Welcome to the sixth episode in the Wolf Ridge Adventures in Learning series! Today, Wolf Ridge naturalists Caroline and Robby are exploring geology. They’re taking a tour of the geology of the North Shore and talking about the rock cycle, glaciers, lava eruptions, and more.

A great place to start thinking about Minnesota geology is with agates. They can be found all over the state; they’re actually the state gemstone!

Agates are a sedimentary rock that forms inside an igneous rock. Igneous rocks are created when liquid magma (lava) cools and hardens. Just like the bubbles in a can of pop, magma has air bubbles floating it. When the magma cools, those bubbles are trapped in the rock leaving air pockets. Over time, water flows into those holes in the igneous rock and deposits minerals in them. Layer after layer of these minerals accumulate until the hole is filled up. We see these layers in the stripes of the agates.

The Rock Cycle
The agate example includes two of the three types of rocks: igneous and sedimentary. The third is metamorphic. All rocks can be put in one of these three categories, but they can also change to another type of rock if certain things happen to them. That’s why it’s a rock cycle.

Check out this model of the rock cycle to see what processes can transform a rock from one type to another.

- **Igneous** rocks come from magma or lava. As it cools it solidifies into igneous rock.

- **Sedimentary rock** is created by layers of sediment becoming smushed together to form a rock. For example if rain eroded a volcanic hillside, depositing smaller rock at the bottom. Over time these little pieces of sediment build up and slowly start to solidify. Eventually the bottom turns into sedimentary rock.

- If heat and pressure are added, the rocks minerals can melt slightly and rearrange into **metamorphic rock**. This happens when a rock gets buried deep in the earth. The pressure of all the rocks above it and the heat of the core of the earth cause it to get gooey and melt. A good example of how pressure creates heat is to press your hands together hard while rubbing them back and forth, which creates heat.

Geology of the North Shore
It’s time to find some real-life examples of these rock types. Geologist and Wolf Ridge Naturalist, Carrie Anderson, is here to help us.
1.1 billion years ago a mid-continental rift that was 50-100 miles wide opened up where Lake Superior is today. This rift thinned the earth’s crust enough that lava bubbled up out of it and flowed across the land. The igneous rock the lava created makes up the north shore of Lake Superior.

These lava flows have distinctive shapes, textures, and colors that tell us about how it formed. As lava first flows out, it is really hot making it move fast and thin. This leaves a ropey texture and is the top of a lava flow. Below is the vesicular layer. This layer is full of gas bubbles. Then, the next layer down is called the massive layer where there are no bubbles. The bottom layer of a lava flow is full of pipe amygdules, tracks where gas tried to travel up the lava flow.

Some lava flows are only a few inches thick and others are several feet thick. Many places on the North Shore you can tell where a new lava flow starts because there is a huge wall of rock marking the edge of a newer flow, often with waterfalls cascading from one flow to another below.

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The steeply sloping shoreline of Lake Superior is evidence of how the lake was formed. The lava from the mid-continental rift flowed out and hardened like a pancake. Thousands of years later, glacial ice that was 2 miles thick slowly sunk the lava “pancake” down with its weight, creating the sunken bowl shape of Lake Superior. The steep shoreline and the hilly Sawtooth Mountains along the shore show where the edge of the lava rose up as the middle sunk.
Cut Face Creek: Sedimentary Rock

This wall of rock at Cut Face Creek near Grand Marais shows our second type of rock: sedimentary.

This sandstone is about 1 billion years old. It was formed by water eroding the top of the dark basalt underneath. You can find ancient ripple marks left behind by the flowing water that eroded the basalt and formed this sand. Over many thousands of years the sand slowly built up and started to solidify into sandstone. Once formed, sandstone is more susceptible to erosion than other rocks.

The reason the sandstone is so red is due to the iron in the stone that has rusted.

This layer of sandstone formed in between two major eruptions from the mid-continental rift. That’s the same rift we learned about at sugarloaf. The two lava flows created a rock sandwich with volcanic crust and a sedimentary rock filling! The pattern of these layers shows the Principle of Superposition. The Principle of Superposition describes a pattern of undisturbed layers where the oldest layer is at the bottom, and successively higher layers are successively younger. So here at Cut Face Creek we have the oldest bottom layer of basalt from the first lava eruption, then the sandstone layer that was deposited next, and finally the second eruption of lava that created another basalt layer.

Ely Greenstone: Metamorphic Rock

The Ely greenstone originally formed 2.7 million years ago as basalt under a shallow sea. We know that because of these really distinctive “pillow” shapes on the rock which is created by lava being instantaneously cooled as it flows underwater.

After it was formed, it was slowly covered by layers and layers of other rocks, slowly pushing it deeper and deeper in the earth’s crust. There, the heat and pressure cooked the rock and allowed some of the minerals in the rock to be rearranged, which changed it from basalt into greenstone. Then all the rock that was covering the greenstone eroded away until it was exposed to the surface. So deposition (rock being added) and erosion (rock being removed) were part of this rock cycle! Because this process takes so long, metamorphic rocks are often some of the oldest rocks in the world.

Glacial Erosion

The rock cycle tour showed us close-up examples of specific rock types. Now it’s time to take a step back and look at the big picture of how rocks shape the landscape.

Landscapes are changed though either the process of deposition (build up of new rocks) or erosion, wearing down existing rocks. One of the major events that shaped the North Shore was the last Ice Age, 10,000 years ago. During that time glaciers covered much of minnesota. A glacier is a giant sheet of ice that does not melt seasonally. During the last Ice Age, the ice covering Minnesota was a mile thick in places.

Glaciers were so powerful that we can still see marks of them today, both in the
landscape and on individual rocks. This rock here has a large glacial striation (a scratch mark) caused by a glacier slowly dragging other rocks stuck to its underside across this bedrock.

As the glaciers got more ice deposited on top of them, they got heavier and heavier until they began to move. As they slid across the landscape they acted like a giant piece of sandpaper. This is called scouring; the ice basically acts like a piece of sandpaper rubbing and smoothing across the ground. But just like sandpaper, the ice had a different amount of smoothing effect depending on how hard the rocks it moved across were. This caused different rocks to be smoothed away to nothing, while other harder rocks to be left behind. This process is called differential erosion, and it's the reason that these tall ridges and hills exist at Wolf Ridge today.

Many of the high points at Wolf Ridge and along the North Shore are made of really hard rock. That's because of differential erosion! If they were soft rock, they would have been eroded away by the glaciers and other forces since then.

Marshall Mountain and Mystical Mountain are two of these hard-rock peaks. They are both made of anorthosite, a hard igneous rock that formed from magma underground and floated to the surface because it was lighter than the rock surrounding it. Think of marshmallows floating to the top of hot cocoa.

The large crystals visible on the anorthosite tell us that the rock cooled slowly, allowing time for the crystals to form. Igneous rocks that cool quickly have small crystals.