Rock cycle

- Shows the interrelationships among the three rock types
- Earth as a system: the rock cycle
  - Magma
    - Crystallization
  - Igneous rock
    - Weathering, transportation, and deposition
Rock cycle

Earth as a system: the rock cycle

- Sediment
  - Lithification
- Sedimentary rock
  - Metamorphism
- Metamorphic rock
  - Melting
- Magma
Earth as a system: the rock cycle

- Full cycle does not always take place due to "shortcuts" or interruptions
  - e.g., Sedimentary rock melts
  - e.g., Igneous rock is metamorphosed
  - e.g., Sedimentary rock is weathered
  - e.g., Metamorphic rock weathers
The rock cycle

Figure 3.2
Igneous rocks

- Form as magma cools and crystallizes
  - Rocks formed inside Earth are called **plutonic** or **intrusive** rocks
  - Rocks formed on the surface
    - Formed from **lava** (a material similar to magma, but without gas)
    - Called **volcanic** or **extrusive** rocks
Igneous rocks

- Crystallization of magma
  - Ions are arranged into orderly patterns
  - Crystal size is determined by the rate of cooling
    - Slow rate forms large crystals
    - Fast rate forms microscopic crystals
    - Very fast rate forms glass
Igneous rocks

- Classification is based on the rock's texture and mineral constituents
  - Texture
    - Size and arrangement of crystals
  - Types
    - Fine-grained – fast rate of cooling
    - Coarse-grained – slow rate of cooling
    - Porphyritic (two crystal sizes) – two rates of cooling
    - Glassy – very fast rate of cooling
Fine-grained igneous texture

Figure 3.4 A
Course-grained igneous texture

B. Coarse-grained

Figure 3.4 B
Porphyritic igneous texture

D. Porphyritic

Figure 3.4 D
Obsidian exhibits a glassy texture.
Igneous rocks

- Classification is based on the rock's texture and mineral constituents
  - Mineral composition
    - Explained by Bowen's reaction series which shows the order of mineral crystallization
    - Influenced by crystal settling in the magma
## Classification of Igneous Rocks

<table>
<thead>
<tr>
<th>Chemical Composition</th>
<th>Granitic (Felsic)</th>
<th>Andesitic (Intermediate)</th>
<th>Basaltic (Mafic)</th>
<th>Ultramafic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dominant Minerals</td>
<td>Quartz Potassium feldspar</td>
<td>Amphibole Sodium- and calcium-rich plagioclase feldspar</td>
<td>Pyroxene Calcium-rich plagioclase feldspar</td>
<td>Olivine Pyroxene</td>
</tr>
<tr>
<td>Texture</td>
<td>Phaneritic (coarse-grained)</td>
<td>Granite</td>
<td>Diorite</td>
<td>Gabbro</td>
</tr>
<tr>
<td></td>
<td>Aphanitic (fine-grained)</td>
<td>Rhyolite</td>
<td>Andesite</td>
<td>Basalt</td>
</tr>
<tr>
<td></td>
<td>Porphyritic</td>
<td>“Porphyritic” precedes any of the above names whenever there are appreciable phenocrysts</td>
<td>Obsidian (compact glass)</td>
<td>Pumice (frothy glass)</td>
</tr>
<tr>
<td></td>
<td>Glassy</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 3.7**

*Rock Color (based on % of dark minerals)*

- 0% to 25%
- 25% to 45%
- 45% to 85%
- 85% to 100%
Figure 3.9

The diagram illustrates Bowen's Reaction Series, which shows the sequence of mineral formation during the cooling of magma. The temperature regimes are divided into high temperature (first to crystallize) and low temperature (last to crystallize). Minerals form in a sequence that reflects the temperature conditions. From top to bottom, the minerals are:

- Olivine
- Pyroxene
- Amphibole
- Biotite mica
- Plagioclase feldspar
- Continuous Series of Crystallization
- Sodium-rich
- Calcium-rich

The final crystallization products are:

- Potassium feldspar + Muscovite mica + Quartz
- Intermediate (diorite/andesite)
- Felsic (granite/rhyolite)
- Ultramafic (peridotite/komatiite)
- Mafic (gabbro/basalt)
Igneous rocks

Naming igneous rocks

• Granitic rocks
  • Composed almost entirely of light-colored silicates - quartz and feldspar
  • Also referred to as *felsic*: feldspar and *silica* (quartz)
  • High silica content (about 70 percent)
  • Common rock is *granite*
Granite
Igneous rocks

Naming igneous rocks

• Basaltic rocks
  • Contain substantial dark silicate minerals and calcium-rich plagioclase feldspar
  • Also referred to as mafic: magnesium and ferrum (iron)
  • Common rock is basalt
Basalt
Igneous rocks

- Naming igneous rocks
  - Other compositional groups
    - Andesitic (or intermediate)
    - Ultramafic
Sedimentary rocks

- Form from sediment (weathered products)
- About 75% of all rock outcrops on the continents
- Used to reconstruct much of Earth's history
  - Clues to past environments
  - Provide information about sediment transport
  - Rocks often contain fossils
Sedimentary rocks

- Economic importance
  - Coal
  - Petroleum and natural gas
  - Sources of iron and aluminum
Sedimentary rocks

Classifying sedimentary rocks

- Two groups based on the source of the material
  - Detrital rocks
    - Material is solid particles
    - Classified by particle size
  - Common rocks include
    - Shale (most abundant)
    - Sandstone
    - Conglomerate
## Classification of Sedimentary Rocks

### Detrital Sedimentary Rocks

<table>
<thead>
<tr>
<th>Texture (grain size)</th>
<th>Sediment Name</th>
<th>Rock Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse (over 2 mm)</td>
<td>Gravel (Rounded fragments)</td>
<td>Conglomerate</td>
</tr>
<tr>
<td></td>
<td>Gravel (Angular fragments)</td>
<td>Breccia</td>
</tr>
<tr>
<td>Medium (1/16 to 2 mm)</td>
<td>Sand (If abundant feldspar is present the rock is called Arkose)</td>
<td>Sandstone</td>
</tr>
<tr>
<td>Fine (1/16 to 1/256 mm)</td>
<td>Mud</td>
<td>Siltstone</td>
</tr>
<tr>
<td>Very fine (less than 1/256 mm)</td>
<td>Mud</td>
<td>Shale</td>
</tr>
</tbody>
</table>

### Chemical Sedimentary Rocks

<table>
<thead>
<tr>
<th>Composition</th>
<th>Texture (grain size)</th>
<th>Rock Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcite, CaCO₃</td>
<td>Fine to coarse crystalline</td>
<td>Crystalline Limestone</td>
</tr>
<tr>
<td></td>
<td>Visible shells and shell fragments loosely cemented</td>
<td>Travertine</td>
</tr>
<tr>
<td>Various size shells and shell fragments cemented with calcite cement</td>
<td>Coquina</td>
<td></td>
</tr>
<tr>
<td>Microscopic shells and clay</td>
<td>Fossiliferous Limestone</td>
<td></td>
</tr>
<tr>
<td>Quartz, SiO₂</td>
<td>Very fine crystalline</td>
<td>Chert (light colored) Flint (dark colored)</td>
</tr>
<tr>
<td>Gypsum CaSO₄•2H₂O</td>
<td>Fine to coarse crystalline</td>
<td>Rock Gypsum</td>
</tr>
<tr>
<td>Halite, NaCl</td>
<td>Fine to coarse crystalline</td>
<td>Rock Salt</td>
</tr>
<tr>
<td>Altered plant fragments</td>
<td>Fine-grained organic matter</td>
<td>Bituminous Coal</td>
</tr>
</tbody>
</table>

**Figure 3.12**
Shale with plant fossils

Figure 3.13 D
Sandstone
Conglomerate

Figure 3.13 A
Sedimentary rocks

Classifying sedimentary rocks

• Two groups based on the source of the material

  • Chemical rocks
    • Derived from material that was once in solution and precipitates to form sediment
      • Directly precipitated as the result of physical processes, or
      • Through life processes (biochemical origin)
Sedimentary rocks

Classifying sedimentary rocks

- Two groups based on the source of the material
  - Chemical rocks
  - Common sedimentary rocks
    - Limestone – the most abundant chemical rock
    - Microcrystalline quartz (precipitated quartz) known as chert, flint, jasper, or agate
    - Evaporites such as rock salt or gypsum
    - Coal
Fossiliferous limestone
Rock salt
Sedimentary rocks

Sedimentary rocks are produced through lithification

- Loose sediments are transformed into solid rock
- Lithification processes
  - Compaction
  - Cementation by
    - Calcite
    - Silica
    - Iron Oxide
Sedimentary rocks

Features of sedimentary rocks

- Strata, or beds (most characteristic)
- Bedding planes separate strata
- Fossils
  - Traces or remains of prehistoric life
  - Are the most important inclusions
  - Help determine past environments
  - Used as time indicators
  - Used for matching rocks from different places
Metamorphic rocks

- "Changed form" rocks
- Produced from preexisting
  - Igneous rocks
  - Sedimentary rocks
  - Other metamorphic rocks
Metamorphic rocks

Metamorphism

- Takes place where preexisting rock is subjected to temperatures and pressures unlike those in which it formed
- Degrees of metamorphism
  - Exhibited by rock texture and mineralogy
  - Low-grade (e.g., shale becomes slate)
  - High-grade (obliteration of original features)
Metamorphic rocks

Metamorphic settings

- Contact, or thermal, metamorphism
  - Occurs near a body of magma
  - Changes are driven by a rise in temperature

- Regional metamorphism
  - Directed pressures and high temperatures during mountain building
  - Produces the greatest volume of metamorphic rock
Metamorphic rocks

- Metamorphic agents
  - Heat
  - Pressure (stress)
    - From burial (confining pressure)
    - From differential stress during mountain building
  - Chemically active fluids
    - Mainly water and other volatiles
    - Promote recrystallization by enhancing ion migration
Origin of pressure in metamorphism

Figure 3.20
Metamorphic rocks

- Metamorphic textures
  - Foliated texture
    - Minerals are in a parallel alignment
    - Minerals are perpendicular to the compressional force
  - Nonfoliated texture
    - Contain equidimensional crystals
    - Resembles a coarse-grained igneous rock
Development of foliation due to directed pressure

Figure 3.22
Common metamorphic rocks

- Foliated rocks
  - Slate
    - Fine-grained
    - Splits easily
  - Schist
    - Strongly foliated
    - "Platy"
    - Types based on composition (e.g., mica schist)
### Classification of metamorphic rocks

<table>
<thead>
<tr>
<th>Rock Name</th>
<th>Texture</th>
<th>Grain Size</th>
<th>Comments</th>
<th>Parent Rock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slate</td>
<td>Foliated</td>
<td>Very fine</td>
<td>Excellent rock cleavage, smooth dull surfaces</td>
<td>Shale, mudstone, or siltstone</td>
</tr>
<tr>
<td>Phyllite</td>
<td>Foliated</td>
<td>Fine</td>
<td>Breaks along wavy surfaces, glossy sheen</td>
<td>Slate</td>
</tr>
<tr>
<td>Schist</td>
<td>Foliated</td>
<td>Medium to Coarse</td>
<td>Micaceous minerals dominate, scaly foliation</td>
<td>Phyllite</td>
</tr>
<tr>
<td>Gneiss</td>
<td>Foliated</td>
<td>Medium to Coarse</td>
<td>Compositional banding due to segregation of minerals</td>
<td>Schist, granite, or volcanic rocks</td>
</tr>
<tr>
<td>Marble</td>
<td>Nonfoliated</td>
<td>Medium to coarse</td>
<td>Interlocking calcite or dolomite grains</td>
<td>Limestone, dolostone</td>
</tr>
<tr>
<td>Quartzite</td>
<td>Nonfoliated</td>
<td>Medium to coarse</td>
<td>Fused quartz grains, massive, very hard</td>
<td>Quartz sandstone</td>
</tr>
<tr>
<td>Anthracite</td>
<td>Nonfoliated</td>
<td>Fine</td>
<td>Shiny black organic rock that may exhibit conchoidal fracture</td>
<td>Bituminous coal</td>
</tr>
</tbody>
</table>

**Figure 3.23**
Metamorphic rocks

- Common metamorphic rocks
  - Foliated rocks
    - Gneiss
      - Strong segregation of silicate minerals
      - "Banded" texture
  - Nonfoliated rocks
    - Marble
      - Parent rock is limestone
      - Large, interlocking calcite crystals
Gneiss typically displays a banded appearance.
Metamorphic rocks

- Common metamorphic rocks
  - Nonfoliated rocks
    - Marble
      - Used as a building stone
      - Variety of colors
    - Quartzite
      - Parent rock – quartz sandstone
      - Quartz grains are fused
Marble – a nonfoliated metamorphic rock
Resources from rocks and minerals

- Metallic mineral resources
  - Gold, silver, copper, mercury, lead, etc.
  - Concentrations of desirable materials are produced by
    - Igneous processes
    - Metamorphic processes
Resources from rocks and minerals

- Metallic mineral resources
  - Most important ore deposits are generated from hydrothermal (hot-water) solutions
    - Hot
    - Contain metal-rich fluids
    - Associated with cooling magma bodies
  - Types of deposits include
    - Vein deposits in fractures or bedding planes, and
    - Disseminated deposits which are distributed throughout the rock
Resources from rocks and minerals

- Nonmetallic mineral resources
  - Make use of the material’s
    - Nonmetallic elements
    - Physical or chemical properties
  - Two broad groups
    - Building materials (e.g., limestone, gypsum)
    - Industrial minerals (e.g., fluorite, corundum, sylvite)
Figure 3.C

Nonmetallic Resources

- Stone: 4100 kg (9040 lbs)
- Sand and gravel: 3860 kg (8510 lbs)
- Cement: 360 kg (790 lbs)
- Clays: 220 kg (485 lbs)
- Salt: 200 kg (440 lbs)
- Phosphate rock: 140 kg (310 lbs)
- Other nonmetals: 480 kg (1060 lbs)

Metallic Resources

- Iron and steel: 550 kg (1200 lbs)
- Aluminum: 25 kg (55 lbs)
- Lead: 6 kg (13 lbs)
- Copper: 10 kg (22 lbs)
- Manganese: 6 kg (13 lbs)
- Zinc: 5 kg (11 lbs)
- Other metals: 9 kg (20 lbs)

Energy Resources

- Petroleum: 3500 kg (7700 lbs)
- Coal: 3700 kg (8140 lbs)
- Natural gas: 3850 kg (8470 lbs)
End of Chapter 3