Chapter 2

Rock-Forming Minerals and Rocks
Guiding Questions

- What traits of minerals determine their physical properties?
- What conditions produce various kinds of igneous rocks?
- What are the ways in which sedimentary rocks form?
- How do metamorphic rocks form from other rocks?
Visual Overview
Rocks and Their Origins

The origins of igneous, sedimentary, and metamorphic rocks are interrelated through the rock cycle.

**IGNEOUS**
- Granite: consists of interlocking grains of mica, quartz, and feldspar.
- Tuff: volcanic ash and pumice, are of low density and light color.
- Blast: igneous rocks, which are rich in iron and magnesium, are of high density and dark color.
- Extrusive igneous rocks are fine-grained, formed by rapid cooling of lava.
- Intrusive igneous rocks are coarse-grained, formed by slow cooling of magma.

**METAMORPHIC**
- High temperatures and pressures produce metamorphic rocks from pre-existing rocks.
- marble: High grade slate: slate: Low grade
gneiss: Grade of metamorphism reflects level of temperature and pressure.

**SEDIMENTARY**
- Chemical sedimentary rocks are products of precipitation.
- Sedimentary rocks are classified by grain size.
- Exposures: Erosion: Precipitation:
- Sedimentary structures:
  - Cross-bedding
  - Graded bed
  - Mudcracks

Sedimentary rocks are formed from pre-existing rocks and can be transformed into another rock belonging to any of these three basic types.
Outline

• Structure of Minerals
• Properties of Minerals
• Types of Rocks
Atom

- Electron
- Nucleus
  - Proton
  - Neutron
Atom

- **Atomic number**
  - Number of protons
  - Unique to element

- **Atomic Weights**
  - Mass of protons and neutrons

Diagram:
- Hydrogen (1P, 1 electron)
- Oxygen (8P, 8 electrons)
- Silicon (14P, 14 electrons)
- Iron (26P, 26 electrons)
Isotope

- Different atomic weights of same element

- Carbon 12: $(6P + 6N)$, Atomic weight = 12
- Carbon 13: $(6P + 7N)$, Atomic weight = 13
- Carbon 14: $(6P + 8N)$, Atomic weight = 14
Chemical Bonds

- **Reaction**
  - Two or more atoms interact to form a molecule

- **Ionic Bond**
  - One atom loses an electron to another atom

- **Ion**
  - Charged atom
    - **Cation**
      - Positive charge
    - **Anion**
      - Negative charge
Chemical Bonds

- Covalent Bond
  - Electrons are shared
  - Very strong bond
    - Diamond
Crystal Lattice

- 3-D molecular structure of a mineral
- Configuration reflects relative sizes and numbers of ions
Crystal Lattice

- **Minerals**
  - May have same composition but different lattice
  - Calcite
  - Aragonite
Mineral Properties

• Hardness
  – Chemical bond strength

• Density
  – g/cm$^3$
  – Atomic weights of atoms
  – Packing

• Fracture
  – Bonding creates lanes of weakness

• Composition and internal structure reflects conditions of formation
Mineral Types

- Silicates (Olivine, Quartz)
- Carbonate minerals (Calcite, Aragonite)
- Sulfate minerals (Gypsum, Anhydrite)
- Oxides (Hematite, Magnetite)
- Native elements (Gold, Copper)
- many other....
Silicates

- Most abundant group of minerals
- Silicate tetrahedra
  - 4 oxygen atoms (−) surrounded by 1 silicon atom (+)
  - Bond with other atoms to form silicate minerals

![Silicate tetrahedron diagram]
Silicate Minerals

- Silica tetrahedron may polymerize to form a variety of geometric structures, alone or in combination with other cations
  - Isolated tetrahedron
  - Single chains
  - Double chains
  - 2-D sheet
  - 3-D frameworks
Silicate Structures
Rock-Forming Minerals

• About 20 common minerals make up most rocks
  – Silicates dominate
    – Quartz, Feldspars, Mica, Amphiboles, Pyroxenes
  – Carbonates are common
  – Evaporite minerals (Halite, Gypsum)
  – Secondary minerals formed during weathering Clays, Iron Oxides,
Felsic Minerals

• Silicate minerals rich in silicon and aluminum
  – Relatively low densities and low crystallization temperatures
  – Quartz
  – Feldspars
    • Potassium feldspar
    • Plagioclase feldspar
  – Mica - muscovite
Mafic Minerals

• Silicate minerals rich in iron and magnesium
  – Relatively high density and higher crystallization temperatures
  – Olivine
  – Pyroxenes
  – Amphiboles
  – Mica - biotite
Carbonate Minerals

• Carbonate
  – Positive ion (Ca, Mg, Fe) bonded to carbonate ion \( \text{CO}_3^{2-} \)
  – Calcite \( \text{CaCO}_3 \)

• Dolomite
  – Half of calcium is replaced by magnesium \( \text{(Ca,Mg)CO}_3 \)
Other Minerals

• Sulfates
  – Positive ions attached to the complex $\text{SO}_4^{2-}$
  – Formed at low temperature

• Oxides
  – Important ore bodies
  – Magnetite ($\text{Fe}_3\text{O}_4$)
  – Hematite ($\text{Fe}_2\text{O}_3$)
Rock Types

Igneous rock

Melting

Magma

Cooling

Weathering, erosion

Sediment

Sedimentary rock

Metamorphic rock

Pressure temperature
Igneous Rocks

• Classified by composition and grain size
  – Composition
    • Felsic: granite, rhyolite
    • Mafic: basalt, gabbro
  – Cooling rate
    • Rapid: fine grained (aphanitic)
    • Slow: large grained (phaneritic)
Igneous Rocks

- Magma cools within the Earth and at the surface
- Intrusions
  - Slow cooling
  - Plutons
    - Sills
    - Dikes
Igneous Rocks

• Lava
  – Molten rock that appears at a vent

• Tuff
  – Loose volcanic debris

• Fissures
  – Lava flowing out of cracks
Igneous Rocks

• Flood basalts
  – Extensive areas covered by mafic lava

• Pillow basalts
  – Rocks formed by cooling rapidly beneath the sea
Flood basalts with several thick and thin layers. Each layer represents a separate eruption.
pillow lavas

Devil’s Tower; a volcanic neck, a feeder pipe
Shiprock, New Mexico; a volcanic neck
Sill; parallels layers in the country rock
Dike; cuts across layers in the country rock
Half Dome; part of the Sierra Nevada batholith
Beginnings of a spatter cone

Large cinder cone
Igneous Rocks

Texture and cooling history
Coarse grained igneous rock
Fine grained igneous rock
Pegmatite:

Very coarse grained igneous rock
Porphyritic igneous rock:
Big xtals in a fine grain matrix
Sedimentary Rocks

• Sediments produced by:
  – Weathering, erosion of other rocks
  – Crystals precipitated from seawater
  – Skeletal debris from organisms
Types of Sedimentary Rocks

Detrital

Clastic Texture

Biologic

Chemical

Crystalline Texture
Sedimentary Rocks

• Sediments produced by:
  – Weathering, erosion of other rocks
  – Crystals precipitated from seawater
  – Skeletal debris from organisms

• Siliciclastic rocks
  – Sedimentary rocks composed of clasts of silicate minerals
    • Quartz is most resistant to weathering
    • Mafic minerals less stable at Earth’s surface
Sedimentary Rocks

Diagram showing the classification of sedimentary rocks based on grain size and compaction.
Siliciclastic Rocks

Classification based on grain size and shape:

• Gravel
  – >2 mm diameter
  – Granules, pebbles, cobbles, boulders

• Conglomerate
  – Rounded grains

• Breccia
  – Angular grains
Siliciclastic Rocks (cont.)

• Sand
  – 1/16-2 mm diameter
  – Often quartz
  – Sandstone

• Silt
  – 1/256-1/16 mm

• Clay
  – Smaller than 1/256 mm
Sedimentary Rocks

Grain size (log scale)

- Boulder: 256 mm
- Cobble: 8 mm
- Pebble: 4 mm
- Gravel: 2 mm
- Very coarse sand: 1 mm
- Coarse sand: 2 mm
- Medium sand: 4 mm
- Fine sand: 8 mm
- Very fine sand: 16 mm

- Silt: 1 mm
- Clay: 0.001 mm

Conglomerate, breccia
Sandstone
Siltstone
Mudstone
Claystone, shale
Mud
Siliciclastic Rocks (cont.)

- Muds form mudstones
- Shale
  - Fissile mudstone
- Fissile
  - breaks along bedding surface
  - Sediment aligned horizontally during deposition
Sorting

• Grains settle out of suspension
  – Coarse, dense material settles first
Sorting

- Measure of similarity in grain size
- Poorly sorted
  - Mixed sizes
- Well sorted
  - Similar sizes
Siliciclastic Rocks: Sandstone

- Not always quartz
- Arkose
  - Feldspar dominated rock
    - Pinkish color
- Graywacke
Lithification

• Process by which siliciclastic sediments become rock
  – Primary process is compaction

• Cementation
  – Chemical process in which minerals crystallize from solution that percolates through the grains of sediment
    • Iron oxide
      – Red beds
Evaporites

• Form from evaporation of seawater
  – Anhydrite
  – Gypsum
  – Halite

• Readily formed, readily dissolved
Other Chemical Sedimentary Rocks

• Chert
  – Flint
  – Extremely small quartz crystals precipitated from watery solutions
  – Brown, gray, or black
    • Impurities

• Banded Iron Formations (BIF)
Carbonate Rocks

- Limestone
  - Chemical and biogenic bodies of rock
- Dolomite
  - Carbonate mineral
  - Uncommon in modern rocks
  - Common in ancient rocks
    - Dolostone
Carbonate Rocks (cont.)

- Carbonate sediments
  - Often skeletal particles
- Carbonate muds
  - Mainly aragonite needles
    - Direct precipitation
    - Collapse of carbonate algal skeletons
Carbonate Rocks (cont.)

- Oolites
  - Nearly spherical sediment
  - Produced in shallow water
  - Formed by rolling and accumulating aragonite needles
Carbonate Rocks (cont.)

- Cross-section of oolith
  - Concentric structure
Oolitic Limestone

Rounded grains of calcite
Limestones
Limestones
Limestones
Chalk
(Coccolithophores)
Coccolithophores: calcareous phytoplankton (photosynthetic/autotrophs)
Foramifera: calcareous (CaCO$_3$) heterotrophs

http://www.ucl.ac.uk/GeolSci/micropal/calcnano.html
Foramifera: calcareous (CaCO₃) heterotrophs

http://www.ucl.ac.uk/GeolSci/micropal/calcnanno.html
Foramifera: calcareous (CaCO$_3$) heterotrophs
Diatoms: siliceous (SiO$_2$) phytoplankton (photosynthetic/autotrophs)

http://www.ucl.ac.uk/GeolSci/micropal/calcnanno.html
Diatoms: siliceous (SiO$_2$) phytoplankton (photosynthetic/autotrophs)

http://www.ucl.ac.uk/GeolSci/micropal/calcnanno.html
Radiolarians: siliceous (SiO₂) heterotrophs

http://www.ucl.ac.uk/GeolSci/micropal/calcnanno.html
Travertine (Limestone)
Dolostone
Chert (Flint, Jasper, Agate...)

![Chert samples](image1)

![Chert tool](image2)
Evaporites:

Bonneville Salt Flats, Utah

Rock

Gypsum

Rock Salt
Sedimentary Structures

• Distinctive arrangements of grains in sedimentary rocks
  – Reflect modes of deposition
  – Useful tools for interpreting ancient environment of deposition

• Graded Bed
  – Grain size increases from top to bottom
    • Normal
Sedimentary Structures

• Ripples
  – Structures formed by wind or water
  – Sediments accumulate downslope (lee)
  – Symmetrical → Bidirectional current
  – Asymmetrical → Unidirectional current

• Cross-bedding or cross-stratification

• Mudcracks
Metamorphic Rocks

• Form by alteration of other rocks at temperatures and pressures greater than at the Earth’s surface

• Grade
  – Level of temperature and pressure of metamorphism

• Regional Metamorphism
  – Transforms deeply buried rocks over great distances

• Foliation
  – Alignment of platy minerals caused by applied pressures
Metamorphic Rocks (foliated)

- **Slate**
  - Fine grained; low grade; fissile

- **Schist**
  - Low-medium grade; platy

- **Gneiss**
  - High-grade metamorphism
    Granular; wavy layers
Metamorphic Rocks (non-foliated)

- **Marble**
  - Calcite and/or dolomite
  - Limestone parent

- **Quartzite**
  - Nearly pure quartz
  - Sandstone parent
Metamorphic Rocks
Agents of Metamorphism

• Contact Metamorphism
  – Igneous intrusion “bakes” surrounding rocks

• Hydrothermal Metamorphism
  – Results from percolation of hot watery fluids

• Burial Metamorphism
  – Rocks are altered when they are buried so deep that they are exposed to temperatures and pressures high enough to change chemical composition
    • Similar to regional metamorphism
Metamorphic Rocks

Progressive metamorphism
Progressive metamorphism of a shale

Shale
Progressive metamorphism of a shale

Slate
Progressive metamorphosis of a shale

Phyllite
Progressive metamorphism of a shale

Schist
Progressive metamorphism of a shale

Gneiss
Change in metamorphic grade with depth
Flattened Pebble Conglomerate = flattening
Sample of quartzite

Thin section of quartzite

Photomicrograph (26.6x)
Sample width is 1.23 mm
Marble
Metamorphic Products

• Coal
  – Low-grade metamorphism of plant debris
Visual Overview
Rocks and Their Origins

The origins of igneous, sedimentary, and metamorphic rocks are interrelated through the rock cycle.

IGNEOUS
- Feldspar
- Quartz
- Mica
- Pegmatite
- Tuff
- Obsidian
- Pumice

METAMORPHIC
- Slate
- Schist
- Gneiss
- Muscovite
- Calcite

SEDIMENTARY
- Sandstone
- Limestone
- Chert
- Coal
- Conglomerate

Chemical sedimentary rocks are products of precipitation.