Chapter 8

Aureole: A zone of altered rock surrounding an intrusion, typically formed by contact metamorphism.
Contact Metamorphism: Metamorphism due to heat from an igneous intrusion, affecting the surrounding rocks.
Gneissic Texture: A texture of metamorphic rocks characterized by a banded or foliated appearance, often seen in gneiss.
Index Mineral: Minerals used as indicators of the metamorphic conditions under which a rock formed.
Migmatite: A rock that is a mixture of metamorphic and igneous components, typically showing evidence of partial melting.
Regional Metamorphism: Metamorphism affecting large areas, often associated with mountain-building processes.
Slaty Cleavage: A type of foliation in fine-grained rocks where the rock can be split into thin layers.
Burial Metamorphism: Metamorphism that occurs due to deep burial under sedimentary layers, with pressure as the dominant factor.
Differential Stress: Stress applied unequally in different directions, leading to deformation in rocks.
Hydrothermal Metamorphism: Metamorphism caused by interactions with high-temperature fluids, altering the rock's composition.
Metamorphism: The process by which rocks are altered in structure or composition due to heat, pressure, or chemically active fluids.
Nonfoliated Texture: A texture in metamorphic rocks that lack a layered or banded appearance.
Rock Cleavage: The tendency of a rock to split along certain planes, often due to the alignment of minerals.
Cataclastic Metamorphism: Metamorphism that results from mechanical deformation, like faulting, typically producing fragmented rocks.
Confining Pressure: Pressure applied equally in all directions, usually due to deep burial under the Earth's surface.
Foliation: A repetitive layering in metamorphic rocks due to the alignment of minerals under directed pressure.
Impact Metamorphism: Metamorphism caused by the intense pressures and temperatures generated by a meteorite impact.
Metasomatism: The process of chemical alteration in a rock due to fluid interaction.
Parent Rock: The original rock from which a metamorphic rock formed.
Schistosity: A type of foliation in schist, where minerals are aligned in a way that allows easy splitting along planes.

Metamorphic Facies: A set of mineral assemblages indicative of a certain range of temperature and pressure conditions during metamorphism.

Foliated Rocks

These rocks display a layered or banded structure due to the alignment of minerals under directed pressure.

1. **Slate**: Very fine-grained rock that splits into thin sheets; formed from shale.
2. **Phyllite**: Slightly coarser than slate, with a shiny appearance due to microscopic mica flakes.
3. **Schist**: Medium to coarse-grained rock with visible mineral alignment, allowing it to split along planes.
4. **Gneiss**: Coarse-grained rock with distinct banding of light and dark minerals.
5. **Migmatite**: Mixed rock that shows partial melting, combining both igneous and metamorphic textures.

Weakly- or Non-Foliated Rocks

These rocks may not show significant foliation, often due to the mineral composition or lack of directed pressure.

1. **Amphibolite**: Medium to coarse-grained, typically dark rock rich in amphibole minerals.
2. **Granulite**: High-grade, coarse-grained rock with minerals that lack significant alignment.
3. **Metaconglomerate**: Rock that forms from conglomerate; contains rounded clasts that may be slightly flattened.
4. **Greenstone**: Low-grade metamorphosed basalt or gabbro, often greenish due to chlorite or epidote.

Non-Foliated Rocks

These rocks do not show any layering or banding, typically formed without directed pressure.

1. **Marble**: Formed from limestone; mainly composed of recrystallized calcite, often used in sculpture and construction.
2. **Quartzite**: Very hard rock formed from quartz sandstone; resistant to weathering.
3. **Hornfel**: Fine-grained rock formed by contact metamorphism, often with a hard, dense structure.

4. **Anthracite**: High-grade metamorphic form of coal, shiny and hard, with a high carbon content.
5. **Fault Breccia**: Formed from the grinding of rocks along fault lines, resulting in angular fragments cemented together.

Agents of Metamorphism: The main agents are heat, pressure, and chemically active fluids. Heat promotes recrystallization and changes in mineral composition. Pressure, especially differential stress, affects mineral alignment and texture. Fluids help in chemical reactions that form new minerals and facilitate ion exchange.
Difference between Differential Stress and Confining Pressure:

- **Differential Stress** is unequal pressure applied in specific directions, leading to deformation and potential foliation in rocks.
- **Confining Pressure** is applied equally in all directions, typically due to deep burial.
- **Foliation** is more likely to occur under **differential stress** because minerals align perpendicularly to the direction of the greatest pressure.

Hydrothermal Metamorphism: This type of metamorphism involves the alteration of rocks by hot, mineral-rich water. It commonly leads to hydration reactions (adding water to minerals) and can cause mineral replacement. It typically occurs at mid-ocean ridges and hot spots. **Greenstone** is a typical product of hydrothermal metamorphism.
Contact Metamorphism: Occurs near igneous intrusions where rocks are heated by nearby magma. It is associated with a high geothermal gradient (temperature increases rapidly with depth) and forms a **contact metamorphic aureole**, a zone of altered rock around the intrusion.
Differences between Burial and Regional Metamorphism:

- **Burial Metamorphism** occurs under the pressure of accumulating sediments; it is generally low-grade.
- **Regional Metamorphism** occurs over large areas, typically during mountain-building events, involving both high pressure and temperature.
- **Regional Metamorphism** is more extensive, with **differential stress** producing foliation, while burial is primarily influenced by **confining pressure**.

Cataclastic Metamorphism: This type occurs along fault zones where rocks are crushed and ground up by movement. **Fault breccia** is formed by fragmented rocks, while **mylonite** is fine-grained due to intense shearing.
How Foliation is Produced:

- **Mechanisms**:
    1. Recrystallization of minerals to align perpendicularly to stress.

    2. Rotation of existing minerals under stress.
    3. Growth of new minerals in a preferred orientation.
- Common platy minerals include **mica** and **chlorite**.
- Non-platy minerals, like **quartz** in **metaconglomerate**, can sometimes show foliation if the rock is deformed enough to produce aligned grains.

Tectonic Environment for Blueschists and Eclogites: These rocks form in **subduction zones** where there are high pressures but relatively low temperatures, typical of convergent boundaries.
Parent Rocks:

- **Slate**: Shale
- **Quartzite**: Quartz sandstone
- **Marble**: Limestone
- **Greenstone**: Basalt
- **Anthracite**: Coal

Increasing Grade of Metamorphism:

- Slate → Phyllite → Schist → Gneiss → Granulite

Migmatites: Rocks that display characteristics of both igneous and metamorphic rocks, formed by partial melting at high temperatures, indicating conditions near the upper limits of metamorphism.
Index Minerals: Minerals that form under specific temperature and pressure conditions, such as garnet and kyanite. They help in mapping metamorphic grades across terrains, showing the progression of metamorphism in a region.
Types of Metamorphism Related to Plate Tectonics:

- **High-Temperature/Low-Pressure**: Contact metamorphism, typically at divergent boundaries or near igneous intrusions.
- **High-Temperature/High-Pressure**: Regional metamorphism, common in collisional mountain belts.
- **Low-Temperature/High-Pressure**: Subduction zone metamorphism, where blueschist and eclogite form.
- **Hydrothermal Metamorphism**: Occurs at mid-ocean ridges and near volcanic activity, where fluids circulate through the crust.

Chapter 9

Angular Unconformity: A type of unconformity where tilted or folded rocks are overlain by flat-lying rocks, indicating a period of deformation and erosion.
Correlation: The process of matching rock layers (strata) from different locations based on age or composition.
Epoch: A subdivision of geological time smaller than a period and part of an era.
Fossil: Remains or traces of ancient life preserved in rock.
Inclusions: Pieces of one rock unit contained within another; used in relative dating to determine which rock is older.
Index Fossil: Fossils of organisms that lived for a short period but were widely distributed, used to identify and date rock layers.
Period: A subdivision of geological time smaller than an era and larger than an epoch.
Radioactivity: The process by which unstable atomic nuclei decay, releasing particles and energy.
Carbon-14 Dating: A method of radiometric dating that measures the decay of carbon-14 in organic material to determine its age, effective for dating recent materials.
Archean Eon: A geologic eon that spans from about 4 billion to 2.5 billion years ago.
Cross-Cutting Relationship: A principle stating that a geological feature that cuts across another is younger than the feature it cuts.
Fossil Succession, Principle of: The concept that fossil assemblages succeed one another in a recognizable order, allowing for the identification of relative ages of rock layers.
Geologic Time Scale: A system that organizes Earth's history into eons, eras, periods, and epochs based on significant geological and biological events.
Numerical (Absolute) Dating: Dating that provides an exact age of rocks or fossils in years, often based on radioactive decay.
Original Horizontality, Principle of: The principle that sedimentary rock layers are originally deposited in horizontal layers.
Phanerozoic Eon: The current eon in Earth's history, starting around 541 million years ago, characterized by abundant fossil evidence.
Radiometric Dating: A technique used to date materials by measuring the decay of radioactive isotopes.
Superposition, Principle of: The principle that in undisturbed rock layers, the oldest layers are on the bottom, with progressively younger layers above.
Cenozoic Era: The current era of geological time, starting around 66 million years ago, known as the "Age of Mammals."
Conformable: Layers of rock that were deposited without interruption or erosion between them.

Disconformity: An unconformity between parallel layers of sedimentary rocks that represents a period of erosion or non-deposition.
Eon: The largest division of geologic time, consisting of multiple eras.
Formation: A body of rock with a recognizable, consistent set of characteristics that distinguish it from adjacent rock layers.
Half-Life: The time required for half of the radioactive atoms in a sample to decay, important in radiometric dating.
Hadean Eon: The earliest eon in Earth's history, before 4 billion years ago, characterized by extreme conditions and the formation of Earth's crust.
Mesozoic Era: The era between the Paleozoic and Cenozoic, from about 252 to 66 million years ago, known as the "Age of Reptiles."
Nonconformity: An unconformity where sedimentary rocks lie on top of eroded igneous or metamorphic rocks.
Original Horizontality: The concept that sedimentary rocks are initially deposited in horizontal layers.
Paleontology: The study of fossils and ancient life.
Paleozoic Era: An era from about 541 to 252 million years ago, known for the development of marine life, plants, and early animals.
Precambrian: The vast span of time before the Phanerozoic Eon, covering roughly 88% of Earth's history.
Proterozoic Eon: The eon from 2.5 billion to 541 million years ago, preceding the Phanerozoic.
Relative Dating: Determining the age of a rock or event in comparison to other rocks or events, without assigning an exact age.
Unconformity: A gap in the geological record, often due to erosion or non-deposition of rock layers.

1. **Relative vs. Absolute Dating**:
    - **Relative Dating**: Determines the sequence of events or rock formation relative to one another (e.g., older or younger).
    - **Absolute (Numerical) Dating**: Provides a specific age of a rock or event in years, often through radiometric techniques.
2. **Correlation of Rock Units**: Correlation is matching rock layers from different locations based on similarities in **lithology** (rock type), **sedimentary structures**, **color**, and **fossils**.
3. **Fossils**: Remains or traces of ancient life. Five types of fossils include:
    - **Body Fossils**: Actual remains like bones or shells.
    - **Trace Fossils**: Evidence of activity, such as footprints or burrows.
    - **Molds and Casts**: Impressions left in the rock that may be filled with minerals.
    - **Petrified Fossils**: Organic material replaced by minerals.

    - **Amber Fossils**: Organisms trapped and preserved in amber (fossilized tree resin).
4. **Principle of Fossil Succession**: Fossil assemblages appear in a specific, recognizable order, allowing for the relative dating of rocks across different areas. A good **index fossil** is widespread, easily identifiable, abundant, and short-lived.
5. **Formation**: A body of rock with a distinct set of characteristics, recognizable across a region. Formations can be grouped based on lithology, age, or fossil content.
6. **Unconformity**: A gap in the geological record representing erosion or non-deposition. Types include:
    - **Angular Unconformity**: Tilted rocks overlain by flat layers.
    - **Disconformity**: Erosion or non-deposition between parallel layers.
    - **Nonconformity**: Sedimentary rocks on top of eroded igneous or metamorphic rocks.
7. **Principles of Relative Dating**:
    - **Superposition**: Older layers are at the bottom in undisturbed sequences.
    - **Original Horizontality**: Sedimentary layers are deposited horizontally.
    - **Cross-Cutting Relationships**: Features that cut across others are younger than the features they cut.
8. **Inclusions**: Fragments of one rock within another. If inclusions of igneous rock are in a sedimentary layer, the igneous rock is older.
9. **Rock and Event Sequence**: In a given diagram, the oldest units are usually at the bottom unless disrupted by faults or intrusions.
10. **Radioactivity**: The spontaneous decay of unstable atomic nuclei. Atoms with excess neutrons or protons undergo radioactive decay.
11. **Isotopes**: Variants of an element with different numbers of neutrons. **Parent isotopes** are unstable and decay into **daughter isotopes**, which are more stable. A parent isotope can decay into a daughter isotope of a different element.
12. **Half-Life**: The time for half of a radioactive isotope to decay. Different isotopic pairs (e.g., uranium-lead) have unique half-lives.
13. **Age Calculation**: Using the ratio of parent to daughter isotopes and the half-life, the age of a rock can be determined.
14. **Metamorphism and Isotopic Dates**: Metamorphism can reset isotopic clocks. Whole-rock ages may represent the original formation, while mineral ages reflect the timing of metamorphism.
15. **Carbon-14 Dating**: Measures decay of carbon-14 in organic material, useful for dating up to about 50,000 years. Not effective for most geological samples due to its short half-life.

16. **Isotopic Dating of Rocks**: Igneous and metamorphic rocks are best dated with isotopes. Sedimentary rocks are challenging to date directly, but ages can be estimated using associated igneous rocks or index fossils.
17. **Geologic Time Scale**: Divided into **eons** (largest), **eras**, **periods**, and **epochs** (smallest). Eons include Hadean, Archean, Proterozoic, and Phanerozoic, with eras like Paleozoic, Mesozoic, and Cenozoic.
18. **Current Geologic Time**: We are in the **Cenozoic Era** of the **Phanerozoic Eon**. Earth originated approximately 4.6 billion years ago, with the Precambrian-Phanerozoic boundary at 541 million years ago. The Precambrian comprises about 88% of Earth's history, while the Phanerozoic contains most fossils. More is known about the Phanerozoic due to the abundance of fossil records.
19. **Riddle**: "What goes up the chimney down but not down the chimney up?"

- Answer: An **umbrella**. It can be opened ("up") to go down a chimney, but it can't go down the chimney if it’s open.

Chapter 10

Anticline: An upward-arching fold in rock layers, with the oldest layers at the core.
Basin: A depression in the Earth's crust where sediment accumulates.
Deformation: The process by which rocks are bent, broken, or otherwise changed due to stress.
Differential Stress: Stress applied unequally in different directions.
Dome: A circular or elliptical uplifted structure with layers that dip away from the center.
Ductile Deformation: Deformation that results in bending and stretching rather than breaking.
Fold: A bend in rock layers caused by compressional forces.
Force: An interaction that changes the motion of an object or applies stress to rocks.
Horst: An elevated block of crust between two faults.
Joint: A fracture in rock where there has been no significant movement.
Normal Fault: A type of fault where the hanging wall moves down relative to the footwall, typically caused by tensional stress.
Reverse Fault: A fault where the hanging wall moves up relative to the footwall, caused by compressional stress.
Stress: The force applied over an area on rocks, which can cause deformation.
Strike: The direction of a horizontal line on an inclined rock layer.
Strike-Slip Fault: A fault where movement is horizontal, parallel to the strike of the fault plane, caused by shear stress.
Syncline: A downward-arching fold in rock layers, with the youngest layers at the core.
Tensional Stress: Stress that pulls rock apart, stretching it.
Symmetrical Fold: A fold with mirror-image sides.
Asymmetrical Fold: A fold where one limb is steeper than the other.
Plunging Fold: A fold with an inclined axis, giving it a plunging appearance.
Hanging Wall: The block of rock that lies above an inclined fault plane.
Footwall: The block of rock that lies below an inclined fault plane.
Brittle Deformation: Deformation that results in breaking or fracturing of the material.
Dip: The angle of inclination of a rock layer or fault from the horizontal.
Fault: A fracture in rock along which there has been movement.
Graben: A down-dropped block of crust between two faults, often associated with tensional stress.
Klippe: An isolated block of rock left from erosion, often part of an overthrust.
Shear: A type of stress that causes parts of rock to slide past each other.
Transform Fault: A type of strike-slip fault at tectonic plate boundaries, where plates slide horizontally past each other.
Thrust Fault: A low-angle reverse fault where the hanging wall moves up relative to the footwall.

Overturned Fold: A fold where one limb is tilted beyond the vertical, often compressional in origin.
Compressional Stress: Stress that squeezes rocks together, shortening and thickening them.
Dip-Slip Fault: A fault where movement is primarily vertical, either normal or reverse.
Fault Scarp: A steep slope or cliff formed by faulting.
Half-Graben: A tilted block of crust with one side dropped down, often formed by normal faulting.
Monocline: A step-like fold in rock layers.
Strain: Deformation or change in shape due to applied stress.
Hinge Line: The line along the crest of a fold where the curvature is greatest.
Axial Plane: An imaginary plane that divides a fold symmetrically.

Ductile vs. Brittle Deformation:

- **Ductile Deformation** occurs when rocks bend or stretch without breaking, typically under high temperatures and pressures.
- **Brittle Deformation** happens when rocks break or fracture, usually at lower temperatures and pressures.

Factors Influencing Rock Deformation:

- **Temperature**: Higher temperatures promote ductile behavior.
- **Pressure**: Greater pressures can make rocks behave more ductilely.
- **Rock Type**: Some rocks (e.g., limestone) are more ductile, while others (e.g., granite) are more brittle.
- **Time**: Longer exposure to stress often leads to ductile deformation.

Effect of Confining Pressure: Higher confining pressure makes rocks less likely to fracture, promoting ductile deformation instead.
Folds and Deformation Type: Folds are usually a result of ductile deformation, as rocks bend rather than break under stress.
Characteristics of Anticlines vs. Synclines:

- **Anticline**: Upward arch; oldest layers in the center; dips away from the axis.
- **Syncline**: Downward arch; youngest layers in the center; dips toward the axis.

Strike-Dip Symbols on Geologic Maps: Indicate the orientation of folded strata and the direction of dip relative to the horizontal.
Relative Ages on Geologic Maps: In folds, anticlines have older rocks in the center, while synclines have younger rocks at the core. Basins and domes also show age patterns based on structural shape.

Plunging Fold Characteristics: Plunging folds have an inclined fold axis, which affects the outcrop pattern. Strike-dip symbols show the plunge direction.
Characteristics of Folds:

- **Symmetrical Fold**: Equal limb dips.
- **Asymmetrical Fold**: Unequal limb dips.
- **Overturned Fold**: One limb tilted beyond vertical.

Joint vs. Fault:

- **Joint**: A fracture with no movement.
- **Fault**: A fracture where movement has occurred.
- **Brittle vs. Ductile**: Joints and faults reflect brittle deformation.

Stresses Producing Faults:

- **Normal Faults**: Tensional stress.
- **Reverse and Thrust Faults**: Compressional stress.
- **Strike-Slip Faults**: Shear stress.

Relative Motion in Faults:

- **Normal Fault**: Hanging wall moves down.
- **Reverse Fault**: Hanging wall moves up.
- **Strike-Slip Fault**: Lateral movement along fault plane.

Thrust Fault: A low-angle reverse fault caused by compressional stress. Thrust faults have shallower dips than regular reverse faults.

Chapter 11

Aftershock: A smaller earthquake following the main shock of a larger earthquake.
Earthquake: The shaking of the Earth’s surface caused by the sudden release of energy along a fault.
Fault: A fracture in the Earth's crust along which movement has occurred.
Fault Creep: Slow, gradual movement along a fault without significant earthquake activity.
Intensity: A measure of the effects of an earthquake on people, buildings, and the Earth's surface.
Primary (P) Waves: Fastest seismic waves, compressional waves that travel through solids, liquids, and gases.
Richter Scale: A logarithmic scale used to measure the magnitude of an earthquake.
Seismogram: A record produced by a seismograph, showing the arrival times and amplitude of seismic waves.
Seismic Waves: Waves of energy generated by an earthquake, including P waves, S waves, and surface waves.
Modified Mercalli Intensity Scale: A scale that assesses earthquake intensity based on observed effects and damage, ranging from I (not felt) to XII (total destruction).
Elastic Rebound: The theory that earthquakes occur as a result of the release of strain energy stored in rocks.
Focus: The point within the Earth where an earthquake originates.
Magnitude: A measure of the energy released during an earthquake.
Secondary (S) Waves: Slower seismic waves that move perpendicular to the direction of travel and only travel through solids.
Seismology: The scientific study of earthquakes and seismic waves.
Seismograph: An instrument that records the motion of the ground during an earthquake.
Tsunami: Large sea waves generated by undersea earthquakes, landslides, or volcanic eruptions.
Epicenter: The point on the Earth’s surface directly above the earthquake focus.
Foreshock: A smaller earthquake that precedes the main shock.
Liquefaction: A process by which saturated soil temporarily loses strength and behaves like a liquid due to earthquake shaking.
Moment Magnitude: A scale that measures the total energy released by an earthquake, providing a more accurate measure for large earthquakes.
Seismic Gaps: Sections along a fault that have not experienced recent earthquakes, suggesting a buildup of strain.
Surface Wave: Seismic waves that travel along the Earth's surface, causing significant ground shaking.

Wadati-Benioff Zones: Zones of earthquake activity that trace the subduction of oceanic plates into the mantle.
Paleoseismology: The study of prehistoric earthquakes through evidence in geological layers.

Stages of the Elastic Rebound Theory:

- **Initial Stress**: Stress builds up in rocks along a fault.
- **Deformation**: Rocks deform elastically as stress increases.
- **Rupture**: When stress exceeds the strength of the rocks, they break, releasing stored energy.
- **Rebound**: The rocks return to their original shape, but are offset along the fault.

Focus (Hypocenter) vs. Epicenter:

- The **focus (hypocenter)** is the point within the Earth where the earthquake originates.
- The **epicenter** is the point on the Earth's surface directly above the focus.

Particle Motions for Seismic Waves:

- **P-Waves**: Compressional waves; particles move back and forth in the direction of the wave.
- **S-Waves**: Shear waves; particles move perpendicular to the wave's direction.
- **Surface Waves**: Complex motion; particles move in a rolling motion (Rayleigh waves) or side-to-side (Love waves).

Seismogram Sketch: A seismogram shows **P-waves** arriving first, followed by **S-waves**, and then **surface waves**. Surface waves typically have the highest amplitude and cause the most ground shaking.
Locating an Earthquake Epicenter:

- Seismologists use the time difference between P-wave and S-wave arrivals at multiple stations.
- By calculating the distance to the epicenter from each station, they can triangulate the epicenter's location.

Factors Affecting Earthquake Damage:

- **Building Structure**: Taller, poorly designed, or older buildings are more vulnerable.
- **Distance from Epicenter**: Closer areas experience stronger shaking.
- **Soil and Bedrock**: Soft soils amplify shaking, while solid bedrock reduces it.

Problems with the Mercalli Scale:

- It's subjective, based on human observation and structural damage.
- It varies based on distance from the epicenter, building types, and local geology, making it inconsistent for comparison.

Richter Magnitude Determination:

- The Richter scale measures the amplitude of seismic waves on a seismogram.
- It is a logarithmic scale, where each unit increase represents a tenfold increase in wave amplitude.

Moment Magnitude:

- Measures the total energy released by an earthquake.
- It considers the area of the fault, the amount of slip, and the rigidity of the rocks.

Global Distribution of Earthquakes:

- Most earthquakes occur along **tectonic plate boundaries**.
- **Intermediate and deep earthquakes** primarily occur at **convergent boundaries** (subduction zones).

Causes of Tsunamis and Their Behavior Near Shore:

- Caused by undersea earthquakes, landslides, or volcanic eruptions.
- As tsunamis approach shore, **wave velocity** decreases, **wave height** increases, **wave spacing** (wavelength) shortens, and **destructive potential** increases.

Earthquake Prediction Methods:

- **Seismic Gaps**: Identifying areas along faults that haven't had recent earthquakes.
- **Historical Records**: Analyzing patterns of past earthquakes.
- **Foreshocks**: Monitoring smaller tremors that may precede a larger quake.
- **Animal Behavior and Radon Emission**: Though inconsistent, these are sometimes monitored for prediction.

Seismic Gaps:

- Sections along a fault that have not experienced recent earthquakes, indicating strain accumulation and a higher potential for a future major earthquake.