



How does debris cover on the Kennicott Glacier influence glacier shrinking?



Photo credit: Leif Anderson

Where is the glacier?

The surface of the Kennicott Glacier near the town of Kennecott (visible in the background) includes exposed ice faces (white), ice faces covered with a very thin layer of wet rock debris (dark grey-brown), and debris-covered cones (light brown) up to 150 feet (46 m) tall.

The average thinning rate of Alaskan glaciers is six feet (two meters) each year.

As the Earth's climate changes and air temperatures rise, many glaciers in Alaska are shrinking—by retreating (smaller area), thinning, or both. Is the Kennicott Glacier in Wrangell-St. Elias National Park and Preserve also shrinking?

Characteristics of the Kennicott Glacier

The Kennicott Glacier gathers ice in the high peaks of the Wrangell Mountains, glides about 26 miles (42 km) down slope past the town of Kennecott (see photo above, note different spelling), and ends at its *terminus* near McCarthy. Tributary glaciers, such as the Gates Glacier (see map on reverse), add ice to the Kennicott, which covers 149 square miles (387 km²).

Based on the work of glaciologists, the terminus has retreated about 0.4 mile (600 m) since 1860 (most of this retreat—about 0.25 mile, or 400 m—has been since 1957) for a reduction in glacier length of about 1.4 percent in the last 150+ years. As for thinning, based on a study of the change in the glacier's surface elevation, between 1957 and 2007, the Kennicott Glacier lost elevation (thinned) by about 115-330 feet (50-100 meters).

Thus, the Kennicott Glacier indeed is losing ice, and the loss of mass or shrinkage is due primarily to ice thinning. So, why is the glacier thinning more than retreating?

Debris-covered glaciers

Part of the answer lies in the fact that the surface of the Kennicott Glacier, like that of many glaciers in

Alaska, has a debris cover of loose rocks. A thick layer of debris cover insulates the ice underneath, while a thin layer will increase melting because the dark debris absorbs solar rays and transfers heat to the ice.

Initially some of this rock debris may have cascaded onto the glacier during landslides or avalanches, while other rocks were plucked from the ground surface by the glacier, carried in the ice, and accumulated during melt out. The color of the debris is determined by the rock type (e.g., gray-brown limestone, red-black basalt) composing the debris.

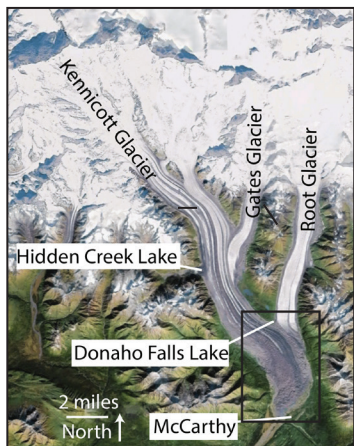
The debris on the Kennicott Glacier originated from 11 distinct *medial moraines*. Each of these stripes of loose rock down the center of the glacier formed when the lateral moraines of two merging glaciers came together. About four miles (seven km) from the terminus, the Kennicott Glacier's medial moraines coalesce to form a nearly continuous debris cover (see photo above). Based on satellite images, over 35,000 distinct ice faces dot the glacier in this area near the terminus. Here, ice cliffs are so steep that debris is absent or can only build to a very thin layer. About 12 percent of the glacier is covered with these "bare" ice faces with a thin debris cover.

Studying the Kennicott Glacier

Because the Kennicott Glacier has been studied extensively in the past, it makes a promising subject for studies of present-day glacier melt. Leif Anderson, formerly a graduate student at the University of Colorado Boulder, spent several weeks



The location of the Kennicott Glacier in Wrangell-St. Elias National Park and Preserve. The black rectangle is the location of the map below.



A satellite image of the Kennicott Glacier. The black box outlines the area of the image at right, where brownish rock debris covers the glacier.



Photo by Craig Anderson

Leif Anderson removed the debris cover at 74 locations on the Kennicott Glacier to drill into the ice. By placing a stake in the drilled hole and replacing the debris, he later could measure the ice melt beneath different thickness of the debris.

on the Kennicott Glacier in 2011. His research focused on understanding ice melt in the debris-covered part of the Kennicott Glacier in relation to the depth of debris cover and the extent of bare ice faces. Specifically, Anderson wanted to answer these questions: (1) How much glacier ice is melting each year? (2) What is the relative importance of melt under debris compared to melt on bare ice faces? and (3) How do these annual melt rates compare to the rate of glacier thinning (loss of elevation)?

Field methods

Anderson safely navigated the debris on the glacier to measure (1) air temperature on the glacier at three locations (green pentagons on map at right), (2) debris surface temperature, using an infrared temperature gun, at 40 locations and (3) debris-cover thickness on the glacier at 165 locations. At nine locations, he placed thermistors in the debris cover to take a temperature profile through the rocks to assess how well heat was conducted to the ice beneath. At 74 locations (pink hexagons), he removed the debris cover and used an ice drill to make holes 6 feet (2 m) deep (see photo at lower left). He placed a 3-foot (3-m) PVC pipe into the hole and replaced the debris. After several weeks, he returned to these locations to measure how much of the pipe was exposed because of the sub-debris melting of glacier ice. In addition, Anderson studied 60 bare ice faces (yellow circles on map), where he measured their height, length, and slope, and documented how fast they were melting.

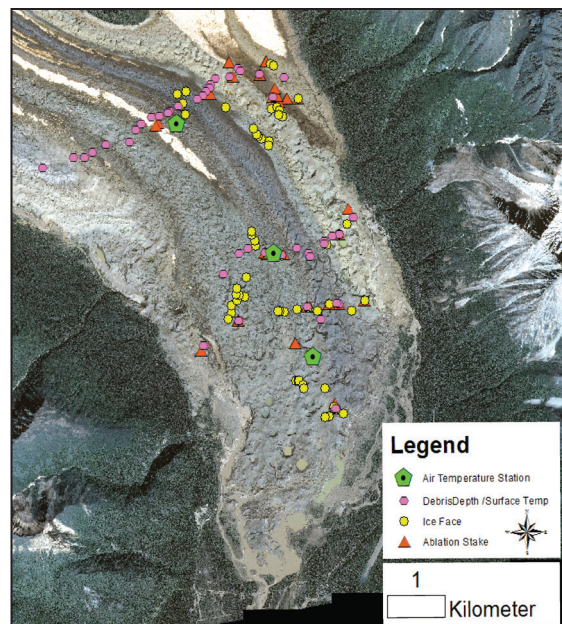
Research findings

In 2011, average air temperatures were greater at lower elevations. Debris surface temperature ranged from 32°F (0°C), where there was little debris cover and the underlying ice influenced the surface temperature, to 86° F (30° C), where debris cover was thickest.

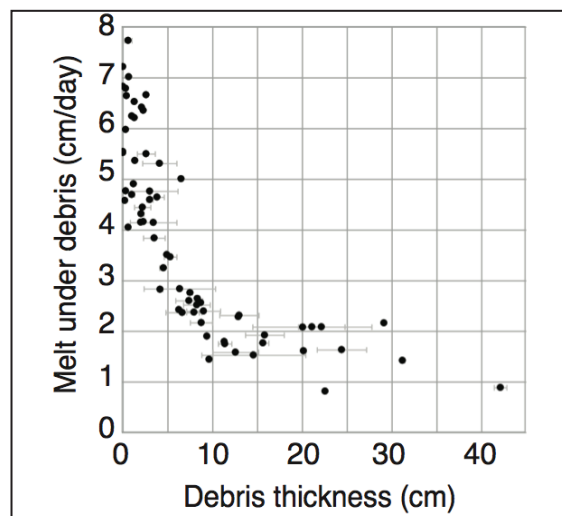
Debris thickness increased toward the terminus (down glacier) and ranged from a few inches (centimeters) above Donaho Falls Lake, where the Root Glacier meets the Kennicott, to 3 feet (1 m) at the very end of the glacier, near the bridge across the Kennicott River.

The ice melt under the debris cover at the stakes in Anderson's study area (pink hexagons on map) ranged from 0.4 to 3.1 inches (1 to 8 cm) per day, for a yearly melt of 6 to 23 feet (2 to 7 meters). Sub-debris melt rates were lowest at low elevations where debris cover was thickest (see graph at right).

In general, above the town of Kennecott, the debris on the glacier was less than 6 inches (15 cm) and the ice underneath melted faster than lower on the glacier. Below the town of Kennecott, the debris was greater than 6 inches and protected the ice from most melting, and thus prevented substantial glacier retreat. However, the "bare" ice faces melted quickly without a thick, insulating debris cover and contributed 50% of the total ice melt in the study area near the terminus. Of the ice faces that Anderson measured, on average, the ice faces were 30 feet (9 m) tall and had a slope of about 45 degrees.



In his study area near the terminus of the Kennicott Glacier, Leif Anderson measured air temperature (green), debris depth and glacier surface temperature (pink), ice faces (yellow), and glacier ice melt using PVC pipes (orange).



The rate of sub-debris melt of glacier ice was least where the thickest cover most insulated the ice from sun and warm air temperatures.

The Kennicott Glacier is interesting because it does not follow the melting pattern expected for a glacier, i.e., warmer temperatures at lower elevations would be expected to cause lots of melting and the cooler temperatures at higher elevations would help preserve glacier ice. On the Kennicott, the thick debris cover actually protects most of the ice at low elevations, but in spite of the reduced melt at low elevations, the Kennicott Glacier is shrinking, primarily by thinning in areas not covered by debris. The shrinking Kennicott Glacier is a complex story of melting related to elevation, debris cover thickness, and the large number of ice faces near the terminus.

For more information

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