

LAB 2: MINERAL PROPERTIES AND NON-SILICATE MINERALS

Lab Structure

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

Learning Objectives

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

- Describe mineral lattices and explain how they influence mineral properties.
- Categorize minerals into groups based on their compositions.
- Describe some of the important techniques for identifying minerals.
- Identify and describe the physical properties of a range of non-silicate minerals in hand sample.
- Discuss the economic uses of non-silicate minerals.

Key Terms

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| <ul style="list-style-type: none">• Cation• Anion• Silicate• Non-silicate• Native element• Sulphide• Oxide• Hydroxide• Sulphate• Carbonate• Halide | <ul style="list-style-type: none">• Phosphate• Colour• Streak• Lustre• Hardness• Crystal habit• Cleavage• Fracture• Conchoidal fracture• Specific gravity |
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Minerals are all around us: the graphite in your pencil, the salt on your table, the plaster on your walls, and the trace amounts of gold in your computer. Minerals can be found in a wide variety of consumer products including paper, medicine, processed foods, cosmetics, electronic devices, and many more. And of course, everything made of metal is also derived from minerals.

As defined in the introductory chapter, a mineral is a naturally occurring combination of specific elements arranged in a particular repeating three-dimensional structure (Figure I4).

“**Naturally occurring**” implies that minerals are not artificially made. Many minerals (e.g., diamond) can be made in laboratories, but if they can also occur naturally, they still qualify as minerals. “**Specific elements**” means that most minerals have a specific chemical formula or composition. The mineral pyrite, for example, is FeS_2 (two atoms of sulfur for each atom of iron), and any significant departure from that would make it a different mineral. But many minerals can have variable compositions within a specific range. The mineral olivine, for example, can range all the way from Fe_2SiO_4 to FeMgSiO_4 to Mg_2SiO_4 . Intervening compositions are written as $(\text{Fe,Mg})_2\text{SiO}_4$ meaning that Fe and Mg can be present in any proportion, and that there are two of them for each Si present. This type of substitution is known as **solid solution**.

Most important of all, a mineral has a specific “**repeating three-dimensional structure**” or “lattice,” which is the way in which the atoms are arranged. We’ve already seen in Figure I4 of the introductory chapter how sodium and chlorine atoms in halite alternate in a regular pattern. Halite happens to have the simplest mineral lattice, most other minerals have more complex lattices. Some substances that we think must be minerals are not because they lack that repeating 3-dimensional structure of atoms. Volcanic glass is an example, as is pearl or opal.

2.1 Bonding and Lattices

In the introductory chapter Minerals and Rocks, you learned that geologists define a mineral as being a naturally occurring, solid material made of an orderly crystalline structure that is represented by a defined chemical formula, and is generally inorganic.

Practice Exercise 2.1

Using the criteria established above, which of the following materials are minerals?

- Amethyst
- Sugar
- Cubic zirconia
- Halite
- Ice
- Obsidian

See Appendix 2 for Practice Exercise 2.1 answers.

As described in the introductory chapter, all minerals are characterized by a specific three-dimensional pattern known as a **lattice** or crystal structure. These structures range from the simple cubic pattern of halite (NaCl) (Figure 14), to the very complex patterns of some silicate minerals. Two minerals may have the same composition, but very different crystal structures and properties. Graphite and diamond, for example, are both composed only of carbon, but while diamond is the hardest substance known, graphite is softer than paper. Their lattice structures are compared in Figure 2.1.1.

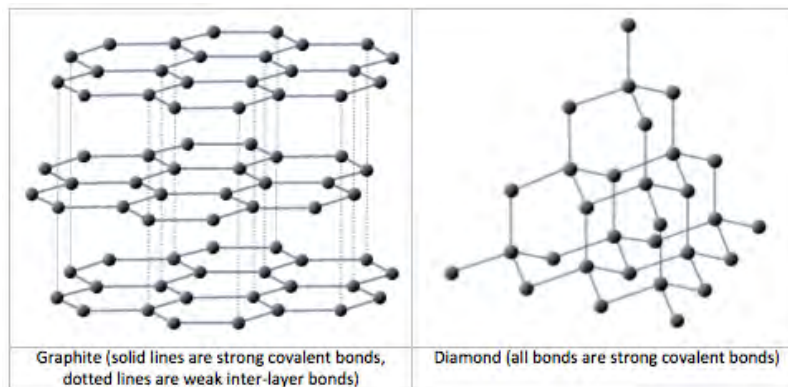


Figure 2.1.1: A depiction of the crystal lattices of graphite and diamond.

Depending on the mineral and its defined chemical formula, the bonds between the atoms that form the lattice may be **ionic** or **covalent**. On a molecular level, slight differences in the type of chemical bonds can have a significant impact on physical properties of the mineral. For example, the minerals diamond and graphite both have the same composition: both are composed exclusively of carbon atoms. In both cases, the crystal lattice is made of carbon atoms sharing electrons to form **covalent bonds**. In the mineral diamond, the car-

bon atoms are linked together in a three-dimensional framework, where each carbon atom is bonded to four other carbon atoms and every bond is a very strong covalent bond. In the mineral graphite, the carbon atoms are linked together in sheets or layers (Figure 2.1.1), and each carbon atom is covalently bonded to three others. Graphite-based compounds, which are strong because of the strong intra-layer covalent bonding, are used in high-end sports equipment such as ultralight racing bicycles. Graphite itself is soft because the bonding between these layers is relatively weak, and it is used in a variety of applications, including lubricants and pencils.

Mineral lattices have important implications for mineral properties, as exemplified by the hardness of diamond and the softness of graphite. Lattices also determine the shape that mineral crystals grow in and how they break. For example, the right angles in the lattice of the mineral halite influence both the shape of its crystals (cubic), and the way those crystals break (Figure 2.1.2).

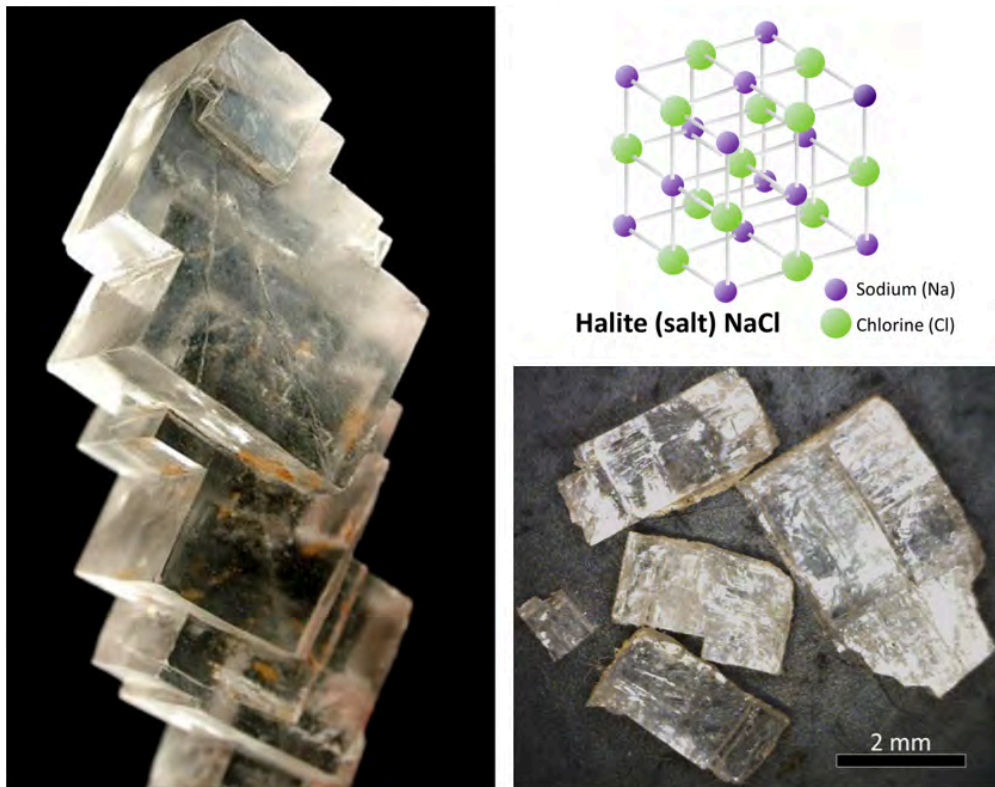


Figure 2.1.2: Cubic crystals (left), lattice structure and composition (top right), and right-angle cleavage planes (bottom right) of the mineral halite. If you look closely at the cleavage fragment on the right, you can see where it would break again (cleave) along a plane parallel to an existing surface. In most minerals, cleavage planes do not align with crystal surfaces.

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2.2 Mineral Groups

Most minerals are made up of a **cation** (a positively charged **ion**) or several cations, plus an **anion** (a negatively charged ion (e.g., S^{2-}) or an anion complex (e.g., SO_4^{2-}). For example, in the mineral hematite (Fe_2O_3), the cation is Fe^{3+} (iron) and the anion is O^{2-} (oxygen). The two Fe^{3+} ions have an overall charge of +6 and that balances the overall charge of -6 from the three O^{2-} ions.

We group minerals into classes on the basis of their predominant anion or anion complex. These include oxides, sulphides, carbonates, silicates, and others. Silicates are by far the predominant group in terms of their abundance within the crust and mantle, and will be discussed in more detail in Lab 3. Some examples of minerals from the different mineral groups are given in Table 2.2.

Table 2.2 The main mineral groups and some examples of minerals in each group.

Group	Examples
Oxides	Hematite (iron oxide Fe_2O_3), corundum (aluminum oxide Al_2O_3), water ice (H_2O)
Sulphides	Galena (lead sulphide PbS), pyrite (iron sulphide FeS_2), chalcopyrite (copper-iron sulphide $CuFeS_2$)
Sulphates	Gypsum (calcium sulphate $CaSO_4 \cdot H_2O$), barite (barium sulphate $BaSO_4$) (Note that sulphates are different from sulphides. Sulphates have the SO_4^{2-} ion while sulphides have the S^{2-} ion)
Halides	Fluorite (calcium fluoride CaF_2), halite (sodium chloride $NaCl$) (Halide minerals have halogen elements as their anion – the minerals in the second last column on the right side of the periodic table, including F, Cl, Br, etc. – see the periodic table in Appendix 1: List of Geologically Important Elements and the Periodic Table.)
Carbonates	Calcite (calcium carbonate $CaCO_3$), dolomite (calcium-magnesium carbonate $(Ca,Mg)CO_3$)
Phosphates	Apatite ($Ca_5(PO_4)_3(OH)$), Turquoise ($CuAl_6(PO_4)_4(OH)_8 \cdot 5H_2O$)
Silicates	Quartz (SiO_2), feldspar (sodium-aluminum silicate $NaAlSi_3O_8$), olivine (iron or magnesium silicate $(Mg,Fe)_2SiO_4$) (Note that in quartz the anion is oxygen, and while it could be argued, therefore, that quartz is an oxide, it is always classed with the silicates.)
Native minerals	Gold (Au), diamond (C), graphite (C), sulphur (S), copper (Cu)

Oxide minerals have oxygen (O^{2-}) as their anion, but they exclude those with oxygen complexes such as carbonate (CO_3^{2-}), sulphate (SO_4^{2-}), and silicate (SiO_4^{4-}). The most important oxides are the iron oxides hematite and magnetite (Fe_2O_3 and Fe_3O_4 , respectively). Both of these are common ores of iron. Corundum (Al_2O_3) is used as an abrasive, but can also be a gemstone in its ruby and sapphire varieties. If the oxygen is also combined with hydrogen to form the hydroxyl anion (OH^-) the mineral is known as a **hydroxide**. Some important hydroxides are limonite and bauxite, which are ores of iron and aluminium respectively. Frozen water (H_2O) is a mineral (an oxide), but liquid water is not because it doesn't have a regular lattice.

Sulphides are minerals with the S^{2-} anion, and they include galena (PbS), sphalerite (ZnS), chalcopyrite ($CuFeS_2$), and molybdenite (MoS_2), which are the most important ores of lead, zinc, copper, and molybdenum respectively. Some other sulphide minerals are pyrite (FeS_2), bornite (Cu_5FeS_4), stibnite (Sb_2S_3), and arsenopyrite ($FeAsS$).

Sulphates are minerals with the SO_4^{2-} anion, and these include anhydrite ($CaSO_4$) and its cousin gypsum ($CaSO_4 \cdot 2H_2O$) and the sulphates of barium and strontium: barite ($BaSO_4$) and celestite ($SrSO_4$). In all of these minerals, the cation has a +2 charge, which balances the -2 charge on the sulphate ion.

The **halides** are so named because the anions include the **halogen** elements chlorine, fluorine, bromine, etc. Examples are halite (NaCl), cryolite (Na₃AlF₆), and fluorite (CaF₂).

The **carbonates** include minerals in which the anion is the CO₃⁻² complex. The carbonate combines with +2 cations to form minerals such as calcite (CaCO₃), magnesite (MgCO₃), dolomite ((Ca,Mg)CO₃)¹, and siderite (FeCO₃). The copper minerals malachite and azurite are also carbonates.

In **phosphate** minerals, the anion is the PO₄⁻³ complex. An important phosphate mineral is apatite (Ca₅(PO₄)₃(OH)), which is what your teeth are made of. Note that it is called a phosphate, not a hydroxide, even though it has a hydroxyl ion.

The silicate minerals include the elements silicon and oxygen in varying proportions ranging from Si : O₂ to Si : O₄. These are discussed at length in Section 2.4.

Native minerals are single-element minerals, such as gold, copper, sulphur, and graphite.

Practice Exercise 2.2

We classify minerals according to the anion part of the mineral formula, and mineral formulas are always written with the anion part on the right. For example, for pyrite (FeS₂), Fe²⁺ is the cation and S⁻ is the anion. This helps us to know that it's a sulphide, but it is not always that obvious. Hematite (Fe₂O₃) is an oxide; that's easy, but anhydrite (CaSO₄) is a sulphate because SO₄²⁻ is the anion, not O. Along the same lines, calcite (CaCO₃) is a carbonate, and olivine (Mg₂SiO₄) is a silicate. Minerals with only one element (such as S) are native minerals, while those with an anion from the halogen column of the periodic table (Cl, F, Br, etc.) are halides. Provide group names for the following minerals:

Table 2.5 Provide group names for the following minerals

Name	Formula	Group
sphalerite	ZnS	
magnetite	Fe ₃ O ₄	
pyroxene	MgSiO ₃	
anglesite	PbSO ₄	
sylvite	KCl	
silver	Ag	
fluorite	CaF ₂	
ilmenite	FeTiO ₃	
siderite	FeCO ₃	
potassium feldspar	KAlSi ₃ O ₈	
sulphur	S	
xenotime	YPO ₄	

See Appendix 2 for Practice Exercise 2.2 answers.

Notes

1. The notations of two (or more) elements enclosed in parentheses with a comma between them: (Ca,Mg), indicates that both can be present, in varying proportions, but that there is still only one of them for each anion present.

2.3 Mineral Properties

Minerals are universal. A crystal of hematite on Mars will have the same properties as one on Earth, and the same as one on a planet orbiting another star. That's good news for geology students who are planning interplanetary travel since we can use those properties to help us identify minerals anywhere. That doesn't mean that it's easy, however; identification of minerals takes a lot of practice. Some of the mineral properties that are useful for identification are as follows: colour, streak, lustre, hardness, crystal habit, cleavage/fracture, specific gravity (density), and a few others.

Colour

For most of us, colour is one of our key ways of identifying objects. While some minerals have particularly distinctive colours that make good diagnostic properties, many do not, and for many, colour is simply unreliable. The mineral sulphur (2.3.1 left) is always a distinctive and unique yellow. Hematite, on the other hand, is an example of a mineral for which colour is not diagnostic. In some forms hematite is deep dull red, but in others it is black and shiny metallic (Figure 2.3.2). Many other minerals can have a wide range of colours (e.g., quartz, feldspar, amphibole, fluorite, and calcite). In most cases, the variations in colours are a result of varying proportions of trace elements within the mineral. In the case of quartz, for example, yellow quartz (citrine) has trace amounts of ferric iron (Fe^{3+}), rose quartz has trace amounts of manganese, purple quartz (amethyst) has trace amounts of iron, and milky quartz, which is very common, has millions of fluid inclusions (tiny cavities, each filled with water).

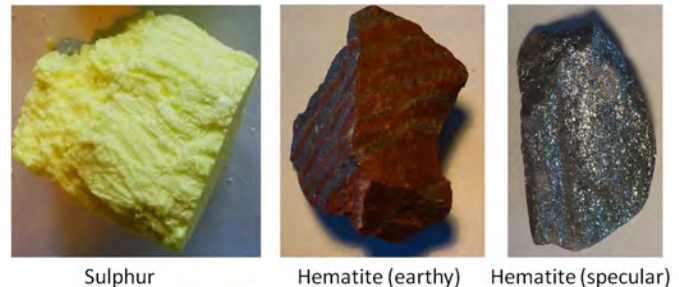


Figure 2.3.1 Examples of the colours of the minerals sulphur and hematite.

Streak

In the context of minerals, “colour” is what you see when light reflects off the surface of the sample. One reason that colour can be so variable is that the type of surface is variable. It may be a crystal face or a fracture surface or a cleavage plane, and the crystals may be large or small depending on the nature of the rock. If we grind a small amount of the sample to a powder we get a much better indication of its actual colour. This can easily be done by scraping a corner of the sample across a streak plate (a piece of unglazed porcelain) to make a



Figure 2.3.2 The streak colours of specular (metallic) hematite (left) and earthy hematite (right). Hematite leaves a distinctive reddish-brown streak whether the sample is metallic or earthy.

streak. The result is that some of the mineral gets ground to a powder and we can get a better impression of its “true” colour (Figure 2.3.2).

Lustre

Lustre is the way light reflects off the surface of a mineral, and the degree to which it penetrates into the interior. The key distinction is between **metallic** and **non-metallic lustre**. Light does not pass through metals, and that is the main reason they look “metallic” (e.g., specular hematite in Figure 2.3.1 and pyrite in Figure 2.3.4b). Even a thin sheet of metal—such as aluminum foil—will not allow light to pass through it. Many non-metallic minerals may look as if light will not pass through them, but if you take a closer look at a thin edge of the mineral you can see that it does. If a non-metallic mineral has a shiny, reflective surface, then it is called “glassy” (Figure 2.3.4a). If it is dull and non-reflective, it is “earthy” (see earthy hematite in Figure 2.3.2). Other types of non-metallic lustres are “silky,” “pearly,” and “resinous.” Lustre is a good diagnostic property since most minerals will always appear either metallic or non-metallic. There are a few exceptions to this (e.g., hematite in Figure 2.3.2).

Hardness

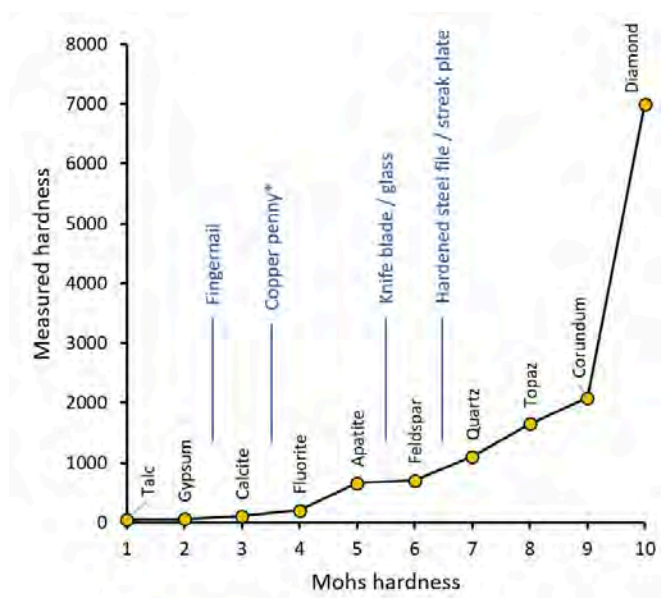


Figure 2.3.3: Minerals and reference materials in the Mohs scale of hardness. The “measured hardness” values are Vickers Hardness numbers. *Note that many modern copper coins are actually copper-plated steel, and are therefore harder.

One of the most important diagnostic properties of a mineral is its hardness. In 1812 German mineralogist Friedrich Mohs came up with a list of 10 reasonably common minerals that had a wide range of hardnesses. These minerals are shown in Figure 2.3.3, with the Mohs scale of hardness along the bottom axis. In fact, while each mineral on the list is harder than the one before it, the relative measured hardnesses (vertical axis) are not linear. For example apatite is about three times harder than fluorite and diamond is three times harder than corundum. Some commonly available reference materials are also shown on this diagram, including a typical fingernail (2.5), a piece of copper wire (3.5), a knife blade or a piece of window glass (5.5), a hardened steel file (6.5), and a porcelain streak plate (6.5 to 7). These are tools that a geologist can use to measure the hardness of unknown minerals. For example, if you have a mineral that you can’t scratch with your fingernail, but you can scratch with a copper wire, then its hardness is between 2.5 and 3.5. And of

course the minerals themselves can be used to test other minerals.

Crystal Habit

When minerals form within rocks, there is a possibility that they will form in distinctive crystal shapes if they formed slowly and if they are not crowded out by other pre-existing minerals. Every mineral has one or more distinctive crystal **habits**, but it is not that common, in ordinary rocks, for the shapes to be obvious. Quartz, for example, will form six-sided prisms with pointed ends (Figure 2.3.4a), but this typically happens only when it crystallizes from a hot water solution within a cavity in an existing rock. Pyrite can form cubic crystals (Figure 2.3.4b), but can also form crystals with 12 faces, known as **dodecahedra** (“dodeca” means 12). The mineral garnet also forms dodecahedral crystals (Figure 2.3.4c).

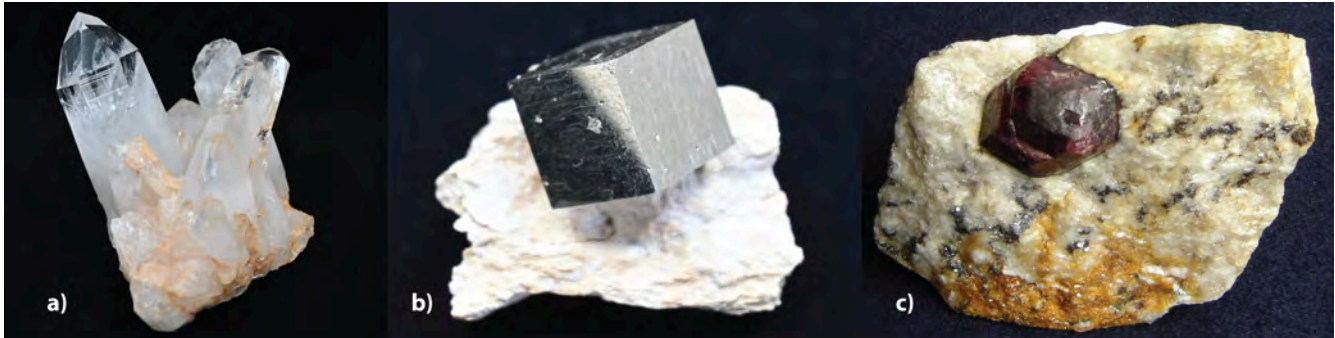


Figure 2.3.4: Hexagonal prisms of quartz with striations visible on crystal faces (a), a cubic crystal of pyrite (b), and a dodecahedral crystal of garnet (c).

Because well-formed crystals are rare in ordinary rocks, habit isn't as useful a diagnostic feature as one might think. However, there are several minerals for which it is important. One is garnet, which is common in some metamorphic rocks and typically displays the dodecahedral shape. Another is amphibole, which forms long thin crystals, and is common in igneous rocks like granite (Figure I5).

Mineral habit is often related to the regular arrangement of the molecules that make up the mineral. Some of the terms that are used to describe habit include bladed, botryoidal (grape-like), dendritic (branched), drusy (an encrustation of minerals), equant (similar in all dimensions), fibrous, platy, prismatic (long and thin), and stubby.

Cleavage and Fracture

Crystal habit is a reflection of how a mineral grows, while cleavage and fracture describe how it breaks. Cleavage and fracture are the most important diagnostic features of many minerals, and often the most difficult to understand and identify. **Cleavage** is what we see when a mineral breaks along a specific plane or planes, while **fracture** is an irregular break. One particularly distinct type of fracture, common in quartz, is called **conchoidal fracture** (top left photograph in Figure 2.3.5). Some minerals tend to cleave along planes at various fixed orientations (Figure 2.3.5), some do not cleave at all (they only fracture). Minerals that have cleavage can also fracture along surfaces that are not parallel to their cleavage planes (Figure 2.3.6).

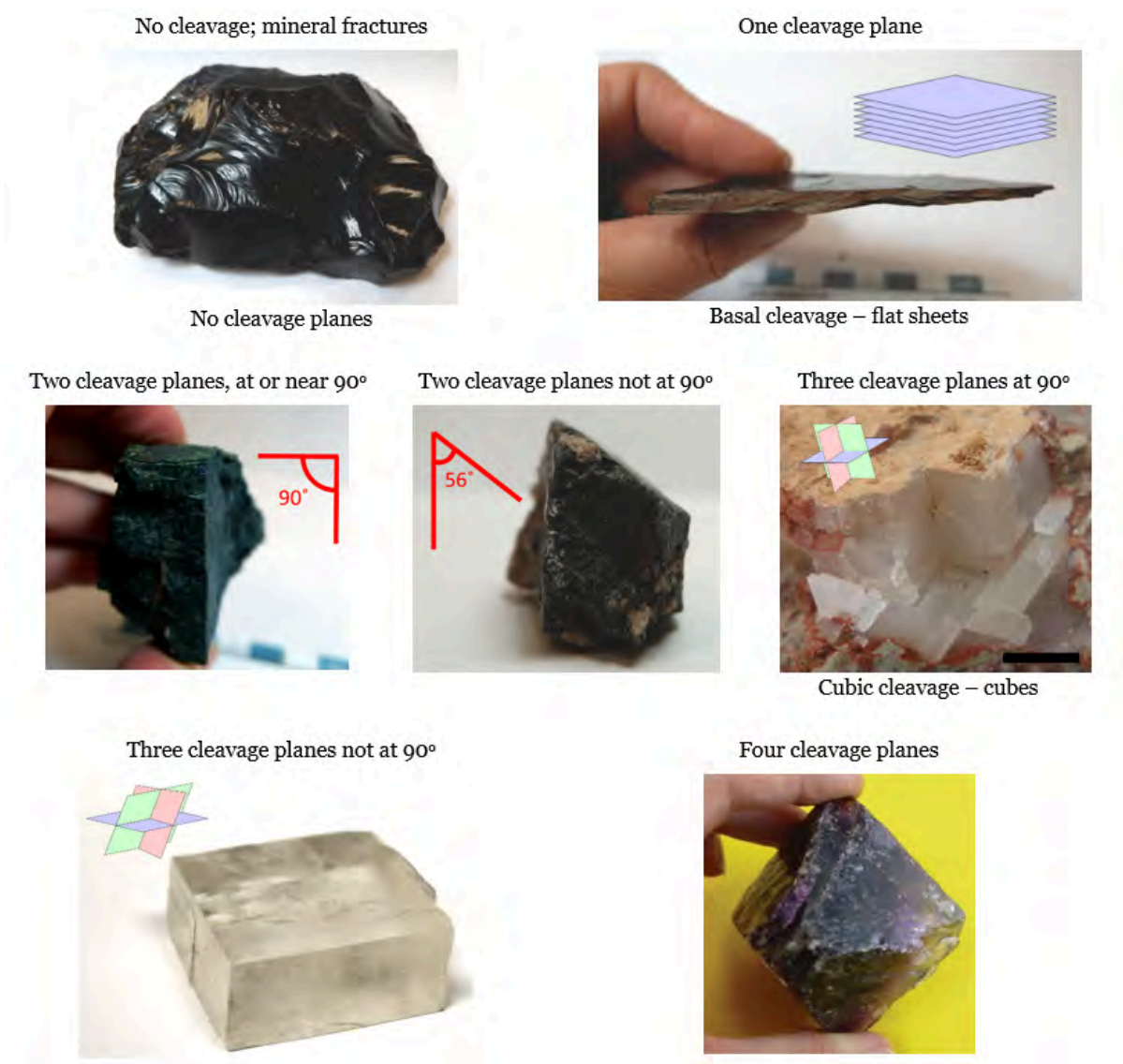


Figure 2.3.5: Common types of cleavage, and conchoidal fracture (top left), with illustrations to indicate cleavage directions and angles between cleavage planes.

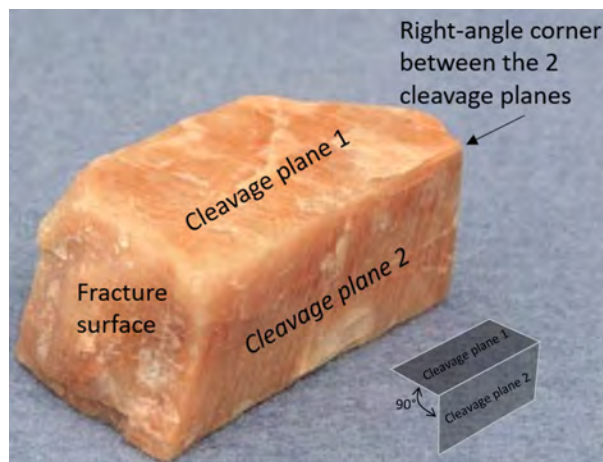


Figure 2.3.6: Cleavage and fracture in potassium feldspar. Feldspar minerals, including plagioclase and potassium feldspar, have two cleavage planes at right-angles to one another. Some feldspar samples may display other flat surfaces, but if you look closely these are fracture surfaces, not cleavage planes.

As we've already discussed, the way that minerals break is determined by their atomic arrangement and specifically by the orientation of weaknesses within the lattice. Graphite and the micas, for example, have cleavage planes parallel to their sheets (Figure 2.1.1), and halite has three cleavage planes parallel to the lattice directions (Figure 2.1.2). Quartz has no cleavage because it has equally strong Si-O bonds in all directions, and feldspar minerals have two cleavages at 90° to each other (Figure 2.3.6). When a mineral has more than one cleavage plane or cleavage direction, it is important to specify the number of cleavage planes and the approximate angle between them.

Tips for recognizing cleavage in mineral samples

There are a few common difficulties that students encounter when learning to recognize and describe cleavage. One of the main difficulties is that cleavage is visible only in individual crystals. Most rocks have small crystals and it's very difficult to see the cleavage within those crystals. Use your hand lens to magnify your field of view, and make sure you have an adequate light source nearby. If crystals are very small, it may not be possible to see cleavage at all.

Some minerals have perfect cleavage, meaning that the cleavage planes are perfectly flat, they glint light back at you as you rotate the mineral around, and are generally easy to recognize. Mica and feldspar minerals commonly have perfect cleavage. Some minerals, on the other hand, have poor cleavage, meaning that the planes are not perfectly flat and may be harder to recognize. Talc is an example of the latter. Talc has one cleavage plane, but with a Mohs hardness of just 1, any recognizable plane is often scratched and uneven, making it more difficult to recognize that talc has cleavage at all!

It can also be easy to misidentify flat crystal faces, or even smooth flat fractures, as cleavage planes. As already noted, crystal faces are related to how a mineral grows while cleavage planes are related to how it breaks. In most minerals cleavage planes and crystal faces do not align with one-another. An exception is halite, which grows in cubic crystals and has cleavage along those same planes (Figure 2.1.2). But this doesn't hold for most minerals. For

example, fluorite forms cubic crystals like those of halite, but it cleaves along planes that differ in orientation from the crystal surfaces. This is illustrated in Figure 2.3.7.

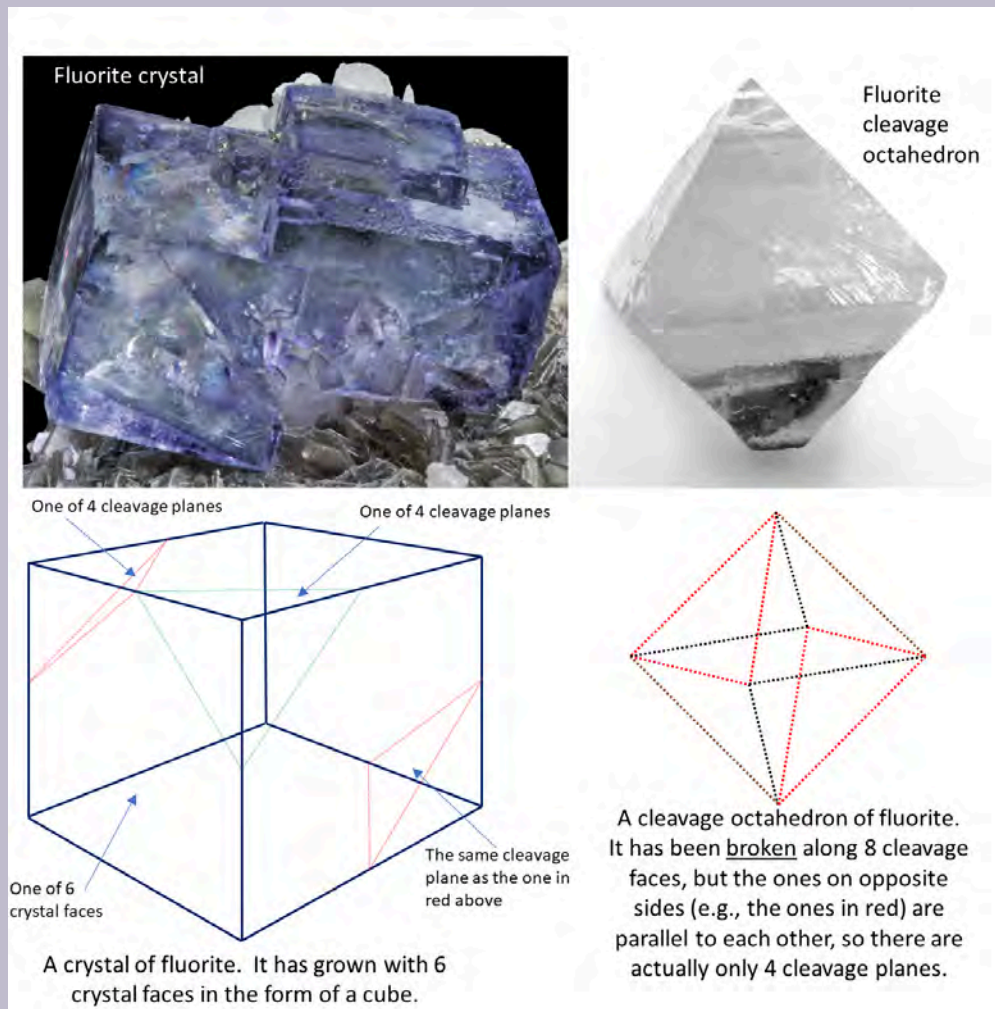


Figure 2.3.7: Crystal faces and cleavage planes in the mineral fluorite. The top-left photo shows a natural crystal of fluorite. It has crystal surfaces but you can see some future cleavage planes inside the crystal. The top-right photo shows what you can create if you take a crystal like the one on the left and carefully break it along its cleavage planes.

Remember that cleavage planes are controlled at the molecular level by the crystal lattice, and so they tend to repeat themselves at different depths throughout the mineral. Planes that are parallel are considered the same direction of cleavage and should only count as one. If you are unsure whether the flat surface you are examining is a cleavage plane, try rotating the mineral under bright light, like a desk lamp. If the mineral has cleavage, you will generally find that all of the cleavage surfaces of a given cleavage direction will glint in the light simultaneously (Figure 2.3.8). Crystal faces will also glint under the light, but do not repeat themselves at depth throughout the mineral. In some minerals, crystal faces have **striations**, as shown by the faint parallel lines on the faces of the quartz crystal in Figure 2.3.4a. Finally, if you have identified more than one cleavage plane or direction

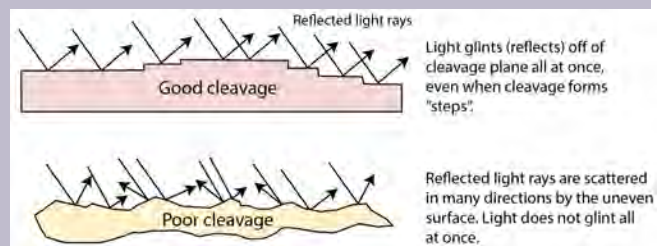


Figure 2.3.8: Examples of a mineral with good (top) and poor (bottom) cleavage planes. [Image description]

within a mineral, it can take practice to describe the angle between those cleavage directions. To help visualize the angle between two cleavage planes try extending the planes using both hands. Place one finger from each hand flat on each cleavage plane, and examine the angle between your fingers. Is the angle between your fingers close to 90°, or definitely not 90°? Remember, for the purposes of this course you do not need to describe cleavage with an exact angle. Geology students have to work hard to understand and recognize cleavage, but it's worth the effort since it is a reliable diagnostic property for most minerals.

Density and Specific Gravity

Density, reported in units of grams per cubic centimetre (g/cm^3), is a useful diagnostic tool in some cases. **Specific gravity** (SG) is a related measure that geologists use to describe the density of a mineral. For the purposes of this course, the specific gravity of a mineral can be described as “low”, “moderate”, or “high”. Most minerals you will encounter in this course like quartz (2.65), feldspar, calcite, amphibole, and mica have “moderate” SG between 2.6 and 3.4, and it would be difficult to tell them apart on the basis of their SG alone. In comparison to these minerals, galena, for example, has distinctly high SG (7.5), while graphite has distinctly low SG (1.75). To determine this qualitatively in the lab, try comparing samples of quartz and galena of roughly the same size by hefting them in your hands. The sample of galena should feel much heavier than the similarly-sized sample of quartz. A limitation of using density (or SG) as a diagnostic tool is that one cannot assess it in minerals that are a small part of a rock that is mostly made up of other minerals.

Other Properties

Several other properties are also useful for identification of some minerals, including:

- Calcite reacts (fizzes vigorously) with dilute acid and will give off bubbles of carbon dioxide.
- Magnetite is strongly magnetic, and some other minerals, like pyrrhotite, are weakly magnetic.
- Halite tastes salty – please do not lick the lab samples; there are other diagnostic properties you should use to identify halite!
- Sphalerite has a pale yellow streak that gives off a sulphurous (rotten egg-like) smell.
- Talc feels soapy to the touch.
- Plagioclase feldspar commonly has striations (Figure 2.3.9).
- Some potassium feldspars have **exsolution lamellae**.

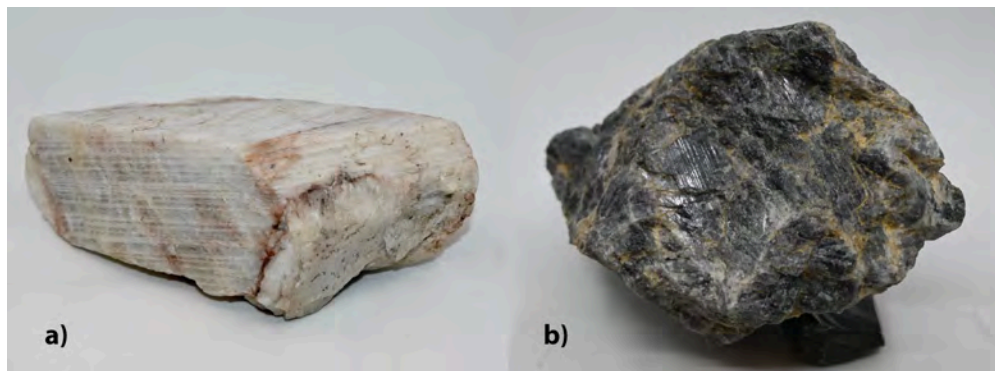


Figure 2.3.9: Striations on light-coloured plagioclase feldspar (albite, a), and dark-coloured plagioclase feldspar (labradorite, b).

Image Descriptions

Figure 2.3.8 image description: As you rotate a mineral with good cleavage (top) under a light source, you will see the light glint back at you all at once, as the rays of light are reflected by the mirror-smooth cleavage plane. Even if the cleavage plane causes the mineral to break along “steps”, you will still see a single glint off of these steps all at once. Minerals with poor cleavage (bottom) do not glint all at once, as their cleavage planes are rough and uneven, causing light rays to scatter. [Return to Figure 2.3.8]

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2.4 Economic Minerals

If you can't grow it, you have to mine it

Anything we can't grow we have to extract from Earth in one way or another. This includes water, of course, our most important resource, but it also includes all the other materials that we need to construct things like roads, dams, and bridges, or manufacture things like plates, toasters, and telephones.

Virtually everything we use every day is made from resources from Earth. For example, let's look at a tablet computer (Figure 2.4.1). Most of the case is made of a plastic known as ABS, which is made from either gas or petroleum. Some tablets have a case made from aluminum. The glass of a touch screen is made mostly from quartz combined with smaller amounts of sodium oxide (Na_2O), sodium carbonate (Na_2CO_3), and calcium oxide (CaO). To make it work as a touch screen, the upper surface is coated with indium tin oxide. When you touch the screen you're actually pushing a thin layer of polycarbonate plastic (made from petroleum) against the coated glass—completing an electrical circuit.

The computer is then able to figure out exactly where you touched the screen. Computer processors are made from silica wafers (more quartz) and also include a significant amount of copper and gold. Gold is used because it is a better conductor than copper and doesn't tarnish the way silver or copper does. Most computers have nickel-metal-hydride (NiMH) batteries, which contain nickel, of course, along with cadmium, cobalt, manganese, aluminum, and the rare-earth elements lanthanum, cerium, neodymium, and praseodymium. The processor and other electronic components are secured to a circuit board, which is a thin layer of fiberglass sandwiched between copper sheets coated with small amounts of tin and lead. Various parts are put together with steel screws that are made of iron and molybdenum.

That's not everything that goes into a tablet computer, but to make just those components we need a pure-silica sand deposit, a salt mine for sodium, a rock quarry for calcium, an oil well, a gas well, an aluminum mine, an iron mine, a manganese mine, a copper-molybdenum-gold mine, a cobalt-nickel mine, a rare-earth element and indium mine, and a source of energy to transport all of the materials, process them, put them together, and finally transport the computer to your house or the store where you bought it.

Case Plastic made from petroleum products. Some have an aluminum base.

Screen Glass made from silica sand with an indium tin oxide coating. The surface layer is made of polycarbonate plastic.



Processor A silica wafer with varying amounts of copper and gold. A typical tablet has about 0.5 g of gold.

Battery A NiMH battery includes nickel, cadmium, lanthanum, cerium, neodymium, praseodymium, cobalt, manganese, and aluminum.

Printed circuit board The electronic components are attached to a printed circuit board made from fiberglass (more silica) plus copper and small amounts of lead and tin.

Figure 2.4.1 The main components of a tablet computer.

Practice Exercise 2.3 Where does it come from?

Look around you and find at least five objects (other than a computer or a phone) that have been made from materials that had to be mined, quarried, or extracted from an oil or gas well. Try to identify the materials involved, and think about where they might have come from. This pen (Figure 2.4.2) is just an example.



Figure 2.4.2 Pieces of a ballpoint pen

You may find it helpful to consult the overview of **ore** and **industrial minerals**, their uses, and notable Canadian sources provided in Appendix 4 to complete this exercise.

See Appendix 2 for Practice Exercise 2.3 answers.

Mining has always been a major part of Canada's economy. Canada has some of the largest mining districts and deposits in the world, and for the past 150 years, we have been one of the world's most important suppliers of metals. Extraction of Earth's resources goes back a long way in Canada. For example, the First Nations of British Columbia extracted obsidian from volcanic regions for tools and traded it up and down the coast. In the 1850s, gold was discovered in central British Columbia, and in the 1890s, even more gold was discovered in the Klondike area of Yukon. These two events were critical to the early development of British Columbia, Yukon, and Alaska.

Canada's mining sector had revenues in the order of \$44 billion in 2017 (Figure 2.4.3). The 4 most valuable commodities were gold, coal, copper and potash, with important amounts from iron, nickel, diamonds, sand and gravel aggregates, stone and zinc. Revenues from the petroleum sector are significantly higher, at over \$100 billion per year.

An ore deposit is a body of rock in which one or more metals have been concentrated to the point of being economically viable for recovery. Some **background** levels of important metals in average rocks are shown on Table 2.4, along with the typical grades necessary to make a viable deposit, and the corresponding concentration factors. Looking at copper, for example, we can see that while average rock has around 40 ppm (parts per million) of copper, a grade of around 10,000 ppm or 1% is necessary to make a viable copper deposit. In other words, copper ore has about 250 times as much copper as typical rock. For the other elements in the list, the concentration factors are much higher. For gold, it's 2,000 times and for silver it's around 10,000 times.

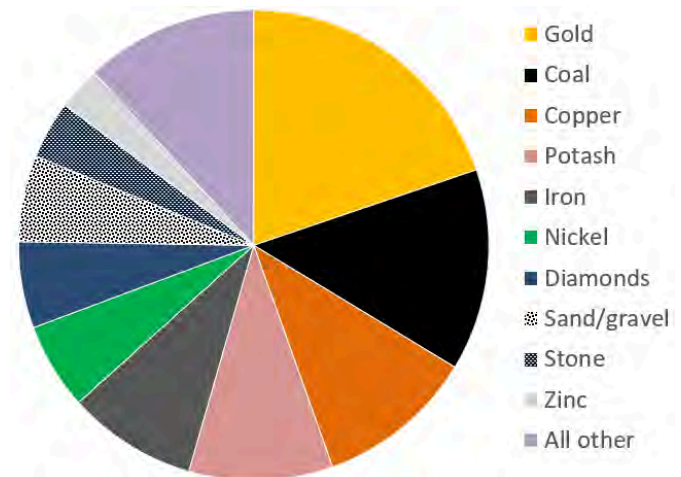


Figure 2.4.3: The value of various Canadian mining sectors in 2017. The total value of these products was about \$44 billion in 2017.

Table 2.4 Typical background and ore levels of some important metals.

Metal	Typical Background Level	Typical Economic Grade*	Concentration Factor
Copper	40 ppm	10,000 ppm (1%)	250 times
Gold	0.003 ppm	6 ppm (0.006%)	2,000 times
Lead	10 ppm	50,000 ppm (5%)	5,000 times
Molybdenum	1 ppm	1,000 ppm (0.1%)	1,000 times
Nickel	25 ppm	20,000 ppm (2%)	800 times
Silver	0.1 ppm	1,000 ppm (0.1%)	10,000 times
Uranium	2 ppm	10,000 ppm (1%)	5,000 times
Zinc	50 ppm	50,000 ppm (5%)	1,000 times

*It's important to note that the economic viability of any deposit depends on a wide range of factors including its grade, size, shape, depth below the surface, and proximity to infrastructure, the current price of the metal, the labour and environmental regulations in the area, and many other factors.

It is clear that some very significant concentration must take place to form a mineable deposit. This concentration may occur during the formation of the host rock, or after the rock forms, through a number of different types of processes. There is a very wide variety of ore-forming processes, and there are hundreds of types of mineral deposits.

Mining and mineral processing

Metal deposits are mined in a variety of different ways depending on their depth, shape, size, and grade. Relatively large deposits that are quite close to the surface and somewhat regular in shape are mined using **open-pit mine** methods (Figure 2.4.4). Creating a giant hole in the ground is generally cheaper than making an underground mine, but it is also less precise, so it is necessary to mine a lot of waste rock along with the ore. Relatively deep deposits or those with elongated or irregular shapes are typically mined from underground with deep vertical **shafts**, **declines** (sloped tunnels), and **levels** (horizontal tunnels) (Figure 2.4.4). In this way, it is possible to focus the mining on the ore body itself. However, with relatively large ore bodies, it may be necessary to leave some pillars to hold up the roof.

In many cases, the near-surface part of an ore body is mined with an open pit, while the deeper parts are mined underground (Figure 2.4.4).

A typical metal deposit might contain a few percent of ore minerals (e.g., chalcopyrite or sphalerite), mixed with the minerals of the original rock (e.g., quartz or feldspar). Other sulphide minerals are commonly present within the ore, especially pyrite.

When ore is processed (typically very close to the mine), it is ground to a fine powder and the ore minerals are physically separated from the rest of the rock to make a **concentrate**. The rest of the rock is known as **tailings**. It comes out of the concentrator as a wet slurry and must be stored near the mine, in most cases, in a tailings pond.

The tailings pond at the Myra Falls Mine on Vancouver Island and the settling ponds for waste water from the concentrator are shown in Figure 2.4.5. The tailings are contained by an embankment. Also visible in the foreground is a pile of waste rock, which is non-ore rock that was mined in order to access the ore. Although this waste rock contains little or no ore minerals, at many mines it contains up to a few percent pyrite. The tailings and the waste rock at most mines are an environmental liability because they contain pyrite plus small amounts of ore minerals. When pyrite is exposed to oxygen and water, it generates sulphuric acid—also known as **acid rock drainage** (ARD). Acidity itself is a problem to the environment, but because the ore elements, such as copper or lead, are more soluble in acidic water than neutral water, ARD is also typically quite rich in metals, many of which are toxic.

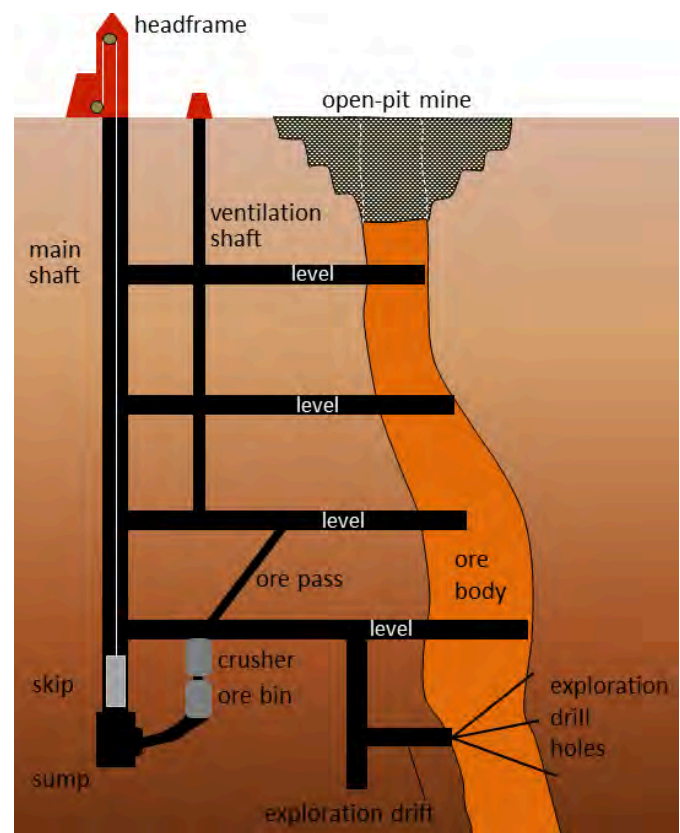


Figure 2.4.4: Schematic cross-section of a typical underground mine. [Image Description]



Figure 2.4.5: The tailings pond at the Myra Falls Mine on Vancouver Island. The dry rock in the middle of the image is waste rock. Myra Creek flows between the tailings pond and the headframe. The settling ponds (right) are used for processing water from the concentrator.

Most mines have concentrators on site because it is relatively simple to separate ore minerals from non-ore minerals and this significantly reduces the costs and other implications of transportation. But separation of ore minerals is only the preliminary stage of metal refinement, for most metals the second stage involves separating the actual elements within the ore minerals. For example, the most common ore of copper is chalcopyrite (CuFeS_2). The copper needs to be separated from the iron and sulphur to make copper metal and that involves complicated and very energy-intensive processes that are done at **smelters** or other types of refineries. Because of their cost and the economies of scale, there are far fewer refineries than there are mines.

There are several metal refineries (including smelters) in Canada; some examples are the aluminum refinery in Kitimat, B.C. (which uses ore from overseas); the lead-zinc smelter in Trail, B.C.; the nickel smelter at Thompson, Manitoba; numerous steel smelters in Ontario, along with several other refining operations for nickel, copper, zinc, and uranium; aluminum refineries in Quebec; and a lead smelter in New Brunswick.

Practice Exercise 2.4 Sources of important lighter metals

When we think of the manufacture of consumer products, plastics and the heavy metals (copper, iron, lead, zinc) easily come to mind, but we often forget about some of the lighter metals and non-metals that are important. Consider the following elements and determine their sources. Answers for all of these except magnesium are given above. See if you can figure out a likely mineral source of magnesium.

What are the sources of the following elements?

Element	Source(s)
Silicon	
Calcium	
Sodium	
Potassium	
Magnesium	

See Appendix 2 for Practice Exercise 2.4 answers.

Image Descriptions

Figure 2.4.4 image description: An open-pit mine is dug to access the ore that is near the surface. For ore farther down, an underground mine will be constructed to access the ore. This diagram shows the main shaft (a large vertical tunnel) with four levels (horizontal tunnels) connected to it. The levels run from the main shaft into the ore body. A ventilation shaft runs up through the four levels in between the main shaft and the ore for air circulation.

[Return to Figure 2.4.4]

Media Attributions

- Figure 2.4.1: “Ipad Air” © Zach Vega. Adapted by Steven Earle. CC BY-SA.
- Figure 2.4.2: “Ballpoint pen parts” by unknown. CC BY-SA.
- Figure 2.4.3: © Steven Earle. CC BY. Based on data from Natural Resources Canada.
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Lab 2 Exercises

The exercises below will guide you through the 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.

Part I: Cleavage and Fracture

The minerals in this part include a mix of silicate and non-silicate minerals found in Mineral Kits 1 and 2.

1. Do the following samples exhibit cleavage or fracture? If the sample exhibits cleavage, specify the number of cleavage planes and approximate angle between them.

Sample	M226S	M225S	M1S	M251S	M111S	M223S	M131S
Cleavage or fracture							

2. What is the difference between a crystal face and a cleavage plane?

3. Look at sample M202(S). This is a good example of a mineral with 2 cleavages at almost right angles to each other. Select two other samples that also demonstrate this type of cleavage.

4. Now select a sample which also appears to have a least two cleavages but with the cleavage surfaces oblique (at some angle other than 90°) to each other.

5. Which sample has one (perfect) cleavage only?

6. Look at the fractured surface of sample M225. Try to describe this surface (rough? curved? splintery? etc.). This is an example of **conchoidal fracture**. Does this sample exhibit any cleavage?

7. What other sample also exhibits conchoidal fracture?

Part II: Non-silicate Minerals

Certain physical properties are diagnostic for a particular mineral. These diagnostic properties will help you distinguish a particular mineral. The questions below will help you identify these diagnostic properties. Remember: you must be able to identify all the physical properties of each mineral, not just the diagnostic properties. You should also know the group to which each mineral belongs (e.g., sulphides, oxides).

Mineral Group: Native Elements

Sample M21

Mineral name:

1. Does this mineral exhibit cleavage? _____ If yes, describe the cleavage: _____
 2. What is the approximate hardness of the sample on the Mohs scale of hardness? _____
 3. What is the specific gravity of the sample (high, medium or low)?
-

4. Describe the lustre of this mineral: _____
 5. Describe the streak: _____
 6. What is a diagnostic property of graphite?
-

Mineral Group: Oxides

Sample M11/M12

Mineral name:

Sample M51/M52

Mineral name:

Sample M53

Mineral name:

1. Do any of these samples exhibit cleavage? _____
 2. If yes, which one? Describe the cleavage: _____
 3. Looking at samples M51/52 and M53, what is the lustre of each sample?
-

Sample M51/M52

Lustre:

Sample M53

Lustre:

4. Compare the streak of each sample. Describe what you see:

5. Do any of the samples attract a magnet? Which one? _____

6. What is the diagnostic property of magnetite?

7. What is the diagnostic property of hematite?

Mineral Group: Carbonates

Sample M251	Mineral name:
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1. Does this mineral exhibit cleavage? _____ If so, describe the cleavage: _____

2. What is the approximate hardness of the sample on the Mohs scale of hardness? _____

3. Describe the lustre of this mineral.

4. Does the sample react to a drop of HCl? _____

5. What is a diagnostic property of calcite?

Mineral Group: Sulphides

Sample M41/M42	Mineral name:
Sample M31	Mineral name:
Sample M1	Mineral name:
Sample M141	Mineral name:

1. What do all these minerals have in common?

2. Test all four minerals for hardness. Do any of these minerals scratch the glass plate? _____

3. Which is harder pyrite or chalcopyrite? _____

4. Describe the streak of sphalerite:

5. What is the lustre of pyrite, chalcopyrite and galena? _____

6. What is the lustre of sphalerite? _____

7. Which mineral has the highest specific gravity? _____

8. Do you see cleavage faces on any of these minerals? _____

9. How can you tell pyrite from chalcopyrite?

10. What is a diagnostic property of galena?

11. What is a diagnostic property of sphalerite?

12. Many sulphide minerals contain valuable ore metals that are used to manufacture the objects and technology you use every day. Using Appendix 4 as a guide, complete the table below.

Sample #	Mineral Name	Mineral Formula	Ore Metal
M1			
M31			
M141			

13. Name two economic uses for the mineral galena.

14. Explain the steps involved in extracting galena from an ore deposit and eventually producing pure lead metal.

Mineral Group: Sulphates

Sample M241

Mineral name:

1. What is the approximate hardness of this mineral? _____
 2. Describe the lustre of this mineral: _____
 3. What is the diagnostic property of gypsum?
-

4. What is the main economic use for gypsum and where is the world's most productive gypsum mining area?

Mineral Group: Halides

Sample M231	Mineral name:
Sample M261	Mineral name:
Sample M262	Mineral name:

1. Describe the cleavage of each sample.

Sample M231	Cleavage:
Sample M261	Cleavage:
Sample M262	Cleavage:

2. What is the approximate hardness of the two minerals on the Mohs scale of hardness?

Halite:	Fluorite:
----------------	------------------

3. Compare the specific gravity of the two minerals. Which is higher? _____
 4. What is a diagnostic property of halite?
-

5. What is a diagnostic property of fluorite?

6. How can you distinguish fluorite from quartz? Quartz is a silicate mineral that will be studied in Lab 3.

Summary

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

Section	Summary
2.1 Bonding and Lattices	The main types of bonding in minerals are ionic bonding (electrons transferred) and covalent bonding (electrons shared). Some minerals have metallic bonding or other forms of weak bonding. Minerals form in specific three-dimensional lattices, and the nature of the lattices and the type of bonding within them have important implications for mineral properties.
2.2 Mineral Groups	Minerals are grouped according to the anion part of their formula, with some common types being oxides, sulphides, sulphates, halides, carbonates, phosphates, silicates, and native minerals.
2.3 Mineral Properties	Some of the important properties for mineral identification include hardness, cleavage/fracture, density, lustre, colour, and streak colour. It's critical to be able to recognize these properties in order to be able to identify minerals.
2.4 Economic Minerals	Geological resources are critical to our way of life and important to the Canadian economy. Gold, coal, iron, copper, nickel, and potash are Canada's most valuable mined commodities. The concentrations of metals in mineral deposits are typically several thousand times higher than those in average rocks, and such concentrations only form through specific geological processes. Mining involves both surface and underground methods, but in either case, rock is brought to surface that can react with water and oxygen to produce acid rock drainage and metal contamination.
Lab 2 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.
