Review
Mid-Term Exam
The Solar System consists of

- 8 classical planets
- 5 dwarf planets
- 240 known satellites (moons)
- Millions of comets and asteroids
- Countless particles; and interplanetary space.

Earth, the Sun, and other objects in the Solar System originated at the same time from the same source and have evolved in varying ways since then.
Edgeworth-Kuiper belt and Oort Cloud
Because the solar nebula was rotating, it contracted into a disc, and the planets formed with orbits lying in nearly the same plane.
Planetesimal accretion - ~5 to 4.6 billion yrs ago
In time EARTH’S interior accumulated heat

New atmosphere created by volcanic outgassing and delivery of gases and water by ice-covered comets.

“Hadean Era”
Early Earth began to heat as the last extraterrestrial collisions subsided
1. Rock is a good insulator – stores heat
2. Collisions produced heat that was stored
3. Radioactivity
4. Gravitational contraction

Earth Developed a Magma Sea
4.5-4.0 billion years ago

What is the physical consequence of melting a ball of rock with many different types of elements and compounds?
There are certain trends in Earth's chemistry. The crust is relatively depleted in Fe, Mg and enriched in Si, O.
Main Types of Plate Motion

- Convergent
- Divergent
- Transform
Plate Tectonics explains chains of volcanic islands.

**Hot Spots**

- Kauai: 1.4–5.7
- Oahu: 1.8–3.8
- Molokai: 1.3–1.8
- Maui: 0.4–1.6
- Hawaii: 0.4–present

Direction of plate motion:
- Emperor Seamounts
- Hawaiian chain

Oceanic lithosphere

Mantle plume
Lithospheric Plates Carry Continents and Oceans.
A Rock is a solid aggregate of minerals.

Four different minerals are obvious in this piece of Granite.
Atoms are the smallest components of nature with the properties of a given substance.

- Electrons (negative charge)
- Protons (positive charge)
- Neutrons (no charge)
Atoms bond to **achieve a stable electron configuration**. Most atoms bond to achieve 8 electrons in the outer shell - the so-called **“Octet Rule”**

<table>
<thead>
<tr>
<th>Element</th>
<th>Symbol</th>
<th>Atomic Number</th>
<th>First (2 is stable)</th>
<th>Second (8 is stable)</th>
<th>Third (8 is stable)</th>
<th>Fourth (8 is stable)</th>
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<tbody>
<tr>
<td>Hydrogen</td>
<td>H</td>
<td>1</td>
<td>1</td>
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<tr>
<td>Helium</td>
<td>He</td>
<td>2</td>
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<tr>
<td>Lithium</td>
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<td>Beryllium</td>
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<td>Boron</td>
<td>B</td>
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<td>2</td>
<td>3</td>
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<td>Carbon</td>
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<td>Nitrogen</td>
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<td>2</td>
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<td>Oxygen</td>
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<td>2</td>
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<td>7</td>
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<td>Sodium</td>
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<td>Magnesium</td>
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<td>Aluminum</td>
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<td>Phosphorus</td>
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<td>15</td>
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<td>Sulfur</td>
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<td>2</td>
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<td>6</td>
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<td>Chlorine</td>
<td>Cl</td>
<td>17</td>
<td>2</td>
<td>8</td>
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<td>Argon</td>
<td>Ar</td>
<td>18</td>
<td>2</td>
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<td>Potassium</td>
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<td>19</td>
<td>2</td>
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<tr>
<td>Calcium</td>
<td>Ca</td>
<td>20</td>
<td>2</td>
<td>8</td>
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</tbody>
</table>
### Types of Silicate Structures

#### Single Tetrahedron

- **Si**<sup>4+</sup>
- **O**<sup>-2</sup>

#### Independent Tetrahedra

- **Si**<sup>4+</sup>
- **O**<sup>-2</sup>
- **Na**<sup>+</sup>
- **Ca**<sup>2+</sup>
- **Al**<sup>3+</sup>
- **Fe**<sup>2+</sup> (3+)
- **Mg**<sup>2+</sup>
- **K**<sup>+</sup>
- **Metallic Cations**

#### Single Chain

- **Si**<sup>2-</sup>
- **O**<sup>-4+</sup>
- **Na**<sup>+</sup>
- **Ca**<sup>2+</sup>
- **Al**<sup>3+</sup>
- **Fe**<sup>2+</sup> (3+)
- **Mg**<sup>2+</sup>
- **K**<sup>+</sup>
- **Metallic Cations**

#### Double Chain

- **Si**<sup>2-</sup>
- **O**<sup>-4+</sup>
- **Na**<sup>+</sup>
- **Ca**<sup>2+</sup>
- **Al**<sup>3+</sup>
- **Fe**<sup>2+</sup> (3+)
- **Mg**<sup>2+</sup>
- **K**<sup>+</sup>
- **Metallic Cations**

#### Sheet

- **Si**<sup>2-</sup>
- **O**<sup>-4+</sup>
- **Na**<sup>+</sup>
- **Ca**<sup>2+</sup>
- **Al**<sup>3+</sup>
- **Fe**<sup>2+</sup> (3+)
- **Mg**<sup>2+</sup>
- **K**<sup>+</sup>
- **Metallic Cations**

#### Three-Dimensional Network

- **Si**<sup>2-</sup>
- **O**<sup>-4+</sup>
- **Na**<sup>+</sup>
- **Ca**<sup>2+</sup>
- **Al**<sup>3+</sup>
- **Fe**<sup>2+</sup> (3+)
- **Mg**<sup>2+</sup>
- **K**<sup>+</sup>
- **Metallic Cations**
Single Substitution

Double Substitution

\( \text{Mg}^{2+} \)
\( \text{Fe}^{2+} \)
\( \text{Al}^{3+} \)
\( \text{Si}^{4+} \)
\( \text{Ca}^{2+} \)
\( \text{Na}^{+} \)
There are seven common rock-forming minerals.

- Olivine
- Pyroxene
- Amphibole
- Biotite
- Quartz
- Calcite
- The Feldspar Group: Orthoclase and Plagioclase
Igneous rock-forming environments

Stratovolcano

Spreading center

Volcanic arc

Mid-ocean ridge

Island arc

Shield Volcano

Hotspot
The Igneous Minerals

The Igneous Rocks

Composition

Texture

Extrusive

Felsic

Intermediate

Mafic

Ultramafic

Intrusive

Granite

Diorite

Gabbro

Rhyolite

Andesite

Basalt

Peridotite
Igneous rock is a ubiquitous component of Earth’s crust because it evolves as a product of tectonic processes.
Hydrolysis, Oxidation, and Dissolution Are Chemical Weathering Processes.

- Water molecule is *polarized*.
- Attracts cations.
- “Universal Solvent”
- Hydrogen bond - polar
Sedimentary Minerals

Microcrystalline **quartz**
(chert, agate, quartz)
SiO$_2$

**Clay** - kaolinite

**Calcite** – CaCO$_3$

**Hematite/limonite**
Fe$_2$O$_3$

Granite – quartz, feldspar, biotite, amphibole

**Bauxite**
Al$_2$O$_3$ H$_2$O

Saprolite – quartz, clay, hematite, Al-oxide
### TABLE 7.2 Mineral and Rock Stability on Earth’s Surface

<table>
<thead>
<tr>
<th>Mineral Stability</th>
<th>Increasing stability on Earth’s surface</th>
<th>Rock Stability</th>
<th>Sedimentary Rocks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Igneous and Metamorphic Minerals</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Olivine</td>
<td>Halite</td>
<td>Basalt</td>
<td>Rock salt</td>
</tr>
<tr>
<td>Pyroxene</td>
<td>Calcite</td>
<td>Granite</td>
<td>Limestone</td>
</tr>
<tr>
<td>Ca-Plagioclase feldspar</td>
<td>Hematite</td>
<td>Marble</td>
<td>Rock gypsum</td>
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<tr>
<td>Biotite</td>
<td>Kaolinite</td>
<td>Gneiss</td>
<td>Siltstone</td>
</tr>
<tr>
<td>Orthoclase feldspar</td>
<td>Bauxite</td>
<td>Schist</td>
<td>Shale</td>
</tr>
<tr>
<td>Quartz</td>
<td>Chert</td>
<td>Quartzite</td>
<td>Quartz sandstone</td>
</tr>
</tbody>
</table>

### Bowen’s Reaction Series

**Temperature**

- **HIGH** (~1200°C)
- **COOLING Magma**
- **LOW** (~750°C)

**MINERALS**

- Continuous Reaction
- Discontinuous Reaction

**Igneous rock types**

- Ca-rich Ultramafic (peridotite)
- Mafic (basalt/gabbro)
- Intermediate (andesite/diorite)
- Na-rich (rhyolite/granite)
- Potassium feldspar
- Muscovite
- Quartz
CLIMATE CRITICAL in SOIL FORMATION

- Physical Weathering dominates in regions of low temperature and low rainfall.

- Chemical Weathering dominates in regions of high temperature and high rainfall.
Weathering Produces Soil

SOIL FORMATION influenced by:
- biological processes,
- nature of parent rock,
- climate,
- topography,
- and time.
Which climate, weathering processes and soil profiles are likely in each of these five settings?
There Are Three Common Types of Sediment: Clastic, Chemical, and Biogenic

CLASTIC SEDIMENTS are broken pieces of crust deposited by water, wind, ice, or some other physical process
CHEMICAL SEDIMENTS  Produced by inorganic (nonbiological) precipitation of dissolved compounds (e.g., through evaporation)

BIOGENIC SEDIMENTS  Produced by organic (biological) precipitation of the remains of living organism
Particle Size Reflects Environmental Energy

**TABLE 8.1 Features of Sedimentary Environments**

<table>
<thead>
<tr>
<th>Sedimentary Environment</th>
<th>Transportation Process</th>
<th>Sediment Size</th>
<th>Sorting</th>
<th>Abrasion (degree of rounding)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind-deposited dune</td>
<td>Wind</td>
<td>Fine to medium sand</td>
<td>Very strong</td>
<td>Strong</td>
</tr>
<tr>
<td>Ocean beach</td>
<td>Waves, currents, wind</td>
<td>Fine sand to gravel</td>
<td>Strong</td>
<td>Very strong</td>
</tr>
<tr>
<td>Wetland</td>
<td>Weakly circulated water, wind</td>
<td>Clay to silt</td>
<td>Strong</td>
<td>Weak</td>
</tr>
<tr>
<td>Stream channel</td>
<td>Running water</td>
<td>Silt to gravel</td>
<td>Moderate</td>
<td>Very strong</td>
</tr>
<tr>
<td>Glacier</td>
<td>Moving ice</td>
<td>Clay to large gravel (boulders)</td>
<td>Weak</td>
<td>Strong</td>
</tr>
<tr>
<td>Steep hillside</td>
<td>Mass wasting</td>
<td>Clay to large gravel (boulders)</td>
<td>Weak</td>
<td>Moderate</td>
</tr>
</tbody>
</table>
Metamorphic Index minerals

- Sedimentation
- Low Grade
- Medium to High Grade

Increasing temperature and pressure

- Clay minerals
- Chlorite
- Muscovite
- Biotite
- Garnet
- Kyanite
- Sillimanite
- Feldspar
- Quartz

... conveniently “indexed” by Index Minerals
Foliated vs Nonfoliated texture

- Shale is parent rock (protolith)
- Marble
- Hornfels
- Anthracite
- Quartzite
- Slate
- Phyllite
- Schist
- Gneiss
Plate Movement Powers
the Rock Cycle