Chapter 7

Minerals

7.1 Minerals

- Minerals have a specialized geologic definition: naturally occurring, (mostly) inorganic crystalline solids formed by geologic processes and with a definite chemical composition.
- Minerals make up most rocks and sediments of the solid Earth.
- Minerals used as resources by mankind:
  - Industrial minerals provide the raw materials for manufacturing chemicals, concrete, and wallboard.
  - Ore minerals are the source of valuable metals, like copper and gold (e.g., Malachite is a type of copper ore ($Cu_2[CO_3][OH]_2$); it contains copper plus other chemicals
  - Gems delight the eye in jewelery.
- Certain minerals pose health and environmental hazards.

7.2 Mineral vs Glass

- Both mineral and glass are solids, but minerals are crystalline, while glass is not.
  - Atoms, ions, or molecules in a *mineral* are ordered into a geometric arrangement.
  - Atoms, ions, or molecules in *glass* are arranged in a semi-chaotic way, in small clusters or chains that are neither oriented in the same way nor spaced at regular intervals.

7.3 Crystals

- A crystal is a single, continuous (uninterrupted) piece of a crystalline material bounded by flat crystal surfaces, called crystal faces, that form naturally as the crystal grows.

- The angle between two adjacent crystal faces of any mineral specimen is identical to the angle between the corresponding faces of any other specimen of the same mineral.
  - e.g., the angle between the faces of the columnar part of a quartz crystal is exactly 120°.
- *All minerals are crystalline, but not all crystals are minerals!*
- Crystals come in a variety of shapes, including cubes, trapezoids, pyramids, octahedrons, blades, needles, columns, and obelisks.
- The geometry of the arrangement defines the crystal structure.

7.4 Inside a Mineral

- X-ray diffraction (XRD) is still used today to identify minerals!
- When an X-ray beam passes through a crystal, it interacts with the regularly spaced atoms inside.
- Because the spacing between atomic planes is similar to the wavelength of X-rays, the beam is diffracted (bent and scattered).
- This diffraction produces a distinctive pattern of spots or rings on a detector screen.

7.5 Crystal's Structure

- The geometry of the atomic packing and the nature of chemical bonding determine the mineral's properties.
  - The way elements are packed into a mineral crystal lattice depends upon the size and the charge of the ions of that element.
  - A large central cation requires a large number of anions; a smaller central cation, fewer anions.
  - e.g., sodium (Na^+) and chloride (Cl^-) ions are bonded in a cubic lattice by ionic bonds to form the mineral halite ($NaCl$), commonly known as salt.

7.5.1 Polymorphs

- Minerals that share the same chemical composition but have different crystal structures, meaning their atoms are arranged differently.
- Diamond vs. Graphite (both Carbon)
  - In diamond, each carbon atom bonds with four neighbors in a tight tetrahedral structure, making diamonds extremely hard.

  - In graphite, carbon atoms form flat sheets arranged in hexagons. The sheets are held together by weak bonds, so they easily slide past each other–this is why graphite is soft and works as "lead" in pencils.

7.6 Formation of Minerals

A new mineral crystal can form in one of five ways:

Solidification of a melt

Precipitation from a water solution - atoms, molecules, or ions dissolved in water bond together and separate out from the water.

Precipitation from a gas - typically occur around volcanic vents or geysers.

Solid-state diffusion - atoms migrate through the crystal and new minerals grow inside the rock.

Biomineralization - minerals can form at interfaces between the physical and biological components of the earth system.

7.7 Growth of Crystals

- The first step in forming a crystal happens when the chance assembly of a seed, an extremely small crystal, takes place.
- Once the seed exists, other atoms in the surrounding material attach themselves to the faces of the seed, and the seed grows into a crystal.
- As the crystal grows, its faces move outward but maintain the same orientation.
- A growing crystal develops its particular crystal shape based on the geometry of its internal crystal structure.

7.8 Destruction of Minerals

A mineral can be destroyed by melting, by dissolution, or by some other chemical reactions:

Melting involves heating a mineral to a temperature at which thermal vibrations of the atoms or ions in the crystal structure break the chemical bonds holding them to the lattice.

Dissolution takes place when a mineral is immersed in a solvent, such as water.

Chemical reactions can destroy a mineral when it comes in contacts with reactive materials.

7.9 Mineral Identification

Mineral identification requires learning mineral physical properties.

7.9.1 Color

- The color or a mineral results from how it interacts with light.
- Minerals absorb specific wavelengths of light, and the color we see is the combination of wavelengths that are not absorbed.
- Small amounts of chemical impurities can change the color dramatically. For example, trace amounts of iron can make quartz appear purple (amethyst) or yellow (citrine).

7.9.2 Streak

- The streak of a mineral is the color of its powdered form, produced by scraping the mineral across an unglazed ceramic plate.
- The streak color can be the same or different from the minerals' outward appearance.
- Streak color is often more consistent and reliable than external color, which may vary due to impurities or surface weathering.
  - e.g., Calcite always leaves a white streak, even though whole crystals may appear white, pink, or clear.
- Limitations: the streak test works best for minerals with a hardness of < 6 on the Mohs scale (so that it can be ground/powdered against the porcelain plate).

7.9.3 Luster

- Luster refers to the way a mineral surface scatters light.
- The two main subdivisions of luster are metallic and nonmetallic:

  Metallic luster : minerals that look like metal

  Nonmetallic luster : minerals that do not look like metal

7.9.4 Hardness

- Hardness indicates a mineral's ability to resist scratching, which depends on the strength of the bonds in its crystal structure.

Relative hardness : hard minerals can scratch softer ones, but soft minerals cannot scratch harder ones.

Mohs hardness scale : Friedrick Mohs arranged common materials in order of relative hardness.

- e.g. If your fingernail (hardness ~ 2.5) scratches a mineral, that mineral must be softer than 2.5.

7.9.5 Crystal Habit

- Crystal habit describes the external shape of a well-formed crystal or the overall appearance of a group of crystals that grew together.
- Habit reflects the internal atomic arrangement of the mineral.
- Common descriptive terms include cubic, prismatic, bladed, platy, and fibrous.
  - Wulfentie commonly forms thin, tabular plates.
  - Kyanite typically forms bladed crystals.

7.9.6 Cleavage

- Cleavage is the tendency of a mineral to break along specific planar surfaces that correspond to zones of weaker atomic bonding within the crystal lattice.
- The number of cleavage planes and the angles between them are diagnostic features used in mineral identification.
- Cleavage can be distinguished from crystal faces because cleavage repeats throughout the mineral, whereas crystal faces are just the external growth surfaces of the crystal.

7.9.7 Fracture

- Minerals that lack cleavage break by fracture, which may appear irregular or uneven.
- Conchoidal fracture is a special type of fracture that produces smoothly curving, clamshell-shaped surfaces. This is commonly seen in glass, quartz, and obsidian.
- Fracture is distinct from cleavage because it does not follow any specific atomic planes within the crystal structure.

7.9.8 Others

Other less common physical properties that are useful for identifying minerals:

Effervescence reactivity with acid

Magnetism magnetic attraction

Taste & smell

Feel tactile response

Elasticity response to bending

Diaphaneity relative transparency

Pizoelectricity electric charge when squeezes

Pyroelectricity electric charge when heated

Refractive Index degree of bending light

Malleability ability to be pounded into thin sheets

Ductility ability to be drawn into this wires

Sectility ability to be shaved with a knife

Specific Gravity

7.10 Hazardous Minerals

Some minerals contain toxic chemicals that can pose serious health risks.

- Arsenopyrite contains arsenic, which can release poisonous compounds when weathered.
- Asbestos is a fibrous silicate mineral; when inhaled, its needle-like fibers can lodge in human lungs, causing diseases such as asbestosis, mesothelioma, and lung cancer.
- Pulverized silicates (like quartz dust) can cause silicosis, a chronic lung disease, when inhaled over long periods.

7.11 Mineral Classification

Mineralogists distinguish **seven principal classes** of minerals:

Silicates all silicates contain the ${SiO_4}^{4-}$ anionic group.

Sulfides consists of a metal cation bonded to a sulfided anion (${S_2}^{-}$).

Oxides consist of metal cations bonded to oxygen atoms.

Halides the anion in a halide is a halogen or salt producing ion (such as chloride (Cl^-) or fluoride (F^-)).

Carbonates in carbonate minerals, the molecule ${CO_3}^{2-}$ serves as the anionic group.

Native metals consist of pure masses of a single metal.

Sulfates consist of metal cations bonded to ${SO_4}^{2-}$.

7.11.1 Silicates

- Silicates are the major rock-forming minerals, making up over 95% of the continental crust.
- All silicates contain the $SiO_4{}^{4-}$ anionic group, also called the silica tetrahedron. In this structure, four oxygen atoms surrounds a single silicon atom, forming a pyramid-like shape with four triangular faces.
- Silicate minerals are grouped based on how these silica tetrahedra are arranged and linked together.
- The arrangement depends on how many oxygen atoms are shared between tetrahedra, which in turn determines the silicon-to-oxygen ratio in the mineral.
  - Isolated tetrahedra (independent)
  - Single-chain silicates
  - Double-chain silicates
  - Sheet silicates
  - Framework silicate

7.11.2 Gemstones and Gems

- A gemstone is a mineral that holds special value because it is rare and considered beautiful.
- Gemstones can form in several ways, including solidification from melt, diffusion, precipitation, or chemical interaction between rock and water near Earth's surface.
- When a gemstone is cut and polished, it becomes a gem, ready to be set into jewelry.
  - Precious stones include diamond, ruby, sapphire, and emerald
  - Semiprecious stones include topaz, tourmaline, aquamarine, and garnet
  - Most gemstones are transparent crystals, often showing vibrant colors that add to their appeal.

Table 7.1: Precious and Semiprecious Materals Used in Jewelry

Gem Name	Material/Formula	Comments
Amber	Fossilized tree sap	Composed of organic chemicals; amber is not strictly a mineral.
Amethyst	Quartz/SiO_2	The best examples precipitate from water in openings in igneous rocks; a deep purple version of quartz.
Aquamarine	Beryl/$Be_3Al_2Si_6O_{18}$	A bluish version of emerald.
Diamond	Diamond/C	Brought to the surface from the mantle in igneous bodies called diamond pipes; may later be mixed in deposits of sediment.
Emerald	Beryl/$Be_3Al_2Si_6O_{18}$	Occurs in coarse igneous rocks (pegmatites)
Garnet		
Jade		
Opal		
Pearl		
Ruby		
Sapphire		
Topaz		
Tourmaline		
Turquoise		