
Chapter 5 Weathering and Soil

Learning Objectives

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

- Explain why rocks formed at depth in the crust are susceptible to weathering at the surface.
- Describe the main processes of mechanical weathering, and the types of materials that are produced when mechanical weathering predominates.
- Describe the main processes of chemical weathering, and the products of chemical weathering of minerals such as feldspar, ferromagnesian silicates, and calcite.
- Explain the type of weathering processes that are likely to have taken place to produce a particular sediment deposit.
- Discuss the relationships between weathering and soil formation, and the origins of soil horizons and some of the different types of soil.
- Describe and explain the distribution of some of the important soil types in Canada.
- Explain the geological carbon cycle, and how variations in rates of weathering can lead to climate change.



Figure 5.01 The Hoodoos, near Drumheller, Alberta, have formed from the differential weathering of sedimentary rock that was buried beneath other rock since about 100 Ma, but has now been exposed for several thousand years.

Weathering is what takes place when a body of rock is exposed to the “weather”—in other words, to the forces and conditions that exist at Earth’s surface. With the exception of volcanic rocks and some sedimentary rocks, most rocks are formed at some depth within the crust. There they experience relatively constant temperature, high pressure, no contact with the atmosphere, and little or no moving water. Once a rock is exposed at the surface, which is what happens when the overlying rock is eroded away, conditions change dramatically. Temperatures vary widely, there is much less pressure, oxygen and other gases are plentiful, and in most climates, water is abundant (Figure 5.01).

Weathering includes two main processes that are quite different. One is the mechanical breakdown of rock into smaller fragments, and the other is the chemical change of the minerals within the rock to forms that are stable in the surface environment. Mechanical weathering provides fresh surfaces for attack by chemical processes, and chemical weathering weakens the rock so that it is more susceptible to mechanical weathering. Together, these processes create two very important products, one being the sedimentary clasts and ions in solution that can eventually become sedimentary rock, and the other being the soil that is necessary for our existence on Earth.

The various processes related to uplift and weathering are summarized in the rock cycle in Figure 5.02.

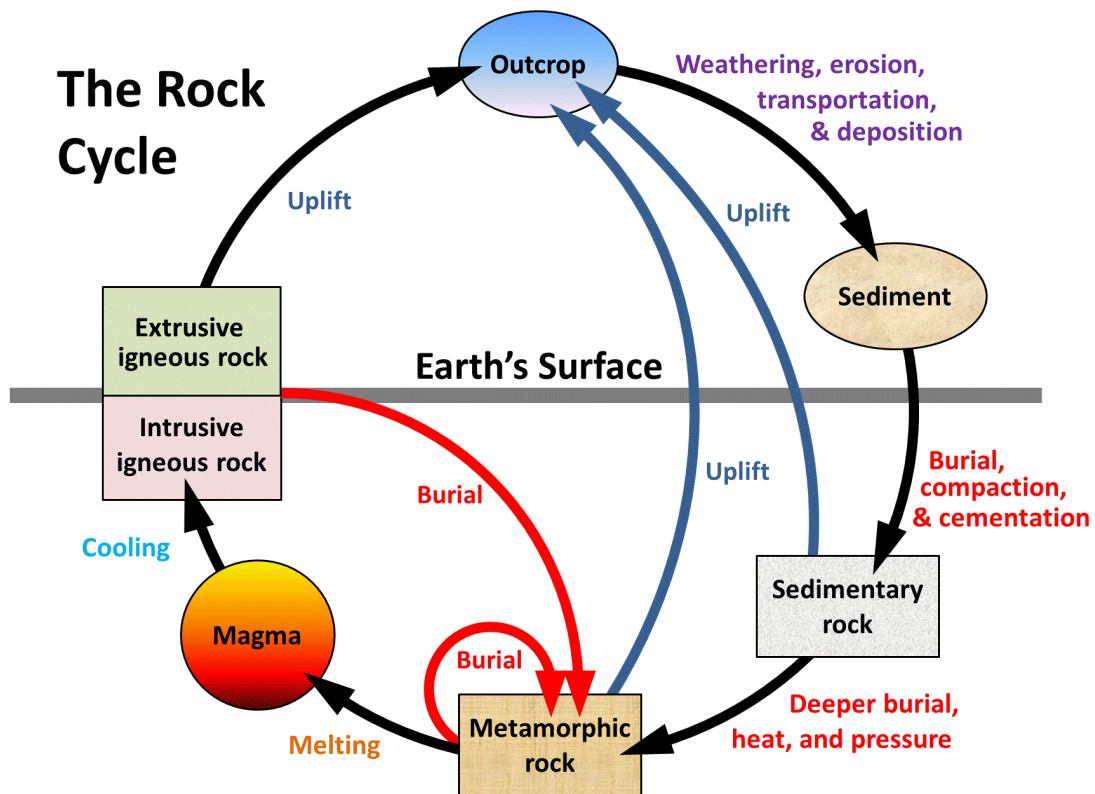


Figure 5.02 Weathering can take place once a rock is exposed at surface by uplift and the removal of the overlying rock. [\[Image Description\]](#)

Image Descriptions

Figure 5.02 image description: “The Rock Cycle.” The rock cycle takes place both above and below the earth’s surface. The rock deepest beneath the earth’s surface and under extreme heat and pressure is metamorphic rock. This metamorphic rock can melt and become magma. When magma cools, if below the earth’s surface it becomes “intrusive igneous rock.” If magma cools above the earth’s surface it is “extrusive igneous rock” and becomes part of the outcrop. The outcrop is subject to weathering and erosion, and can be moved and redeposited around the earth by forces such as water and wind. As the outcrop is eroded, it becomes sediment which can be buried, compacted, and cemented beneath the earth’s surface to become sedimentary rock. As sedimentary rock gets buried deeper and comes under increased heat and pressure, it returns to its original state as metamorphic rock. Rocks in the rock cycle do not always make a complete loop. It is possible for sedimentary rock to be uplifted back above the Earth’s surface and for intrusive and extrusive igneous rock to be reburied and become metamorphic rock. [\[Return to Figure 5.02\]](#)

Media Attributions

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5.1 Mechanical Weathering

Intrusive igneous rocks form at depths of several hundreds of metres to several tens of kilometres. Sediments are turned into sedimentary rocks only when they are buried by other sediments to depths in excess of several hundreds of metres. Most metamorphic rocks are formed at depths of kilometres to tens of kilometres. Weathering cannot even begin until these rocks are uplifted through various processes of mountain building—most of which are related to plate tectonics—and the overlying material has been eroded away and the rock is exposed as an **outcrop**.¹

The most important agents of mechanical weathering are:

- The decrease in pressure that results from removal of overlying rock
- Freezing and thawing of water in cracks in the rock
- Formation of salt crystals within the rock
- Cracking from plant roots and removal of material by burrowing animals

When a mass of rock is exposed by weathering and removal of the overlying rock, there is a decrease in the confining pressure on the rock, and the rock expands. This unloading promotes cracking of the rock, known as **exfoliation**, as shown in the granitic rock in Figure 5.1.1., which, in places, is peeling off like the layers of an onion.

1. To a geologist, an outcrop is an exposure of bedrock, the solid rock of the crust.



Figure 5.1.1 Exfoliation fractures in granitic rock exposed on the side of the Coquihalla Highway north of Hope, B.C.



Figure 5.1.2 Exfoliation of slate at a road cut in the Columbia Mountains west of Golden, B.C.

Granitic rock tends to exfoliate parallel to the exposed surface because the rock is typically homogenous,

and it doesn't have predetermined planes along which it must fracture. Sedimentary and metamorphic rocks, on the other hand, tend to exfoliate along predetermined planes (Figure 5.1.2).

Frost wedging is the process by which water seeps into cracks in a rock, expands on freezing, and thus enlarges the cracks (Figure 5.1.3). The effectiveness of frost wedging is related to the frequency of freezing and thawing. Frost wedging is most effective in a climate like Canada's. In warm areas where freezing is infrequent, in very cold areas where thawing is infrequent, or in very dry areas, where there is little water to seep into cracks, the role of frost wedging is limited. If you are ever hiking in the mountains you might hear the effects of frost wedging when the Sun warms a steep rocky slope and the fragments of rock that were pried away from the surface by freezing the night before are released as that ice melts.

In many parts of Canada, the transition between freezing nighttime temperatures and thawing daytime temperatures is frequent — tens to hundreds of times a year. Even in warm coastal areas of southern B.C., freezing and thawing transitions are common at higher elevations. A common feature in areas of effective frost wedging is a **talus slope**—a fan-shaped deposit of fragments removed by frost wedging from the steep rocky slopes above (Figure 5.1.4).

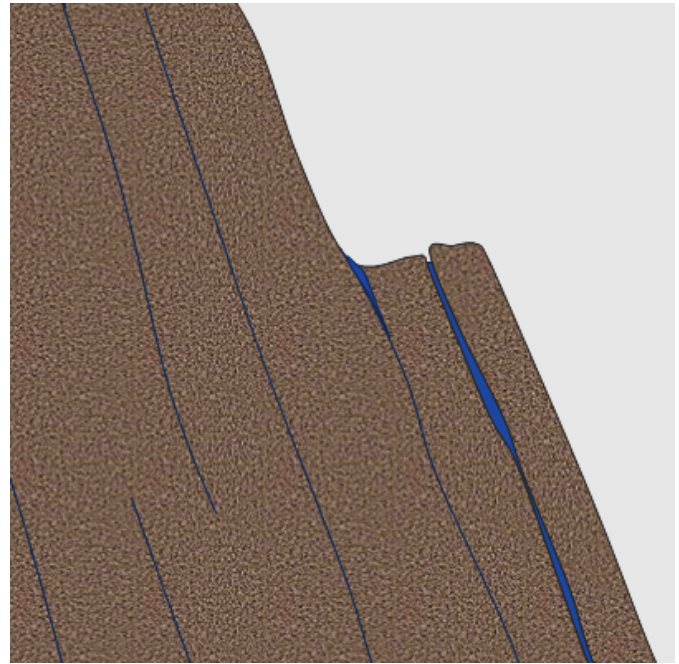


Figure 5.1.3 The process of frost wedging on a steep slope. Water gets into fractures and then freezes, expanding the fracture a little. When the water thaws it seeps a little farther into the expanded crack. The process is repeated many times, and eventually a piece of rock will be wedged away.



Figure 5.1.4 An area with very effective frost-wedging near Keremeos, B.C. The fragments that have been wedged away from the cliffs above have accumulated in a talus deposit at the base of the slope. The rocks in this area have quite varied colours, and those are reflected in the colours of the talus.

A related process, frost heaving, takes place within unconsolidated materials on gentle slopes. In this case, water in the soil freezes and expands, pushing the overlying material up. Frost heaving is responsible for winter damage to roads all over North America.

When salt water seeps into rocks and then evaporates on a hot sunny day, salt crystals grow within cracks and pores in the rock. The growth of these crystals exerts pressure on the rock and can push grains apart, causing the rock to weaken and break. There are many examples of this on the rocky shorelines of Vancouver Island and the Gulf Islands, where sandstone outcrops are common and salty seawater is readily available (Figure 5.1.5). Salt weathering can also occur away from the coast, because most environments have some salt in them.



Figure 5.1.5 Honeycomb weathering of sandstone on Gabriola Island, B.C. The holes are caused by crystallization of salt within rock pores, and the seemingly regular pattern is related to the original roughness of the surface. It's a positive-feedback process because the holes collect salt water at high tide, and so the effect is accentuated around existing holes. This type of weathering is most pronounced on south-facing sunny exposures

The effects of plants and animals are significant in mechanical weathering. Roots can force their way into even the tiniest cracks, and then they exert tremendous pressure on the rocks as they grow, widening the cracks and breaking the rock (Figure 5.1.6). Although animals do not normally burrow through solid rock, they can excavate and remove huge volumes of soil, and thus expose the rock to weathering by other mechanisms.



Figure 5.1.6 Conifers growing on granitic rocks at The Lions, near Vancouver, B.C.

Mechanical weathering is greatly facilitated by erosion, which is the removal of weathering products, allowing for the exposure of more rock for weathering. A good example of this is shown in Figure 5.1.4. On the steep rock faces at the top of the cliff, rock fragments have been broken off by ice wedging, and then removed by gravity. This is a form of mass wasting, which is discussed in more detail in Chapter 15. Other important agents of erosion that also have the effect of removing the products of weathering include water in streams (Chapter 13), glacial ice (Chapter 16), and waves on the coasts (Chapter 17).

Exercise 5.1 Mechanical weathering

This photo shows granitic rock at the top of Stawamus Chief near Squamish, B.C. Identify the mechanical weathering processes that you can see taking place, or you think probably take place at this location.



Figure 5.1.7

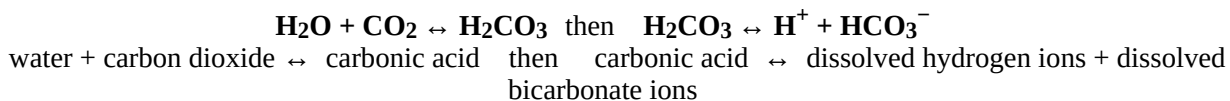
See Appendix 3 for [Exercise 5.1 answers](#).

Media Attributions

- Figures 5.1.1, 5.1.2, 5.1.3, 5.1.4, 5.1.5, 5.1.6, 5.1.7: © Steven Earle. CC BY.

5.2 Chemical Weathering

Chemical weathering results from chemical changes to minerals that become unstable when they are exposed to surface conditions. The kinds of changes that take place are highly specific to the mineral and the environmental conditions. Some minerals, like quartz, are virtually unaffected by chemical weathering, while others, like feldspar, are easily altered. In general, the degree of chemical weathering is greatest in warm and wet climates, and least in cold and dry climates. The important characteristics of surface conditions that lead to chemical weathering are the presence of water (in the air and on the ground surface), the abundance of oxygen, and the presence of carbon dioxide, which produces weak carbonic acid when combined with water. That process, which is fundamental to most chemical weathering, can be shown as follows:



Yikes! Chemical formulas

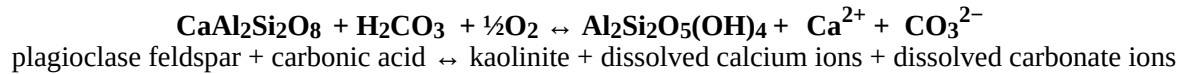
Lots of people seize up when they are asked to read chemical or mathematical formulas. It's OK, you don't necessarily have to! If you don't like the formulas just read the text underneath them. In time you may get used to reading the formulas.

The double-ended arrow " \leftrightarrow " indicates that the reaction can go either way, but for our purposes these reactions are going towards the right.

Here we have water (e.g., as rain) plus carbon dioxide in the atmosphere, combining to create carbonic acid. Then carbonic acid dissociates (comes apart) to form hydrogen and bicarbonate ions. The amount of CO_2 in the air is enough to make weak carbonic acid. There is typically much more CO_2 in the soil, so water that percolates through the soil can become more acidic. In either case, this acidic water is a critical to chemical weathering.

In some types of chemical weathering the original mineral becomes altered to a different mineral. For example, feldspar is altered—by **hydrolysis**—to form **clay minerals** plus some ions in solution. In other cases the minerals dissolve completely, and their components go into solution. For example, calcite (CaCO_3) is soluble in acidic solutions.

The hydrolysis of feldspar can be written like this:



This reaction shows calcium-bearing plagioclase feldspar, but similar reactions could also be written for sodium or potassium feldspars. In this case, we end up with the mineral kaolinite, along with calcium and carbonate ions in solution. Those ions can eventually combine (probably in the ocean) to form the mineral calcite. The hydrolysis of feldspar to clay is illustrated in Figure 5.2.1, which shows two images of the same granitic rock, a recently broken fresh surface on the left and a clay-altered weathered surface on the right. Other silicate minerals can also go through hydrolysis, although the end results will be a little different. For example, pyroxene can be converted to the clay minerals chlorite or smectite, and olivine can be converted to the clay mineral serpentine.

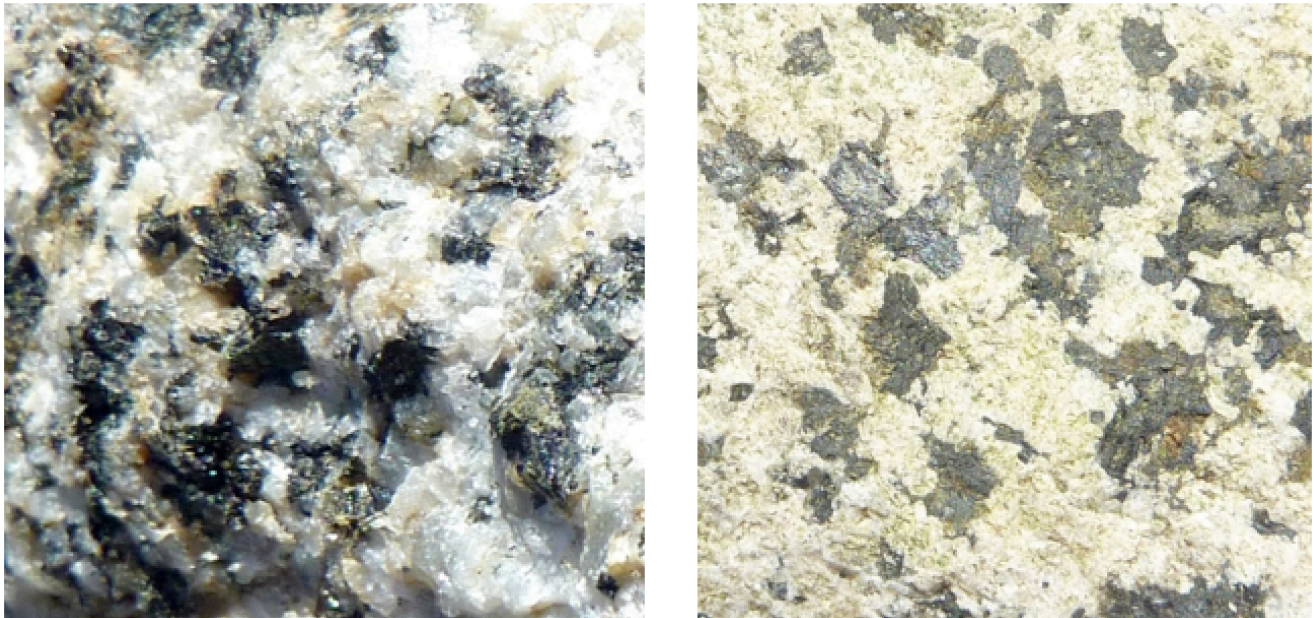
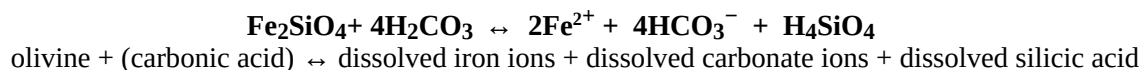
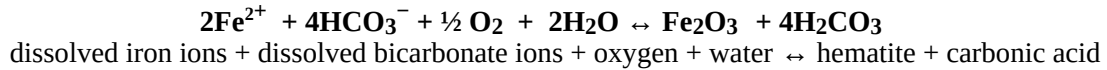


Figure 5.2.1 Unweathered (left) and weathered (right) surfaces of the same piece of granitic rock. On the unweathered surfaces the feldspars are still fresh and glassy-looking. On the weathered surface much of the feldspar has been altered to the chalky-looking clay mineral kaolinite.

Oxidation is another very important chemical weathering process. The oxidation of the iron in a ferromagnesian silicate starts with the dissolution of the iron. For olivine, the process looks like this, where olivine in the presence of carbonic acid is converted to dissolved iron, carbonate, and silicic acid:



But in the presence of oxygen and carbonic acid, the dissolved iron is then quickly converted to the mineral hematite:

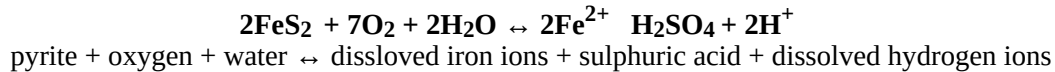


The equation shown here is for olivine, but it could apply to almost any other ferromagnesian silicate, including pyroxene, amphibole, or biotite. Iron in the sulphide minerals (e.g., pyrite) can also be oxidized in this way. And the mineral hematite is not the only possible end result, as there is a wide range of iron oxide minerals that can form in this way. The results of this process are illustrated in Figure 5.2.2, which shows a granitic rock in which some of the biotite and amphibole have been altered to form the iron oxide mineral limonite.



Figure 5.2.2 A granitic rock containing biotite and amphibole which have been altered near to the rock's surface to limonite, which is a mixture of iron oxide minerals.

A special type of oxidation takes place in areas where the rocks have elevated levels of sulphide minerals, especially pyrite (FeS_2). Pyrite reacts with water and oxygen to form sulphuric acid, as follows:



The runoff from areas where this process is taking place is known as **acid rock drainage** (ARD), and even a rock with 1% or 2% pyrite can produce significant ARD. Some of the worst examples of ARD are at metal mine sites, especially where pyrite-bearing rock and waste material have been mined from deep underground and then piled up and left exposed to water and oxygen. One example of that is the Mt. Washington Mine near Courtenay on Vancouver Island (Figure 5.2.3), but there are many similar sites across Canada and around the world.

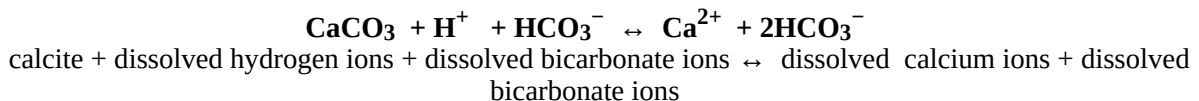


Figure 5.2.3 Exposed oxidizing and acid generating rocks and mine waste at the abandoned Mt. Washington Mine, B.C. (left), and an example of acid drainage downstream from the mine site (right).

At many ARD sites, the pH of the runoff water is less than 4 (very acidic). Under these conditions, metals such as copper, zinc, and lead are quite soluble, and this can lead to toxicity for aquatic and other organisms. For many years, the river downstream from the Mt. Washington Mine had so much dissolved copper in it that it was toxic to salmon. Remediation work has since been carried out at the mine and the situation has improved.

The hydrolysis of feldspar and other silicate minerals and the oxidation of iron in ferromagnesian silicates all serve to create rocks that are softer and weaker than they were to begin with, and thus more susceptible to mechanical weathering.

The weathering reactions that we've discussed so far involved the transformation of one mineral to another mineral (e.g., feldspar to clay), and the release of some ions in solution (e.g., Ca^{2+} or Fe^{2+}). Some weathering processes involve the complete dissolution of a mineral. Calcite, for example, will dissolve in weak acid, to produce calcium and bicarbonate ions. The equation is as follows:



Calcite is the major component of limestone (typically more than 95%), and under surface conditions, limestone can dissolve completely, as shown in Figure 5.2.4. Limestone also dissolves at relatively shallow depths underground, forming limestone caves. This is discussed in more detail in Chapter 14, where we look at **groundwater**.



Figure 5.2.4 A limestone outcrop on Quadra Island, B.C. The limestone, which is primarily made up of the mineral calcite, has been dissolved to different degrees in different areas because of compositional differences. The buff-coloured bands are chert, which stands out because it is not soluble.

Exercise 5.2 Chemical Weathering

The main processes of chemical weathering are hydrolysis, oxidation, and dissolution. Indicate which process is primarily involved during each of the following chemical weathering changes:

1. Pyrite to hematite
2. Calcite to calcium and bicarbonate ions
3. Feldspar to clay
4. Olivine to serpentine

See Appendix 3 for [Exercise 5.2 answers](#).

Media Attributions

- Figure 5.2.1, 5.2.2, 5.2.3, 5.2.4: © Steven Earle. CC BY.

5.3 The Products of Weathering and Erosion

The products of weathering and erosion are the unconsolidated materials that we find around us on slopes, beneath, beside and on top of glaciers, in stream valleys, on beaches, and in deserts. The nature of these materials—their composition, size, degree of sorting, and degree of rounding—is determined by the type of rock that is being weathered, the nature of the weathering, the erosion and transportation processes, and the climate.

In addition to these solid sediments, the other important products of weathering are several different types of ions in solution.

A summary of the weathering products of some of the common minerals present in rocks is provided in Table 5.1. In addition to the weathering products listed in the table, most of the larger fragments—larger than sand grains—that make up sediments will be pieces of rock as opposed to individual minerals.

Table 5.1 A list of the typical weathering products of some of the minerals in common rocks

Common Mineral	Typical Weathering Products
Quartz	Quartz as sand grains
Feldspar	Clay minerals plus potassium, sodium, and calcium in solution
Biotite and amphibole	Chlorite plus iron and magnesium in solution
Pyroxene and olivine	Serpentine plus iron and magnesium in solution
Calcite	Calcium and carbonate in solution
Pyrite	Iron oxide minerals plus iron in solution and sulphuric acid

Some examples of the products of weathering are shown in Figure 5.3.1. They range widely in size and shape depending on the processes involved in their transportation. If and when deposits like these are turned into sedimentary rocks, the textures of those rocks will vary significantly. Importantly, when we describe sedimentary rocks that formed millions of years in the past, we can use those properties to make inferences about the conditions that existed during their formation.



Boulders in a talus deposit at Keremeos. All are angular fragments from the same rock source.



Pebbles on a beach in Victoria. All are rounded fragments of rock from different sources.



Sand from a beach at Gabriola. Most are angular quartz grains, some are fragments of rock.



Sand from a dune in Utah. All are rounded quartz grains.

Figure 5.3.1 Products of weathering and erosion formed under different conditions. [\[Image Description\]](#)

We'll talk more about the nature and interpretation of sediments and sedimentary rocks in Chapter 6, but it's worth considering here why the sand-sized sediments shown in Figure 5.3.1 are so strongly dominated by the mineral quartz, even though quartz makes up less than 20% of Earth's crust. The explanation is that quartz is highly resistant to the types of weathering that occur at Earth's surface. It is not affected by weak acids or the presence of oxygen. This makes it unique among the minerals that are common in igneous rocks. Quartz is also very hard, and doesn't have cleavage, so it is resistant to mechanical erosion.

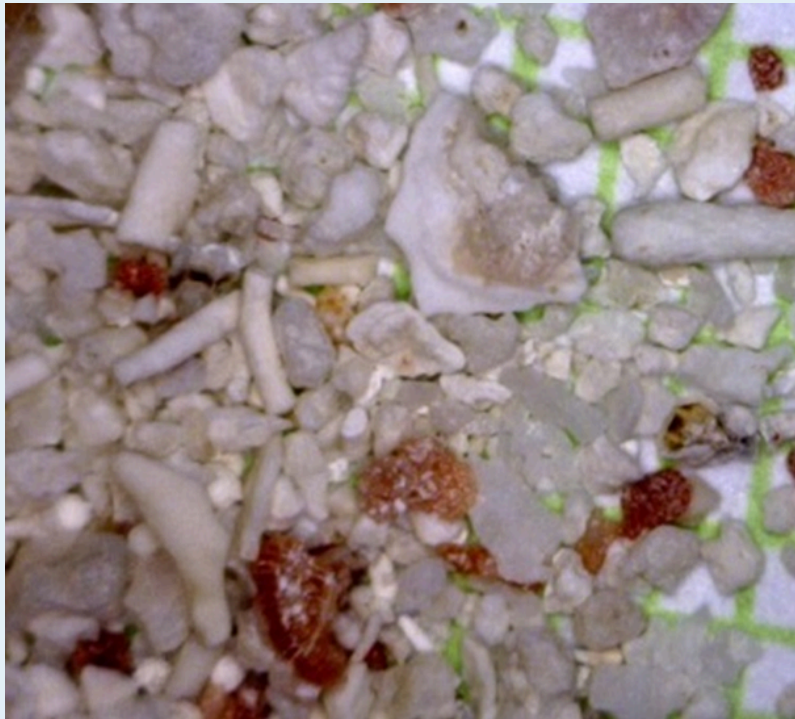
So when a rock like granite is subject to chemical weathering the feldspar and the ferromagnesian silicates get converted to clays and dissolved ions such as: Ca^{2+} , Na^+ , K^+ , Fe^{2+} , Mg^{2+} , and H_4SiO_4 , but the quartz is resistant to those processes and remains intact. The clay gradually gets eroded away, then the rock breaks apart leaving lots of grains of quartz. In other words, quartz, clay minerals, and dissolved ions are the most common products of weathering. Quartz and some of the clay minerals tend to form sedimentary deposits on and at the edges of continents, while the rest of the clay minerals and the dissolved ions tend to be washed out into the oceans to form sediments on the sea floor.

Exercise 5.3 Describing the weathering origins of sand

In the left side of the following table, a number of different sands are pictured and described. Describe some of the important weathering processes that might have led to the development of these sands.

See Appendix 3 for [Exercise 5.3 answers](#).

Image



Description and Location

Fragments of coral, algae, and urchin from a shallow water area (roughly 2 metres deep) near a reef in Belize. The grain diameters are between 0.1 and 1 millimetres.



Angular quartz and rock fragments from a glacial stream deposit near Osoyoos, B.C. The grain diameters are between 0.25 and 0.5 millimetres.


Image	Description and Location
	<p>Rounded grains of olivine (green) and volcanic glass (black) from a beach on the big island of Hawaii. The grains are approximately 1 millimetre across.</p>

Image Descriptions

Figure 5.3.1 image description: Examples of weathering and erosion.

1. Boulders in a talus deposit at Keremeos. All are angular fragments from the same rock source.
2. Pebbles on a beach in Victoria. All are rounded fragments of rock from different sources.
3. Sand from a beach at Gabriola Island. most are angular quartz grains, some are sand-sized fragments of rock.
4. Sand from a dune in Utah. All are rounded quartz grains.

[\[Return to Figure 5.3.1\]](#)

Media Attributions

- Figure 5.3.1: © Steven Earle. CC BY.

5.4 Weathering and the Formation of Soil

Weathering is a key part of the process of soil formation, and soil is critical to our existence on Earth. In other words, we owe our existence to weathering, and we need to take care of our soil!

Many people refer to any loose material on Earth's surface as soil, but to geologists (and geology students) soil is the material that includes organic matter, lies within the top few tens of centimetres of the surface, and is important in sustaining plant growth.

Soil is a complex mixture of minerals (approximately 45%), organic matter (approximately 5%), and empty space (approximately 50%, filled to varying degrees with air and water). The mineral content of soils is variable, but is dominated by clay minerals and quartz, along with minor amounts of feldspar and small fragments of rock. The types of weathering that take place within a region have a major influence on soil composition and texture. For example, in a warm climate, where chemical weathering dominates, soils tend to be richer in clay. Soil scientists describe soil texture in terms of the relative proportions of sand, silt, and clay, as shown in Figure 5.4.1. The sand and silt components in this diagram are dominated by quartz, with lesser amounts of feldspar and rock fragments, while the clay component is dominated by the clay minerals.

Soil forms through accumulation and decay of organic matter and through the mechanical and chemical weathering processes described above. The factors that affect the nature of soil and the rate of its formation include climate (especially average temperature and precipitation amounts, and the consequent types and intensity of vegetation), the type of parent material, the slope of the surface, and the amount of time available.

Climate

Soils develop because of the weathering of materials on Earth's surface, including the mechanical breakup of rocks, and the chemical weathering of minerals. Soil development is facilitated by the downward percolation of water. Soil forms most readily under temperate to tropical conditions (not cold) and where precipitation amounts are moderate (not dry, but not too wet). Chemical weathering reactions (especially the formation of clay minerals) and biochemical reactions proceed fastest under warm conditions, and plant growth is enhanced in warm climates. Too much water (e.g., in rainforests) can lead to the leaching of important chemical nutrients and hence to acidic soils. In humid and poorly drained regions, swampy conditions may prevail, producing soil that is dominated by organic matter. Too little water (e.g., in deserts and semi-deserts), results in very limited downward chemical transportation and the accumulation of salts and carbonate minerals (e.g., calcite)

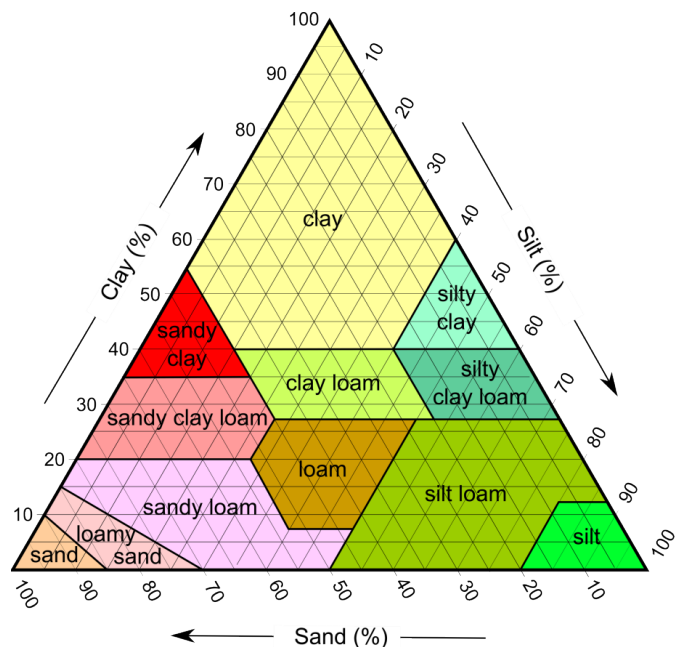


Figure 5.4.1 This diagram applies only to the mineral component of soils, and the names are textural descriptions, not soil classes.

from upward-moving water. Soils in dry regions also suffer from a lack of organic material (Figure 5.4.2).



Figure 5.4.2 Poorly developed soil on wind-blown silt (loess) in an arid part of northeastern Washington State. The thickness shown is about 1 m, and the “soil” is just the upper 2 or 3 cm.

Parent Material

Soil parent materials can include all different types of bedrock and any type of unconsolidated sediments, such as glacial deposits and stream deposits. Soils are described as **residual soils** if they develop on bedrock, and transported soils if they develop on transported material such as glacial sediments. Other sources may use the term “transported soil” to imply that the soil itself has been transported, but in this text “transported soil” is soil that is developed on transported materials, like the

very thin soil shown in Figure 5.4.2. When referring to such soil, it is better to be specific and say “soil developed on unconsolidated material,” because that distinguishes it from soil developed on bedrock.

Quartz-rich parent material, such as granite, sandstone, or loose sand, leads to the development of sandy soils. Quartz-poor material, such as shale or basalt, generates soils with little sand.

Parent materials provide important nutrients to residual soils. For example, a minor constituent of granitic rocks is the calcium-phosphate mineral apatite ($\text{Ca}_5(\text{PO}_4)_3(\text{F},\text{Cl},\text{OH})$), which is a source of the important soil nutrient phosphorus. Basaltic parent material tends to generate very fertile soils because it also provides phosphorus, along with significant amounts of iron, magnesium, and calcium.

Some unconsolidated materials, such as river-flood deposits, make for especially good soils because they tend to be rich in clay minerals. Clay minerals have large surface areas with negative charges that are attractive to positively charged elements like calcium, magnesium, iron, and potassium—important nutrients for plant growth.

Slope

Soil can only develop where surface materials remain in place and are not frequently moved away by mass wasting. Soils cannot develop where the rate of soil formation is less than the rate of erosion, so steep slopes tend to have little or no soil.

Time

Even under ideal conditions, soil takes thousands of years to develop. Virtually all of southern Canada was still glaciated up until 14 ka, and most of the central and northern parts of B.C., the prairies, Ontario, and Quebec were still glaciated at 12 ka. Glaciers still dominated the central and northern parts of Canada until around 10 ka, and so, at that time, conditions were still not ideal for soil development even in the southern regions. Therefore, soils in Canada, and especially in central and northern Canada, are relatively young and not well developed.

The same applies to soils that are forming on newly created surfaces, such as recent deltas or sand bars, or in areas of mass wasting.

Soil Horizons

The process of soil formation generally involves the downward movement of clay, water, and dissolved ions, and a common result of that is the development of chemically and texturally different layers known as **soil horizons**. The typically developed soil horizons, as illustrated in Figure 5.4.3, are:

- O — the layer of organic matter
- A — the layer of partially decayed organic matter mixed with mineral material
- E— the eluviated (leached) layer from which some of the clay and iron have been removed to create a pale layer that may be sandier than the other layers
- B — the layer of accumulation of clay, iron, and other elements from the overlying soil
- C — the layer of incomplete weathering

Although rare in Canada, another type of layer that develops in hot arid regions is known as **caliche** (pronounced *ca-lee-chee*). It forms from the downward (or in some cases upward) movement of calcium ions, and the precipitation of calcite within the soil. When well developed, caliche cements the surrounding material together to form a layer that has the consistency of concrete.

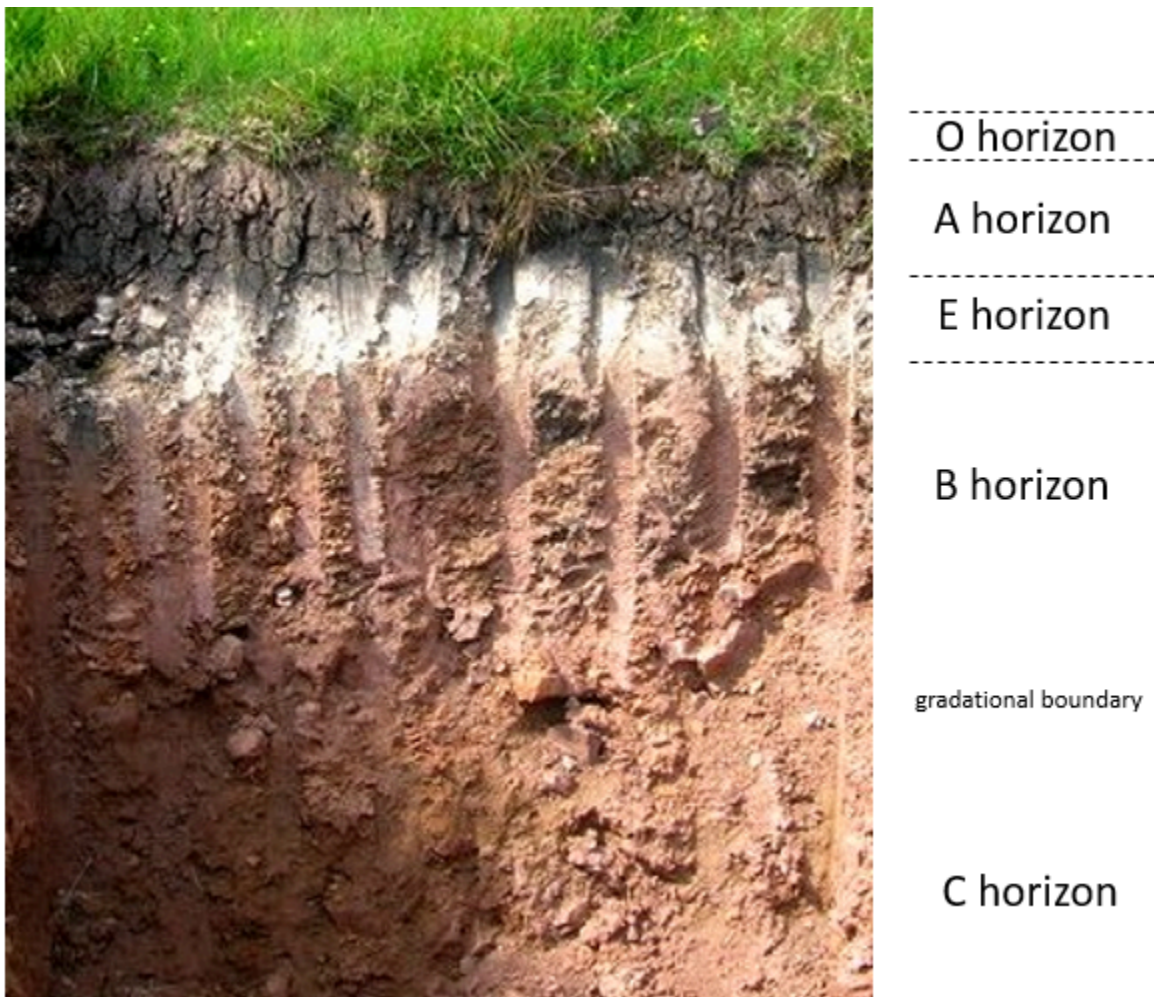


Figure 5.4.3 Soil horizons in a podsol from a site in northeastern Scotland.

Like all geological materials, soil is subject to erosion, although under natural conditions on gentle slopes, the rate of soil formation either balances or exceeds the rate of erosion. Human practices, especially those related to forestry and agriculture, have significantly upset this balance.

Soils are held in place by vegetation. When vegetation is removed, either through cutting trees or routinely harvesting crops and tilling the soil, that protection is either temporarily or permanently lost. The primary agents of the erosion of unprotected soil are water and wind.

Water erosion is accentuated on sloped surfaces because fast-flowing water obviously has greater eroding power than slow-flowing or still water (Figure 5.4.4). Raindrops can disaggregate exposed soil particles, putting the finer material (e.g., clays) into suspension in the water. **Sheetwash**—unchannelled flow across a surface—carries suspended material away, and channels erode right through the soil layer, removing both fine and coarse material.



Figure 5.4.4 Soil erosion by rain and channelled runoff on a field in Alberta.

Wind erosion is exacerbated by the removal of trees that act as wind breaks and by agricultural practices that leave bare soil exposed (Figure 5.4.5).

Tillage is also a factor in soil erosion, especially on slopes, because each time the soil is lifted by a cultivator, it is moved a few centimetres down the slope.



Figure 5.4.5 Soil erosion by wind in Alberta.

Media Attributions

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- Figure 5.4.2: © Steven Earle. CC BY.
- Figure 5.4.3: [Podzol](#) © [Ailith Stewart](#). CC BY-SA.
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5.5 The Soils of Canada

Up until the 1950s, the classification of soils in Canada was based on the system used in the United States. However, it was long recognized that the U.S. system did not apply well to many parts of Canada because of climate and environmental differences. The Canadian System of Soil Classification was first outlined in 1955 and has been refined and modified numerous times since then.

There are 10 orders of soil recognized in Canada. Each one is divided into groups, and then families, and then series, but we will only look at the orders, some of which are summarized in Table 5.2. The distribution of these types of soils (and a few others) in Canada is shown in Figure 5.5.1.

Table 5.2 The nature, origins and distributions of the more important soil orders in Canada

Order	Type	Brief Description	Environment
Forest soils	Podsol	Well-developed A and B horizons	Coniferous forests throughout Canada
	Luvisol	Clay rich B horizon	Northern prairies and central B.C., mostly on sedimentary rocks
	Brunisol	Poorly developed or immature soil, that does not have the well-defined horizons of podsol or luvisol	Boreal-forest soils in the discontinuous permafrost areas of central and western Canada, and also in southern B.C.
Grassland soils	Chernozem	High levels of organic matter and an A horizon at least 10 centimetres thick	Southern prairies (and parts of B.C.'s southern interior), in areas that experience water deficits during the summer
	Solonetzic	A clay-rich B horizon, commonly with a salt-bearing C horizon	Southern prairies, in areas that experience water deficits during the summer
Other important soils	Organic	Dominated by organic matter; mineral horizons are typically absent	Wetland areas, especially along the western edge of Hudson Bay, and in the area between the prairies and the boreal forest
	Cryosol	Poorly developed soil, mostly C horizon	Permafrost areas of northern Canada

There is an excellent website on Canadian soils, with videos describing the origins and characteristics of the soils, at: [Soil Classification: Soil Orders of Canada](#).

As we've discussed, the processes of soil formation are dominated by the downward transportation of clays and certain elements dissolved in water, and the nature of those processes depends in large part on the climate. In Canada's predominantly cool and humid climate (which applies to most places other than the far north), **podsolization** is the norm. This involves downward transportation of hydrogen, iron, and aluminum (and other elements) from the upper part of the soil profile, and accumulation of clay, iron, and aluminum in the B horizon. Most of the **podsols**, **luvisols**, and **brunisols** of Canada form through various types of podsolization.

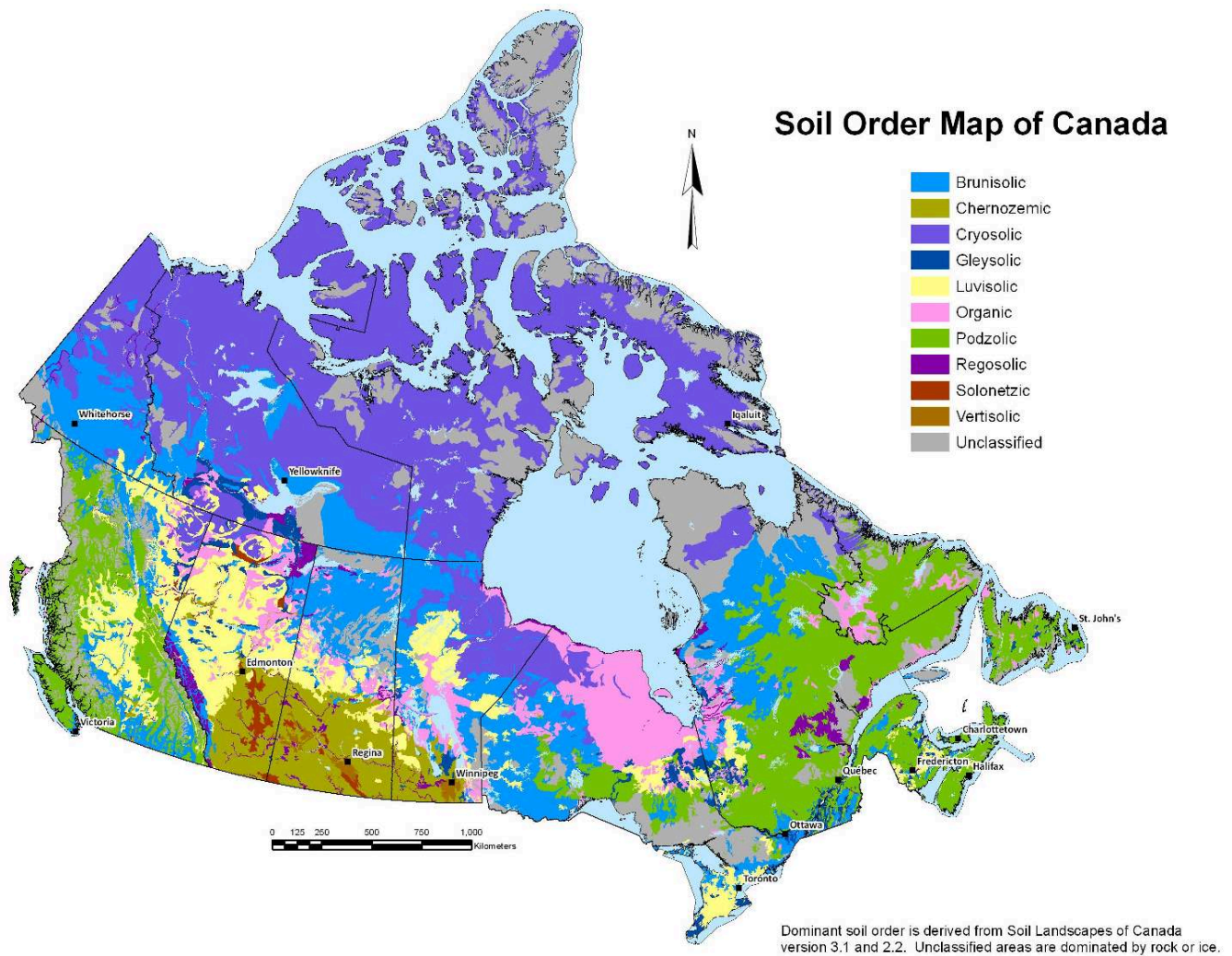


Figure 5.5.1 The soil order map of Canada. [\[Image Description\]](#)

In the grasslands of the dry southern parts of the prairie provinces and in some of the drier parts of southern B.C., dark brown organic-rich chernozem soils are dominant. In some parts of these areas, weak calcification takes place with leaching of calcium from the upper layers and accumulation of calcium in the B layer. Development of caliche layers is rare in Canada.

Organic soils form in areas with poor drainage (i.e., swamps) and a rich supply of organic matter. These soils have very little mineral matter.

In the permafrost regions of the north, where glacial retreat was most recent, the time available for soil formation has been short and the rate of soil formation is very slow. The soils are called cryosols (*cryo* means “ice cold”). Permafrost areas are also characterized by the churning of the soil by freeze-thaw processes, and as a result, development of soil horizons is very limited.

Examine Figure 5.5.1, which shows the distribution of soils in Canada. Briefly describe the distributions of the five soils types listed. For each one, explain its distribution based on what you know about the conditions under which the soil forms and the variations in climate and vegetation related to it.

1. Chernozem
2. Luvisol
3. Podsol
4. Brunisol
5. Organic

See Appendix 3 for [Exercise 5.4 answers](#).

Image Descriptions

Figure 5.5.1 image description: Soil order map of Canada. Chernozem is found in the southern parts of the prairies provinces (Alberta, Saskatchewan, and Manitoba). Luvisol is found in the BC interior, most of central and northern Alberta, and a strip through central Saskatchewan and Manitoba. Podsol is common on the eastern and western coastal areas, as well as northern BC, and much of Quebec and the maritime provinces. Brunisol is common in the southern parts of the territories, northern Saskatchewan and Manitoba, as well as parts of Ontario and Quebec. Organic soil is scattered all over the country, but most concentrated in northern Ontario and the lowlands around Hudson Bay. Cryosol is predominant in the far north. [\[Return to Figure 5.5.1\]](#)

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5.6 Weathering and Climate Change

Earth has two important carbon cycles. One is the biological one, wherein living organisms—mostly plants—consume carbon dioxide from the atmosphere to make their tissues. After they die almost all of that carbon is released back into the atmosphere when they decay over a period of years or decades. A small proportion of this biological-cycle carbon becomes buried in sedimentary rocks: during the slow formation of coal, as tiny fragments and molecules in organic-rich shale, and as the shells and other parts of marine organisms in limestone. This then becomes part of the geological carbon cycle, a cycle that actually involves a majority of Earth’s carbon, but one that operates very slowly.

The geological carbon cycle is shown diagrammatically in Figure 5.6.1. The various steps in the process (not necessarily in this order) are as follows (the letters are shown on Figure 5.6.1):

a) Organic matter from plants is stored in lake sediments, peat, and permafrost for up to tens of thousands of years, and some may be buried deeper to form coal that can be stored for tens of millions of years.

b) Weathering of silicate minerals converts atmospheric carbon dioxide to dissolved bicarbonate, which is stored in the oceans for thousands to tens of thousands of years.

c) Dissolved carbon is converted by marine organisms to calcite, which is stored in carbonate rocks for hundreds of millions of years.

d) Organic and inorganic carbon compounds are stored in sediments for tens to hundreds of millions of years; some end up in petroleum deposits.

e) Carbon-bearing sediments are transferred to the mantle, where the carbon may be stored for tens of millions to billions of years.

f) During volcanic eruptions, carbon dioxide is released back to the atmosphere, where it is stored for years to decades.

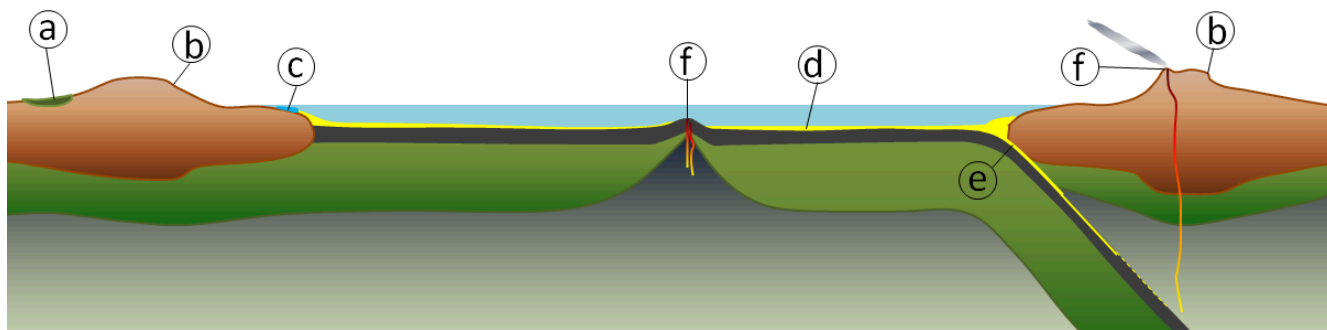


Figure 5.6.1 A representation of the geological carbon cycle. The processes represented by the letters are described in the text above.

During much of Earth’s history, the geological carbon cycle has been balanced, with carbon being released by volcanism at approximately the same rate that it is stored by the other processes. Under these conditions, the climate remains relatively stable.

During some periods of Earth’s history, that balance has been upset. This can happen during prolonged

periods of greater than average volcanism. One example is the eruption of the Siberian Traps at around 250 Ma, which appears to have led to strong climate warming over a few million years because of the slow but steady input of extra volcanic CO₂ into the atmosphere.

A carbon imbalance is also associated with significant mountain-building events. For example, the Himalayan Range was formed between about 40 and 10 Ma and over that time period—and still today—the rate of weathering on Earth has been enhanced because those mountains are so high and steep and the range is so extensive. The weathering of these rocks—most importantly the hydrolysis of feldspar—has resulted in consumption of atmospheric carbon dioxide and transfer of the carbon to the oceans and to ocean-floor carbonate minerals. The steady drop in carbon dioxide levels over the past 40 million years, which led to the Pleistocene glaciations, is partly attributable to the formation of the Himalayan Range.

A non-geological form of carbon-cycle imbalance is happening today on a very rapid time scale. We are in the process of extracting vast volumes of fossil fuels (coal, oil, and gas) that was stored in rocks over the past several hundred million years, and then converting these fuels to energy and carbon dioxide. By doing so, we are changing the climate faster than has ever happened in the past, and putting both ecosystems and our descendants at significant risk.

Media Attributions

- Figure 5.6.1: © Steven Earle. CC BY.

Summary

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

Section	Summary
5.1 Mechanical Weathering	Rocks weather when they are exposed to surface conditions, which in most case are quite different from those at which they formed. The main processes of mechanical weathering include exfoliation, freeze-thaw, salt crystallization, and the effects of plant growth.
5.2 Chemical Weathering	Chemical weathering takes place when minerals within rocks are not stable in their existing environment. Some of the important chemical weathering processes are hydrolysis of silicate minerals to form clay minerals, oxidation of iron in silicate and other minerals to form iron oxide minerals, and dissolution of calcite.
5.3 The Products of Weathering and Erosion	The main products of weathering and erosion are grains of quartz (because quartz is resistant to chemical weathering), clay minerals, iron oxide minerals, rock fragments, and a wide range of ions in solution.
5.4 Weathering and the Formation of Soil	Soil is a mixture of fine mineral fragments (including quartz and clay minerals), organic matter, and empty spaces that may be partially filled with water. Soil formation is controlled by climate (especially temperature and humidity), the nature of the parent material, the slope (because soil can't accumulate on steep slopes), and the amount of time available. Typical soils have layers called horizons which form because of differences in the conditions with depth.
5.5 The Soils of Canada	Canada has a range of soil types related to our unique conditions. The main types of soil form in forested and grassland regions, but there are extensive wetlands in Canada that produce organic soils, and large areas where soil development is poor because of cold conditions.
5.6 Weathering and Climate Change	The geological carbon cycle plays a critical role in balancing Earth's climate. Carbon is released to the atmosphere during volcanic eruptions. Carbon is extracted from the atmosphere during weathering of silicate minerals and this is eventually stored in the ocean and in sediments. Atmospheric carbon is also transferred to organic matter and some of that is later stored in soil, permafrost, and rocks. Our use of geologically stored carbon (fossil fuels) has upset this balance and that has created a climate crisis.

Questions for Review

Answers to Review Questions at the end of each chapter can be found in [Appendix 2](#).

1. What has to happen to a body of rock before exfoliation can take place?
2. The climate of central B.C. is consistently cold in the winter and consistently warm in the

- summer. At what times of year would you expect frost wedging to be most effective?
3. What are the likely products of the hydrolysis of the feldspar albite ($\text{NaAlSi}_3\text{O}_8$)?
 4. Oxidation weathering of the sulphide mineral pyrite (FeS_2) can lead to development of acid rock drainage (ARD). What are the environmental implications of ARD?
 5. Most sand deposits are dominated by quartz, with very little feldspar. Under what weathering and erosion conditions would you expect to find feldspar-rich sand?
 6. What ultimately happens to most of the clay that forms during the hydrolysis of silicate minerals?
 7. Why are the slope and the parent materials important factors in soil formation?
 8. Which soil constituents move downward to produce the B horizon of a soil?
 9. What are the main processes that lead to the erosion of soils in Canada?
 10. Where in Canada would you expect to find a chernozemic soil? What characteristics of this region produce this type of soil?
 11. Where are luvisolic soils found in B.C.?
 12. Why does weathering of silicate minerals, especially feldspar, lead to consumption of atmospheric carbon dioxide? What eventually happens to the carbon that is involved in that process?