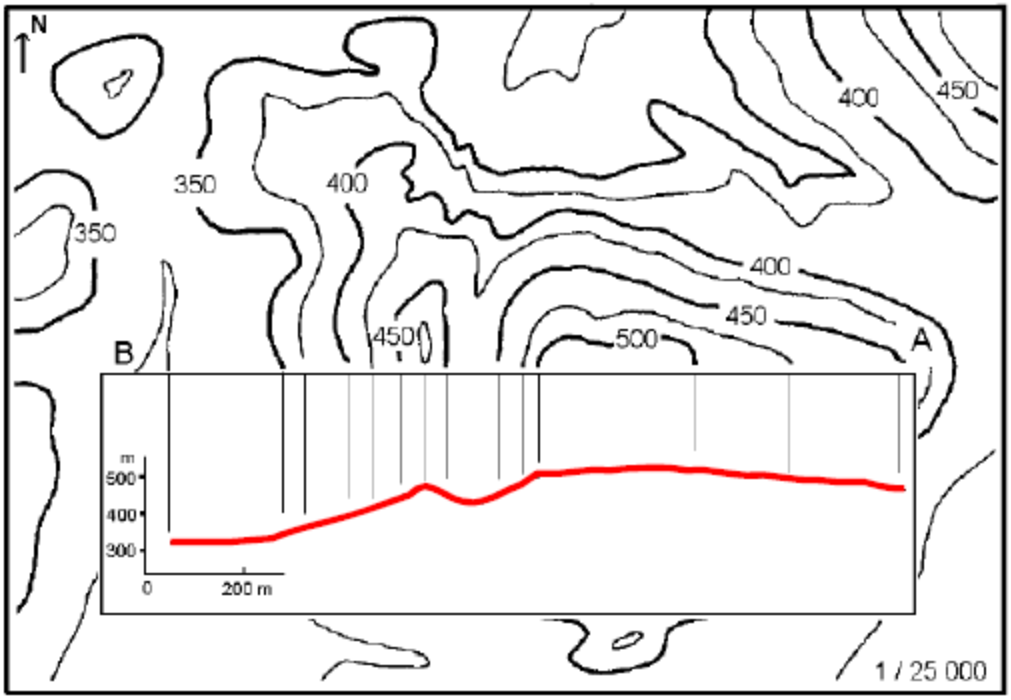


Figure 56: example 2 of topographic Cross-Section map

4.2. Establishment of a Geological Cross-Section

The establishment of a geological cross-section is one of the most important steps in geological interpretation for civil engineering. It provides a vertical profile through the Earth's surface that illustrates the arrangement and structure of the different geological formations. This representation allows engineers to visualize subsurface conditions and anticipate potential construction challenges such as weak layers, fault zones, or groundwater-bearing strata.

A geological cross-section translates two-dimensional map information into a three-dimensional understanding of the subsurface. It helps in:

- identifying the sequence and thickness of strata beneath a project site,
- locating faults, folds, and zones of deformation,
- correlating data from boreholes and field measurements, and
- supporting the design of engineering structures such as tunnels, foundations, and slopes.

Through cross-sections, civil engineers can predict how geological formations extend below the surface and how they may influence excavation, stability, and groundwater flow.

Methodology

The construction of a geological cross-section follows a systematic approach that integrates field observations, cartographic data, and topographic information.

- Selection of the Profile Line
  The first step is to choose an appropriate line of section on the geological map. This line should generally be oriented perpendicular to the main geological structures (for example, the direction of strike of bedding or faults) to best represent the true geometry of the formations.
- Preparation of the Topographic Profile
  Using the topographic map, the ground surface along the chosen line is drawn to scale. This profile represents the natural relief and forms the upper boundary of the cross-section.
- Projection of Geological Contacts and Outcrops
  All geological boundaries observed along the section line are projected downward from the map onto the topographic profile. These projections must correspond to the surface positions and altitudes of outcrops observed in the field.
- Plotting of Structural Data
  The dip and strike of each layer, measured during fieldwork, are used to determine the orientation of the strata below the surface. The layers are then drawn at the correct inclination and thickness.
- Representation of Structural Features
  Faults, folds, joints, and other discontinuities are added based on field measurements and their expression on the geological map. Special attention is given to the relative displacement of formations along faults and to the geometry of folded structures.
- Interpretation and Completion
  Once all the observed data are plotted, the geologist interprets the subsurface structure between outcrops, ensuring consistency with known geological principles such as superposition, continuity, and cross-cutting relationships. The final section must be geometrically coherent and consistent with field evidence.

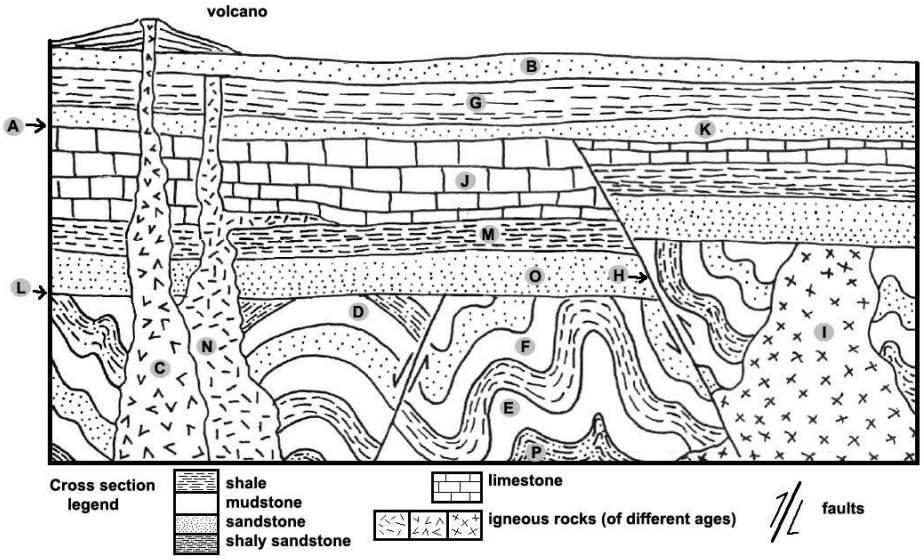


Figure 57: example 1 of geological Cross-Section map

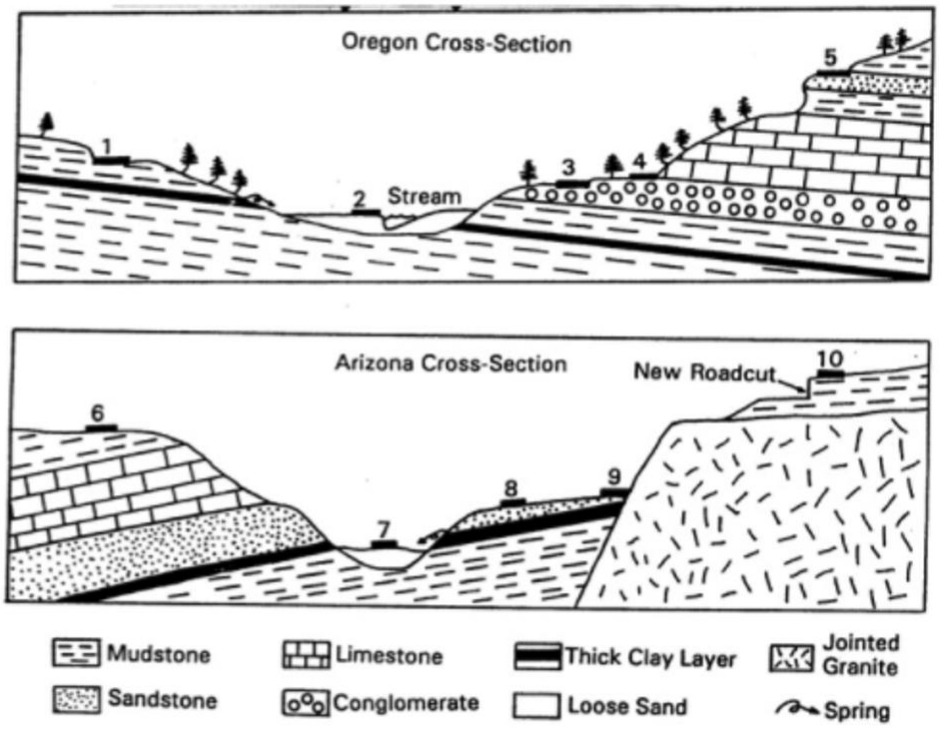


Figure 58: example 2 of geological Cross-Section map

Conclusion

This chapter highlighted how geological techniques support civil engineering by providing a clear understanding of subsurface conditions. Geological mapping, graphical constructions, and discontinuity surveys allow engineers to visualize and interpret the structure of the ground, while stereographic projection helps assess rock and slope stability. The integration of these methods enables safer, more efficient, and sustainable engineering designs by linking geological knowledge with practical construction needs.

General Conclusion

Geology, as the science of the Earth, provides a comprehensive understanding of our planet's structure, composition, and dynamic evolution. Through the study of rocks, minerals, and geological processes, we uncover the history of the Earth from its formation to the present and gain insight into the natural forces that continuously shape its surface.

Throughout this course, we have explored the foundations of geology, the nature of minerals and rocks, the impact of external agents such as wind, water, and glaciers, and the internal mechanisms that drive geodynamic activity, including earthquakes and volcanoes. Each of these aspects contributes to a unified vision of how the Earth functions as a complex and living system.

Beyond scientific knowledge, geology has profound practical importance. It provides essential tools for civil engineering, environmental protection, and the sustainable management of natural resources. Understanding geological phenomena enables engineers and scientists to anticipate risks, design safer infrastructures, and promote responsible interaction with our environment.

In essence, geology is not only the study of the Earth it is the key to understanding the balance between natural processes and human development, guiding us toward a more informed and sustainable future.

Bibliography

[1] Foucault, A., & Raoult, J.-F. (1995). *Dictionary of Geology* (4th ed.). Éditions Masson.

[2] Parriaux, A., & Arnould, M. (2009). *Geology: Foundations for the Engineer*. Presses Polytechniques et Universitaires Romandes.

[3] Pomerol, C., Lagabrielle, Y., & Renard, M. (2005). *Éléments de géologie* (13e éd.). Éditions Dunod.

[4] Bogomolov, G. (n.d.). *Hydrogeology and Concepts of Engineering Geology* .

[5] Benamara, F. Z. (2022). *Polycopié de cours de Géologie*. Faculté des Sciences et de la Technologie, Département de Génie Civil & Hydraulique, Université du 8 Mai 1945 de Guelma.

[6] Éditions du BRGM. (1984). *Hydrogeology, Engineering Geology*. Bureau de Recherches Géologiques et Minières (BRGM).

[7] Cojean, R., & Audiguier, M. (2011). *Engineering Geology: Bilingual French/English*. Presses de l'École Nationale des Ponts et Chaussées.