LAB 4: IGNEOUS ROCKS

Lab Structure

Recommended additional work	None
Required materials	Mineral ID kit, Rock Kits 1 and 2, pencil

Learning Objectives

After carefully reading this chapter, completing the exercises within it, and answering the questions at the end, you should be able to:

- Describe, in general terms, the range of chemical compositions of magmas.
- Discuss the processes that take place during the cooling and crystallization of magma, and the typical order of mineral crystallization according to the Bowen reaction series.
- Describe the origins of phaneritic, porphyritic, and vesicular rock textures.
- Apply the criteria for igneous rock classification based on mineral proportions.
- Use observations of mineralogy and texture to correctly identify and name an igneous rock.

Key Terms

- Magma
- Lava
- Partial melting
- Crystallization
- Intrusive
- Extrusive
- Felsic
- Intermediate
- Mafic
- Ultramafic
- Phaneritic
- Aphanitic
- Porphyritic
- Vesicular
- Glassy
- Phenocrysts
- Groundmass

A rock is a consolidated mixture of minerals. By *consolidated*, we mean hard and strong; real rocks don't fall apart in your hands! A *mixture of minerals* implies the presence of more than one mineral grain, but not necessarily more than one type of mineral. A rock can be composed of only one type of mineral (e.g., limestone is commonly made up of only calcite), but most rocks are composed of several different minerals. A rock can also include non-minerals, such as fossils or the organic matter within a coal bed or in some types of mudstone.

Rocks are grouped into three main categories based on how they form:

1. **Igneous:** formed from the cooling and crystallization of magma (molten rock)
2. **Sedimentary**: formed when weathered fragments of other rocks are buried, compressed, and cemented together, or when minerals precipitate directly from solution
3. **Metamorphic**: formed by alteration (due to heat, pressure, and/or chemical action) of a pre-existing igneous or sedimentary rock

For the next few weeks you will learn about each of these categories of rock in the lab, beginning with igneous rocks in Lab 4. You will practice identifying minerals and textures, and you will use your observations to classify samples of rocks. Finally, by Lab 6, you will use the processes of the rock cycle to link all three categories of rocks together.

4.1 Magma and Magma Formation

Magmas can vary widely in composition, but in general they are made up of only eight elements; in order of importance: oxygen, silicon, aluminum, iron, calcium, sodium, magnesium, and potassium (Figure 4.1.1). Oxygen, the most abundant element in magma, comprises a little less than half the total, followed by silicon at just over one-quarter. The remaining elements make up the other one-quarter. Magmas derived from crustal material are dominated by oxygen, silicon, aluminum, sodium, and potassium.

The composition of magma depends on the rock it was formed from (by melting), and the conditions of that melting. Magmas derived from the mantle have higher levels of iron, magnesium, and calcium, but they are still likely to be dominated by oxygen and silicon. All magmas have varying proportions of elements such as hydrogen, carbon, and sulphur, which are converted into gases like water vapour, carbon dioxide, and hydrogen sulphide as the magma cools.

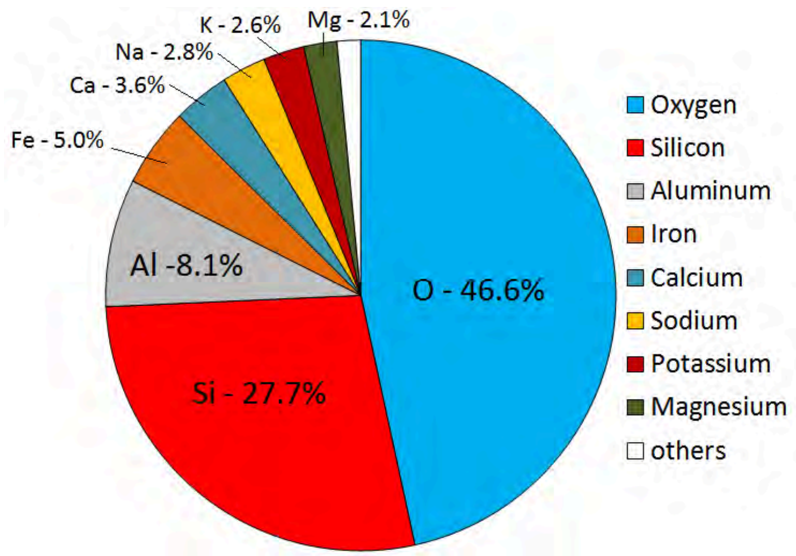


Figure 4.1.1: Average elemental proportions in Earth's crust, which is close to the average composition of magmas within the crust. [Image Description]

Virtually all of the igneous rocks that we see on Earth are derived from magmas that formed from **partial melting** of existing rock, either in the upper mantle or the crust. Partial melting is what happens when only some parts of a rock melt; it takes place because rocks are not pure materials. Most rocks are made up of several minerals, each of which has a different melting temperature. The wax in a candle is a pure material. If you put some wax into a warm oven (50°C will do as the melting temperature of most wax is about 40°C) and leave it there for a while, it will soon start to melt. That's complete melting, not partial melting. If instead you took a mixture of wax, plastic, aluminum, and glass and put it into the same warm oven, the wax would soon start to melt, but the plastic, aluminum, and glass would not melt (Figure 4.1.2a). That's partial melting and the result would be solid plastic, aluminum, and glass surrounded by liquid wax (Figure 4.1.2b). If we heat the oven up to around 120°C, the plastic would melt too and mix with the liquid wax, but the aluminum and glass would remain solid (Figure 4.1.2c). Again this is partial melting. If we separated the wax/plastic "magma" from the other components and let it cool, it would eventually harden. As you can see from Figure 4.1.2d, the liquid wax and plastic have mixed, and on cooling, have formed what looks like a single solid substance. It is most likely that this is a very fine-grained mixture of solid wax and solid plastic, but it could also be some other substance that has formed from the combination of the two.

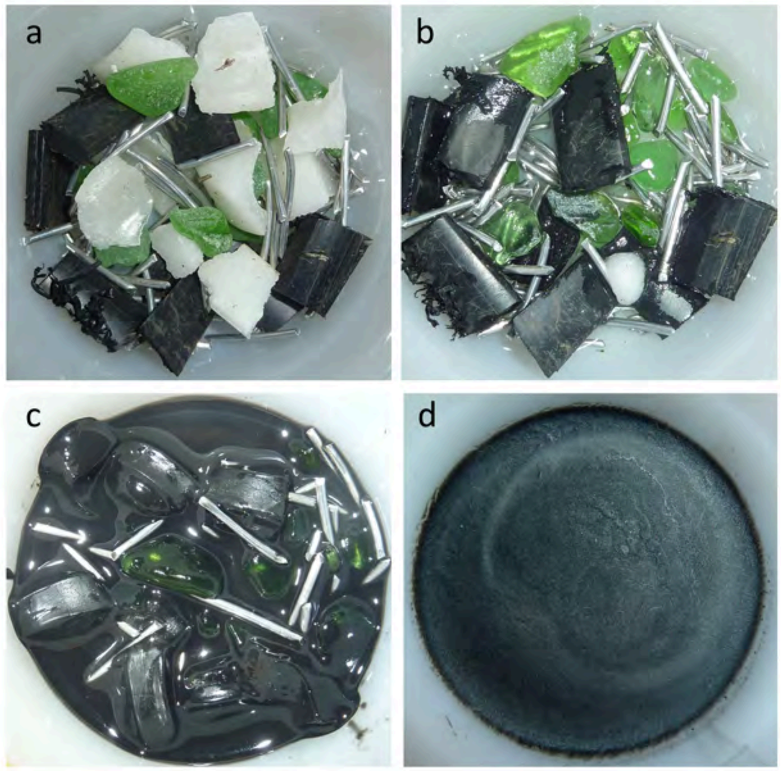


Figure 4.1.2: Partial melting of "pretend rock": (a) the original components of white candle wax, black plastic pipe, green beach glass, and aluminum wire, (b) after heating to 50°C for 30 minutes only the wax has melted, (c) after heating to 120°C for 60 minutes much of the plastic has melted and the two liquids have mixed, (d) the liquid has been separated from the solids and allowed to cool to make a "pretend rock" with a different overall composition.

In this example, we partially melted some pretend rock to create some pretend magma. We then separated the magma from the source and allowed it to cool to make a new pretend rock with a composition quite different from the original material (it lacks glass and aluminum).

Of course partial melting in the real world isn't exactly the same as in our pretend-rock example. The main differences are that rocks are much more complex than the four-component system we used, and the mineral components of most rocks have more similar melting temperatures, so two or more minerals are likely to melt at the same time to varying degrees. Another important difference is that when rocks melt, the process takes thousands to millions of years, not the 90 minutes it took in the pretend-rock example.

Contrary to what one might expect, and contrary to what we did to make our pretend rock, most partial melting of real rock does not involve heating the rock up. The two main mechanisms through which rocks melt are **decompression melting** and **flux melting.** Decompression melting takes place within Earth when a body of rock is held at approximately the same temperature but the pressure is reduced. Flux melting is facilitated by the addition of a flux (typically water and other volatiles) that lowers the melting point of the rock.

The partial melting of rock happens in a wide range of situations, most of which are related to plate tectonics. The more important of these are shown in Figure 4.1.3. Decompression melting occurs when rock is being moved toward the surface, either at a **mantle plume**, or in the upwelling part of a mantle convection cell (e.g., at a spreading centre formed at a divergent plate boundary, like a mid-ocean ridge). At subduction zones, water from the wet, subducting oceanic crust is transferred into the overlying hot mantle. This provides the flux needed to lower the melting temperature. In both of these cases, only partial melting takes place—typically only about 10% of the rock melts—and it is always the most silica-rich components of the rock that melt, creating a magma that is more silica-rich than the rock from which it is derived. (By analogy, the melt from our pretend rock is richer in wax and plastic than the "rock" from which it was derived.) The magma produced, being less dense than the surrounding rock, moves up through the mantle, and eventually into the crust.

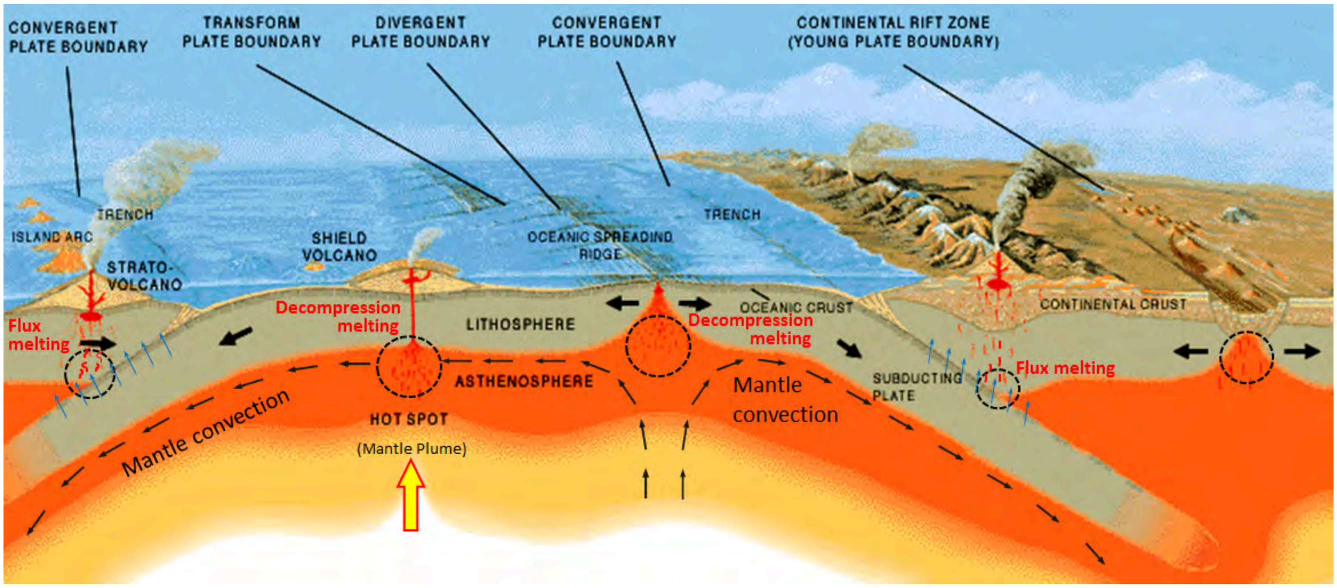


Figure 4.1.3: Common sites of magma formation in the upper mantle. The black circles are regions of partial melting. The blue arrows represent water being transferred from the subducting plates into the overlying mantle.

As it moves toward the surface, and especially when it moves from the mantle into the lower crust, the hot magma interacts with the surrounding rock. This typically leads to partial melting of the surrounding rock because most such magmas are hotter than the melting temperature of crustal rock. (In this case, melting is caused by an increase in temperature.) Again, the more silica-rich parts of the surrounding rock are preferentially melted, and this contributes to an increase in the silica content of the magma.

At very high temperatures (over 1300°C), most magma is entirely liquid because there is too much energy for the atoms to bond together. As the temperature drops, usually because the magma is slowly moving upward, things start to change. Silicon and oxygen combine to form silica tetrahedra, and then, as cooling continues, the tetrahedra start to link together to make chains (**polymerize**). These silica chains have the important effect of making the magma more viscous (less runny), which has significant implications for volcanic eruptions. As the magma continues to cool, crystals start to form.

Image Descriptions

Figure 4.1.1 image description: The average elemental proportions in the Earth's crust from the largest amount to the smallest amount. Oxygen (46.6%), Silicon (27.7%), Aluminum (8.1%), Iron (5.0%), Calcium (3.6%), Sodium (2.8%), Potassium (2.6%), Magnesium (2.1%), Others (1.5%). [Return to Figure 4.1.1]

Media Attributions

- Figure 4.1.1, 4.1.2: © Steven Earle. CC BY.
- Figure 4.1.3: “Cross section” by José F. Vigil from *This Dynamic Planet* — a wall map produced jointly by the U.S. Geological Survey, the Smithsonian Institution, and the U.S. Naval Research Laboratory. Adapted by Steven Earle. Public domain.

4.2 Crystallization of Magma

The minerals that make up igneous rocks crystallize at a range of different temperatures. This explains why a cooling magma can have some crystals within it and yet remain predominantly liquid. The sequence in which minerals crystallize from a magma is known as the **Bowen Reaction Series** (Figures 4.2.1 and 4.2.2).

Of the common silicate minerals, olivine normally crystallizes first, at between 1200° and 1300°C. As the temperature drops, and assuming that some silica remains in the magma, the olivine crystals will react (combine) with some of the silica in the magma to form pyroxene. As long as there is silica remaining and the rate of cooling is slow, this process continues down the discontinuous branch: olivine to pyroxene, pyroxene to amphibole, and (under the right conditions) amphibole to biotite.

At about the point where pyroxene begins to crystallize, plagioclase feldspar also begins to crystallize. At that temperature, the plagioclase is calcium-rich (**anorthite**) (see Figure 3.1.6). As the temperature drops, and providing that there is sodium left in the magma, the plagioclase that forms is a more sodium-rich variety (e.g., **albite**).

Finally, if the magma is quite silica-rich to begin with, there will still be some left at around 750° to 800°C, and from this last magma, potassium feldspar, quartz, and maybe muscovite will form.

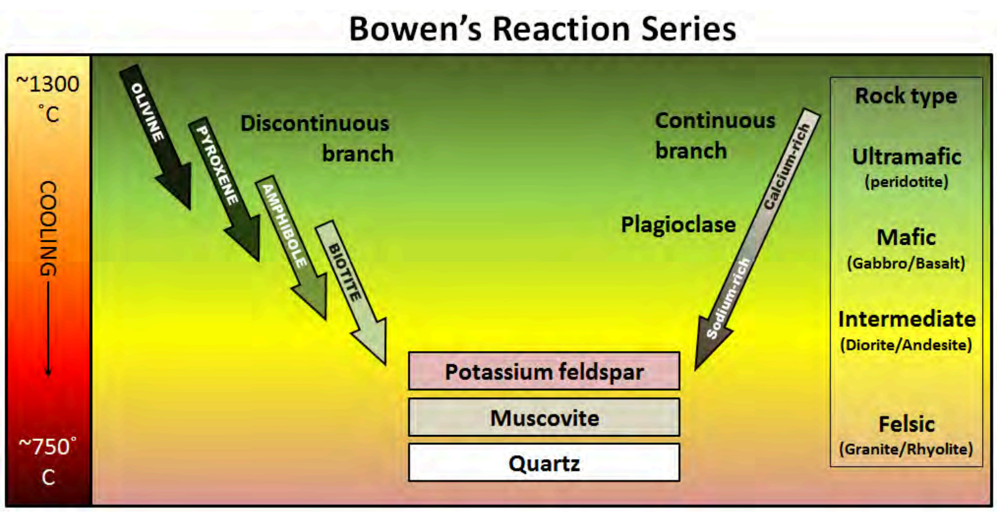


Figure 4.2.1: The Bowen reaction series describes the process of magma crystallization.

Who was Bowen, and what is a reaction series?

Figure 4.2.2

Norman Levi Bowen, born in Kingston, Ontario, studied geology at Queen's University and then at MIT in Boston. In 1912, he joined the Carnegie Institution in Washington, D.C., where he carried out groundbreaking experimental research into the processes of cooling magmas. Working mostly with basaltic magmas, he determined the order of crystallization of minerals as the temperature drops. The method, in brief, was to melt the rock to a magma in a specially-made kiln, allow it to cool slowly to a specific temperature (allowing some minerals to form), and then quench it (cool it quickly) so that no new minerals form (only glass). The results were studied under the microscope and by chemical analysis. This was done over and over, each time allowing the magma to cool to a lower temperature before quenching.

The Bowen reaction series is one of the results of his work, and even a century later, it is an important basis for our understanding of igneous rocks. The word *reaction* is critical. In the discontinuous branch, olivine is typically the first mineral to form (at just below 1300°C). As the temperature continues to drop, olivine becomes unstable while pyroxene becomes stable. The early-forming olivine crystals *react* with silica in the remaining liquid magma and are converted into pyroxene, something like this:

Mg_2SiO_4 (olivine) + SiO_2 becomes $2MgSiO_3$ (pyroxene)

This continues down the chain, as long as there is still silica left in the liquid.

The composition of the original magma is critical to magma crystallization because it determines how far the reaction process can continue before all of the silica is used up. The compositions of typical **mafic**, intermediate, and **felsic** magmas are shown in Figure 4.2.3. Note that, unlike Figure 4.1.1, these compositions are expressed in terms of "oxides" (e.g., Al_2O_3 rather than just Al). There are two reasons for this: one is that in the early analytical procedures, the results were always expressed that way, and the other is that all of these elements combine readily with oxygen to form oxides.

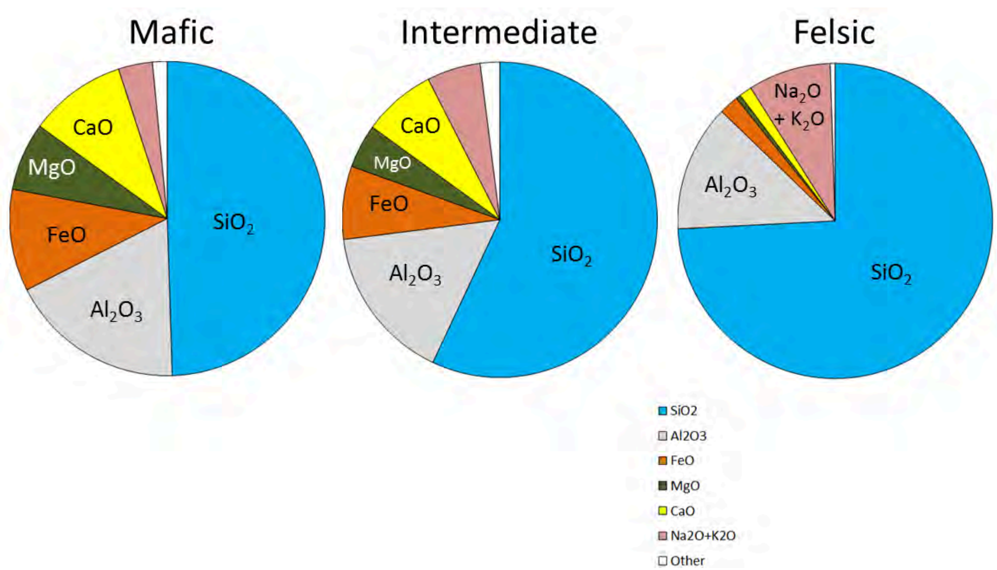


Figure 4.2.3: The chemical compositions of typical mafic, intermediate, and felsic magmas and the types of rocks that form from them.

Mafic magmas have 45% to 55% SiO_2, about 25% total of FeO and MgO plus CaO, and about 5% Na_2O + K_2O. Felsic magmas, on the other hand, have much more SiO_2 (65% to 75%) and Na_2O + K_2O (around 10%) and much less FeO and MgO plus CaO (about 5%).

Practice Exercise 4.1 Determining rock types based on magma composition

The proportions of the main chemical components of felsic, intermediate, and mafic magmas are listed in the table below. (The values are similar to those shown in Figure 4.2.3)

Table 4.1 Proportions of the main chemical components in felsic, intermediate, and mafic magma

Oxide	Felsic Magma	Intermediate Magma	Mafic Magma
SiO_2	65% to 75%	55% to 65%	45% to 55%
Al_2O_3	12% to 16%	14% to 18%	14% to 18%
FeO	2% to 4%	4% to 8%	8% to 12%
CaO	1% to 4%	4% to 7%	7% to 11%
MgO	0% to 3%	2% to 6%	5% to 9%
Na_2O	2% to 6%	3% to 7%	1% to 3%
K_2O	3% to 5%	2% to 4%	0.5% to 3%

Chemical data for four rock samples are shown in the following table. Compare these with those in the table above to determine whether each of these samples is felsic, intermediate, or mafic.

Table 4.2 Chemical Data for Four Unidentified Rock Samples

Rock Sample	SiO_2	Al_2O_3	FeO	CaO	MgO	Na_2O	K_2O	What type of magma is it?
Rock 1	55%	17%	5%	6%	3%	4%	3%	
Rock 2	74%	14%	3%	3%	0.5%	5%	4%	
Rock 3	47%	14%	8%	10%	8%	1%	2%	
Rock 4	65%	14%	4%	5%	4%	3%	3%	

See Appendix 2 for Practice Exercise 4.1 answers.

As a *mafic* magma starts to cool, some of the silica combines with iron and magnesium to make olivine. As it cools further, much of the remaining silica goes into calcium-rich plagioclase, and any silica left may be used to convert some of the olivine to pyroxene. Soon after that, all of the magma is used up and no further changes takes place. The minerals present will be olivine, pyroxene, and calcium-rich plagioclase. If the magma cools slowly underground, the product will be **gabbro**; if it cools quickly at the surface, the product will be **basalt** (Figure 4.2.4).

Felsic magmas tend to be cooler than mafic magmas when crystallization begins (because they don't have to be as hot to remain liquid), and so they may start out crystallizing pyroxene (not olivine) and plagioclase. As cooling continues, the various reactions on the discontinuous branch will proceed because silica is abundant, the plagioclase will become increasingly sodium-rich, and eventually potassium feldspar and quartz will form. Commonly even very felsic rocks will not have biotite or muscovite because they may not have enough aluminum or enough hydrogen to make the OH complexes that are necessary for mica minerals. Typical felsic rocks are **granite** and **rhyolite** (Figure 4.2.4).

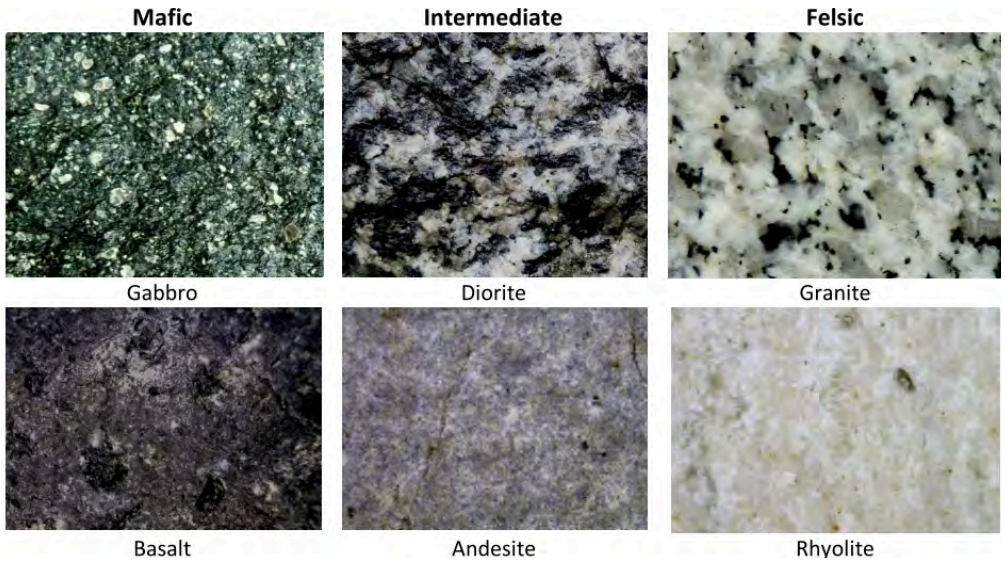


Figure 4.2.4: Examples of the igneous rocks that form from mafic, intermediate, and felsic magmas.

The cooling behaviour of intermediate magmas lie somewhere between those of mafic and felsic magmas. Typical mafic rocks are gabbro (intrusive) and basalt (extrusive). Typical intermediate rocks are **diorite** and **andesite**. Typical felsic rocks are granite and rhyolite (Figure 4.2.4).

An igneous rock with large crystals, called **phenocrysts**, embedded in a **groundmass** of much finer crystals is indicative of a two-stage cooling process, and the texture is **porphyritic** (Figure 4.2.5). For the rock to be called "porphyritic" there has to be a significant difference in crystal size, where the larger crystals are at least 10 times larger than the average size of the smaller crystals.

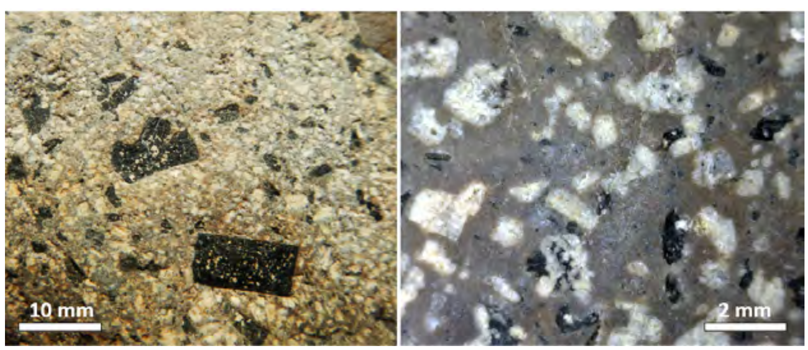


Figure 4.2.5: Porphyritic textures, left: 1.3 cm long amphibole crystals in an intrusive igneous rock in which most of the crystals are less than 1 mm, right: 1 to 2 mm long feldspar crystals and 1 mm long amphibole crystals in a volcanic rock where most of the crystals are less than 0.1 mm.

Practice Exercise 4.2 Porphyritic minerals

As a magma cools below 1300°C, minerals start to crystallize within it. If that magma is then involved in a volcanic eruption, the rest of the liquid will cool quickly to form a **porphyritic** texture. The rock will have some relatively large crystals (**phenocrysts**) of the minerals that crystallized early, and the rest will be very fine grained or even glassy. Using Figure 4.2.6, predict what phenocrysts might be present where the magma cooled as far as line **a** in one case, and line **b** in another.

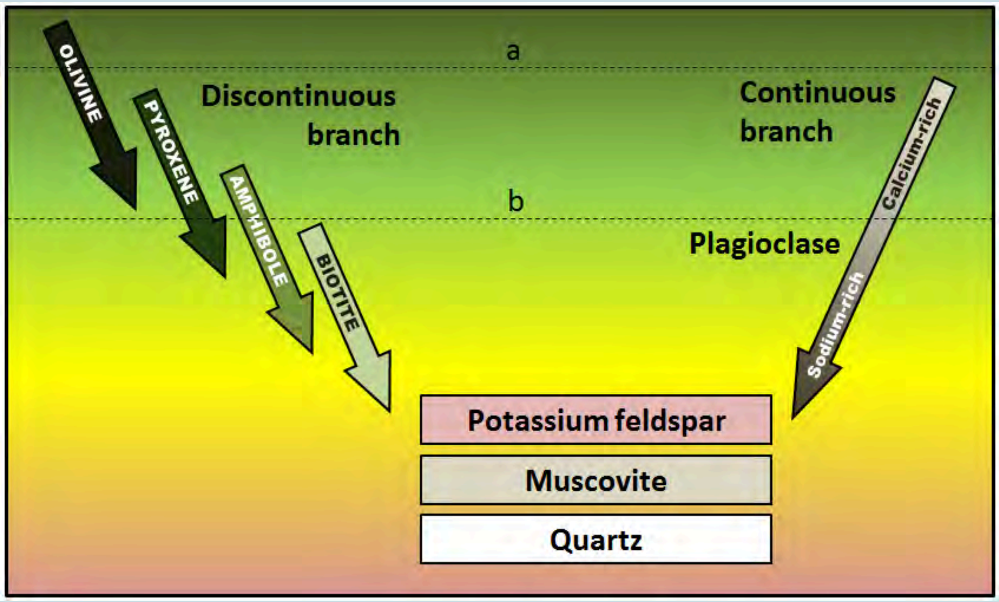


Figure 4.2.6: Bowen reaction series. Line a – at high temperature – intersects olivine, Line b – at a lower temperature – intersects pyroxene and amphibole on the left, and plagioclase feldspar on the right

See Appendix 2 for Practice Exercise 4.2 answers.

Media Attributions

- Figure 4.2.1, 4.2.3, 4.2.4, 4.2.5, 4.2.6: © Steven Earle. CC BY.
- Figure 4.2.2: "Norman L. Bowen." Public domain.

4.3 Classification of Igneous Rocks

Igneous rocks are classified into four categories: felsic, intermediate, mafic, and ultramafic, based on either their chemistry or their mineral composition. The diagram in Figure 4.3.1 can be used to help classify igneous rocks by their mineral composition. An important feature to note on this diagram is the red line separating the **non-ferromagnesian** silicates in the lower left (K-feldspar, quartz, and plagioclase feldspar) from the **ferromagnesian** silicates in the upper right (biotite, amphibole, pyroxene, and olivine). In classifying **intrusive** igneous rocks, the first thing to consider is the percentage of ferromagnesian silicates. In most igneous rocks the ferromagnesian silicate minerals are clearly darker than the others, but it is still quite difficult to estimate the proportions of minerals in a rock.

Based on the position of the red line in Figure 4.3.1, it is evident that felsic rocks can have between 1% and 20% ferromagnesian silicates (the red line intersects the left side of the felsic zone 1% of the distance from the top of the diagram, and it intersects the right side of the felsic zone 20% of the distance from the top). Intermediate rocks have between 20% and 50% ferromagnesian silicates, and mafic rocks have 50% to 100% ferromagnesian silicates. To be more specific, felsic rocks typically have biotite and/or amphibole; intermediate rocks have amphibole and, in some cases, pyroxene; and mafic rocks have pyroxene and, in some cases, olivine.

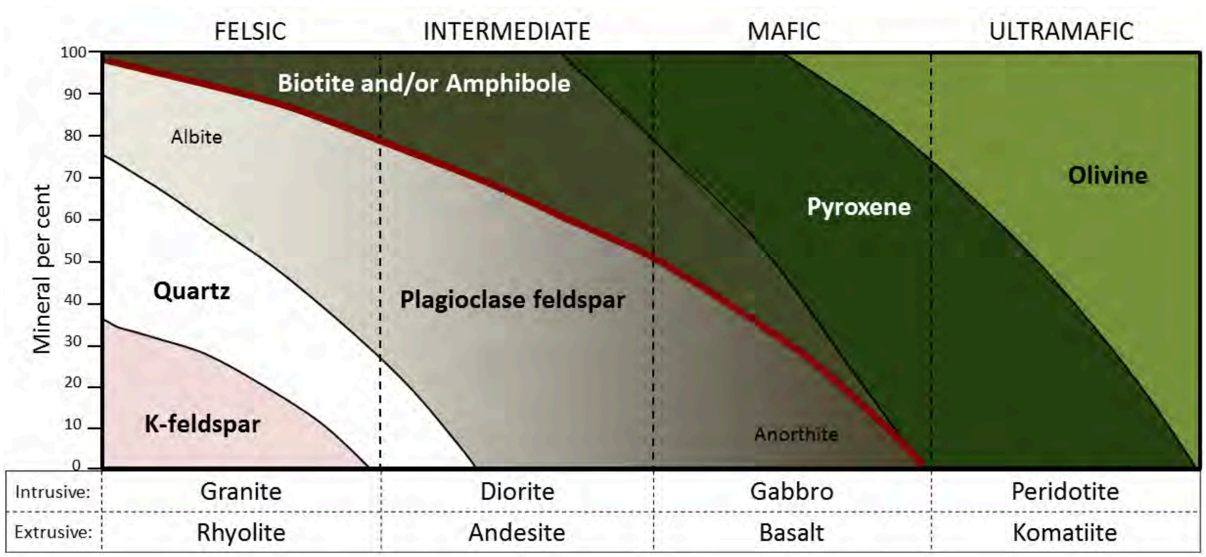


Figure 4.3.1: A simplified classification diagram for igneous rocks based on their mineral compositions. [Image Description]

If we focus on the non-ferromagnesian silicates, it is evident that felsic rocks can have from 0% to 35% K-feldspar, from 25% to 35% quartz (the vertical thickness of the quartz field varies from 25% to 35%), and from 25% to 50% plagioclase (and that plagioclase will be sodium-rich, or albitic). Intermediate rocks can have up to 25% quartz and 50% to 75% plagioclase. Mafic rocks only have plagioclase (up to 50%), and that plagioclase will be calcium-rich, or anorthitic.

Practice Exercise 4.3 Mineral proportions in igneous rocks

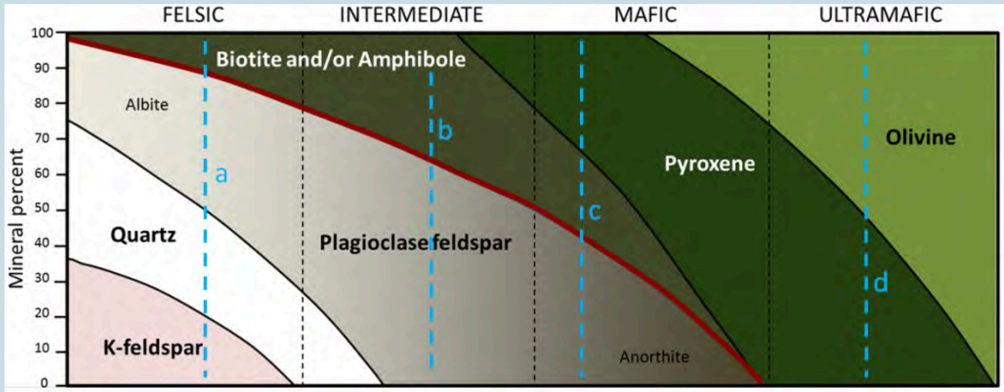


Figure 4.3.2

The dashed blue lines (labelled a, b, c, d) in Figure 4.3.2 represent four igneous rocks. Complete the table by estimating the mineral proportions (percent) of the four rocks (to the nearest 10%).

Hint: Rocks **b** and **d** are the easiest; start with those.

Rock	Biotite/amphibole	Pyroxene	Olivine	Plagioclase	Quartz	K-feldspar
a						
b						
c						
d						

See Appendix 2 for Practice Exercise 4.3 answers.

Figure 4.3.3 provides a diagrammatic representation of the proportions of dark minerals in light-coloured rocks. You can use that when trying to estimate the ferromagnesian mineral content of actual rocks, and you can get some practice doing that by completing Practice Exercise 4.4. Be warned! Geology students almost universally over-estimate the proportion of dark minerals.

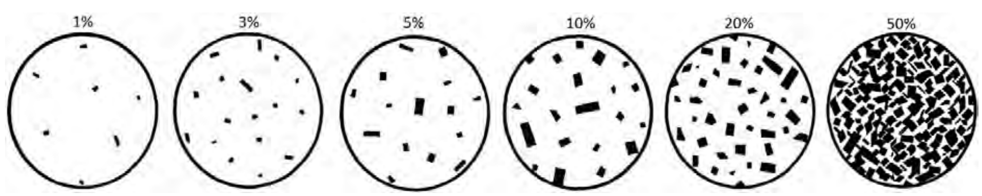
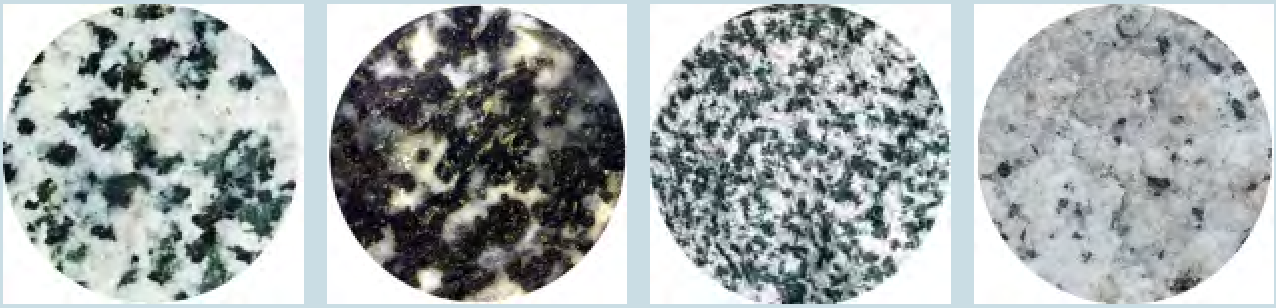


Figure 4.3.3: A guide to estimating the proportions of dark minerals in light-coloured rocks.

Practice Exercise 4.4 Proportions of ferromagnesian silicates

The four igneous rocks shown below have differing proportions of ferromagnesian silicates. Estimate those proportions using the diagrams in Figure 4.3.3, and then use Figure 4.3.1 to determine the likely rock name for each one.



___%　__________

___%　__________

___%　__________

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See Appendix 2 for Practice Exercise 4.4 answers.

Igneous rocks are also classified according to their textures. Almost all **intrusive** igneous rocks are **phaneritic** (from the Greek word *phaneros* meaning visible), meaning that they have crystals that are large enough to see with the naked eye. Typically that means they are larger than about 0.5 millitmeres (mm) — the thickness of a strong line made with a ballpoint pen. The intrusive rocks shown in Figure 4.2.4 are all phaneritic, as are those shown in Practice Exercise 4.4. If the crystals are too small to distinguish, which is typical of most **extrusive** (volcanic) rocks, we use the term **aphanitic** (from the Greek word *aphanos* – unseen). Although the individual crystals in an aphantic rock cannot be observed with the naked eye, they still influence the physical properties of the rock, specifically its colour. In an aphanitic rock, the colour of the groundmass, as seen on a fresh non-weathered surface, can provide clues about its mineral composition. Mafic rocks (basalt) tend to be dark black to grey in colour, intermediate rocks (andesite) tend to be a lighter grey, and felsic rocks (rhyolite) tend to be pale grey, white, cream or pale pink in colour.

In general, the size of crystals is proportional to the rate of cooling. The longer it takes for a body of magma to cool, the larger the crystals can grow. As already described, if an igneous rock goes through a two-stage cooling process, its texture will be **porphyritic** (Figure 4.2.5).

Igneous rocks that form when lava cools so rapidly that few, if any, crystals form, are often glassy. Two common glassy rocks formed rapid cooling (or quenching) of lava are **pumice** and **obsidian**. Pumice is typically light in colour owing to its felsic composition, and is distinguished by its frothy glassy texture and low density. Obsidian is distinguished by its vitreous lustre and pronounced conchoidal fracture. Although obsidian is typically black to dark brown in colour, it is actually felsic in composition.

One final textural term for igneous rocks is **vesicular**. The **vesicles** in vesicular rocks form when gasses exsolve from the magma as it rises toward the surface of the Earth. When magma is deep beneath the surface and under high pressure from the surrounding rocks, the gases remain dissolved in the magma, much like the dissolved CO_2 gas in an unopened bottle of pop. As magma approaches the surface, the pressure exerted on it decreases, and gas bubbles start to form, much like once a bottle of pop has been opened. The more gas there is in the magma, the more bubbles form. If the magma is runny enough, the gases will rise up through it and escape to surface. In some cases, however, the bubbles of gas are "frozen" in the lava as it cools and form vesicles as it crystallizes into solid rock at the surface.

Names of igneous rocks, based on both composition and texture as described above, can be enhanced by adding using terms like vesicular or porphyritic as modifiers. For example, an andesite that contains hornblende and plagioclase phenocrysts would be described as a hornblende plagioclase porphyritic andesite. A basalt that contains olivine phenocrysts and vesicles would be called an olivine porphyritic vesicular basalt.

Image Descriptions

Figure 4.3.1 image description: Mineral composition of igneous rocks

Igneous Rocks	**Felsic**	**Intermediate**	**Mafic**	**Ultramafic**
K-feldspar	0 to 35%	0%	0%	0%
Quartz	25 to 35%	0 to 25%	0%	0%
Plagioclase feldspar	25 to 50%	50 to 70%	0 to 50%	0%
Biotite and/or Amphibole	0 to 20%	20 to 40%	0 to 30%	0%
Pyroxene	0%	0 to 20%	20 to 75%	0% to 75%
Olivine	0%	0%	0 to 25 %	25% to 100%
Intrusive	Granite	Diorite	Gabbro	Peridotite
Extrusive	Rhyolite	Andesite	Basalt	Komatiite

[Return to Figure 4.3.1]

Media Attributions

- Figure 4.3.1, 4.3.2, 4.3.3: © Steven Earle. CC BY.

Lab 4 Exercises

Classifying Rocks

<u>All</u> rocks are classified by just **<u>two</u>** characteristics: texture and mineralogy. The 20 or so minerals which form most rocks are already very familiar to you, the remaining 6000 are not very common and not significant in rock classification, and you can manage in this course without being able to identify them.

The two main textural terms you will use as you examine rocks in labs 4, 5 and 6 are:

Crystalline: consisting of a network of interlocking crystals. Igneous, sedimentary and metamorphic rocks may have a crystalline texture.

Clastic: consisting of grains eroded from pre-existing rocks. These grains have been transported at least some distance from their place of origin. Only some sedimentary rocks have a clastic texture.

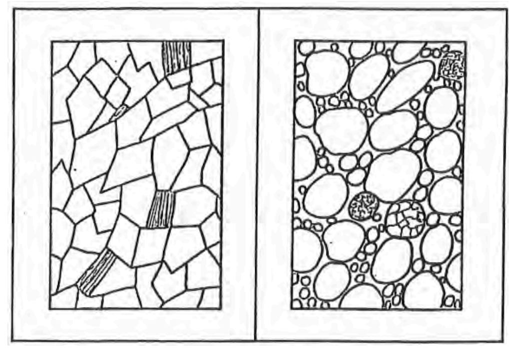

Figure A: (left) crystalline texture produced by a mosaic of interlocking crystals, and (right) clastic texture composed of individual grains bonded by a chemical cement. Grains may consist of a single mineral, or fragments from pre-existing rocks.

It is essential that you are able to recognize these textures (Figure A). They form the major division between many rocks. Failure to differentiate between a crystalline versus a clastic texture could result in you being responsible for drilling through granite instead of sandstone!

1. Examine samples R2, R151, and R281 and identify the texture of each sample to complete the table below.

Sample R2	**Texture:**
Sample R151	**Texture:**
Sample R281	**Texture:**

The exercises below will guide you through the igneous rock samples in Rock Kits 1 and 2. Review the background information presented in Chapters 4.1 to 4.3 before you begin these exercises. You may wish to consult the Rock Classification Tables at the back of this manual as you complete the exercises below.

Tips for Identifying Igneous Rocks

- Your first step when examining any igneous rock is to look closely at the size of the crystals and to determine if its texture is **aphanitic** (individual crystals are too fine to be visible with the naked eye), **phaneritic** (individual crystals are visible with the naked eye), or **porphyritic** (crystals of two or more distinctly different sizes present). If the sample contains no crystals at all and has a vitreous lustre, its texture can be described as glassy. If the sample contains gas bubbles called **vesicles**, its texture is **vesicular**.
- If the sample is phaneritic, or contains **phenocrysts**, try to identify the minerals within the sample.

This will be tricky, as the crystals are much smaller than the samples you examined in Labs 2 and 3. Make sure you examine the sample carefully with your hand lens. You will see much more than with your naked eye alone!

- Start by asking yourself, “how many different minerals can I see in this sample?” and make a short list of the physical properties you observe (e.g., colour, lustre, cleavage).
- Use your observations and the mineral identification tables to identify the minerals present, and make an estimate of their proportions using Figure A in the Rock Classification Tables appendix as a guide. Some mineral-specific hints are outlined here:
  - Quartz crystals come in many colours, but quartz always has vitreous lustre and is often translucent.
  - Potassium feldspar (K-feldspar) is commonly white or pink in colour, and is often opaque (milky) to semi-translucent.
  - Plagioclase feldspar is commonly white to dark bluish grey in colour (depending on the composition), is often opaque (milky) to semi-translucent, and has striations.
  - Examining a weathered surface can help to differentiate quartz from feldspar minerals: feldspars chemically weather tend to look chalky and dull (see Figure 5.1.4), whereas quartz always looks glassy. If you look for freshly broken surfaces or edges of the sample you may even see that the feldspar crystals break along cleavage planes while the quartz crystals have conchoidal fracture.
  - Muscovite (colourless, translucent) and biotite (dark brown to black) both appear as thin sheets or flakes.
  - To tell biotite from other ferromagnesian minerals, test its hardness with a steel file or thin knife: biotite has a Mohs hardness of ~ 2.5-3 whereas amphibole and pyroxene are much harder (H = 5-6).
  - It can be difficult to tell amphibole from pyroxene in rocks, as they have similar hardnesses, form blocky crystals, and can be found in similar colours (shades of green to black). Look closely for cleavage: amphibole has 2 planes not at 90°, whereas pyroxene has 2 planes at 90°. If you are unsure whether a ferromagnesian mineral is amphibole or pyroxene and have already identified the other minerals present, it may help to use Figure 4.3.1 as a guide. For example, if you have identified K-feldspar, quartz, and white plagioclase in a sample, chances are the dark coloured blocky mineral you see is amphibole and not pyroxene. Why? Because a **felsic** magma that is crystallizing K-feldspar and quartz will not normally also crystallize pyroxene.
  - Olivine can be distinguished by its vitreous lustre and olive green to yellow-green colour. Caution: weathered olivine may appear dull or rusty (from iron oxide staining).
- If the sample is aphanitic, use the colour of a fresh surface to estimate the composition: felsic rocks are light-coloured (beige, buff, tan, pink, white, pale grey) whereas mafic rocks are dark-coloured (dark grey to black).
- Finally, combine your observations of texture and composition, and use Figure B in the Rock Classification Tables appendix to name the rock.
  - If the sample is porphyritic with an aphanitic **groundmass**, identify the phenocryst mineral(s), interpret the overall composition based on the colour of the groundmass, and name the rock as [phenocryst mineral name] porphyritic [rock name]. For example, a porphyritic volcanic rock with pyroxene phenocrysts in a dark grey aphanitic groundmass is a pyroxene porphyritic basalt.
  - Rock names can likewise be modified by other textural terms (e.g., vesicular basalt).

2. Remove samples R1, R2, R11, R21, R31, R41, R42, R51, R61, and R71 from Rock Kit 1 and place the samples on the table in front of you. Arrange these samples according to colour, in a line or into groups. What does the colour of an igneous rock tell you?

3. Keeping the same colour groups you just arranged, within each group arrange the same set of samples according to their grain size (the size of the crystals that make up these rocks). As you examine each sample decide whether:

- all or most of the crystals are large enough for you to see with your naked eye,
- all or most of the crystals are too fine to see clearly with your naked eye, or
- there are no crystals at all (sample is glassy).

4. What does grain size tell you about the cooling history of an igneous rock?

The groups of igneous rocks you just arranged should reflect the classification presented in Figure B in the Rock Classification Tables. Now that you have had a chance to compare all the samples, let's examine each sample in more detail.

Sample R1	**Rock name:**
Sample R2	**Rock name:**

5. It can be useful to look at both weathered and fresh (unweathered) surfaces of a rock sample, as both can be useful when identifying minerals. However, it is important to make note of what type of surface you are describing in your notes. Are you looking at a fresh or a weathered surface? _______________________
6. Are these rocks comprised of grains or crystals? _______________________
7. These samples are both crystalline rocks (in contrast to clastic rocks which you will be examining in lab 5). Notice the prominent cleavage faces which can be seen on some of the crystals. Which mineral(s) is (are) showing cleavage?

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8. Are these rocks aphanitic or phaneritic? _______________________
9. Are the crystals all of relatively similar size or obviously different sizes? __________________________
10. Describe the colour of the rock: ____
11. What do you estimate is the percentage of light (non-ferromagnesian) and dark-coloured (ferromagnesian) minerals?

Non-ferromagnesian:	%	Ferromagnesian:	%

12. List below the minerals which you recognize in order of abundance (remember to use your hand lens).

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13. Which mineral is responsible for unique colour of sample R2? _______________________

Sample R11	**Rock name:**

14. Are you looking at a fresh or a weathered surface? ______________________
15. Choose a term which best describes the texture of this rock: ______________________
16. Describe the colour of this rock (light/intermediate/dark):______________________
17. What do you think is the basic difference between specimens R1 and R11?

____

____

18. Did sample R11 cool slowly (intrusive) or rapidly (extrusive) compared to R1? ______________________

Sample R21	**Rock name:**

19. Are you looking at a fresh or a weathered surface? ______________________
20. Which textural term best describes this rock?______________________
21. The larger crystals in the aphanitic groundmass are called ______________________.
22. Do you see cleavage planes on any of the larger crystals? ______________________
23. What size (in mm) are the larger crystals? ______________________
24. Are these crystals all the same mineral? ______________________
25. Describe the overall colour of the rock (light/intermediate/dark): ______________________

Sample R31	**Rock name:**

26. Are you looking at a fresh or a weathered surface? ______________________
27. Is the rock aphanitic or phaneritic? ______________________
28. Does the textural term, 'porphyritic' apply to this rock? ______________________
29. Did the rock cool slowly or rapidly? ______________________
30. List the minerals in this rock in order of abundance:

____

____

31. What do you estimate is the percentage of light and dark-coloured minerals?

Non-ferromagnesian:	%	Ferromagnesian:	%

32. Do you see cleavage planes on any of the minerals? ______________________If so, which ones? _________
____

33. Describe the colour of this rock (compare the colour to that of R1 and R51):

____

Sample R51	**Rock name:**

34. Are you looking at a fresh or a weathered surface? ______________________
35. Which textural term best describes this rock?______________________

36. Do any of the crystals exhibit cleavage planes? ______________________ If so, which ones? ____________
____

37. What do you estimate is the percentage of light and dark-coloured minerals?

Non-ferromagnesian:	%	Ferromagnesian:	%

38. Would you say that texture (grain size) or mineralogy (mineral composition) is the basic difference between R1, R31, and R51?

Sample R41	**Rock name:**

39. Which textural term best describes this rock? ______________________
40. Do you see any phenocrysts in this rock? ______________________
41. Describe the colour of the rock on a fresh surface ______________________
42. Is this rock intrusive or extrusive? ______________________ What evidence supports your answer? _____
____

43. What is the basic difference between this rock and R51?

Sample R42	**Rock name:**

44. Which textural term applies to this sample? ______________________
45. What are the small spherical cavities occurring throughout the rock called, and how did they form?

46. What is the difference between this rock and R41?

Sample R61	**Rock name:**

47. Describe the texture of this rock (Hint: what substance does it resemble):

48. Can you see the individual crystals in this rock? __________
49. What term best describes the type of fracture of this rock? ____
____

This is a sample of **obsidian** and its texture is due to the super cooling of magma, resulting in a non-crystalline, glassy texture.

50. Compare this specimen to R71 (**pumice**) which is also a type of glass. How do they differ?

Media Attributions

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Summary

The topics covered in this chapter can be summarized as follows:

Section	Summary
4.1 Magma and Magma Formation	Magma is molten rock, and in most cases, it forms from partial melting of existing rock. The two main processes of magma formation are decompression melting and flux melting. Magmas range in composition from ultramafic to felsic. Mafic rocks are rich in iron, magnesium, and calcium, and have around 50% silica. Felsic rocks are rich in silica (~75%) and have lower levels of iron, magnesium, and calcium and higher levels of sodium and potassium than mafic rocks. Intermediate rocks have compositions between felsic and mafic.
4.2 Crystallization of Magma	As a body of magma starts to cool, the first process to take place is the polymerization of silica tetrahedra into chains. This increases the magma's viscosity (makes it thicker) and because felsic magmas have more silica than mafic magmas, they tend to be more viscous. The Bowen reaction series allows us to predict the order of crystallization of magma as it cools.
4.3 Classification of Igneous Rock	Igneous rocks are classified based on their mineral composition and texture. Felsic igneous rocks have less than 20% ferromagnesian silicates (amphibole and/or biotite) plus varying amounts of quartz and both potassium and plagioclase feldspars. Mafic igneous rocks have more than 50% ferromagnesian silicates (primarily pyroxene) plus plagioclase feldspar. Most intrusive igneous rocks are phaneritic (crystals are visible to the naked eye), whereas most extrusive (volcanic) rocks are aphanitic (crystals are too small to be seen with the naked eye). If there were two stages of cooling (slow then fast), the texture may be porphyritic (large crystals in a matrix of smaller crystals). Gas bubbles "frozen" in an igneous rock are called vesicles, and the textural term for a rock with vesicles is vesicular.
Lab 4 Exercises	The best way to learn rock identification is to practice by examining the samples in your Rock Kit 1 and 2. Igneous rocks are classified according to their mineral composition (or colour, in the case of aphanitic rocks), and texture (size of the crystals). Knowing the diagnostic properties of the minerals within an igneous rock help you identify its composition as mafic, intermediate, or felsic. Just as with mineral samples, different samples of the same rock may not always look exactly the same (e.g., pink versus white granite), but they can always be identified by closely examining the mineral composition and texture.