Weathering and Sedimentation – Tutorial Script

Earth's surface is covered by rocks, each one telling a story – actually at least two stories – the original formation story of the rock and then the more recent story of its breakdown at Earth's surface. When rocks break down chemically or physically at Earth's surface, we call those processes **weathering**. **Chemical weathering** breaks down the chemical bonds in the minerals, such as when dissolving a crystal or rusting iron. **Physical or mechanical weathering** breaks down or cracks the rock into smaller and smaller pieces. When weathered rock material is picked up and removed by agents like wind, running water, glaciers, waves, gravity, or humans, the processes are called **erosion**. Weathering and erosion work together to sculpt the landscape into a variety of landforms such as cliffs, caves, arches, and more. In this video we will focus on the processes of weathering and sedimentation or deposition of the weathered material. Look to future video tutorials for further explorations of the erosional processes.

Chemical weathering happens when water and atmospheric gases at Earth's surface interact with the surfaces of a rock. Three major types of chemical reactions can occur during those interactions including dissolution, oxidation, and hydrolysis.

Dissolution happens when the atomic bonds in glass or a mineral or shell are broken by water molecules. As described in the Water Molecule Shape video tutorial, polar water molecules will pull apart ions from solid crystals and surround those ions in hydration spheres. These hydration spheres keep the ions separated so they can't recombine. The ions stay dissolved in the water as long as there is enough water to keep them separated. The opposite of dissolution is precipitation, the combining of ions to form solid crystals that settle out of water. Precipitation happens when waters rich in dissolved ions evaporate, taking the water molecules away and allowing the ions to find each other again. If the water involved with dissolution is flowing water, like rain water or river water or waves, the dissolved ions will be removed from the rock and the environment and taken to a new environment where precipitation may later happen (as for example a cement between sediment grains).

Oxidation happens when oxygen in the atmosphere gets together with dissolving ions and creates a new oxide mineral – such as iron oxide, or rust. This new oxide will coat the surface of the rock where the dissolution was taking place. We see evidence of oxidation when we see stained surfaces on rocks. These stains will come in a multitude of colors depending on which ion oxidized. Iron oxides can be yellow, orange, red, or brown depending mostly on how much oxygen is available. Manganese oxides are black. Copper oxides are bright blue. Iron oxides are the most common oxides found on the surface of rocks, and usually when you see a red-colored rock from a distance, you're looking at the oxide stains on its surface.

Hydrolysis happens when water interacts with a mineral that contains aluminum (Al), oxygen (O), and Silicon (Si). During dissolution of such a mineral, the water will react with the ingredients to form a new **clay** family mineral. For example, when potassium feldspar reacts with water, it forms the clay mineral **Kaolinite**. Clay minerals are often white, though they can come in multiple colors, and the crystals that form are microscopic, so they end up appearing like a fine powder, like grains of flour. This image shows kaolinite (the white powder) forming along the edges of an altered potassium feldspar in a granite.

Which of the three main chemical weathering processes will occur in a rock depends on the minerals within. First step in determining the likely chemical weathering fate of a mineral is to look closely at its chemical formula. If there is any iron (Fe) in the rock, then there will be oxidation and a rust will form. If there is aluminum, silicon, and oxygen (Al, Si, O) altogether, then a clay mineral will form. If the mineral has electron-giving ions, like Calcium, Magnesium, or Potassium

(Ca, Mg, K), shown at the left of the formula, these ions tend to be dissolved and carried away by water (though some might end up part of a clay mineral that forms). Let's review some examples, starting with quartz, SiO_2. No iron (Fe) in the chemical formula, so no rust. No aluminum (Al), so no clay. As we know, quartz is composed entirely of covalently bonded silicon oxygen tetrahedra. So what happens to quartz during chemical weathering? Under all but the most extreme environments, nothing. It remains in the rock and thus it's one of the most common sediments found on Earth's surface and is what makes up most mature beach sands. We'll get back to mature sediment at the end of this video tutorial. As already mentioned, potassium feldspar, $KAlSi_3O_8$, because of the presence of aluminum, silicon, and oxygen altogether in the same mineral, will turn into a clay mineral. The potassium (K), will dissolve and be removed in water. What about calcite? $CaCO_3$? No iron, so no rust. No Al, Si, O together, so no clay formation. Calcite simply dissolves into Ca^{2+} calcium and CO_3^{2-} carbonate, both of which are removed by the water. So far nothing has rusted. What are some examples of rocks that will rust? Let's look at olivine, $(Fe,Mg)_2SiO_4$. What happens to olivine? The iron, Fe, rusts and the rest is dissolved and removed by water.

Now let's take a closer look at mechanical or physical weathering. This type of weathering happens when a rock cracks or breaks into smaller pieces. There are a number of ways mechanical weathering can happen naturally.

Frost wedging is a process where water fills cracks or holes in a rock during the day, and at night freezes. Since frozen water has a higher volume than liquid water, as the ice expands each night, it wedges the cracks or holes open deeper. As rock is broken off, pieces fall and collect at the base of the cliff below creating a talus slope, a good clue that frost wedging is happening above.

Exfoliation is a process where a rock is unburdened by its overlying rocks during erosion. The result is a reduction in pressure. Under less pressure, the surface of the rock expands outward and can shed layers like an onion. This is a common mechanical weathering process seen in settings where plutonic igneous rocks that formed in cooling magma chambers under volcanoes have had their surface volcanic edifices eroded away exposing the underlying rock. A form of exfoliation can also happen when the surface of a rock is heated up during the day and expands and then cools at night and contracts. The continual expansion and contraction can weaken the outer layer of a rock and make it shed in onion-like layers.

Spheroidal weathering is a process where the cracked angular edges of a rock have a greater surface area and thus chemical weathering happens in these areas more rapidly than other areas of the rock. The increased chemical weathering weakens the rock in these areas and makes it easier to physically wear down. The net result is that angular or square edges will become the focus of chemical weathering and will over time round.

Mechanical weathering can also be increased when the roots of trees and plants grow inside cracks in the rock and wedge them open larger. Tidepool organisms such as sea urchins can dig holes into a rock and increase the rate of mechanical weathering. Of course as mechanical weathering increases, so too does chemical weathering and vice versa.

Chemical weathering happens faster when there is greater exposed surface. When rock break down into smaller pieces through mechanical weathering, they now have collectively a much greater surface area. The more chemical weathering that occurs, the more pits and holes in the rocks as minerals dissolve or turn into easily eroded clays, which gives more opportunity for things like frost wedging to occur.

Another thing that can speed up chemical weathering are acidic waters. The most common naturally formed acid is **carbonic acid** which forms whenever carbon dioxide mixes with water – a common occurrence in all natural waters on

Earth's surface. This acid is what makes carbonated beverages acidic and what can thus increase the acidity of your stomach when you drink sodas in high amounts. Waters rich in carbonic acid will make chemical weathering happen faster.

What else can speed up any kind of weathering? The rock type and the climate or environment. As described in the Inside Minerals video tutorial, minerals with the strongest covalently bonded silicon oxygen tetrahedra, such as quartz, which was described already, have the strongest bonds and are least likely to be dissolved by water. Chemical weathering will happen very slowly with these minerals because it's so hard to break through the bonded tetrahedra, both physically and chemically. On the other hand, minerals with weaker ionic bonds will dissolve more readily, as will minerals with good cleavage. So the minerals in a rock will determine in large part how fast it will weather. In addition to the rock type, the environment makes a big difference in weathering rates. Chemical weathering requires water, so the wetter the climate, the more chemical weathering will occur. Heat speeds up the rate of chemical reactions, so hot wet climates have the highest rates of chemical weathering. Cold dry climates (like at the poles or at high elevations) have the slowest rates of chemical weathering. And of course, climates with regular freeze/thaw cycles will have increased rates of frost wedging; climates with hot days and cool nights, increased rates of exfoliation.

Once rocks have weathered, the weathered pieces can collect on Earth's surface in low-lying areas. They can get picked up by the erosional agents of running water, glaciers, wind, gravity, or humans and moved along to a new surface where they settle out. During the process of movement at Earth's surface, the erosional processes, the pieces will continue to break down chemically and physically, such that after many hundreds of years and many hundreds of kilometers from their place of origin, what's primarily left are the finest sands and muds, made of the most resistant material. The two most abundant minerals that are found in these long-travelled mature sediment piles are quartz and clays. Why? Quartz is the second most common because it doesn't cleave (only conchoidally fractures) and has a hardness of 7 (both of which make it physically strong) and also because chemically it's stable (doesn't dissolve or oxidize or turn to clay under most common surface conditions). Clay is the most common because feldspars, plus all other aluminum silicates such as hornblende and micas, will alter to clay during hydrolysis at Earth's surface. Feldspars are the most abundant minerals in Earth's crust (found throughout Bowen's Reaction Series, remember, so present in 100% of igneous rocks). Thus the most abundant minerals turning into clay make clay the most common sediment that you would find in a pile of weathered debris at Earth's surface.

Because sediment piles will vary around the planet depending on the materials that feed into them, they all have a fingerprint – a distinct character of varying grain compositions, sizes, shapes, and sorting. We can describe those characteristics and use them to interpret the travel history and maturity of the sediment. For example, as sediments migrate downhill towards low-lying areas, especially if carried by running water, they knock about and get smaller and rounder. If deposited by waves or rivers in the normal course of movement, they will do so because of gradual slowing of the water and thus only grains of the size no longer able to be carried due to the drop in velocity will settle out. So all the grains in a given pile of river sediment (**alluvium**) will be the same size. And all the easily rusted, dissolved, and hydrolyzed minerals will be gone, leaving only the most stable ones. Note: when sediments are transported by glaciers they are trapped in the ice at the base of the glacier and so don't knock about so much or weather. Glacial deposits known as **moraines** form when glaciers melt and leave the sediment they carried behind in one big pile of unsorted, angular grains of all sizes, very different from river-deposited sediment.

Sometimes a flash flood in the mountains or an avalanche of sediment off the continental shelf will pick up grains of all sizes and then drop them all at the same time at the foot of the slopes where they hit the flat valley floor. In these cases, as the water movement stops quickly and the grains settle in one spot, the largest, heaviest grains will settle out first, followed by smaller and smaller ones. This settling can result in a texture in the sediment called **graded bedding**, which if buried by additional future deposits can eventually be turned into rock, retaining fossil evidence of the past graded bedding event.

If not buried and lithified, sediment piles in windy areas can change over time when the wind blows across them, picking up the finest sediment grains and leaving the larger ones behind. As these fine sand particles migrate with the wind, they can produce sand dunes. In sand dunes, the wind pushes the grains up the windward side of the dune gradually, and then they are left to fall down by gravity on the steeper leeward side. Through continual migration, we see the continual addition of inclined layers of sand accumulating. If later these dunes are covered by other dunes and over time buried and cemented, the **cross-bedding** texture within can be trapped as fossil evidence of the former formation environment.

Ultimately all these described piles of sediment of varying maturity will turn themselves into rocks either through **compaction** or **cementation**. Compaction happens when mud-size grains are squeezed, water is released, and the clay particles within stick together. Cementation happens when ground waters rich in dissolved ions percolate through the grains. Eventually as the water leaves or evaporates, crystals are left behind. These crystals will grow between and cement together the grains. Examples of common cements include hematite, rust, calcite, and quartz. Because there are a multitude of different surface environments where sediments can collect or precipitate, there are a multitude of sedimentary rocks. For more information and detail on the names of and stories behind a variety of sedimentary rocks, continue on to the next video in this series.

[end credits]

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