Chapter 3

Minerals and Rocks

Introduction to Environmental Geology, 5e

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Chapter Three: Overview

- Introduction to minerals: chemistry & structure
- Introduction to major rock-forming minerals
- Know the rock cycle and interaction with plate tectonics
- Discuss three ‘rock laws’
- Introduction to basic rock types and environmental significance
- Know basic rock structures

Case History: Asbestos

- A group of silicate minerals
- Some are hazardous to human health: Causing fatal lung diseases
- Useful mineral Material: Fire retardant property for brake lining and insulations
- Fibrous minerals: White asbestos (less harmful), blue asbestos (hazardous)
- Removal of asbestos: Depending upon the properties of the asbestos used and the context in which they are used

Importance of Rocks and Minerals

- Fundamental building blocks of Earth
- Various uses for modern economic developments
- Important clues for interpreting Earth’s history
- Knowledge of minerals & rocks is the first important step to better manage Earth’s resources
- Important to our health and environment

Basic Chemistry Review

- All matter, including minerals and rocks, made of atoms
- *Atom structure:* Nucleus (proton and neutron) and surrounding electrons
- *Atomic number:* The unique number of protons in an element’s nucleus
- *Atomic mass number:* The sum of the member of protons and neutrons

Rock-Forming Mineral Groups

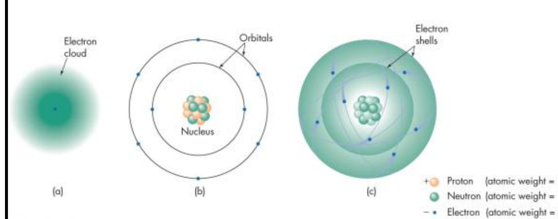


Figure 3.2

Basic Chemistry Review

- *Ion*: Charged atom particles, reactions between different types of atoms
- *Isotopes*: Atoms of the same element with varied number of neutrons
- Chemical bonding
  - Ionic bonds
  - Covalent bonds
  - Metallic bonds
  - van der Waals bond

Mineral Definitive Properties

- Made of an element or a chemical compound
- Definitive chemical composition
- Orderly, regular repeating internal atomic arrangement (i.e., crystalline structure)
- Inorganic solids
- Formed by natural (geologic) processes

Crystalline Structure

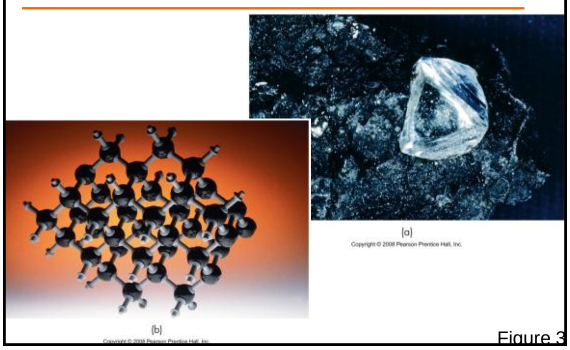


Figure 3

Mineral Diagnostic Properties

- Color and streak
- Luster
- Crystal form
- Cleavage
- Hardness
- Special properties (taste, smell, feel, tenacity, reaction to acid, magnetism)

Important Rock-Forming Minerals

- More than 4000 known minerals
- Only a few dozen are common constituents of rocks at or near Earth's surface
- Hand specimen identification involves appearance and physical properties
  - Mineral properties summarized in Appendix A
- Weathering
  - Physical and chemical breakdown of rocks at or near Earth's surface
  - Important in forming sediments and soils

Important Rock-Forming Minerals

- Common mineral groups are primarily classified by chemical composition
  - Silicates: Contain Si-O tetrahedron fundamental building unit, the most abundant mineral group
  - Silcates: comprise most of Earth's crust made up of O, Si, Al, Fe, Ca, Mg, Na, and K.
  - Common mineral groups: quartz, feldspar group, mica group, and ferromagnesian groups.

Rock-Forming Mineral Groups

- Other common non-silicate mineral groups:
  - Carbonates: contain containing the carbonate ion CO_3^{2-} [calcite and dolomite for building]
  - Oxides: Contain oxygen atoms bonded to an atom of another element [hematite for iron]
  - Sulfides: Contain sulfur atoms bonded to one or more metallic elements [sphalerite for zinc]
  - Native elements: Made of single element

Rock-Forming Mineral Groups

TABLE 3.2 Rock-Forming Minerals by Groups, Based Mostly on Chemistry

Mineral Group	Examples	Chemical Formula	Comments
Silicates	Quartz	SiO_2	Common
	Plagioclase feldspars	$(Na, Ca)Al(Si, Al)_2 O_8$	Very common
	Pyroxene	$(Ca, Mg, Fe)_2 Si_2O_6$	Ferromagnesian mineral
Carbonates	Calcite	$CaCO_3$	Main minerals in limestone and marbles
	Dolomite	$(Ca, Mg)CO_3$	
Oxides	Hematite	Fe_2O_3	Primary ore of iron
	Bauxite	Hydrous aluminum oxides	Primary ore of aluminum
Sulfides	Pyrite	FeS_2	Major constituent of acid mine drainage
	Galena	PbS	Primary ore of lead
Native elements	Gold	Au	Precious metal, industrial uses
	Diamond	C	Jewelry, industrial uses
	Sulfur	S	Used to produce sulfuric acid

Note: A more extensive list is in Appendix A.

Table 3.2

Rocks

- Aggregated solids of minerals, organics, and/or fossil fragments
- Three major types of rocks classified by origin, the way the rocks formed
- Fundamental links between rocks and environment (resources, sources for acid rain drainage, land subsidence, structure foundation failures, etc.)
- Rocks identified by mineralogy and texture

Rock Cycl

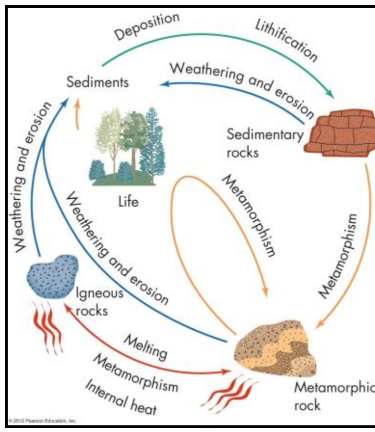


Figure 3.13

Three Fundamental Rock Laws

- The law of crosscutting relationships
  - **Rock is younger than the one is cuts across**
- The law of original horizontality
  - **Sedimentary rock layers generally for at near horizontal under normal conditions**
- The law of superposition
  - **Rocks become progressively younger towards the top in an undisturbed/undeformed rock unit**

Igneous Rocks

- Cooled, crystallized/solidified from magma
- Records of Earth's thermal cooling history
- *Intrusive rocks:* Crystallized/solidified beneath the Earth surface
- *Extrusive rocks:* Crystallized/solidified at or near the Earth surface
- *Classification*- Based on:
  - Texture (cooling rate and environment)
  - Composition (what minerals make up the rock)

Igneous Rock Texture

- Dictated by the rates of magma or lava cooling
- Slower rates of cooling beneath the surface …faster rates of cooling at or near the surface
- The slower the magma cools, the coarser the mineral particles in igneous rocks
- Igneous rocks formed from two stages of cooling having distinctive, different-sized particles (minerals)

Intrusive Igneous Rocks

- Cool slowly and crystallizes well below the surface to form course grains (phaneritic)
- Mineral grains can be seen with naked eye
- Phenocrysts - crystals larger than surrounding crystals (matrix)
- Inclusions are pieces of surrounding rock incorporated into crystallizing magma
- Batholiths and plutons
  - Batholiths are the largest masses of igneous rock, often exceeding thousands of cubic kilometers…plutons are small intrusions

Extrusive Igneous Rocks

- Cool quickly at or near the surface of Earth
- Form from lava or pyroclastic debris
- Fine-grained because rapidly cooled (aphanitic)
- Porphyritic textures have large crystals surrounded by smaller crystals
- Volcanic breccia
  - Lava flow mixed with cemented fragments of broken lava and ash
- Pyroclastic debris forms tuff and agglomerate

Igneous Rock Texture

- Phaneritic
- Aphanitic
- Porphyritic
- Vitreous or glassy
- Vesicular or frothy
- Pyroclastic

(a)

Figure 3.16a

Igneous Rock Composition

- Depending on the composition of magma
- *Felsic/granitic:* silica-rich, typically related to continental crust, lighter colors, lower density
- *Intermediate/andesitic:* 50:50 composition, commonly associated with convergent plate boundaries along the Pacific rim, eruptive volcanism
- *Mafic/basaltic:* silica poor, usually related to oceanic crust, darker colors, higher density

Common Igneous Rocks

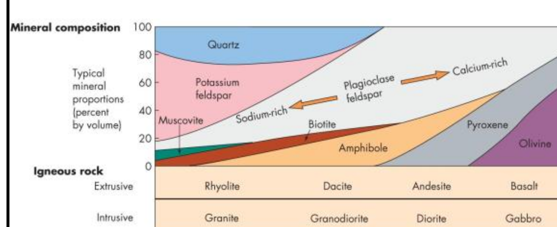


Figure 3.15

Common Igneous Rocks

Composition Texture	Felsic	Intermediate	Mafic
Intrusive	Granite	Diorite	Gabbro
Extrusive	Rhyolite	Andesite	Basalt


Figure 3.16c


Figure 3.16b

Igneous Rocks and the Environment

- Intrusive rocks are generally strong and more resistant to weathering
- Lava flows often exhibit columnar jointing and lava tubes, both of which impart weaknesses
- Tuff is generally a soft, weak rock
- Careful field investigation is always necessary before large structures are built on igneous rocks

Sedimentary Rocks

- Form at or near surface environments
- Constitutes about 75% of all rocks exposed at the surface
- Contains records of present and past surface environments (landscape and climate)
- Diagenesis - processes that take place after sediment comes to rest and forms rock
- Two major types of sedimentary rock:
  - Detrital
  - Chemical

Detrital Sedimentary Rocks

- Compacted and cemented from sediments
- 'Clastic' texture…made of pieces of mineral or other rock fragments
- ***Formation process***: transportation, deposition, compaction, and cementation
- Fossil-fuel bearing rocks (shale…sandstone)
- Classified by size of the particle/grain
- ***Shale***: the most abundant clastic rock

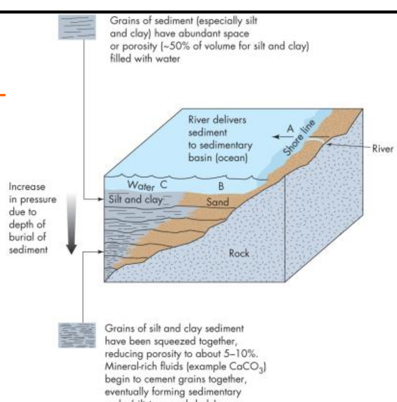


Figure 3.22

Chemical Sedimentary Rocks

- Precipitated from chemical solutions and/or an accumulation of chemical or *biological* matter in water
- Classified based on composition and texture (clastic or nonclastic)
- Common textural terms are: crystalline, skeletal, oolitic, massive (microcrystalline)
- ***Limestone***: the most abundant chemical sedimentary rock

(f)

Common Sedimentary Rocks

TABLE 3.3 Detrital (A) and Chemical (B) Sedimentary Rocks

	Size	Sediment	Rock
(A) Detrital (Clastic) Sedimentary Rocks	Greater than 2 mm	Gravel	**Conglomerate:** often has a sandy matrix. If particles are angular, rock is called breccia (Figure 3.17d).
	$\frac{1}{16}$ – 2 mm	Sand	**Sandstone:** generally designated as coarse (0.5–1 mm), medium (0.25–0.49 mm), or fine (0.13–0.24 mm) if well-sorted (consisting of sand particles of approximately the same size). Have also been subdivided on the basis of the composition; the more important types are: **Quartzose sandstone** (mainly quartz; see Figure 3.17c) **Arkosic sandstone** (arkose): over 20 percent feldspar **Graywacke:** poorly sorted (consisting of sand particles of many sizes mixed together); contains rock fragments with a clay matrix
	$\frac{1}{256}$ – $\frac{1}{16}$ mm	Silt	**Siltstone** (mudstone): compacted or cemented silt and clay lacking fine lamination
	Less than $\frac{1}{256}$ mm	Clay	**Shale:** compacted or cemented silt and/or clay with fine laminations along which rock easily splits (fissility). Rocks composed of clay that lack fissility are called claystone. Mudstone is an unlaminated mixture of silt and clay.

Table 3.3a

Common Sedimentary Rocks

TABLE 3.3 Detrital (A) and Chemical (B) Sedimentary Rocks

	Principal Composition	Principal Texture	Rock
(B) Chemical (Nonclastic) Sedimentary Rocks	Calcite, $CaCO_3$	Fine[1]	**Limestone:** often of biologic origin and may contain fossils. *Coquina* is limestone composed mainly of fossils or fossil fragments. Effervesces in diluted hydrochloric acid.
	Calcite, $CaCO_3$	Fine	**Chalk:** soft, white limestone formed by the accumulation of microscopic shells. Effervesces with dilute hydrochloric acid.
	Silica, SiO_2	Fine	**Chert:** hardness 6 or 7,[3] often white, flint is black or dark gray.
	Gypsum, $CaSO_4 \cdot 2H_2O$	Fine to coarse[2]	**Gypsum:** hardness 2. One good cleavage and two poorer cleavages.
	Halite, NaCl	Fine to coarse	**Rock salt:** cubic crystals and cleavage may be visible. Salty taste.
	Silica, SiO_2	Fine	**Diatomite:** soft, white rock formed by the accumulation of microscopic shells composed of silica. Distinguished from chalk by lack of effervescence in diluted hydrochloric acid.

[1]Cannot see grains with naked eye; generally grain size is less than 1/16 mm.

[2]Can see grains with naked eye; generally grain size is greater than 2 mm.

[3]See Appendix A for definition of hardness.

Modified after Foster, R. J. 1991. Geology, 6th ed. Upper Saddle River, NJ: Prentice Hall.

Table 3.3b

Sedimentary Structure and Environment

- *Stratification:* Law of original horizontality, law of supposition
- *Cross-bedding:* Movement direction of ancient currents
- *Fossil content:* Environment setting (continental, marine, or transitional)

Sedimentary Rocks and the Environment

- Three primary environmental concerns:
  - shale, mudstone, and siltstone are often very weak
  - limestone generally not well suited for human use and activity, because of weathering characteristics
  - cementation may be weak
- Tends to contain fossil fuel and ore deposits
- Reservoir rock for groundwater supply
- Fine-grained clastic rocks and limestone in humid region: Very weak rocks causing environmental problems

Metamorphic Rocks

- Changed rocks from preexisting rocks under solid state (not re-melted)
- Changes in mineralogy and rock textures
- Agents of changes: temperature, pressure (both confining and differential), and chemically active fluids
- Records of Earth's dynamic processes: Tectonic movement and igneous intrusion

Metamorphic Rock Texture

- *Foliation:* Preferred alignment of platy minerals or particles
  - Minerals align perpendicular to stress
  - Rocks typically classified by texture: Slate, phyllite, schist, gneiss (fine to course grained)
- *Nonfoliation:* Random arranged and interlocked minerals or particles
  - Fine grained or coarse grained
  - Typically classified by composition: Marble, quartzite

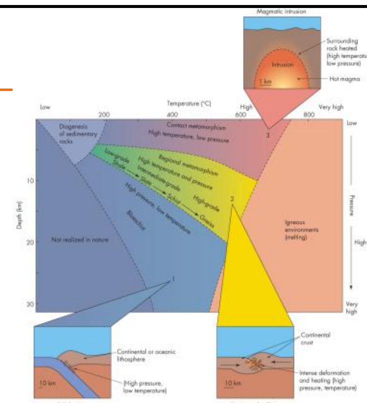
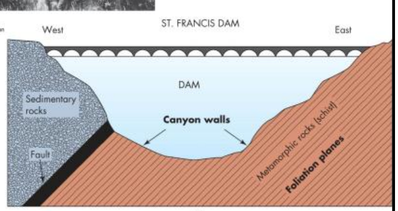


Figure 3.24

(a)

Metamorphic Foliation and Weakness



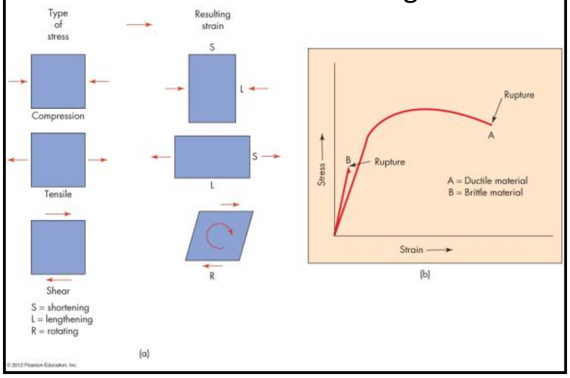
(b)

Figure 3.B

Metamorphic Rocks and the Environment

- Foundation materials
  - Slate is excellent for foundation material and other uses
  - Schist is poor because of soft minerals
  - Gneiss usually of suitable strength
- Foliation planes are potential planes of weakness
- Rock foliation and strength: site stability for facilities (nuclear power plants, dams,

Rock Structure and Strength



Rock Structure

- Deformation in response to stress (pressure and or temperature)
- ***Brittle deformation***: fractures, joints, and faults
  - Conduits for fluid movement, possibly pollutants
  - Weak surfaces for landslide, earthquake, and failures of infrastructure
- ***Ductile deformation***: folds (anticline & syncline)
  - Mountainous terrain
  - Related to active plate boundaries, linked to environmental problems
- **Deformation encourages weathering**

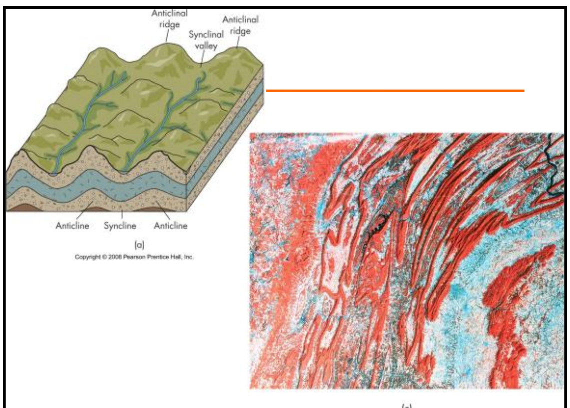


Figure 3.3 a/c

Rock Structure

- *Unconformity:* Contact structure of rocks
- Representing geologic time gap in geologic records, ancient erosion surface
  - Types: Nonconformity, angular unconformity, and disconformity
- Clues for ancient geologic environment

Figure 3.35

Critical-Thinking Topics

- Discuss different ways that rocks and minerals are used to benefit or to harm the environment
- What rock property and rock structure factors should you consider for a major engineering site selection?
- How can the composition and texture of a rock contribute to environmental risks?
- What factors contributed to the failure of the St. Francis Dam?