LAB 5: SEDIMENTS AND SEDIMENTARY ROCKS

Lab Structure

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

Learning Objectives

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

- Describe 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.
- Describe the differences between cobbles, pebbles, sand, silt, and clay and explain the relationship between clast size and the extent to which clasts can be transported by moving water or by wind.
- Identify and describe the characteristics of the various types of clastic and chemical sedimentary rock based on their texture and mineralogy.

Key Terms

- Sediment
- Sedimentary rock
- Mechanical weathering
- Chemical weathering
- Erosion
- Deposition
- Lithification

- Clast
- Boulder
- Cobble
- Pebble
- Granule
- Sand
- Silt
- Clay

- Cement
- Crystalline
- Clastic
- Oolitic
- Amorphous
- Bioclastic
- Fossiliferous

Figure 5.0.1: The Hoodoos, near Drumheller, Alberta, have formed from the differential weathering of sedimentary rock that was buried beneath other rock for close to 100 Ma.

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 5.0.1). The various processes related to uplift and weathering are summarized in the rock cycle in Figure 5.0.2.
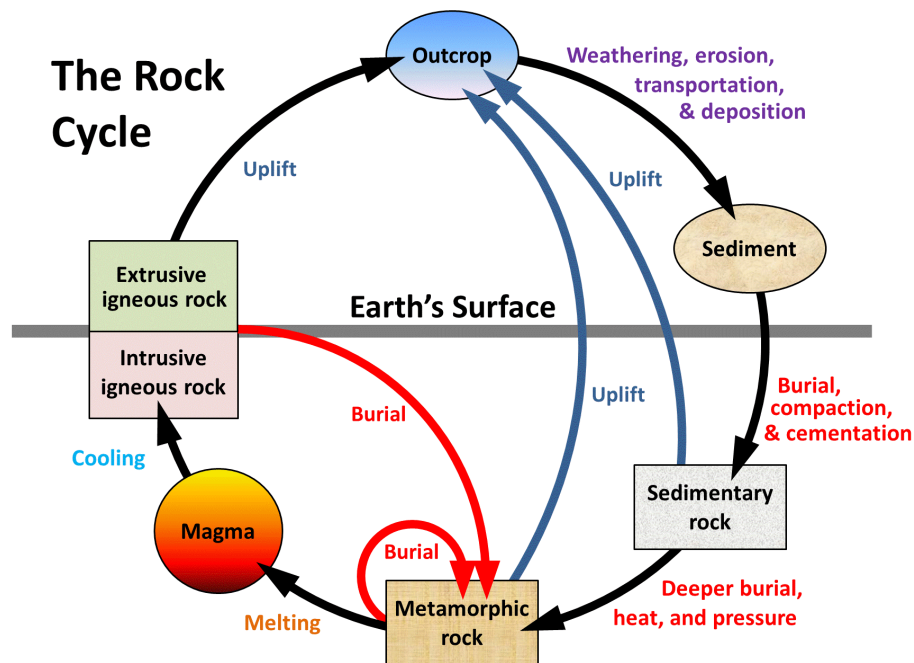

Figure 5.0.2: The rock cycle, showing the processes related to sedimentary rocks on the right-hand side.[Image description]

In this chapter, we will cover three core concepts: the formation of sediment through the weathering of rocks at the Earth's surface, the formation of sedimentary rocks from accumulated sediments, and the classification of various types of sedimentary rocks. The weathering and erosion of existing rocks at the Earth's surface are the first two steps in the transformation of existing rocks into sedimentary rocks. The remaining steps in the formation of sedimentary rocks-transportation, deposition, burial, and lithification (Figure 5.0.2) – will be discussed in more detail in chapter 5.3.

In this course, we divide sedimentary rocks into two main types: **clastic** and **chemical**. Clastic sedimentary rocks are mainly composed of material that has been transported as solid fragments (**clasts**). Chemical sedimentary rocks are mainly composed of material that has been transported as ions in solution. It's important *not* to assume that mechanical weathering leads only to clastic sedimentary rocks, while chemical weathering leads only to chemical sedimentary rocks. In most cases, millions of years separate the weathering and depositional processes, and both types of sedimentary rocks tend to include at least some material derived from both types of weathering.

Image Descriptions

Figure 5.0.2 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 changes into a 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 became metamorphic rock. [Return to Figure 5.0.2]

Media Attributions

5.1 Weathering

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**.

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
- Cracking from plant roots and removal of material by burrowing animals
- Formation of salt crystals within the rock

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.

Frost wedging is the process by which water seeps into cracks in a rock, expands on freezing, and thus enlarges the cracks (Figure 5.1.1). 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. 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 5.1.2).
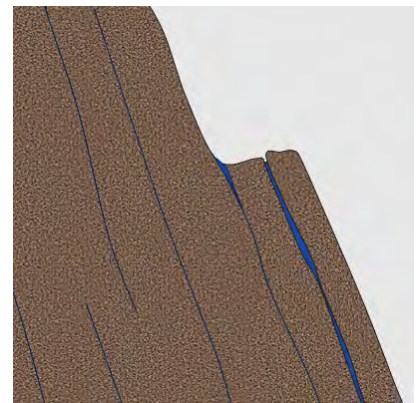

Figure 5.1.1: The process of frost wedging on a steep slope. Water gets into fractures and then freezes, expanding the fracture a little. When the water thaws it seeps a little farther into the expanded crack. The process is repeated many times, and eventually a piece of rock will be wedged away.
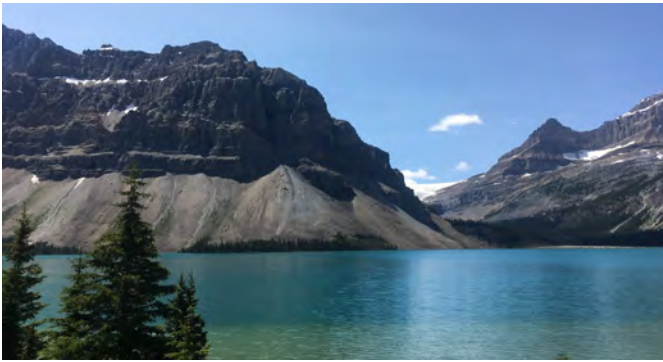
Figure 5.1.2: An area with very effective frost-wedging along glacial-fed Bow Lake in Banff National Park. The fragments that have been wedged away from the cliffs above have accumulated in a talus deposit at the base of the slope.
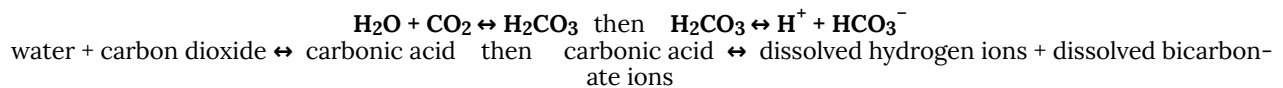
A related process, frost heaving, takes place within unconsolidated materials on gentle slopes. In this case, water in the soil freezes and expands, pushing the overlying material up. Frost heaving is responsible for winter damage to roads all over North America.

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 5.1.2. 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**. Other important agents of erosion that also have the effect of removing the products of weathering include water in streams (Lab 8), glacial ice, and waves on the coasts.

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 (H_2CO_3) when combined with water. That process, which is fundamental to most chemical weathering, can be shown as follows:

$$H_2O + CO_2 \leftrightarrow H_2CO_3 \quad \text{then} \quad H_2CO_3 \leftrightarrow H^+ + HCO_3^-$$

water + carbon dioxide ↔ carbonic acid   then   carbonic acid ↔ dissolved hydrogen ions + dissolved bicarbonate ions

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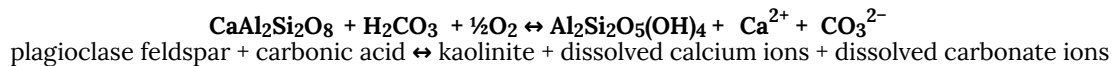
The double-ended arrow "↔" indicates that the reaction can go either way, but for our purposes these reactions are going towards the right.

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:

$$CaAl_2Si_2O_8 + H_2CO_3 + \tfrac{1}{2}O_2 \leftrightarrow Al_2Si_2O_5(OH)_4 + Ca^{2+} + CO_3^{2-}$$
plagioclase feldspar + carbonic acid ↔ kaolinite + dissolved calcium ions + dissolved carbonate ions

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 5.1.3, 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 minerals chlorite or smectite, and olivine can be converted to the mineral serpentine.
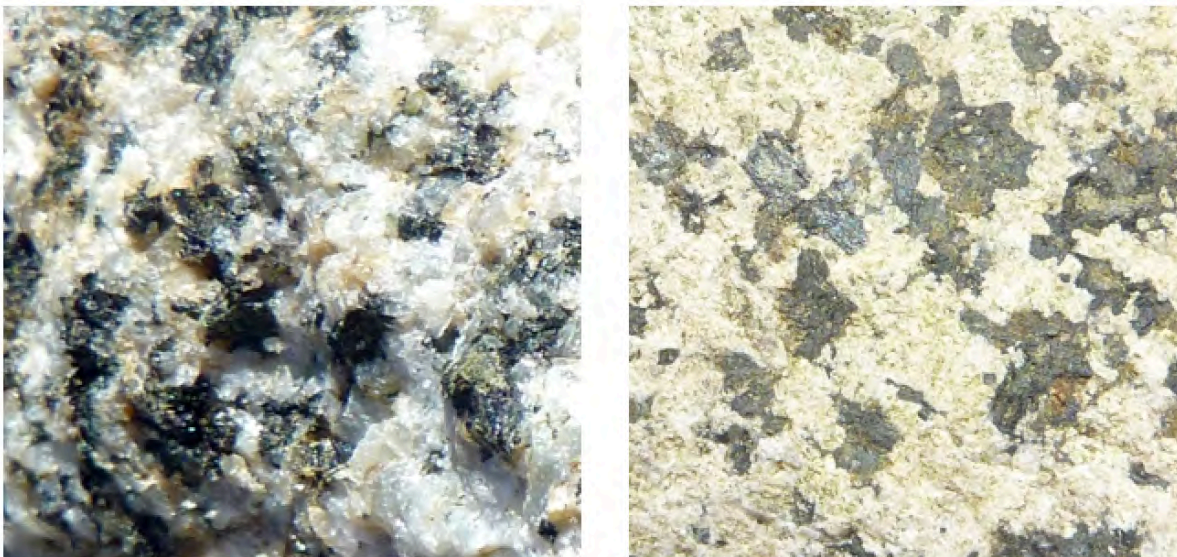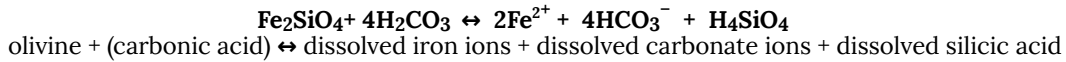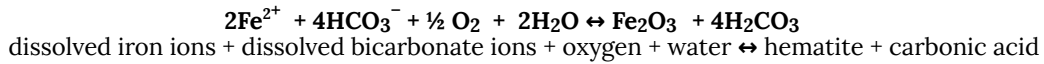

Figure 5.1.3: Unweathered (left) and weathered (right) surfaces of the same piece of granitic rock. On the unweathered surfaces the feldspars are still fresh and glassy-looking. On the weathered surface much of the feldspar has been altered to the chalky-looking clay mineral kaolinite.

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:

$$\text{Fe}_2\text{SiO}_4 + 4\text{H}_2\text{CO}_3 \leftrightarrow 2\text{Fe}^{2+} + 4\text{HCO}_3^- + \text{H}_4\text{SiO}_4$$

olivine + (carbonic acid) ↔ dissolved iron ions + dissolved carbonate ions + dissolved silicic acid

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

$$2\text{Fe}^{2+} + 4\text{HCO}_3^- + \tfrac{1}{2}\,\text{O}_2 + 2\text{H}_2\text{O} \leftrightarrow \text{Fe}_2\text{O}_3 + 4\text{H}_2\text{CO}_3$$

dissolved iron ions + dissolved bicarbonate ions + oxygen + water ↔ hematite + carbonic acid
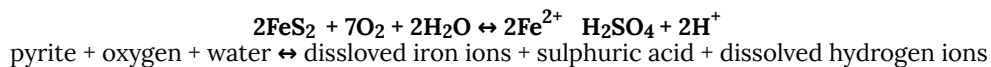
The equation shown here is for olivine, but it could apply to almost any other ferromagnesian silicate, including pyroxene, amphibole, or biotite. Iron in the sulphide minerals (e.g., pyrite) can also be oxidized in this way. And the mineral hematite is not the only possible end result, as there is a wide range of iron oxide minerals that can form in this way. The results of this process are illustrated in Figure 5.1.4, which shows a granitic rock in which some of the biotite and amphibole have been altered to form the iron oxide mineral limonite.

Figure 5.1.4: 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:

$$2\text{FeS}_2 + 7\text{O}_2 + 2\text{H}_2\text{O} \leftrightarrow 2\text{Fe}^{2+}\ \text{H}_2\text{SO}_4 + 2\text{H}^+$$

pyrite + oxygen + water ↔ dissloved iron ions + sulphuric acid + dissolved hydrogen ions

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. While ARD does occur naturally when rocks con-
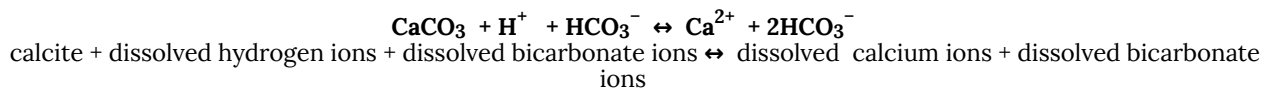
taining pyrite are exposed at the Earth's surface, some of the worst examples of ARD are at mine sites. These sites can have significant problems with ARD, especially where pyrite-bearing rock and waste material have been mined from deep underground and then piled up and left exposed to water and oxygen. One example of that is the Mt. Washington Mine on Vancouver Island in B.C. (Figure 5.1.5), but there are many similar sites across Canada and around the world.

Figure 5.1.5: 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).

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:

$$CaCO_3 + H^+ + HCO_3^- \leftrightarrow Ca^{2+} + 2HCO_3^-$$

calcite + dissolved hydrogen ions + dissolved bicarbonate ions ↔ dissolved calcium ions + dissolved bicarbonate ions

Calcite is the major component of limestone (typically more than 95%), and under surface conditions, limestone can dissolve completely. Limestone also dissolves at relatively shallow depths underground, forming limestone caves.

Practice Exercise 5.1 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

See Appendix 2 for Practice Exercise 5.1 answers.

Media Attributions

- Figures 5.1.1, 5.1.3, 5.1.4, 5.1.5: © Steven Earle. CC BY.
- Figure 5.1.2: © Siobhan McGoldrick. CC BY.

5.2 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 5.2.1. 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.

Figure 5.2.1: *Products of weathering and erosion formed under different conditions.*
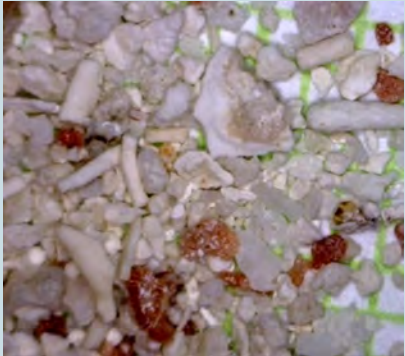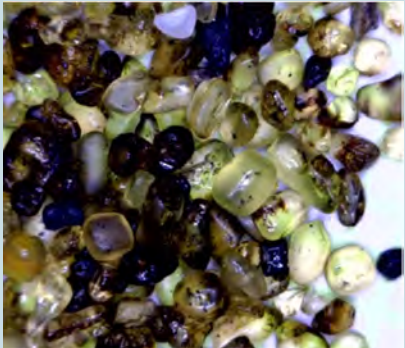
We'll talk more about the nature and interpretation of sediments and sedimentary rocks in the next section, but it's worth considering here why the sand-sized sediments shown in Figure 5.2.1 are so strongly dominated by the mineral quartz, even though quartz makes up less than 20% of Earth's crust. The 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 weathering.

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.

Practice Exercise 5.2 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 2 for Practice Exercise 5.2 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 milimetres.
	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.

Media Attributions

- Figure 5.2.1 and Practice Exercise 5.2 images: © Steven Earle. CC BY.

5.3 Clastic Sedimentary Rocks

A **clast** is a fragment of rock or mineral, ranging in size from less than a micron[1] (too small to see) to as big as an apartment block. Various types of clasts are shown in Figure 5.2.1 and in Practice Exercise 5.2. The smaller ones tend to be composed of a single mineral crystal, and the larger ones are typically composed of pieces of rock. As we've seen, most sand-sized clasts are made of quartz because quartz is more resistant to weathering than any other common mineral. Many of the clasts that are smaller than sand size (less than $^1/_{16}$ or 0.063 mm) are made of clay minerals. Most clasts larger than sand size (greater than 2 mm) are actual fragments of rock, and commonly these might be fine-grained rock like basalt or andesite, or if they are bigger, coarse-grained rock like granite or gneiss. Sedimentary rocks that are made up of clasts are called **clastic sedimentary rocks**. A comparable term is "detrital sedimentary rocks".

Grain-Size Classification

Geologists that study sediments and sedimentary rocks use the Udden-Wentworth grain-size scale for describing the sizes of the grains in these materials (Table 5.2). There are six main grain-size categories; five are broken down into subcategories, with **clay** being the exception. The diameter limits for each successive subcategory are twice as large as the one beneath it. In general, a **boulder** is bigger than a toaster and difficult to lift. There is no upper limit to the size of boulder.[2] **Sand** ranges from 2 millimetres down to 0.063 millimetres, and its key characteristic is that it feels "sandy" or gritty between your fingers—even the finest sand grains feel that way. **Silt** is essentially too small for individual grains to be visible, and while sand feels sandy to your fingers, silt feels smooth to your fingers but gritty in your mouth. Clay is so fine that it feels smooth even in your mouth.

Table 5.2 The Udden-Wentworth grain-size scale for classifying sediments and the grains that make up clastic sedimentary rocks

Type	Description	Size range (millimetres, mm)	Size range (microns, μm)
Boulder	large	1024 and up	
	medium	512 to 1024	
	small	256 to 512	
Cobble	large	128 to 256	
	small	64 to 128	
Pebble (Granule)	very coarse	32 to 64	
	coarse	16 to 32	
	medium	8 to 16	
	fine	4 to 8	
	very fine	2 to 4	
Sand	very coarse	1 to 2	1000 to 2000
	coarse	0.5 to 1	500 to 1000
	medium	0.25 to 0.5 ($^1/_4$ to $^1/_2$ mm)	250 to 500
	fine	0.125 to 0.25 ($^1/_8$ to $^1/_4$ mm)	125 to 250
	very fine	0.063 to 0.125 ($^1/_{16}$ to $^1/_8$ mm)	63 to 125
Silt	very coarse		32 to 63
	course		16 to 32
	medium		8 to 16
	fine		4 to 8
	very fine		2 to 4
Clay	clay		0 to 2

If you drop a **granule** into a glass of water, it will sink quickly to the bottom (less than half a second). If you drop a grain of sand into the same glass, it will sink more slowly (a second or two depending on the size). A grain of silt will take several seconds to get to the bottom, and a particle of fine clay may never get there. The rate of settling is determined by the balance between gravity and friction, as shown in Figure 5.3.1. Large particles settle quickly because the gravitational force (which is proportional to the mass, and therefore to the volume of the particle) is much greater than the frictional resistance (which is proportional to the surface area of the particle). For smaller particles the difference between gravitational push and frictional resistance is less, so they settle slowly.

Small particles that settle slowly spend longer suspended in the water, and therefore tend to get moved farther than large particles if the water is moving.
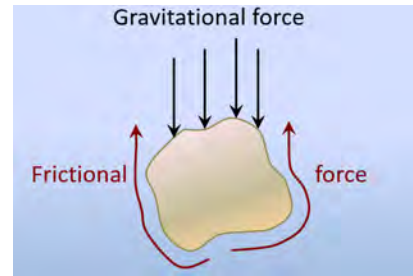
Transportation

One of the key principles of sedimentary geology is that the ability of a moving medium (air, ice, or water) to move sedimentary particles—and keep them moving—is dependent on the velocity of flow. The faster the medium flows, and therefore the higher the energy of the flow, the larger the particles it can move. This is illustrated in Figure 5.3.2. Parts of the river are moving faster than other parts, especially where the slope is greatest and the channel is narrow. Not only does the velocity of a river change from place to place, but it changes from season to season. During peak **discharge**[3] at the location of Figure 5.3.2, the water is high enough to flow over the embankment on the right, and it flows fast enough to move the boulders that cannot be moved during low flows.
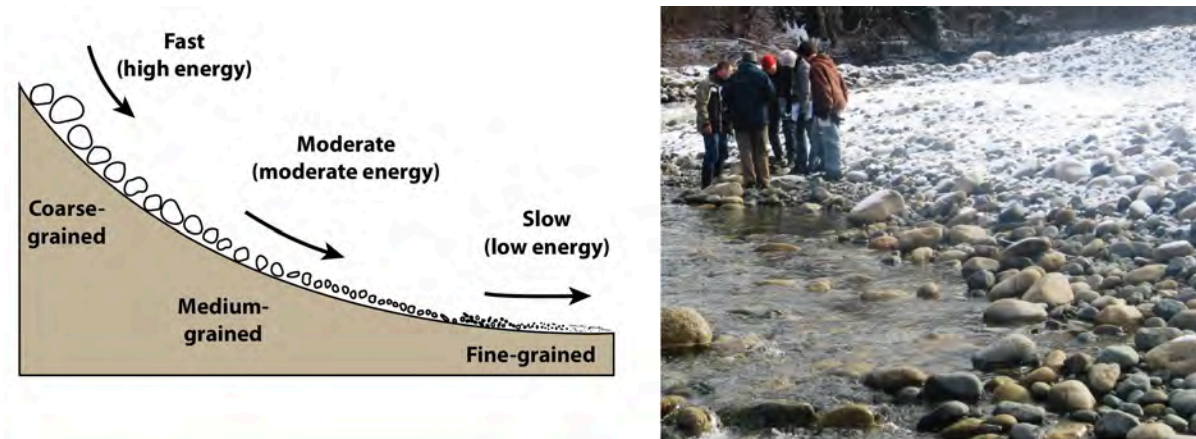

Figure 5.3.2: (left) Schematic relationship between flow velocity (fast, moderate, slow), energy, and clast size. (right) Variations in flow velocity on the Englishman River near Parksville, B.C. When the photo was taken the river was not flowing fast enough anywhere to move the boulders and cobbles visible here. During flood events the water flows right over the snow-covered bank on the right, and is fast enough to move boulders.

Clasts within streams are moved in several different ways, as illustrated in Figure 5.3.3. Large **bed load** clasts are pushed (by traction) or bounced along the bottom (by saltation), while smaller clasts are suspended in the water and kept there by the turbulence of the flow. As the flow velocity changes, different-sized clasts may be either incorporated into the flow or deposited on the bottom. At various places along a river, there are always some clasts being deposited, some staying where they are, and some being eroded and transported. This changes over time as the discharge of the river changes in response to changing weather conditions.
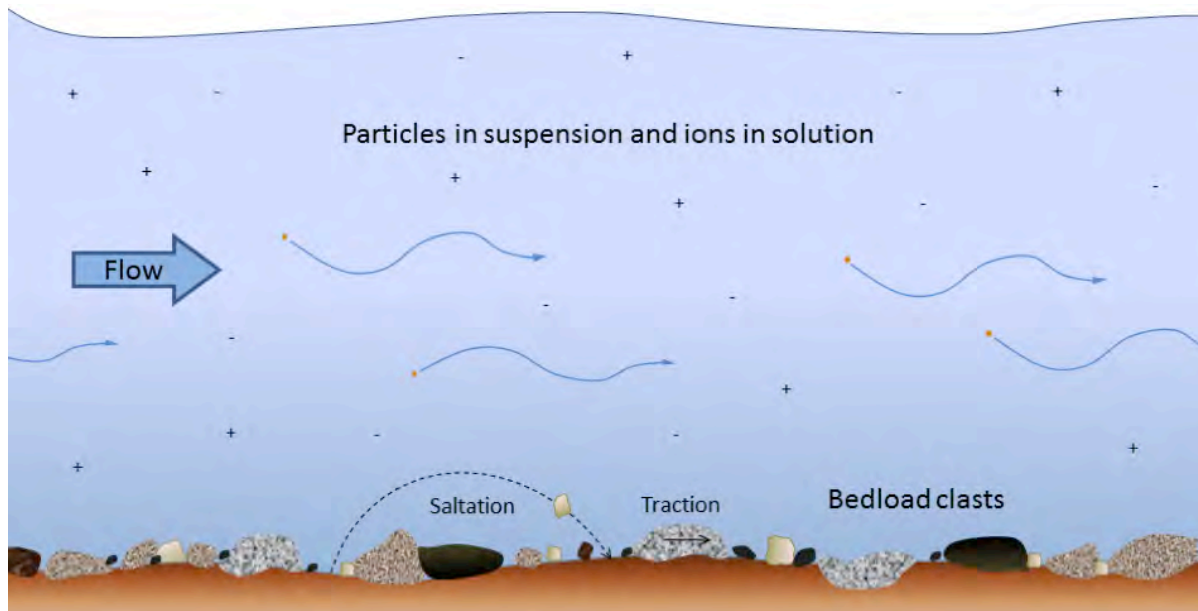
Figure 5.3.3: Transportation of sediment clasts by stream flow. The larger clasts, resting on the bottom (bedload), are moved by traction (sliding) or by saltation (bouncing). Smaller clasts are kept in suspension by turbulence in the flow. Ions (depicted as + and – in the image, but invisible in real life) are dissolved in the water.

Other sediment transportation media, such as waves, ocean currents, and wind, operate under similar principles, with flow velocity as the key underlying factor that controls transportation and deposition.

Deposition

When the velocity, and the energy level, of the transporting medium (e.g., flowing water in a river, ice in a glacier, wind) decreases and it no longer has sufficient energy to continue transporting sediment, the sediment is deposited. For example, where a river flows into the sea, the velocity of the water decreases abruptly, and the sediment that can no longer be carried is deposited to form a delta. Clastic sediments are deposited in a wide range of environments, including glacial environments, talus slopes, alluvial fans, rivers—both fast and slow—lakes, deltas, and ocean environments—both shallow and deep. If the sedimentary deposits last long enough to be covered with other sediments they may eventually form into rocks ranging from fine shale to coarse conglomerate.

Burial and Lithification

Lithification is the term used to describe a number of different processes that take place within a deposit of sediment to turn it into solid rock (Figure 5.3.4). One of these processes is burial by other sediments, which leads to compaction of the material and removal of some of the intervening water and air. After this stage, the individual clasts are touching one another. **Cementation** is the process of crystallization of minerals within the pores (void space) between the small clasts, and especially at the points of contact between clasts. Depending on the pressure, temperature, and chemical conditions, this **cement** might be formed by

a range of minerals, the common ones being calcite, hematite, and quartz. You can determine whether a clastic sedimentary rock, like a sandstone, is cemented with calcite by adding a drop of dilute acid to a fresh surface on the sample. If the sample reacts readily with the acid, it is likely cemented by calcite.
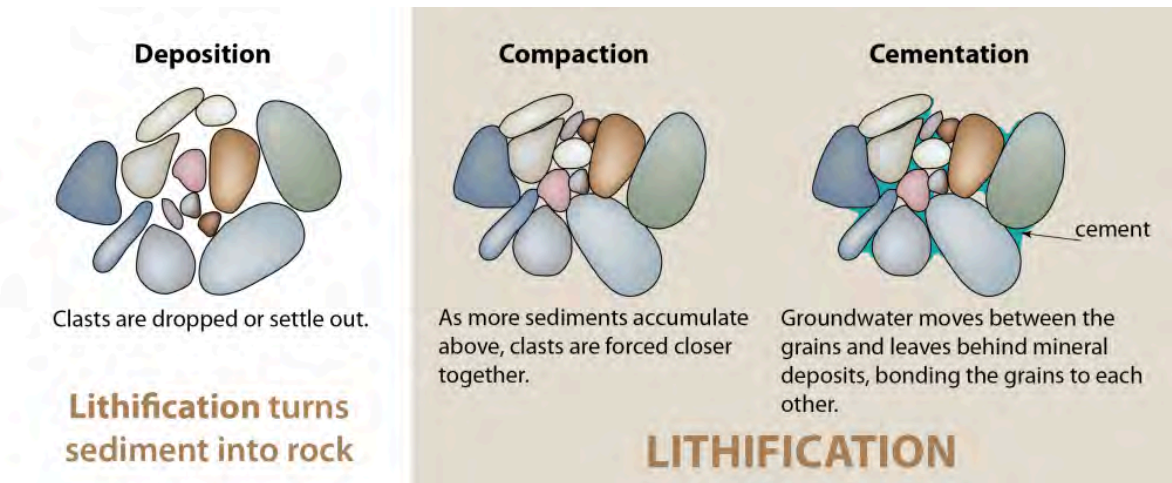

Figure 5.3.4: Lithification turns sediments into solid rock. Lithification involves the compaction of sediments and then the cementation of grains by minerals that precipitate from groundwater in the spaces between these grains.

Roundness and Sorting

For any geologist describing sediments and clastic sedimentary rocks, it is not only the size of the clasts that is important for classification, but also the range of sizes and shapes. To describe the shape of clasts in a sedimentary rock, or grains in a unconsolidated sediment, geologists use the term **roundness**. This scale of roundness from angular to well-rounded is illustrated in Figure 5.3.5. The roundness of a clast tends to reflect the extent to which it has been transported, but keep in mind that the composition of the clast also plays an important role! Grains of phyllosilicate minerals such as biotite or muscovite, for example, will never form rounded grains due to their sheet-like shape. Typically, the longer a clast is in transport, the more it is abraded by other clasts and the more rounded it becomes. Angular clasts, like those common to talus slopes beneath steep mountains, tend to indicate deposition very close to their source, meaning that they have not experienced significant transport.
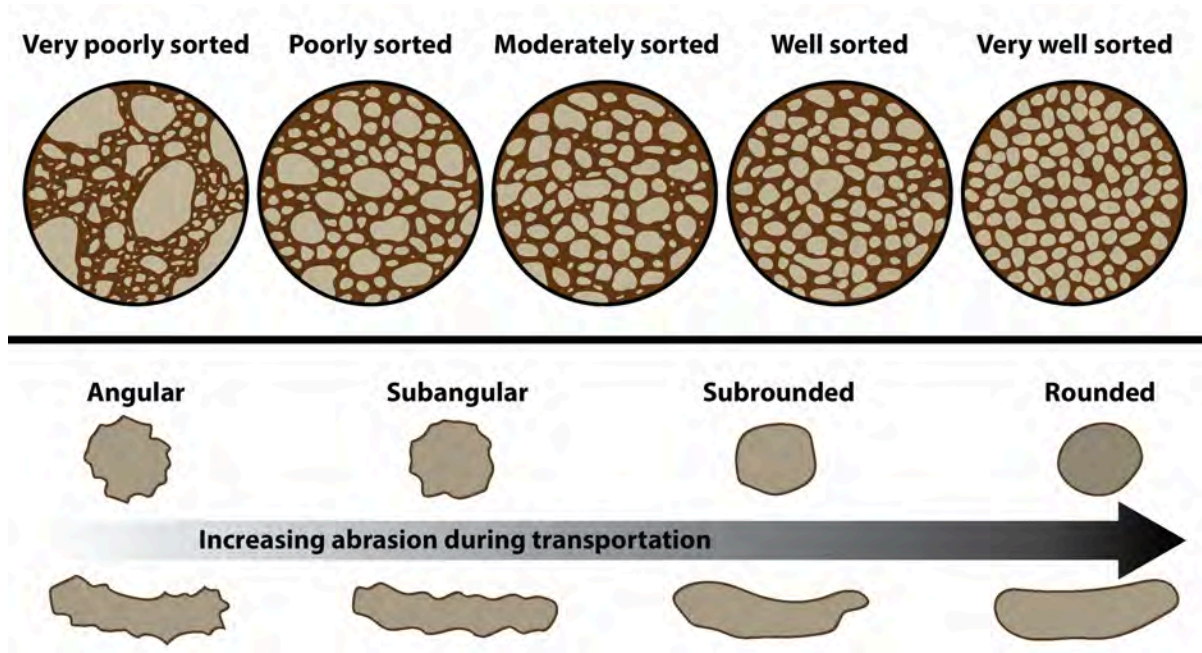
Figure 5.3.5: A visual reference for descriptions of sorting (top) and roundness (bottom) of sediments and grains in clastic sedimentary rocks. Note that rounded grains are not necessarily spherical in shape! Grain shapes are controlled by both the extent of transportation (and abrasion) and by the physical properties of the grain.

Increased transport also tends to result in well-sorted sediment deposits. **Sorting** refers to the range of grain sizes in a sediment deposit or in a clastic sedimentary rock (Figure 5.3.5). Poorly sorted sediments contain a wide range of grain sizes. Deposits of glacial **till**, for example, tend to be very poorly sorted as they contain grain sizes ranging from house-sized boulders to very fine grains of clay. A deposit of fine sand on a beautiful sandy beach, on the other hand, is an example of a well-sorted sediment, as all the grains are sand-sized.

Classification of Clastic Sedimentary Rocks

Clastic sedimentary rocks are classified and named based on both composition and texture. The composition of the grains is particularly important for sandstones, as described below and in Figure 5.3.6. Texture in this case refers to grain size (using the Udden-Wentworth grain-size scale in Table 5.2), roundness, and sorting. The characteristics and distinguishing features of clastic sedimentary rocks are summarized in Table 5.3.

Table 5.3 The main types of clastic sedimentary rocks and their characteristics. You are expected to be able to identify the bolded rock names in this course.

Group	Examples	Characteristics
Conglomerate		Dominated by rounded clasts, granule size and larger (>2 mm), poorly to very poorly sorted
Breccia		Dominated by angular clasts, granule size and larger (>2 mm), poorly to very poorly sorted
Sandstone	**quartz sandstone**	Dominated by sand (1/16 to 2 mm), greater than 90% quartz, range of roundness and sorting possible
	arkose (feldspathic sandstone)	Dominated by sand (1/16 to 2 mm), greater than 10% feldspar, range of roundness and sorting possible
	lithic wacke	Dominated by sand (1/16 to 2 mm), greater than 10% rock fragments, greater than 15% silt and clay, range of roundness and sorting possible
Mudrock	mudstone	Greater than 75% silt (1/256 to 1/16 mm) and clay (<1/256 mm), not bedded, well-sorted, grains too fine to judge roundness using hand lens
	shale	Greater than 75% silt (1/256 to 1/16 mm) and clay (<1/256 mm), thinly bedded, well-sorted, grains too fine to judge roundness using hand lens

Mudrock is composed of at least 75% silt- and clay-sized fragments. If it shows evidence of **bedding** or fine laminations, it is **shale**; otherwise, it is mudstone. Mudrocks form in very low energy environments, such as lakes, river backwaters, and the deep ocean.

It's worth taking a closer look at the different types of sandstone because sandstone is a common and important sedimentary rock. Typical sandstone compositions are shown in Figure 5.3.6. Sandstones are mostly made up of sand-sized grains of course, but they also include some finer material—both silt and clay. The term **arenite** applies to a so-called "clean" sandstone, meaning one with less than 15% silt and clay. Considering the sand-sized grains only (the grains larger than $^1/_{16}$ or 0.063 mm), arenites with greater than 90% quartz are called *quartz arenites*. If they have more than 10% feldspar and more feldspar than rock fragments, they are called *feldspathic arenites* or **arkosic arenites** (or just **arkose**). If they have more than 10% rock fragments, and more rock fragments than feldspar, they are **lithic arenites.**[4] A sandstone with more than 15% silt or clay is called a **wacke** (pronounced *wackie*). The terms *quartz wacke*, *lithic wacke*, and *feldspathic wacke* are used with limits similar to those on the arenite diagram. Another name for a lithic wacke is **greywacke**. Sandstones form in a wide range of environments, including rivers, lakes, beaches, deserts, and shallow oceans.
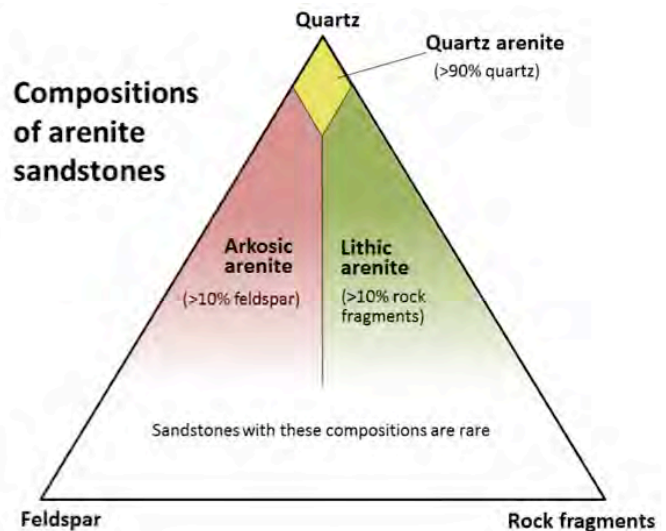

Figure 5.3.6: *A compositional triangle for arenite sandstones, with the three most common components of sand-sized grains: quartz, feldspar, and rock fragments. Arenites have less than 15% silt or clay. Sandstones with more than 15% silt and clay are called* **wackes** *(e.g., quartz wacke, lithic wacke).*

Some examples of sandstones, magnified in **thin section** are shown in Figure 5.3.7. (A thin section is rock sliced thin enough so that light can shine through.)
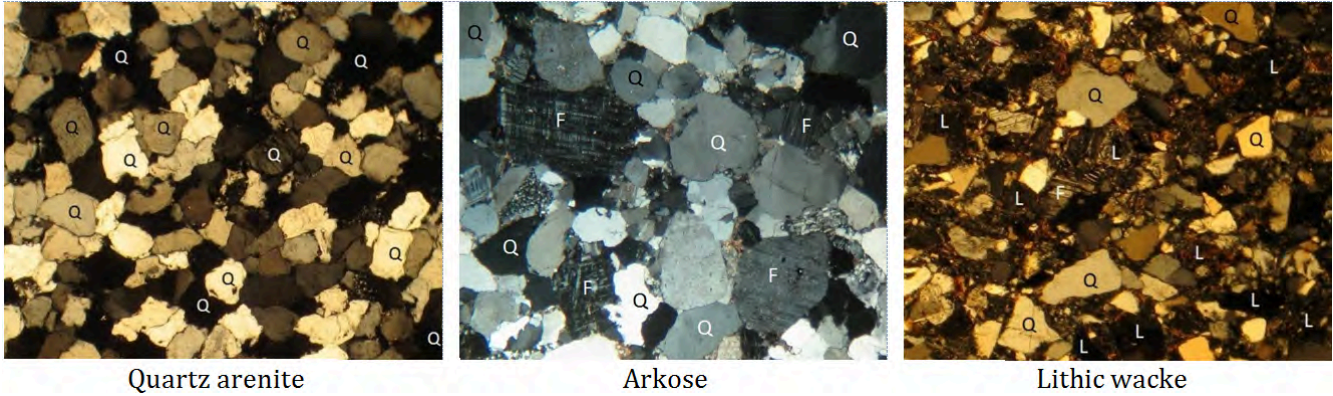
Figure 5.3.7: *Microscope photos of three types of sandstone in thin-section. Some of the minerals are labelled: Q=quartz, F=feldspar and L= lithic (rock fragments). The quartz arenite and arkose have relatively little silt-clay matrix between the larger sand-sized grains, while the lithic wacke has abundant matrix.*

Clastic sedimentary rocks in which a significant proportion of the clasts are larger than 2 mm are known as **conglomerate** if the clasts are well rounded, and **breccia** if they are angular. Conglomerates form in high-energy environments such as fast-flowing rivers, where the particles can become rounded. Breccias, characterized by their granule and larger-sized angular clasts, typically form where the particles are not transported a significant distance in water, such as alluvial fans and talus slopes. Some examples of clastic sedimentary rocks are shown on Figure 5.3.8.

(a) Mudrock with bivalve impressions, Cretaceous Nanaimo Group, Browns River, Vancouver Island

(b) Coarse sandstone with cross-bedding, Cambrian Tapeats Formation Chino Valley, Arizona

(c) Conglomerate with imbricate (aligned, tilted down to the left) cobbles, Cretaceous Geoffrey Formation, Hornby Island, BC
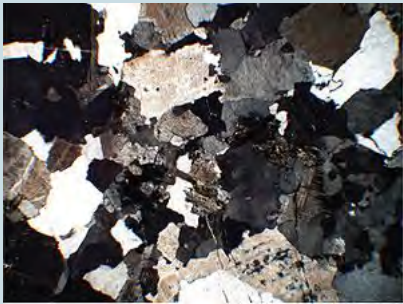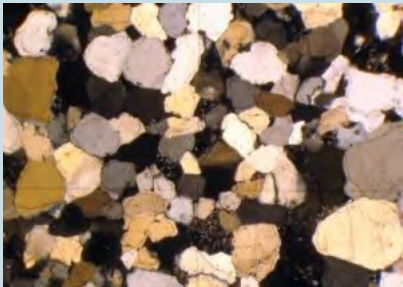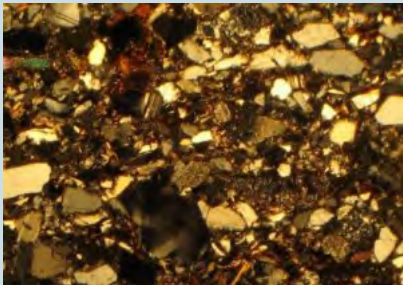
(d) Sedimentary breccia, the Pre-Cambrian Toby Formation, east of Castlegar, BC (image is approx. 1 m across)

Figure 5.3.8: Examples of various clastic sedimentary rocks.

Practice Exercise 5.3 Classifying sandstones

Table 5.4 below shows magnified thin sections of three sandstones, along with descriptions of their compositions. Using Table 5.3 and Figure 5.3.6, find an appropriate name for each of these rocks. Using Figure 5.3.5, describe the roundness and sorting in each of the sandstones.

Table 5.4 Classifying sandstones

Magnified Thin Section	Description
	Angular sand-sized grains are approximately 85% quartz and 15% feldspar. Silt and clay make up less than 5% of the rock.
	Rounded sand-sized grains are approximately 99% quartz and 1% feldspar. Silt and clay make up less than 2% of the rock.
	Angular sand-sized grains are approximately 70% quartz, 20% lithic, and 10% feldspar. Silt and clay make up about 20% of the rock.

See Appendix 2 for Practice Exercise 5.3 answers.

Media Attributions

Notes

1. A micron is a millionth of a metre. There are 1,000 microns in a millimetre.
2. The largest known free-standing rock (i.e., not part of bedrock) is Giant Rock in the Mojave Desert, California. It's about as big as an apartment building—seven stories high!
3. Discharge of a stream is the volume of flow passing a point per unit time. It's normally measured in cubic metres per second (m^3/s).
4. "Lithic" means "rock." Lithic clasts are rock fragments, as opposed to mineral fragments.

5.4 Chemical Sedimentary Rocks

Whereas clastic sedimentary rocks are dominated by components that have been transported as solid clasts (clay, silt, sand, etc.), chemical sedimentary rocks are dominated by components that have been transported as ions in solution (Na^+, Ca^{2+}, HCO_3^-, etc.). There is some overlap between the two because almost all clastic sedimentary rocks contain cement formed from dissolved ions, and many chemical sedimentary rocks include some clasts. Since ions can stay in solution for tens of thousands of years (some much longer), and can travel for tens of thousands of kilometres, it is virtually impossible to relate chemical sediments back to their source rocks.

Chemical weathering and chemical sedimentary rocks

Many students confuse chemical weathering with chemical sedimentary rocks, or mistakenly assume that when and where chemical weathering is taking place, chemical sedimentary rocks will accumulate. Most ions in solution in rivers, lakes and the ocean are produced during chemical weathering, but those ions can remain in solution for millions of years, and during that time they can travel hundreds of thousands of km (yes, literally around the world, several times). They might eventually come out of solution as a result of a biological process or a change in the chemical conditions and will then become a mineral crystal that can settle to form a chemical sediment.

So the calcium ions that are part of a calcite mud on the sea floor near Australia's Great Barrier Reef could literally have come from anywhere on Earth (and almost certainly came from many different places), and might have been in solution for as little as a few days or for as long as tens of millions of years.

The most common chemical sedimentary rock, by far, is **limestone**. Others include **chert**, **chalk, evaporites** like rock gypsum and rock salt, and coal. Biological processes are important in the formation of some chemical sedimentary rocks, especially limestone, chert, and coal. For example, limestone is made up almost entirely of fragments of marine[1] organisms that manufacture calcite for their shells and other hard parts, and most chert includes at least some of the silica tests (shells) of tiny marine organisms (such as diatoms and radiolarians). Coal forms in fluvial or delta environments from decaying plant matter that accumulates in long-lasting swamps with low oxygen levels.

Chemical sedimentary rocks are classified based on their composition. As these rocks are often **monomineralic**, you will find that some of the same physical properties you learned in Lab 2 can be utilized to identify chemical sedimentary rocks. For instance, rock gypsum is comprised predominantly of the mineral gypsum and can be easily identified by its hardness (H = 2, can be scratched with a fingernail).

The name of a chemical sedimentary rock can be modified by a textural term, to create a more descriptive and meaningful name. Some important textures for chemical sedimentary rocks include **crystalline**, **oolitic**, **bioclastic**, **fossiliferous**[2], and **amorphous**. A simplified classification chart for chemical sedimentary rocks is presented in Table 5.5.

Composition	Texture	Distinctive Properties	Rock Name
Calcite (CaCO$_3$) *Note that all lime-stones will react with dilute HCl.*	Crystalline	Crystalline; fine to coarse grained	**Crystalline limestone**
	Fossiliferous	Various fossil fragments well cemented together	**Fossiliferous limestone**
	Oolitic	Comprised of ooids (spheroidal particles typically <2 mm in diameter)	**Oolitic limestone**
	Bioclastic	Visible shell fragments weakly cemented together	**Coquina**
	Bioclastic	Soft rock made of microscopic shells	**Chalk**
Quartz (SiO$_2$)	Microcrystalline	Microcrystalline; hardness of ~7 (can scratch glass); may exhibit conchoidal fracture	**Chert** (note that dark coloured varieties may be called **flint** and red coloured varieties may be called **jasper**)
Halite (NaCl)	Crystalline	Crystalline; fine to coarse grained; commonly forms cubic crystals; tastes salty	**Rock salt**
Gypsum (CaSO$_4$·H$_2$O)	Crystalline	Crystalline; fine to coarse grained; hardness ~2 (can scratch with fingernail)	**Rock gypsum**
Organic material (plant fragments)	Amorphous	Black brittle rock with amorphous texture; low density	**Coal**

Limestone

Almost all limestone forms in the oceans, and most of that forms on the shallow continental shelves, especially in tropical regions with coral reefs. Reefs are highly productive ecosystems populated by a wide range of organisms, many of which use calcium and bicarbonate ions in seawater to make carbonate minerals (especially calcite) for their shells and other structures. These include corals, of course, but also green and red algae, urchins, sponges, molluscs, and crustaceans. The hard parts of these organisms are eroded by waves and currents to produce carbonate fragments that accumulate in the surrounding region.

Figure 5.4.1 shows a cross-section through a typical reef in a tropical environment (normally between 40° N and 40° S). Reefs tend to form in areas with clear water (e.g., not close to the mouths of large rivers), and near the edges of steep drop-offs because the reef organisms thrive on nutrient-rich upwelling currents. As the reef builds up, it is eroded by waves and currents to produce carbonate sediments that are transported into the steep offshore **fore reef** area and the shallower inshore **back reef** area. These sediments are dominated by reef-type carbonate fragments of all sizes, including mud. In many such areas, carbonate-rich sediments also accumulate in quiet lagoons, where mud and mollusc-shell fragments predominate (Figure 5.4.2a) or in offshore areas with strong currents, where either foraminifera tests accumulate (Figure 5.4.2b) or calcite crystallizes inorganically to form **ooids**—spheres of calcite that form in shallow tropical ocean water with strong currents (Figure 5.4.2c). **Coquina**, another type of limestone, forms from shells and shell fragments mechanically broken by waves and once deposited, loosely cemented together.
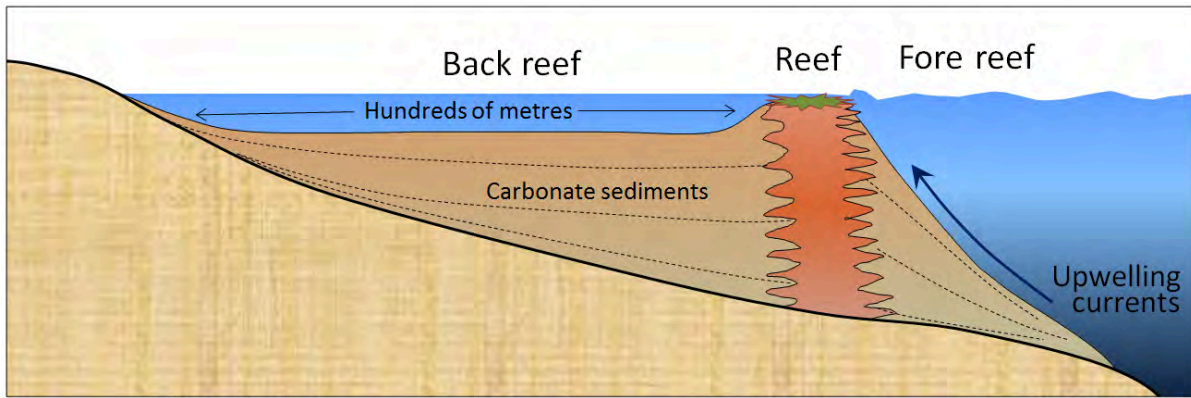
Figure 5.4.1: Schematic cross-section through a typical tropical reef.

Figure 5.4.2: Carbonate rocks and sediments: (a) mollusc-rich limestone formed in a lagoon area at Ambergris, Belize, (b) foraminifera-rich sediment from a submerged carbonate sandbar in Belize (c) ooids from a beach at Joulters Cay, Bahamas.

Limestone also accumulates in deeper water, from the steady rain of the carbonate shells of tiny organisms that lived near the ocean surface. For example, **chalk** forms from the accumulation of the calcite shells of microscopic organisms like foraminifera and coccoliths. The lower limit for limestone accumulation is around 4,000 metres. Beneath that depth, calcite is soluble so limestone does not accumulate.

Calcite can also form on land in a number of environments. **Tufa** forms at springs (Figure 5.4.3) and **travertine** forms at hot springs. Similar material precipitates within limestone caves to form **stalactites**, **stalagmites,** and a wide range of other **speleothems**. Tufa, travertine and speleothems make up only a tiny proportion of all limestone.

Figure 5.4.3: Tufa (yellow-brown colour to the right) formed at a spring at Johnston Creek, Alberta. The bedded grey rock to the left is limestone.

As all limestones are composed predominately of the carbonate mineral calcite, the fresh surface of a limestone will produce a strong reaction with dilute acid (i.e., will fizz vigorously). The carbonate mineral **dolomite (CaMg(CO$_3$)$_2$)**, on the other hand, only produces a weak reaction with dilute acid if powdered. This is one way to distinguish the mineral dolomite from calcite, and the rock dolomite from limestone. [3] Dolomite rock is quite common (there's a whole Italian mountain range named after it), which is surprising since marine organisms don't make dolomite. All of the dolomite found in ancient rocks has been formed through the chemical process of magnesium replacing some of the calcium in the calcite in carbonate muds and sands. This process is known as **dolomitization**, and it is thought to take place where magnesium-rich water percolates through the sediments in carbonate tidal flat environments.

Chert

Not all marine organisms make their hard parts out of calcite; some, like radiolarians and diatoms, use silica (SiO_2), and when they die their tiny shells (or tests) settle slowly to the bottom where they accumulate as **chert**. In some cases, chert is deposited along with limestone in the moderately deep ocean, but the two tend to remain separate, so chert beds within limestone are quite common (Figure 5.4.4), as are nodules, like the flint nodules within the Cretaceous chalk of southeastern England. In other situations, and especially in very deep water, chert accumulates on its own, commonly in thin beds.

Figure 5.4.4: Chert (brown layers) interbedded with Triassic Quatsino Formation limestone on Quadra Island, B.C. All of the layers have been folded, and the chert, being insoluble and harder than limestone, stands out.

Evaporites

In arid regions many lakes and inland seas have no stream outlet and the water that flows into them is removed only by evaporation. Under these conditions, the water becomes increasingly concentrated with dissolved salts, and eventually some of these salts reach saturation levels and start to crystallize (Figure 5.4.5). Although all evaporite deposits are unique because of differences in the chemistry of the water, in most cases minor amounts of carbonates start to precipitate when the solution is reduced to about 50% of its original volume. Gypsum ($CaSO_4·H_2O$) precipitates at about 20% of the original volume and halite (NaCl) precipitates at 10%. Other important evaporite minerals include sylvite (KCl) and borax ($Na_2B_4O_7·10H_2O$). Sylvite is mined at numerous locations across Saskatchewan from evaporites that were deposited during the Devonian (~385 Ma) when an inland sea occupied much of the region.

Figure 5.4.5: Spotted Lake, near Osoyoos, B.C. The patterns on the surface are salt. This photo was taken in May when the water was relatively fresh because of winter rains. By the end of the summer the surface of this lake is typically fully encrusted with salt deposits.

Coal

Coal, the first fossil fuel to be widely used, forms mostly on land in swampy areas adjacent to rivers and deltas in areas with humid tropical to temperate climates. The vigorous growth of vegetation leads to an abundance of organic matter that accumulates within stagnant water, and thus does not decay and oxidize. This situation, where the dead organic matter is submerged in oxygen-poor water, must be maintained for centuries to millennia in order for enough material to accumulate to form a thick layer (Figure 5.4.6a). At some point, the swamp deposit is covered with more sediment — typically because a river changes its course or sea level rises (Figure 5.4.6b). As more sediments are added, the organic matter starts to become compressed and heated. Low-grade **lignite** coal forms at depths between a few 100 m and 1,500 m and temperatures up to about 50°C (Figure 5.4.6c). At between 1,000 m to 5,000 m depth and temperatures up to 150°C m, **bituminous** coal forms (Figure 5.4.6d). At depths beyond 5,000 m and temperatures over 150°C, **anthracite** coal forms.
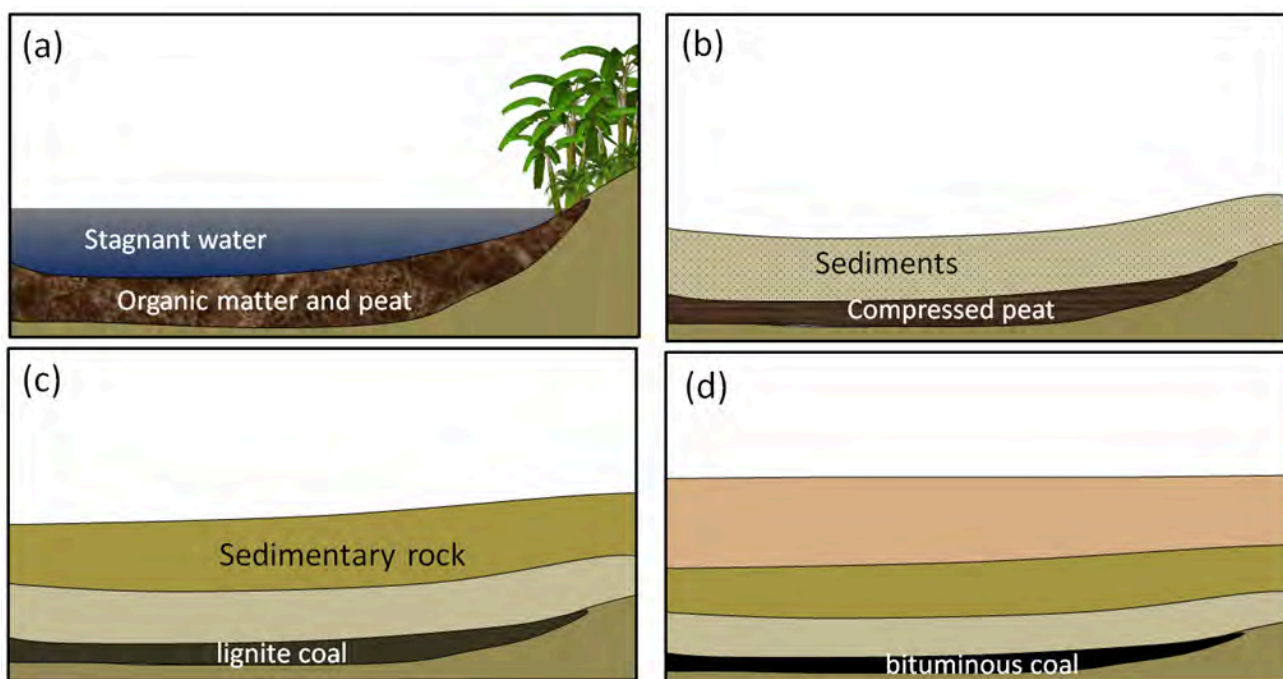

Figure 5.4.6: Formation of coal: (a) accumulation of organic matter within a swampy area; (b) the organic matter is covered and compressed by deposition of a new layer of clastic sediments; (c) with greater burial, lignite coal forms; and (d) at even greater depths, bituminous and eventually anthracite coal form.

There are significant coal deposits in many parts of Canada, including the Maritimes, Ontario, Saskatchewan, Alberta, and British Columbia. In Alberta and Saskatchewan, much of the coal is used for electricity generation. Coal from the Highvale Mine, Canada's largest, is used to feed the Sundance and Keephills power stations west of Edmonton. Almost all of the coal mined in British Columbia is exported for use in manufacturing steel.

Media Attributions

- Figure 5.4.2c: JoultersCayOoids by Wilson44691. Public domain.

Notes

1. We use the word *marine* when referring to salt water (i.e., oceanic) environments, and the word *aquatic* when referring to freshwater environments.
2. Note that the term "fossiliferous" can also be used to modify the name of a clastic sedimentary rock (e.g., shale, mudstone, sandstone) that contains recognizable evidence of past life.
3. Dolomite is both a name for a mineral and for a rock composed of the mineral dolomite (although some geologists use the term **dolostone** to avoid confusion).

5.5 Depositional Environments and Sedimentary Basins

Sediments accumulate in a wide variety of environments, both on the continents and in the oceans. Some of the more important of these environments are illustrated in Figure 5.5.1.
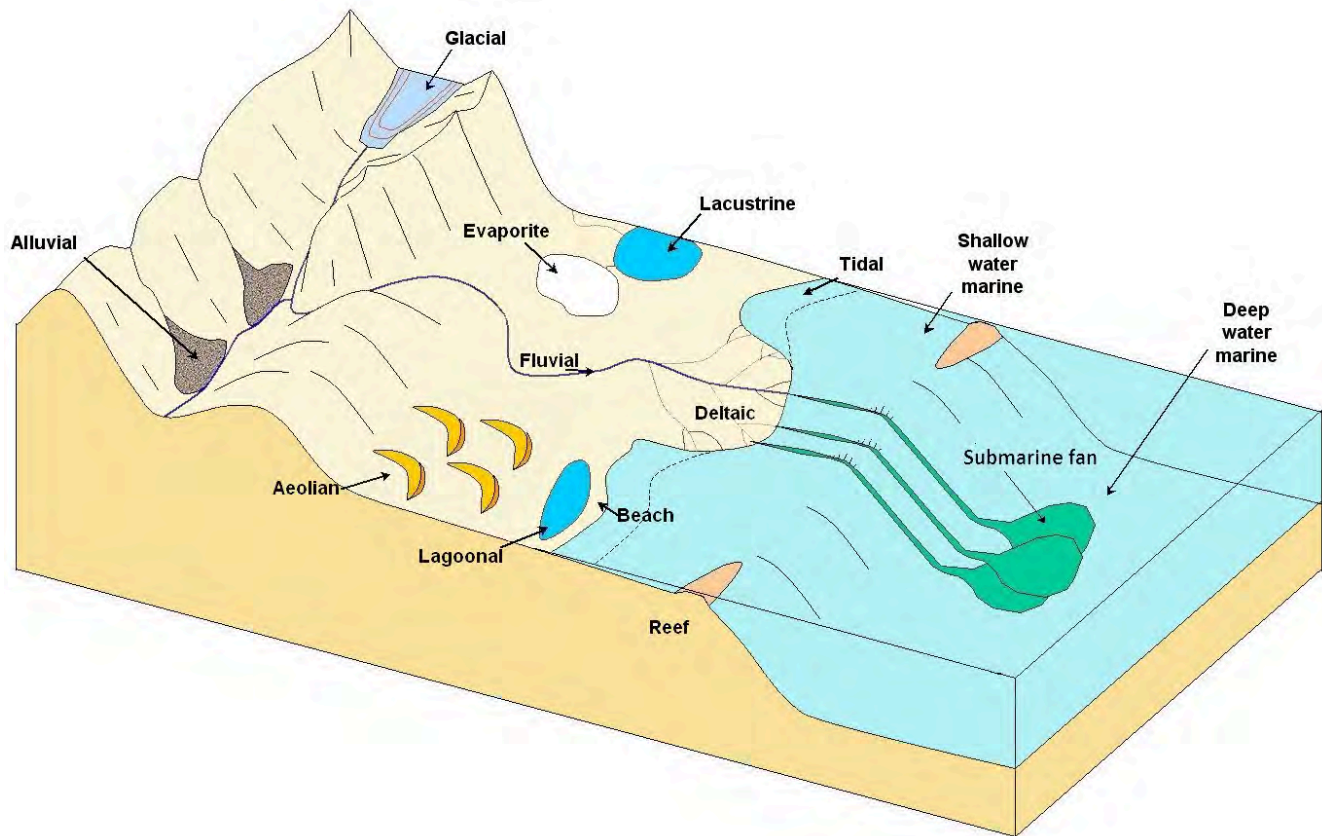
Figure 5.5.1: Some of the important depositional environments for sediments and sedimentary rocks.

Tables 5.6 and 5.7 provide a summary of the processes and sediment types that pertain to the various depositional environments illustrated in Figure 5.5.1. Careful observations of a sedimentary rock, including identifying its composition and texture, can provide clues about the ancient depositional environment in which it formed. We'll look more closely at the types of sediments that accumulate in these environments, and how sedimentary rocks and fossils can be used to interpret ancient environments and climates, in the subsequent geology course: GEOL 1103 Earth Through Time. The characteristics of these various environments, and the processes that take place within them, are also discussed in GEOL 1103.

Table 5.6 The important terrestrial depositional environments and their characteristics

Environment	Important transport processes	Depositional environments	Typical sediment types
Glacial	gravity, moving ice, moving water	valleys, plains, streams, lakes	glacial till, gravel, sand, silt, and clay
Alluvial	gravity	steep-sided valleys	coarse angular fragments
Fluvial	moving water	streams	gravel, sand, silt, and organic matter (in swampy parts only)
Aeolian	wind	deserts and coastal regions	sand, silt
Lacustrine	moving water (flowing into a lake)	lakes	sand (near the edges only), silt, clay, and organic matter
Evaporite	moving water (flowing into a lake)	lakes in arid regions	salts, clay

Table 5.7 The important transitional and marine depositional environments and their characteristics

Environment	Important Transport Processes	Depositional Environments	Typical Sediment Types
Deltaic	moving water	deltas	sand, silt, clay, and organic matter (in swampy parts only)
Beach	waves, longshore currents	beaches, spits, sand bars	gravel, sand
Tidal	tidal currents	tidal flats	silt, clay
Reefs	waves and tidal currents	reefs and adjacent basins	carbonates
Shallow water marine	waves and tidal currents	shelves and slopes, lagoons	carbonates in tropical climates, sand/silt/clay elsewhere
Lagoonal	little transportation	lagoon bottom	carbonates in tropical climates
Submarine fan	underwater gravity flows	continental slopes and abyssal plains	gravel, sand, mud
Deep water marine	ocean currents	deep-ocean abyssal plains	clay, carbonate mud, silica mud

Most of the sediments that you might see around you, including talus on steep slopes, sand bars in streams, or gravel in road cuts, will never become sedimentary rocks because they have only been deposited relatively recently—perhaps a few centuries or millennia ago—and are likely to be re-eroded before they are buried deep enough beneath other sediments to be lithified. In order for sediments to be preserved long enough to be turned into rock—a process that takes millions or tens of millions of years—they need to have been deposited in a basin that will last that long. Most such basins are formed by plate tectonic processes that create enough space for sediments to accumulate in great thicknesses, and some of the more important examples of tectonic basins are shown in Figure 5.5.2.

 Trench basins (a in Figure 5.5.2) form where a subducting oceanic plate dips beneath the overriding continental or oceanic crust. They can be several kilometres deep, and in many cases, host thick sequences of sediments from eroding coastal mountains. There is a well-developed trench basin off the west coast of Vancouver Island, B.C. A **forearc basin** (b in Figure 5.5.2) lies between the subduction zone and the volcanic arc, and may be formed in part by friction between the subducting plate and the overriding plate, which pulls part of the overriding plate down. The Strait of Georgia, the part of the Pacific Ocean between Vancouver Island and mainland North America, is a forearc basin. A **foreland basin** (c in Figure 5.5.2) is caused by the mass of the volcanic range depressing the crust on either side. Foreland basins are not only related to volcanic ranges, but can form adjacent to fold belt mountains like the Canadian Rockies. A **rift basin** (d in

Figure 5.5.2) forms where continental crust is being pulled apart, and the crust on both sides of the rift sub-sides. As rifting continues this eventually becomes a narrow sea, and then an ocean basin. The East African rift basin represents an early stage in this process.
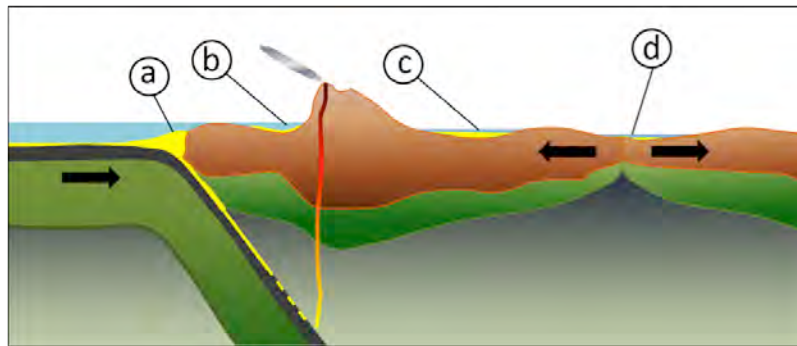

Figure 5.5.2: Some of the more important types of tectonically produced basins: (a) trench basin, (b) forearc basin, (c) foreland basin, and (d) rift basin.

Media Attributions

- Figure 5.5.1: Schematic diagram showing types of depositional environment © Mike Norton. Adapted by Steven Earle. CC BY-SA.
- Figure 5.5.2: © Steven Earle. CC BY.

Lab 5 Exercises

The exercises below will guide you through the sedimentary rock samples in Rock Kits 1 and 2. Review the background information presented in Chapters 5.1 to 5.5 before you begin these exercises. You may wish to consult the Rock Classification Tables at the back of this manual as you complete the exercises below.

Tips for Classifying Sedimentary Rocks

- Your first step when examining any sedimentary rock is to determine if its texture is **clastic** or **crystalline**.
- If the texture is clastic, next determine the predominant size of the grains by looking closely through your hand lens and using the grain size chart (see Table A in the Rock Classification Tables appendix).
- Next, describe the sorting, and the shape (roundness) of the grains (Figure C in the Rock Classification Tables appendix). Remember that you are not describing the shape or size of the sample, but of the grains within it!
- If the texture is crystalline, test the sample with a drop (only a drop!) of dilute HCl. If the rock reacts with HCl, look carefully to determine what exactly is reacting (e.g., cement between grains of quartz sand? The entire sample of limestone?).
- Quartz grains come in many colours, but always have vitreous lustre.
- Feldspar grains are commonly white or pink in colour, and in very coarse-grained clastic sedimentary rocks, you may even see feldspar grains broken along cleavage planes. Feldspar grains that have been chemically weathered tend to look chalky and dull (see Figure 5.1.4), which can help you differentiate them from quartz grains.

1. Using your hand lens, carefully examine samples R151, R161, R162, and R181 from your Rock Kit to complete the table below. The example provided indicates the level of detail expected of your observations.

Sample #	Grain Size (mm)	Energy Level	Roundness	Sorting	Composition (grains and cement)	Rock Name
Example	0.5–2 mm (sand)	Moderate	Sub-rounded	Moderately sorted	65% quartz, 35% rock fragments, calcite cement	Lithic arenite
R151						
R161						
R162						
R181						

2. Are all four samples in the table above chemical or detrital (clastic) in origin? How can you tell?

_____

_____

3. Indicate where on the diagram each of the samples from the table above is most likely to have formed by considering the grain size, roundness, sorting, and composition.
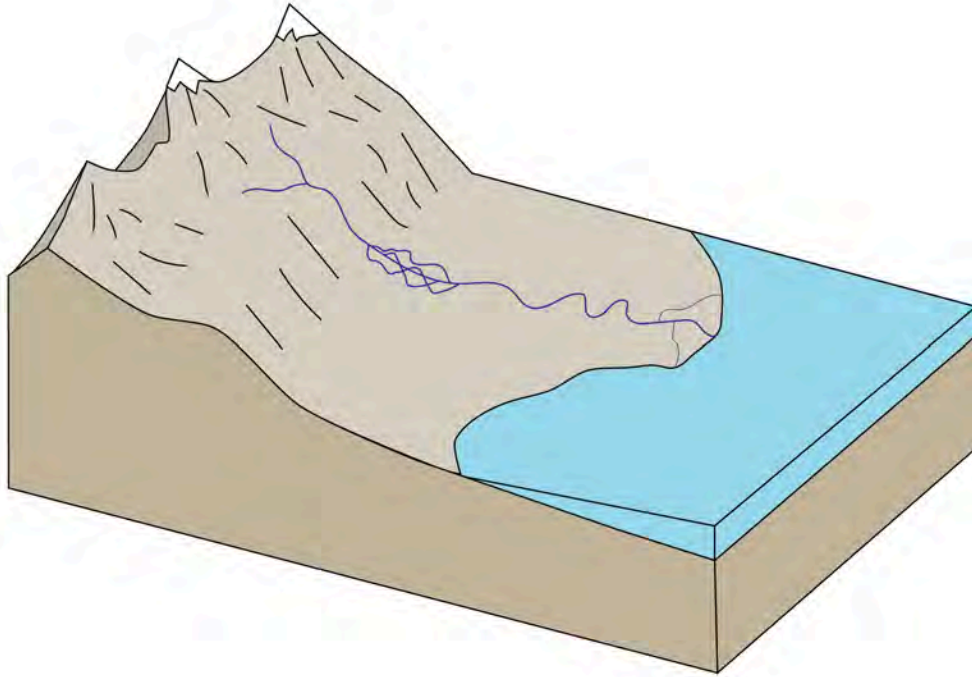

Figure A

4. Imagine a large granite **pluton** has been uplifted and exposed at the surface. Imagine that this granite is the source material for samples R161 and R162.
    a) List the minerals you would expect to find in this granite, and their typical weathering products.

_____

_____

_____

b) If these two samples originated from the same source material, explain what process(es) are responsible for the key difference(s) between them? Hint: examine your answers in the table above.

_____

_____

_____

_____

5. Examine chemical sedimentary rock samples RI91, R201, R211, R221, R231, R251, R261, R271, and R281. In the table below, name the mineral and chemical sedimentary rock(s) from your rock kits that correspond to the composition provided. As you examine each rock sample, think about what physical properties the mineral and the rock have in common. You may want to review the physical properties of minerals summarized in Labs 2 and 3, and in the mineral identification tables.

Composition	Mineral Name	Rock Sample #	Rock Name	Diagnostic Properties Common to Both Rock and Mineral
$CaCO_3$				
SiO_2				
NaCl				
$CaSO_4 \cdot H_2O$				
C (mostly)	N/A			

6. Examine sample R201. What shape are the grains? _____

7. The small rounded grains that you see are called **ooids**, and the textural term for a rock with ooids is ____ _____.

   8. How do you think the ooids formed?

_____

_____

9. Name this rock: _____

   10. Examine sample R211 (coquina). Look closely at the larger grains. What would be a more appropriate term than 'grains'?

_____

11. What is the main component of the rock? _____

12. Compare samples R211 and R221. How are these two samples similar? How do they differ, and how would you distinguish one from the other?

_____

13. Examine sample R231. This is a type of limestone known as **chalk**. It is composed mainly of shelly remains of microscopic animals. Scratch this sample with your fingernail. Why does it seem so much softer than a crystal of calcite?

_____

_____

14. Examine sample R251. The black colour is due to the very high organic content of the rock. This type of rock is combustible. Name this rock: _____

   15. How does this type of sedimentary rock form?

_____

_____

16. Examine samples R271 and R281. These are both examples of **evaporites** – they have formed by precipitation of crystals from a solution. In what ways do these two different samples differ?

_____

_____

17. Studying sedimentary rocks provides geologists with a window into the past. Simple observations about composition and texture of a rock sample can give a geologist important clues about the ancient environment in which a sedimentary rock formed. Use your observations of sedimentary rock samples R151, R161, R181, R221 and R281, and the information provided in Chapter 5.5 to complete the table below. You should find more than one possible depositional environment for most samples. In higher level geology courses, you will learn additional features to observe to narrow down the possible depositional environments for a sample.

Sample	Possible environment(s) of deposition	Evidence
R151		
R161		
R181		
R281		
R221		

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Summary

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

Section	Summary
5.1 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. 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.
5.2 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. Without weathering, there would not be sediment available to eventually form sedimentary rocks!
5.3 Clastic Sedimentary Rocks	Sedimentary clasts are classified based on their size, and variations in clast size and shape have important implications for transportation and deposition. Clastic sedimentary rocks are classified based on their grain size and composition. Clast size, sorting, composition, and shape are important features that allow us to differentiate clastic rocks and understand the processes that took place during their deposition.
5.4 Chemical Sedimentary Rocks	Chemical sedimentary rocks form from ions that were transported in solution, and then converted into minerals by biological and/or chemical processes. The most common chemical rock, limestone, typically forms in shallow tropical environments, where biological activity is a very important factor. Names of limestones can be modified with textural terms like crystalline, oolitic, or fossiliferous. Chert is a deep-ocean sedimentary rocks. Evaporites (rock salt and rock gypsum) form where the water of lakes and inland seas becomes supersaturated due to evaporation. Coal forms in swamps from decaying plant remains.
5.5 Depositional Environments and Sedimentary Basins	There is a wide range of depositional environments, both on land (glaciers, lakes, rivers, etc.) and in the ocean (deltas, reefs, shelves, and the deep-ocean floor). In order to be preserved, sediments must accumulate in long-lasting sedimentary basins, most of which form through plate tectonic processes.
Lab 5 Exercises	The best way to learn rock identification is to practice by examining the samples in your Rock Kit 1 and 2. The first step when examining a sedimentary rock is to identify the texture. Clastic sedimentary rocks have clastic textures, and are classified based on grain size, and for sandstones, also by composition. Chemical sedimentary rocks are often monomineralic and are classified based on composition. Chemical sedimentary rocks can have a range of textures (crystalline, clastic, bioclastic, fossiliferous, oolitic, and amorphous). Knowing the diagnostic properties of the main minerals that form chemical sedimentary rocks will help you correctly identify the rock. Just as with mineral samples, different samples of the same rock may not always look exactly the same (e.g., tan versus blue-grey crystalline limestone), but they can always be identified by closely examining the mineral composition and texture.