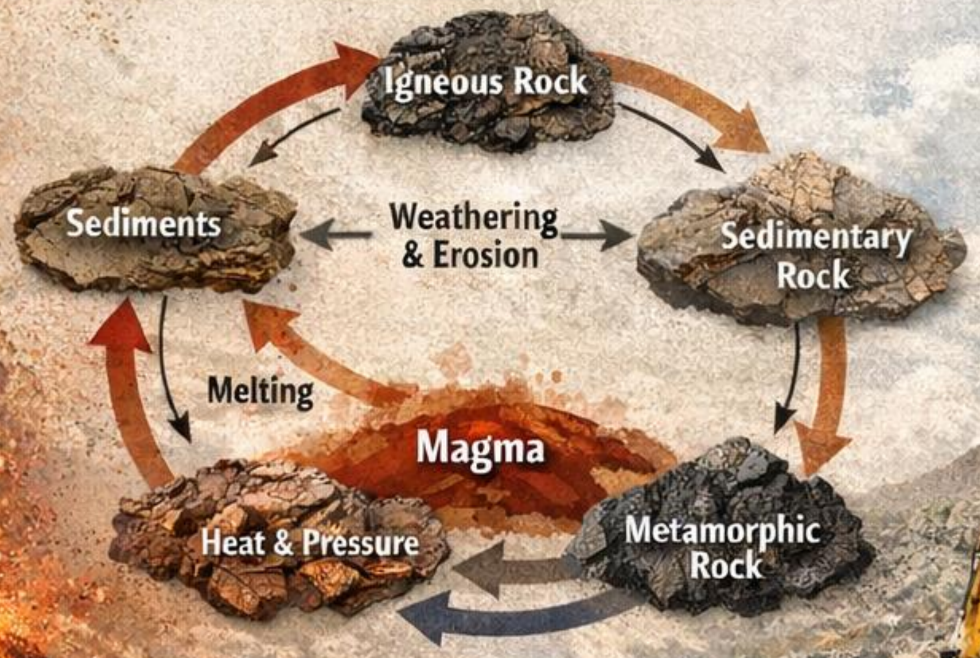
Minerals & ROCK FORMING PROCESS

For Civil Engineering



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MINERALS AND ROCK FORMING PROCESS

INTRODUCTION

The formation of the universe created conditions necessary for the organization of matter. As the temperature of the universe dropped, subatomic particles such as quarks and electrons were able to form. Further cooling allowed quarks to assemble into protons and neutrons, which then combined to form simple atomic nuclei. Eventually, when temperatures decreased even more, neutral atoms of hydrogen and helium could form, setting the stage for the creation of more complex elements and materials on Earth.

Figure 1: Minerals and Rocks

MINERALS

Minerals, the building blocks of rocks, are inorganic solids with a specific internal structure and definite chemical composition (which varies only within a narrow range). Some minerals are visible to the naked eye, while others require magnification. Examples include Mica, Feldspar, Quartz, and Granite. Minerals are essential in geology and civil engineering, as they determine the properties and classification of rocks used in construction.

Minerals can form through various natural processes:

1. **Cooling of molten materials** – e.g., granite and steel crystals
2. **Evaporation of liquids** – e.g., salt from seawater, sugar from syrup
3. **Cooling of liquids** – e.g., slow cooling of a sugar solution forms sugar crystals
4. **High temperature and pressure in solids** – e.g., diamond formation

Figure 2: Minerals precipitation from solution

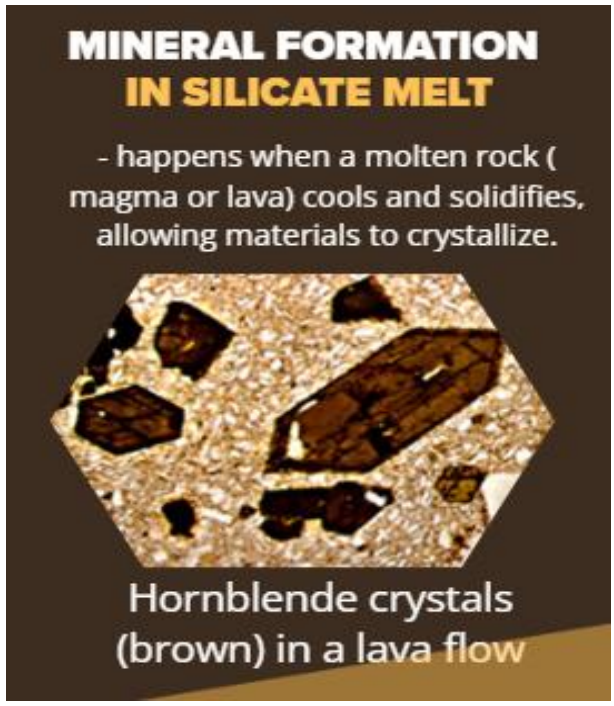

Figure 3: Minerals formation in silicate melt

Figure 4: Minerals precipitation from solution

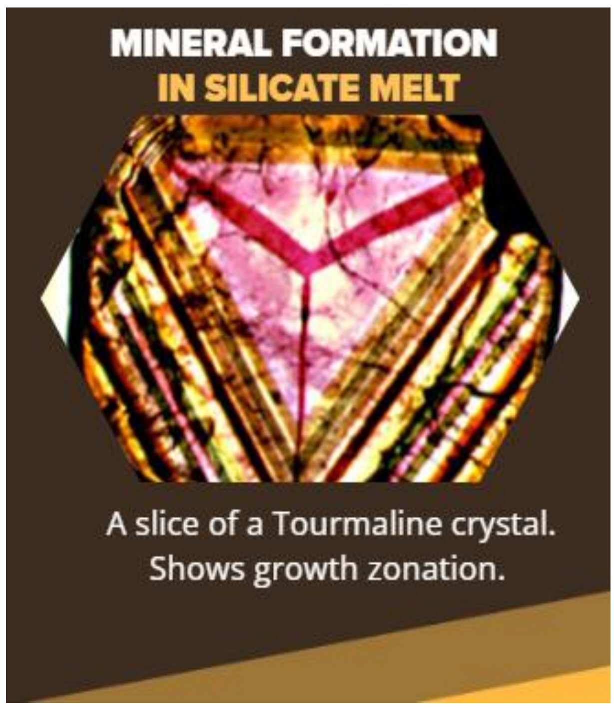

Figure 5: Minerals formation in silicate melt

Classification of Minerals

- **Elements:** pure elements like Carbon (diamond), Sulfur, Zinc, Gold
- **Halides:** combination of an element with a halogen (chlorine, bromine, iodine)
- **Oxides:** element combined with oxygen (e.g., Hematite – iron oxide)
- **Sulfides:** element combined with sulfur (e.g., Pyrite – iron sulfide, Galena – lead sulfide)
- **Elements and Complex Ions:** minerals containing charged ions, not just single atoms

THE RELATIVE ABUNDANCE OF MINERALS in the earth's crust and mantle is governed by the relative abundance of the elements in these units. If we for example consider the weight fractions of elements in the crust, it is obvious that

Element	Approximate Percentage by Weight
Oxygen (O)	46.6
Silicon (Si)	27.7
Aluminum (Al)	8.1
Iron (Fe)	5.0
Calcium (Ca)	3.6
Sodium (Na)	2.8
Potassium (K)	2.6
Magnesium (Mg)	2.1
All others	1.5
Total	100

Table 1: Element Percentage

Oxygen is by far the most abundant, followed by Silica and Aluminum. The elements from Oxygen to Magnesium make up 98.5% of the crust and are called "major" elements. The elements that make up the remaining 1.5% are called the minor elements (abundance some tenth of a percent) and the trace elements (abundance measured in ppm)

Minerals in the Earth’s Crust

The Earth’s crust is composed of a vast variety of minerals, with over **3,000 identified types**, and the number continues to grow as new minerals are discovered. Despite this diversity, only about **20 minerals are relatively common**, and out of these, just **9 minerals make up approximately 95% of the Earth’s crust**. These dominant minerals are all **silicates**, which are minerals containing silicon and oxygen in their structure, making them the primary **rock-forming minerals**.

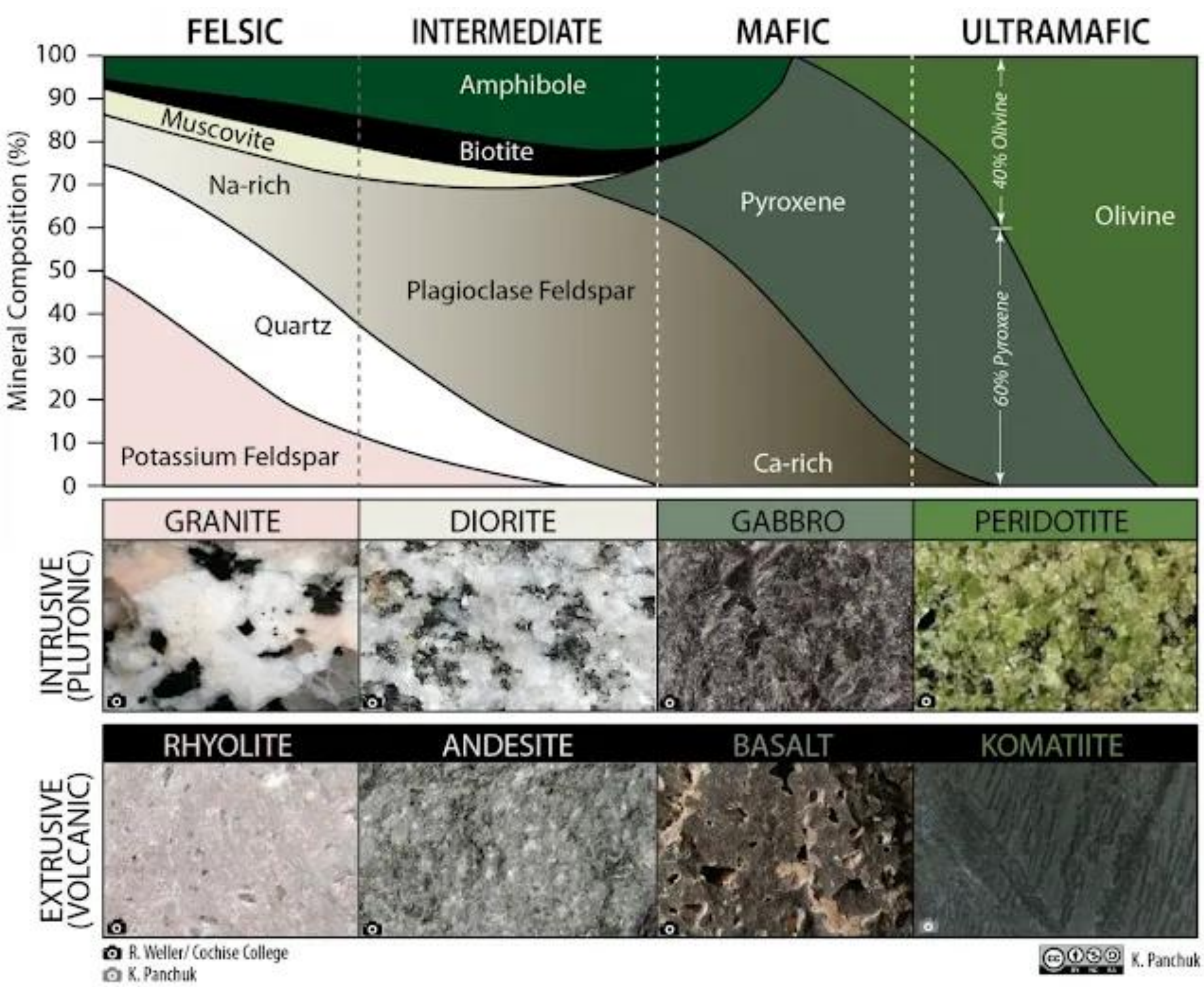

Figure 6: Minerals composition

Silicate Minerals

Silicate minerals are minerals that contain **silicon (Si)** and **oxygen (O)** as their main components. They are the **most abundant mineral group** in the Earth's crust, making up about **90%** of all minerals.

Examples: Quartz, Feldspar, Mica, Olivine

Basic Structure:

- Built from the silicon–oxygen tetrahedron $(SiO_4)^{4-}$
- One silicon atom bonded to four oxygen atoms

Figure 7: Silicate Minerals

Non-Silicate Minerals

Non-silicate minerals are minerals that **do not contain the silicon–oxygen tetrahedron**. They are classified based on their dominant chemical element or ion.

Major Groups and Examples:

- **Carbonates** – Calcite, Dolomite
- **Oxides** – Hematite, Magnetite
- **Sulfides** – Pyrite, Galena
- **Sulfates** – Gypsum
- **Halides** – Halite

Figure 8: Non-Silicate Minerals

Difference of Silicate Minerals and Non-Silicate Minerals

Aspect	Silicate Minerals	Non-Silicate Minerals
Main Elements	Silicon and Oxygen	Various elements (C, S, Cl, Fe, etc.)
Abundance	Most abundant in Earth's crust	Less abundant
Basic Structure	Silicon–oxygen tetrahedron	No tetrahedral structure
Examples	Quartz, Feldspar, Mica	Calcite, Gypsum, Halite
Engineering Use	Aggregates, building stones	Cement, plaster, industrial materials

Table 2: Silicate Minerals vs. Non-Silicate Minerals

Mafic Minerals

Mafic minerals are rich in magnesium (Mg) and iron (Fe). The term *mafic* comes from **MA**gnesium and **F**erric (iron). These minerals usually have dark colors and are denser.

Characteristics:

- Dark-colored (black, dark green)
- High density
- Low silica content
- Crystallize at high temperatures
- Common in the Earth's mantle

Examples:

Figure 9: Biotite

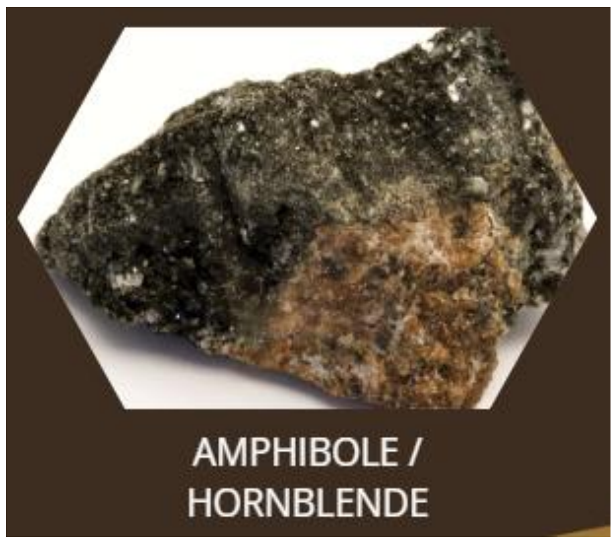

Figure 10: Amphibole / Hornblende

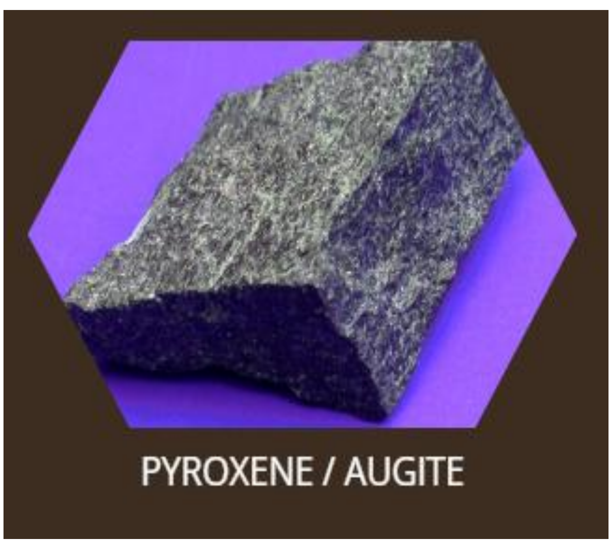

Figure 11: Pyroxene / Augite

Figure 12: Olivine

Felsic Minerals

Felsic minerals are rich in silica (SiO_2), feldspar, and aluminum (Al). The term *felsic* comes from **FEL**dspar and **SIC**a. These minerals are generally light-colored and less dense.

Characteristics:

- Light-colored (white, pink, light gray)
- Low density
- High silica content
- Crystallize at low temperatures
- Common in the continental crust

Examples:

Figure 13: Quartz

Figure 14: Muscovite

Figure 15: Orthoclase

Figure 16: Na-plagioclase / Albite

ROCKS

Rocks are solid materials that make up the Earth's crust, composed of minerals. Minerals in rocks determine rock type, strength, and properties. Geologists classify rocks into three main groups: Igneous, Sedimentary, and Metamorphic.

The Rock Cycle

The rock cycle is a continuous natural process that explains how rocks are formed, changed, destroyed, and reformed through time by geological processes occurring both on and beneath the Earth's surface. It shows the dynamic relationship among the three main rock types—igneous, sedimentary, and metamorphic rocks and demonstrates that rocks are not permanent but are constantly being transformed due to changes in temperature, pressure, and environmental conditions.

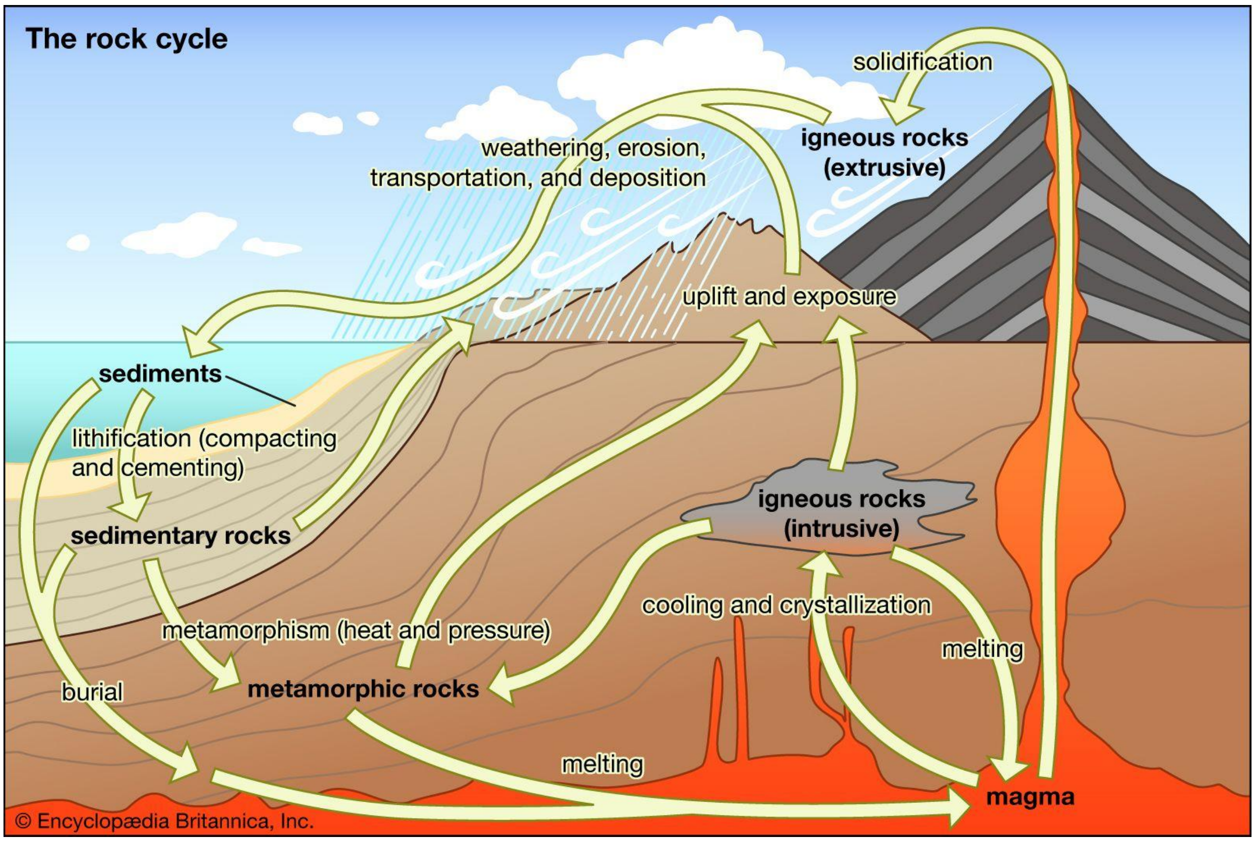

Figure 17: The Rock Cycle

The cycle begins with magma, molten material beneath the Earth's surface. When magma cools and solidifies, it forms igneous rocks, either intrusive (cooling slowly beneath the surface) or extrusive (cooling rapidly at the surface as lava). Over time, igneous rocks exposed at the surface undergo weathering and erosion, breaking down into sediments that are transported by wind, water, or ice. These sediments are deposited, compacted, and cemented to form sedimentary rocks.

As sedimentary or igneous rocks are buried deeper within the Earth, they may be subjected to high temperatures and pressures, causing physical and chemical changes without melting. This process results in the formation of metamorphic rocks. If metamorphic rocks are exposed to extreme heat, they may melt and return to magma, completing the cycle.

Igneous Rocks

Igneous Rocks are formed by the cooling and crystallization of a silicate melt (dominated by oxygen and silicon, with a variety of other metals). The occurrence and distribution of igneous rocks and igneous rocks types can be related to the operation of plate tectonics. The molten rock material from which igneous rocks form is called **magma**. Magma is molten silicate material and may include already formed crystals and dissolved gases. The name magma applies to silicate melts within the Earth's crust, when magmas reach the surface they are referred to as **lava**. Magma Families

What is Magma?

The origin of magmas has been a subject for considerable scientific debate in the first half of this century, but today it is basically agreed that three principal magma families (see above) can distinguished, basaltic, andesitic, and granitic, and that they are all the product of partial melting.

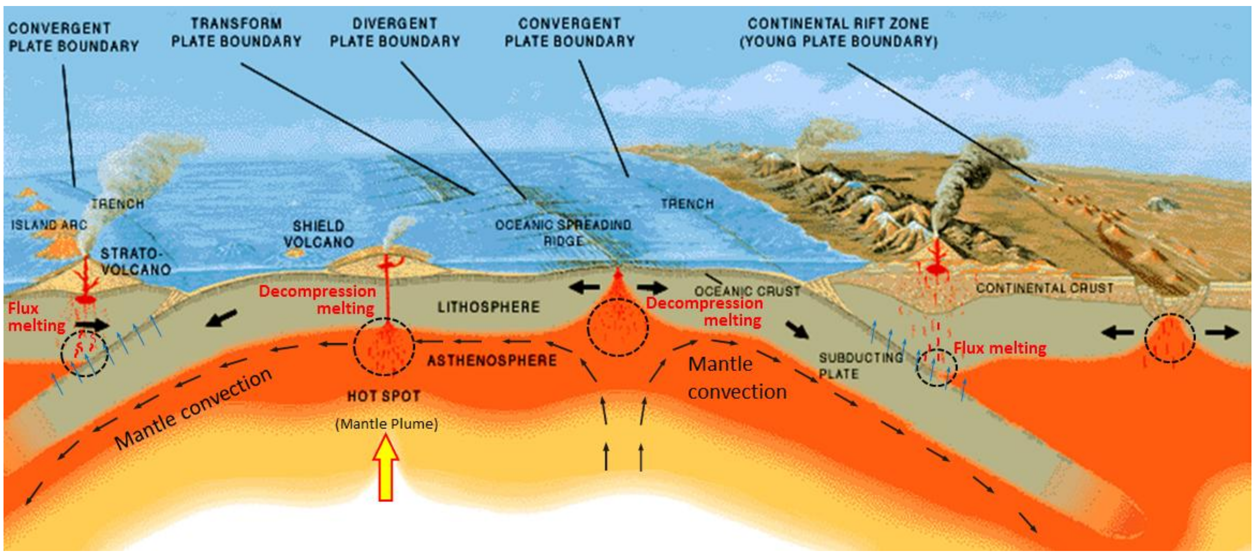

Figure 18: Magma

Three Principles of Magma Families

- **Basaltic Magmas** have comparatively low silica contents (about 50%) and have temperatures between 900 and 1200 degrees Celsius. They are rich in iron and magnesium and form through partial melting of the upper mantle (from peridotite) in areas of mantle upwelling and high heat flow (mid-oceanic ridges; continental rifts).
- **Andesitic Magmas** are intermediate in composition between basalts and granites. They form trough partial melting of subducted ocean crust in areas of crustal convergence (subduction zones). In areas of island arc formation, they are the dominant magma type. In areas of crustal compression and thickening (subduction near continent) they occur together with granitic magmas that originate in the lower crust.
- **Granitic Magmas** have high silica contents (60-70%) and usually have temperatures below 800 degrees Celsius. They originate in the lower crust in the deeply buried "root zones" of mountain belts. In these areas the temperatures of deeply buried rocks become high enough to allow partial melting. The melts that form under these conditions are granitic in composition.

Two main types of Igneous Rocks

- **Extrusive Rocks -** are igneous rocks that form when magma reaches the Earth's surface as lava and cools rapidly. Because cooling happens very fast, crystals do not have enough time to grow large, resulting in fine-grained or glassy textures. These rocks are commonly formed during volcanic eruptions. Examples of extrusive rocks include basalt, obsidian, and pumice.
- **Intrusive Rocks -** form when magma cools slowly beneath the Earth's surface. The slow cooling allows crystals to grow larger, producing a coarse-grained texture. Intrusive rocks make up a significant portion of the Earth's crust and are often exposed at the surface through erosion over long periods of time. Common examples include granite, diorite, and gabbro.

Igneous Rocks and Mineral Composition

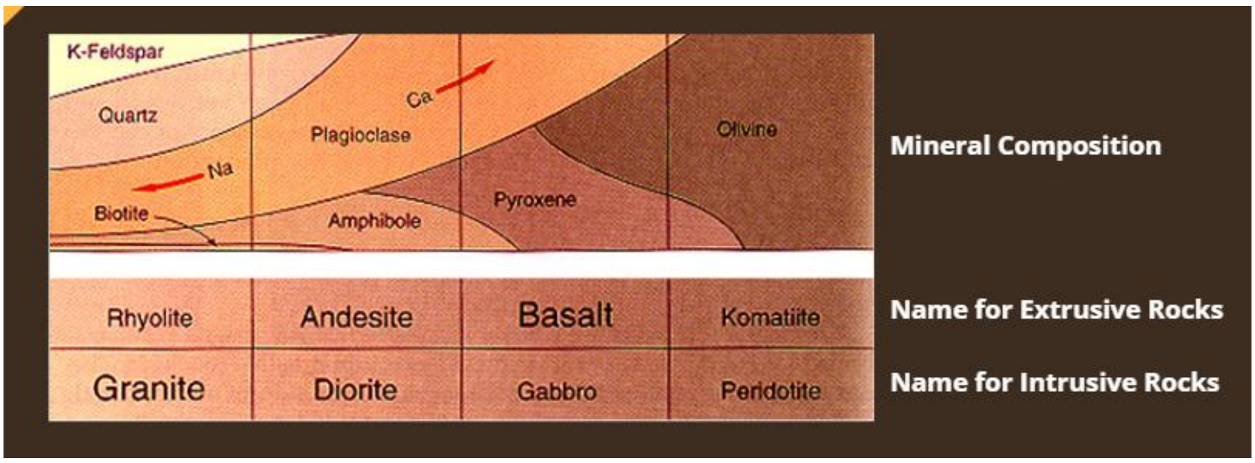

Figure 19: Composition

This diagram shows the main groups of igneous rocks, their main mineral constituents and their intrusive (cooling in the crust) and extrusive (cooling as lava flow) equivalents. For example: granitic magmas solidify to granite if they cool in the crust (intrusive), but are called rhyolites if they cool down after they reach the Earth's surface as lava flows (extrusive). Both, rhyolites and granites, are composed of K-feldspar, Quartz, Sodium Plagioclase, and Biotite. Peridotite is the name for rocks of the upper mantle, and Komatiite is the name for extrusive lavas that are essentially of Peridotite composition. The latter are found primarily in very old rocks (Archean) that formed soon after the formation of the first crust (crust was thin, very mobile, and convection was vigorous).

Sedimentary Rocks

Sedimentary Rocks are a product of the surface processes of the earth (weathering, erosion, rain, streamflow, wind, wave action, ocean circulation). The starting material for sedimentary rocks is the rocks outcropping on the continents. Processes of physical and chemical weathering break down these source materials into the following components: small fragments of the source rock (gravel, sand, or silt size) that may be identifiable rock fragments or individual minerals new minerals produced by weathering processes (mainly clays) dissolved portions of the source rock (dissolved salts in river and ocean water).

Formation of Sedimentary Rocks

Sedimentary rocks form when loose sediments become solid through the processes of compaction and cementation, creating layered structures known as stratification. Each layer represents a specific period of time, with older layers beneath and younger layers above, making sedimentary rocks an important record of past climates, landscapes, and geological events. These rocks also preserve fossils, providing evidence of plant and animal life over more than 3 billion years and serving as a key foundation for the theory of evolution. Because sedimentary processes shape the Earth's surface and are easily observed, and since about 75% of the Earth's exposed land surface is made up of sediments and sedimentary rocks, they are more familiar and better understood than igneous and metamorphic rocks, even being observed on other planets such as Mars.

Metamorphic Rocks

Metamorphic rocks are those whose original texture, composition and mineralogy have been changed by conditions of high pressure and temperature (higher than conditions of formation of starting material). The materials from which metamorphic rocks form are igneous rocks, sedimentary rocks, and previously existing metamorphic rocks.

Formation of Metamorphic Rocks

Metamorphic rocks form when pre-existing rocks igneous, sedimentary, or older metamorphic rocks are transformed by high temperature, high pressure, and chemically active fluids deep within the Earth, without melting. These conditions cause changes in the rock's mineral composition, texture, and structure, resulting in new minerals and stronger, more compact rocks. Metamorphism commonly occurs during mountain-building processes, deep burial, or near molten magma, producing rocks such as marble, slate, schist, and gneiss.

Role of Rock Formation in Civil Engineering

Rock formation plays a crucial role in civil engineering as it directly affects the **strength, durability, and stability** of rocks, which determines their ability to safely support loads for buildings, roads, bridges, and other structures. Understanding how rocks form helps engineers design **safe and stable foundations** for major structures such as high-rise buildings, dams, and tunnels by accurately assessing subsurface conditions. Knowledge of rock-forming processes also guides the **selection of appropriate construction materials**, including aggregates, cement raw materials, and building stones, ensuring long-lasting and reliable structures. Additionally, studying rock formation enables engineers to identify and mitigate **geologic hazards** such as earthquakes, landslides, and ground instability, leading to safer infrastructure design and more effective site selection.

REFERENCES

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