GLACIERS – Tutorial Script

Glaciated regions of our planet (both those currently hosting glaciers, and those that hosted glaciers in the past) can be recognized by spectacular landforms, including broad U-shaped valleys with high relief, sharp ridges and peaks, and rounded bowls. In this video, we will discuss what glaciers are, where they are found, and how they sculpt the land.

What exactly IS a **glacier**? A glacier is a mass of compressed ice that has accumulated on land over many years of snowfall and that moves under its own weight. Ice found in the oceans is not considered a glacier and will not be discussed in this video. Glaciers are found where snow can collect in the winter and not fully melt in the summer. As such, they are found at high elevations in the mountains, called **alpine glaciers**, or on continents near the north and south pole, called **continental ice sheets**.

Alpine glaciers can be found in mountains all over the world including near the equator, but of course there they form only at the highest evaluations (4700 meters or higher above sea level). The further north and south of the equator a mountain lies, the lower in elevation the glaciers can be maintained. For example, in Alaska, glaciers extend all the way to sea level. Within glaciated mountains, glaciers that fill the area between peaks in the center of the mountains are called **ice fields**. **Valley glaciers** extend out of those high elevations carving and filling U-shaped valleys, spilling out onto the flat land next to the mountains. Where valley glaciers meet the ocean, they are called **tidewater glaciers**. If the end of a valley glacier extends outward onto a flat plain of land, not the ocean, it is called a **piedmont glacier**.

Continental ice sheets are found in only two places on our planet: covering Greenland and Antarctica. These glaciers are many kilometers thick and are so heavy they depress the land beneath them isostatically, making that land sink into the underlying mantle much like a ship laden with cargo.

Remember, all glaciers will move under their own weight or they're not considered glaciers. Alpine glaciers move downhill – continental ice sheets move outward from their center, where the mass of ice is greatest. Glaciers move either through plastic flow or by sliding on a layer of melt water at their base. When glaciers flow plastically, it's like silly putty – they remain solid, but the solid changes shape over time in response to the forces around it. During plastic flow, the edges of the glacier, where it encounters rock will move the slowest due to drag and friction. The fastest movement occurs in the center of the glacier where it's furthest from the rocks and has the least drag and friction. It's similar in rivers – fastest flow in the center of the river, slowest along the sides where friction is greatest. Glaciers can be thought of as slow rivers of ice. The average speed of cold-based, nonsliding ice sheets is only a few meters a year. The average speed of warm-based, sliding alpine glaciers on steep slopes is 300 meters or more a year (just less than 1 m/day). Surging glaciers, however, can move 100x faster than normal for several months to a few years. The most rapid surge known was in 1953 in northern Pakistan – 100 meters per day! (~12.5 m/hour or ½ meter a minute!) For continental ice sheets, the fastest moving ice stream is 34 meters per day – that's 1.4 meters per hour! And it's found in Greenland.

In addition to all glaciers moving continuously downhill or outward under their own weight, they can also advance or retreat (grow or shrink) over time depending on their snow supply. When more snow is added each year than lost (accumulation is greater than ablation), the glacier is advancing. When there's more snow lost than gained (ablation is greater than accumulation), the glacier is retreating. Whether a glacier is advancing or retreating, it still always moves, like a conveyor belt, outward or downward. Think of it as a slow escalator with steps added or removed with time, but continually cycling snow and anything that falls into that snow downward and outward.

As glaciers move, rocks are weathered, eroded, and deposited. Let's look more closely at that work and the landforms that result. To review, the breaking down of rock chemically or physically is called **weathering**. The term **erosion** means the physical removal of rock fragments from one location and transport of them to another location. The dropping of the rock into a new location is called **deposition**.

Glaciers weather rock through two main methods: **frost wedging** and **abrasion**. When the base of glaciers melt, the melt water will migrate into cracks in the rocks and freeze. Frozen water takes up more space than liquid water, and the increased volume will wedge the cracks open. Through a series of melt and freeze cycles, cracks will widen, and the rocks will be wedged apart. Glaciers pick up and carry away weathered pieces of rock by surrounding them with liquid water, which then freezes, trapping the rock within the glacier. These frozen fragments at the base of a glacier abrade and weather the rock over which they move, grinding them smooth or leaving striations in the rock surface. In addition to carrying weathered rock frozen in its base and sides, glaciers also carry any weathered rocks that drop on their surfaces as they move through the landscape. All these pieces are continually conveyed downward to the toe of the glacier, where they are spit out or dropped. If the glacier is advancing, those deposits are also bulldozed or pushed forward in advance of the glacier. If the glacier is retreating, those deposits are left strewn across the ground.

The sediment carried by glaciers experiences no knocking about during transport and no chemical weathering. As such, glacial deposits can be identified by their angular-shaped grains of all sizes from the tiniest muds to boulders as large as houses. We characterize this wide range of grain sizes as poorly sorted. We can see these larger house-sized grains left isolated on glacial plains long after the glaciers have left and the surrounding smaller sediment grains have been removed. These isolated large-grain remnants of glacial deposits are called **glacial erratics**.

Piles of sediment dropped or spit out by glaciers are called **moraines**. **Lateral moraines** are the bulldozed piles of glacial sediment found along the edges of a valley glacier as it moves out of the mountains. **Terminal moraines** are the bulldozed piles found at the front or toe of an advancing glacier. When a glacier retreats, the material it drops strewn across the land is called a **ground moraine**. When two glaciers meet and join, the lateral moraines that join up and combine and then continue to separate them are called **medial moraines**. When glaciers advance again over land they retreated from before, they can reshape the ground moraines into mounds known as **drumlins**. If we look more closely at the toe of an active glacier, we can also see that melt water pours out from under its base into an **outwash plain** in front of the glacier. The sediments in this plain are carried by water and as such are smaller, more rounded, and well sorted. In many cases, the melt water can more easily erode the ice than the ground, so it carves its stream channel above ground as a tunnel or cave in the ice, depositing its bed load at its base, which is above the surrounding land. When the glacier retreats, these raised river beds, called **eskers**, can be seen sinuously migrating across the landscape.

Once the glaciers have completely retreated and disappeared, we can see the erosional landforms left behind. Valley glaciers carve downward into a **U-shaped valley** with steep almost vertical edges. At the tops of these valleys, glaciers erode upward and outward, carving bowls called **cirques**. The bigger the glacier, the deeper the valley and cirque. Where small tributary valley glaciers joined up with larger main valley glaciers in the past, we see now these smaller tributary U-shaped valleys hanging over the larger valley below. We call these **hanging valleys**. Where two valley glaciers run parallel to each other, the rock in between can be carved upward and downward into sharp knife-like thin ridges, which we call **arêtes**. And where many valley glaciers form outward from a single point, eroding downward, sideways and backwards, their respective cirques can collectively carve back and meet at a single sharp peak called a **horn**. When U-shaped valleys fill with ocean water, we call them **fjords**.

This map shows you where glaciers are found today – covering roughly 10% of the land surface of the planet. This map shows glacial coverage 20,000 years ago, during the last **ice age**, when glaciers advanced and covered 30% of the land surface. How do we know? We can see, map, and date the deposits these ice-age glaciers left behind: the moraines and the striations. We can also study sediments left behind in lakes and oceans. One of the major impacts of ice ages and a cooling planet is migration of flora and fauna. In lake sediments, we see in ice-age sediments, spores from colder-adapted tree species. In ice-age sediments in the ocean, we find shells from cold-water species taking the place of what used to be warmer-water species.

For example, in California, glacial erosion, moraines and striations are found in the high mountains. We find no evidence of glaciers covering the rest of the state. But we do see evidence of ice-age impacts everywhere: lower sea level; fast-moving erosive rivers coming out of the Sierra with loads of sediment from glacial erosion; large lakes forming east of the Sierras; and migration of colder-adapted flora and fauna into the state and warmer-adapted ones out of the state. San Francisco itself is built on the ancient sand dunes produced during the erosion of the Sierras by ice-age glaciers, when the Sacramento River dumped its sediment load 27 miles off the current coastline, which would have been sea level at the time, and winds blew that sand back over the continental shelf creating a massive sand dune province.

Throughout most of Earth's history the planet was much warmer than it is today. About 2 million years ago, the start of the geologic period known as the Pleistocene, Earth cooled enough to form glaciers that alternately advanced across the land and then retreated backwards. When the glaciers advanced and grew, we referred to it as an **Ice age**. Intervening periods of time when Earth warmed and those glaciers retreated are called **Interglacials**.

What causes the cycles in and out of ice ages? Small perturbations in Earth's climate that are reinforced over time with positive feedback. For example, when Earth's tilt lessens, more sunlight reaches the poles throughout the year which melts more of the ice. Since ice reflects a lot of sunlight, less ice means less reflection and more absorption of sunlight. More sunlight absorbed means more melting of the ice and so on in a positive feedback loop. Similarly, when Earth's tilt increases, less sunlight will reach the poles during the winters, which allows more ice to form, which means more reflection of sunlight. Less sunlight means colder, which means more ice, more reflection, more cold, and so on. There are plenty of additional factors that also contribute to surface cooling and warming. The amount of energy the sun radiates will fluctuate over time in cycles. The amount of greenhouse gases in our atmosphere changes with time. When sunlight passes through the atmosphere it does so as short-wavelength radiation, mostly ultraviolet (UV) and visible. This radiation heats the planet's surface. That heat radiates back out to the atmosphere, but as longer-wavelength IR or infrared radiation. Greenhouse gases in the atmosphere trap those longer IR waves and thereby keep the planet warm. More greenhouse gases, the warmer the climate. Important greenhouse gases on our planet are water, carbon dioxide, and methane. Methane is produced by melting hydrates on the bottom of the seafloor, which happens when the oceans warm. It is also produced through livestock waste and decomposition in rice paddies. Carbon dioxide is produced through volcanism, decomposition, and fossil fuel burning. Ocean currents help distribute heat. When currents are trapped by land masses that move through plate tectonics, it can be harder to distribute heat across the planet, and some areas will be isolated and cooled. That's what happened to Antarctica about 30-40 million years ago when it separated from the remnants of Pangaea. As a result of this isolation, the ice age in Antarctica began at that time. Ice has covered Antarctica much longer than the first ice age appeared on all the other continents, 2 million years ago. All of these factors have combined to modify Earth's climate and contribute to its alternating warming and cooling cycles during the past few million years. As so much of our society is impacted by the results of rising temperatures – from melting glaciers, rising shorelines, and shifting climate zones which changes our agricultural locations, we need to be prepared for the consequences of these changes.

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Produced by Katryn Wiese
City College of San Francisco

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