Objectives of this Lab

1. Understand how the minerals and textures of rocks reflect the processes by which they were formed.
2. Understand how rocks are named and classified based on their textures the minerals (and amorphous substances) they contain.

Introduction

Rock is a naturally occurring aggregate of minerals, mineraloids, glass and organic particles. Most rocks consist of several such minerals or mineraloids; a few, such as quartzite and dunite, are composed of only one and are said to be monomineralic. Other rocks, such as coal, opal, and obsidian, are made up entirely, or nearly so, of amorphous substances.

Rocks are the history book of the planet. Meteorite impacts, collisions and rifting of ancient continents, erosion of long vanished mountain ranges, ice ages, and the life itself have all left records in this book. Unfortunately, the book is written in a complex code; a code we are still struggling to understand. The subdiscipline of geology that attempts to read and interpret the rock record is called petrology. This week’s exercise will provide you with a brief introduction to petrology.

The Petrographic Microscope

As you know, light is an electromagnetic wave; we can think of it as a vibrating electromagnetic field. In general, the vibration can be in any direction (up-down, side-to-side, etc). Some materials, and many minerals in particular transmit only that part of light that is vibrating in particular directions. Furthermore, the speed at which light is transmitted through a mineral depends on its vibration direction relative to the alignment of atoms in the crystal (i.e., relative to crystallographic orientation). This leads to a number of interesting optical properties than help us distinguish minerals.

Today’s exercise will make use of the petrographic microscope. This microscope is designed to take advantage of the optical properties of minerals. A petrographic microscope projects light through a polarizing filter (a “polaroid”) up through a glass slide containing a slice of rock cut very thin, called a thin section. A second polaroid, whose direction of polarization is 90° to the first, can be inserted between the thin section and the eye piece. If there is nothing between the two polarizers, no light is transmitted: the field of view will appear black. This is because the first polarizer eliminates all light except for that vibrating in one direction and the second polarizer eliminates the remaining light. The stage on the petrographic microscope can be rotated, allowing you to change the optical orientation of the mineral in view.
Optical Properties of Minerals

Most minerals can have the effect of rotating the direction of polarization of light passing through them. Thus when such a mineral is present between the polarizers, some light may still be transmitted, because its direction of vibration is no longer perpendicular to the second polarizer. Amorphous substances, such as glass, as well as “isotropic” minerals, do not have this property and will appear black when viewed with crossed polarizers. Non-isotropic minerals will also appear black where properly oriented. When they do, they are said to go to “extinction”. You will notice this when you rotate the stage with polarizers crossed.

Opacity

Some minerals, oxides and sulfides in particular, do not transmit light at all and hence appear black, or opaque, even with the top polarizer removed. In the rocks we will view, most will be oxides of iron and titanium.

Interference Colors

Non-isotropic minerals will appear colored when the polarizers are crossed. These colors are not the natural ones, but rather interference colors. The result from the fact that the speed of light transmitted through the mineral depends on its vibration direction. Hence light transmitted in vibrating in plane A will travel slower and arrive at your eye than light vibrating in direction B. The light your eye detects is the sum of these two waves. This summed wave will have a frequency of vibration that depends on the difference in travel time. Your eye interprets the frequency of vibration as color. This interference color is also useful in identifying minerals.

Relief

If the refractive index (actually, the speed at which light is transmitted through the substance) of a substance is similar to that of air, its surface is difficult to see and it will almost seem to disappear under the microscope with the top polarizer removed. On the other hand, if the refractive index is much different than air, the surface is easy to see. In this case, the mineral is said to have relief. Quartz and feldspar have little relief, ferromagnesian minerals have moderate to high relief.

Color

You can see the natural color of the minerals when the top polarizer is removed. Quartz, feldspar, and calcite appear colorless in thin section. Ferromagnesian minerals have varying degrees of color, ranging from slight in olivine to strong in amphibole and biotite.

Pleochroism

With the top polarizer removed, the color of some minerals will change as the stage is rotated. This is a phenomenon known as pleochroism.
Twinning

Twinning is not strictly an optical property, but is most apparent when viewing minerals in thin sections. Twinning is a phenomenon in which the crystallographic orientation of a crystal (that is, the alignment of atoms), changes across a plane, called a twinning plane, that is interior to the crystal. For example, the crystallographic orientation on one side of a twinning plane might be the mirror image of that on the other side.

Twinning is most obvious when the stage is rotated: part of the crystal will go extinct at one angle, while other parts will go extinct at another angle. Feldspar crystals are almost always twinned and can readily be identified this way. Quartz, which can otherwise appear similar to feldspar, is rarely twinned. Pyroxene is also sometimes twinned, but less often that feldspar.

Optical Properties of Common Minerals

The following summarizes some of the optical properties of common minerals and mineraloids:

- **Isotropic**
  - Glass
  - Garnet

- **Interference colors**
  - Strong: Calcite and ferromagnesian minerals such as olivine, pyroxene, amphibole, and mica
  - Weak: Feldspars and quartz (appear gray, white, or yellow)

- **Opaque**
  - Sulfides
  - Oxides of iron and titanium such as magnetite, hematite, and ilmenite

- **Color**
  - Little or no color
    - Quartz, feldspar, calcite, olivine
  - Moderate to strong color
    - Pyroxene (usually light brown, sometimes greenish or purplish)
    - Amphibole (usually brown or green)
    - Biotite (brown or green)

- **Pleochroism**
  - Biotite and hornblende (amphibole) are often strongly pleochroic. Pyroxene occasionally shows weak pleochroism.

Igneous Rocks

The principal minerals in igneous rocks are shown in the figure below.

Rock Texture

The following textural features of igneous rocks are important:
• **Grain size**: intrusive rocks are coarse-grained; intrusive ones are coarse-grained. Rocks in which the crystals are too small to see with the naked eye are called *aphanitic*; those in which all the crystals are large enough to see are called *phaneritic*.

• **Distribution of grain sizes**
  Crystals much larger than average are called *phenocrysts*; rocks containing them are called porphyritic.

• Presence or absence of *vesicles*; only extrusive rocks have vesicles. Rocks containing vesicles are called *vesicular*. Rocks dominated by vesicles are called pumice when they are felsic or intermediate in composition and scoria when they are mafic.

• **Alignment** of crystals; flow of lava sometimes produces an alignment of crystals or banding. Banding may also occur in intrusive igneous rocks as different crystals successively settle out of a magma.

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**Igneous Minerals**

The figure below illustrates the minerals occurring in the various igneous rocks.

- Increasing $\text{SiO}_2$
- Decreasing density
- Decreasing $\text{Fe, Mg}$

1600°C decreasing melting point/eruption temperature → 700°C

- Plagioclase (Ca,Na) feldspar
- K-feldspar
- Quartz
- Biotite (mica)
- Amphibole
- Olivine

**dark colored**
- komatiite
- peridotite

**light colored**
- basalt
- gabbro
- andesite/dacite
- diorite/granodiorite
- rhyolite
- granite

Increasing cooling rate → Increasing grain size

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*EAS 302*  
*Lab 6*

*Introduction to Petrology*
Metamorphic Rocks

Metamorphic rocks are rocks that have undergone changes as a result of elevated temperature or pressure or reaction with a fluid. A variety of changes may occur. In some cases, change is limited to an increase in grain-size. In other cases, the original minerals are replaced by ones stable at the temperature and pressure at which metamorphism occurred. At low temperature (room temperature up to 500 or 600°C), the stable minerals are often hydrous minerals such as amphiboles and micas and other sheet silicates. Hence originally anhydrous rocks generally become hydrated during metamorphism. At high temperature, these hydrous minerals break down and are replaced by anhydrous minerals. Metamorphism can occur without net chemical change to the rock. In this case, the process is said to be isochemical. In other cases, metamorphism is accompanied by gain of some elements and loss of others. This process is called metasomatism.

Metamorphic rocks are sometimes named according to their origin: hence they sometimes called names such as metabasalt, metasediment, or metadacite. More often, they are named based on the minerals they contain and their textures. This in turn reflects (a) the original composition of the rock and (b) the temperature and pressure at which it was metamorphosed.

An important concept in metamorphic petrology is that of metamorphic grade. Grade corresponds more or less to the highest temperature at which metamorphism occurred. Hence low grade rocks were metamorphosed at low temperature and high grade ones at high temperature. In general, as one goes from low to high grade, grain size increases and hydrous (water-bearing) minerals are replaced by anhydrous ones. Usually, increasing pressure accompanies increasing temperature, so rocks metamorphosed at high temperatures have also experienced moderate to high pressures.

For fine-grained sediments such as shales, mudstones, etc., the sequence of metamorphic rocks formed going from low grade to high grade is:

- Slate
- Phyllite
- Schist
- Gneiss
- Granulite

For (mafic) igneous rocks, the sequence is a bit simpler:

- Greenschist
- Amphibolite
- Granulite

There are a few other metamorphic rock names you should be familiar with:

1. *Blueschist* is a rock formed at high pressures and low temperatures.
2. *Eclogite* is a rock consisting of garnet and pyroxene formed at very high pressure and moderate to high temperatures.
3. *Hornfels* is a pyroxene-plagioclase rock formed under low pressure and high temperature, conditions that occur during contact metamorphism.
4. *Marble* is formed by metamorphism of limestone.
5. *Quartzite* is formed by metamorphism of quartz sandstone.
At low grade, sheet silicates such as chlorite and mica, are often the dominant minerals, sometimes giving the rock a shiny appearance. These minerals are often aligned. If so, the rock is said to be foliated.

At higher grade, this foliation is often replaced by segregation of light and dark minerals (usually quartz and feldspar and amphibole and mica respectively) into bands. Banding is characteristic and diagnostic of gneisses.

Sometimes, some crystals in a metamorphic rock may grow to larger sizes than surrounding ones. These crystals are called porphyroblasts.

Exercise

Examine the hand specimens and microscope slides of the samples in lab. Then write a brief description of the rock. For igneous rocks, your description should include the following:

- Color of the rock (concentrate on fresh surfaces)
- Minerals present (both your TA and your lab manual can help you identify them)
- Grain size
- Other textural features, including presence or absence of phenocrysts and vesicles

For metamorphic rocks, your description should include the following:

- Color of the rock (concentrate on fresh surfaces)
- Grain size
- Textural features, including presence or absence of foliation, banding, schistosity, and porphyroblasts
- Minerals present (your TA can help you identify them)

Finally, make a guess as to the name of the rock.