Lab 3: The rock cycle, minerals 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 (located in Tub 4) and mineral samples M-1 through M-18 (Tubs 1 and 2). 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.

1. a. Look at minerals M-3, M-5 and M-6. Only one of these samples has a metallic luster. Which one?

b. Now examine minerals M-2 and M-12; again, only one of these has a metallic luster. Which one? Hint: you may need to look at different specimens of the same mineral.

By the way, since you’ll be eventually filling out the table on the next to last page, you might as well fill in the appropriate cells in the table with the information above.

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.

2. a. Use the porcelain streak plate on sample M-4; what color does the streak turn out to be? Is it the same as the color of the mineral?

b. Try streaking a few of the nonmetallic luster minerals. What seems to be the problem with the streak test and nonmetallic minerals?

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

3. Use the magnet to determine if M-2, M-3 or M-4 is magnetic. “Weakly magnetic”, “strongly magnetic” and “not magnetic” are acceptable answers. In addition to writing your answer here, enter the information under “other properties” in the table on the appropriate row.

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.

4. Look at samples M-15 and M-17. Which one is dark-colored? Which is light?
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.

5. Use the corner of a glass plate and scratch minerals M-1, M-7 and M-13 and record the results below. Then scratch a corner of each mineral on the flat surface and record the results. Be sure to brush off any flakes of mineral to make sure that you’ve actually left a scratch! Then combine the information to draw a conclusion. Hint: there’s one of each “type”.

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Does the glass scratch the mineral?</th>
<th>Does the mineral scratch the glass?</th>
<th>The mineral is “harder than”, “softer than” or “the same hardness as” the glass?</th>
</tr>
</thead>
<tbody>
<tr>
<td>M-1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M-7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M-13</td>
<td></td>
<td></td>
<td></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><img src="image" alt="Sketch" /></td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>NA</td>
<td>Flat sheets</td>
<td><img src="image" alt="Sketch" /></td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>90°</td>
<td>Elongate form with rectangle cross-section</td>
<td><img src="image" alt="Sketch" /></td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>not at 90°</td>
<td>Elongate form with parallelogram cross-section</td>
<td><img src="image" alt="Sketch" /></td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>90°</td>
<td>Cube</td>
<td><img src="image" alt="Sketch" /></td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>not at 90°</td>
<td>Rhombohedron (Smeared out cube)</td>
<td><img src="image" alt="Sketch" /></td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>not at 90°</td>
<td>Octahedron</td>
<td><img src="image" alt="Sketch" /></td>
<td>8</td>
</tr>
<tr>
<td>6</td>
<td>not at 90°</td>
<td>Dodecahedron</td>
<td><img src="image" alt="Sketch" /></td>
<td>12</td>
</tr>
</tbody>
</table>

6. a. How many cleavages does M-5 have? Hint: It’s called a “sheet silicate” for a good reason!

b. How many cleavages does M-10 have? Remember not to count parallel faces twice. What **angle** separates each distinct cleavage?

c. How many cleavages does M-15 have? So what shape-related property does it have, then?

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).

7. Obtain an acid dropper bottle and place **one** drop of (hydrochloric) acid on a sample of M-7 and M-8. Which one **reacts**? How can you tell?

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. You will need a calculator for this part, as well as the **specific gravity worksheet**.

8. Measure the specific gravity of M-1 and M-2, and record those numbers. Keeping in mind that specific gravity is very nearly density, heft these minerals; do your results make sense?

9. A practical use: a friend claims to have a ruby, which is the red/pink form of the mineral **corundum** (this is sample M-18). You suspect that what he has is **rose quartz**, a form of the common mineral quartz. Measure the specific gravity of M-18, then compare the result to the number given in the table. What **conclusion** do you draw?

10. All right, now put it all together and fill in the following chart using the mineral samples.

    **Mineral ID Chart**

<table>
<thead>
<tr>
<th>Sample</th>
<th>Luster</th>
<th>Streak (if it is useful)</th>
<th>Hardness (relative to glass)</th>
<th>Cleavage/Fracture</th>
<th>Other Properties</th>
<th>Mineral Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
11. Name three physical characteristics you can use to distinguish quartz from calcite.

12. What characteristic is useful in distinguishing amphibole from biotite?

*Needed: rock samples R1 through R3 (Tub 3)*

13. Using your new-found mineral identifying powers, figure out what minerals you can see in each of the samples R-1, R-2 and R-3. Enter your data on the table on the next page.

14. From the table of common rock-forming minerals at the beginning of the lab, and from the texture of the samples (layered, foliated, crystalline), identify each
rock as igneous, metamorphic or sedimentary and complete the table on the next page.

<table>
<thead>
<tr>
<th>Rock sample</th>
<th>Mineral(s)</th>
<th>Igneous, metamorphic or sedimentary?</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>1.</td>
<td></td>
</tr>
<tr>
<td>R2</td>
<td>1.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.</td>
<td></td>
</tr>
<tr>
<td>R3</td>
<td>1.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.</td>
<td></td>
</tr>
</tbody>
</table>

**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. The advantage of this classification system is that 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)
- Magnesium (Mg)
- Iron (Fe)
- Sodium (Na)
- Aluminum (Al)
- Calcium (Ca)
- 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** $\text{(Mg,Fe)}_2\text{SiO}_4$
- **Plagioclase** $\text{NaAlSi}_3\text{O}_8$ (sodium-rich) $\text{CaAl}_2\text{Si}_2\text{O}_8$ (calcium-rich)
- **Pyroxene** Complex Ca-Mg-Fe-Al silicates
- **Amphibole** Complex water-bearing Na-Ca-Mg-Fe-Al silicates
- **Biotite** $\text{K(Mg,Fe)}_3\text{AlSi}_3\text{O}_{10}(\text{OH})_2$
- **Orthoclase** $\text{KAlSi}_3\text{O}_8$
- **Muscovite** $\text{KAl}_3\text{AlSi}_3\text{O}_{10}$
- **Quartz** $\text{SiO}_2$

Note that you have seen all of these minerals in the previous part of this lab; go back and look at those samples if you are unclear about what minerals you are seeing in this lab’s rocks.

**Needed:** R4 (Tub 5), R5 (Tub 6), R8 (Tub 9)

### Identifying igneous rocks

15. 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?
16. a. Look at rock samples R-4 and R-5 (one without visible grains). 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-5</td>
<td>Ca-rich plagioclase Olivine Pyroxene</td>
<td></td>
</tr>
</tbody>
</table>

b. What prevented you from determining the mineralogy of R-5 for yourself?

17. a. Let’s check question 15b’s conclusion, because as far as you know, there is no connection between specific gravity and density. Determine the density of samples R-4 and R-5. Note 1 mL = 1 cm³.

<table>
<thead>
<tr>
<th></th>
<th>mass (grams)</th>
<th>volume (mL)</th>
<th>volume (cm³)</th>
<th>Density (g/ cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R-4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

b. From the table above, mafic rocks tend to have a ________________ density than felsic rocks. Therefore, question 15b’s conclusion is consistent with observations.

c. 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”).

18. 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.
19. Which minerals would you find in a rock of **intermediate** composition?

20. a. A **prophyritic** igneous rock contains minerals of two distinct **grain sizes** (generally, **coarse** and **fine**). The **phenocrysts** are the larger, easily-identified minerals within the finer, difficult-to-discern-individual-grain **groundmass**. What mineral is the phenocryst in R-8?

b. Find a sample of R-5 that has phenocrysts. Identify the phenocrysts.