# What is a glacier?

Glaciers are made up of fallen snow that, over many years, compresses into large, thickened ice masses. Glaciers form when snow remains in one location long enough to transform into ice. What makes glaciers unique is their ability to move. Due to sheer mass, glaciers flow like very slow rivers. Some glaciers are as small as football fields, while others grow to be over a hundred kilometers long.

Since the mid-nineteenth century, scientists and naturalists have closely studied glaciers. In this photograph from 1894, two men approach a yawning crevasse. For safety, they use rope harnesses, attaching themselves to more stable ground further away from the crevasse. Even today, people doing fieldwork on glaciers take these precautions.

Presently, glaciers occupy about 10 percent of the world's total land area, with most located in polar regions like Antarctica and Greenland. Glaciers can be thought as remnants from the last Ice Age, when ice covered nearly 32 percent of the land, and 30 percent of the oceans. An Ice Age occurs when cool temperature endure for extended periods of time, allowing polar ice to advance into lower latitudes. For example, during the last Ice Age, giant glacial ice sheets extended from the poles to cover most of Canada, all of New England, much of the upper Midwest, large areas of Alaska, most of Greenland, Iceland, Svalbard and other arctic islands, Scandinavia, much of Great Britain and Ireland, and the northwestern part of the former Soviet Union.

Within the past 750,000 years, scientists know that there have been eight Ice Age cycles, separated by warmer periods called interglacial periods. Currently, the Earth is nearing the end of an interglacial, meaning that another Ice Age is due in a few thousand years. This is part of the normal climate variation cycle. Greenhouse warming may delay the onset of another glacial era, but scientists still have many questions to answer about climate change. Although glaciers change very slowly over long periods, they may provide important global climate change signals.

### How is a glacier formed?

Glaciers begin to form when snow remains in the same area year-round, where enough snow accumulates to transform into ice. Each year, new layers of snow bury and compress the previous layers. This compression forces the snow to re-crystallize, forming grains similar in size and shape to grains of sugar. Gradually the grains grow larger and the air pockets between the grains get smaller, causing the snow to slowly compact and increase in density. After about two winters, the snow turns into firn -- an intermediate state between snow and glacier ice. At this point, it is about half as dense as water. Over time, larger ice crystals become so compressed that any air pockets between them are very tiny. In very old glacier ice, crystals can reach several inches in length. For most glaciers, this process takes over a hundred years.

### Why do glaciers move?

Once a mass of compressed ice reaches a critical thickness, around 18 meters thick, it becomes so heavy that it begins to deform and move. The sheer girth of the ice, combined with gravity's influence, causes glaciers to flow very slowly. Ice may flow down mountain valleys, fan across plains, or in some locations, spread out to the sea. Movement along the underside of a glacier is slower than movement at the top due to the friction created as it slides along the ground's surface.

Glaciers periodically retreat or advance, depending on the amount of snow accumulation or albation that occurs. This retreat or advance refers only to the position of the terminus, or snout, of the glacier. Even as it retreats, the glacier still deforms and moves downslope, like a conveyor belt. For most glaciers, retreating and advancing are very slow occurrences, noticeable only over a long time. However, when glaciers retreat rapidly, movement may be visible over a few months or years. For instance, massive glacier retreat has been recorded in Glacier Bay, Alaska. Other glaciers have been photographed at intervals showing dramatic recession.

Alternatively, glaciers may surge, racing forward several meters per day for weeks or even months. In 1986, the Hubbard Glacier in Alaska began to surge at the rate of 10 meters per day across the mouth of Russell Fiord. In only two months, the glacier had dammed water in the fiord and created a lake. This illustrates how quickly a surging glacier can change its surroundings.

### What are the components of a glacier?

Glaciers live a dynamic existence. Several elements contribute to glacier formation and sustainment. Snow falls in the accumulation area, usually the highest part of the glacier, adding to the glacier's mass. As the snow slowly turns to ice, the glacier increases in weight, forcing glacial movement. Further down the glacier is the ablation area, where most of the melting and evaporation occur. Between these two areas a balance is reached, where snowfall equals snowmelt. Here, the glacier is in equilibrium. Whenever this equilibrium is disturbed, either by increased snowfall or by excessive melting, the glacier either retreats or advances at more than its normal pace.

Several visible features are common to most glaciers. The awesome force of the glacier's own movement causes it to deform, often creating giant cracks in the ice called crevasses, which may make travel across a glacier treacherous. Underneath the glacier, where glacier ice meets the ground, large amounts of rock and soil are ground up by the tremendous weight of the glacier.

Another glacial feature are moraines, created when the glacier pushes or carries along this rocky debris as it moves. These long, dark bands of debris are visible on top and along the edges of glaciers. Medial moraines run down the middle of a glacier, lateral moraines along the sides, and terminal moraines are found at the terminus, or snout, of a glacier. Sometimes one glacier flows into another, also creating moraines. Because they represent evidence of glacial motion, crevasses and moraines are features that often help scientists decide whether a mass of ice is truly a glacier.

**Where are glaciers located?**

Most of the world's glacial ice is found in Antarctica and Greenland, but glaciers are found on nearly every continent, even Africa. Because certain climatic and geographic conditions must be present for glaciers to exist, they are most commonly found above snow line: regions of high snowfall in winter, and cool temperatures in summer. This condition allows more snow to accumulate on the glacier in the winter than will melt from it in the summer. This is why most glaciers are found either in mountainous areas or the polar regions. However, snow line occurs at different altitudes: in Washington State the snow line is around 1600 meters (or 5,500 feet), while in Africa it is over 5100 meters, and in Antarctica it is at sea level. The amount of snowfall a glacier can transform into ice is very important to its survival, which is why even a cold region like Siberia experiences almost no glaciation--there is not enough snowfall.

Approximate Worldwide Area Covered by Glaciers (square kilometers)

| | |
|---|---|
| Antarctica | 13,586,000 |
| Greenland | 1,700,000 |
| Canada | 200,000 |
| Central Asia | 109,000 |
| Russia | 82,000 |
| United States | 75,000 |
| China and Tibet | 33,000 |
| South America | 26,000 |
| Iceland | 12,000 |
| Scandinavia | 3,100 |
| Alps | 2,900 |
| New Zealand | 1,000 |
| New Guinea | 15 |
| Africa | 12 |

Total glacier coverage is over 15,800,000 square kilometers, or a little less than the total area of the South American continent.

**What types of glaciers are there?**

There are Ice Sheets, Ice Shelves, Ice Caps, Mountain Glaciers, Valley Glaciers, Piedmont Glaciers, Cirque Glaciers, Hanging Glaciers, and Tidewater Glaciers.

**Ice Sheets**

Found only in Antarctica and Greenland, ice sheets are enormous masses of glacial ice and snow expanding over 50,000 square kilometers. The ice sheet on Antarctica is over 4200 meters thick in some areas, covering nearly all of the land features except the Transantarctic Mountains, which protrude above the ice.

**Ice Shelves**

Ice shelves occur when ice sheets extend over the sea, floating on the water. In thickness they range from a few hundred meters to over 1000 meters. Ice shelves surround nearly all of the Antarctic continent. Retreating ice shelves may provide indications of climate change. For example, the Larsen Ice Shelf began retreating in spring 1998 and lost nearly 3000 square kilometers during the follwoing year. Check out some of the remotely sensed satellite images scientists used to monitor the ice shelf breakup.

**Ice Caps**

Ice caps are miniature ice sheets. An ice cap covers less than 50,000 square kilometers. They form primarily in polar and sub-polar regions that are relatively flat and high in elevation.

**Mountain Glaciers**

These glaciers develop in high mountainous regions, often flowing out of icefields that span several peaks or even a mountain range. The largest mountain glaciers are found in Arctic Canada, Alaska, the Andes in South America, the Himalayas in Asia, and on Antarctica.

**Valley Glaciers**

Commonly originating from mountain glaciers or ice fields, these glaciers spill down valleys, looking much like giant tongues. Valley glaciers may be very long, often flowing down beyond the snow line, sometimes reaching sea level.

**Piedmont Glaciers**

Piedmont glaciers occur when steep valley glaciers spill into relatively flat plains, where they spread out into bulb-like lobes. The Malaspina Glacier in Alaska, covering over 5,000 square kilometers is one of the most famous examples of this type of glacier.

**Cirque Glaciers**

Cirque Glaciers are named for the bowl-like hollows they occupy, which are called cirques. Typically, they are found high on mountainsides and tend to be wide rather than long.

**Hanging Glaciers**

Also called ice aprons, these glaciers cling to steep mountainsides. Like cirque glaciers, they are wider than they are long. Hanging glaciers are common in the Alps, where they often cause avalanches due to the steep inclines they occupy.

**Tidewater Glaciers**

As the name implies, these are valley glaciers that flow far enough to reach out into the sea. Tidewater glaciers are responsible for calving numerous small icebergs, while not as imposing as Antarctic icebergs, can still pose problems for shipping lanes.

**How do glaciers affect the land?**

Glaciers not only transport material as they move, but they also sculpt and carve away the land beneath them. A glacier's weight, combined with its gradual movement, can drastically reshape the landscape. Over hundreds or even thousands of years, the ice totally changes the landscape. The ice erodes the land surface and carries the broken rocks and soil debris far from their original places, resulting in some interesting glacial landforms.

**Glacial Erosion**

Common all over the world, glaciated valleys are probably the most readily visible glacial landform. Similar to fjords, they are trough-shaped, often with steep vertical cliffs where entire mountainsides were removed by glacial action. One of the most striking examples of glaciated valleys can be seen in Yosemite National Park, where glaciers literally sheared away mountainsides, creating deep valleys with vertical walls.

Fjords, such as those in Norway, are long, narrow coastal valleys that were originally carved out by glaciers. Steep sides and rounded bottoms give them a trough-like appearance. Because of glacial erosion on the below sea level land surface, when glaciers finally disappear, sea water covers the valley floor.

Cirques are created when glaciers erode backwards, into the mountainside, creating rounded hollows shaped like a shallow bowls. Aretes are jagged, narrow ridges created where the back walls of two cirque glaciers meet, eroding the ridge on both sides. Horns, such as the famous Matterhorn in Switzerland, are created when several cirque glaciers erode a mountain until all that is left is a steep, pointed peak with sharp, ridge-like aretes leading up to the top.

**Glacial Landforms**

Fjords, glaciated valleys, and horns are all erosional types of landforms, created when a glacier cuts away at the landscape. Another type of glacial landform is created by deposition, or what a glacier leaves as it retreats or melts away.

Till is material that is deposited as glaciers retreat, leaving behind mounds of gravel, small rocks, sand and mud. It is made from the rock and soil ground up beneath the glacier as it moves. Glacial till can form excellent soil for farmland.

Material a glacier picks up or pushes as it moves forms moraines along the surface and sides of the glacier. As a glacier retreats, the ice literally melts away from underneath the moraines, so they leave long, narrow ridges that show where the glacier used to be. Glaciers don't always leave moraines behind, because sometimes the glacier's own meltwater carries the material away.

Streams flowing from glaciers often carry some of the rock and soil debris out with them. These streams deposit the debris as they flow. Consequently, after many years, small steep-sided mounds of soil and gravel begin to form adjacent to the glacier, called kames.

Kettle lakes form when a piece of glacier ice breaks off and becomes buried by glacial till or moraine deposits. Over time the ice melts,leaving a small depression in the land, filled with water. Kettle lakes are usually very small, and are more like ponds than lakes.

Glaciers leave behind anything they pick up along the way, and sometimes this includes huge rocks. Called erratic boulders, these rocks might seem a little out of place, which is true, because glaciers have literally moved them far away from their source before melting away.

Drumlins are long, tear-drop-shaped sedimentary formations. What caused drumlins to form is poorly understood, but scientists believe that they were created subglacially as the ice sheets moved across the landscape during the various ice ages. Theories suggest that drumlins might have been formed as glaciers scraped up sediment from the underlying ground surface, or from erosion or deposition of sediment by glacial meltwater, or some combination of these processes. Because the till, sand and gravel that form drumlins, are deposited and shaped by glacier movement, all drumlins created by a particular glacier face the same direction, running parallel to the glacier's flow. Often, hundreds to thousand of drumlins are found in one place, looking very much like whalebacks when seen from above.

### Do glaciers affect people?

Today, glaciers often are tourist attractions in mountainous areas. But glaciers are also a natural resource, and people all over the world are trying to harness the power of these frozen streams.

### Glaciers Provide Drinking Water

People living in the city of La Paz, Bolivia, rely on glacial melting from a nearby ice cap to provide water during the significant dry spells they experience.

Although parts of Japan receive tremendous amounts of snow, there are no glaciers. Because the Japanese must endure frequent droughts, scientists are examining ways to create artificial glaciers that could provide more water for people when the weather is dry.

### Glaciers Irrigate Crops

Over a thousand years ago, farmers in Asia knew that dark colors absorb the solar energy. So, they spread dark-colored materials such as soil and ashes over snow to promoted melting, and this is how they watered their crops in the springtime. Chinese and Russian researchers have recently tried something similar by sprinkling coal dust onto glaciers, hoping that the melting will provide water to the drought-stricken countries of India, Afghanistan, and Pakistan. However, the experiment proved to be too costly, and they have abandoned the idea.

In Switzerland's Rhone Valley, farmers have irrigated their crops for hundreds of years, by channeling meltwater from glaciers to their fields.

### Glaciers Help Generate Hydroelectric Power

Scientists and engineers in Norway, Canada, New Zealand and the Alps have worked together to tap into glacial resources, using electricity that has been generated in part by damming glacial meltwater.

### Are glaciers dangerous?

Glaciers usually are found in remote mountainous areas. However, some are found near cities or towns and sometimes present a danger to people living close by. On land, lakes formed on top of a glacier during the melt season may cause floods. At the snout (or terminus) of a valley glacier, ice falling from the glacier presents a hazard to hikers below. When ice breaks off over the ocean, an iceberg is formed. Some examples of these hazards are listed below.

### Flooding Caused by a Glacier

In Peru in 1941, 6,000 people perished when a glacial lake suddenly burst open, flooding the town of Huaraz below it. Since then, another lake has formed at the base of the glacier, but engineers have created artificial channels to prevent future flooding.

### Avalanches from Glaciers

Ice avalanches from glacier snouts have been recorded in the Swiss Alps for centuries, and they still happen despite attempts to prevent them. In 1965, Switzerland was constructing a dam for a hydro-electric plant above the town of Mattmark. Without warning, an enormous mass of ice from the tongue of the nearby Allalingletscher broke off. In mere seconds, the avalanche had rushed down the slopes and buried much of the construction camp, killing 88 workers.

### The Threat of Icebergs

Icebergs broken off, or calved, from ice shelves and tidewater glaciers pose a significant threat to sea lanes worldwide. One of the most famous examples is the Titanic, which in April 1912 carried 1,503 passengers to a watery grave after a collision with an iceberg that ripped a 90 meter hole in the ship. Shipping lanes along the coasts of Greenland and Newfoundland are historically iceberg-infested waters.

Icebergs calved by glacial ice continue to present problems even today. Recently, an enormous iceberg, over 80 kilometers long and 40 kilometers wide, broke away from the Larsen Ice Shelf in Antarctica. Because this iceberg may threaten southern shipping routes, it is being carefully observed by satellites and aerial survey.

### How do glaciers reflect climate change?

Glacial ice can range in age from several thousands to millions of years, making it valuable for climate research. To see a long-term climate record, an ice core is drilled and extracted from the glacier. Ice cores have been taken from around the world, including Peru, Canada, Greenland, Antarctica, Europe, and Asia. These cores are continuous records providing scientists with information regarding past climate. Scientists analyze various components of cores, particularly trapped air bubbles, which reveal past atmospheric composition, temperature variations, and types of vegetation. Glaciers literally preserve bits of atmosphere from thousands of years ago in these tiny air bubbles. This is how scientists know that there have been several Ice Ages. Past eras can be reconstructed, showing how and why climate changed, and how it might change in the future.

Scientists are also finding that glaciers reveal clues about global warming. How much does our atmosphere naturally warm up between Ice Ages? How does human activity affect climate? Because glaciers are so sensitive to temperature fluctuations accompanying climate change, direct glacier observation may help answer these questions. Since the early twentieth century, with few exceptions, glaciers around the world have been retreating at unprecedented rates. Some scientists attribute this massive glacial retreat to the Industrial Revolution, which began around 1760. In fact, some ice caps, glaciers and even an ice shelf have disappeared altogether in this century. Many more are retreating so rapidly that they may vanish within a matter of decades. Scientists are discovering that production of electricity, along with coal and petroleum use in industry, affects our environment in ways we did not understand before. Within the past 200 years or so, human activity has increased the amount of carbon dioxide and other greenhouse gases released into the atmosphere.

The 1991 discovery of the 5,000 year-old "ice man," preserved in a glacier in the European Alps, fascinated the world (see National Geographic, June 1 1993, volume 183, number 6, for an article titled "Ice Man" by David Roberts). Tragically, this also means that this glacier is retreating farther now than it has in 5,000 years, and no doubt other glaciers are as well. Scientists, still trying to piece together all of the data they are collecting, want to find out whether human-induced global warming is tipping the delicate balance of the world's glaciers.

**Presently, 10% of land area is covered with glaciers.**

**Glaciers store about 75% of the world's freshwater.**

**Glacierized areas cover over 15,000,000 square kilometers.**

**Antarctic ice is over 4,200 meters thick in some areas.**

**In the United States, glaciers cover over 75,000 square kilometers, with most of the glaciers located in Alaska.**

**During the last Ice Age, glaciers covered 32% of the total land area.**

**If all land ice melted, sea level would rise approximately 70 meters worldwide.**

**Glacier ice crystals can grow to be as large as baseballs.**

**The land underneath parts of the West Antarctic Ice Sheet may be up to 2.5 kilometers below sea level, due to the weight of the ice.**

**North America's longest glacier is the Bering Glacier in Alaska, measuring 204 kilometers long.**

**The Malaspina Glacier in Alaska is the world's largest piedmont glacier, covering over 8,000 square kilometers and measuring over 193 kilometers across at its widest point.**

**Glacial ice often appears blue because ice absorbs all other colors and reflects blue.**

**The Kutiah Glacier in Pakistan holds the record for the fastest glacial surge. In 1953, it raced more than 12 kilometers in three months, averaging about 112 meters per day.**

**In Washington state alone, glaciers provide 470 billion gallons of water each summer.**

**Antarctic ice shelves may calve icebergs that are over 80 kilometers long.**

**Almost 90% of an iceberg is below water--only about 10% shows above water.**

**The Antarctic ice sheet has been in existence for at least 40 million years.**

**From the 17th century to the late 19th century, the world experienced a "Little Ice Age," when temperatures were consistently cool enough for significant glacier advances.**