LAB 3: SILICATE MINERALS

Lab Structure

Recommended additional work	Yes – review concepts from Labs 1, 2 and 3 in preparation for Test 1
Required materials	Mineral ID kit, Mineral Kits 1 and 2, pencil

Learning Objectives

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

- Describe a silica tetrahedron and the ways in which tetrahedra combine to make silicate minerals.
- Differentiate between ferromagnesian and other silicate minerals.
- Identify and describe the physical properties of a range of silicate minerals in hand sample, and how these properties are used to identify minerals.

Key Terms

- Isolated silicate
- Single chain silicate
- Double chain silicate
- Phyllosilicate (sheet silicate)
- Framework silicate
- Colour
- Streak
- Lustre
- Hardness
- Crystal habit
- Cleavage
- Fracture
- Conchoidal fracture
- Specific gravity

3.1 Silicate Mineral Groups

The vast majority of the minerals that make up the rocks of Earth's crust are **silicate** minerals. These include minerals such as quartz, feldspar, mica, amphibole, pyroxene, olivine, and a variety of clay minerals. The building block of all of these minerals is the **silica tetrahedron**, a combination of four oxygen atoms and one silicon atom that form a four-sided pyramid shape with O at each corner and Si in the middle (Figure 3.1.1). The bonds in a silica tetrahedron have some of the properties of covalent bonds and some of the properties of ionic bonds. As a result of the ionic character, silicon becomes a cation (with a charge of +4) and oxygen becomes an anion (with a charge of −2). The net charge of a silica tetrahedron (SiO_4) is: 4 + 4(−2) = 4 − 8 = −4. As we will see later, silica tetrahedra (plural of *tetrahedron*) link together in a variety of ways to form most of the common minerals of the crust.

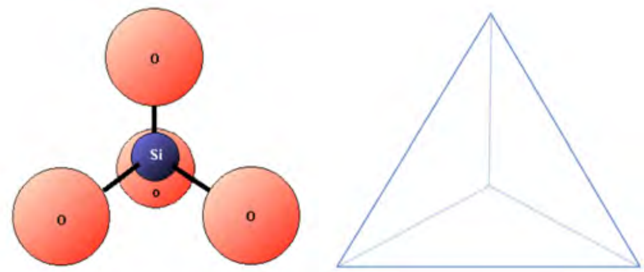


Figure 3.1.1: The silica tetrahedron, the building block of all silicate minerals. (Because the silicon ion has a charge of +4 and the four oxygen ions each have a charge of −2, the silica tetrahedron has a net charge of −4.)

What's with all of these "sili" names?

The element **silicon (Si)** is one of the most important geological elements and is the second-most abundant element in Earth's crust (after oxygen). Silicon bonds readily with oxygen to form a **silica** tetrahedron (Figure 3.1.1). Pure silicon crystals (created in a lab) are used to make semi-conductive media for electronic devices. A **silicate** mineral is one in which silicon and oxygen are present as silica tetrahedra. Silica also refers to a chemical component of a rock and is expressed as % SiO_2. The mineral quartz is made up entirely of silica tetrahedra, and some forms of quartz are also known as "silica". **Silicone** is a synthetic product (e.g., silicone rubber, resin, or caulking) made from silicon-oxygen chains and various organic molecules. To help you keep the "sili" names straight, here is a summary table:

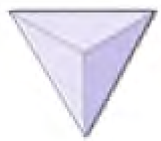
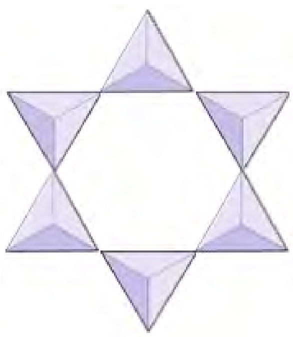
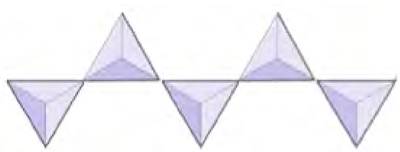
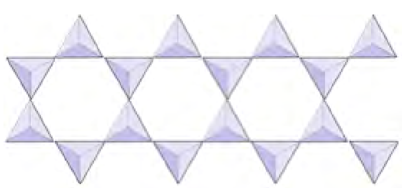
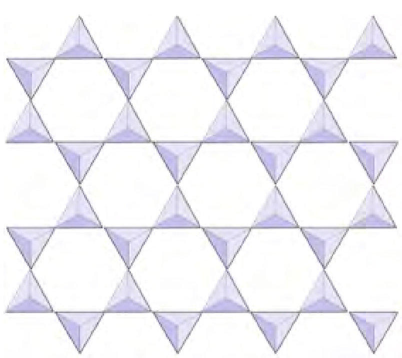
Table 3.1 Summary of "Sili" names

"Sili" name	Definition
Silicon	The 14th element on the periodic table (Si)
Silicon wafer	A crystal of pure silicon sliced very thinly and used for electronics
Silica tetrahedron	A combination of one silicon atom and four oxygen atoms that form a tetrahedron
% silica	The proportion of a rock that is composed of the component SiO_2
Silica	A solid made out of SiO_2 (but not necessarily a mineral – e.g., opal)
Silicate	A mineral that contains silica tetrahedra (e.g., quartz, feldspar, mica, olivine)
Silicone	A flexible synthetic material made up of Si–O chains with attached organic molecules

In silicate minerals, these tetrahedra are arranged and linked together in a variety of ways, from single units to complex frameworks (Table 3.2). The simplest silicate structure, that of the mineral **olivine**, is composed of isolated tetrahedra bonded to iron and/or magnesium ions. In olivine, the −4 charge of each silica tetrahedron is balanced by two **divalent** (i.e., +2) iron or magnesium cations. Olivine can be either Mg_2SiO_4 or Fe_2SiO_4, or some combination of the two $(Mg,Fe)_2SiO_4$. The divalent cations of magnesium and iron are quite close in radius (0.73 versus 0.62 angstroms[1]). Because of this size similarity, and because they are both divalent cations (both can have a charge of +2), iron and magnesium can readily substitute for each other in olivine and in many other minerals.

Recall that for non-silicate minerals, we classified minerals into groups according to their anion or anionic group. For silicate minerals, we group minerals based on their silicate structure into groups called: isolated, pair, ring, single chain, double chain, sheet, and framework silicates. In this course, we will focus on just the isolated, single chain, double chain, sheet, and framework silicates.

Table 3.2 Silicate mineral configurations. The triangles represent silica tetrahedra.

Tetrahedron Configuration Picture	Tetrahedron Configuration Name	Example Minerals
	Isolated (nesosilicates)	Olivine, garnet, zircon, kyanite
	Pairs (sorosilicates)	Epidote, zoisite
	Rings (cyclosilicates)	Tourmaline
	Single chains (inosilicates)	Pyroxenes, wollastonite
	Double chains (inosilicates)	Amphiboles
	Sheets (phyllosilicates)	Micas, clay minerals, serpentine, chlorite
3-dimensional structure	Framework (tectosilicates)	Feldspars, quartz, zeolite

In olivine, unlike most other silicate minerals, the silica tetrahedra are not bonded to each other. Instead they are bonded to the iron and/or magnesium ions, in the configuration shown on Figure 3.1.2.

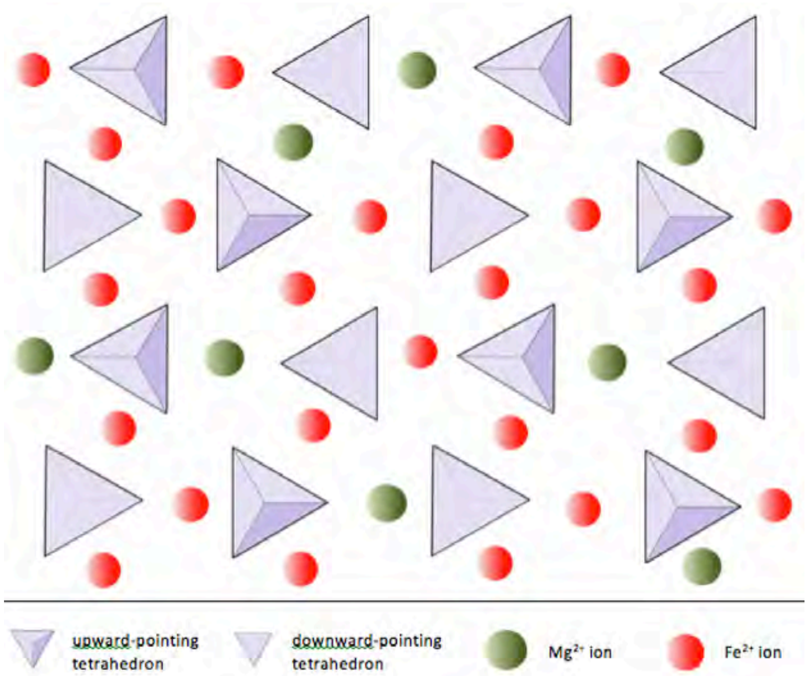


Figure 3.1.2: A depiction of the structure of olivine as seen from above. The formula for this particular olivine, which has three Fe ions for each Mg ion, could be written: $Mg_{0.5}Fe_{1.5}SiO_4$.

As already noted, the 2 ions of iron and magnesium are similar in size (although not quite the same). This allows them to substitute for each other in some silicate minerals. In fact, the ions that are common in silicate minerals have a wide range of sizes, as depicted in Figure 3.1.3. All of the ions shown are cations, except for oxygen. Note that iron can exist as both a +2 ion (if it loses two electrons during ionization) or a +3 ion (if it loses three). Fe^{2+} is known as **ferrous** iron. Fe^{3+} is known as **ferric** iron. Ionic radii are critical to the composition of silicate minerals, so we'll be referring to this diagram again.

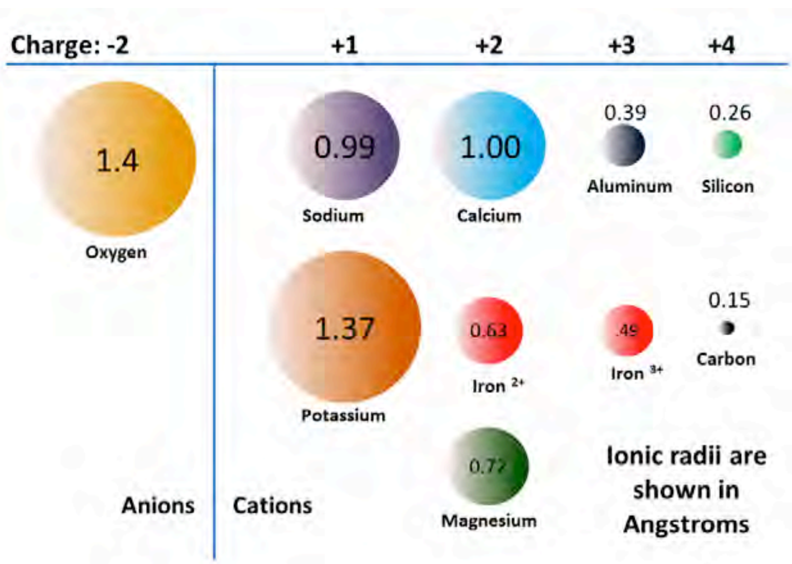


Figure 3.1.3: The ionic radii (effective sizes) in angstroms, of some of the common ions in silicate minerals.

The structure of the single-chain silicate pyroxene is shown on Figures 3.1.4 and 3.1.5. In **pyroxene**, silica tetrahedra are linked together in a single chain, where one oxygen ion from each tetrahedron is shared with the adjacent tetrahedron, hence there are fewer oxygens in the structure. The result is that the oxygen-to-silicon ratio is lower than in olivine (3:1 instead of 4:1), and the net charge per silicon atom is less (−2 instead of −4). Therefore, fewer cations are necessary to balance that charge. The structure of pyroxene is more "permissive" than that of olivine—meaning that cations with a wider range of ionic radii can fit into it. That's why pyroxenes can have iron (radius 0.63 Å) or magnesium (radius 0.72 Å) or calcium (radius 1.00 Å) cations (see Figure 3.1.3 above). Pyroxene compositions are of the type $MgSiO_3$, $FeSiO_3$, and $CaSiO_3$, or some combination of these, written as $(Mg,Fe,Ca)SiO_3$, where the elements in the brackets can be present in any proportion.

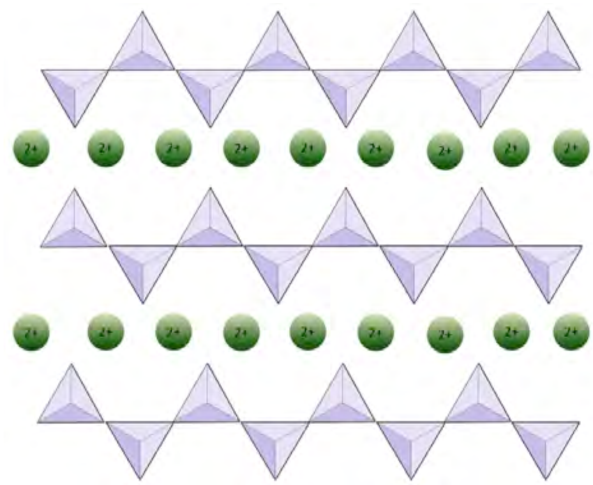


Figure 3.1.4: A depiction of the structure of pyroxene. The tetrahedral chains continue to left and right and each is interspersed with a series of divalent cations. If these are Mg ions, then the formula is $MgSiO_3$.

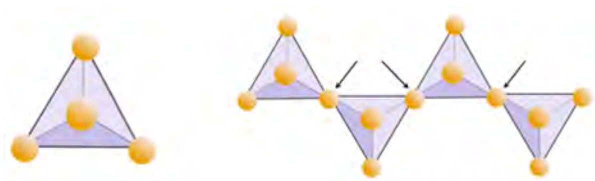


Figure 3.1.5: A single silica tetrahedron (left) with four oxygen ions per silicon ion (SiO_4). Part of a single chain of tetrahedra (right), where the oxygen atoms at the adjoining corners are shared between two tetrahedra (arrows). For a very long chain the resulting ratio of silicon to oxygen is 1 to 3 (SiO_3).

In **amphibole** structures, the silica tetrahedra are linked in a double chain that has an oxygen-to-silicon ratio lower than that of pyroxene, and hence still fewer cations are necessary to balance the charge. Amphibole is even more permissive than pyroxene and its compositions can be very complex. Hornblende, for example, can include sodium, potassium, calcium, magnesium, iron, aluminum, silicon, oxygen, fluorine, and the hydroxyl ion (OH^-).

In **mica** minerals, the silica tetrahedra are arranged in continuous sheets. There is even more sharing of oxygens between adjacent tetrahedra and hence fewer cations are needed to balance the charge of the silica-tetrahedra structure in sheet silicate minerals. Bonding between sheets is relatively weak, and this accounts for the well-developed one-directional cleavage in micas. **Biotite** mica can have iron and/or magnesium in it and that makes it a **ferromagnesian** silicate mineral (like olivine, pyroxene, and amphibole). **Chlorite** is another similar mineral that commonly includes magnesium. In **muscovite** mica, the only cations present are aluminum and potassium; hence it is a non-ferromagnesian silicate mineral.

Apart from muscovite, biotite, and chlorite, there are many other **sheet silicates** (a.k.a. **phyllosilicates**), many of which exist as clay-sized fragments (i.e., less than 0.004 millimetres). These include the clay minerals **kaolinite**, **illite**, and **smectite**, and although they are difficult to study because of their very small size, they are extremely important components of rocks and especially of soils.

Silica tetrahedra are bonded in three-dimensional frameworks in both the **feldspars** and **quartz**. These are **non-ferromagnesian minerals**—they don't contain any iron or magnesium. In addition to silica tetrahedra, feldspars include the cations aluminum, potassium, sodium, and calcium in various combinations. Quartz contains only silica tetrahedra.

The three main **feldspar** minerals are **potassium feldspar**, (a.k.a. K-feldspar or K-spar) and two types of plagioclase feldspar: **albite** (sodium only) and **anorthite** (calcium only). As is the case for iron and magnesium in olivine, there is a continuous range of compositions (**solid solution** series) between albite and anorthite in plagioclase. Because the calcium and sodium ions are almost identical in size (1.00 Å versus 0.99 Å) any intermediate compositions between $CaAl_2Si_3O_8$ and $NaAlSi_3O_8$ can exist (Figure 3.1.6).

The intermediate-composition plagioclase feldspars are oligoclase (10% to 30% Ca), andesine (30% to 50% Ca), labradorite (50% to 70% Ca), and bytownite (70% to 90% Ca). **Potassium feldspar**($KAlSi_3O_8$) has a slightly different structure than that of plagioclase, owing to the larger size of the potassium ion (1.37 Å) and because of this large size, potassium and sodium do not readily substitute for each other, except at high temperatures. These high-temperature feldspars are likely to be found only in volcanic rocks because intrusive igneous rocks cool slowly enough to low temperatures for the feldspars to change into one of the lower-temperature forms.

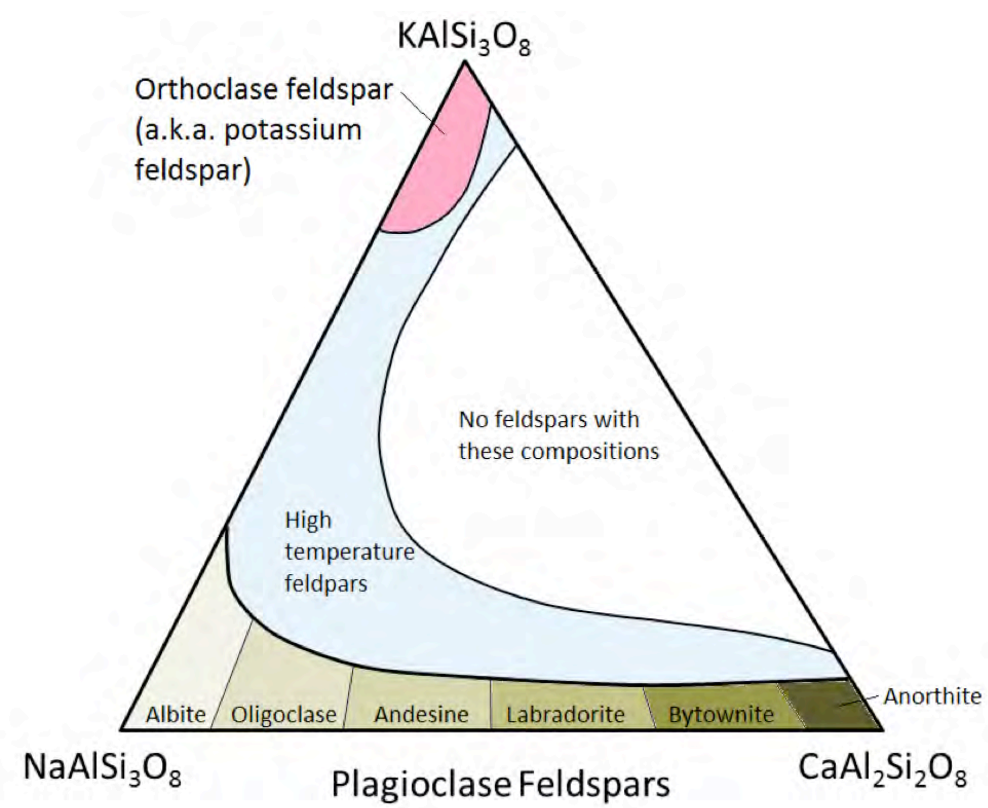


Figure 3.1.6: Compositions of the feldspar minerals.

Family names versus mineral names

The names “pyroxene”, “amphibole”, “mica”, and “feldspar” can be confusing at first, as these are technically names of mineral “families” and not names of a specific mineral. Minerals within the same family tend to share common structures, but each individual mineral is distinguished by its chemical formula. In the examples below the mineral names are **bolded.**

- One type of pyroxene mineral that you will see in this course is called **augite** ($(Ca,Na)(Mg,Fe,Al,Ti)(Si,Al)_2O_6$). Augite is one of many minerals within the pyroxene family.
- One of the most common amphibole minerals is called **hornblende** ($(Ca,Na)_2(Mg,Fe,Al)_5(Al,Si)_8O_{22}(OH)_2$), which is just one of many minerals within the amphibole family.
- Two common minerals from the mica family that you will see in this course are **biotite** ($K(Mg,Fe)_3AlSi_3O_{10}(OH)_2$) and **muscovite** ($KAl_2(AlSi_3O_{10}(F,OH)_2$).
- Three feldspar minerals you will encounter in this course are **potassium feldspar** ($KAlSi_3O_8$), **albite** ($NaAlSi_3O_8$), and **labradorite** ($(Ca, Na)(Al, Si)_4O_8$).

In **quartz** (SiO_2**),** the silica tetrahedra are bonded in a “perfect” three-dimensional framework. Since in every silica tetrahedron one silicon cation has a +4 charge and the two oxygen anions each have a −2 charge, the charge is balanced. There is no need for aluminum or any of the other cations such as sodium or potassium. The hardness and lack of cleavage in quartz result from the strong bonds characteristic of the silica tetrahedron.

Practice Exercise 3.1 Ferromagnesian silicates?

Silicate minerals are classified as being either ferromagnesian or non-ferromagnesian depending on whether or not they have iron (Fe) and/or magnesium (Mg) in their formula. A number of minerals and their formulas are listed below. For each one, indicate whether or not it is a *ferromagnesian silicate.*

Mineral	**Formula**	**Ferromagnesian silicate?**
olivine	$(Mg,Fe)_2SiO_4$	.
pyrite	FeS_2	.
plagioclase feldspar	$CaAl_2Si_2O_8$	.
pyroxene	$MgSiO_3$	.
hematite	Fe_2O_3	.
orthoclase feldspar	$KAlSi_3O_8$	.
quartz	SiO_2	.

See Appendix 2 for Practice Exercise 3.1 answers.*Some of the formulas, especially the more complicated ones, have been simplified.

Media Attributions

- Figures 3.1.1, 3.1.2, 3.1.3, 3.1.4, 3.1.5, 3.1.6: © Steven Earle. CC BY.

Notes

1. An angstrom is the unit commonly used for the expression of atomic-scale dimensions. One angstrom is 10^{-10} metres or 0.0000000001 metres. The symbol for an angstrom is Å.

Lab 3 Exercises

The exercises below will guide you through the silicate mineral samples in Mineral Kits 1 and 2. Review the physical properties of minerals presented in Chapter 2.3 before you begin these exercises. You may wish to consult the mineral identification tables at the back of this manual as you complete the exercises below. Note that all **silicate** minerals have **non-metallic lustre**. As you are observing the following samples keep in mind you have to classify the lustre using more descriptive terms such as vitreous, earthy or dull, pearly, satiny, etc. Remember: you must be able to identify all the physical properties of each mineral, not just the diagnostic properties.

Silicate Mineral Group: Framework Silicates

1. Examine samples M221, M223, and M225. All of these samples are varieties of the same mineral. Name the mineral: ______________________
2. Describe the cleavage or fracture exhibited in these samples: ____
3. How can you distinguish between a cleavage plane and a crystal face?

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4. Test all four minerals for hardness. What is the hardness of quartz? ___________
5. Describe the lustre of the samples. ____
6. What is a diagnostic property of quartz?

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7. Sample M225 is flint, an example of microcrystalline quartz that is always grey to black in colour. Do the diagnostic properties for quartz apply to flint as well?

Feldspars

Sample M201	**Mineral name:**
Sample M202	**Mineral name:**
Sample M211	**Mineral name:**

You have a pink/salmon coloured sample and a white sample of **potassium feldspar (K-feldspar)**. A pink feldspar will always be K-feldspar, and may show **exsolution lamellae**. A white feldspar may be K-feldspar or plagioclase feldspar (**albite**). If you have a white K-feldspar and a white plagioclase feldspar look for **stria-**

tions on the plagioclase feldspar and that will differentiate them. The dark plagioclase feldspar (labradorite) will exhibit striations and has diagnostic iridescence.

1. Examine all your K-feldspar and plagioclase feldspars. These minerals are all **feldspars** however, we will refer to them by their mineral names and classify them as framework silicates. Test each sample for hardness:

Sample M201	**Hardness:**
Sample M202	**Hardness:**
Sample M211	**Hardness:**

2. Describe the cleavage exhibited by these samples: ____

3. Looking at M201 and M211, do either of these samples exhibit striations? Do either of the samples exhibit iridescence?

4. How can you distinguish between K-feldspar and plagioclase feldspar?

Silicate Mineral Group: Sheet Silicates (phyllosilicates)

Sample M121	**Mineral name:**
Sample M271	**Mineral name:**

1. Describe the cleavage of these two minerals: ____
2. What is the hardness of these two minerals? ____
3. What is a diagnostic property of mica minerals? ____
4. How can you distinguish between muscovite and biotite?

Sample M281	**Mineral name:**

5. What is the hardness of the sample? _______________________
6. Describe the lustre of this mineral: ____
7. What is a diagnostic property of talc?

Sample M291	**Mineral name:**

8. Describe the lustre of this mineral: ____
9. What is a diagnostic property of kaolinite?

Silicate Mineral Group: Single Chain Silicates

Single chain silicates include the **pyroxene** family of minerals. There is one pyroxene (augite) in the mineral kit and the samples vary in colour.

Sample M101	**Mineral name:**

1. Describe the cleavage of the pyroxene: ____________________
2. What is the colour of this mineral? ____________________
3. What is a diagnostic property of pyroxene?

Silicate Mineral Group: Double Chain Silicates

Double chain silicates include the **amphibole** family of minerals. There is one amphibole (hornblende) in the mineral kit and the samples vary in colour.

Sample M111	**Mineral name:**

1. Describe the cleavage of hornblende: ____________________
2. What is the colour of this mineral? ____________________
3. What is a diagnostic property of hornblende?

Silicate Mineral Group: Isolated Silicates

Sample M131	**Mineral name:**

The garnet family also contains various kinds of garnet. The most common is almandine, a dark ruby red coloured garnet.

1. Do you see any crystal faces on your sample? ___________
2. What is the hardness of the sample? ____________________
3. What is the lustre of garnet? ____________________
4. What is a diagnostic property of garnet?

Sample M301	Mineral name:

Olivine is an igneous mineral that is green, one of the few minerals that can be identified by colour. The samples of olivine in your kit are actually samples of an ultramafic igneous rock composed of many small crystals of olivine.

5. What is the hardness of olivine? ______________________

6. Describe the feel of the sample: ____

7. What is a diagnostic property of olivine?

Summary

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

Section	Summary
3.1 Silicate Minerals	Silicate minerals are, by far, the most important minerals in Earth's crust. They all include silica tetrahedra (four oxygens surrounding a single silicon atom) arranged in different structures (chains, sheets, etc.). Some silicate minerals include iron or magnesium and are called ferromagnesian silicates.
Lab 3 Exercises	The best way to learn mineral identification is to practice by examining the mineral samples in your Mineral Kit 1 and 2. It is important to know all the properties of each mineral in your kits, but especially the diagnostic properties that are most helpful for identifying each mineral. Remember, different samples of the same mineral may not always look exactly the same, but their other physical properties (e.g, hardness, cleavage, lustre) will be consistent.