Chapter 3: Igneous Rocks

Adapted by Lyndsay R. Hauber & Joyce M. McBeth (2018) University of Saskatchewan from Deline B, Harris R & Tefend K. (2015) "Laboratory Manual for Introductory Geology". First Edition. Chapter 8 "Igneous Rocks" by Karen Tefend, CC BY-SA 4.0. Last edited: 8 Jan 2020

Note: much of the overview material for this chapter is replicated in this exercise section for your reference as you complete the lab. ***You will NOT have access to your lab book or notes for the rock and mineral exam!***

Your name: ________________

NSID and Student number: _____________

Date and lab section time: ______________

TAs' names: ________________ ____________________

Your TA will check that you have completed the questions at the end of the lab. Please hold on to your lab notes to help you prepare for the rock and mineral quiz and your lab final exam.

3.2 IGNEOUS ROCK ORIGIN

3.2.1 Magma Composition

Before any igneous rock can form, there must be molten material, known as magma, produced; therefore, you must have a rock to melt to make the magma, which then cools to become an igneous rock. There are many factors which may affect the composition of the igneous rock, including the initial rock or rocks that melt to form the magma, the degree of melt, the cooling process of the magma, etc. These are things one should consider when studying the origin of igneous rocks.

Most rocks contain minerals that are crystalline solids composed of the chemical elements. All minerals have a certain set of conditions, such as temperature, at which they can melt; since rocks contain a mixture of minerals, some of the minerals in a rock may melt, while others remain solid. Temperature conditions are important, as only minerals that can melt at "lower" temperatures may experience melting, whereas the temperature would have to increase in order for other minerals to *also* melt and add their chemical components to the magma that is being generated. Therefore, if the same types of rocks are melting, different magma compositions are generated simply by melting at different temperatures!

As the magma cools, mafic minerals tend to crystallize first at relatively high temperatures; these minerals (olivine, pyroxene, amphibole, biotite, calcium-rich plagioclase feldspar) tend to crystallize in a specific sequence and remove iron, magnesium and calcium from the magma during crystallization. Iron- and magnesium-rich minerals are referred to as **ferromagnesian** minerals (ferro = iron) and are usually green, dark gray, or black in colour. The removal of iron and magnesium from the magma results in the formation of minerals that are deficient in these elements; as such, these minerals are referred to as **nonferromagnesian** minerals. They generally crystallize at lower temperatures to form pale-coloured minerals (quartz, muscovite, sodium-rich plagioclase feldspar, potassium feldspar), which are richer in silica, sodium, and potassium.

3.3 IGNEOUS ROCK COMPOSITION

Igneous rocks created in different environments typically have certain characteristics. For example, you can expect to find abundant olivine, and maybe some pyroxene and Ca-rich plagioclase, in an **ultramafic** rock called peridotite or komatiite, or that pyroxene, plagioclase, and possibly some olivine or amphibole may be present in a **mafic** rock such as gabbro or basalt. You can also expect to see quartz, muscovite, potassium feldspar, and some biotite and Na-rich plagioclase in a **felsic** (or **silicic**) rock such as granite or rhyolite. The classification of an igneous rock depends partly on the minerals that may be present in the rock, and since the minerals have certain colours due to their chemical makeup, then the rocks must have certain colours. For example, a rock composed of mostly olivine will be green in colour due to olivine's green colour; such a rock would be called ultramafic. A rock that has a large amount of ferromagnesian minerals in it will be a dark-coloured rock because the ferromagnesian minerals (other than olivine) tend to be dark coloured; an igneous rock that is dark in colour is called a **mafic** rock ("ma-" comes from magnesium, and "fic" from ferric iron). An igneous rock with a large amount of nonferromagnesian minerals will be light in colour, such as the silicic or felsic rocks ("fel" from feldspar, and "sic" from silica-rich quartz). So, based on colour alone, we've been able to start classifying the igneous rocks.

Figure 3.2 shows examples of igneous rocks representing mafic and felsic rock compositions (Figures 3.2A and 3.2C, respectively), as well as an **intermediate** rock type (Figure 3.2B). Felsic rocks may have small amounts of dark-coloured minerals, but are predominately composed of light-coloured minerals, whereas mafic rocks have a higher percentage of dark-coloured minerals, which results in a darker-coloured rock. A rock that is considered intermediate between the mafic and felsic rocks is truly an intermediate in terms of the colour and mineral composition; such a rock would have less dark minerals than the mafic rocks, yet more dark minerals than the felsic rocks.

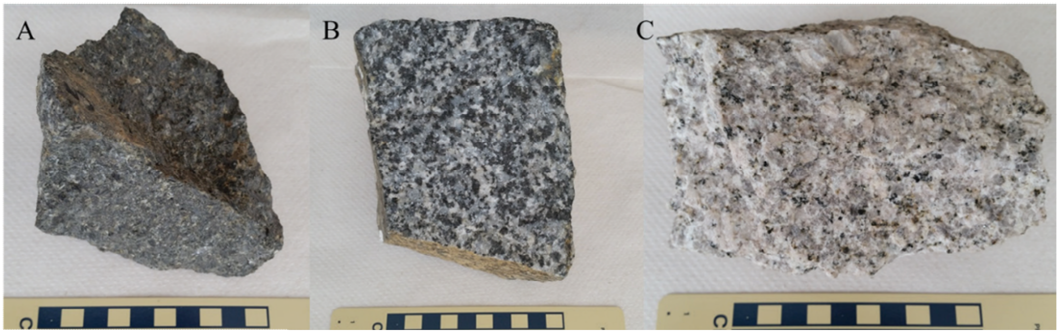

Figure 3.2 | Examples of igneous rocks from the mafic (A), intermediate (B), and felsic (C) rock compositions. Photo scale on bottom is in centimeters. Source: Karen Tefend (2015) CC BY-SA 3.0

As previously mentioned, classifying rocks into one of the igneous rock compositions (ultramafic, mafic, intermediate, and felsic) depends on the minerals that each rock contains. Identification of the minerals can be difficult in rocks such as in Figure 3.2A, as the majority of minerals are dark in colour and it can be difficult to distinguish each mineral. An easy method of determining the igneous rock composition is by estimating the percentage of dark-coloured minerals in the rock, without trying to identify the actual minerals present. Estimating the percentage of dark-coloured minerals is only possible if the minerals are large enough to see; in that case a person can still recognize a mafic rock by its dark-coloured appearance, and a felsic rock by its light-coloured appearance. An intermediate rock will be somewhat lighter than a mafic rock, yet darker than a felsic rock. Finally, an ultramafic rock is typically green in colour, due to the large amount of green-coloured olivine in the rock. Such rocks that contain minerals that are too small to see are shown in Figure 3.4; note that you can still distinguish between mafic (Figure 3.4A),

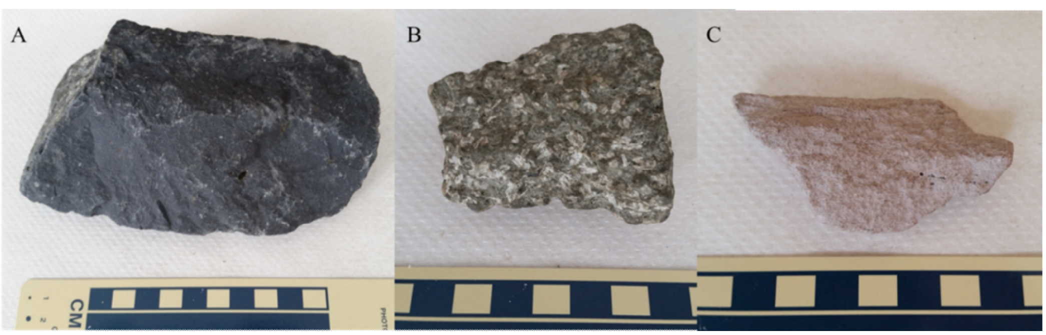

Figure 3.4 | Examples of igneous rocks from the mafic (A), intermediate (B), and felsic (C) rock compositions. Notice the difference in appearance between these rocks and those in Figure 3.2. Source: Karen Tefend (2015) CC BY-SA 3.0

intermediate (Figure 3.4B) and felsic (Figure 3.4C) by the overall colour of the rock. The intermediate igneous rock in Figure 3.3B does have a few visible phenocrysts; this odd texture will be covered later in this chapter.

3.4 IGNEOUS ROCK TEXTURE

The classification of igneous rocks is based not just on composition, but also on texture. As mentioned earlier, texture refers to the features that we see in the rock such as the mineral sizes or the presence of glass, fragmented material, or vesicles (holes) in the igneous rock. We will cover mineral crystal sizes and vesicles in this section.

Since the crystals or **phenocrysts** form while the magma is cooling, then the size of the crystals must have something to do with the cooling process. The chemical elements that become part of the mineral must migrate from the liquid magma to bond with other elements in a certain way to form the unique crystal structure for that mineral. When magma cools slowly, the chemical elements needed to form a certain mineral have time to migrate; that mineral can become large enough to see without the aid of a microscope. This igneous rock is said to have a **phaneritic** texture (phan = large). The rock samples shown in Figure 3.2 are all phaneritic rocks; Figure 3.2A is a phaneritic mafic rock called gabbro, Figures 3.2B and 3.4B are a phaneritic intermediate rock called diorite, and the rock in Figure 3.2C is a phaneritic felsic rock known as granite. Magma that cools relatively quickly will result in a different rock; there is less time for the chemical elements to migrate and form large mineral crystals. Therefore, many small, microscopic crystals of a particular mineral will form; these igneous rocks are called **aphanitic** igneous rocks. Figure 3.4A and 3.4C are aphanitic rocks; since Figure 3.4A is dark in colour, it is a mafic aphanitic rock called basalt, and the felsic rock in Figure 3.4C is called rhyolite.

There can be equivalent extrusive and intrusive rocks, which appear to different but are chemically identical. For example, basalt and gabbro are both mafic rocks and have the same composition, but basalt represents a magma that cooled fast, and gabbro represents a magma that cooled slowly. The same can be said for the other rock compositions: the felsic rocks rhyolite and granite have identical compositions but rhyolite cooled fast and granite cooled slower. The intermediate rocks diorite (Figure 3.2B) and andesite (Figure 3.4B) also represent magmas that cooled slowly or a bit faster, respectively. Sometimes there are some visible crystals in an otherwise aphanitic rock, such as the andesite in Figure 3.4B. The texture of such a rock is referred to as **porphyritic**, or more accurately porphyritic-aphanitic since it is a porphyritic andesite, and all andesites are aphanitic. Two different crystal sizes within an igneous rock indicates that the cooling rate of the magma increased; while the magma was cooling slowly, larger crystals can form, but if the magma starts to cool faster, then only small crystals can form. A phaneritic rock can also be referred to as a porphyritic-phaneritic rock if the phaneritic rock contains some very large crystals in addition to the other visible crystals. In Figure

3.5 are two porphyritic rocks: a porphyritic-aphanitic basalt, and a porphyritic-phaneritic granite.

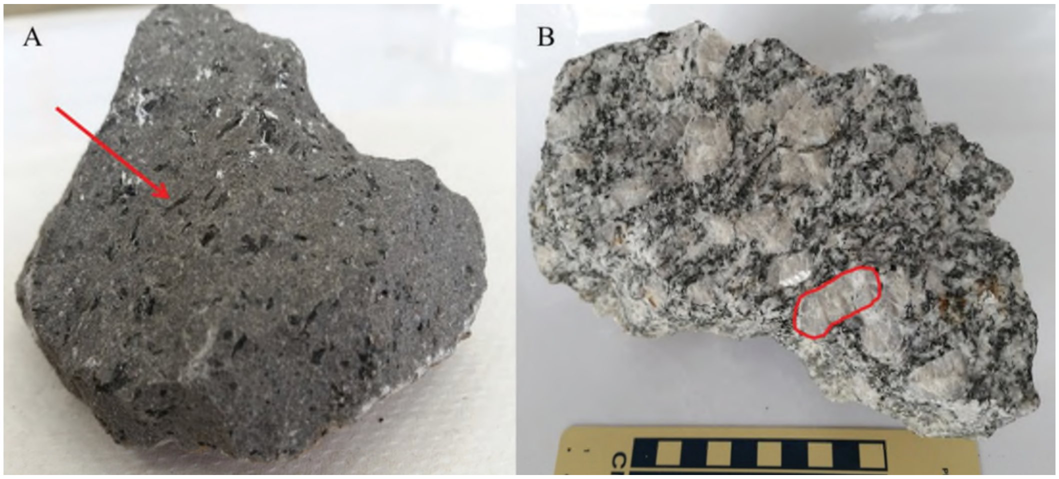

Figure 3.5 | (A) An example of a porphyritic-aphanitic mafic rock with needle-shaped amphibole phenocrysts (arrow points to one phenocryst that is 1cm in length); No other minerals in (A) are large enough to see. (B) An example of a porphyritic-phaneritic felsic rock with large feldspars (outlined phenocryst is 3 cm length). Surrounding these large feldspars are smaller (yet still visible) dark and light coloured minerals. Source: Karen Tefend (2015) CC BY-SA 3.0

Sometimes, the magma cools so quickly there isn't time to form minerals, as the chemical elements in the magma have no time to migrate into a crystal structure. When this happens, the magma becomes a dense glass called **obsidian** (Figure 3.6A). By definition, glass is a chaotic arrangement of the chemical elements, and therefore not considered to be a mineral; igneous rocks composed primarily of glass are said to have a **glassy** texture. The identification of a glassy rock such as obsidian is easy once you recall the properties of glass; any thick glass pane or a glass

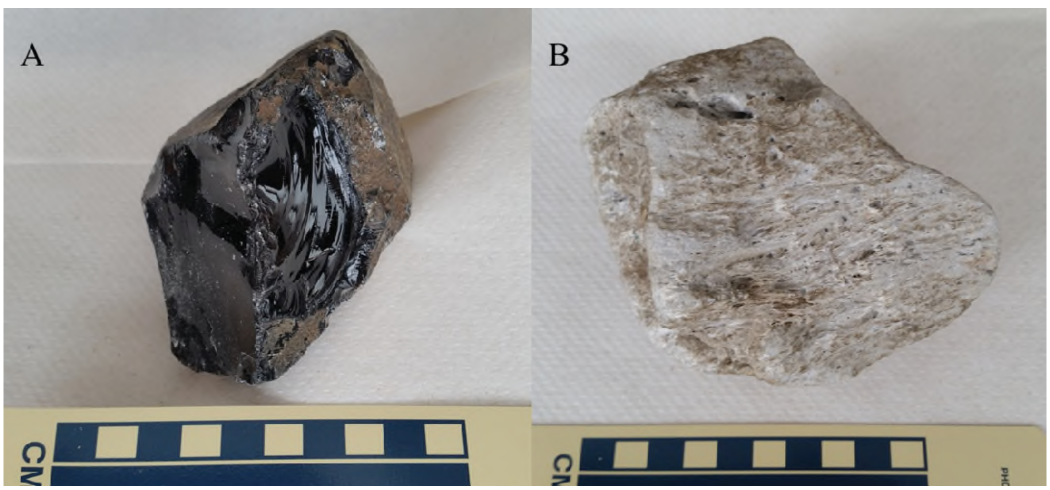

Figure 3.6 | Igneous rocks with glassy texture: obsidian (A) and pumice (B). Source: Karen Tefend (2015) CC BY-SA 3.0

bottle that is broken will have this smooth, curve shaped pattern on the broken edge called conchoidal fracture. Even though obsidian is naturally occurring, and not man made, it still breaks in this conchoidal pattern. If you look closely at the obsidian in Figure 3.6A, you will see the curved surfaces on the rock. Obsidian appears quite dark in colour regardless of its composition because it is a dense glass, and light cannot pass through this thick glass.

In Figure 3.6B, there is another igneous rock that is also composed primarily of glass due to a very fast rate of magma cooling. This rock is called pumice and is commonly known as the rock that floats on water due to its low density. The glass in this rock is stretched out into very fine fibers of glass which formed during the eruptive phase of a volcano. Because these fibers are so thin, they are easy to break and any conchoidal fractures on these fibers are too small to see without the aid of a microscope. Pumice can have any composition (felsic to mafic), but, unlike obsidian, the colour of the pumice can be used to determine the magma composition, as felsic pumice is always light in colour and mafic pumice will be dark in colour. Mafic pumice with a dark grey, red or black colour is also known as scoria.

3.5 IGNEOUS ROCK FORMATION—INTRUSIVE VS. EXTRUSIVE

The different crystal sizes and presence or absence of glass in an igneous rock is primarily controlled by the rate of magma cooling. Magmas that cool below the surface of the earth tend to cool slowly, as the surrounding rock acts as an insulator, which slows the rate of cooling. Magma that stays below the surface of the earth can take tens of thousands of years to completely crystallize, depending on the size of the magma body. Upon inspection of this rock, you would see that it is composed of minerals that are large enough to see without the aid of a microscope. Any igneous rock sample that is considered to have a phaneritic texture (or porphyritic-phaneritic), is referred to as an **intrusive** rock, as it is derived from magma that intruded the rock layers but never reached the earth’s surface.

If magma reaches the earth's surface, it is no longer insulated by the rocks around it and will cool rapidly. Magma that reaches the earth's surface through a fissure or central vent will lose some of its dissolved gas and becomes lava, and any rock that forms from lava will have either an aphanitic texture due to fast cooling, or a glassy texture due to very fast cooling. Flowing lava may continue to release gas while cooling; this is typical of mafic lava flows. If the lava hardens while these gases are bubbling out of the lava, a small hole or vesicle may form in the rock, the term "**vesicular**" is given to the rock to indicate the presence of these vesicles. For example, a basalt with vesicles is called vesicular basalt (Figure 3.7). These vesicles can be filled with a secondary mineral, such as quartz or calcite, long after the rock was formed; these filled vesicles are known as "amygdaloids", giving an **amygdaloidal** texture (e.g. Figure 3.8).

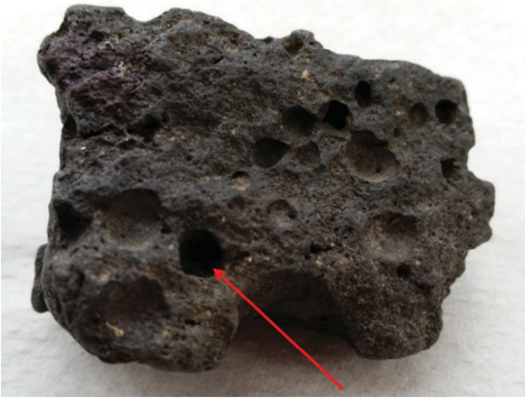

Figure 3.7 | An aphanitic mafic rock (basalt), with gas escape structures called vesicles. Arrow points to one vesicle that is ~1cm in diameter. This is an example of another texture type, called vesicular texture, and the name of this rock is a vesicular basalt. Source: Karen Tefend (2015) CC BY-SA 3.0

Aphanitic rocks and rocks with a glassy texture are also known as **extrusive** igneous rocks, as the magma was extruded onto the surface of the earth. Porphyritic-aphanitic rocks are also considered to be extrusive rocks, as these rocks began crystallizing under the earth's surface, forming visible crystals, but this magma later emerged onto the surface as lava, crystallizing to form an extrusive igneous rock with a porphyritic-aphanitic texture.

Figure 3.8 | An aphanitic mafic rock (basalt) with amygdaloids, which are vesicles filled with a secondary mineral. Arrows point to amygdaloids that are both partially and completely filled. This is an example of another texture type, called amygdaloidal texture, and the name of this rock is an amygdaloidal basalt. Source: Joyce M. McBeth (2018) CC BY 4.0

A summary of the terms used to classify the igneous rocks are provided in Figure 3.9 in order to help with the identification of the igneous rock in this lab. Refer to the preceding figures for further help.

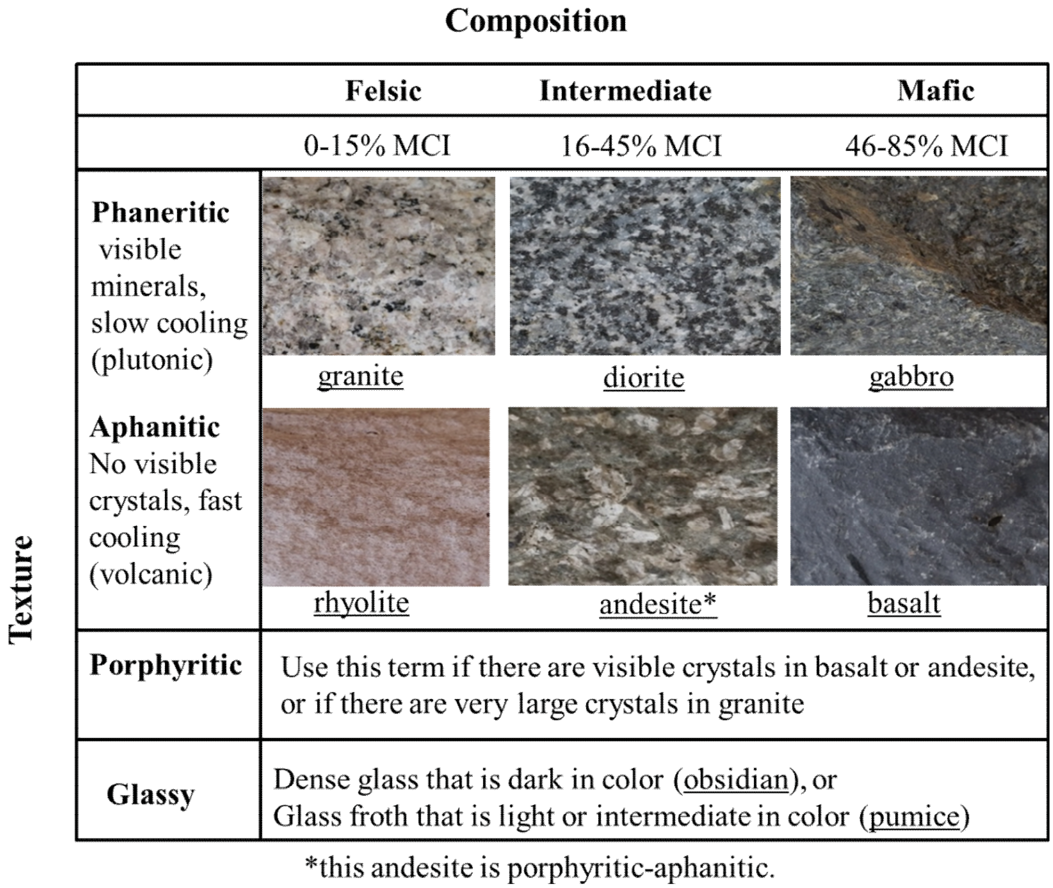

Figure 3.9 | Chart showing some common igneous rock textures and compositions. MCI is the mafic colour index, or the percentage of dark coloured ferromagnesian minerals present. Recall that any composition can be phaneritic, aphanitic, porphyritic or glassy. Vesicular texture is not as common and is only seen in some aphanitic rocks. Source: Karen Tefend (2015) CC BY-SA 3.0

3-E1 LAB EXERCISES – IGNEOUS ROCK IDENTIFICATION

Before attempting to answer the following questions, obtain the 13 rock samples from the drawers provided by your TA; they will be numbered 28-40. As you work through the questions fill in Chart 5-E1 (found at the end of this lab). You do not have to fill out every column for every rock – just follow along in the lab and determine the properties you are asked about.

Separate the samples into three groups based on their color (dark, light or intermediate). Take a close look at the dark colored rocks; how are they different? When you hold them closer to a light source, notice how they reflect light; they may be dull looking, they may have small shiny surfaces, or they may be extremely shiny and smooth. The rock that is very smooth and shiny is not a mafic rock, even though it is dark in color. This particular rock is an example of that rock type that lacks mineral crystals; instead, it is almost entirely made of glass, and is most probably felsic in composition. Separate this rock into its own group. Now take a close look at the light-colored rocks. Some may have several minerals visible that you will see as different colors. Others may be fairly uniform in color; some may be composed of very tiny minerals that require a microscope to view them, while another may seem to be fragile and light-weight. The fragile appearing rock is another example of rock that is again almost entirely glass with a very few, tiny phenocrysts; set this rock aside with the other glassy rock.

Now you should have four piles, please answer the following questions. Refer to the images in figures 3.2-3.9 to help with identification.

1. Sample 28: The pink-coloured minerals are most likely ___________.
    a. quartz
    b. biotite
    c. orthoclase
    d. Ca-rich plagioclase
2. Sample 28: The small, dark colored minerals are most likely __________.
    a. quartz
    b. biotite
    c. orthoclase
    d. Na-rich plagioclase
3. Sample 28: This rock belongs to which igneous rock classification?
    a. mafic
    b. intermediate
    c. felsic
    d. any of the above
4. Sample 29: This rock belongs to which igneous rock classification?
    a. mafic
    b. intermediate
    c. felsic
    d. any of the above
5. Sample 32: This rock belongs to which igneous rock classification?
    a. mafic
    b. intermediate
    c. felsic
    d. any of the above

6. Sample 32: According to Figure 3.1 in the lab manual textbook online (Bowen's reaction series), this rock must contain which mineral?
    a. olivine
    b. pyroxene
    c. amphibole
    d. quartz
7. Sample 33: The white minerals are most likely __________.
    a. quartz
    b. biotite
    c. orthoclase
    d. plagioclase
8. Sample 33: This rock belongs to which igneous rock classification?
    a. mafic
    b. intermediate
    c. felsic
    d. any of the above
9. Sample 35: This rock belongs to which igneous rock classification?
    a. mafic
    b. intermediate
    c. felsic
    d. any of the above
10. Sample 35: According to Figure 3.1 in the lab manual textbook online (Bowen's reaction series), which mineral would you NOT expect to find in this rock?
    a. olivine
    b. pyroxene
    c. amphibole
    d. quartz
11. Sample 36: This rock belongs to which igneous rock classification?
    a. mafic
    b. intermediate
    c. felsic
    d. any of the above
12. Sample 29: This rock has which textures? (choose 2)
    a. phaneritic
    b. aphanitic
    c. porphyritic-aphanitic
    d. glassy
    e. vesicular
    f. amygdaloidal

13. Sample 29: What is this rock called?
    a. obsidian
    b. pumice
    c. granite
    d. rhyolite
    e. diorite
    f. andesite
    g. gabbro
    h. basalt
14. Sample 31: This rock has what texture?
    a. phaneritic
    b. aphanitic
    c. porphyritic-aphanitic
    d. glassy
    e. vesicular
    f. amygdaloidal
15. Sample 31: How did this rock form?
    a. by magma that cooled very slowly
    b. by magma that cooled slowly
    c. by very fast cooling of a magma
16. Sample 31: What is this rock called?
    a. obsidian
    b. pumice
    c. granite
    d. rhyolite
    e. diorite
    f. andesite
    g. gabbro
    h. basalt
17. Sample 33: This rock has what texture?
    a. phaneritic
    b. aphanitic
    c. porphyritic-aphanitic
    d. glassy
    e. vesicular
    f. amygdaloidal
18. Sample 33: How did this rock form?
    a. by magma that cooled slowly
    b. by fast cooling lava
    c. by a very fast cooling of a lava
    d. by a very fast cooling magma during a volcanic eruption
    e. by magma that was cooling slowly, then as a lava that cooled quickly

19. Sample 33: What is this rock called?
    a. obsidian
    b. pumice
    c. granite
    d. rhyolite
    e. diorite
    f. andesite
    g. gabbro
    h. basalt
20. Sample 33: This rock can also be called __________.
    a. extrusive
    b. intrusive
21. Sample 34: This rock has what texture?
    a. phaneritic
    b. aphanitic
    c. porphyritic-aphanitic
    d. glassy
    e. vesicular
    f. amygdaloidal
22. Sample 34: How did this rock form?
    a. by magma that cooled slowly
    b. by fast cooling lava
    c. by a very fast cooling of a lava
    d. by a very fast cooling magma during a volcanic eruption
    e. by magma that was cooling slowly, then as a lava that cooled quickly
23. Sample 34: What is this rock called?
    a. obsidian
    b. pumice
    c. granite
    d. rhyolite
    e. diorite
    f. andesite
    g. gabbro
    h. basalt
24. Sample 34: This rock can also be called __________.
    a. extrusive
    b. intrusive
25. Sample 36: This rock has what texture?
    a. phaneritic
    b. aphanitic
    c. porphyritic-aphanitic
    d. glassy
    e. vesicular
    f. amygdaloidal

26. Sample 36: How did this rock form?
    a. by magma that cooled slowly
    b. by fast cooling lava
    c. by a very fast cooling of a lava
    d. by a very fast cooling magma during a volcanic eruption
    e. by magma that was cooling slowly, then as a lava that cooled quickly
27. Sample 36: What is this rock called?
    a. obsidian
    b. pumice
    c. granite
    d. rhyolite
    e. diorite
    f. andesite
    g. gabbro
    h. basalt
28. Sample 37: This rock has what texture?
    a. phaneritic
    b. aphanitic
    c. porphyritic-aphanitic
    d. glassy
    e. vesicular
    f. amygdaloidal
29. Sample 37: How did this rock form?
    a. by magma that cooled slowly
    b. by fast cooling lava
    c. by a very fast cooling of a lava
    d. by a very fast cooling magma during a volcanic eruption
    e. by magma that was cooling slowly, then as a lava that cooled quickly
30. Sample 37: What is this rock called?
    a. obsidian
    b. pumice
    c. granite
    d. rhyolite
    e. diorite
    f. andesite
    g. gabbro
    h. basalt
31. Sample 37: This rock can also be called ___________.
    a. extrusive
    b. intrusive

32. Sample 38: This rock has what texture?
    a. phaneritic
    b. aphanitic
    c. porphyritic-aphanitic
    d. glassy
    e. vesicular
    f. amygdaloidal
33. Sample 38: This rock has what composition?
    a. felsic
    b. intermediate
    c. mafic
    d. any of the above
34. Sample 38: How did this rock form?
    a. by magma that cooled slowly
    b. by fast cooling lava
    c. by a very fast cooling of a lava
    d. by a very fast cooling magma during a volcanic eruption
    e. by magma that was cooling slowly, then as a lava that cooled quickly
35. Sample 38: What is this rock called?
    a. obsidian
    b. pumice
    c. granite
    d. rhyolite
    e. diorite
    f. andesite
    g. gabbro
    h. basalt
36. Sample 39: This rock has which textures? (choose 2)
    a. phaneritic
    b. aphanitic
    c. porphyritic-aphanitic
    d. glassy
    e. vesicular
    f. amygdaloidal
37. Sample 39: How did this rock initially form?
    a. by magma that cooled slowly
    b. by fast cooling lava
    c. by a very fast cooling of a lava
    d. by a very fast cooling magma during a volcanic eruption
    e. by magma that was cooling slowly, then as a lava that cooled quickly

38. Sample 39: What is this rock called?
    a. obsidian
    b. pumice
    c. granite
    d. rhyolite
    e. diorite
    f. andesite
    g. gabbro
    h. basalt
39. Sample 39: This rock can also be called __________.
    a. extrusive
    b. intrusive
40. Sample 40: This rock has what texture?
    a. phaneritic
    b. aphanitic
    c. porphyritic-aphanitic
    d. glassy
    e. vesicular
    f. amygdaloidal
41. Sample 40: How did this rock form?
    a. by magma that cooled slowly
    b. by fast cooling lava
    c. by a very fast cooling of a lava
    d. by a very fast cooling magma during a volcanic eruption
    e. by magma that was cooling slowly, then as a lava that cooled quickly
42. Sample 40: What is this rock called?
    a. obsidian
    b. pumice
    c. granite
    d. rhyolite
    e. diorite
    f. andesite
    g. gabbro
    h. basalt

Table 3-E1 | Igneous Rock Notation Chart – Download and fill in this chart as you work through the lab, similar to the chart you completed in the minerals lab. An example of a rock you do not have available (#0) is included. You do not have to fill out every column for every rock – just follow along in the lab and determine the properties you are asked about. Source: Lyndsay Hauber (2018) CC BY 4.0

Sample #	Textures	Chemical Composition	Colour	Major Minerals Present	Name
0	Phaneritic	Ultra-mafic	Dark; green	Olivine, Pyroxene	Peridotite
28					
29					
30					
31					
32					

Sample #	Textures	Chemical Composition	Colour	Major Minerals Present	Name
33					
34					
35					
36					
37					
38					
39					
40					