Field Trips

- Saturday field trips have been scheduled
- October 9, October 23 and December 4
  - Last all day (9:00 AM to 4:00 PM)
  - Bus transportation provided from campus
  - Joint with GG101 laboratory, GG101 Section 2, GG103 Geology of the Hawaiian Islands, GG106 Humans and the Environment and GG170 Advanced Dynamic Earth
  - Likely be field exercises
  - Participation on the field trips encouraged and extra credit given

Field Trips

- Tentative Saturday field trip on development of the new tsunami inundation maps
- Gerard Fryer, Pacific Tsunami Warning Center
- October 30, November 6 or November 13
  - Saturday
  - Half day (9:00 AM to noon)
  - Meet at Round Top Lookout
  - Joint with GG101 laboratory, GG101 Section 2, GG103 Geology of the Hawaiian Islands, GG106 Humans and the Environment and GG170 Advanced Dynamic Earth
  - Likely be field exercises
  - Participation encouraged and extra credit given
Big Island Field Trip

- Tentatively scheduled for October 15-17
- Leave Friday afternoon, return Sunday afternoon or evening
- Stay in Hawaii Volcanoes National Park
- Know within a week when deposits are required and the exact dates

Minerals: Building Blocks of Rocks

A key to understanding composition of Earth is knowing how chemical elements are organized into minerals.
Minerals and Rocks

• Minerals - A naturally occurring, inorganic solid with an ordered internal structure and a narrow range of chemical composition

• Rocks - A naturally occurring consolidated mixture of minerals or mineral-like substances
Granite (Rock)

Quartz (Mineral)
Hornblende (Mineral)
Feldspar (Mineral)
What Qualifies as a Mineral?

- Substance must be found in nature
  - Synthetic diamonds are not minerals

- Minerals are crystalline
  - Atoms are arranged in an orderly, repeating 3-D array
    - Without order, considered glassy or amorphous
      - Window glass
      - Volcanic glass

- Minerals are inorganic
  - Coal is not a mineral
  - Minerals can be formed biologically
    - The shell of an oyster is the mineral calcite (CaCO₃)

- What else makes minerals unique?
  - Chemical composition
  - Arrangement of atoms in an internal structure

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Natural</th>
<th>Solid</th>
<th>Inorganic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron ore</td>
<td>Sand</td>
<td>Rock salt</td>
<td></td>
</tr>
<tr>
<td>(hematite)</td>
<td>(quartz)</td>
<td>(halite)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nonmineral</th>
<th>Artificial</th>
<th>Liquid</th>
<th>Organic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cast iron</td>
<td>Seawater</td>
<td>Vegetation</td>
<td></td>
</tr>
<tr>
<td>(metallic iron)</td>
<td>(H₂O 1 salts)</td>
<td>(cellulose)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gas</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Air</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(oxygen)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Atoms

- A rigid sphere about 1 angstrom (Å) in diameter -- an angstrom is $10^{-10}$ m
- At the center of an atom is a nucleus which contains most of the mass of the atom
  - Protons with a positive charge
  - Neutrons with no charge -- neutral

Atoms

- **Electrons (E):**
  - Negative charge, very little mass
- **Protons (Z):**
  - Positive charge, mass 1832 times greater than electron
- **Neutrons (N):**
  - No electric charge, mass 1833 times greater than electron
Atomic Structure

- **Nucleus:** protons, neutrons
  - Electrons orbit around the nucleus in discrete shells.
Stable Isotopes

- In chemical behavior, all isotopes of the same element are not identical.
- Isotopes have different masses and they react slightly differently in chemical reactions. Those differences are easily measured.
- Those differences provide information about how the compound formed.
- For example, during evaporation and condensation, isotopes of H and O in water react differently.
- During glaciation, $^{16}\text{O}$ and $^1\text{H}$ are concentrated in glacial ice and $^{18}\text{O}$ and $^2\text{H}$ are concentrated in seawater.
- The oxygen isotope composition of seawater is recorded in the CaCO$_3$ minerals made by organisms living in the ocean.

Radioactive Isotopes

- A radioactive isotope is unstable and undergoes decay.
- Rates of decay are constant and provide a measure of time since formation.
Atomic structure

- Chemical characteristics of elements determined largely by number of protons
  - # of protons = atomic number (A)
  - # of neutrons (N) + A = atomic weight (Z)

Ion

- An electrically charged particle composed of an atom that has either lost or gained electron(s) to or from another atom
Ions

- When an atom loses or gains an electron it is called an ion
- Positively charged ions (loss of electron) are called cations
- Negatively charged ions (gain of electron) are called anions

Consider Salt (NaCl)

- Why would Na and Cl react?
  - Na has an atomic number of 11
    - Three electron shells
      - Inner shell with 2 electrons (max)
      - Middle shell with eight (max)
      - Outer shell with one
  - Cl has an atomic number of 17
    - Three electron shells
      - Inner shell with 2 electrons (max)
      - Middle shell with eight (max)
      - Outer shell with seven

- Tendency for atoms to fill outer shell with electrons either by gaining or losing
  - Na loses one to have second shell filled
  - Cl gains one to fill outer shell
Ionic Attraction Forms NaCl (Halite)

Sodium atom: 1 electron in outer shell

Chlorine atom: 7 electrons in outer shell

Chemical reaction

Sodium loses 1 electron to become sodium ion

Electrical attraction

Chlorine gains 1 electron to become chloride ion

Compound, sodium chloride (NaCl), formed by electrical attraction between Na\(^+\) and Cl\(^-\)

Transfer of Electrons: Ionic Bonds

Proton

Neutron

Electron

Lithium (Li) (element) + Fluorine (F) (element) → Lithium fluoride (LiF) (compound)
Ionic Bonds

• Simplest form of bond
  - Gain and loss of electrons
• Strength of bond decreases
  - As distance between ions increases
• Strength of bond increases
  - As the electrical charge of ions increases
• Ionic Bonds are the dominant type of bond in minerals
  - ~90% of all minerals, ionic compounds

Electron Sharing: Covalent Bonding

• Not all atoms react by gaining or losing electrons
  - Some atoms engage in electron sharing
  - Achieve a stable configuration
• Shared electrons are neither gained or lost
  - In a sense, nuclei gain an electron for some fraction of time
• Covalent bonds are very strong bonds
- Single electron in outer shell
- As they near, orbitals overlap
- When they meet, electrons occupy space between H atoms
- Electrons shared by both H atoms
  - Attracted by the positive charge of proton in nucleus

Electron Sharing in Diamond
Covalent Bonding in Diamond

Carbon Tetrahedron of Diamond

Shares an electron with each of four neighboring atoms
Network of Carbon Tetrahedra

What Controls Arrangement of Ions in Crystal Structure?

- Two major factors
  - 1. number of neighbor ions
  - 2. their size or ionic radius
- Ionic radius related to atomic structure of element
  - Increases with increasing number of electron shells
    » More electrons an element loses to become a cation
    » Stronger its positive charge
    » Stronger its electrical attraction of its nucleus to the remaining electrons
Ionic Radii and Ion Substitution

- Ion substitution is common
- Ions of similar size and charge
  - Substitute for one another
- Example Fe$^{+2}$ and Mg$^{+2}$
  - Similar ionic radii
  - Charge of +2
Ionic Radius and Charge

<table>
<thead>
<tr>
<th>Ion</th>
<th>Ionic Radius (Å)</th>
</tr>
</thead>
<tbody>
<tr>
<td>O²⁻</td>
<td>1.40</td>
</tr>
<tr>
<td>F¹⁻</td>
<td>1.81</td>
</tr>
<tr>
<td>S²⁻</td>
<td>1.84</td>
</tr>
<tr>
<td>Cl¹⁻</td>
<td>1.81</td>
</tr>
<tr>
<td>Na¹⁺</td>
<td>1.00</td>
</tr>
<tr>
<td>K¹⁺</td>
<td>1.37</td>
</tr>
<tr>
<td>Mg²⁺</td>
<td>0.72</td>
</tr>
<tr>
<td>Al³⁺</td>
<td>0.49</td>
</tr>
<tr>
<td>Si⁴⁺</td>
<td>0.15</td>
</tr>
<tr>
<td>Ca²⁺</td>
<td>0.63</td>
</tr>
<tr>
<td>Fe²⁺</td>
<td>0.39</td>
</tr>
<tr>
<td>Fe³⁺</td>
<td>0.26</td>
</tr>
</tbody>
</table>

Atomic Structure of Sodium Chloride (Halite)

- Sodium ion
- Chloride ion

Chloride ions are located at the corners of a cubic unit cell, with each chloride ion surrounded by six sodium ions. Sodium ions are located at the center of each face of the unit cell.
Halite
(Cubic Mineral)

Packing Order of Atoms in a Galena Crystal
Galena

Ultrahigh Vacuum Scanning Tunneling Microscope Image of Galena

Sulfur
Lead
Polymorphs

- Minerals with the same chemical composition but different structure
- Examples - diamond and graphite; andalusite, kyanite, and sillimanite

Diamond

Atomic Structure

Crystal Form

Diamond
Graphite

Atomic Structure

Crystal Form

(a) Graphite

Polymorphs of Carbon
There are some 3,500 recognized minerals found on Earth. However, for our purpose, we can focus on about a dozen.

- Silicates - Si, O and other elements, the most abundant mineral group in the Earth’s crust
- Carbonates - Ca, Mg and CO$_3$
- Salts - NaCl

**Silicate Ion**

- Basis for all silicates is the silica tetrahedron
  - Also known as the silicate ion
- Silica tetrahedron has net negative charge of -4
- Net negative charge must be balanced
  - By bonding with cations
  - By sharing electrons with other tetrahedron
- Bonding pattern give rise to several classes of silicate minerals
- Classification according to the way the tetrahedron are linked
Silicate Ion: $[\text{SiO}_4]^{-4}$

- Silica: $\text{O}_2$
- Oxygen Tetrahedra: Four oxygens surrounding a silicon ion
- Different combinations produce different structures

Silica-Oxygen Tetrahedra:
- Four oxygens surrounding a silicon ion
- These tetrahedra combine to make the framework of the silicate minerals
- Different combinations produce different structures
Isolated Tetrahedra Silicate (example: olivine)

- Silica tetrahedron apex toward you
- Silica tetrahedron apex away from you
- Mg$^{2+}$ or Fe$^{2+}$

(a) Isolated tetrahedra (example: olivine)
Single- and Double-Chain Silicates

(a) Isolated tetrahedra
(example: olivine)

(b) Single chain
(example: pyroxene)

(c) Double chain
(example: amphibole)

Sheet Silicate (example: mica)

(d) Sheet
(example: mica)
Atomic Structure of Micas

- Tetrahedral layers
- Aluminum hydroxide sheets
- Interlayer cations
- Cleavage along interlayer plane
- Interlayer cations

Types of Chain Formation:
- Single chain
- Double Chain
- Sheet
Framework Silicate
(example: quartz)
Some Silicate Minerals

Feldspar

Mica

Olivine

Pyroxene

Quartz
## Important mineral groups

<table>
<thead>
<tr>
<th>Name</th>
<th>Important constituents (other than O)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Olivine</td>
<td>Si, Fe, Mg</td>
</tr>
<tr>
<td>Pyroxene</td>
<td>Si, Fe, Mg, Ca</td>
</tr>
<tr>
<td>Amphibole</td>
<td>Si, Ca, Mg, Fe, Na, K</td>
</tr>
<tr>
<td>Micas</td>
<td>Si, Al, K, Fe, Mg</td>
</tr>
<tr>
<td>Feldspars</td>
<td>Si, Al, Ca, Na, K</td>
</tr>
<tr>
<td>Carbonates</td>
<td>C, Ca, Mg</td>
</tr>
<tr>
<td>Evaporites</td>
<td>K, Cl, Ca, S</td>
</tr>
</tbody>
</table>

## Abundance of the elements (wt. %)

<table>
<thead>
<tr>
<th>Element</th>
<th>Crust</th>
<th>Whole Earth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen</td>
<td>46.3%</td>
<td>29.5%</td>
</tr>
<tr>
<td>Silicon</td>
<td>28.2%</td>
<td>15.2%</td>
</tr>
<tr>
<td>Aluminum</td>
<td>8.2%</td>
<td>1.1%</td>
</tr>
<tr>
<td>Iron</td>
<td>5.6%</td>
<td>34.6%</td>
</tr>
<tr>
<td>Calcium</td>
<td>4.1%</td>
<td>1.1%</td>
</tr>
<tr>
<td>Sodium</td>
<td>2.4%</td>
<td>0.6%</td>
</tr>
<tr>
<td>Potassium</td>
<td>2.1%</td>
<td>0.1%</td>
</tr>
<tr>
<td>Magnesium</td>
<td>2.3%</td>
<td>12.7%</td>
</tr>
<tr>
<td>Titanium</td>
<td>0.5%</td>
<td>0.1%</td>
</tr>
<tr>
<td>Nickel</td>
<td>trace</td>
<td>2.4%</td>
</tr>
<tr>
<td>All others</td>
<td>trace</td>
<td>2.7%</td>
</tr>
</tbody>
</table>
Atomic Structure of Carbonate Ion

Oxygen

Carbon

(a) Carbonate ion (CO$_3^{2-}$)

---

Atomic Structure of Calcium Carbonate (Calcite)

Calcium ion

Carbonate ion

(b) Calcium carbonate structure
Mineral Identification

- Close link between the structure of a mineral and its physical properties which are invaluable in identification

  - Density: Mass per unit volume
    - Density depends on:
      - Kinds of atoms in the structure
      - Packing of the atoms
  - Hardness: Resistance of minerals to scratching or abrasion
  - Cleavage: Plane of weakness along which a crystal will break
    - Related to the atomic structure
  - Fracture: Way mineral breaks along irregular surface
  - Luster: Nature and amount of light reflected
    - Metallic or Nonmetallic
  - Color:
  - Streak: Color of a powdered mineral
  - Other Properties:
    - Magnetism, electrical and radioactive properties, taste