



Chapter 6: Glaciers in the Western US

The vast majority (nearly 97%) of the **glaciers** in the United States are found in the Western States. Although the bulk of these are found in Alaska, small glaciers are found as far south as California and Nevada. These glaciers have a profound impact on the West's scenery, geology, and water resources. Furthermore, ongoing research into how they have changed since the last major **ice age** is proving invaluable to our understanding of **climate change**.

What is a glacier?

A glacier is a large mass of ice (usually covered by snow) that is heavy enough to flow like a very thick fluid. Glaciers form in areas where more snow accumulates than is lost each year. As new snow accumulates, it buries and **compresses** old snow, transforming it from a fluffy mass of snowflakes into ice crystals with the appearance of wet sugar, known as **firn**. As this firn is buried yet deeper, it coalesces into a mass of hard, dense ice that is riddled with air bubbles. Much of this transformation takes place in the high part of a glacier where annual snow accumulation outpaces snow loss—a place called the **accumulation zone**. At a depth greater than about 50 meters (165 feet), the pressure is high enough for plastic flow to occur. Ice flow is driven by gravity, and it causes movement downhill and out from the center (*Figure 6.1*). Once the ice becomes thick enough, it flows outward to the **ablation zone**, where the ice is lost due to melting and **calving** (*Figure 6.2*). The boundary between these two zones, the equilibrium line, is where annual ice accumulation equals annual ice loss. Because the altitude of this line is dependent on local temperature and precipitation, glaciologists frequently use it to assess the impact of climate change on glaciers.

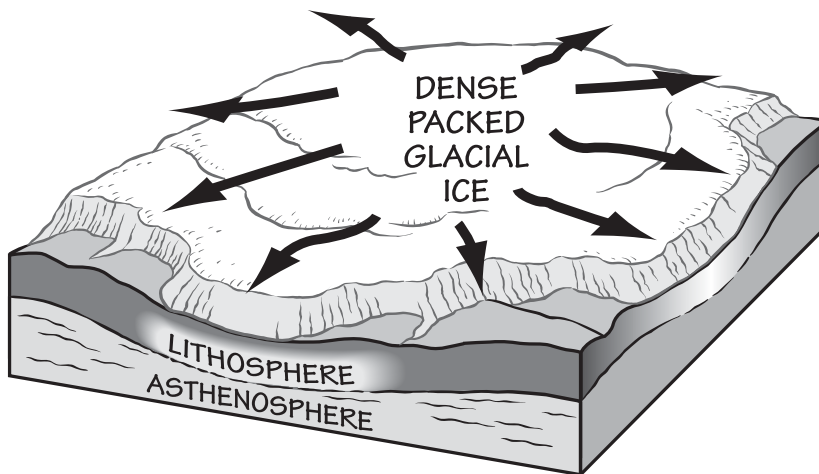


Figure 6.1: As dense glacial ice piles up, a glacier is formed. The ice begins to move under its own weight and pressure.

ice age • a period of global cooling of the Earth's surface and atmosphere, resulting in the presence or expansion of ice sheets and glaciers.

climate change • See global warming: the current increase in the average temperature worldwide, caused by the buildup of greenhouse gases in the atmosphere.

compression • flattening or squeezing as a result of forces acting on an object from all or most directions.

firn • compacted glacial ice, formed by the weight of snow on top.

calving • when ice breaks off from the end of a glacier.

CHAPTER AUTHOR

Frank D. Granshaw

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Glaciers

Review

Most broadly, there are two types of glaciers: smaller alpine glaciers and larger continental glaciers (Figure 6.3). Found in mountainous areas, alpine glaciers have a shape and motion that is largely controlled by **topography**, and they naturally flow from higher to lower altitudes. Glaciers confined to valleys are called valley glaciers, while bowl-shaped depressions called **cirques** are located in mountainous areas.

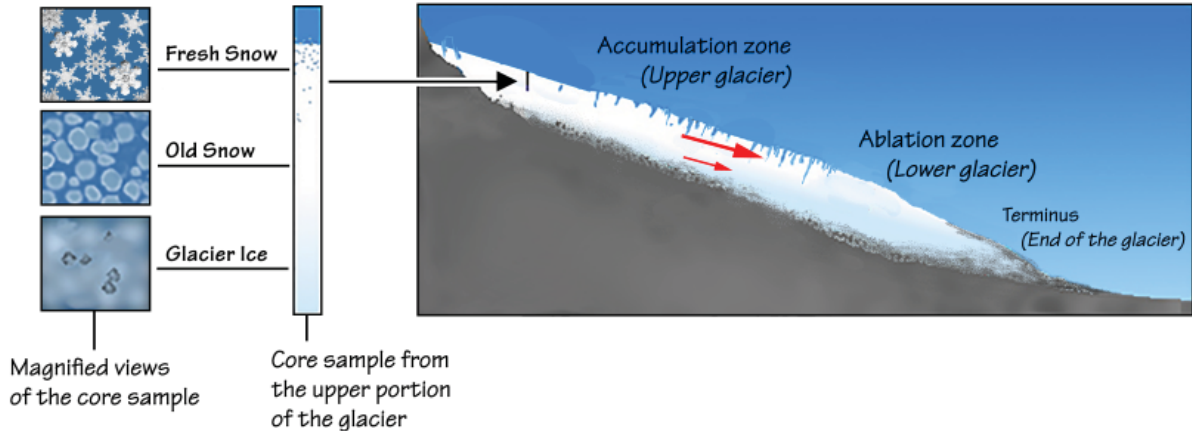


Figure 6.2: Cross section of an alpine (valley) glacier showing snow being converted into glacial ice and the two major zones of a glacier's surface. The red arrows show the direction and relative speed of different parts of the glacier. The longer the arrow, the faster the ice is moving.

topography • the landscape of an area, including the presence or absence of hills and the slopes between high and low areas.

erosion • the transport of weathered materials.

plucking • process in which a glacier "plucks" sediments and larger chunks of rock from the bedrock.

scouring • erosion resulting from glacial abrasion on the landscape.

sand • rock material in the form of loose, rounded, or angular grains, and formed as a result of the weathering and decomposition of rocks.

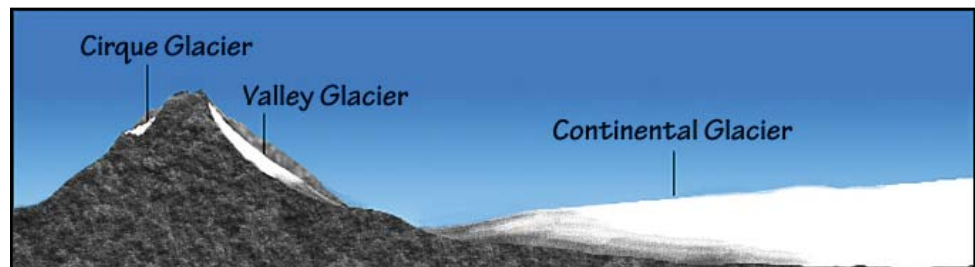


Figure 6.3: The cirque and valley glaciers shown here are types of alpine glaciers. Both alpine and continental glaciers flow downhill. Although this is obvious with an alpine glacier, it is not as much so with a continental glacier. In the case of the latter, the glacier flows from its thicker middle to its lower edges.

Continental glaciers are much larger, and they are less controlled by the landscape, tending to flow outward from their center of accumulation. **Ice sheets** are large masses of ice that cover continents (such as those found in Greenland) or smaller masses that cover large parts of mountain ranges (**ice fields**, such as the Juneau Ice Field in Alaska). Because ice fields often appear to be crowning a mountain range, they are sometimes called **ice caps** as well. Mountains fringing the ice sheets cause the descending ice to break up into outlet glaciers (streams of ice resembling alpine glaciers) or broad tongues of ice called piedmont glaciers, such as the Malaspina Glacier of Alaska.



Glacial Landscapes

The interaction of the glaciers with the landscape is a complex process. Glaciers alter landscapes by **eroding**, transporting, and depositing rock and sediment. They erode the land they flow over via abrasion and **plucking**. Harder bedrock will be scratched and polished by sediment stuck in the ice, while **frost wedging**, when water freezes and expands in cracks, can eventually break chunks of rock away. Softer bedrock is much more easily carved and crushed. Abrasion, or **scouring**, occurs when rock fragments in the ice erode bedrock as the glacier moves over it. Plucking involves glaciers literally pulling rock from underlying bedrock. The flowing ice cracks and breaks rock as it passes over, pieces of which become incorporated in the sheet or bulldozed forward, in front of the glacier's margin. The less resistant rock over which glaciers move is often eroded and ground-up into very fine **sand** and **clay** (called **rock flour**). Once eroded, this material is carried away by the ice and deposited wherever it melts out (Figure 6.4).

Landscapes

clay • the common name for a number of very fine-grained, earthy materials that become plastic (flow or change shape) when wet.

relief • the change in elevation over a distance.

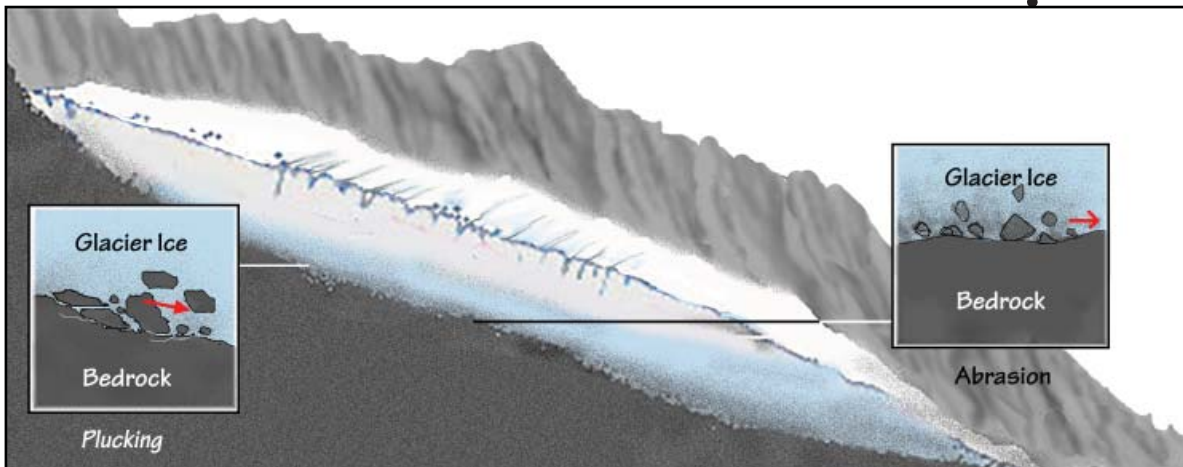


Figure 6.4: Rock and sediment derived by plucking and abrasion. These loose materials are subsequently transported to a glacier's ablation zone where they are deposited by melting ice.

crust • the uppermost, rigid outer layer of the Earth, composed of tectonic plates.

The nature of the glacier causing the erosion is also crucial. Because continental glaciers spread from a central accumulation zone, they can't go around peaks in their path, so they instead slowly crush and scrape them away. For the most part, this results in flatter landscapes. Conversely, alpine glaciers tend to follow the existing topography, flowing downhill. This frequently causes them to scour existing low places, making them lower still. While this gouging increases the overall **relief** of an area, anything directly in the path of the ice is flattened.

Continental glaciers also affect the landscape by depressing the Earth's **crust** with their enormous mass, just as a person standing on a trampoline will cause the center to bulge downwards. The effect is quite substantial, with surfaces being lowered by hundreds of meters. Of course, this means that when the glacier retreats and the mass is removed, the crust will rise to its former height

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Landscapes

isostasy • an equilibrium between the weight of the crust and the buoyancy of the mantle.

reef • a feature lying beneath the surface of the water, which is a buildup of sediment or other material built by organisms, and which has positive relief from the sea floor.

till • unconsolidated sediment that is eroded from the bedrock, then carried and eventually deposited by glaciers as they recede.

fjord • a deep, narrow, glacially scoured valley that is flooded by ocean water.

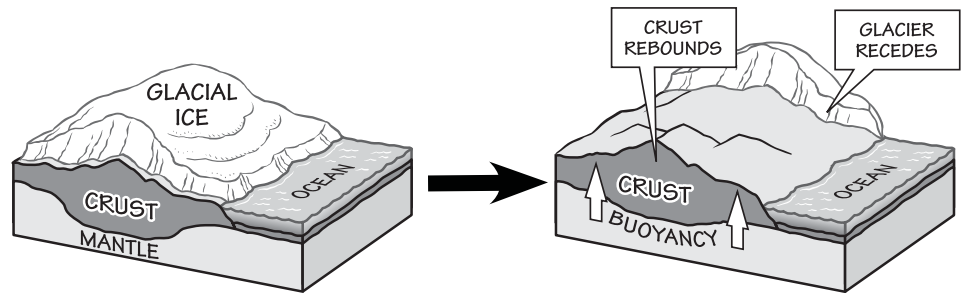


Figure 6.5: Isostatic rebound resulting from glacial retreat.

in a process known as **isostasy** (Figure 6.5). Dramatic results include marine **reefs** lifted high above sea level and marine sediments found as coastal bluffs.

Glacial erosion can produce rugged mountainous areas with knife-edge ridges (**arêtes**), pointed rocky peaks (**horns**), and bowl-shaped depressions (cirques). These landscapes are most visible in areas where glaciers have retreated (Figure 6.6).

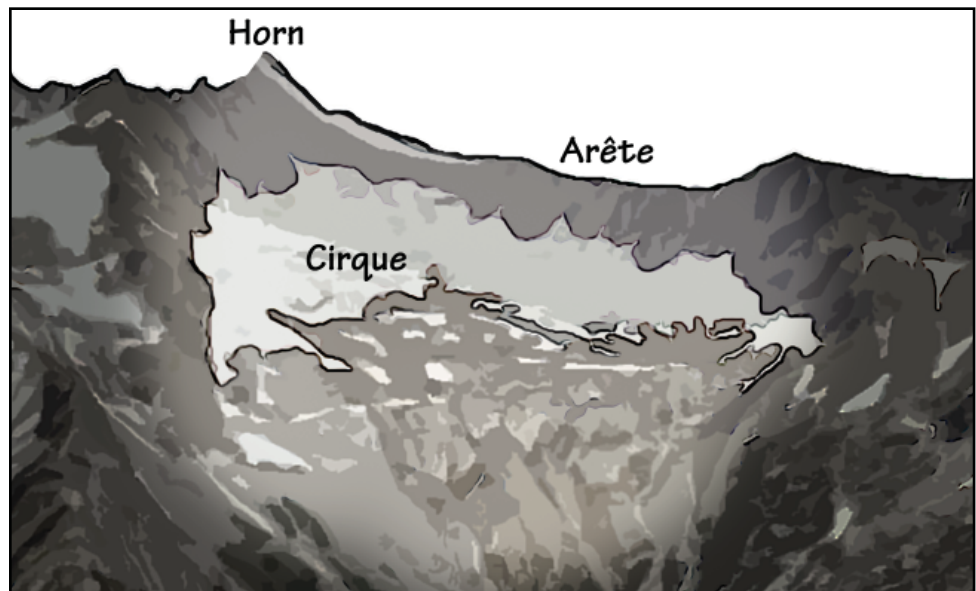


Figure 6.6: Glacial features in Cascade Pass—North Cascades National Park, Washington.

Valley glaciers carve long, U-shaped, steep-walled valleys (Figure 6.7). A river, in contrast, will erode a sharp notch, creating V-shaped valleys. As the glaciers retreat from these valleys, they leave behind thick layers of **till**, a chaotic mix of rock and sediment that covers the valley floor. If the valley is flooded with seawater as a glacier recedes it becomes a **fjord** (Figure 6.8).



Figure 6.7: A glacial valley on Steens Mountain, Oregon.

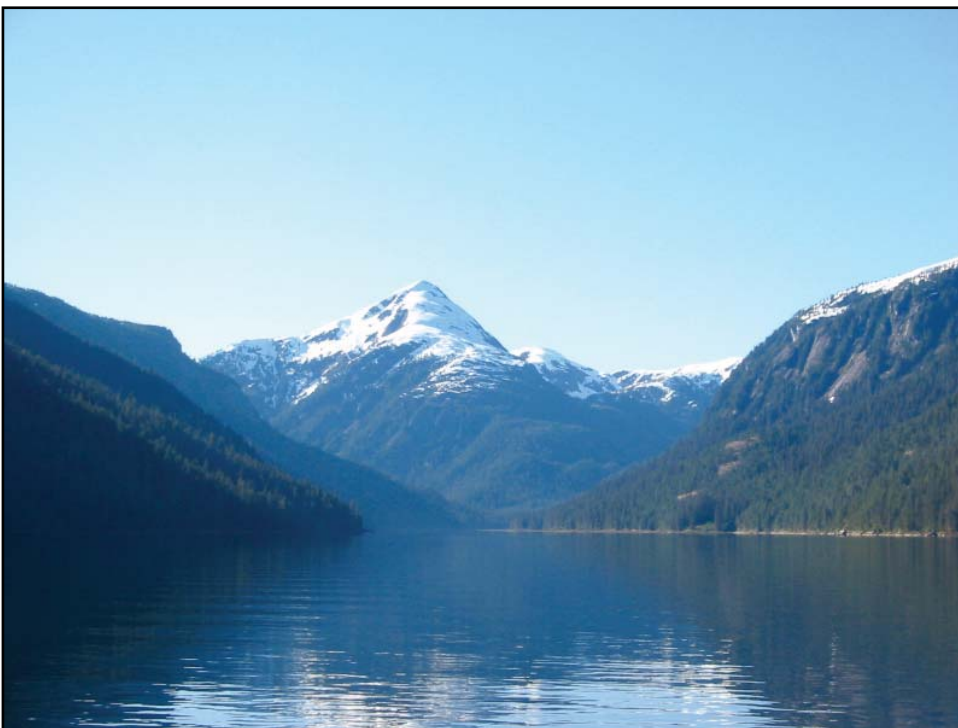


Figure 6.8: Misty Fjords National Monument in the Tongass National Forest, Alaska.

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Climate

drift • unconsolidated debris transported and deposited by a glacier.

Drift-covered plains with lakes and low ridges and hills appear near the end, or terminus, of a glacier as dwindling ice leaves behind glacial till. Beyond the terminus, meltwater streams leave more orderly deposits of sediment, creating an **outwash plain** where the finest sediments are farthest from the terminus, while cobbles and boulders are found much closer. Spoon-shaped hills called **drumlins** (Figure 6.9) are composed largely of till and reflect the final flow direction before the glacier receded. Small **kettle** lakes are formed by blocks of ice that calved from the glacier as it melted onto the outwash plain (Figure 6.10).



Figure 6.9: A drumlin field.

outwash plain • large sandy flats created by sediment-laden water deposited when a glacier melts.

kettle • a lake formed where a large, isolated block of ice became separated from the retreating ice sheet.

climate • a description of the average temperature, range of temperature, humidity, precipitation, and other atmospheric/hydrospheric conditions a region experiences over a period of many years (usually more than 30).

Glaciers and Climate

Glaciers are sometimes called the “canary in the coal mine” when it comes to climate change. This is because alpine glaciers are highly sensitive to changes in **climate**. For instance, a glacier grows (advances) when it accumulates more ice than it loses from melting or calving. Advances tend to happen when cold, wet years dominate the local climate. On the other hand, a glacier will shrink (retreat) during warm, dry periods as it loses more ice than it gains each year.

As discussed in the chapter on climate, for much of Earth’s history there have not been persistent ice sheets in high latitudes. Any time that the world is cool enough to allow them to form is called an “ice age.” We are therefore living in an ice age right now! The current ice age began about 34 million years ago when ice sheets were first forming on Antarctica, followed by Greenland at least 18 million years ago, and finally on North

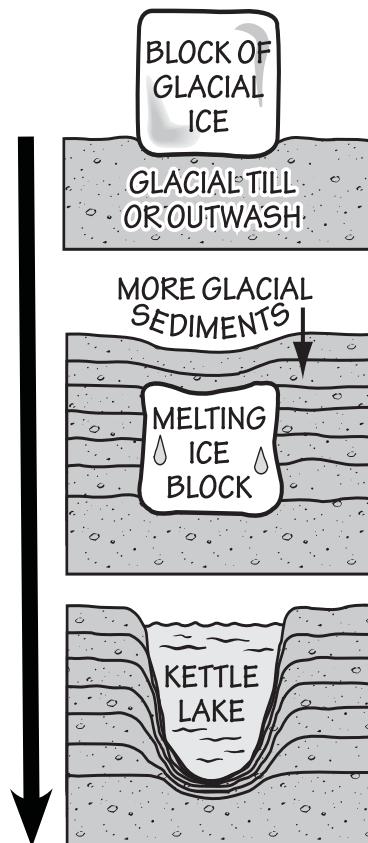


Figure 6.10: Steps in the formation of a kettle lake.



America, which defined the beginning of the **Quaternary** period (about 2.6 million years ago). When most people use the phrase “the ice age,” however, they are referring to the **last glacial maximum** that saw much of North America and Europe covered in ice thousands of meters (yards) thick, while many kinds of large, woolly mammals roamed the unfrozen portions of those continents.

Age of the Quaternary

In 2009, scientists at the International Commission on *Stratigraphy* voted to move the base of the Quaternary period to 2.6 million years ago, bumping it to 0.8 million years earlier than the previous date of 1.8 million years ago—a date set in 1985. They argued that the previous date was based on data that reflected climatic cooling that was only local to the region in Italy where it was first observed. On the other hand, the 2.6-million-year mark shows a global drop in temperature, and it includes the entirety of North American and Eurasian glaciation, rather than dividing it between the Quaternary and the earlier *Neogene* period.

The Quaternary period is divided into two epochs. The earlier **Pleistocene** encompasses the time from 2.6 million to 11,700 years ago, including all of the Quaternary up until the most recent episode of glacial retreat. Most of the glacial features in the West were created during the Pleistocene, because by the beginning of the **Holocene** 11,700 years ago, the glaciers had already retreated from much of the area.

Ice on a Schedule

The enormous continental glaciers that define an ice age are so large that their extent is most directly affected by global trends, while mountain glaciers are much more susceptible to local and short-term changes in climate. Continental ice sheets advance and retreat in cycles that last tens of thousands of years, controlled to a large extent by astronomic cycles.

Scientists continue to debate the particular causes of the onset of glaciation in North America over two million years ago. Movement of the Earth’s tectonic **plates** may have been a direct or indirect cause of the glaciation. As plates shifted, continents moved together and apart, changing the size and shape of the ocean basins. This, in turn, altered oceanic currents. Mountain building, which occurred when continents collided, erected obstacles to prevailing **winds** and changed moisture conditions. The freshly exposed rock from the rising of the Himalayas also combined with **atmospheric** carbon dioxide through chemical

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Quaternary • a geologic time period that extends from 2.6 million years ago to the present.

last glacial maximum • the most recent time the ice sheets reached their largest size and extended farthest towards the equator, about 26,000 to 19,000 years ago.

stratigraphy • the branch of geology specifically concerned with the arrangement and age of rock units.

Neogene • the geologic time period extending from 23 to 2.6 million years ago.

plates • large, rigid pieces of the Earth’s crust and upper mantle, which move and interact with one another at their boundaries.

wind • the movement of air from areas of high pressure to areas of low pressure.

atmosphere • a layer of gases surrounding a planet.



Climate

weathering • the breakdown of rocks by physical or chemical means.

Astronomic Cycles and Ice Sheets

The cyclical movements of ice sheets seem primarily to be caused by specific astronomic cycles called *Milankovitch cycles*, which change the amount of light the Earth receives, particularly when comparing the summer to the winter. The cycles, predicted through principles of physics a century ago, are related to the degree of tilt of the Earth, the Earth's distance to the sun, and the point in the Earth's revolution around the sun that the Northern Hemisphere experiences summer. When the cycles interact such that there are cool summers at high latitudes in the Northern Hemisphere (milder rather than extreme seasonality), glaciers can accumulate and thus advance. The cyclicity of glacial-interglacial advances was about 40,000 years from before the start of the Quaternary until about a million years ago. For reasons that aren't clear, however, the cycles changed to about 100,000 years. If not for human-induced climate change, we might expect glaciers to cover the West again in about 80,000 years!

weathering; the consequent decrease in levels of atmospheric carbon dioxide was at least partially responsible for global cooling. Finally, the presence of continental landmasses over one pole and near the other was also a major factor enabling the development of continental glaciers.

Seeking Detailed Records of Glacial-Interglacial Cycles

When glaciers advance over the land, the historical rock records are largely erased with each glacial advance. Therefore, to investigate the details of any associated climate change we must seek environments that record climate change but are preserved. Since the 1970s, the international Deep Sea Drilling Project has provided a treasure trove of data on coincident changes in the ocean, preserved in sediments at the ocean bottom (*Figure 6.11*). In the 1980s, coring of ice sheets in Greenland and Antarctica provided similarly high-resolution data on atmospheric composition and temperature back nearly one million years. The data from these programs have revealed that the Earth experienced dozens of warming and cooling cycles over the course of the Quaternary period.

Because of the large number of alpine glaciers in the Western States, this area is one of the world's "hotbeds" for glacier and climate research. Much of this work involves making regular inventories of existing glaciers and their

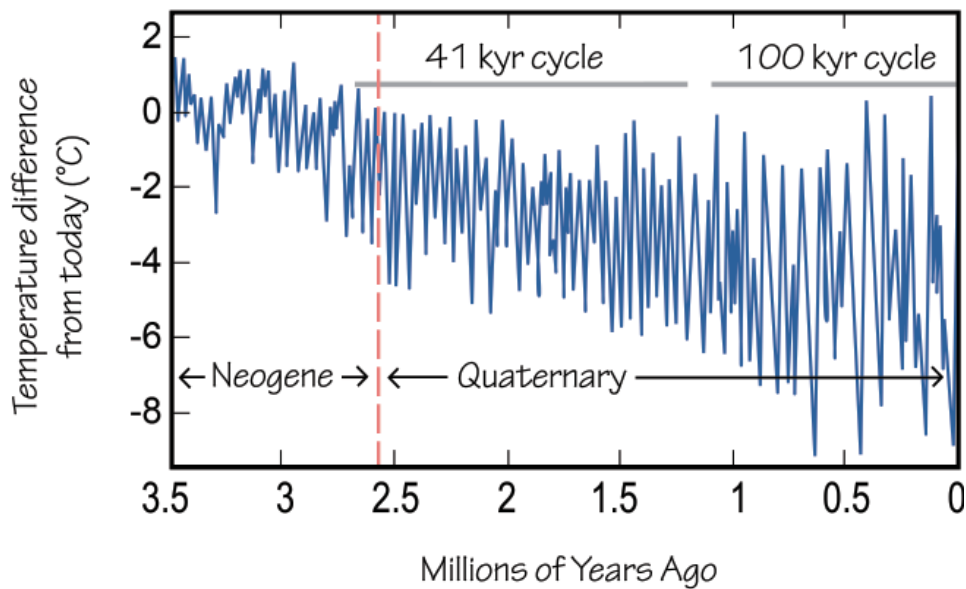


Figure 6.11: Ocean bottom temperatures from 3.6 million years ago to present, based on chemical analyses of foraminifera shells. Notice how the amplitude of glacial-interglacial variations increases through time, and how the lengths of the cycles change.

History

tree • any woody perennial plant with a central trunk.

system • a set of connected things or parts forming a complex whole.

loess • very fine grained, wind-blown sediment, usually rock flour left behind by the grinding action of flowing glaciers.

characteristics to determine how they are impacted by global, regional, and local climate changes. Equally important is determining the impact of the changing glaciers on seasonal streamflow. Glaciers act as water reservoirs where winter snowfall is released as meltwater during summer, when precipitation is low. This characteristic is particularly important to farms and fisheries in areas downslope from glaciated mountains like the Cascades or Sierra Nevada.

In addition to investigating present-day glacier behavior, researchers use clues from the landscape to reconstruct ancient glaciers. This information, along with climate evidence from **tree** rings and lake sediments, provides a long view of climate change that has done much to improve our understanding of how climate **systems** work, and what the future might have in store for us.

A Brief History of Glaciers in the West

During the Pleistocene, continental glaciers covered much of Canada, Alaska, and the northern edge of the continental United States (Figure 6.12). Besides carving vast sections of the northern landscape and depositing huge quantities of sediment in low-lying areas, their impact was felt farther south as glacial outburst floods and winds laden with glacial **loess** reached deep into Washington and Oregon. Furthermore, in the colder climate of the Pleistocene, large ice caps mantled mountain ranges as far south as Central California, while large freshwater lakes flooded a number of present-day desert valleys in Nevada, California, and Oregon.

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History

Cordilleran Ice Sheet • one of two continental glaciers that covered Canada and parts of the Western US during the last major Pleistocene ice age.

interglacial • a period of geologic time between two successive glacial stages.



Figure 6.12: Extent of glaciation over North America at the Last Glacial Maximum.

As the last Pleistocene ice age came to a close, both the **Cordilleran Ice Sheet** and the alpine ice caps to the south retreated, leaving behind rugged mountain ranges, deep glacial valleys and bays, and plains covered with thick deposits of glacial sediment. Equally important was the impact of glacial retreat on coastlines. As global ice diminished, sea level rose, radically altering the location and character of the Western coasts.

The time from the end of the Pleistocene to now is regarded as an **interglacial** period (a warm spell with diminished glaciers), but it has not been without its minor ice ages. The most recent of these, the Little Ice Age, began somewhere between 1300 and 1500 CE and ended by the late 19th century. Presently, the continental ice sheets and ice caps of the Pleistocene are gone, but some 150,000 alpine glaciers remain worldwide, and the impact of the ancient ice sheets and caps can be seen in nearly every region of the Western States.



Alpine Glaciers in the Western States

During the late Pleistocene, alpine glaciers could be found in all seven regions of the Western States, including Hawai'i. In several cases, these glaciers coalesced into ice caps covering entire mountain ranges. In other instances, they merged with advancing continental ice sheets, eventually becoming indistinguishable as separate glaciers, only to regain their distinctiveness as the ice sheets retreated.

Today, alpine glaciers are found largely in the mountains of Alaska and some of the higher ranges in Oregon, Washington, and California. Although the majority of the remaining glaciers tend to be small cirque glaciers or larger valley glaciers, a few large ice caps remain in southeastern Alaska. Modern glacier settings range from non-volcanic mountains like the Olympics and Sierra Nevada to active **volcanic** peaks found in the Cascade Range and the Aleutian Islands. As one moves farther south in the Western States, the glaciers tend to get smaller and higher. For instance, in southeastern Alaska, large outlet glaciers flow out of the massive Juneau Ice Field into the Pacific Ocean through a network of majestic fjords (*Figure 6.13*). In contrast, in the Sierra Nevada, a collection of small cirque glaciers perch precariously in mountains at well over 2700 meters (9000 feet) above sea level.

History

volcanism • the eruption of molten rock onto the surface of the crust.



Figure 6.13: Mendenhall Glacier, flowing from the Juneau Ice Field.

One of the hallmarks of the alpine glaciers of the Western States is the rugged mountain terrain they carve. As these glaciers retreat, they not only expose characteristic U-shaped valleys, but they also reveal a diverse collection of peaks, bowls, ridges, and lakes scraped into bedrock. For instance, in the North Cascades of Washington and in the Willowa Mountains of Oregon, glaciers

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moraine • an accumulation of unconsolidated glacial debris (soil and rock) that can occur in currently glaciated and formerly glaciated regions.

have carved a series of horns, arêtes, and cirques (*Figure 6.14*). Below these prominent features, we often find chains of lakes that form as meltwater ponds up behind lateral and terminal **moraines**. Likewise, in the Yosemite Valley of the Sierra Nevada, a network of small Pleistocene glaciers merged like streams flowing into a large river. As the glaciers retreated, they left behind a collection



Figure 6.14: The glacially sculpted features of the Wallowa Mountains in Oregon.



Figure 6.15: Upper Yosemite Falls in California plunges 440 meters (1420 feet) from a hanging valley into the Yosemite chasm.



of smaller U-shaped valleys (known as **hanging valleys**) that drop abruptly into a much larger valley. This is the principal reason that such spectacular waterfalls are found in the Yosemite Valley (*Figure 6.15*).

Glaciers also impact landscapes as they melt and deposit sediment, creating features such as Lake Wallowa in the Blue Mountains of northeastern Oregon. Lake Wallowa formed when a large glacier emptied into a broad basin and produced a high moraine that completely surrounded the lower part of the glacier. As the glacier retreated, the depression behind the moraine filled with meltwater, forming the present-day lake.

Among the most dramatic glacial deposits found in the Western States are those produced by glacial outburst floods. These floods occur when a pocket of meltwater that has developed underneath a glacier suddenly breaks through the restraining ice. As the torrent rushes downhill, it picks up rock, sediment, vegetation, and any other debris it can carry, forming a fast-moving slurry that is a significant hazard for many mountain communities. With a number of glaciers in the Cascades and Alaska situated on steep, debris-covered volcanoes, glacial outburst floods are all too common.

Glaciers and Deserts

The arid climate of the Basin and Range and Columbia Plateau may seem like an unlikely place to study glaciers, but even these regions did not escape the influence of the last ice age. The cooler climate of the late Pleistocene glaciation allowed ice caps to mantle entire mountain ranges, while meltwater ponded in basins between these ranges to form numerous, large, shallow, **pluvial lakes**, such as Lake Bonneville, which covered much of the Basin and Range.

As the climate warmed, the ice caps disappeared, leaving in their wake a multitude of cirques and U-shaped valleys. At the base of the mountains, moraines and deposits of till testify to the lower extent of the glaciers, while glacial drift deposits and dry waterfalls reflect the power of the meltwater streams issuing from them. The pluvial lakes are now gone, leaving behind **salt** flats and pockets of fine-grained lake sediment buried under the coarser desert sediment. In many of the West's deserts, wave-cut benches that resemble bathtub rings are visible around the upper perimeter of the basins.

Continental Glaciation in the Western States

Continental glaciers are now only a geologic memory in the Western States, yet the picture was much different during the Pleistocene. Nearly 20,000 years ago, the Cordilleran Ice Sheet covered nearly all of western Canada and parts of the United States. In Alaska, it covered only the southern half of the state, a result of **weather** patterns that drove snow-laden storms away from the state's northern section. In northern Washington, outlet glaciers and **ice lobes** reached down through the Okanogan Highlands and Puget Sound before spilling out onto the lowlands of the Columbia Plateau and southern portions of the Sound. In the vicinity of the North Cascade and Olympic ranges, the outlet glaciers merged with the ice caps that had formed over the range.

History

pluvial lake • a landlocked basin that fills with rainwater or meltwater during times of glaciation.

salt • a mineral composed primarily of sodium chloride (NaCl).

weather • the measure of short-term conditions of the atmosphere such as temperature, wind speed, and humidity.

ice lobe • a broad, rounded section of a continental glacier that flows out near the glacier's terminus.

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esker • a sinuous, elongated ridge of sand and gravel.

erratic • a piece of rock that differs from the type of rock native to the area in which it rests, carried there by glaciers often over long distances.

silt • fine granular sediment most commonly composed of quartz and feldspar crystals.

iceberg • a large chunk of ice, generally ranging in height from 1 to 75 meters (3 to 246 feet) above sea level, that has broken off of an ice sheet or glacier and floats freely in open water.

estuary • a place where freshwater and saltwater mix, created when sea level rises to flood a river valley.

plate tectonics • the way by which the plates of the Earth's crust move and interact with one another at their boundaries.

subduction • the process by which one plate moves under another, sinking into the mantle.

One result of the Pleistocene glaciations were huge, U-shaped valleys in the Okanogan Highlands, North Cascades, and Olympics that were carved by outlet glaciers of the Cordilleran Ice Sheet. In Puget Sound, a large lobe, along with the meltwater draining it, sculpted a complex system of fjords while dumping masses of drift nearly 300 meters (1000 feet) thick. This flowing ice and water also sculpted hundreds of drumlins and bedrock hills into linear shapes that marked the flow direction of the ice. Farther to the east, in the Columbia Plateau, the deposits were sculpted into snake-like ridges called **eskers**. These are believed to be the result of streams flowing through tunnels at the bottom of the glacier that filled up with sediment. In the northern section of the plateau, house-sized boulders (**erratics**) left behind by the receding ice force farmers to creatively plow their fields. In other parts of the plateau, **silt** blown from the outwash plains (loess) was deposited well over a hundred miles south of the ice sheet terminus.

Another way the Cordilleran Ice Sheet shaped the Columbia Plateau was by numerous catastrophic floods emanating from the Pleistocene-age glacial Lake Missoula. These flows, sometimes called the Bretz Floods after the geologist who discovered them, would periodically race across the plateau, scouring bedrock and transporting massive amounts of sediment and rock to the Willamette Valley and beyond. The cause of the floods is commonly attributed to meltwater lakes dammed by glacial ice that drained as their ice dams abruptly failed. During the Pleistocene, similar floods occurred in east and south central Alaska and in the Sierra Nevada.

Glaciers and Coastlines

Glaciers have shaped the coastlines of the Western States in three ways. In Alaska, where they reach to the sea, outlet glaciers carve intricate systems of fjords, creating exceedingly rugged coastlines. Since many of these glaciers flow into the ocean, they lose mass by calving. In this way, they create countless **icebergs** that deposit a chaotic mix of rock and sediment on the seafloor as they melt. Though these sediments are not readily visible in Alaska, they are common along the coast of Washington.

Another way that glaciers have shaped the West Coast is through the rise and fall of sea level. Approximately 20,000 years ago, the coast of Oregon, Washington, and California was 65 to 130 kilometers (40 to 80 miles) farther west than it is now, since sea level was nearly 90 meters (300 feet) lower. At that time, the coast was most likely a broad plain that gradually rose to the base of the present-day coastal mountain ranges. As the ice sheet retreated, increased meltwater flowed back into the sea. As the sea rose, the shoreline advanced eastward towards the mountain ranges, eventually resulting in a shoreline characterized by rocky headlands, small beaches, and large **estuaries**. As present-day glaciers diminish in size and sea level continues to rise due to changes in global climate, several factors complicate our predictions of how the coastlines of the Western States will change. Chief among these is the slow rise of the crust at the western edge of North America due to **plate tectonics** and **subduction**. Another significant influence is the continuing slow rebound of the northern half of North America, brought about by the disappearance of



the great Pleistocene ice sheets. The degree to which these factors will offset rising sea levels is both a practical and theoretical concern, given the vast number of people living on or near the coastline of the Western States.

Glaciers in Hawai'i

Since Hawai'i is a tropical **volcanic island**, most people do not think about glaciers or snow ever having existed there. However, glacial deposits—moraines and till—beginning from approximately 70,000 years ago are preserved on the flanks of Mauna Kea volcano. Similar deposits may have once existed on Mauna Loa as well, but they have since been covered by **lava** flows. Due to the immense height of these volcanoes, snowfall still accumulates on both Mauna Kea and Mauna Loa in winter (*Figure 6.16*).

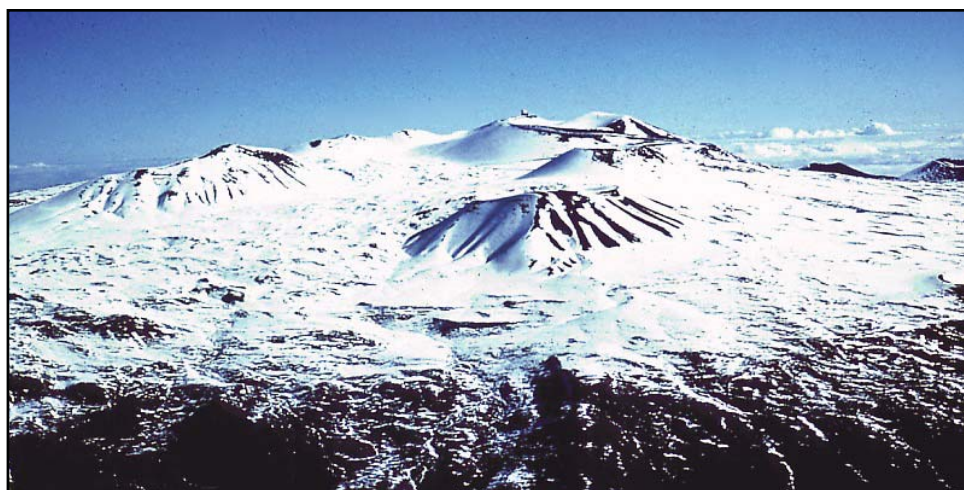


Figure 6.16: Snowfall on the peaks of Mauna Kea in winter.

History

volcanic island • one of a string of islands created when molten rock rises upward through oceanic crust.

lava • molten rock located on the Earth's surface.



Resources

Resources

Books

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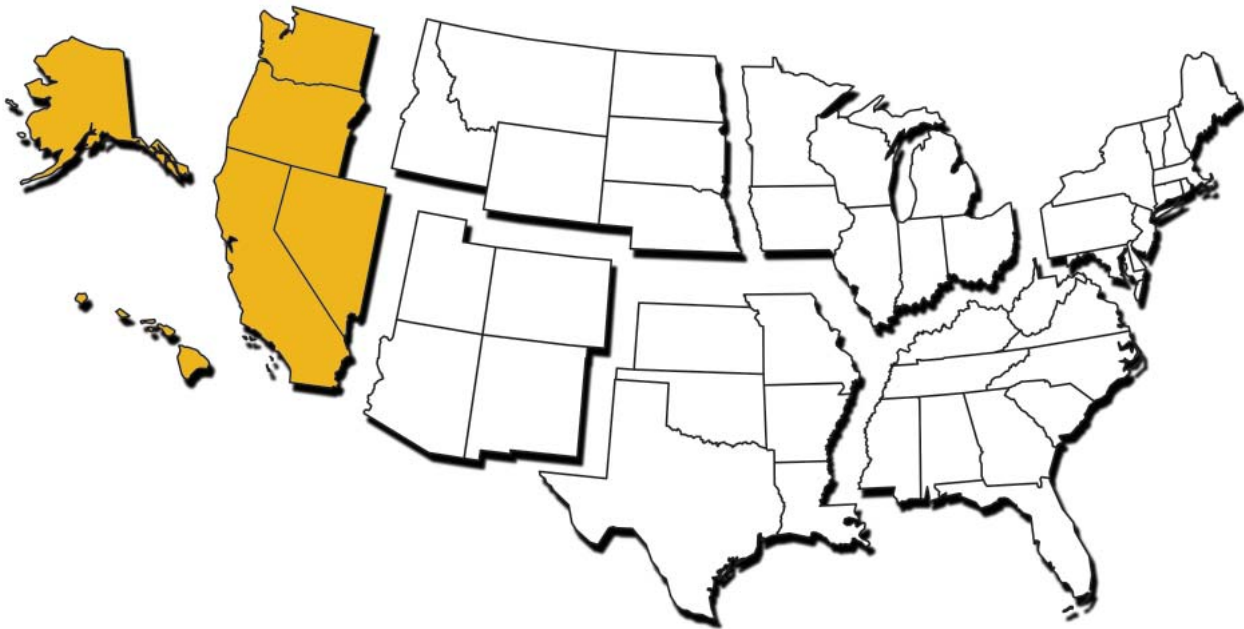


Activities

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The
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Guide™

to the Earth Science of the
Western US



Edited by Mark D. Lucas, Robert M. Ross, & Andrielle N. Swaby

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