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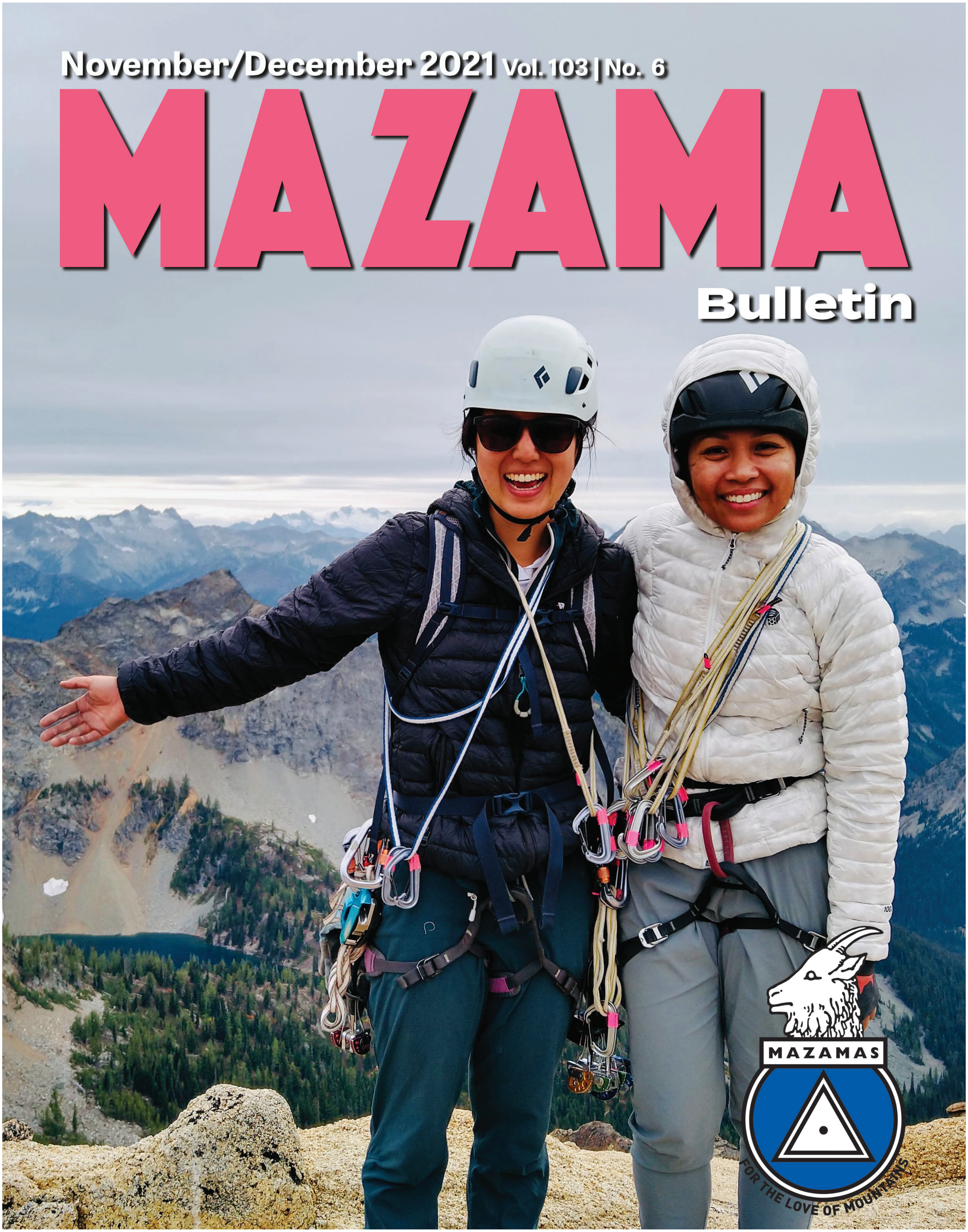

MAZAMAS
FOR THE LOVE OF MOUNTAINS

WHAT IS A GLACIER?

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Above: Eugene Glacier on South Sister. Eugene Glacier recently stagnated and ceased to flow. It is no longer a glacier as denoted by its lack of crevasses, concave terminus, and the clear meltwater coming from under the ice. Photo by Anders Carlson.

What is a glacier? As more and more people head into the backcountry and travel to remote peaks, this question pops up at growing frequency in social media posts, comments, and in professional journalism. Many a snowfield is misidentified as a glacier and many a glacier has now diminished to the point that it is now a semi-permanent snowfield. What's the difference? How does one tell between the two? And why does it matter?

Glaciers

Going back to 1840 when Louis Agassiz published *Études sur les glaciers* (Studies on Glaciers), a glacier is defined as ice that flows under its own weight. That is, a glacier is an ice body that moves. For this to happen, ice must reach a certain thickness so that the pressure on the bottom ice is so great that it ceases to be brittle and deforms like toothpaste. This thickness is about 100 feet (30 meters), with the measurement taken in the direction of Earth's gravitational pull (i.e., not necessarily perpendicular to the ice surface or the glacier bed).

To be a glacier then, ice must first accumulate to at least 100 feet, which means snow must accumulate over many years, turn into ice, with that ice building up to 100 feet thick. Consequently, ice-growth occurs at high elevations in what is called the accumulation zone. The accumulation zone is the area on the glacier where some of the prior winter's snow persists through the summer and is then buried by the next winter's snow. This snow accumulates year after year and slowly turns into glacial ice. Once thick enough, ice flows downhill to warmer elevations and terminates where it is so warm that all ice is melted. The region below the accumulation zone is called the ablation zone; this is where all the prior winter's snow is melted away at the end of the summer. The ablation zone is where the glacier loses mass due to melting, breaking off icebergs, and the direct transfer of ice to water vapor called sublimation. The dividing line between the two zones is the end-of-summer snowline on the glacier and is called the equilibrium line. Above the equilibrium line the glacier gains mass, while below the line the glacier loses mass. At the equilibrium line the glacier's losses equal its gains and there is no net change in mass.

A glacier is thus a manifestation of climate on the landscape. It accumulates where the landscape is cold enough for snow to persist year-round and then flows downslope to a zone where the landscape is warm enough in the summer to melt all the ice that can flow to that elevation. Similarly, the equilibrium line altitude reflects the elevation where the yearly average temperature is freezing (0°C; 32°F) in the atmosphere. But it is the flow of ice from the accumulation zone to the ablation zone that makes a pile of ice a glacier. See the photograph of Eliot Glacier on Mt. Hood, where ice flows from near the summit and its accumulation zone downslope to its terminus in the ablation zone.

A glacial moraine on the north side of North Sister that held a glacier at least in the 1960s. Note the lack of surface water outside the two little evaporative ponds. This region is dry and contains limited vegetation due to the lack of glacial meltwater. Photo by Anders Carlson.

Snowfields

Ice less than 100 feet thick is too thin to flow and is called a stagnant ice body; a body of ice on the landscape that is stationary. Many stagnant ice bodies underlie snowfields, which are semi-permanent snow patches that also do not flow. In general, snowfields will periodically disappear; otherwise the snow will accumulate over time and turn into ice that can then turn into a glacier. Therefore, snowfields in a cooling climate can grow into glaciers. Conversely, glaciers in a warming climate will lose their accumulation zone, thin to the point of stagnation, and then constitute an ice body at the core of a snowfield. For example, take the photograph of the remains of Glisan Glacier on Mt. Hood (note in the far right of the photo is the edge of the Sandy Glacier, which still flows). In 2003, Glisan was an active glacier according to observations. However, in the last 20 years, the climate has warmed enough to where the glacier lost its accumulation zone and melted to just a scrap of ice smeared on the mountainside with some snowfield cover.

A good example of the transition between glacier to snowfield/stagnant ice to ephemeral snowfield is Palmer Glacier on Mt. Hood. This snow-ice body is called both a glacier and a snowfield. In 1981, the U.S. Geological Survey measured the thickness of numerous glaciers on many of the Cascade volcanos to determine flood risks from glacier melt following the eruption of Mount St. Helens. They determined that the Palmer Glacier reached a thickness of 200 feet, meaning it was a glacier in 1981. Looking at archived photographs, no glacial ice was observable by the early 1990s, meaning the glacier had thinned and stagnated into a semi-permanent snowfield. More recently, this snowfield is gone in late September to early October despite the efforts of Timberline Lodge management to maintain the snow through the summer.

Differentiating the two

How does one differentiate between a glacier and a snowfield/stagnant ice body? Well, one should look for evidence of ice flow, which is what Louis Agassiz did in the early 1800s. In his case, he identified rocks on the surface of glaciers in the Alps and measured their orientation to a fixed point off the glacier. He would return at frequent intervals and found that the rock's orientation relative to his fixed point changed, demonstrating the movement of the ice downslope. This approach is no different than what is done today to measure ice flow with satellites: fixed locations are chosen, and their displacement measured over and over again by satellites. Or, global position system (GPS) stations are fixed on the ice, with their differential movement relative to a fixed point off the glacier measured near continuously. It's the same method as Agassiz's, just with more bells and whistles, and a little rocket science. However, these approaches require repeat visits to the glacier over months and years (whether manually measuring the movement of boulders or servicing GPS stations) or access to satellites. But what can one do while on a hike or climb? Well, one should look for evidence of ice flow, the defining feature of glaciers.

Crevasses are the most obvious evidence of ice flow. While ice with 100 feet of ice pressing down on it can deform and flow, the ice at the top of the glacier is still brittle as it lacks the necessary overlying pressure to deform. To keep up with the movement of the bottom ice, the upper ice cracks, making crevasses. Compare the adjacent photographs: the Glacier has many crevasses while the Glisan has none. However, in 2003, Glisan still had crevasses.

Another line of evidence for ice flow is the glacier terminus. If ice is flowing, then it will bulge out with a convex terminus, like a pile of Silly Putty that was allowed to flow out into a pancake shape with its convex margin. One can see this bulging ice on the Eliot Glacier. In contrast, stagnant ice and snowfields do not bulge forward and rather are melting back, which produces a concave terminus/edge; this is observable in the shape of the Glisan's remaining ice. In the case of the Palmer example, glacial ice with a

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Glacier, continued from previous page.

Left: The Glisan Glacier on Mt. Hood. The Glisan is no longer a glacier and rather just a bit of stagnant ice usually covered by a snowfield. It lacks crevasses and has a concave shape.
Below: The Eliot Glacier on Mt. Hood. This picture shows the ice flowing from the accumulation zone down to the ablation zone, with a convex terminus and many crevasses indicative of ice flow.
Photos by Anders Carlson.

convex terminus is found in photographs up to the late 1980s, with this convex ice absent in early 1990s photos.

Lastly, the flow of ice grinds the rock underneath the glacier, producing very fine-grained sediment called glacial flour. Thus, the meltwater streams originating from underneath a glacier have very high amounts of suspended sediment; one cannot drink the water. the Carver Glacier on South Sister, the meltwater is full of glacial flour with a convex terminus. In contrast, a stagnant ice body or snowfield does not grind the underlying rock and thus water flowing out from the ice/snow will be clear and drinkable. This can be seen in the photograph of the Eugene Glacier also on South Sister. The Eugene Glacier is now a stagnant ice mass (note the concave terminus); the ice below the waterline (that is not a reflection) is easily observable due to water clarity due to the lack of glacial flour, which reflects the lack of glacier movement.

Why does this matter?

As mentioned above, snowfields will occasionally disappear, and a stagnant ice mass is on its way to being an ephemeral snowfield. In contrast, a glacier reflects a climate that can sustain snow throughout the summer, year after year, decade after decade. Otherwise, the glacier would not exist. Therefore, the glacier and its meltwater constitute a permanent surface water source throughout the summer months while a snowfield will be gone in some years. You can rely on the glacier for consistent water flow but not the snowfield. But when a glacier transitions to a stagnant ice body, then that consistent water source is in jeopardy.

In the drought-prone American West, the distinction between glacier and snowfield is acutely important. In this region, most of the precipitation falls in the winter months as snow. During the dry summer months, this snowmelt keeps streams flowing. By the end of the summer, however, the snow is gone and what remains is just the glacier meltwater that sustains streams until the wet winter months return. Those are normal years.

Nowadays, with low snowfall winters and summer heatwaves, the snowpack either begins the summer already depleted, rapidly vanishes during the summer, or both, as was the case in the summer of 2021. Glaciers therefore play an outsized role in keeping streams flowing that would otherwise run dry. And those streams that had only snowfields in their catchment? They cease to flow. An example of a formerly glaciated basin is shown in the photograph from North Sister in Oregon where two little ephemeral lakes dammed behind the glacier moraine (a moraine is a pile of debris at the terminus of the glacier) are evaporating away in a landscape that less than 60 years ago had an active, yet unnamed, glacier, then a snowfield, and now bare rock. Consequently, properly differentiating between glaciers and snowfields/stagnant ice bodies is crucial for water resource planning for sustaining ecosystems and economies in the present and in the future.