Lab 4: Minerals, the rock cycle and igneous rocks

Rocks are divided into three major categories on the basis of their origin:

**Igneous** rocks (from the Latin word, *ignis* = fire) are composed of minerals which crystallized from molten rock, called *magma*. This category includes rocks that formed as a result of volcanic activity and those that crystallized from magmas cooling under the Earth’s surface.

**Metamorphic** rocks (from the Greek word, *metamorphose* = to transform) are derived from existing rocks which have been exposed to increased pressure and/or temperature to the point where they begin to alter, both texturally and mineralogically.

**Sedimentary** rocks (from the Latin word, *sedimentum* = settling) form by the accumulation and consolidation of unconsolidated material from weathered and eroded rocks.

Rocks do not remain the same throughout geologic time. They are constantly being changed by external forces. Given time, the effect of these forces is to change any one rock type into any rock type. These relationships constitute the rock cycle, as shown in the following figure:

The texture and the mineralogical composition of a rock frequently reflect its geologic history and help us determine whether it has an igneous, metamorphic or sedimentary origin. Texture refers to the size, shape and relationship of
minerals within a rock. In general, igneous rocks have a **crystalline** texture, in which different mineral crystals have grown together and are interlocking. Metamorphic rocks often have a **foliated** texture, where rippled layers of single minerals align roughly parallel to each other (some single mineral metamorphic rocks have a crystalline texture). Sedimentary rocks usually have a **clastic** texture because they are made up of fragments (clasts) of other rocks, and often are **layered**. Sedimentary rocks may also contain **fossils**.

A **mineral** is a naturally-occurring, solid, usually inorganic element or compound with a definite crystal structure and chemical composition which varies only within specific limits. Rocks are merely **aggregates** of minerals.

The mineralogical composition of a rock depends on the conditions under which that rock formed. Igneous rocks tend to have minerals that form at high temperatures; sedimentary rocks contain minerals that are stable at Earth-surface conditions. Metamorphic rocks consist of minerals that form under a range of pressure and temperature conditions within the Earth.

**Common rock-forming minerals:**

<table>
<thead>
<tr>
<th>Minerals in igneous rocks</th>
<th>Minerals in metamorphic rocks</th>
<th>Minerals in sedimentary rocks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
<td>Quartz</td>
<td>Quartz</td>
</tr>
<tr>
<td>Orthoclase</td>
<td>Biotite</td>
<td>Clay minerals</td>
</tr>
<tr>
<td>Plagioclase</td>
<td>Muscovite</td>
<td>Iron oxide (rust)</td>
</tr>
<tr>
<td>Biotite</td>
<td>Amphibole</td>
<td>Orthoclase</td>
</tr>
<tr>
<td>Muscovite</td>
<td>Garnet</td>
<td>Biotite</td>
</tr>
<tr>
<td>Amphibole</td>
<td>Talc</td>
<td>Muscovite</td>
</tr>
<tr>
<td>Pyroxene</td>
<td>Chlorite</td>
<td>Calcite</td>
</tr>
<tr>
<td>Olivine</td>
<td>Staurolite</td>
<td>Dolomite</td>
</tr>
<tr>
<td></td>
<td>Kyanite</td>
<td>Halite</td>
</tr>
<tr>
<td></td>
<td>Orthoclase</td>
<td>Gypsum</td>
</tr>
<tr>
<td></td>
<td>Plagioclase</td>
<td></td>
</tr>
</tbody>
</table>

The first part of this lab is to identify mineral specimens, using the **flow charts** provided (Tables A-1, A-2 and A-3). Note that most rock samples will not have minerals as large as the ones you will see in this part of the lab, so take notice of diagnostic characteristics that do **not** depend on mineral size.

**Needed:** Mineral testing kit and mineral samples M-16 through M-23. Please label the minerals with their M-numbers (use the lab tape and a pen) so that they can be returned to their rightful box.

**Using the flowcharts:**

To begin, determine if the mineral's **luster** is **metallic** or **non-metallic**. Luster refers to how the mineral reflects light; a metallic luster is how a piece of steel or
bronze or copper would reflect light. Compare a piece of metal’s luster to the luster of a piece of glass; the glass’ luster (vitreous) is not a metallic luster. Of course, if the mineral has a dull or pearly luster, it is a non-metallic luster.

If the mineral has a metallic luster, determine the mineral’s **streak** color. Streak refers to the color of the powderized mineral, most easily accomplished by rubbing a corner of the mineral sample against the porcelain streak plate provided.

If necessary, use hardness (explained below) or **magnetism** or cleavage (explained below) or **specific gravity** to identify the mineral.

If the mineral has a non-metallic luster, determine if the mineral has a light (closer to white than black) or a dark (closer to black than white) **color**. Look at the appropriate table.

To narrow down the possible candidate minerals, determine the relative **hardness** of the mineral by scratching a corner of the mineral on a piece of glass (or scratching a corner of the glass plate on the mineral). Hardness is the mineral’s ability to resist scratching or abrasion. A mineral will scratch all softer minerals and will be scratched by all harder minerals. The hardness of the mineral is determined by its crystal structure and the strength of bonds which hold the crystal together. Certain **index minerals** define the **Mohs Hardness Scale**, so you can get a numerical value for hardness.

<table>
<thead>
<tr>
<th>INDEX MINERALS</th>
<th>COMMON OBJECTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diamond</td>
<td>10</td>
</tr>
<tr>
<td>Corundum</td>
<td>9</td>
</tr>
<tr>
<td>Topaz</td>
<td>8</td>
</tr>
<tr>
<td>Quartz</td>
<td>7</td>
</tr>
<tr>
<td>Orthoclase</td>
<td>6</td>
</tr>
<tr>
<td>Apatite</td>
<td>5</td>
</tr>
<tr>
<td>Fluorite</td>
<td>4</td>
</tr>
<tr>
<td>Calcite</td>
<td>3</td>
</tr>
<tr>
<td>Gypsum</td>
<td>2</td>
</tr>
<tr>
<td>Talc</td>
<td>1</td>
</tr>
</tbody>
</table>

**Cleavage** is the next property that helps narrow down the identity of the mineral. Cleavage is the ability of the mineral to split along closely spaced parallel planes. The planes along which a mineral cleaves (when hit with a hammer, for instance) are the planes where all the weak atomic bonds in the
crystal structure exist. Notice that if all bonds are uniformly strong (like in a piece of quartz), the mineral will not cleave along a plane; instead, it will break unevenly and roughly...it will fracture. Cleavage is sometimes confusing because some minerals have good cleavage, some have poor cleavage and still others have no cleavage (they fracture). The table below should help identify different types of cleavages, but ask if this concept is confusing!

<table>
<thead>
<tr>
<th># of Cleavage Planes</th>
<th>Angle Between Planes</th>
<th>Shape</th>
<th>Sketch</th>
<th>Number of Flat Surfaces</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>NA</td>
<td>Irregular masses</td>
<td>![Sketch]</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>NA</td>
<td>Flat sheets</td>
<td>![Sketch]</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>90°</td>
<td>Elongate form with rectangle cross-section</td>
<td>![Sketch]</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>not at 90°</td>
<td>Elongate form with parallelogram cross-section</td>
<td>![Sketch]</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>90°</td>
<td>Cube</td>
<td>![Sketch]</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>not at 90°</td>
<td>Rhombohedron (Smeared out cube)</td>
<td>![Sketch]</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>not at 90°</td>
<td>Octahedron</td>
<td>![Sketch]</td>
<td>8</td>
</tr>
<tr>
<td>6</td>
<td>not at 90°</td>
<td>Dodecahedron</td>
<td>![Sketch]</td>
<td>12</td>
</tr>
</tbody>
</table>

One other complication: since cleavage planes represent planes which minerals break along, crystal growth faces are not cleavage planes. That gorgeous hexagon-shaped piece of quartz does not show cleavage; it grew that way! If you can bear to, whack it with a hammer and you'll see that quartz merely fractures (don't do this with my sample!).

Other tests you can perform involve color (which is a misleading characteristic in the case of quartz and similar kinds of minerals) and reaction to weak acid (in the squeeze bottles).

One more complex test is the specific gravity test. The specific gravity of a mineral is defined as the ratio of a mineral’s weight to the weight of an equivalent volume of water. This number is quite nearly the mineral’s density. Since water is hard to mold into the shape of a mineral, there is a cleverly-designed instrument called the hydrometer which will assist you in measuring the specific gravity of some of these mineral samples.

_Igneous rocks_
Igneous rocks form when magma (molten rock) cools and crystallizes. Volcanic eruptions take place when magma reaches the surface before it solidifies. The
magma flows onto the surface as lava or erupts explosively as rapidly expanding gas propels bits of lava and rock outward. The rocks resulting from eruptions are called **volcanic** or **extrusive** igneous rocks. On the other hand, the magma can crystallize before it reaches the surface, in which case they are called **plutonic** or **intrusive** igneous rocks.

*Historical note:* Vulcan was the blacksmith god of the Romans, forging the tools of the gods inside volcanoes. Pluto was the Roman god of the underworld.

Igneous rocks are classified based on their mineral composition and their mineral grain texture. This classification system is interpretive because it says something about the source of the magma and the conditions under which the rocks were formed.

The mineralogy of an igneous rock is controlled by the chemical composition of its parent magma. Most igneous rocks are composed primarily of the following eight elements:

- Silicon (Si)
- Oxygen (O)
- Sodium (Na)
- Aluminum (Al)
- Magnesium (Mg)
- Calcium (Ca)
- Iron (Fe)
- Potassium (K)

These elements occur in the crystal structure of eight common igneous rock-forming minerals. These minerals in turn make up 95% of the volume of all igneous rocks. The names and chemical formulae for these minerals:

- **Olivine**: (Mg,Fe)₂SiO₄
- **Plagioclase**: NaAlSi₃O₈ (sodium-rich) CaAl₂Si₂O₈ (calcium-rich)
- **Pyroxene**: Complex Ca-Mg-Fe-Al silicates
- **Amphibole**: Complex water-bearing Na-Ca-Mg-Fe-Al silicates
- **Biotite**: K(Mg,Fe)₃AlSi₃O₁₀(OH)₂
- **Orthoclase**: KA½Si₃O₈
- **Muscovite**: KAl₃Si₂O₁₀
- **Quartz**: SiO₂
1. Fill in the following chart using the eight common igneous rock-forming minerals (M16 through M23). Refer to the attached mineral ID charts (Tables A-1 through A-3).

<table>
<thead>
<tr>
<th>Sample</th>
<th>Luster (NM or M)</th>
<th>Streak (if it is useful)</th>
<th>Hardness (harder, softer or similar to glass)</th>
<th>Cleavage (number) or fracture</th>
<th>Other properties</th>
<th>Mineral Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>M16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M17</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M18</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M19</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M21</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M22</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M23</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. a. List the eight minerals above in the appropriate squares in the table below, according to color. Darker-colored minerals will be classified as “mafic”; lighter-colored minerals will be called “felsic”. The exceptions will be plagioclase, which is considered to be mafic, and biotite, which is considered to be felsic. Then use the mineral ID charts to (roughly) calculate the average specific gravity (i.e., density) of each class of mineral. Finally, the diagnostic (characteristic) chemical elements of each class of mineral are given.

<table>
<thead>
<tr>
<th>Color</th>
<th>Minerals</th>
<th>Average specific gravity</th>
<th>Diagnostic elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dark-colored (mafic)</td>
<td>Ca-rich plagioclase</td>
<td></td>
<td>Mg, Al, Fe also Ca</td>
</tr>
<tr>
<td>Light-colored (felsic)</td>
<td>Biotite</td>
<td></td>
<td>Na, K also more Si, O than mafic</td>
</tr>
</tbody>
</table>
b. What does your **average specific gravity calculation** suggest about the **density** of minerals containing magnesium, iron and aluminum versus the density of minerals containing sodium and potassium?

3. a. Look at rock samples R-4 and R-6. Identify the minerals that are present in each sample, then determine if the samples as a whole rock are mafic, felsic or intermediate.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Minerals present</th>
<th>Mafic, felsic or intermediate?</th>
</tr>
</thead>
<tbody>
<tr>
<td>R-4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-6</td>
<td>Ca-rich plagioclase, Olivine, Pyroxene</td>
<td></td>
</tr>
</tbody>
</table>

b. What prevented you from determining the **mineralogy** of R-6 for yourself?

4. From the table in problem 2, mafic rocks tend to have a ________________ density than felsic rocks. So ________________ rocks will subduct under ________________ rocks, or, more generally, ________________ lithosphere will subduct under ________________ lithosphere. (Hint: in the last two blanks, use the words “continental” and “oceanic”).

5. On the diagram of Bowen’s reaction series on the next page, circle and label the areas where a) the **mafic** minerals (as a group) are located and b) the **felsic** minerals (as a group) are located.
6. Which minerals would you find in a rock of \textit{intermediate} composition?

7. An igneous rock may be identified by either its texture or its characteristic mineralogy and grain size. The rocks in the table below can be identified by their grain size and mineralogy. Use Table B-1a to aid your identification. For predominant grain size, simply write either “coarse” or “fine”.

<table>
<thead>
<tr>
<th>Rock #</th>
<th>Felsic, mafic or intermediate?</th>
<th>Predominant grain size</th>
<th>Rock name</th>
</tr>
</thead>
<tbody>
<tr>
<td>R4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R9</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
8. The rocks in the table below can be identified by their texture. Use Table B-1b to aid your identification. Under the texture column, write the descriptive word or words from Table B-1b that helps you categorize the rock.

<table>
<thead>
<tr>
<th>Rock #</th>
<th>Texture</th>
<th>Rock name</th>
</tr>
</thead>
<tbody>
<tr>
<td>R12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R16</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

9. The viscosity of a fluid is its ability to resist flow; higher viscosity means that the fluid doesn't flow very fast. Mafic magma is very fluid compared to more felsic magmas. As a result, mafic lava travels further from the volcano than does felsic lava, which tends to pile up near the eruption point. Felsic lava, because of its viscosity, also traps volatiles (gases). Circle the correct choice below:

a. Which temperature magma would tend to have less viscosity (more fluidity)?
   - 1200°C
   - 900°C
   - 600°C

b. Which temperature magma would tend to have more iron in its molten state?
   - 1200°C
   - 900°C
   - 600°C

c. Which temperature magma would contain the least amount of dissolved gases, and therefore be more fluid?
   - 1200°C
   - 900°C
   - 600°C

d. So which word best describes the composition of the magma that satisfies the temperature requirements above?
   - mafic
   - intermediate
   - felsic

10. Using the results of question 8, answer the following questions with mafic, felsic, intermediate or any:

a. Which magma will likely erupt explosively?

b. Which magma will likely erupt effusively (quiescently)?

c. Which magma will produce volcanoes with steep slopes?

d. Which magma will produce volcanoes with gentle slopes?
Table B-1a. Igneous rocks which are identified by their composition/grain size

<table>
<thead>
<tr>
<th>COMPOSITION (Minerals present)</th>
<th>Felsic</th>
<th>Intermediate</th>
<th>Mafic</th>
</tr>
</thead>
<tbody>
<tr>
<td>coarse-grained (mostly visible)</td>
<td>quartz orthoclase biotite Na-plagioclase</td>
<td>Na-plagioclase amphibole pyroxene biotite</td>
<td>Ca-plagioclase olivine pyroxene</td>
</tr>
<tr>
<td>Fine-grained (mostly invisible)</td>
<td>RHYOLITE</td>
<td>ANDESITE</td>
<td>BASALT</td>
</tr>
</tbody>
</table>

Table B-1b. Igneous rocks which are identified by their texture

1. Is the rock **glassy** on any fresh surface?  
   Yes — **Obsidian**  
   No — Go to #2.

2. Is the rock **vesicular** (containing gas bubbles)?  
   Yes — Go to #3  
   No — Go to #4

3. Is the rock dark-colored on a fresh surface?  
   Yes — **Scoria**  
   No — **Pumice**

4. Is the rock composed of large pieces of broken rocks?  
   Yes — **Breccia**  
   No — Go to #5

5. Is the rock well-**cemented** (doesn't crumble easily)?  
   Yes — **Welded tuff**  
   No — **Tuff**

Tuff and pumice are sometimes difficult to tell apart; however, a simple test distinguishes them: pumice floats on water and tuff sinks.