Rocks

Rocks are mixtures of one or more minerals. Sedimentary rocks are made of solid, loose pieces of rocks (in the form of sand, silt, clay, and gravel), or the remains of living things found at the surface of the Earth, that over a very long period of time, has become compacted and cemented into sedimentary rock. Igneous rocks come from melted rock material, or magma, that lies beneath Earth's surface. Metamorphic rocks are rocks that have become changed by intense heat or pressure while forming.

What are sedimentary rocks?

Figure 1. Sedimentary rocks showing the common feature of horizontal layers, form by deposition of sediment. Credit: M. Miller.

Sediment is made up of solid, loose pieces of rocks (in the form of sand, silt, clay, and gravel), or the remains of living things found at the surface of the Earth. Sediment is material that has been eroded and deposited by wind, running water, waves, and ice.

Sediment can also form from material left behind by the evaporation of seawater, or the settling of the remains of animals and plants in oceans, lakes, and swamps. In certain conditions, and over a very long period of time, sediment can become compacted and cemented into sedimentary rock. Sedimentary rock is often found in layers. One way to tell if a rock sample is sedimentary is to see if it is made from grains.

What are igneous rocks?

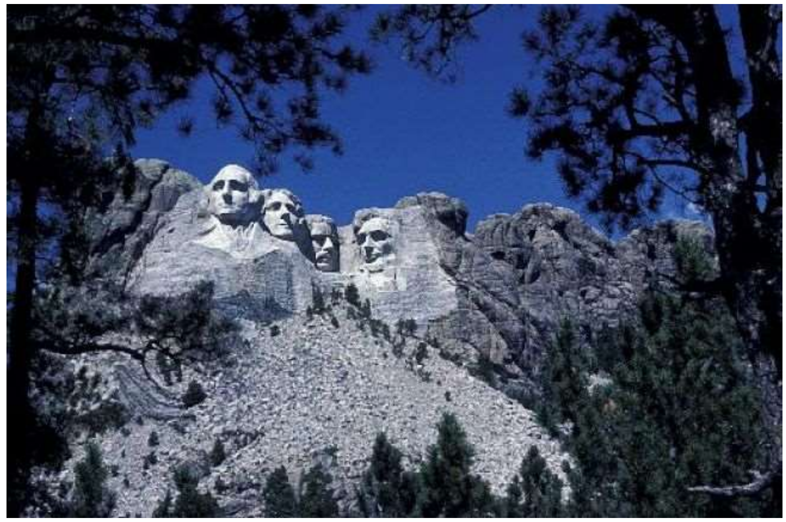

Figure 2. Igneous rock is ideal for carving, as it has a high resistance to weathering. Credit: D. Spier.

Rocks are mixtures of one or more minerals. Just like the apples, butter, flour, and sugar are the ingredients of apple pie, minerals like quartz, mica, and feldspar are the ingredients of an igneous (from the Latin word for fire) rock called granite.

Igneous rocks come from melted rock material, or magma, that lies beneath Earth's surface. Igneous rocks form when magma from inside the Earth moves toward the surface, or is forced above the Earth's surface as lava and ash by a volcano. Here it cools and crystallizes into rock. There are two categories of igneous rocks. When magma crystallizes under Earth's surface, it produces intrusive igneous rock with large crystals. When lava crystallizes above Earth's surface, it produces extrusive igneous rock with crystals that are too small to see. Igneous rocks are very hard and made of interlocking crystals.

What are metamorphic rocks?

Figure 3. An example of metamorphic rock showing characteristic folded layers formed by increased pressure and/or temperature. Credit: Miller.

Metamorphic rocks are rocks that have become changed by intense heat or pressure while forming. In the very hot and pressured conditions deep inside the Earth's crust, both sedimentary and igneous rocks can be changed into metamorphic rock. In certain conditions these rocks cool and crystallize usually into bands of crystals. Later they can become exposed on Earth's surface. One way to tell if a rock sample is metamorphic is to see if the crystals within it are arranged in bands.

One way to think about the metamorphic process (metamorphism) is to consider what happens when soft clay objects are put into a kiln and heated to a very high temperature. They change from being squashy to rock hard. They cannot be changed back to their original form. The material has been changed. This is what happens on a huge scale underground producing metamorphic rock.

What is weathering?

Rock is either broken into smaller particles (disintegration-physical weathering) or altered into other kinds of minerals (decomposition - chemical weathering). Although these processes do not occur in isolation, it is easier to understand them by considering them separately.

What is physical weathering?

Sometimes called mechanical weathering, physical weathering is the process that breaks rocks apart without changing their chemical composition. These examples illustrate physical weathering:

- *Swiftly moving water*

  Rapidly moving water can lift rocks from the stream bottom. When these rocks drop, they collide with other rocks, breaking tiny pieces off.

- *Ice wedging*

  Ice wedging causes many rocks to break due to repeated freezing and melting of water within small crevices in the rock surface. This expansion and contraction is also a major cause of potholes in streets. Water seeps into cracks in the rocks, and, as the temperature drops below freezing, the water expands as ice in the cracks. The expansion exerts tremendous pressure on the surrounding rock and acts like a wedge, making cracks wider. After repeated freezing and thawing of water, the rock breaks apart.

- *Plant roots/growth*

  Plant roots can grow in cracks. The pressure of a confined growing root can be substantial. These pressures make cracks in the rocks larger, and, as roots grow, they can break rocks apart.

What is chemical weathering?

This is the decomposition of rocks due to chemical reactions occurring between the minerals in rocks and the environment. The examples below illustrate chemical weathering.

- *Water*

  Water is the main agent of chemical weathering. Feldspar, one of the most abundant rock-forming minerals, chemically reacts with water and water-soluble compounds to form clay.

- *Acids*

  Water contains many weak acids such as carbonic acid. This weak, but abundant, acid is formed when carbon dioxide gas from the atmosphere mixes with rainwater. Sulfur dioxide and nitrogen gases (both from many sources, like power plants and volcanoes) create other types of acid rain that act as chemical weathering agents. Although relatively weak, acid's abundance and long-term effects produce noticeable damage to vegetation, fabrics, paints and rocks.

Figure 4. A statue made of limestone is worn away by acid rain. Credit: Creative Commons 3.0.

- *Oxidation*

  Oxidation is another kind of chemical weathering that occurs when oxygen combines with another substance and creates compounds called oxides. Rust, for example, is iron oxide. When rocks, particularly those with iron in them, are exposed to air and water, the iron undergoes oxidation, which can weaken the rocks and make them crumble.

What are the biological processes of weathering?

Figure 5. Lichen weathers rocks and other substrates on which they grow. Credit: Fellows.

Living things also help form soil. Once rock is weathered into smaller particles, microorganisms and small plants begin to establish themselves there. The microorganisms' metabolisms release carbon dioxide which readily dissolves in water, forming additional amounts of carbonic acid. The weathering process continues, creating finer particles of new minerals.

Burrowing animals

Soil formation is enhanced by many organisms, from one-cell organisms to the mammals that make a temporary or permanent home in soil. One of the best known burrowing animals is the earthworm (*Lumbricus terrestris*). This organism plays an important role in soil ecology. As they tunnel through soil, earthworms make a network of spaces which help aerate the soil, improving the soil's texture and water drainage. Earthworms also deposit waste along the burrow, which enrich soil with both organic and inorganic materials that the earthworm has eaten.

Organic material

Organic material is added to the soil from the decomposition of animals and plants. The remains of once living things in soil provide nutrients for other organisms. Soil fertility is increased as more organisms inhabit the soil and as decayed material (humus) is added to mineral particles. Humus also increases the soil's capacity for holding water and air, both necessary for plant growth.

Lichens

Lichens are some of the first living organisms that establish themselves on barren rock. Lichens are made up of algae and fungi, which live together in a symbiotic, mutualistic relationship (an interaction in which two organisms depend upon each other). The algae produce food for the fungi and the fungi provide water and protection for the algae. Lichens produce a dilute, acidic solution that slowly causes some minerals in rock to decompose.

What is river and stream erosion?

Streams erode and transport sediment. As the loose sediments are moved along the bottom of the river channel, small bedforms (formations of sediment on the bottom of the stream bed) can develop, such as ripples and sand dunes. The total load (quantity of sediment) of a stream can be described as consisting of three components:

Figure 6. Rivers and streams can erode rock and move sediment. Credit: M. Collier.

1. the bed load - materials bounced along the stream bottom
2. the suspended load - material carried in suspension in the stream water
3. the dissolved load - material carried as dissolved solids in the stream water

The maximum size of particle that is stream is capable of transporting is termed its competence and is strongly related to velocity. The capacity of a stream is a measure of the total load that a stream can carry and is controlled by the discharge.

- *Alluvium*

  All material moved and deposited by streams is termed alluvium. Alluvial rivers are those streams whose bed and banks consist of alluvium, and can be divided into three main types: braided, meandering and straight channels.

- *Deltas*

  Deltas are depositional landforms that consist largely of alluvium, where a river enters a standing body of water and deposits sediment. Alluvial fans are similar, but are deposited in areas where there are abrupt changes in channel gradient. These landforms are best observed in arid settings at the base of a mountain range.

- *Floodplain*

  The floodplain of a stream is the low-lying land adjacent to the channel that periodically is flooded. The position of an alluvial stream channel can, through time, move across the floodplain as the channel erodes and re-deposits the sediment.

- *Drainage basin*

  A drainage basin is the area of land that drains to a given stream, and is bound by a high topographic ridge called a drainage divide. The drainage pattern is the arrangement of streams within a drainage basin. For example, the most common drainage pattern is termed dendritic, because streams tend to branch into smaller and smaller tributaries in an upstream direction.

- *Rivers and streams*

  Rivers or streams behave as systems. If you disturb one part of the stream channel, it will cause changes in an upstream and downstream direction. Constructing a dam will cause deposition in the reservoir behind the dam and erosion downstream. Constructing levies will reduce the amount of sediment delivered to floodplains and increase the amount of sediment carried and deposited downstream.

What is shoreline erosion?

Erosion always has been, and still is, a natural part of the rock cycle. The landforms that you can see along any coastline have evolved naturally over millions of years.

Figure 7. Waves can break down rock along shorelines and can also transport sediment. Credit: M. Collier.

How beaches form

The accumulation of sediment along a coast produces depositional landforms. A beach consists of sand, gravel, or crushed seashells that have been brought to the body of water by rivers and streams, carried by waves, and deposited on the coast.

Beach formation begins as eroded continental material--sand, gravel, and cobble fragments--is washed to sea by streams and rivers. Two processes result in the deposition of this sediment on the shore. Most sediment is suspended in sea water and transported along the coast by the longshore current, a stream of water flowing parallel to the beach that is created by the action of waves breaking at an angle to shore. In the second process, sand deposited onshore by the longshore current is then oscillated by waves breaking onto and receding from the beach. This continual onshore-offshore movement gradually pushes the sand along the beach edge. If wave movements were identical in speed and duration, the sediments would not be left behind on shore and beaches could not form.

Beaches as landforms

Beaches are dynamic landforms. They are altered by wind and waves in a continual process of creation and erosion. Seasonal cycles of sand deposition and loss dramatically affect the appearance of beaches from summer to winter. Wide and gently sloping in summer, they become steep-fronted and narrow in winter, and can vanish overnight, stripped of sand by violent storm waves. Most of the sand removed from winter beaches is deposited in offshore sandbars and is returned to the beach during the mild summer months by gentle swells that push the sand to the exposed shore. River sediments are the source of 80 to 90 per cent of beach sand; some beaches are built to great widths by sediments washed to the sea by episodic floods, gradually eroding until the next major flood replenishes the sand.

Coastline changes

Coastlines are constantly changing due to the action of waves, currents, and tides. Landslides and cliff retreat are part of the natural process of coastal erosion along the shore. Waves that undercut bluffs often initiate landslides. Lake Erie, Ohio is an excellent example. The eastern side of the Lake Erie shoreline in Ohio is made of unconsolidated glacial sediments. These deposits (glacial till and lake clays and silts) are prone to wave erosion at the base of the bluff. This erosion is greater when the lake level is high during large storms. The constant removal of sediment at the base of the bluff by waves prevents the slope from stabilizing. Many lakeshore homes, roads, and other structures have been destroyed in these areas, where the rate of bluff retreat approaches 7 feet per year.

Material types and shorelines

A great variety of depositional and erosional landforms can develop along shorelines. A major control on the appearance of the shoreline is kind of rock acted upon by water and wind. Volcanic rock cliffs are usually steep. Granite normally erodes into rounded domes, while limestone may form nearly vertical cliffs. The type of material at the shoreline has a significant effect on the rate of erosion.

Techniques that try to prevent beach erosion revolve around methods to limit the removal of sediment along specific areas of the coast or involve adding material to areas undergoing erosion. Examples include jetties, groins, and breakwaters. Jetties and groins are artificial structures built perpendicular to the shoreline to prevent longshore drift. Breakwaters are artificial structures built parallel to the shoreline in order to protect the shore from wave action. Unfortunately, nearly all these methods have shortcomings.

How do you deal with shoreline erosion?

The desire to build structures on coastlines has often interfered with the natural erosion processes. There are many kinds of human-built structures that can be found on coastlines. They include lighthouses, commercial shipping ports, hotels, recreational marinas, and houses.

Protecting human-built structures from coastline erosion has been going on for centuries. Humans have devised many different ways of doing this. Examples include groins, jetties, and breakwaters.

Groins

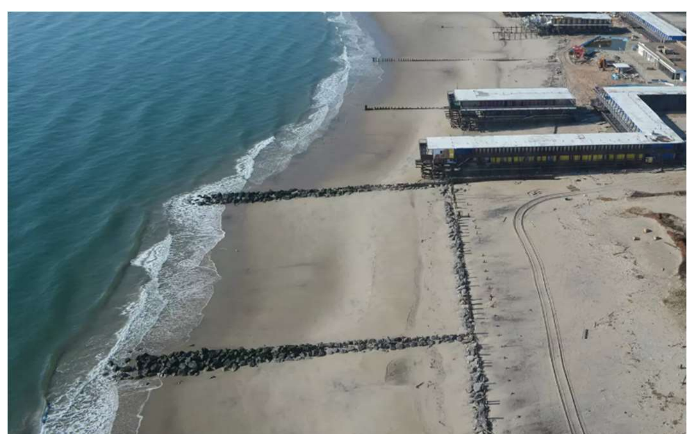
Figure 8. A series of groins built along a shoreline to slow erosion of the beach. Credit: NPS.

Groins are long, wall-like structures built along beaches that extend out into the ocean. Groins are constructed of stone rip rap, steel sheet pilings, or timber pilings. Their purpose is to act as barriers to longshore currents in order to control or modify sand movement. A longshore current will lose velocity as it meets the groin, causing the current to dump part of its sediment load on the upcurrent side of the groin. This builds up the adjacent beach. However, as the current passes the groin it picks up additional sediment on the downcurrent side of the structure. This causes local erosion. Although this method of ceasing beach erosion can be very effective, its drawbacks are obvious. Wherever sand on one beach is increased, other beaches down the coast lose a lot of sand. This process often leads to a domino effect. Once one groin is put into place, another is needed at the beach next door.

Jetties

Jetties are long structures built perpendicular to the shoreline and extending out into the ocean. They are constructed of timber, stone, concrete, or steel. Their main function is to keep sand from flowing into a ship channel, which would make the channel increasingly shallow over time (shallow waters cause for ships to run aground). There are often two jetties used, one for each side of the channel. Erosion prevention is another benefit of jetties. Sand that builds up against the jetty can be redistributed along the beach. Jetties also prevent littoral drift and storm waves from entering protected channels. There are drawbacks to jetties, though. Sand starvation and retreat of the shoreline on the downdrift side are possible.

Breakwaters

Breakwaters are barriers built offshore to protect part of the shoreline. They act as a barrier to waves, preventing erosion and allowing the beach to grow. The dissipation of wave energy allows material carried by longshore currents to be deposited behind the breakwater. This protects the shore. However, the beach behind the breakwater often grows at the expense of the shoreline that is not protected by the structure. The amount of deposition depends on the site characteristics and the design of the breakwater. Breakwaters may be either fixed or floating: the choice depends on normal water depth and tidal range.

What is glacial erosion?

How Glaciers Form

Glaciers are sheets of solidly packed ice and snow that cover large areas of land. They are formed in areas where the general temperature is usually below freezing. This can be near the North and South poles, and also on very high ground, such as large mountains. Snow upon snow on the land becomes compacted and turns into ice. Think about when you make a snowball. You gather fluffy snow in your hands and then press it together. The heat and pressure from your hands make some of the snow melt. When you take a hand away, the liquid water freezes again. The fluffy snow has been compacted into a hard snowball.

Glaciers are formed in a similar way, but on a much larger scale. Sunlight melts some of the snow. Then it freezes during the night, or if the temperature drops. More snow falls onto the surface. Eventually, the weight of snow layers upon snow layers, and the melting and freezing, turns the layers into solid ice. If this ice forms at a high elevation, it starts to slowly slip downhill as an ice "river." It is called a glacier. On flat land this ice is called an ice cap.

Ice changing the land

Ice can change the surface of the land. When you look around you, you may not see snow or ice that lasts all year long. That's what it takes to make a glacier. More snow must fall in a region in winter than melts in summer. When this happens, the amount of snow builds up over time. It's a lot like money in the bank. If you put more in than you take out, your bank account will grow. Glaciers work the same way. When enough snow builds up in an area, the snow on the bottom becomes compacted by the weight above, changing it into ice. You may have simulated this when making an ice ball out of snow or crushed ice.

Ice flows

Figure 9. The weight of a glacier can cause it to flow downhill, eroding away rock as it flows. Credit: NOAA.

What's amazing about ice is that it can flow. This means that ice in glaciers can move from one place to another. It's not easy to comprehend how a solid can actually flow. Think about candy licorice. It's a solid, but if you pull on both ends, it can be stretched, right? The force applied by your hands can make solid licorice flow. In glaciers, the force applied to ice by the weight of all the ice and snow above it can make it flow. As snow piles up, glacial ice flows sideways and downhill, making the glacier cover larger and larger areas over time. The growth of glaciers continues so long as there is more snow being added to the glacier than removed or melted away.

Maple syrup is a useful way to model the way the piling up of ice makes it flow. Pour a single small drop of syrup onto a flat plate, and it will just sit there. Try the experiment again, but this time keep pouring out the syrup, and you will find that the weight of the "pile" makes the syrup flow away from the center. Glacial ice does the same thing - it flows under its own weight. Glacial ice can also flow downhill by the force of gravity. Try the syrup test again. Place a small drop on a plate, and nothing happens. But then tilt the plate at an angle, and the drop of syrup will begin to flow downhill under the force of gravity.

All glaciers are not the same. There are two major types of glaciers. One type, called continental glaciers (or ice sheets) is more like the pile of syrup on the flat plate. They form in polar climates by the buildup of vast amounts of snow in a region over time. The Antarctic and Greenland Ice sheets are two current examples of continental glaciers. Valley glaciers are more like the drop of syrup that flows down a sloping plate. They form in areas of high elevation, where snowfall is high, and the weather is cold most of the year. Valley glaciers tend to be long and small compared to ice sheets, which are large. The higher elevation region of valley glacier receives more snow than melts. The bottom or downhill end of valley glaciers is just the opposite - there is more melting than adding going on. Overall, if there is more snow being added than is being melted, on either a continental or valley glacier, the glacier will advance or grow.

It may be difficult to imagine, but the Earth's climate has changed greatly over time. The Earth has gone through many cycles of warmer and colder average temperatures. Although the overall change in average global temperature may be as little as several degrees C, this is enough to change the amount of snow that falls or melts in a given region in a year. Suppose for example that the Earth goes through a cooling cycle for several thousand years. More snow falls than melts, and glaciers grow over time. In the past one million years, glaciers have advanced and retreated great distances (thousands of kilometers) at least four times. The last advance was enough to cover vast portions of the northern United States with a thick continental glacier.

As glaciers spread out over the surface of the land, (grow), they can change the shape of the land. They scrape away at the surface of the land, erode rock and sediment, carry it from one place to another, and leave it somewhere else. Thus, glaciers cause both erosional and depositional landforms.