

EARTH AND SPACE SCIENCES 212

Lab 2 (4 hours): PLUTONIC IGNEOUS ROCKS

This lab will introduce you to the variety of plutonic rocks and rock suites. A **suite** is a group of **petrogenetically related** rocks. The lab will also acquaint you with the most widely used classification schemes for plutonic rocks, and will give you practice at determining mineral assemblages and modes in coarse-grained rocks [which you should find easier than volcanic rocks.] The **IUGS** system of classification is the recommended method used by petrologists. Almost all common volcanic rocks have a plutonic counterpart [the converse is not the case], but intrusive and extrusive equivalents are not necessarily found in the same abundance on Earth. The IUGS **quartz--alkali feldspar--plagioclase--feldspathoid** double triangle is not adequate for classifying mafic and ultramafic rocks since diorites, gabbros, norites, gabbronorites, troctolites and anorthosites all fall in the same area of the IUGS diagram. Mafic and ultramafic rocks are classified on the basis of the modal abundances of olivine, orthopyroxene, clinopyroxene, and plagioclase. The classification scheme for plutonic rocks, including mafic and ultramafic rocks, is included in this week's lab handout (also posted on the web page).

As you recall, the **mode** is the **volume percent** of all minerals present. (When you use a hand sample of a rock to estimate the mode or a thin section to measure the mode, you are really estimating an *area percent* but the difference between volume % and area % is usually not significant). Once you have identified the minerals present, estimating a mode to within 5 or 10% for the major minerals is usually not too difficult, but it does take some practice. It is often helpful to look at a weathered surface since many minerals take on a characteristic appearance when weathered. It is also possible to stain a sawn rock surface with chemical reagents that differentiate between otherwise similar minerals, such as alkali feldspar and plagioclase. The various plutonic rocks for study are grouped below in suites that represent the more common types of occurrence in the Earth's crust. As with volcanic suites, similar rock types can occur in more than one geologic setting.

Textures of plutonic rocks:

Refer to the lab handout on volcanic rocks because many of the same terms apply to plutonic rocks, e.g., crystallinity, grain size, crystal form, shapes and habits.

The following textural terms are commonly used for plutonic rocks. These terms are used to describe the **aggregate** of minerals/glass within a rock]

IDIOMORPHIC: a rock in which all crystals are euhedral. (Such textures are rare in plutonic rocks because crystals will interfere with each other during growth and faces are not preserved.

HYPIDIOMORPHIC: a rock with a mixture of euhedral, subhedral or anhedral mineral grains (common in holocrystalline plutonic igneous rocks.)

XENOMORPHIC: a rock consisting entirely of anhedral crystals (common).

EQUIGRANULAR: most of the minerals are *approximately* the same size.

PORPHYRITIC: an inequigranular texture characterized by the presence of one (or more) mineral of *conspicuously* larger grain size than those of the rest of the rock.

****MIAROLITIC** (*best seen in the field*): a crystal-lined cavity in granite, e.g., Golden Horn batholith in the North Cascades National Park. Cavities presumably formed where gases escaping from the cooling magma were trapped. These cavities commonly contain beautifully faceted rare minerals.

The mineralogical classification of plutonic rocks is based on the following criteria:

a. Presence or absence of Quartz or Feldspathoids

Since quartz and feldspathoids (leucite and nepheline) are incompatible, a rock can have one or the other but not both.

b. Alkali feldspar/[Alkali feldspar + plagioclase]

Alkali feldspar includes orthoclase, sanidine, microcline, perthite, anorthoclase and albite ($Ab_{100-95}An_{0-5}$). *Plagioclase* includes all plagioclase with An content $> 5\%$ [$An_5 - An_{100}$]

c. Relative amounts of plagioclase, pyroxenes, and olivines

Used to subdivide **mafic** rocks (gabbros, norites, troctolites, etc.).

f. Relative amounts of olivine, orthopyroxene, clinopyroxene

Used to subdivide **ultramafic** rocks, i.e., rocks with > 90 mafic minerals.

Exercise: For practice in classifying and naming plutonic rocks, use the IUGS system (see the plutonic diagram in the classification handout) to name the rocks 1 to 4.

1. A phaneritic rock containing 57% plagioclase, 20% orthopyroxene, 19% clinopyroxene, and 4% hornblende.
2. A phaneritic rock containing 3% plagioclase, 71% olivine, 13 % orthopyroxene, 11% clinopyroxene and 2% chromite.
3. A phaneritic rock with 11% quartz, 1% orthoclase, 68% plagioclase, 5% biotite, and 15% hornblende.
4. A phaneritic rock containing 16% orthoclase (as large phenocrysts) in a medium-grained groundmass containing 20% quartz, 17% orthoclase, 37% plagioclase, 7% hornblende and 3% biotite.

In the following exercises, it is a good idea to look at more than one sample—some are larger and better than others. For most of the rocks there is a thin section.

I. Ophiolite Suite

It has long been known that a distinctive suite of ultramafic rocks, gabbros, pillow basalts and pelagic sedimentary rocks commonly occur together. This association of rocks has become known as the **ophiolite** suite and it is widely believed to represent a section of ocean crust and upper mantle that have been thrust over continental crust at an active margin; the process is sometimes called **obduction**. Examples of local rocks that would be classified as ophiolites are the Fidalgo Island serpentinite, the Ingalls Ultramafic Complex (near Mount Stuart), and the Twin Sisters Dunite (North Cascades). Other well known ophiolites include the Bay of Islands (Newfoundland), Semail (Oman), Canyon Mountain (Oregon), Smartville (California), and Troodos (Cyprus) Complexes.

321-6 Serpentinized Harzburgite, Fidalgo Island, Washington

This is actually a metamorphic rock formed by low temperature alteration of **harzburgite**. Check the IUGS classification scheme to determine what minerals would be present in the harzburgite prior to alteration. The rock is now composed of serpentine along with small amounts of magnetite.

Questions: (1) What mineral does the serpentine replace?

(2) What is the major chemical change which occurs in the replacement process?

321-142 Layered Gabbro, Feather River, Smartville Ophiolite, California

This rock has an obvious planar structure defined by variations in **mode** rather than by preferred orientation of minerals. This type of planar structure is called **modal layering**.

Question: Identify the minerals, describe the changes in mode which produce the layering, and suggest an origin for the layering.

321-28 Dunite, Twin Sisters, Washington

The Twin Sisters massif in the North Cascades represents the lowermost part of a “dismembered” ophiolite. Some samples show the characteristic tan (“dun”) weathering surface, the appearance of which is responsible for the rock's name. [Type locality is Dun Mountain, New Zealand.] Strictly speaking this is a metamorphic rock since it has been deformed and recrystallized in the solid state.

Questions: (1) What is the major mineral in this rock?

(2) Locate the black spinel in the rock, and identify it (Hint: it is rich in Cr).

(3) What evidence might you look for to indicate that the rock had been deformed?

II. Layered Mafic Intrusions

The term “**layered mafic intrusion**” is applied to layered, plutonic complexes, most of which are Precambrian. These complexes occur in continents and are most commonly of overall *gabbroic* composition. The most extensively studied examples are the **Stillwater Complex** in Montana, the **Skaergaard Intrusion** in Greenland, and the **Bushveld Complex** in South Africa. These intrusions are important because they illustrate the results of crystal-liquid fractionation processes in gabbroic (= basaltic) magmas and they are the source of nearly all the world's reserves of platinum, palladium, chromium and vanadium. Most of the rocks are **cumulates** which is the name given to rocks which may have formed by gravitational separation of crystals (sinking of the denser minerals, and flotation of the lighter ones). Ultramafic rocks (peridotites, dunites, pyroxenites) occur at the base of the Stillwater and Bushveld Complexes, and are overlain by a variety of norites, troctolites, gabbros, and anorthosites.

321-177 Olivine Chromitite, Stillwater Complex, Montana

This rock is the major ore of chromium and was mined at the Stillwater Complex until recently.

Questions: (1) Identify the two minerals in this rock, and estimate the mode.

(2) This rock is dense. Look up the specific gravity of the constituent minerals and determine if the minerals in this rock would sink or float in a gabbroic magma ($\rho_{\text{magma}} = 2.7 \text{ g/cc}$)

202 SC-964 Harzburgite, Stillwater Complex, Montana

This rock contains nearly equal amounts of olivine (green) and orthopyroxene (brown).

Questions: (1) What is the white mineral interstitial to the mafic minerals? Hint: It has polysynthetic twinning

(2) Do you think that the interstitial mineral grew before or after the olivine and orthopyroxene?

- (3) Would you expect the olivine and opx to be Mg-rich or Fe-rich?

321-149 Orthopyroxenite (Bronzite), Stillwater Complex, Montana

This rock is composed dominantly of orthopyroxene (this variety of opx is commonly referred to as **bronzite** because it tends to weather a “bronzy” color).

- Questions: (1) What is the compositional range of bronzite? (Look up in book)
- (2) How might a rock like this (or any nearly monomineralic igneous rock) have formed?
- (3) Identify the bright green minor mineral (color is due to Cr in structure).
- (4) Identify the white to translucent interstitial mineral and estimate its modal abundance.

202 SC-938 Norite, Stillwater Complex, Montana

Question: (1) Identify the two main minerals and estimate the mode of this rock. You may find it easier to identify minerals on a weathered surface.

202 SC-962 Gabbronorite, Stillwater Complex, Montana

- Questions: (1) Identify the three main minerals in this rock. Clue: two pyroxenes and a feldspar.
- (2) Estimate the mode of the rock
- (3) How do the habits of the two pyroxenes differ?

202 SC-960 Anorthosite, Stillwater Complex, Montana

This is an excellent example of a monomineralic rock, i.e., a rock composed entirely of a single mineral.

- Questions: (1) What is the mineral making up this rock?
- (2) How might a rock such as this form?

III. Calc-alkaline Plutonic Rocks of magmatic arcs

The plutonic counterparts of calc-alkaline volcanic rocks (basalts--andesites--dacites--rhyolites) that form in island arcs and continental arcs. The plutonic rocks occur as large composite batholiths and smaller plutons within orogenic belts at continental margins. The

batholiths typically contain cogenetic suites ranging in composition from mafic to felsic. In the plutonic case, gabbro--diorite--tonalite--granodiorite--granite are the most common rock types. The intermediate members of the calc-alkaline series (Quartz diorite-tonalite-granodiorite) are typically the most important in terms of relative volume within batholiths. The chief felsic minerals are **plagioclase, orthoclase or microcline, and quartz** and the chief mafic minerals are **pyroxene, hornblende, and biotite**. Common accessory minerals are **titanite and magnetite**.

321-27 Diorite, Mount Stuart batholith, Washington

The Mount Stuart batholith in the Cascades is an example of a composite batholith (one which is composed of multiple plutons).

Questions: (1) Identify the main minerals and estimate the mode of this rock

(2) Describe the overall texture of the rock, paying attention to mineral orientations.

(3) How would you distinguish diorites from quartz diorites and tonalites? [Check the IUGS classification]

321-239 Granodiorite, Snoqualmie batholith, Washington

Although this rock contains a significant amount of interstitial quartz and potassium feldspar [orthoclase], the abundant medium-grained subhedral plagioclase grains are the most obvious constituent. Try to locate a grain showing albite twinning, and note its appearance versus the matrix of the rock, and then examine the matrix with a hand lens to see the quartz and the other whitish feldspar. There is a simple staining technique that can be used to distinguish K-feldspar from plagioclase.

Question: (1) The two mafic minerals in this rock are typical in granodiorites and tonalites. What are they?

321-08 Granite, Yosemite National Park, Sierra Nevada Batholith, California

The Sierra Nevada batholith is one of the largest and most comprehensively studied Cretaceous composite batholiths in the western U. S. This particular sample comes from one of the major units, the Cathedral Peak Granite. [Note: before the IUGS classification was adopted, the Geological Survey, which mapped this region, referred to this rock as a "quartz monzonite" rather than granite. A similar nomenclature problem exists with rocks which formerly were called "quartz diorite", but are now called "tonalite". You will run into this problem with any literature published before 1975.]

Question: (1) what mineral forms the large megacrysts in this sample?

321-219 Granite, Idaho batholith, Idaho

Some granites contain two micas, i.e., biotite and muscovite. Such granites are called **S-type** meaning that they formed by partial melting of a sedimentary protolith (most likely a deeply buried pelite—metamorphosed shale).

Questions: (1) What evidence in this rock suggests that the muscovite is a primary igneous mineral and not the result of subsolidus alteration?

(2) Based on the presence of muscovite, this rock is assumed to be peraluminous. Explain why? [You might have to look up the definition of peraluminous in the classification handout].

IV. Other Continental Plutonic Rocks

I have included in this category a variety of continental plutonic rocks which represent a range of compositions, but are not very common in the exposed geologic record. Some of these are associated with rocks of the orogenic calc-alkaline suite in some areas, but generally these rocks show no obvious relation to orogenic magmas.

321-29 Alkali feldspar granite, Unknown locality in New England

A rock like this is sometimes referred to as a *hypersolvus granite* which means that the magma crystallized at a temperature above the solvus in the alkali feldspar system (recall you mineralogy and the earlier discussion of the alkali feldspar solvus).

Questions: (1) Identify the feldspar in this rock (look carefully at the internal structure of the grains before choosing your name).

(2) What is the mafic mineral in this rock? (type locality of this mineral)

321-178 Granite, Golden Horn batholith, Washington Pass, North Cascades

This rock contains alkali feldspar, plagioclase, quartz, biotite, riebeckite (*an alkali amphibole*), and some titanite. The Golden Horn batholith has large miarolitic cavities and is a favorite site for mineral collectors.

Question: (1) Describe the textures of the feldspars and estimate the mode of the rock.

321-151: This is a *graphic texture*, so termed because of its similarity to cuneiform writing. It is common in granitic pegmatite and is probably the result of simultaneous crystallization and intergrowth of quartz and orthoclase.

Question: (1) Identify the minerals in this **graphic granite**?

(2) How do you think such a texture might have formed?

321-133 Alkali feldspar syenite, Brazil

Note the absence of quartz and the presence of two amphiboles. Note the strong fabric in this rock.

Question: (1) Estimate the mode of this sample.

(2) Why would the name “syenite” be inappropriate for this rock under the IUGS classification scheme,

321-179 Sodalite syenite, Square Butte, Montana

This is an example of a silica-undersaturated rock from a thick sill of Eocene age located in central Montana. The sodalite (which is not blue in this sample) resembles quartz in hand sample. The feldspar in this rock is sanidine. The mafic mineral is a variety of amphibole called ferrohastingsite.

Questions: (1) Estimate the modal abundance of the minerals.

(2) What are the cavities in a rock like this called, and how do they form?

321-94 Porphyritic quartz monzonite, Kanisku Batholith, Idaho

Write and hand in a complete rock report on this sample

321-11 Ribbon Cliffs (Pateros), Washington

Question: Estimate the mode, and describe the texture of this sample, and name the rock type.

321-255 Titanite-rich felsic dike in tonalite (Banks, Idaho) (single sample)

Note the characteristic form of the large, euhedral **titanite** (CaTiSiO_5). [In older literature this mineral is called **sphene**.] Titanite usually occurs as an accessory (i.e., minor) mineral in silicic plutonic rocks.

Questions: (1) Why is titanite always an accessory mineral?

(2) What are the other two minerals in this rock?

321-256 Dike rock (Straight Creek, Washington) (single sample)

This rock contains garnet--rare in igneous rocks. Garnets of igneous origin occur in some **peraluminous** felsic rocks (formed by melting a shale protolith at relatively high pressures). Garnets in this rock are almandines, i.e., rich in the $\text{Fe}_3\text{Al}_2\text{Si}_3\text{O}_{12}$ component.

Question: What do we mean by the term “peraluminous?” Look up classification handout for definition.

321-326 Mantle xenolith (San Quintin, New Mexico) (single sample)

The black vesicular rock forming the rind on this rock is an alkali basalt, while the interior of the sample is a xenolith of **spinel lherzolite** derived from a depth of between 40 and 60 km in the mantle. Note the high density of the sample. Lherzolite has a density of 3.4 g cm^{-3} and is much denser than the host magma (approximately 2.7 g cm^{-3}). The magma must have traveled very quickly from great depth (50-60 km) to allow the lherzolite xenolith to be entrained and then ejected onto the surface.

Questions: (1) What are the main minerals in the xenolith?

(2) What is the cause of the faint foliation in this xenolith?

321-253 Carbonatite (Magnet Cove, Arkansas) (single sample)

This rare rock consists of **igneous calcite** along with a variety of silicates typical of carbonate lavas - **monticellite** (CaMgSiO_4) and green **phlogopite**, as well as **apatite** and **perovskite** (CaTiO_3). Carbonatites are enriched in Nb, Zr, Ta, and the rare earth elements, and sometimes mined as commercial sources of these elements.

This rock contains true perovskite, not be confused with deep mantle “perovskite” which has the same crystal structure but the composition of pyroxene MgSiO_3 .

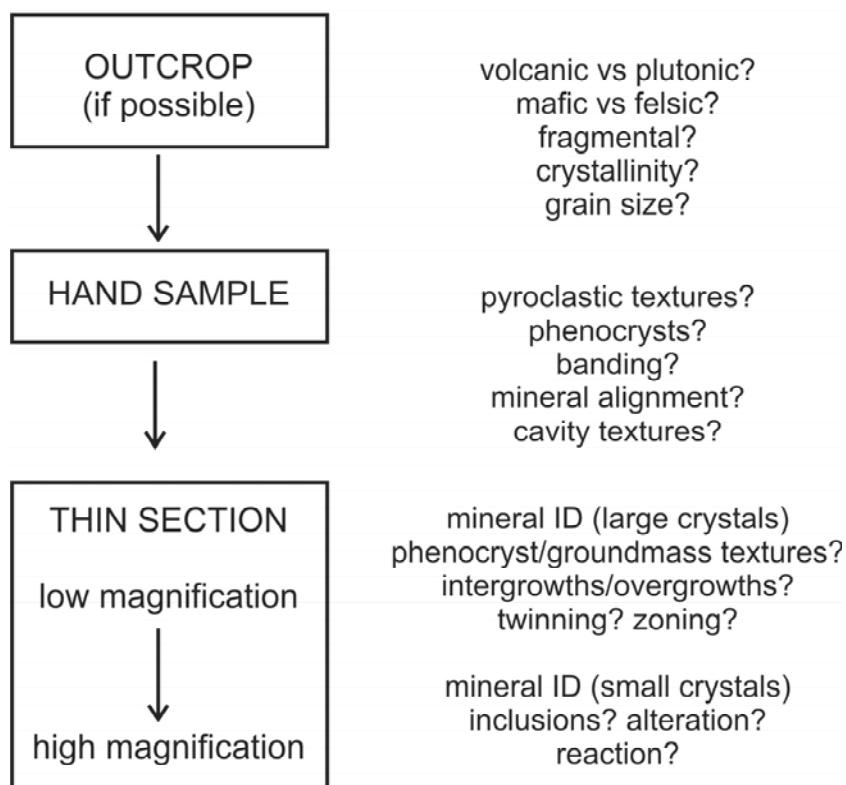
202-TC-1 Hornblende diorite, Texas Creek Stock, WA (single sample)

This sample is an excellent example of “**comb**” layering, also known as “**Willow Lake**” layering. This type of layering develops along near-vertical walls and its origin is not yet fully understood. However, because of the orientation of the layers it is clear that settling or floatation of crystals had nothing to do with the formation of layering in this particular sample.

Question: Do you have any suggestions as to how such layering might form?

PROCEDURE FOR DESCRIBING IGNEOUS ROCKS

(follow same general steps for metamorphic and sedimentary rocks; only specific types of observations will differ)



More sophisticated analyses can be performed after this (e.g., microprobe, bulk geochemistry, isotopes), but these should not be necessary to classify and name the rock!

