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

Mineral Diagnostic Properties

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

Crystalline Structure

![Image of a crystalline structure](image.png)

Figure 3

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
  - Silicates: 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 \( \text{CO}_3^{2-} \) [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

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**Rock Cycle**

- Deposition
- Weathering and erosion
- Metamorphism
- Melting
- Life

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**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

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**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

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**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:
  - Textures (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

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

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Common Igneous Rocks

<table>
<thead>
<tr>
<th>Composition</th>
<th>Texture</th>
<th>Felsic</th>
<th>Intermediate</th>
<th>Mafic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intrusive</td>
<td>Granite</td>
<td>Diorite</td>
<td>Gabbro</td>
<td></td>
</tr>
<tr>
<td>Extrusive</td>
<td>Rhyolite</td>
<td>Andesite</td>
<td>Basalt</td>
<td></td>
</tr>
</tbody>
</table>

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
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

Common Sedimentary Rocks

<table>
<thead>
<tr>
<th>TABLE 3.3</th>
<th>Detrital (A) and Chemical (B) Sedimentary Rocks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>Sediment</td>
</tr>
<tr>
<td>Greater than 2 mm</td>
<td>Gravel</td>
</tr>
<tr>
<td>1 to 2 mm</td>
<td>Sand</td>
</tr>
<tr>
<td>0.0625 to 0.25 mm</td>
<td>Silt</td>
</tr>
<tr>
<td>Less than 0.0625 mm</td>
<td>Clay</td>
</tr>
</tbody>
</table>

Limestone: the most abundant chemical sedimentary rock

**Figure 3.16(f)**, 4th ed

**Table 3.3a**

Common Sedimentary Rocks

**Stratification**: Law of original horizontality, law of superposition

**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

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, etc.)
**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**

**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

**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?