



جامعة علي كافي تندوف

University of Ali Kafi Tindouf

Institute of Science and Technology

Department of Earth and Universe Sciences

COMPREHENSIVE GEOLOGY COURSE:

Geology 1

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Course Description

Course Title	Geology 1
Nature of the Course (Fundamental/Complementary)	Fundamental
Semester	Semester I
Department	Earth and Universe Sciences
University	University of Ali kafi Tindouf

Code	UEF111
Crédits	08
Coef	04

Semestre : 1

Unité : UEF111

Matière : Géologie 1

Coef. 4 Crédit 8

Cours : 03h00 TP : 03h 00

Objectifs de l'enseignement

L'enseignement de géologie vise l'acquisition d'une connaissance de base des grands phénomènes qui régissent la Terre et à montrer que celle-ci est une planète active caractérisée par une dynamique dont il faut tenter de comprendre le fonctionnement.

Connaissances préalables recommandées

Notions de géologie acquises au Lycée.

Contenu de la matière :

Cours

Chapitre 1 : La Terre dans l'Univers

- 1.1 Introduction : objets de la géologie
- 1.2 Structure de l'univers et naissance du système solaire
- 1.3 La terre et les planètes du système solaire.

Chapitre 2 : Géodynamique interne

- 2.1 Structure du globe terrestre et notion de géoïde
- 2.2 Répartition actuelle des terres et des mers
- 2.3 Le champ magnétique terrestre
- 2.4 Dérive des continents et tectonique des plaques
- 2.5 Les séismes
- 2.6 Les volcans

Chapitre3 : Tectonique

- 3.1. Déformation cassante : les failles
- 3.2. La tectonique souple : les plis
- 3.3. Chevauchement et nappes
- 3.4. La formation des chaînes de montagnes

Preface

This geology course booklet is intended for first-year LMD (Licence) students in Earth and Universe Sciences, and for anyone interested in the scientific study of our planet (teachers, geological engineers, researchers in Earth sciences...). It represents an essential resource from the very beginning of a university student's career in the field of Earth and Universe Sciences.

To properly understand the fundamental concepts of geology, it is recommended that the student has prerequisites from the 2nd and 3rd year of secondary school in Natural Sciences and Life and Earth Sciences (high school baccalaureate).

This booklet provides the student with the basic knowledge in Geology, which constitutes a necessary and indispensable tool for pursuing the modules offered in subsequent semesters (External Geodynamics, Petrology, Stratigraphy, etc.). The pedagogical objectives of the course are as follows:

- Understand the Earth's place in the Universe and the Solar System, and its particularities as a habitable planet.
- Describe the internal structure of the globe and the concept of the geoid.
- Understand the fundamental principles of the Theory of Plate Tectonics.
- Describe the mechanisms behind major internal geological phenomena, such as earthquakes and volcanism.
- Analyze and classify geological structures resulting from rock deformation (faults, folds, thrust nappes).

This module is accompanied by practical and tutorial sessions (TP) which focus on the identification of rocks and minerals, the interpretation of geological maps, and the analysis of cross-sections and geophysical data. Mastering the concepts acquired during the tutorials and practical work is necessary for the proper understanding of most chapters in this module.

This booklet comprises three chapters. The first chapter deals with the Earth's place in the Universe, the birth of the solar system, and the characteristics of the planets. The second chapter is dedicated to internal geodynamics, detailing the structure of the globe, the Earth's magnetic field, and the major mechanisms of continental drift, plate tectonics, earthquakes, and volcanism. The third chapter addresses tectonics and rock deformation, explaining brittle deformations (faults) and ductile deformations (folds), as well as the formation of mountain chains.

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- 2.2 Current Distribution of Lands and Seas
- 2.3 Earth's Magnetic Field
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- 2.5 Earthquakes
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CHAPTER 1:
THE EARTH IN THE UNIVERSE

1.1 Introduction: The Objects of Geology

Definition and Scope

Geology (from Greek "gê" meaning Earth and "logos" meaning discourse) is the scientific study of the Earth, its composition, structure, physical properties, history, and the processes that shape it. Unlike other sciences that might focus on laboratory experiments, geology often deals with events that occurred over millions of years and at scales ranging from atomic to planetary.

The primary object of geological study is the lithosphere - the rigid outer layer of the Earth that includes the crust and upper mantle. However, modern geology also considers interactions with the atmosphere, hydrosphere, and biosphere, recognizing that Earth is an integrated system.

Major Subdisciplines of Geology

Mineralogy

The study of minerals, which are naturally occurring, inorganic solids with definite chemical compositions and crystalline structures. Mineralogists identify and classify minerals, study their physical and chemical properties, and understand their conditions of formation. There are over 5,000 known mineral species, each with unique characteristics that tell stories about Earth's history.

Petrology

This branch focuses on rocks - aggregates of minerals or mineraloids. Petrologists study:

- Igneous rocks formed from molten material
- Sedimentary rocks formed from accumulated sediments
- Metamorphic rocks transformed by heat and pressure

Petrology investigates rock origins, compositions, textures, and the processes that form and transform them.

Sedimentology

The study of sedimentary processes and products. Sedimentologists examine how

sediments are transported, deposited, and lithified into rock. This includes understanding modern sedimentary environments (rivers, deltas, deserts, deep marine) to interpret ancient rock records. Sedimentary rocks preserve most of Earth's historical record, including fossils and climate indicators.

Paleontology

The study of life's history through fossils - preserved remains or traces of ancient organisms. Paleontologists not only identify and classify fossils but also use them to:

- Date rock layers (biostratigraphy)
- Reconstruct ancient environments
- Trace evolutionary pathways
- Understand mass extinction events

Tectonics

The study of large-scale deformation and structures of Earth's lithosphere. Tectonics investigates:

- Plate movements and boundaries
- Mountain building processes
- Basin formation
- Continental configurations through time

Plate tectonics represents the unifying theory that explains most large-scale geological phenomena.

Geochemistry

The study of the chemical composition of Earth materials and the chemical processes that occur within and on the Earth. Geochemists investigate:

- Element distribution and cycling
- Rock and mineral formation conditions
- Environmental contamination

- Planetary formation and differentiation

Additional Important Subdisciplines

- *Geophysics*: Application of physics to study Earth's interior
- *Stratigraphy*: Study of rock layers and layering
- *Volcanology*: Study of volcanoes and volcanic phenomena
- *Seismology*: Study of earthquakes and seismic waves
- *Hydrogeology*: Study of groundwater
- *Economic Geology*: Study of ore formation and extraction

Interconnected Nature of Geological Disciplines

These subdisciplines are not isolated but interconnected. For example, understanding mountain building requires knowledge of tectonics (structural deformation), petrology (rock formation), geochemistry (metamorphic processes), and stratigraphy (sedimentary record). This integrated approach allows geologists to reconstruct Earth's complex history and predict future changes.

1.2 Structure of the Universe and Birth of the Solar System

Fundamental Concepts and Definitions

The Universe

The Universe encompasses all matter, energy, space, and time that exists. Current estimates suggest it contains over 100 billion galaxies and has been expanding for approximately 13.8 billion years since the Big Bang. The observable universe has a diameter of about 93 billion light-years, though the total size may be infinite.

Cosmology

Cosmology is the scientific study of the Universe's origin, evolution, large-scale structure, and ultimate fate. Key cosmological concepts include:

- The Big Bang theory
- Cosmic inflation

- Dark matter and dark energy
- The cosmic microwave background radiation

Astronomy

Astronomy focuses on the observation and study of celestial objects (stars, planets, galaxies) and phenomena originating outside Earth's atmosphere. It includes:

- Observational astronomy (using telescopes and detectors)
- Theoretical astronomy (modeling celestial phenomena)
- Subfields like planetary astronomy, stellar astronomy, and galactic astronomy

Astrophysics

Astrophysics applies physical laws and theories to understand astronomical objects and phenomena. It investigates:

- Stellar structure and evolution
- Galactic dynamics
- High-energy astrophysics (black holes, neutron stars)
- Cosmochemical evolution

Measuring Cosmic Distances

Light-Year (ly)

A light-year is the distance light travels in one year in vacuum. Since light speed is 299,792 km/s, one light-year equals approximately 9.46 trillion kilometers (9.46×10^{12} km). This unit is ideal for expressing stellar and galactic distances.

Example Calculation: If sunlight takes 8 minutes to reach Earth, the Earth-Sun distance is:

$$\text{Distance} = \text{Speed} \times \text{Time} = 300,000 \text{ km/s} \times 480 \text{ s} = 144,000,000 \text{ km}$$

Astronomical Unit (AU)

One AU is the average distance between Earth and Sun, approximately 149.6 million kilometers. This unit is convenient for measuring distances within solar systems.

Parsec (pc)

A parsec is defined as the distance at which one astronomical unit subtends an angle of one arcsecond. One parsec equals:

- 206,265 AU
- 3.26 light-years
- 30.9 trillion kilometers

For larger distances, kiloparsecs (kpc) and megaparsecs (Mpc) are used.

Cosmic Hierarchy and Structure

Stars

Stars are massive, luminous spheres of plasma held together by gravity. They generate energy through nuclear fusion in their cores, converting hydrogen to helium and heavier elements. Stars vary widely in size, mass, temperature, and lifespan.

Galaxies

Galaxies are vast collections of stars, gas, dust, and dark matter bound by gravity. The three main types are:

- *Spiral galaxies*: Disk-shaped with spiral arms (e.g., Milky Way)
- *Elliptical galaxies*: Spheroidal, containing older stars
- *Irregular galaxies*: Without definite structure

Our Milky Way galaxy contains 100-400 billion stars and has a diameter of about 100,000 light-years.

Galaxy Clusters and Superclusters

- *Galaxy clusters*: Groups of hundreds to thousands of galaxies
- *Superclusters*: Even larger structures containing multiple clusters

The Milky Way belongs to the Local Group cluster, which is part of the Laniakea Supercluster.

Our Home: The Milky Way Galaxy

Structure and Composition

The Milky Way is a barred spiral galaxy consisting of:

- *Galactic bulge*: Central, densely packed spherical region
- *Galactic disk*: Flattened region containing spiral arms
- *Galactic halo*: Sparse spherical component surrounding the disk
- *Dark matter halo*: Invisible matter providing most of the galaxy's mass

The disk is approximately 100,000 light-years in diameter but only about 1,000 light-years thick. The Solar System resides in the Orion Arm, about 27,000 light-years from the galactic center.

Rotation and Dynamics

The Milky Way rotates differentially, with inner regions completing orbits faster than outer regions. The Sun orbits the galactic center at about 220 km/s, completing one revolution every 225-250 million years (a "galactic year").

The Galactic Center

The galactic center contains a supermassive black hole named Sagittarius A*, with mass equivalent to 4.3 million Suns. This region exhibits intense radiation and complex dynamics.

In figure 1.1, cross-section showing the galactic bulge, disk, spiral arms, and halo of the Milky Way.

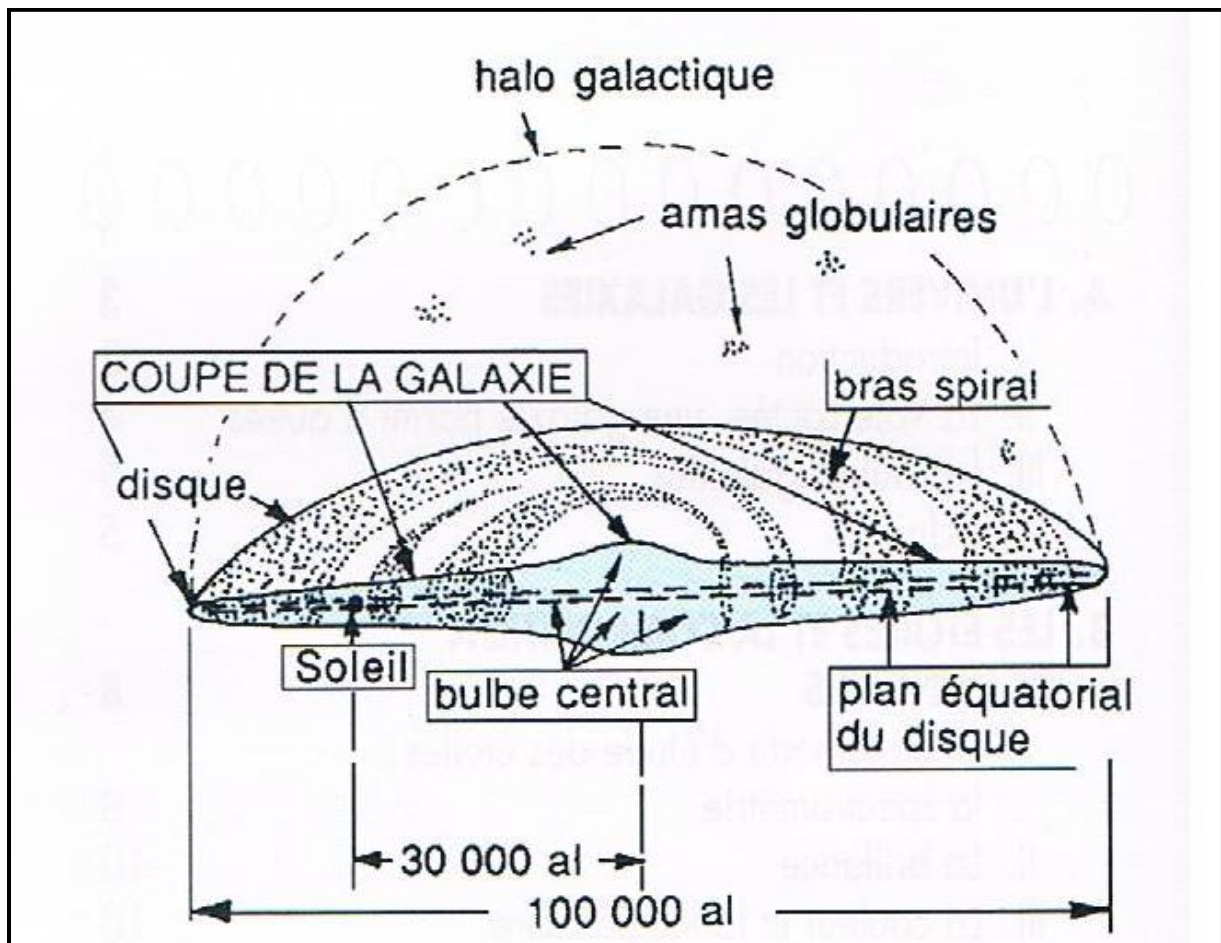


Fig 1.1: Cross-section of the solar galaxy: three-dimensional view of half of the Milky Way

Galaxy Classification

Hubble Classification Scheme

Edwin Hubble developed a classification system known as the "Hubble tuning fork":

- **Elliptical galaxies (E0-E7)**: Range from spherical (E0) to highly elongated (E7)
- *Lenticular galaxies (S0)*: Intermediate between ellipticals and spirals
- *Spiral galaxies*: Divided into normal spirals (Sa, Sb, Sc) and barred spirals (SBa, SBb, SBc)
- *Irregular galaxies (Irr)*: No regular structure

Distribution in the Universe

- Spiral and barred spiral galaxies: ~72%
- Elliptical galaxies: ~10%
- Lenticular galaxies: ~16%
- Irregular galaxies: ~2%

Most large galaxies contain supermassive black holes at their centers, which significantly influence galactic evolution.

Formation of the Solar System

The Solar Nebula Hypothesis

The Solar System formed approximately 4.6 billion years ago from a giant molecular cloud—a fragment of an interstellar cloud of gas and dust. Key stages included:

1. *Cloud collapse*: Triggered possibly by a nearby supernova shockwave
2. *Disk formation*: Conservation of angular momentum created a protoplanetary disk
3. *Sun formation*: Center accumulated most mass, initiating nuclear fusion

4. *Planet formation*: Dust grains collided and accreted into planetesimals, then protoplanets
5. *Planetary differentiation*: Heating caused separation into core, mantle, and crust

Evidence Supporting the Nebular Hypothesis

- All planets orbit in nearly the same plane (ecliptic)
- Planetary orbits are nearly circular
- Most planets rotate and revolve in the same direction
- Compositional gradient from inner rocky planets to outer gas giants

1.3 The Earth and Planets of the Solar System

The Sun: Our Central Star

Characteristics and Composition

The Sun is a G-type main-sequence star (G2V) with:

- Mass: 1.989×10^{30} kg (333,000 Earth masses)
- Radius: 696,000 km (109 Earth radii)
- Composition: 74.9% hydrogen, 23.8% helium, 1.3% heavier elements
- Surface temperature: 5,772 K
- Core temperature: 15.7 million K

Energy Production

The Sun generates energy through proton-proton chain nuclear fusion, converting hydrogen to helium. Each second, approximately 600 million tons of hydrogen fuse into 596 million tons of helium, with 4 million tons converted to energy according to $E=mc^2$.

Solar Structure

- *Core*: Where nuclear fusion occurs
- *Radiative zone*: Energy transported by radiation

- *Convective zone*: Energy transported by convection
- *Photosphere*: Visible "surface"
- *Chromosphere*: Lower atmosphere
- *Corona*: Outer atmosphere extending millions of kilometers

Planetary Classification and Characteristics

Definition of a Planet

According to the International Astronomical Union (2006), a planet must:

1. Orbit the Sun
2. Have sufficient mass for self-gravity to overcome rigid body forces (assume hydrostatic equilibrium - nearly round shape)
3. Have cleared the neighborhood around its orbit

Terrestrial (Rocky) Planets

The inner Solar System contains four terrestrial planets:

Mercury

- Closest to Sun, no atmosphere
- Heavily cratered surface
- Large iron core relative to size
- Extreme temperature variations (-173°C to 427°C)

Venus

- Similar size to Earth but extreme greenhouse effect
- Surface temperature: 462°C (hottest planet)
- Thick CO₂ atmosphere with sulfuric acid clouds
- Retrograde rotation (spins opposite to orbital direction)

Earth

- Only planet with confirmed life
- Active plate tectonics
- Surface liquid water
- Protective magnetic field

Mars

- Thin CO₂ atmosphere
- Evidence of past liquid water
- Largest volcano in Solar System (Olympus Mons)
- Two small moons (Phobos and Deimos)

Jovian (Gaseous) Planets

The outer Solar System contains four gas giants:

Jupiter

- Largest planet (mass greater than all other planets combined)
- Composed mainly of hydrogen and helium
- Great Red Spot - giant storm larger than Earth
- Strong magnetic field and extensive moon system

Saturn

- Prominent ring system of ice and rock particles
- Low density (would float in water)
- Numerous moons, including Titan with thick atmosphere

Uranus

- Tilted on its side (98° axial tilt)

- Ice giant with water, ammonia, methane ices
- Faint ring system
- Blue-green color from methane absorption

Neptune

- Windiest planet with speeds up to 2,100 km/h
- Similar composition to Uranus
- Great Dark Spot observed by Voyager 2
- Faint, incomplete ring arcs

Dwarf Planets

- *Pluto*: Kuiper Belt object with complex geology and atmosphere
- *Eris*: More massive than Pluto, scattered disk object
- *Ceres*: Largest object in asteroid belt
- *Haumea*: Rapidly rotating, elongated shape
- *Makemake*: Bright surface, no atmosphere detected

Small Solar System Bodies

Asteroids

Most asteroids orbit in the Main Belt between Mars and Jupiter. They are remnants from Solar System formation and vary in composition:

- C-type (carbonaceous): Most common, dark surfaces
- S-type (silicaceous): Metallic nickel-iron with silicates
- M-type (metallic): Mostly iron-nickel

Comets

Icy bodies that develop atmospheres (comas) and tails when approaching the Sun. Two main reservoirs:

- *Kuiper Belt*: Beyond Neptune's orbit
- *Oort Cloud*: Spherical shell up to 100,000 AU from Sun

Meteoroids, Meteors, and Meteorites

- Meteoroids: Small rocky or metallic bodies in space
- Meteors: "Shooting stars" - meteoroids vaporizing in atmosphere
- Meteorites: Surviving fragments that reach Earth's surface

Figure 1.2 represents a relative arrangement of the Sun, the terrestrial planets, gas giants, and dwarf planets of the Solar System.

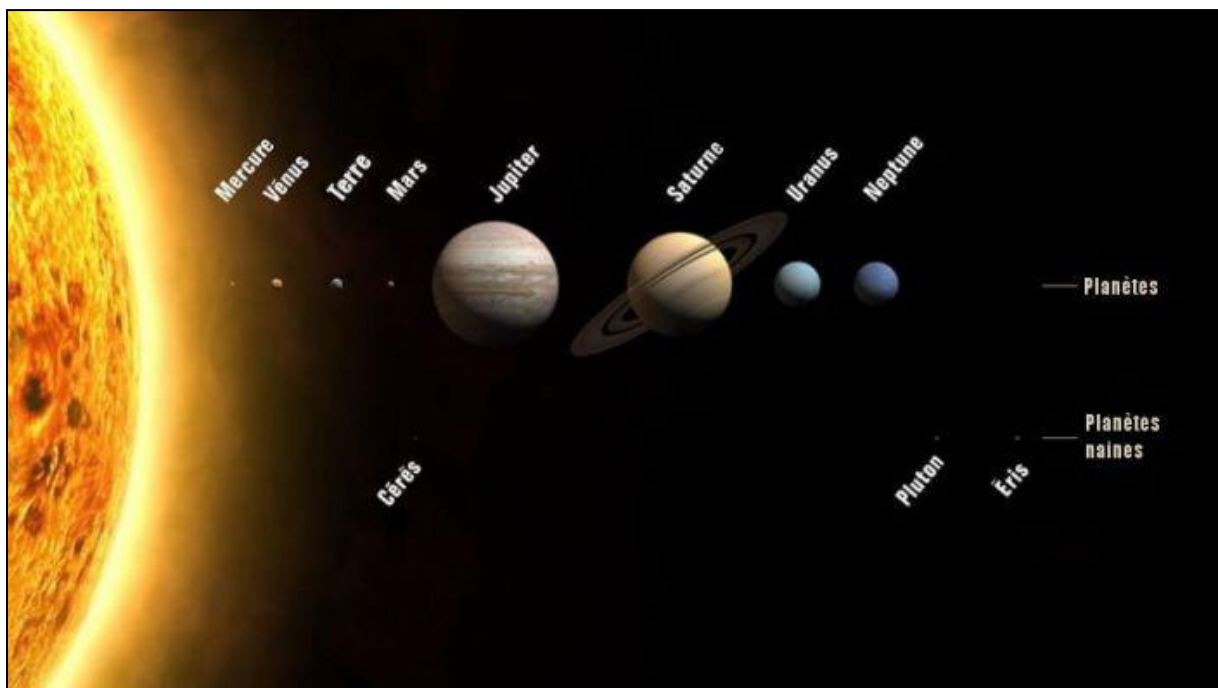


Fig 1.2: Sun, planets and dwarf planets of the solar system

- **Comparison of the Terrestrial Planets**

Physical characteristics (size, density, atmosphere, surface conditions) of Mercury, Venus, Earth, and Mars

	 Mercure 	 Vénus 	 Terre 	 Mars
Distance moyenne au Soleil (en UA)	0,39	0,72	1	1,52
Diamètre (en km)	4878	12104	12756	6787
Densité globale	5,4	5,2	5,5	4
Atmosphère	Non	Oui	Oui	Oui
Autres			Eau liquide	Eau sous forme de glace

- **Comparison of the Gas Giant Planets**

Main physical and atmospheric characteristics of Jupiter, Saturn, Uranus, and Neptune

	 Jupiter 	 Saturne 	 Uranus 	 Neptune
Distance moyenne au Soleil (en UA)	5,2	9,5	19,2	30,1
Diamètre (en km)	142984	120536	51118	49528
Densité globale	1,32	0,69	1,3	4,6
Atmosphère	Oui	Oui	Oui	Oui
Autres	Présence d'anneaux 16 satellites	Présence d'anneaux 18 satellites	Présence d'anneaux 15 satellites	Présence d'anneaux 8 satellites

Solar Energy and Planetary Conditions

Solar Radiation and Planetary Energy

The solar constant (energy received at Earth's distance) is approximately 1,361 W/m².

The energy received by a planet follows the inverse square law:

$$P_{\text{received}} = P_{\text{sun}} / (4\pi R^2)$$

Where R is the distance from the Sun.

Temperature Calculations

The theoretical equilibrium temperature of a planet (without atmosphere) can be calculated as:

$$T_{\text{eq}} = [S(1-A) / (4\epsilon\sigma)]^{1/4}$$

Where:

- S = solar constant at planet's distance
- A = albedo (reflectivity)
- ϵ = emissivity
- σ = Stefan-Boltzmann constant

Actual vs. Theoretical Temperatures

Real planetary temperatures differ from theoretical due to:

- Atmospheric greenhouse effect
- Internal heat sources
- Albedo variations
- Atmospheric circulation

Figure 1.3 represents a graph showing how the energy received by a planet decreases with increasing distance from the Sun

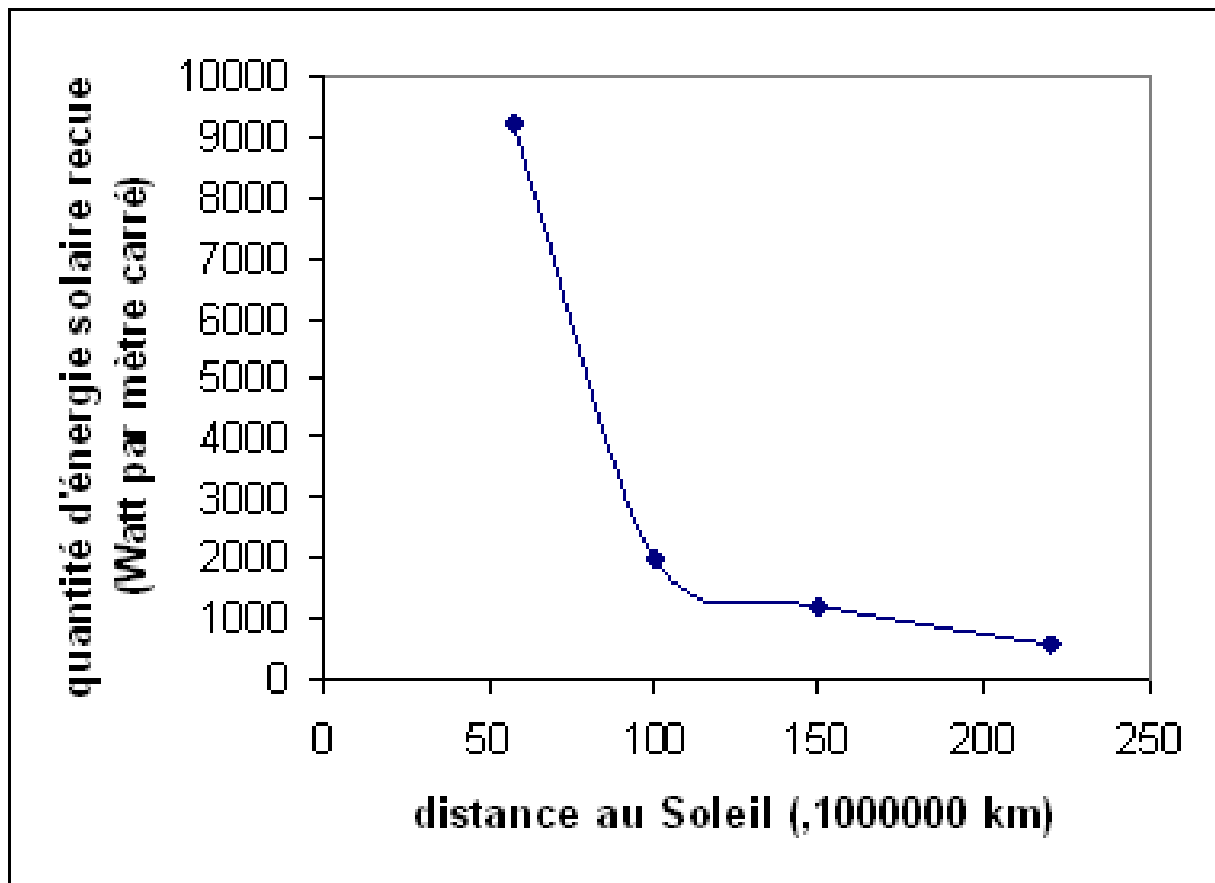


Fig 1.3: Graph of the energy received by a planet as a function of its distance from the Sun

Earth's Unique Characteristics Supporting Life

Position in Habitable Zone

Earth orbits within the Sun's habitable zone (or Goldilocks zone) where temperatures allow liquid water to exist. This zone is approximately 0.95-1.37 AU for Sun-like stars.

Atmospheric Composition

Earth's atmosphere has unique properties:

- 78% nitrogen, 21% oxygen, 1% other gases
- Protective ozone layer
- Greenhouse effect maintaining habitable temperatures
- Appropriate density and pressure for liquid water

Magnetic Field

Earth's magnetic field, generated by core dynamo, provides crucial protection:

- Deflects solar wind and cosmic radiation
- Prevents atmospheric erosion
- Creates magnetosphere shielding the planet

Plate Tectonics

Earth is the only planet with active plate tectonics, which:

- Recycles carbon and regulates climate
- Creates diverse habitats and topography
- Generates magnetic field through core cooling
- Forms mineral and energy resources

Hydrological Cycle

The presence of liquid water enables:

- Solvent for biochemical reactions

- Climate regulation through phase changes
- Erosion and sediment transport
- Habitat for diverse life forms

Comparative Planetology Insights

Runaway Greenhouse Effect (Venus)

Venus demonstrates extreme greenhouse warming due to thick CO₂ atmosphere, showing the importance of carbon cycle regulation.

Atmospheric Loss (Mars)

Mars lost most of its atmosphere due to:

- Low gravity unable to retain gases
- Lack of magnetic field protection
- Cessation of volcanic outgassing

Planetary Evolution

The terrestrial planets illustrate different evolutionary paths based on:

- Size and mass
- Distance from Sun
- Geological activity
- Atmospheric development

Understanding these planetary differences helps us appreciate Earth's unique characteristics and the delicate balance that supports life.

Figure 1.4 is a comparative diagram illustrating differences in atmospheric composition and pressure between Earth, Venus, Mars, and the Moon.

Planète et satellite de la Terre		Mercure	Vénus	Terre	Lune	Mars
Distance moyenne au Soleil (en 10^6 km)		57	108	150	150	228
Diamètre (en km)		4878	12104	12756	3476	6794
Durée de la révolution autour du Soleil (en jours)		88	224,7	365,2	Tour de la Terre en 27,32 jours	687
Composition chimique		Silicates, fer, nickel	Silicates, fer, nickel	Silicates, fer, nickel	Silicates, fer, nickel	Silicates, fer, soufre
Atmosphère	Présence	Non	Oui, épaisse (350 km d'épaisseur)	Oui, épaisse (500 km d'épaisseur)	Non	Oui, très mince (120 km d'épaisseur)
	Pression atmosphérique		$95 \cdot 10^5$ Pa	10^5 Pa		$6 \cdot 10^2$ Pa
	Composition (en %)		CO ₂ : 96,5 N ₂ : 3,5 H ₂ O : 10^{-4} Nuage d'acide sulfurique	N ₂ : 78 O ₂ : 21 CO ₂ : 0,03 H ₂ O : 10^{-4}		CO ₂ : 95 N ₂ : 5 H ₂ O : 0,03

Fig 1.4. Comparison of the atmospheres of the terrestrial planets and the Moon.

CHAPTER 2:
INTERNAL GEODYNAMICS

2.1 Structure of the Earth and the Concept of the Geoid

Earth's Form, Dimensions, and Density

The Earth is not a perfect sphere but an oblate spheroid, meaning it is slightly flattened at the poles and bulging at the equator. This shape is a result of its rotation.

- **Equatorial Diameter:** Approximately 12,756 km
- **Polar Diameter:** Approximately 12,714 km
- **Equatorial Circumference:** Approximately 40,075 km
- **Total Surface Area:** 510 million km² (29% land, 71% water)
- **Volume:** 1.083×10^{12} km³
- **Mass:** 5.972×10^{24} kg
- **Mean Density:** 5.52 g/cm³ (significantly higher than the average crustal density of 2.7-3.0 g/cm³, indicating a dense interior).

Figure 2.1 is a comparative diagram illustrating differences in atmospheric composition and pressure between Earth, Venus, Mars, and the Moon

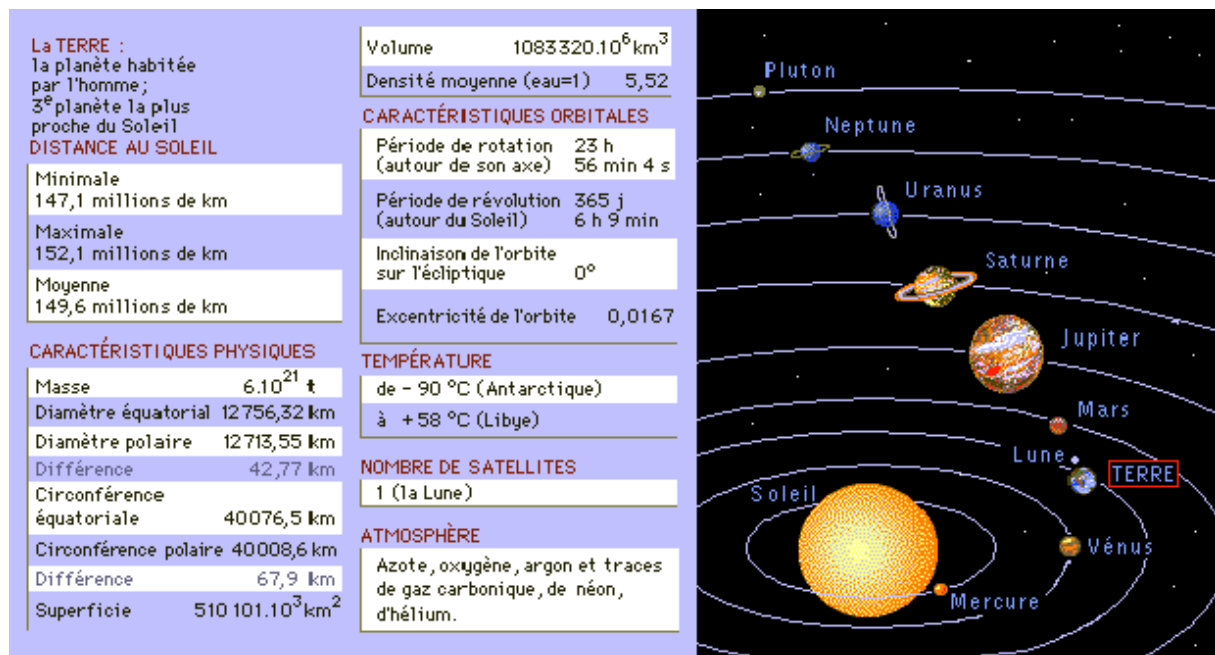


Fig 2.1. Atmospheric Composition of Terrestrial Planets and the Moon

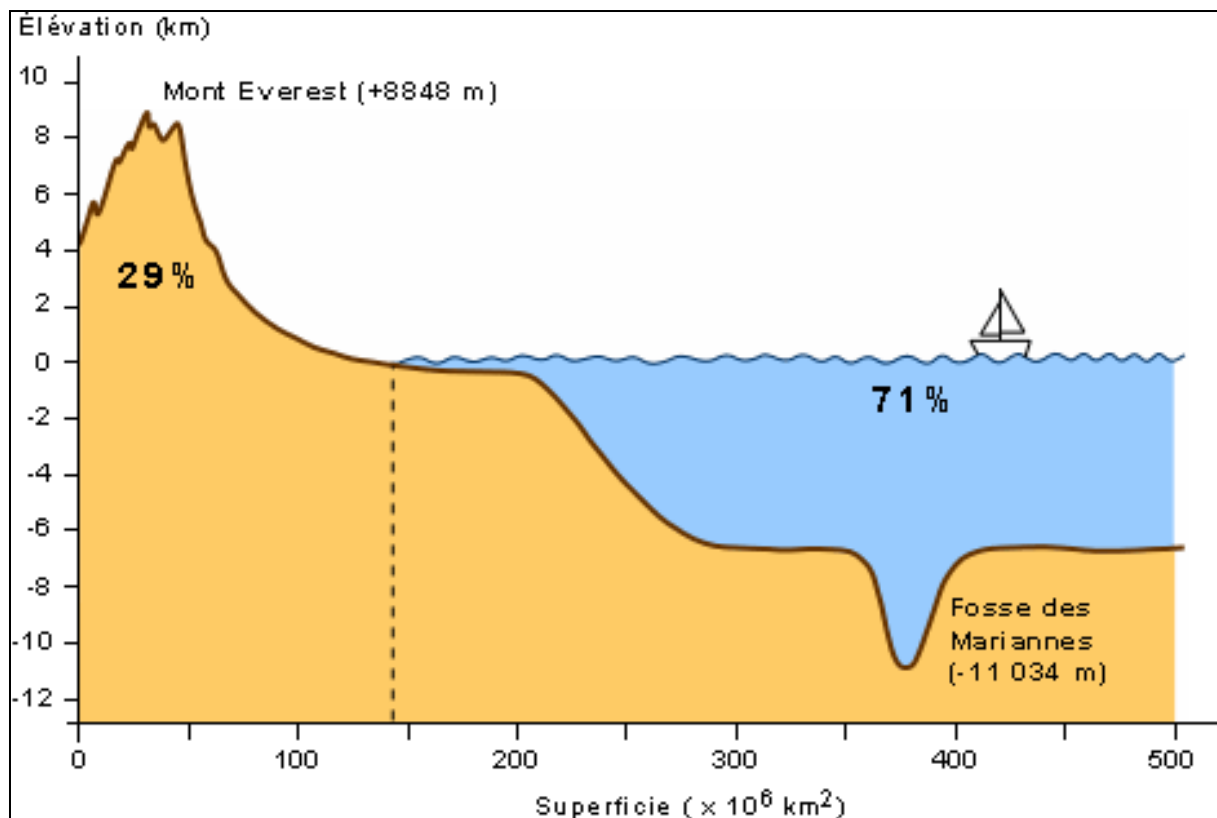


Fig 2.2: Simplified hypsometric curve of the Earth's surface

The Geoid: Earth's True Shape

The **geoid** is defined as the equipotential surface of Earth's gravity field that most closely coincides with mean sea level in the open ocean. It represents the "level" surface where the gravitational potential is the same everywhere. Imagine if the oceans were extended through the continents in narrow canals; the surface the water would settle to is the geoid.

- **Why is it irregular?** The geoid is not smooth. It has bumps and depressions (deviations of up to ± 100 meters from the reference ellipsoid) due to uneven mass distribution within the Earth. Large mountain ranges, variations in crustal thickness, and density contrasts in the mantle all perturb the gravity field, causing the geoid to rise or fall.
- **Practical Importance:** The geoid is the fundamental reference for topographic mapping and measuring elevations. GPS systems use the geoid to convert

ellipsoidal heights (based on a mathematical model) into actual heights above mean sea level.

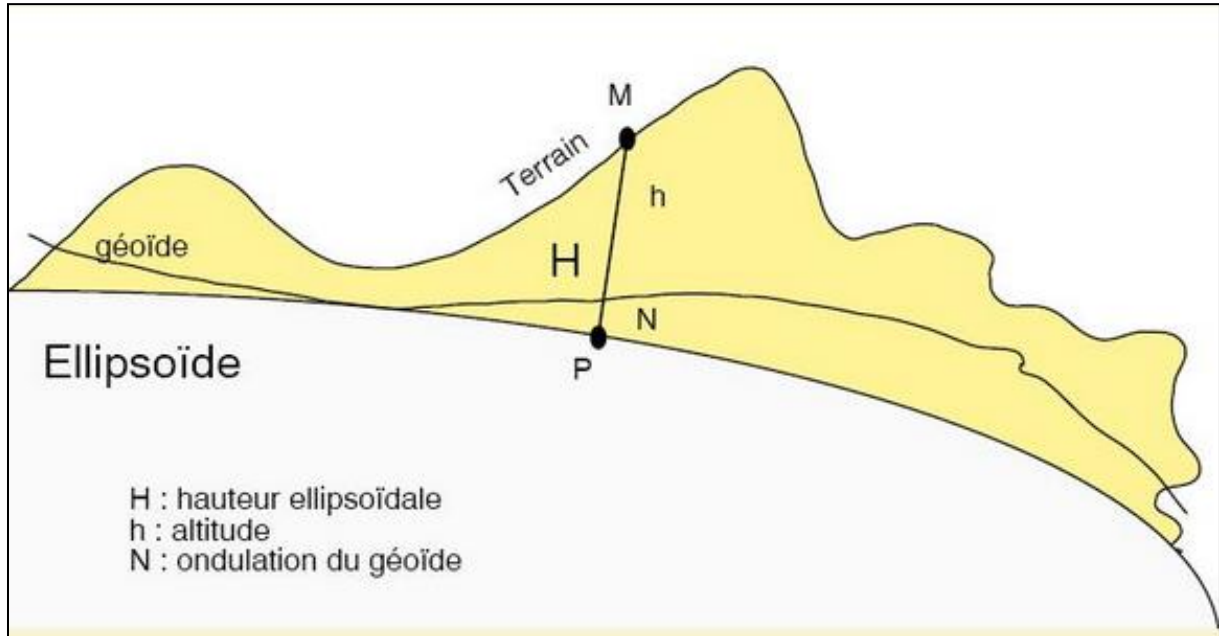


Fig 2.3: Ellipsoïde, geodetic coordinate system

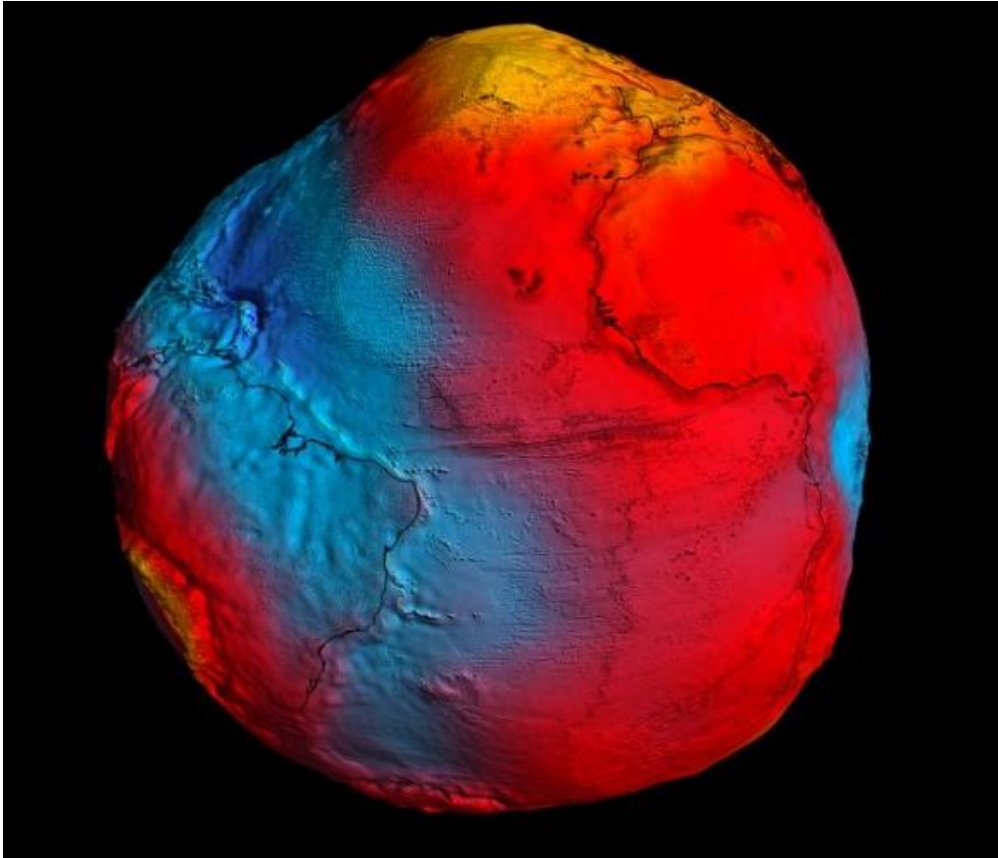


Fig 2.4: A 3D overview of the geoid's undulations relative to the ellipsoid

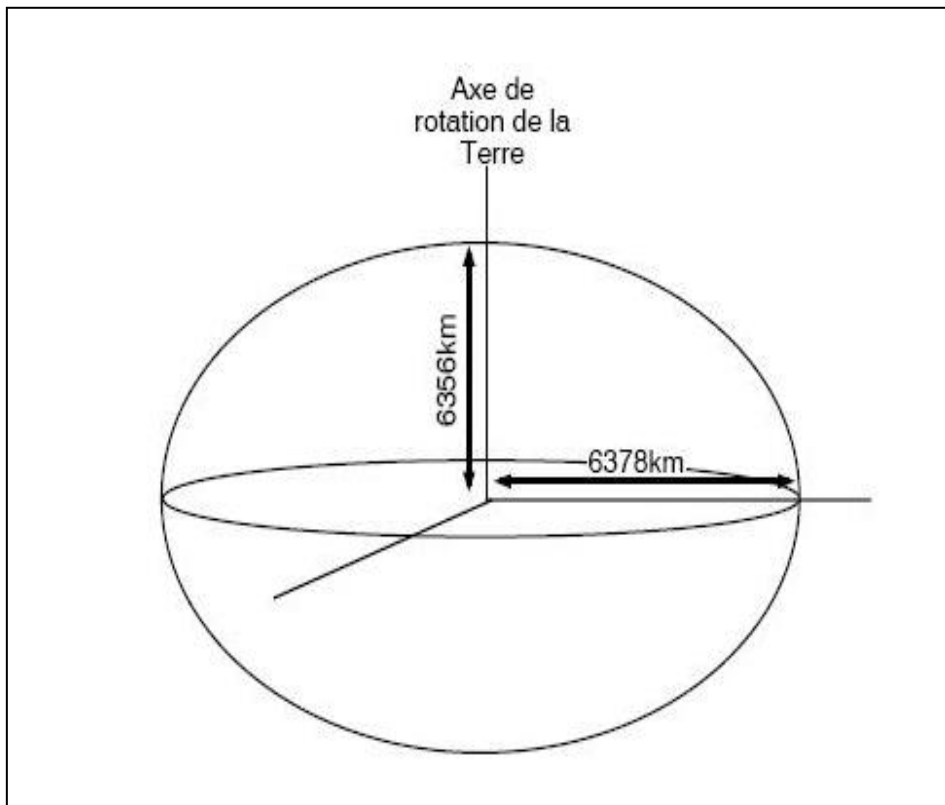


Fig 2.5: Geocentric Cartesian coordinates

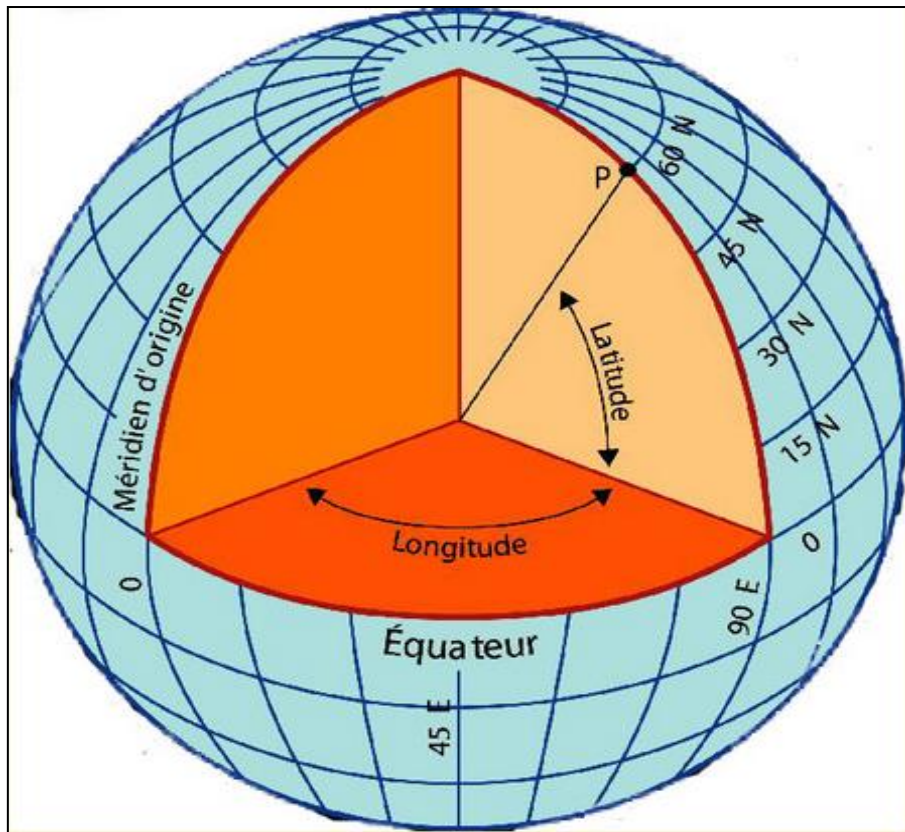


Fig 2.6: Coordinates system

In summary: the ellipsoid models the shape of our globe. It does not model our topography. The geoid, on the other hand, models a surface where all points experience the same gravitational effect. It is an equipotential surface.

Earth's Internal Structure: A Layered Planet

Our understanding of Earth's interior comes primarily from seismology—the study of how seismic waves (energy from earthquakes or explosions) travel through the Earth. Changes in wave speed, direction, and type reveal the planet's internal layers.

A. The Crust: Earth's Thin, Outer Shell

The crust is the outermost solid layer, heterogeneous and variable in thickness and composition. It is separated from the mantle beneath by the **Mohorovičić Discontinuity (Moho)**.

- **Continental Crust:**

- **Thickness:** 30-50 km on average (up to 70+ km under major mountain ranges like the Himalayas).
- **Composition:** Felsic to intermediate, rich in Silicon (Si) and Aluminum (Al). Its average composition is similar to **granite**.
- **Density:** $\sim 2.7 \text{ g/cm}^3$.
- **Age:** Very old, with some rocks dating back over 4 billion years. It is permanently buoyant and not easily subducted.
- **Oceanic Crust:**
 - **Thickness:** $\sim 7\text{-}10 \text{ km}$.
 - **Composition:** Mafic, rich in Silicon (Si) and Magnesium (Mg). It is primarily composed of **basalt** and **gabbro**.
 - **Density:** $\sim 3.0 \text{ g/cm}^3$.
 - **Age:** Geologically young (< 200 million years old), as it is continuously created and destroyed.

B. The Mantle: The Rocky Middle Layer

The mantle extends from the base of the crust (Moho) to the core-mantle boundary at $\sim 2,900 \text{ km}$ depth, comprising about 84% of Earth's volume and 67% of its mass. It is composed primarily of ultramafic silicate rocks rich in iron and magnesium.

- **Upper Mantle (to 660 km):**
 - **Lithospheric Mantle:** The rigid, uppermost part of the mantle (to $\sim 100 \text{ km}$). It is fused to the overlying crust to form the **lithosphere**.
 - **Asthenosphere:** A ductile, mechanically weak layer from $\sim 100 \text{ km}$ to 660 km . Although mostly solid, it can flow over geological time scales (plastic behavior) due to extremely high temperature and pressure. This

zone is crucial for plate tectonics, as it allows the rigid lithospheric plates to move. Seismic waves slow down here (Low-Velocity Zone).

- **Lower Mantle (660 km to 2,900 km):**

- This region is solid but undergoes slow, convective flow over millions of years. Pressure increases dramatically with depth, causing minerals to transform into denser crystal structures.

The boundary between the mantle and core is marked by the **Gutenberg Discontinuity**.

C. The Core: Earth's Metallic Heart

The core is predominantly composed of iron and nickel, with minor amounts of lighter elements. It is divided into two distinct parts.

- **Outer Core (2,900 km to 5,150 km):**

- **State:** Liquid.
- **Density:** 9.9-12.2 g/cm³.
- **Significance:** The convective motion of this electrically conductive liquid iron generates Earth's **magnetic field** through the geodynamo process.

- **Inner Core (5,150 km to 6,371 km center):**

- **State:** Solid.
- **Density:** ~12.6-13.0 g/cm³.
- **Significance:** Despite temperatures estimated at 5,700°C (hotter than the Sun's surface), immense pressure (over 3 million atmospheres) keeps the inner core solid. It grows very slowly as the planet cools.

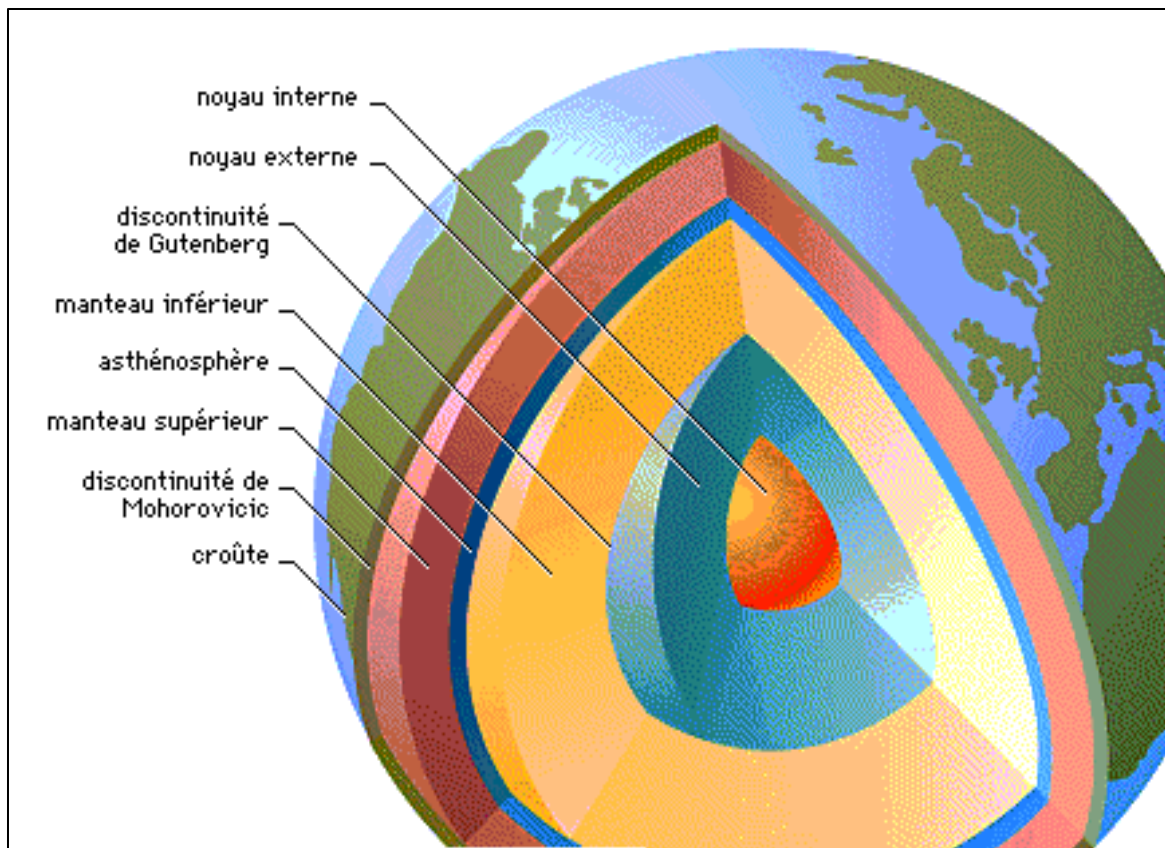


Fig 2.7: Structure of the earth

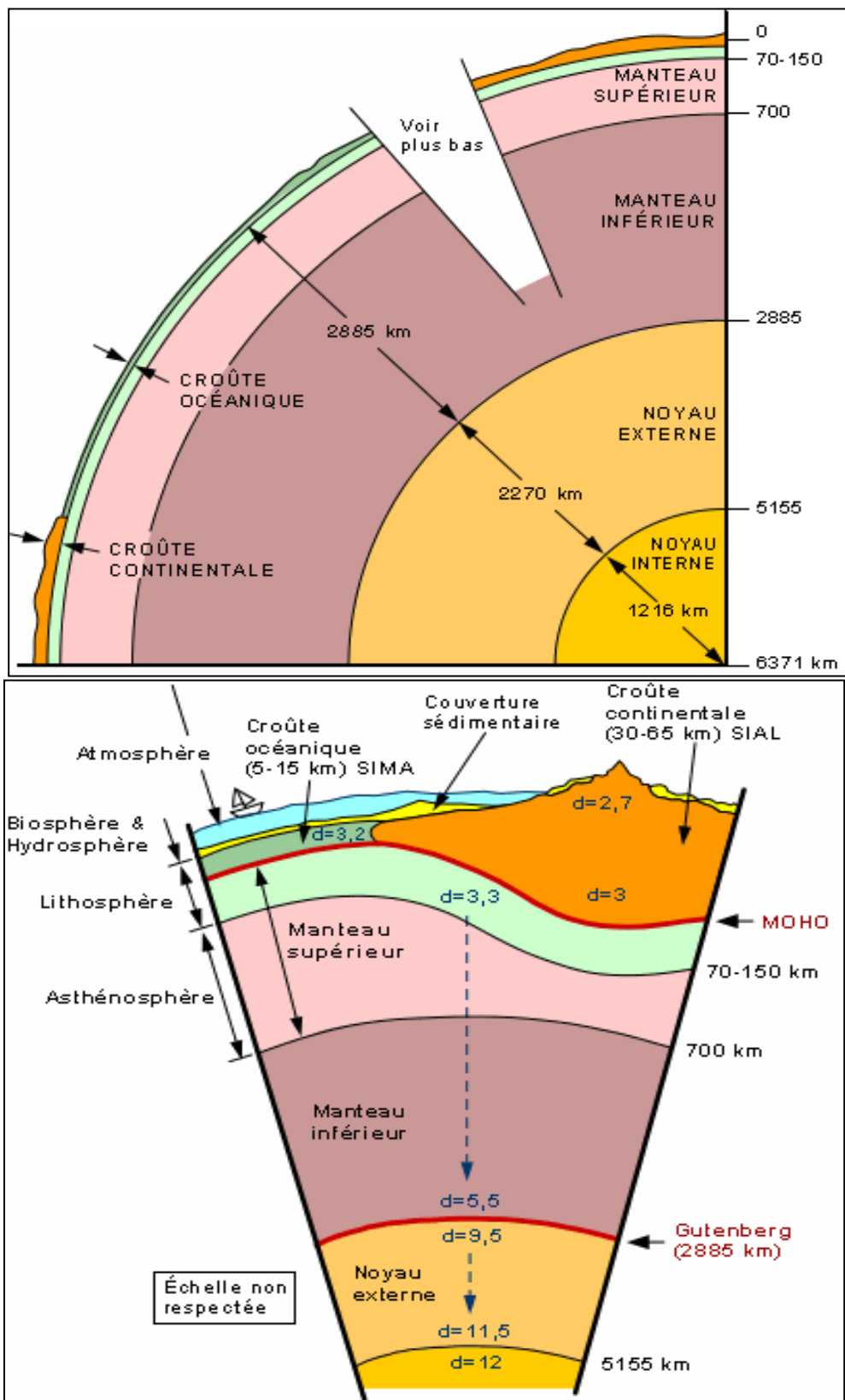


Fig 2.8: Structure of the Earth

Table: Summary of the characteristics of the Earth's internal structure

<i>Structure interne de la Terre</i>		<i>Epaisseur</i>	<i>Densité</i>	<i>Température</i>
Croûte terrestre	Croûte continentale	30 - 65 km	2,7 à 3	Elle augmente en fonction de la profondeur ³
	Croûte océanique	5 – 15 km	3,2 en moyenne	
Manteau	Manteau supérieur (= lithosphère ⁴ + asthénosphère)	Jusqu'à 670 km de profondeur	3,3 à 4,4	< 2000 °C
	Manteau inférieur	De 670 km à 2900 km de profondeur	Jusqu'à 5,5	< 3000 °C
Noyau	Noyau externe liquide	De 2900 km à 5100 km de profondeur	9,5 à 11,5	< 4000 °C
	Noyau interne solide = graine	De 5100 km au centre de la terre	12 à 13	< 5000 °C

The Earth's interior is therefore made up of a number of superimposed layers, distinguished by their solid, liquid, or plastic state, as well as by their density. A kind of ultrasound of the Earth's interior has been established based on the behavior of seismic waves during earthquakes.

Origin of Earthquakes

Under the influence of stresses most often caused by the movement of tectonic plates, the lithosphere accumulates energy. When the elastic limit is reached in certain areas, one or more ruptures occur, resulting in faults. The energy suddenly released along these faults causes earthquakes. If the stresses continue in the same region, energy will accumulate again, and the resulting rupture will occur along the existing fault planes.

Due to frictional forces between the two walls of a fault, movement along the fault is not continuous and uniform, but occurs in successive bursts, each triggering an earthquake. Consequently, earthquakes will always occur in the lithosphere, never in the asthenosphere, which is plastic.

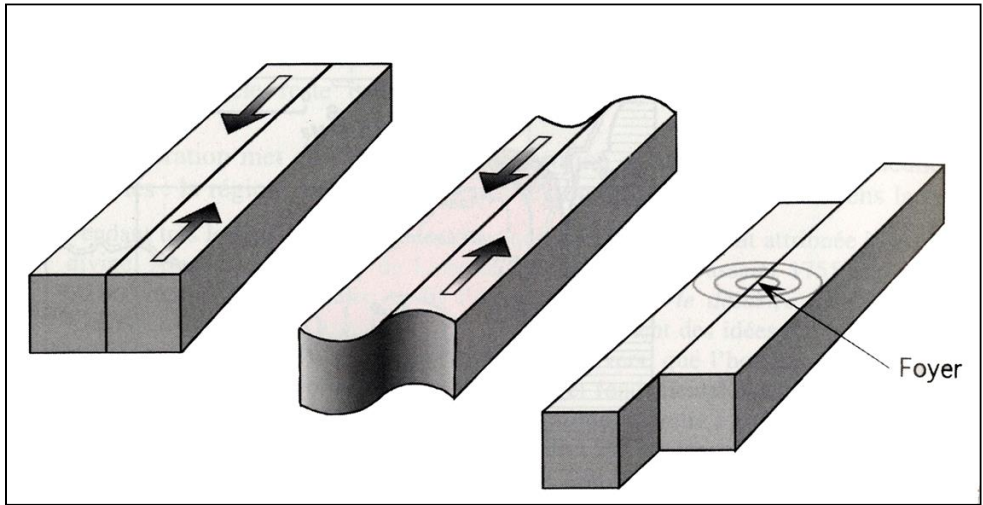


Fig 2.9: Illustration of different types of geological faults or cracks

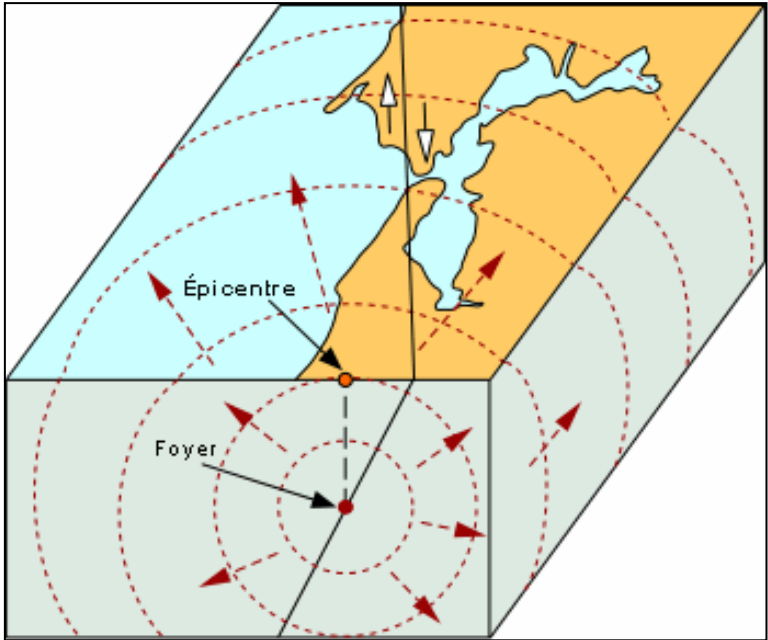


Fig 2.10: Epicentre: the point on the Earth's surface that is directly above the focus

2.2 Current Distribution of Lands and Seas

Continents and Ocean Basins: A Global Overview

The fundamental division of Earth's surface is between continents and ocean basins, a distribution controlled by the principles of isostasy and plate tectonics.

- **Continents:** The large, buoyant masses of granitic crust. They generally stand high because they are thick and less dense.
- **Ocean Basins:** The low-lying, denser basaltic crust that forms the floor of the major oceans.

The Continents

There are seven commonly recognized continents, though Europe and Asia are sometimes combined as "Eurasia" on geological grounds.

1. **Asia:** The largest continent (44.6 million km²), containing Earth's highest point (Mount Everest, 8,848 m) and a complex geological history involving multiple continental collisions.
2. **Africa:** The second-largest (30.4 million km²), characterized by ancient cratons (stable continental interiors) and the Great Rift Valley, an active divergent plate boundary.
3. **North America:** (24.7 million km²) Features the stable Canadian Shield in the east and young, tectonically active mountain ranges (the Rockies, Sierra Nevada) in the west.
4. **South America:** (17.8 million km²) Dominated by the Andes Mountains, the world's longest continental mountain range, formed by the subduction of the Nazca Plate under the South American Plate.
5. **Antarctica:** (14.2 million km²) The coldest, driest, and windiest continent, buried under a vast ice sheet averaging 2 km thick. It is a key area for understanding past climate change.

6. **Europe:** (10.2 million km²) A geologically diverse continent with ancient mountains (Scandinavian Caledonides) and younger ranges (the Alps).
7. **Australia:** (7.7 million km²) The smallest and flattest continent, composed largely of a stable, ancient craton.

Islands and Archipelagos

- **Continental Islands:** Formed on the continental shelf (e.g., British Isles, Newfoundland). They are geologically part of a nearby continent.
- **Oceanic Islands:** Formed by volcanic activity on the ocean floor, independent of continents.
 - **Hotspot Islands:** Chains like Hawaii, formed as a plate moves over a stationary mantle plume.
 - **Island Arcs:** Curved chains like Japan and the Aleutians, formed by subduction zone volcanism.
- **Archipelagos:** Groups of islands clustered together, often formed by the same tectonic process (e.g., the Philippines, Indonesia).

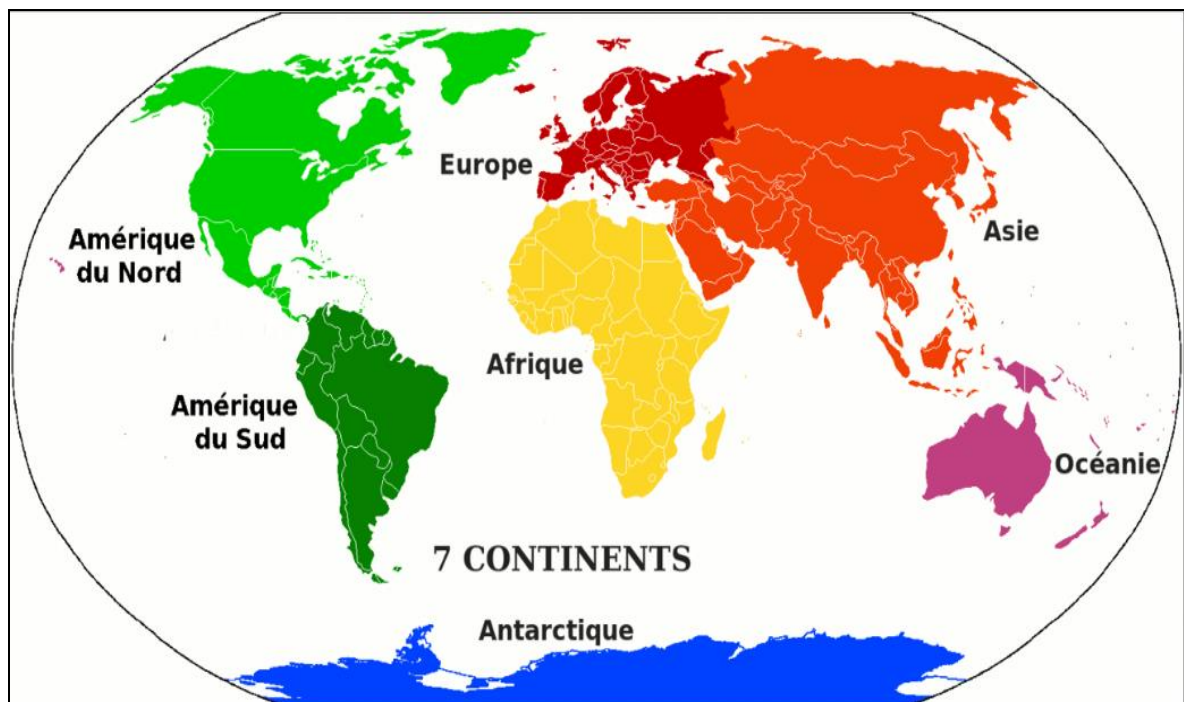


Fig 2.11: Map showing the different continental systems

The Global Ocean

The world ocean, a continuous body of water, is conventionally divided into four or five major basins.

1. **Pacific Ocean:** The largest and deepest (average depth ~4,280 m), covering about one-third of Earth's surface. It is surrounded by the "Ring of Fire," a zone of intense volcanic and seismic activity.
2. **Atlantic Ocean:** The second-largest, characterized by a prominent mid-ocean ridge running roughly north-south, marking the divergent boundary between plates.
3. **Indian Ocean:** The third-largest, mostly in the Southern Hemisphere. Its northern boundary is complex, involving the collision of India with Asia.
4. **Southern Ocean:** The ocean surrounding Antarctica, defined by the Antarctic Circumpolar Current.
5. **Arctic Ocean:** The smallest and shallowest, largely covered by sea ice.

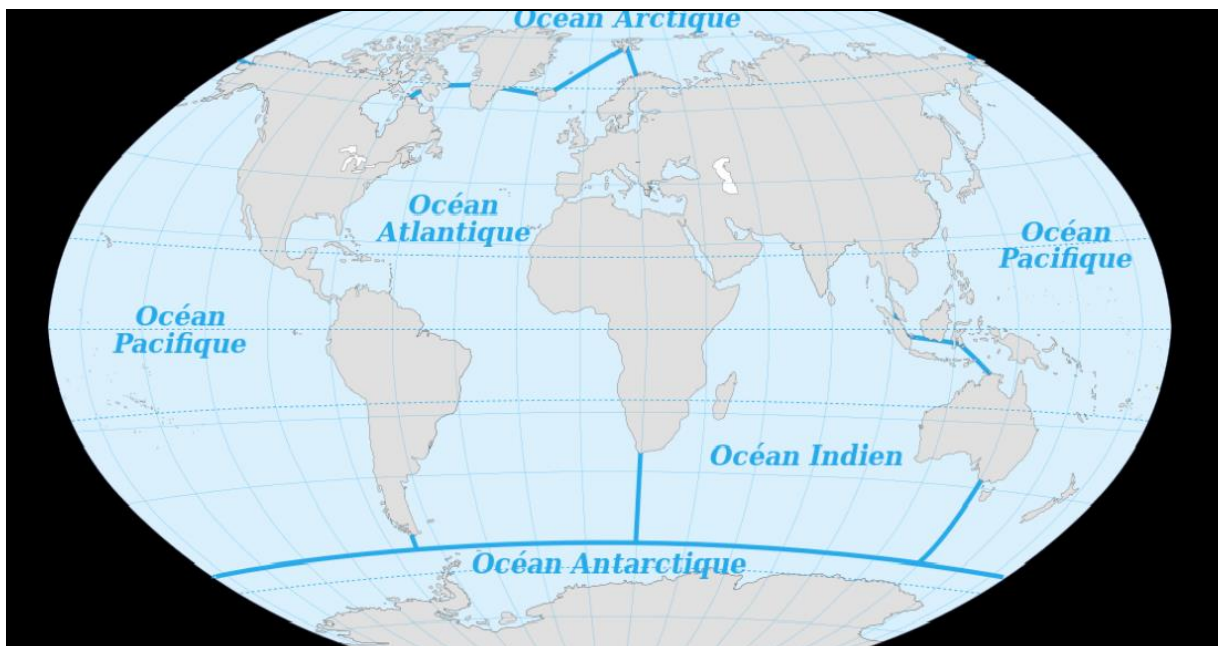


Fig 2.12: Map of the world's oceans

Area, population, population density and number of countries on each continent

Continent	Superficie (km ²)	Superficie (%)	Population approchée (2013)	Pourcentage de la population totale	Densité de population par km ²	Nombre de pays
Asie	44 579 000	30 %	4 384 844 000	60 %	87,01	47
Afrique	30 065 000	20 %	1 166 239 000	14 %	29,19	54
Amérique du Nord	24 256 000	16 %	361 128 000	8 %	20,68	23
Amérique du Sud	17 819 000	12 %	630 089 000	6 %	21,30	12
Antarctique	13 209 000	9 %	1500	0,00002 %	0,00007	
Europe	9 938 000	7 %	743 123 000	11 %	73,15	45
Océanie	7 687 000	5 %	39 359 000	0,5 %	4,16	14

The list of continents according to their highest point

Continent	Pays	Point culminant	Altitude (mètres)
Asie	Chine/Népal	Everest	8 848
Amérique du Sud	Argentine	Aconcagua	6 960
Amérique du Nord	États-Unis	Denali	6 190
Afrique	Tanzanie	Kilimandjaro	5 892
Europe	Russie	Elbrouz	5 642

Classification of Seas

Seas are smaller subdivisions of the ocean, partly enclosed by land.

- **Marginal Seas:** Adjacent to continents, separated by island arcs or peninsulas (e.g., South China Sea, Sea of Japan).
- **Mediterranean Seas:** Mostly enclosed by land, connected to the ocean by narrow straits (e.g., Mediterranean Sea, Gulf of Mexico).
- **Inland Seas:** Completely surrounded by land, with no natural outlet (e.g., Caspian Sea, Aral Sea). The Caspian Sea is the world's largest inland water body.

2.3 Earth's Magnetic Field

The Geodynamo: Generating a Planetary Magnet

Earth's magnetic field is generated by the **geodynamo effect** in the liquid outer core.

This self-sustaining process converts kinetic energy from convective fluid motion into magnetic energy.

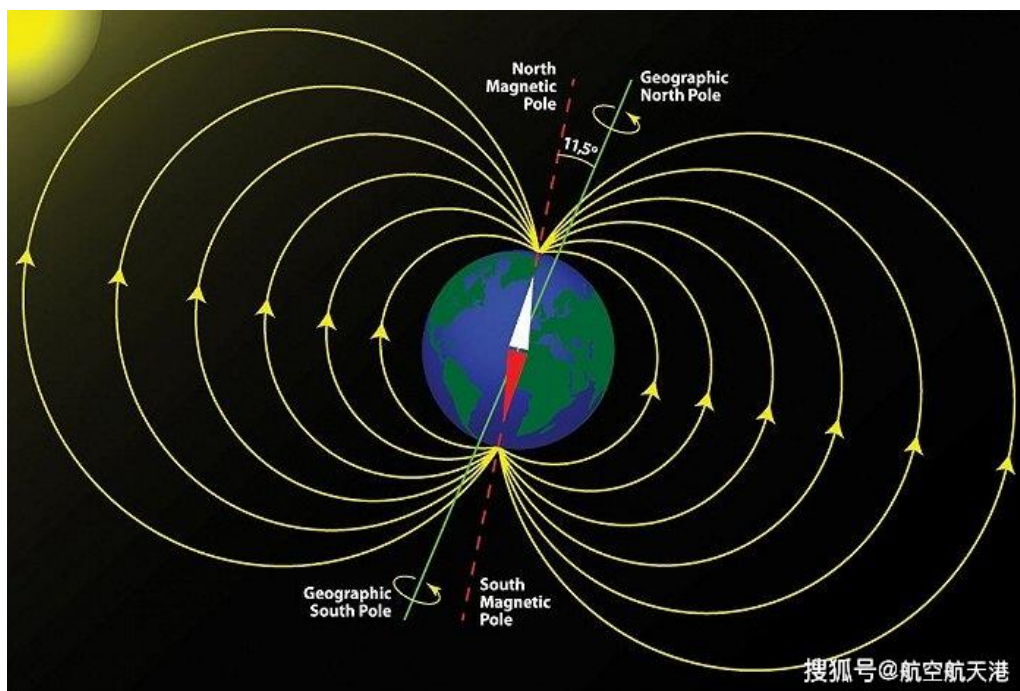


Fig 2.13: Earth's Magnetic Field Diagram

- **Requirements for a Dynamo:**

1. A rotating planet.
 2. A fluid layer capable of convection (the liquid outer core).
 3. An energy source to drive the convection (heat released from the cooling of Earth + latent heat from the solidification of the inner core + gravitational energy from differentiation).
- **The Process:** The convective motion of the molten iron, combined with Earth's rotation (Coriolis effect), organizes the fluid motion into complex helical patterns. These motions stretch, twist, and amplify magnetic field lines, generating and sustaining the global magnetic field.

Structure of the Magnetosphere

The magnetic field creates a protective region in space called the **magnetosphere**, which deflects the charged particles of the **solar wind**.

- **Bow Shock:** The boundary where the solar wind is initially slowed.
- **Magnetopause:** The outer boundary of the magnetosphere.
- **Magnetotail:** The elongated part of the magnetosphere pointing away from the Sun.
- **Van Allen Radiation Belts:** Zones of trapped high-energy charged particles held by the magnetic field.

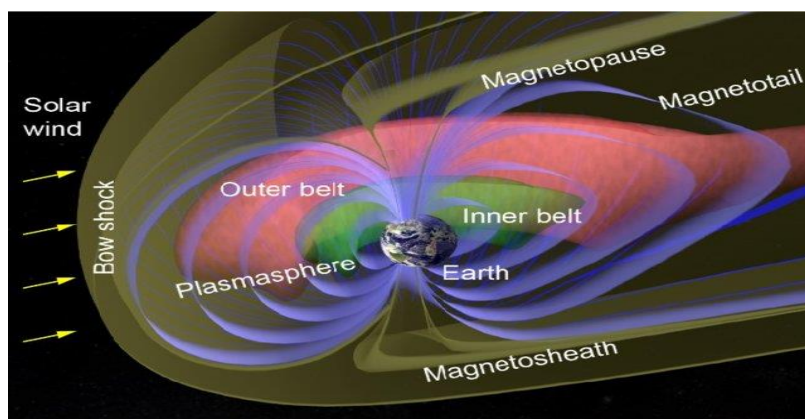


Fig 2.14: Earth's magnetosphere

Paleomagnetism and Magnetic Reversals

- **Paleomagnetism:** When certain iron-rich minerals in rocks (like magnetite) form, they align with Earth's magnetic field and preserve a record of its direction and strength. This is a crucial tool for plate tectonics.
- **Magnetic Reversals:** The Earth's magnetic field has completely reversed its polarity (North and South magnetic poles swap) hundreds of times throughout history. These reversals are recorded symmetrically in the oceanic crust as "magnetic stripes," providing definitive proof for seafloor spreading.

Importance of the Magnetic Field

1. **Shielding from Radiation:** It deflects harmful solar and cosmic radiation, protecting Earth's atmosphere and life.
2. **Atmosphere Preservation:** It prevents the solar wind from directly striking and eroding the atmosphere (a fate thought to have befallen Mars).
3. **Navigation:** Used by animals (birds, sea turtles) and humans for orientation.

2.4 Continental Drift and Plate Tectonics

From Hypothesis to Theory: A Scientific Revolution

- **Continental Drift (Alfred Wegener, 1912):** Wegener proposed that continents had once been joined in a supercontinent called **Pangaea** and had since "drifted" to their present positions.
 - **Evidence He Cited:**
 - Jigsaw-fit of continents (especially South America and Africa).
 - Fossil correlation across oceans (e.g., *Mesosaurus*).
 - Rock type and structural similarities (mountain belts match across oceans).
 - Paleoclimatic evidence (glacial deposits in now-tropical regions).

- **The Flaw:** Wegener could not propose a plausible mechanism for the movement.

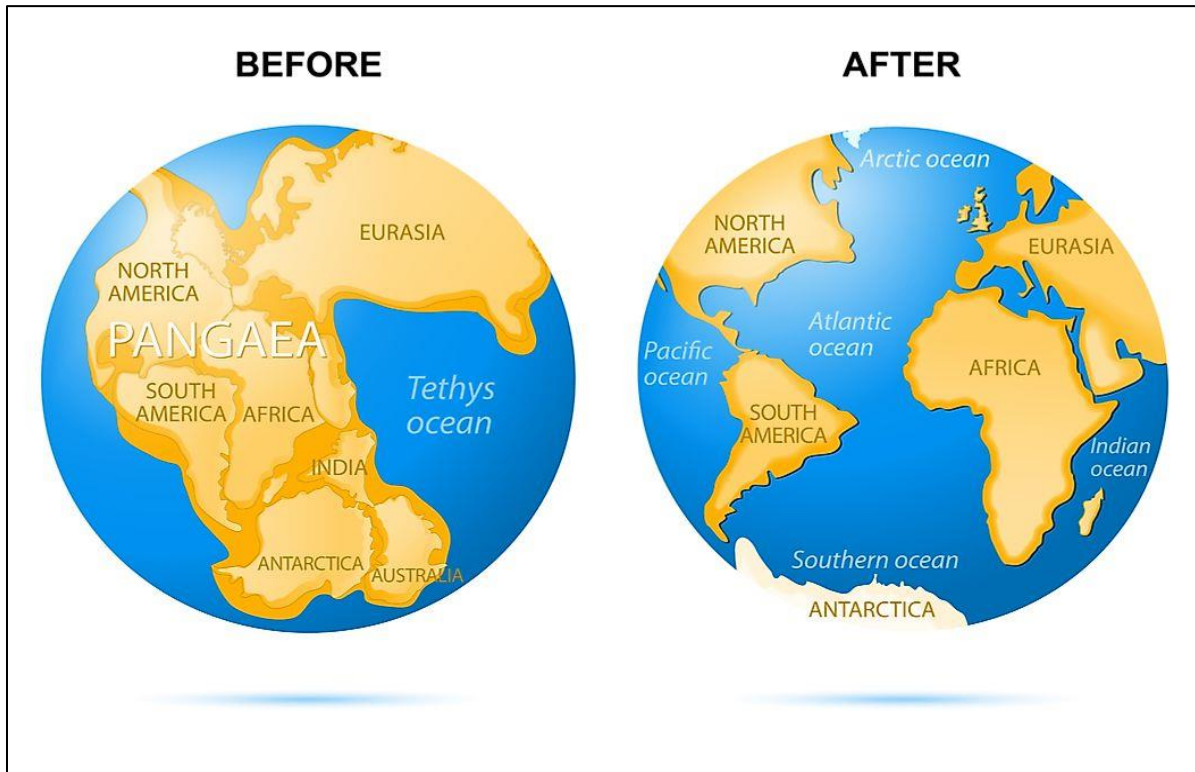


Fig 2.15: illustrates the supercontinent Pangaea and its subsequent breakup into the current continents

- **Seafloor Spreading (Hess & Dietz, 1960s):** This key discovery provided the mechanism. It proposed that new oceanic crust is formed at **mid-ocean ridges** by upwelling magma and then moves away, acting like a conveyor belt.
 - **Key Evidence:**
 - **Magnetic Reversal Stripes:** Symmetrical patterns of magnetic anomalies parallel to mid-ocean ridges.
 - **Age of the Ocean Floor:** The ocean floor is young (<200 Ma) and gets progressively older away from the ridges.
 - **Heat Flow:** High at ridges, low in trenches.

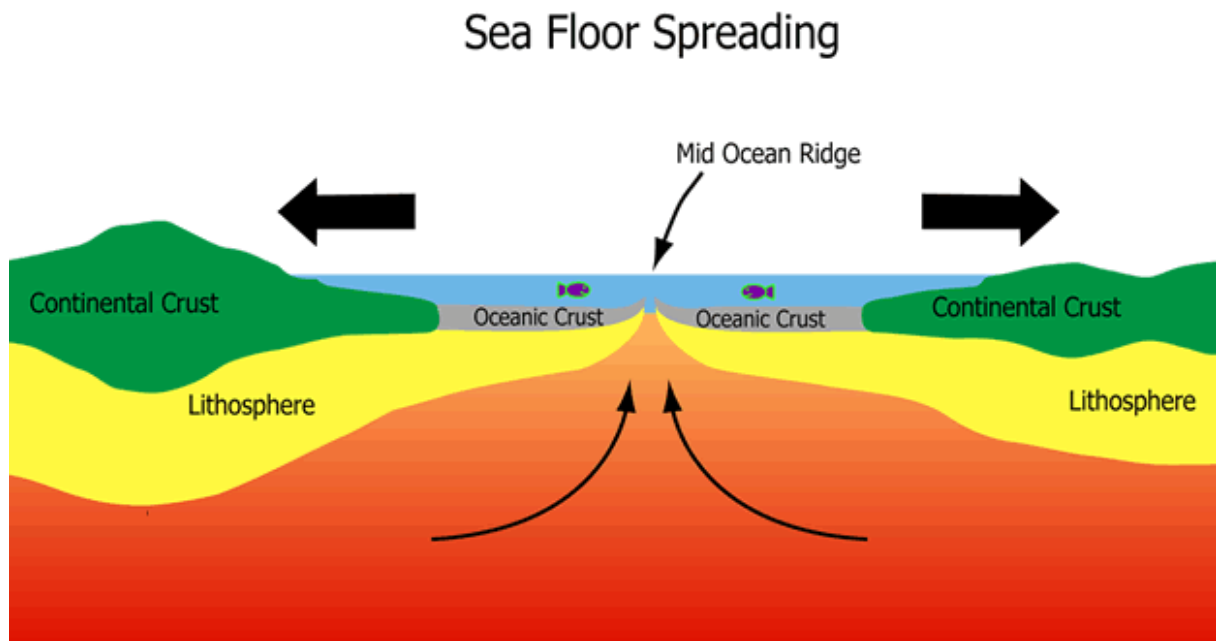


Fig 2.16: Cross-section diagram of Seafloor Spreading

The Unified Theory of Plate Tectonics

The theory states that Earth's lithosphere is broken into rigid **plates** that move relative to each other over the ductile asthenosphere. The boundaries between these plates are sites of intense geological activity.

Types of Plate Boundaries

1. Divergent Boundaries (Constructive):

- **Process:** Plates move apart.
- **Location:** Mid-ocean ridges (e.g., Mid-Atlantic Ridge), continental rift valleys (e.g., East African Rift).
- **Geologic Features:** New oceanic crust, shallow earthquakes, volcanic activity (basaltic).

2. Convergent Boundaries (Destructive):

- **Process:** Plates move toward each other.

- **Three Types:**

- **Oceanic-Continental:** Denser oceanic plate subducts under continental plate. Forms volcanic mountain arcs (Andes) and deep ocean trenches.
- **Oceanic-Oceanic:** One oceanic plate subducts under another. Forms volcanic island arcs (Japan) and trenches.
- **Continental-Continental:** Neither plate subducts; they collide and crumple. Forms massive, high mountain ranges with no active volcanoes (Himalayas).

3. Transform Boundaries (Conservative):

- **Process:** Plates slide horizontally past one another.
- **Location:** Mid-ocean ridge offsets (fracture zones), continental transforms (e.g., San Andreas Fault).
- **Geologic Features:** Frequent shallow-focus earthquakes, no significant volcanism.

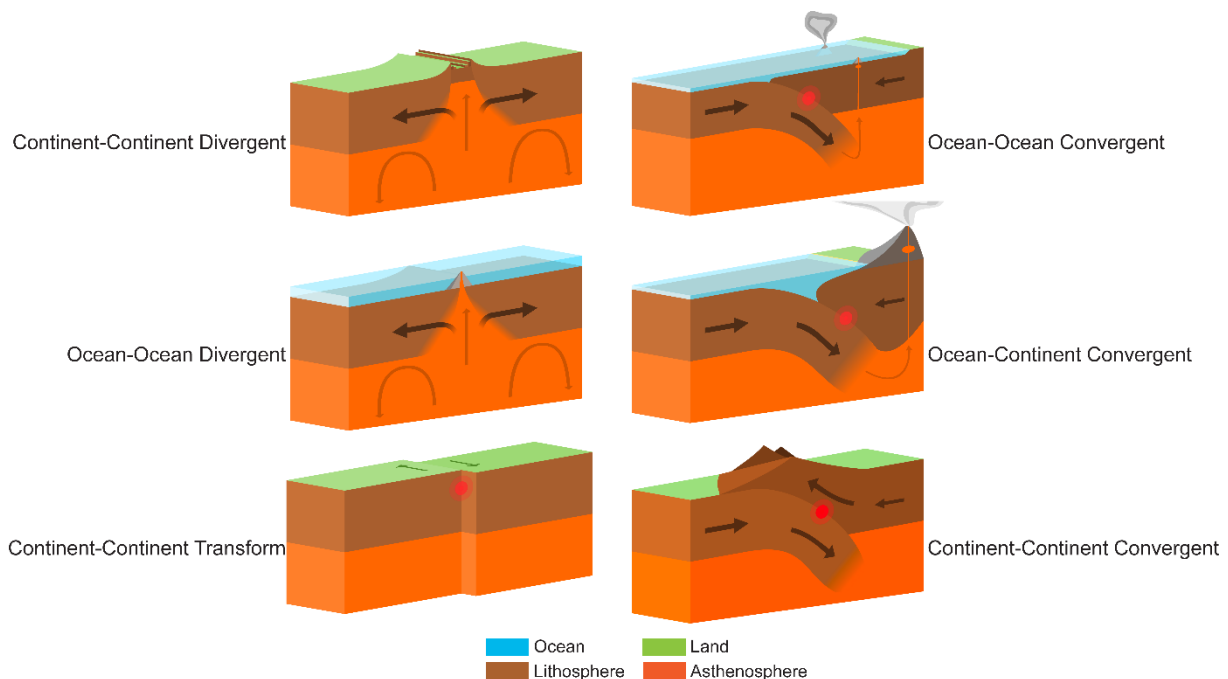


Fig 2.17: Models showing 6 main types of plate tectonic boundaries

Driving Forces of Plate Motion

While not fully understood, the primary drivers are thought to be:

- **Ridge Push:** The gravitational sliding of the elevated lithosphere at ridges away from the crest.
- **Slab Pull:** The gravitational pull of a cold, dense subducting plate into the mantle. This is considered the dominant force.

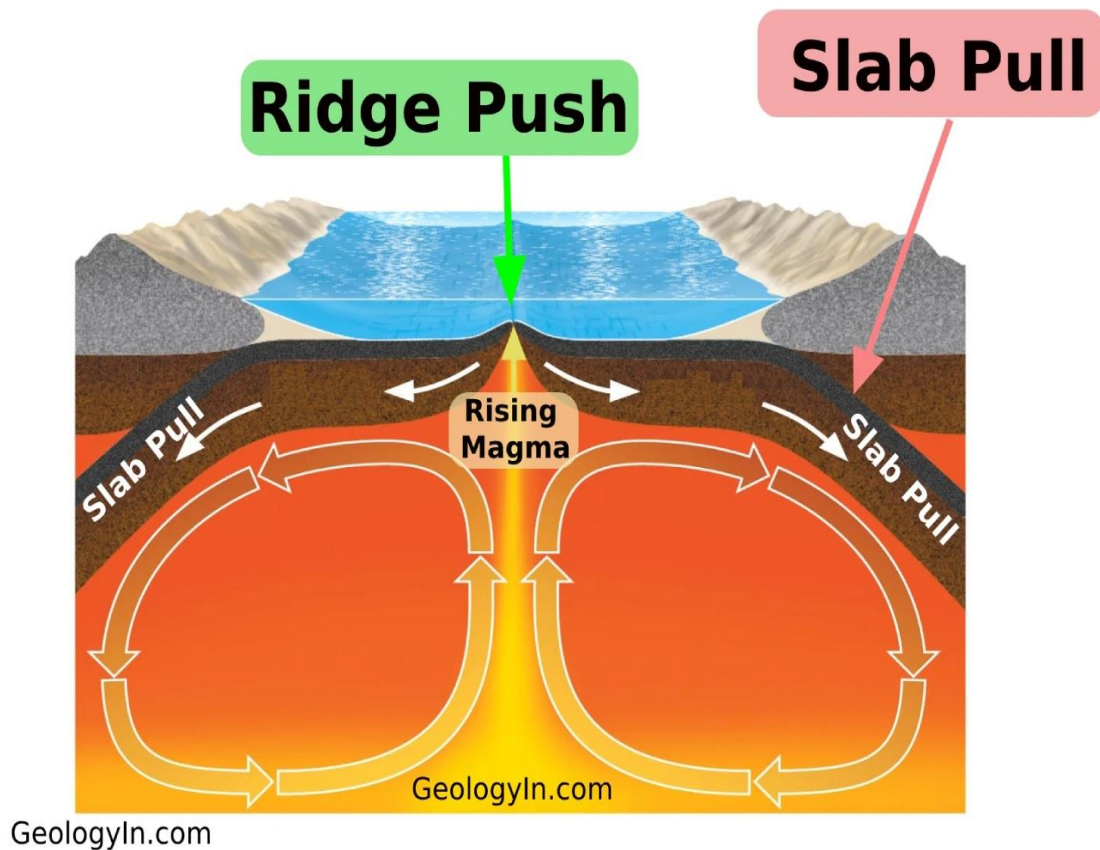


Fig 2.18: Illustration of plate tectonics and the forces that drive the movement of Earth's tectonic plates

2.5 Earthquakes

The Earthquake Process

An earthquake is the sudden release of stored elastic energy in the Earth's lithosphere, which generates seismic waves.

- **Elastic Rebound Theory:** This is the fundamental model.
 1. Tectonic forces slowly deform rocks, storing elastic energy (like bending a stick).
 2. When the stress exceeds the rock's strength, it ruptures along a fault.
 3. The rocks "rebound" to their original, unstressed shape on either side of the fault, but are now offset. The stored energy is released as seismic waves.

Fault Anatomy and Classification

- **Focus (Hypocenter):** The point within the Earth where the rupture initiates.
- **Epicenter:** The point on the Earth's surface directly above the focus.
- **Fault Plane:** The surface along which the rupture occurs.

Seismic Waves: Carriers of Destruction

- **Body Waves:** Travel through Earth's interior.
 - **P-waves (Primary/Pressure):** Compressional waves, fastest, travel through solids and liquids.
 - **S-waves (Secondary/Shear):** Shear waves, slower than P-waves, only travel through solids. Their absence in "shadow zones" provided key evidence for a liquid outer core.
- **Surface Waves:** Travel along Earth's surface, most destructive.
 - **Love Waves:** Side-to-side motion.
 - **Rayleigh Waves:** Rolling motion like ocean waves.

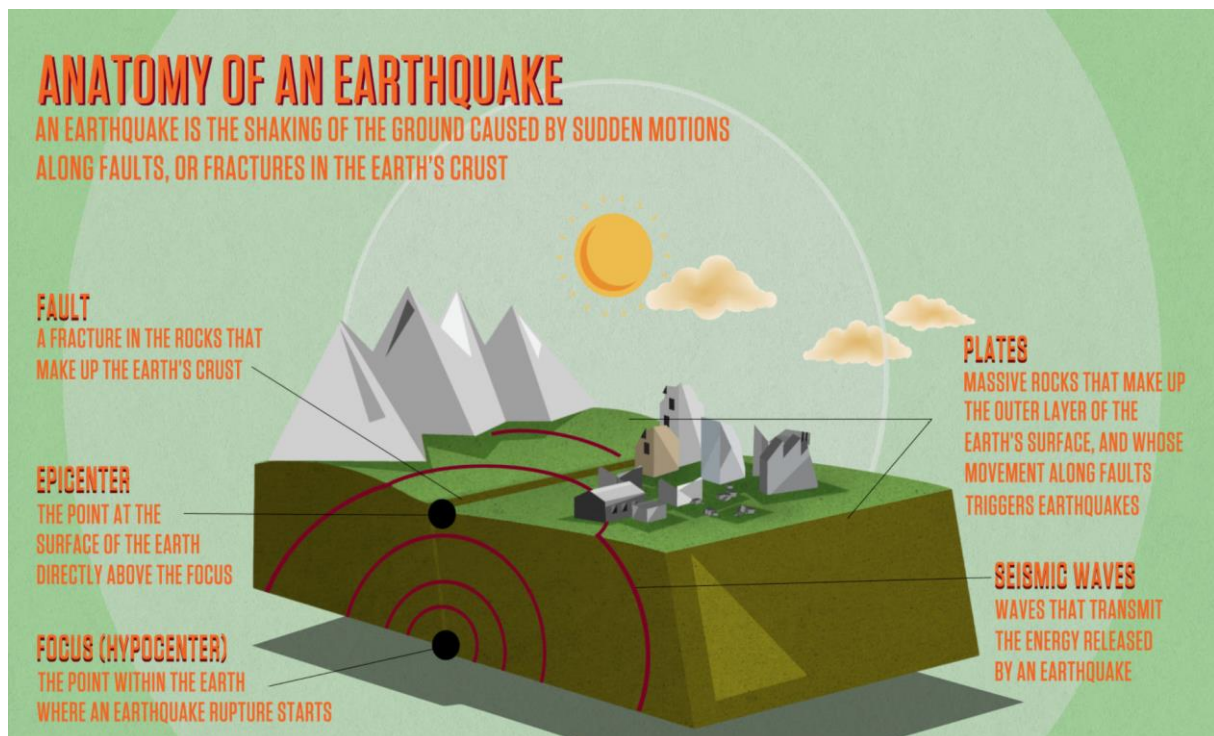


Fig 2.19: Anatomy of an Earthquake

Measuring and Locating Earthquakes

- **Seismograph/Seismometer:** The instrument that detects and records ground motion.
- **Magnitude:** A measure of the energy released.
 - **Richter Scale:** Original local magnitude scale (logarithmic).
 - **Moment Magnitude (M_w):** Preferred modern scale, based on the seismic moment (a product of fault area, slip distance, and rock rigidity).
- **Intensity:** A measure of the shaking and damage at a specific location.
 - **Modified Mercalli Intensity Scale:** Ranges from I (not felt) to XII (total destruction).

Earthquake Hazards

1. **Ground Shaking:** The primary cause of damage.
2. **Surface Rupture:** The fault breaking the surface.
3. **Liquefaction:** Saturated soil loses strength and behaves like a liquid.
4. **Landslides and Ground Failure.**
5. **Tsunamis:** Long-wavelength Sea waves generated by submarine earthquakes, landslides, or volcanic eruptions.

2.6 Volcanoes

Magma Generation: Where Does Molten Rock Come From?

Magma forms when solid rock in the mantle or crust melts. This occurs under specific conditions:

1. **Decompression Melting:** The most common mechanism. As mantle rock rises (e.g., at a mid-ocean ridge or hotspot), pressure decreases while its temperature remains high, crossing the melting point.
2. **Flux Melting:** The addition of volatiles (water, CO₂) lowers the melting point of rock. This is the primary mechanism at subduction zones, where water from the subducting slab hydrates the mantle wedge above.
3. **Heat-Transfer Melting:** Hot magma from the mantle rises into the crust, transferring heat and melting surrounding crustal rocks.

Factors Controlling Eruption Style

The violence of a volcanic eruption is determined by magma's ability to release dissolved gases.

- **Magma Composition :**
 - **Mafic (Basaltic):** Low silica, low viscosity, gases escape easily. Results in **effusive** eruptions (lava flows).

- **Felsic (Rhyolitic):** High silica, high viscosity, traps gases. Results in **explosive** eruptions (pyroclastic flows, ash clouds).
- **Intermediate (Andesitic):** Intermediate properties, can produce both effusive and explosive eruptions.
- **Gas Content:** Higher gas content leads to more explosive potential.
- **Temperature:** Hotter magmas are generally less viscous.

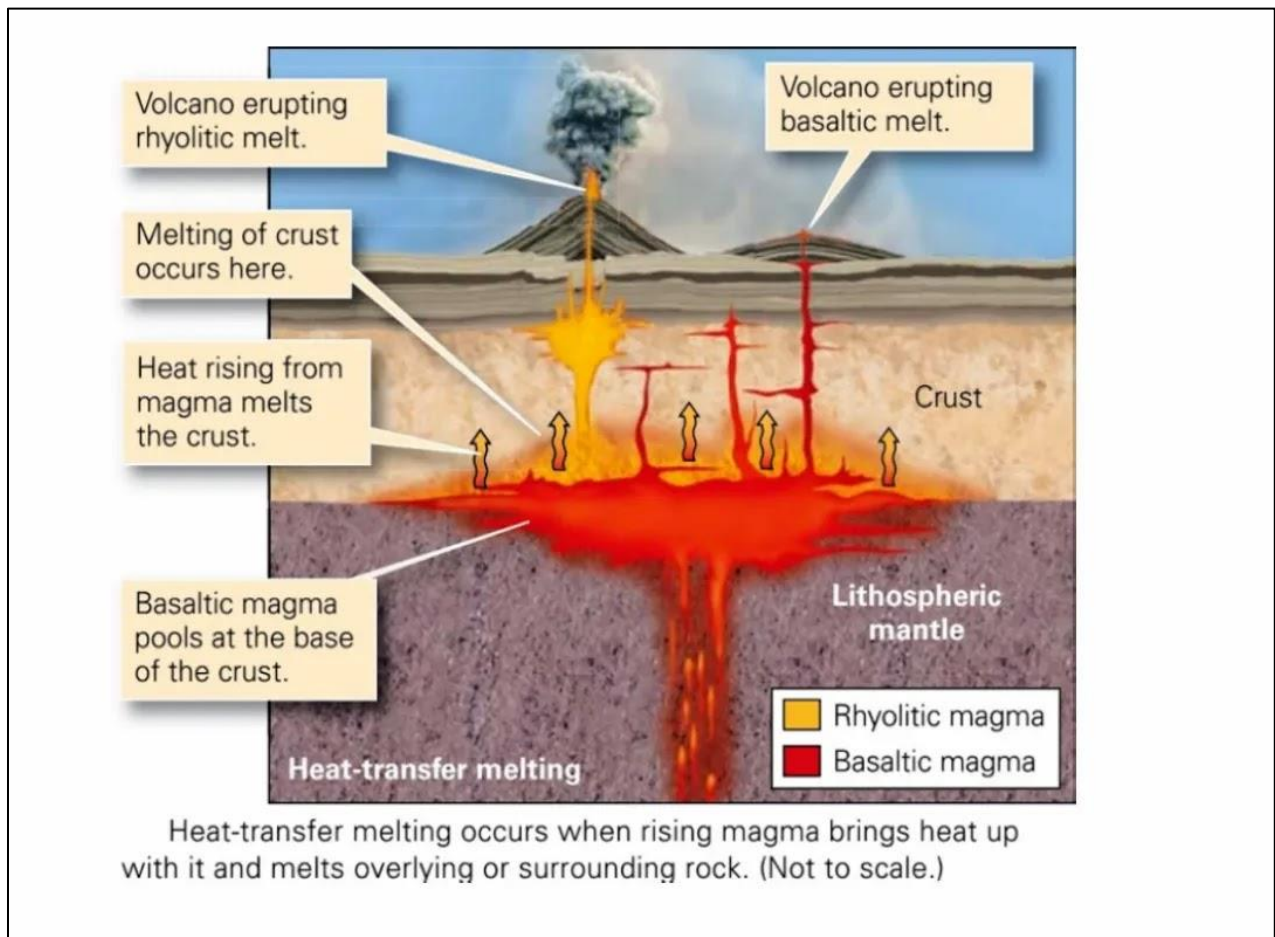


Fig 2.20: The process of heat-transfer melting

Volcanic Landforms

- **Shield Volcanoes:** Broad, gently sloping cones built by successive flows of low-viscosity basaltic lava (e.g., Mauna Loa, Hawaii).
- **Stratovolcanoes (Composite Cones):** Large, steep-sided cones of interlayered lava flows and pyroclastic deposits. Associated with subduction zones and explosive eruptions (e.g., Mount Fuji, Mount St. Helens).
- **Cinder Cones:** Small, steep-sided cones built from ejected lava fragments (cinders).
- **Lava Domes:** Mounds of viscous felsic lava that pile up around a vent.
- **Calderas:** Large, basin-shaped depressions formed by the collapse of a volcano's summit after a massive eruption empties the underlying magma chamber (e.g., Crater Lake, Yellowstone).

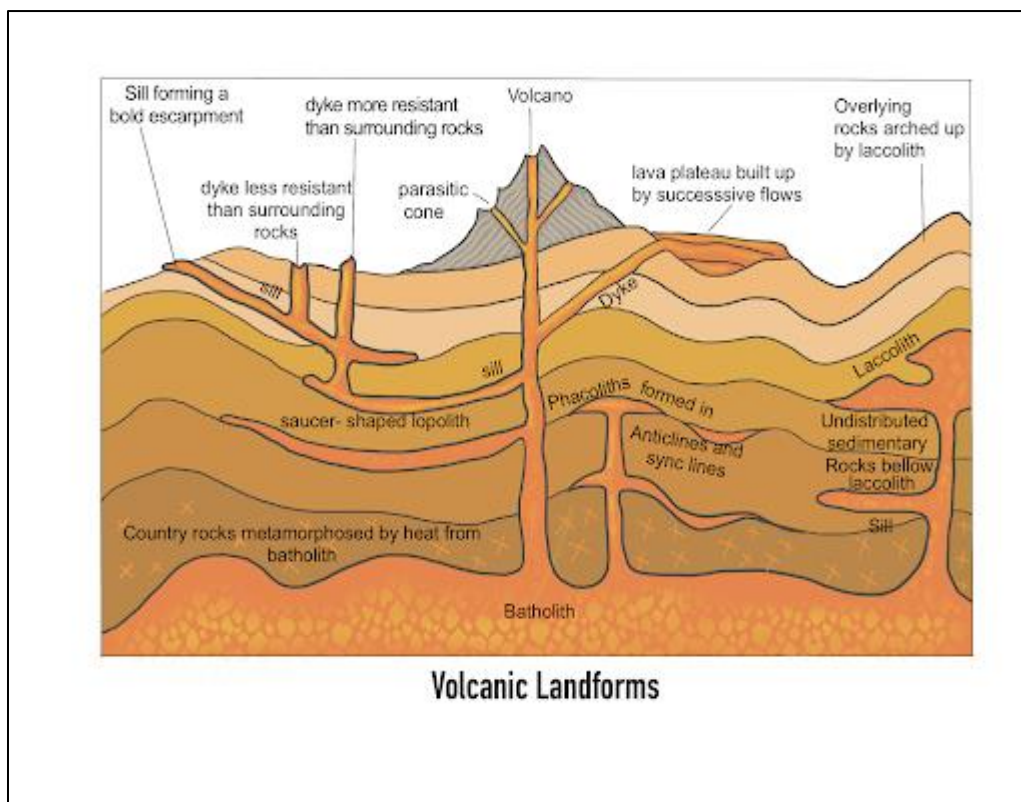


Fig 2.21: Cross-section of various volcanic landform

Volcanic Hazards

1. **Pyroclastic Flows:** Avalanches of hot ash, rock, and gas that race down slopes at hundreds of km/h; the most deadly volcanic hazard.
2. **Lahars:** Volcanic mudflows that can travel great distances, burying towns.
3. **Ash Fall:** Can collapse roofs, disrupt aviation, and cause respiratory issues.
4. **Lava Flows:** Generally slow-moving, destructive to property but less lethal.
5. **Volcanic Gases:** CO₂, SO₂ can be toxic and, in the case of SO₂, lead to global cooling.

Global Distribution of Volcanoes

Volcanoes are not randomly distributed. They occur at:

- **Divergent Plate Boundaries:** Mid-ocean ridges (mostly submarine).
- **Convergent Plate Boundaries:** The "Ring of Fire" around the Pacific Ocean.
- **Hotspots:** Intraplate volcanic regions fed by mantle plumes (e.g., Hawaii, Yellowstone).

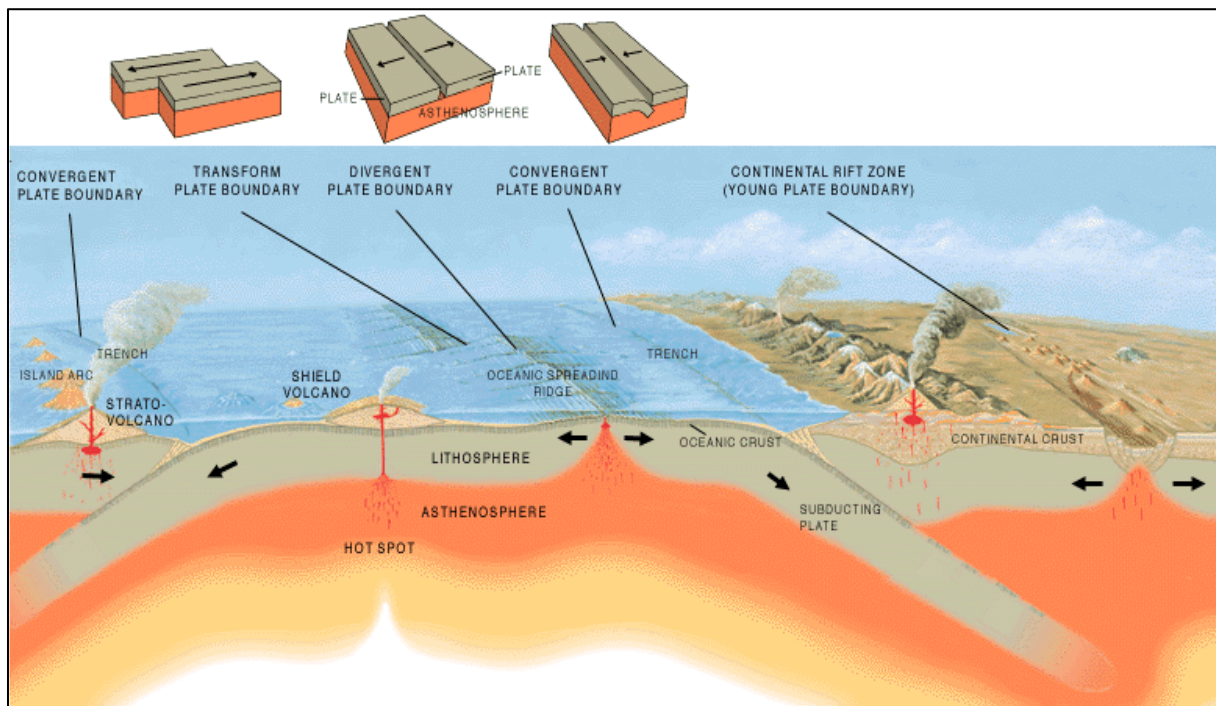


Fig 2.22: Cross section of the Earth's Plate Tectonic Structure

CHAPTER 3:
TECTONICS AND ROCK
DEFORMATION

Introduction to Structural Geology

Tectonics, or structural geology, is the study of the deformation of Earth's lithosphere and the geological structures that result. Initially horizontal layers of sedimentary rock can be tilted, folded, fractured, and displaced over geological time due to tectonic forces. Understanding these structures allows geologists to reconstruct the stress fields and history of a region.

3.1 Stress, Strain, and Rock Behavior

Fundamental Concepts

- **Stress (σ):** The force applied per unit area. It is the *cause* of deformation.
 - **Confining Pressure:** Stress applied equally in all directions, as in deep burial. It results in volume change but not shape change.
 - **Differential Stress:** Stress that is not equal in all directions, which leads to deformation.
 - **Compressional Stress:** Shortens a rock body. Common at convergent plate boundaries.
 - **Tensional Stress:** Stretches a rock body. Common at divergent plate boundaries.
 - **Shear Stress:** Causes parallel surfaces to slide past one another. Common at transform boundaries.
- **Strain (ϵ):** The change in shape or volume of a rock in response to stress. It is the *effect* or result of deformation.

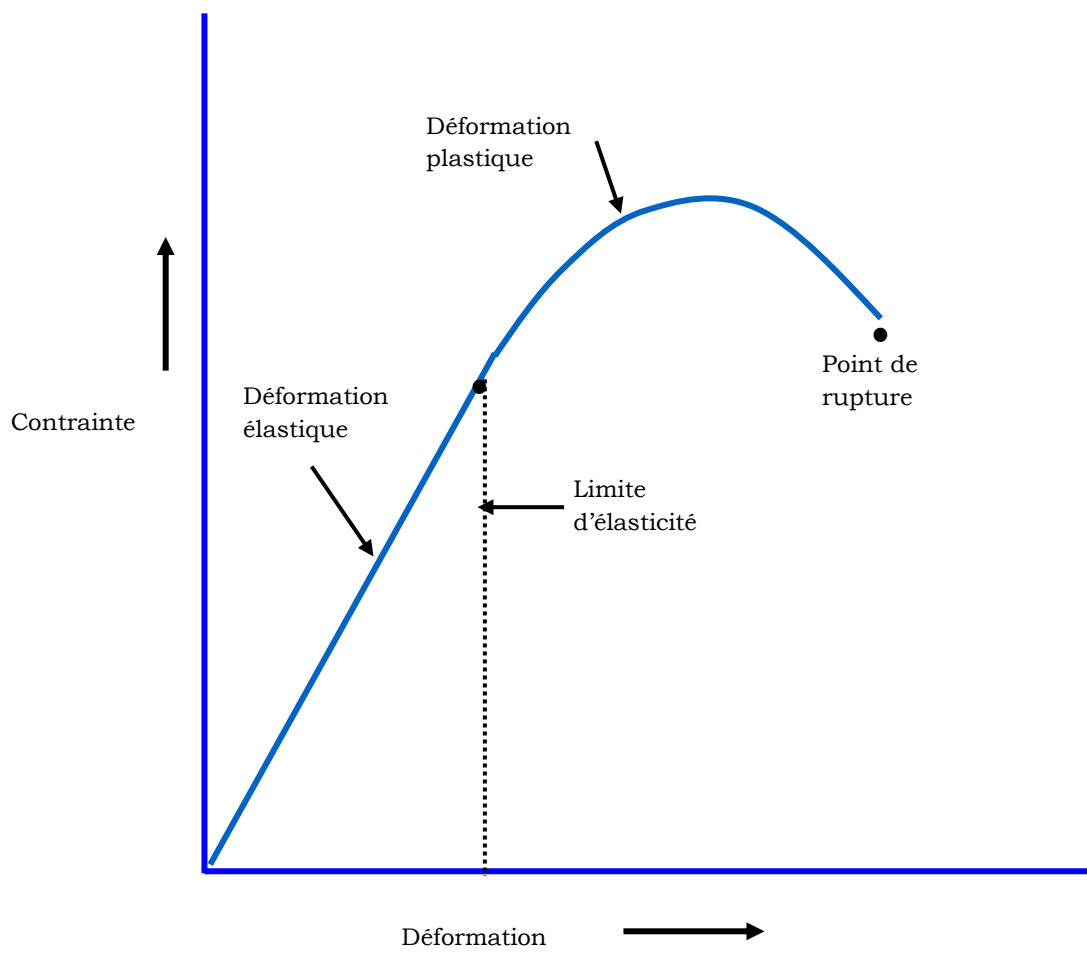


Fig 3.1: Stress Deformation graph

Types of Rock Deformation

The way a rock responds to stress depends on four key factors: **Temperature, Pressure, Strain Rate, and Rock Composition.**

1. Elastic Deformation:

- **Behavior:** The rock deforms under stress but returns to its original shape when the stress is removed, like a rubber band.
- **Result:** No permanent deformation. Energy is stored elastically.
- **Geological Significance:** This is the mechanism behind earthquakes. When the elastic limit (strength) of the rock is exceeded, it fails, releasing the stored energy as seismic waves.

2. Ductile (Plastic) Deformation:

- **Behavior:** The rock flows and bends under stress, undergoing permanent change without fracturing.
- **Conditions:** High temperature, high confining pressure, slow strain rate. Typical of deeper crustal levels.
- **Result:** Folds, foliation in metamorphic rocks.
- **Analogy:** Bending a piece of soft clay.

3. Brittle Deformation:

- **Behavior:** The rock fractures and breaks once its strength is exceeded.
- **Conditions:** Low temperature, low confining pressure, rapid strain rate. Typical of shallow crustal levels.
- **Result:** Faults and joints.
- **Analogy:** Snapping a brittle stick.

The transition from brittle to ductile behavior with increasing depth is known as the **Brittle-Ductile Transition Zone**, typically occurring at around 10-15 km depth in the continental crust.

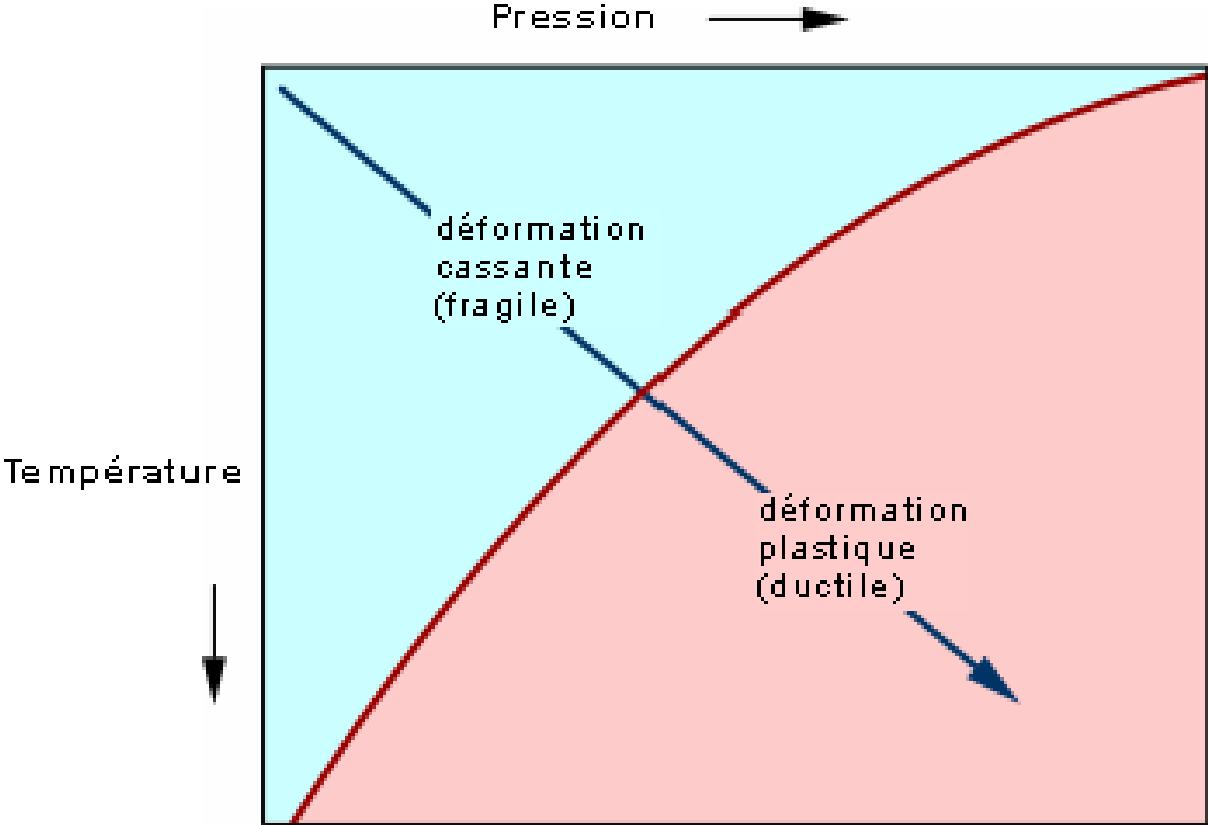


Fig 3.2: Diagram illustrating the influence of the pressure and the temperature of the mechanical equipment on the ground and on the materials

3.2 Brittle Deformation: Faults and Joints

Joints

- **Definition:** Fractures in rock along which there has been no appreciable displacement. They form when rock is pulled apart by tension.
- **Significance:** Control weathering, erosion, and fluid flow (water, hydrocarbons).

Faults

- **Definition:** Fractures in rock along which there *has* been displacement.

Fault Anatomy:

- **Fault Plane:** The surface of the fracture.
- **Hanging Wall:** The rock block above the fault plane.
- **Footwall:** The rock block below the fault plane.
- **Slip:** The relative displacement vector. It can be described by its:
 - **Dip-Slip Component:** Movement parallel to the dip direction (up or down).
 - **Strike-Slip Component:** Movement parallel to the strike direction (horizontal).

Classification of Faults

Faults are classified based on the relative motion of the hanging wall and footwall, and the dominant stress regime.

1. **Dip-Slip Faults** (Movement is primarily vertical):
 - **Normal Fault:** The hanging wall moves down relative to the footwall.
 - **Caused by:** Tensional stress (crustal extension).

- **Tectonic Setting:** Divergent boundaries, continental rifts.
- **Associated Structures: Horsts** (uplifted blocks) and **Grabens** (down-dropped blocks), e.g., the Basin and Range Province (USA), East African Rift.
- **Reverse Fault:** The hanging wall moves up relative to the footwall.
 - **Caused by:** Compressional stress (crustal shortening).
 - **Thrust Fault:** A low-angle reverse fault (dip angle $< 30^\circ$). These are responsible for major crustal stacking and mountain building, e.g., the Rocky Mountains.

2. Strike-Slip Faults (Movement is primarily horizontal):

- **Caused by:** Shear stress.
- **Right-Lateral (Dextral):** When you stand on one side of the fault, the block on the other side appears to have moved to the right.
- **Left-Lateral (Sinistral):** When you stand on one side of the fault, the block on the other side appears to have moved to the left.
- **Tectonic Setting:** Transform plate boundaries, e.g., San Andreas Fault (right-lateral).

3. Oblique-Slip Faults: A combination of dip-slip and strike-slip movement.

3.3 Ductile Deformation: Folds

Folds are wavelike bends in layered rock that form due to ductile deformation under compressional stresses.

Fold Anatomy:

- **Limb:** The two sides of a fold.
- **Hinge:** The zone of maximum curvature.

- **Axial Plane:** An imaginary plane that divides the fold as symmetrically as possible.
- **Axis:** The line formed by the intersection of the axial plane with a folded surface.

Types of Folds:

1. **Anticline:** An arch-like fold where the oldest rocks are in the core (center). Limbs dip away from the hinge.
2. **Syncline:** A trough-like fold where the youngest rocks are in the core. Limbs dip towards the hinge.
3. **Monocline:** A step-like fold in otherwise horizontal or gently dipping strata.
4. **Dome:** A circular or elliptical anticlinal structure where beds dip radially away from a central point. Oldest rocks are in the center.
5. **Basin:** A circular or elliptical synclinal structure where beds dip radially toward a central point. Youngest rocks are in the center.

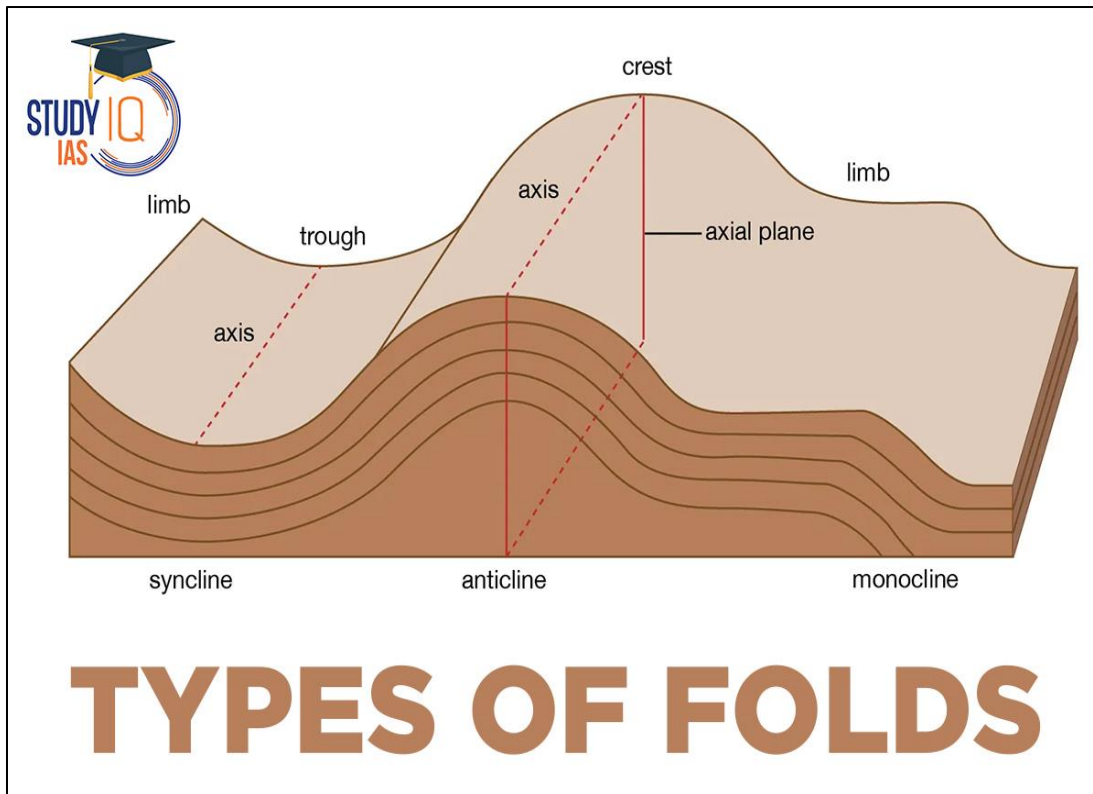


Fig 3.3: Types of Folds

Fold Geometry (Based on Axial Plane Orientation):

- **Symmetrical Fold:** Axial plane is vertical, limbs have the same dip angle.
- **Asymmetrical Fold:** Axial plane is inclined, limbs have different dip angles.
- **Overtured Fold:** Axial plane is inclined to such a degree that one limb is tilted beyond vertical.
- **Recumbent Fold:** Axial plane is nearly horizontal. An extreme type of overturned fold.

Large-Scale Fold Structures:

- **Anticlinorium:** A large, composite anticline with smaller folds on its limbs.
- **Synclinorium:** A large, composite syncline with smaller folds on its limbs.

3.4 Thrusting, Nappes, and Mountain Building

Thrust Faults and Imbricate Fans

As compression continues, thrust faults can stack slices of crust on top of one another, forming an **imbricate fan**. This is a primary mechanism for crustal thickening.

Nappes

A **nappe** (or thrust nappe) is a large, sheet-like body of rock that has been moved a significant distance (kilometers to tens of kilometers) over underlying rocks by thrust faulting or recumbent folding.

- **Formation:** Often evolves from a recumbent fold whose lower limb is sheared out, becoming a thrust fault.
- **Terminology:**
 - **Allochthonous:** The rock unit that has been transported (the nappe itself).
 - **Autochthonous:** The underlying, in-place rock unit.
 - **Fenster (Window):** An erosional hole through a nappe, exposing the autochthon below.
 - **Klippe (Klippen):** An isolated erosional remnant of a nappe sitting on the autochthon.

The Formation of Mountain Chains (Orogeny)

Orogeny is the process of mountain building, typically occurring at convergent plate boundaries. It involves intense deformation, metamorphism, and igneous activity.

Major Orogenic Processes:

1. **Andean-Type Orogeny (Oceanic-Continental Convergence):**
 - Subduction leads to the formation of a magmatic arc on the overriding continental plate (e.g., Andes). Compression also causes folding and thrust faulting, thickening the crust and building mountains.
2. **Continental Collision Orogeny (Continental-Continental Convergence):**

- When an ocean basin closes, two continental masses collide. Since continental crust is buoyant, it cannot be subducted. Instead, the crust is massively thickened and deformed.
- **Processes:** Large-scale thrusting, nappe formation, intense folding, and regional metamorphism.
- **Example:** The Himalayas, formed by the collision of India with Asia. This is the world's most dramatic example of ongoing continental collision.

Isostasy and Mountain Roots

- **Principle of Isostasy:** The lithosphere "floats" on the denser, ductile asthenosphere. A topographic high, like a mountain range, must be compensated for by a deep "root" of buoyant crustal material that extends into the mantle.
- **Mountain Root:** The thick crust beneath a mountain range (e.g., the crust is over 70 km thick under the Himalayas, compared to ~35 km for normal continents). This is analogous to an iceberg floating in water.
- **Erosion and Isostatic Rebound:** As a mountain is eroded, mass is removed. The crust, being buoyant, will rise (rebound) in response, bringing deeper rocks to the surface. This process can exhume rocks that were once 20-30 km deep.

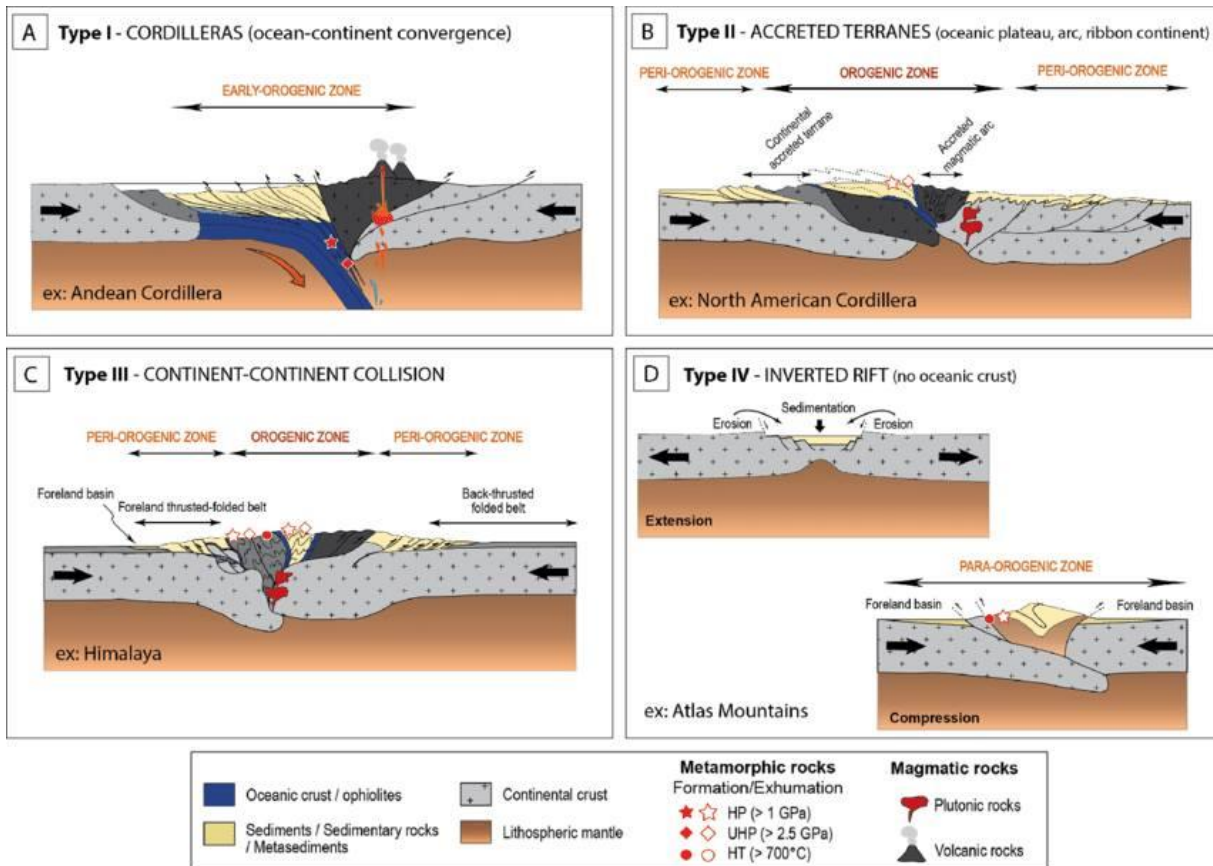


Fig 3.4: Types of orogenesis (the process of mountain building) categorized by the tectonic environment

APPENDICES

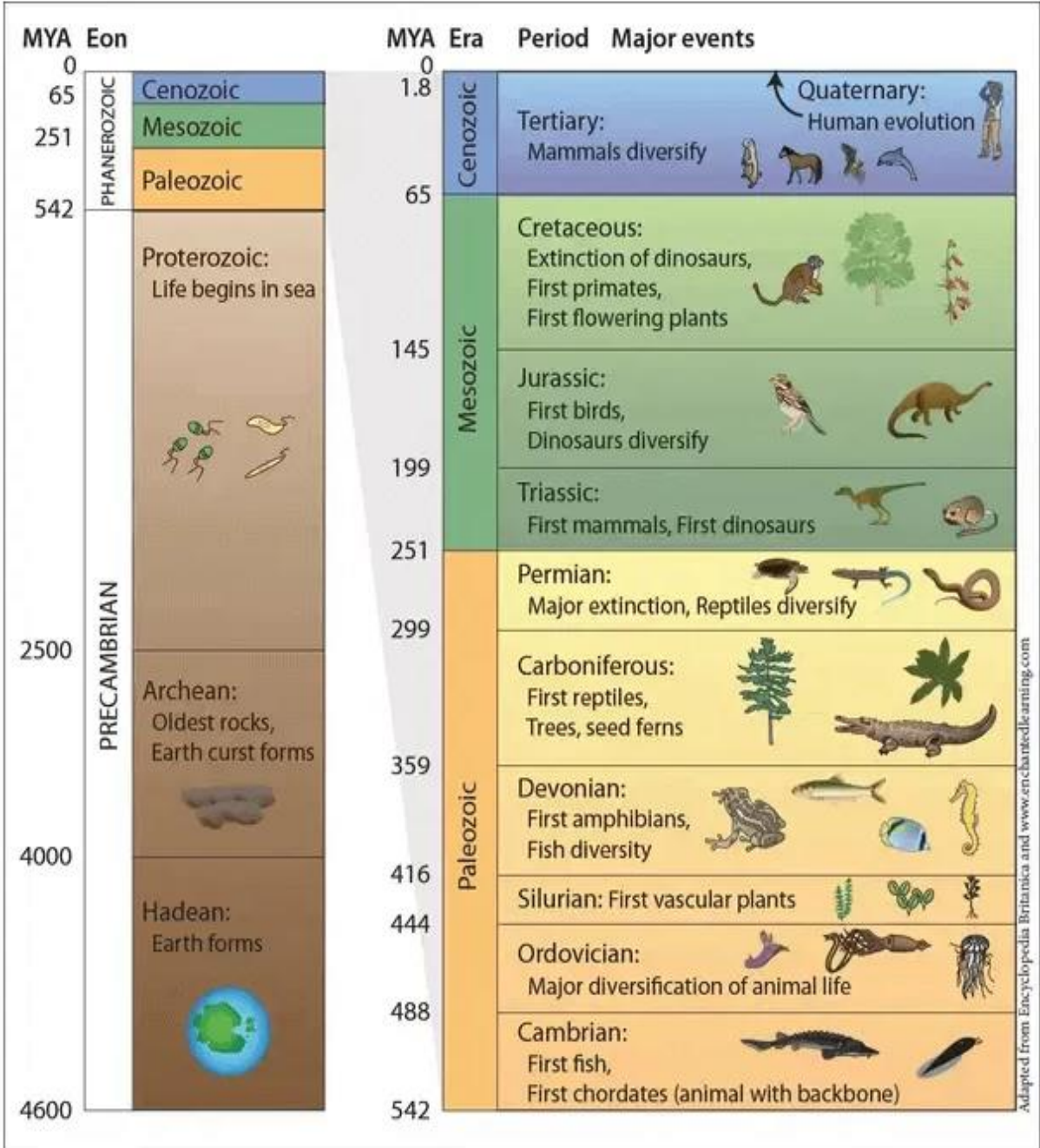
Appendix A: Geological Timeline (The Geologic Time Scale)

The geologic time scale divides Earth's 4.6-billion-year history into hierarchical units based on major geological and biological events.

- **Eons:** The largest divisions (Hadean, Archean, Proterozoic, Phanerozoic).
- **Eras:** Divisions of eons (Paleozoic, Mesozoic, Cenozoic in the Phanerozoic).
- **Periods:** Divisions of eras (e.g., Jurassic, Cretaceous).
- **Epochs:** Divisions of periods (e.g., Pleistocene, Holocene).

Key Events:

- **~4.6 Ga:** Formation of Earth.
- **~4.0 Ga:** First evidence of life (prokaryotes).
- **~2.4 Ga:** Great Oxidation Event.
- **~541 Ma:** Cambrian Explosion - rapid diversification of complex life.
- **~252 Ma:** Permian-Triassic Extinction (the "Great Dying").
- **~66 Ma:** Cretaceous-Paleogene Extinction (dinosaurs go extinct).
- **~2.6 Ma:** Beginning of the current Ice Age (Quaternary Period).



Geological Time Scale

Appendix B: Mineral and Rock Identification Guide

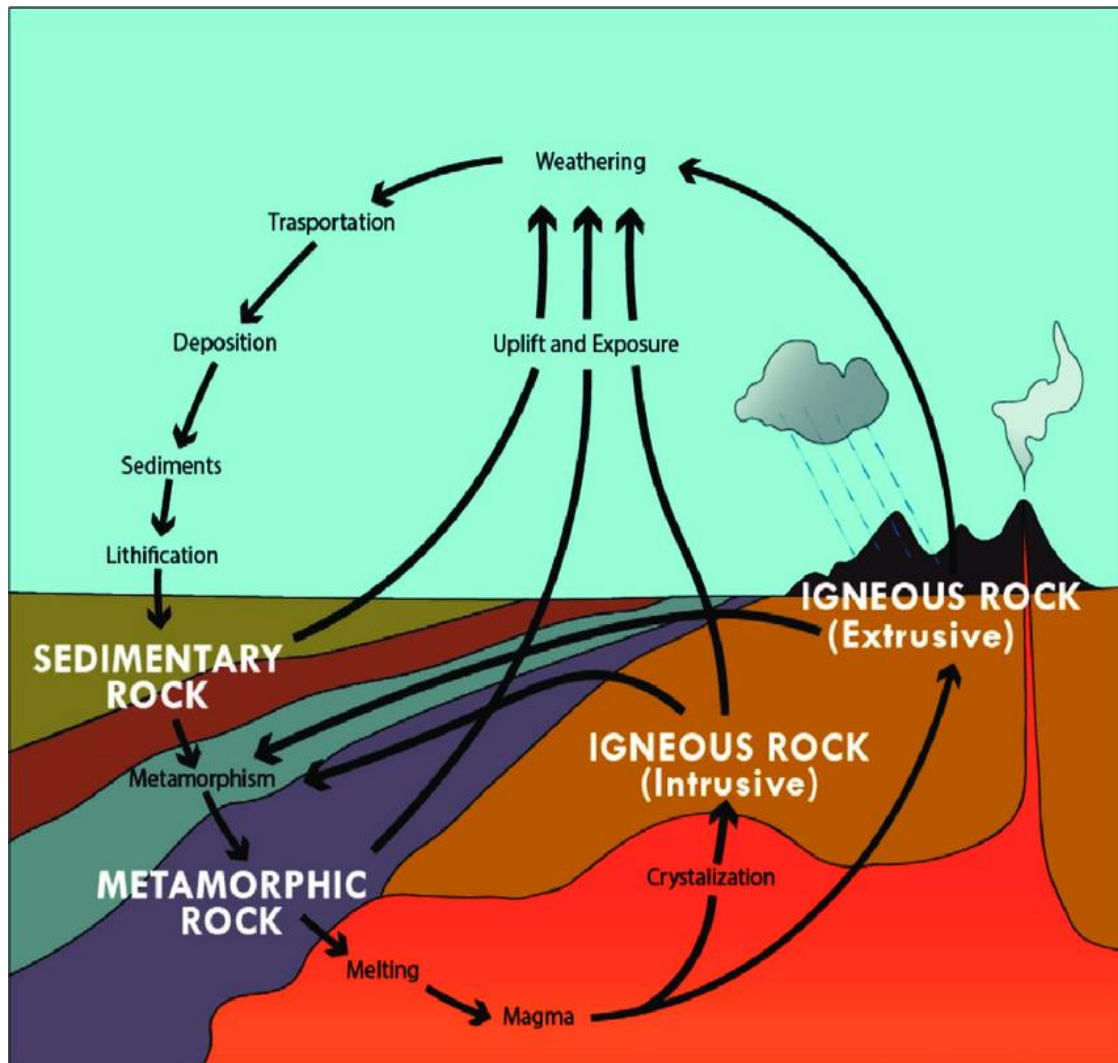
Mineral Identification Key Properties:

1. **Color:** Not always diagnostic due to impurities.
2. **Streak:** Color of the powdered mineral.
3. **Luster:** How it reflects light (metallic, vitreous, earthy, etc.).
4. **Hardness:** Resistance to scratching (Mohs Scale: 1=Talc, 10=Diamond).
5. **Cleavage:** Tendency to break along planes of weak atomic bonds.
6. **Fracture:** How it breaks when no cleavage is present (e.g., conchoidal).
7. **Crystal Form:** Shape of well-formed crystals.
8. **Other:** Specific Gravity, Magnetism, Reactivity with acid.

Rock Type Overview:

- **Igneous:** Form from cooling magma.
 - *Intrusive (Plutonic):* Cooled slowly underground (e.g., Granite, Gabbro).
Coarse-grained.
 - *Extrusive (Volcanic):* Cooled rapidly at surface (e.g., Basalt, Rhyolite).
Fine-grained or glassy.
- **Sedimentary:** Form from weathering, transport, deposition, and lithification of pre-existing rocks or biological material.
 - *Clastic:* From rock fragments (e.g., Sandstone, Shale).
 - *Chemical:* From precipitation of minerals from water (e.g., Limestone, Rock Salt).
 - *Biochemical:* From organic remains (e.g., Coal, Chalk).
- **Metamorphic:** Form from pre-existing rocks changed by heat, pressure, and chemically active fluids.

- *Foliated*: With a planar fabric (e.g., Slate, Schist, Gneiss).
- *Non-Foliated*: Without a planar fabric (e.g., Marble, Quartzite).



the Rock Cycle

Appendix C: Glossary of Key Terms

- **Asthenosphere:** The ductile, partially molten layer of the upper mantle below the lithosphere.
- **Dip:** The angle at which a rock layer or fault plane is inclined from the horizontal.
- **Lithosphere:** The rigid outer layer of Earth, comprising the crust and uppermost mantle.
- **Magma:** Molten rock beneath Earth's surface.
- **Metamorphism:** The process of changing rocks in the solid state due to changes in temperature, pressure, and chemical environment.
- **Strike:** The compass direction of a line formed by the intersection of a rock layer with a horizontal plane.
- **Subduction:** The process where one tectonic plate moves under another and sinks into the mantle.

Appendix D: Chapter Review Questions

Chapter 1:

1. Define geology and list its three main subdisciplines, explaining the focus of each.
2. Compare and contrast a light-year and an astronomical unit.
3. What are the three key differences between terrestrial and Jovian planets?
4. Explain why Earth's distance from the Sun alone is insufficient to explain its habitable temperature.

Chapter 2:

1. Describe the differences between continental and oceanic crust in terms of composition, density, and thickness.

2. Explain how the geodynamo process generates Earth's magnetic field.
3. List and describe the three main types of plate boundaries and provide a real-world example of each.
4. What is the difference between an earthquake's focus and its epicenter? Why can't S-waves travel through the outer core?

Chapter 3:

1. Differentiate between brittle and ductile deformation. What factors control which type occurs?
2. Draw and label a diagram of a normal fault and a reverse fault, indicating the dominant stress for each.
3. Sketch a symmetrical anticline and syncline, showing the relative age of rocks in the core of each.
4. What is isostasy, and how does it explain the presence of deep crustal roots beneath mountain ranges?

Appendix E: Suggested Readings and Online Resources

- **Interactive Plate Tectonic Maps:**

<https://www.ucmp.berkeley.edu/geology/tectonics.html>

References :

Textbooks :

- **Grotzinger, J., & Jordan, T. H. (2020).** *Understanding Earth* (8th ed.). W. H. Freeman.
- **Marshak, S. (2022).** *Earth: Portrait of a planet* (7th ed.). W. W. Norton & Company.
- **Plummer, C. C., Carlson, D. H., & Hammersley, L. (2021).** *Physical geology* (17th ed.). McGraw-Hill Education.

- **Park, G. (2018).** *Introducing geology: A guide to the world of rocks* (3rd ed.). Dunedin Academic Press.

Online Resources :

- Geological Society of America. (n.d.). *GSA resources*.
<https://www.geosociety.org>
- NASA. (n.d.). *Earth observatory*. <https://earthobservatory.nasa.gov>
- United States Geological Survey. (n.d.). *Earthquake hazards*.
<https://earthquake.usgs.gov>
- United States Geological Survey. (n.d.). *Volcano hazards*.
<https://volcanoes.usgs.gov>
- University of California Museum of Paleontology. (n.d.). *Plate tectonics mechanisms*. <https://www.ucmp.berkeley.edu/geology/tectonics.html>

Scientific Databases & Journals

- GeoScienceWorld. (n.d.). *Journals and eBooks database*.
<https://pubs.geoscienceworld.org>
 - **Note:** A comprehensive resource for high-impact research papers across forty global geological societies.
- British Geological Survey. (n.d.). *Discovering geology*.
<https://www.bgs.ac.uk/discovering-geology/>
 - **Note:** Provides excellent visual explanations of rock cycles, fossils, and geological time.

General Subject References :

- Ouadadi, S. (2025). *Geology 1: Comprehensive geology course* [Course booklet]. Department of Earth and Universe Sciences, University of Ali Kafi Tindouf.