Courtesy of Anchorage Museum of History and Art, MoC 1935-1 A

Exit Glacier in 1948, photo taken by Steve McCutcheon.

Left: Over 100,000 visitors hiked to Exit Glacier this past summer.

National Park Service photograph

The Retreat of Exit Glacier

by Susan Huse

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As thousands of visitors hike up the Exit Glacier valley this summer, they will benefit from work completed in 2001 by Joel Cusick, a mapping specialist for the National Park Service. His work has recreated the history of Exit Glacier's movement over the last 200 years, using techniques such as aerial photography and tree coring to identify and date the extent of the glacier. His findings will help further biological research and park planning, and it will help visitors gain insight into the magnitude and the time scale of glacier movements. Scientists studying plant and soil growth in a glacial environment gain a chronology of the valley's exposure, which helps determine when plants began to reestablish and the soil chemistry began its progression from glacial till to forest soil.

Kenai Fjords National Park

Kenai Fjords National Park lies along the Kenai Peninsula coast in southcentral Alaska, just southwest of Prince William Sound. The park landscape is a dramatic juxtaposition of land and water, shaped by the advance and retreat of glaciers. The park is capped by the largest icefield entirely contained within the United States, Harding Icefield, a 300 square mile expanse covering a mountain range under ice several thousand feet thick.

Exit Glacier is one of 38 glaciers that flow out from the Harding Icefield. During the early nineteenth century, the glacier almost reached the Resurrection River, approximately 1.25 miles (2 km) below its present location. In the last 200 years, the glacier retreated exposing the valley below. The exposed valley is a natural laboratory where we can see the processes of life reclaiming a barren landscape: moss, lichen and fireweed colonize the bare rock; followed by grasses, shrubs, alders, and cottonwood; and finally, a spruce-hemlock forest grows where 200 years ago only ice and rock existed. Exit Glacier is accessible by road and thousands of park visitors have an opportunity to experience the glacier firsthand.

Understanding Glaciers

To map the history of a glacier's movements, one must first understand how glaciers work. Alpine glaciers, like Exit Glacier, form when more snow falls on mountain peaks during the year than melts during the summer. As the snow pack builds up and thickens, its weight compresses the snow beneath and turns it to ice. As more and more snow and ice accumulate, the glacier grows. The weight of the ice high in the mountains begins to push the ice below, down the mountain, and it actually flows very slowly down through the valley. The movement of the glacier scrapes the ground beneath, scouring the valley floor, and carrying along the dislodged rocks and debris. Rock avalanches from the peaks and the valley surrounding the glacier add more debris. With time the growing glacier becomes a jumbled mix of rock and ice.

Even as the snow falls in the colder alpine environment at the top of the glacier, the accumulation zone, the ice is continually melting in the warmer regions at the bottom of the glacier, the ablation zone. When the accumulation at the top pushes the ice down through the valley faster than the ice melts at the bottom, the front edge of the glacier advances. When the ice at the bottom melts faster than the ice is pushed downhill, the glacier recedes.

During a recession, the ice and rock continue to flow downhill to the toe of the

National Park Service photograph

Roadside sign showing the extent of Exit Glacier in 1899.

glacier. As the ice melts, rock deposits are left on the ground in front of the leading edge of the glacier, glacial till. In this way a continuous layer of till is left across the newly exposed valley floor. There are also periods when the ice at the front melts at essentially the same rate as the ice flows down. This is called a period of stagnation, and the front edge of the glacier stays in one place, neither receding nor advancing. The rock and debris, however, continue to be pushed downward to the leading edge of the glacier where it is deposited as the ice melts away. If a period of stagnation lasts for several years, the till will build up higher and higher at the stationary leading edge, creating a long mound of rock at the front of the glacier. When the glacier begins to recede again, this moraine is left behind outlining the leading edge of the glacier. If a glacier advances after a period of stagnation, it will plow away the newly formed moraine. The moraine that marks a glacier's maximum advance is called the terminal moraine. The series of moraines that are left behind as the glacier goes through periods of recession and stagnation are called linear moraines. These linear moraines show a series of glacier outlines during the recession period.

Mapping Glaciers Over Time

In particular, how can a researcher reconstruct the retreat of a glacier as it melts back? Joel Cusick, a mapping specialist at the National Park Service's office in Anchorage, undertook the task of recreating Exit Glacier's retreat as one part of his University of Alaska-Anchorage Master's thesis. To identify and map the changes, Cusick had to use several techniques to piece together the history of Exit Glacier.

Using Aerial Photographs

The easiest way to map a glacier's changes is to look at historic aerial photographs. The edge of the ice can be traced on the photograph and dated to when the photograph was taken. Cusick compiled photographs from collections around the state, including federal and state agencies, libraries and museums, the University of Alaska, the City of Seward, and Aeromap US Inc. The series of photos almost covered a 50-year span: 1950, 1961, 1973, 1974, 1978, 1984, 1985, 1993, 1996, 1997, and 1998. Unfortunately, although nearby Seward was incorporated in 1903, the Exit Glacier area had little commercial value and photos found prior to 1950 were oblique. Oblique photos are not taken looking directly downward, and so they could not be used effectively in the computer.

Cusick was able to use some photographs, which he scanned so they could be used in a digital format. To use the photographs together, Cusick needed to georeference them, or specify exact real-world coordinates in the photographs. This then enabled computer mapping software known as GIS (Geographic Information Systems) to overlay each photograph exactly on top of the others, correcting for scale, direction and center point. In order to georeference the photographs, Cusick identified control points that were clear landmarks both in

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the photographs and on the ground. He determined the real-world coordinates of each control point with a Pathfinder Pro XR GPS receiver and fed these data into the GIS. Once the photographs were scanned and georeferenced, reconstructing the leading edge of the glacier during the past 50 years was a straightforward process: trace the edge of the glacier as it appears in the photograph for each date.

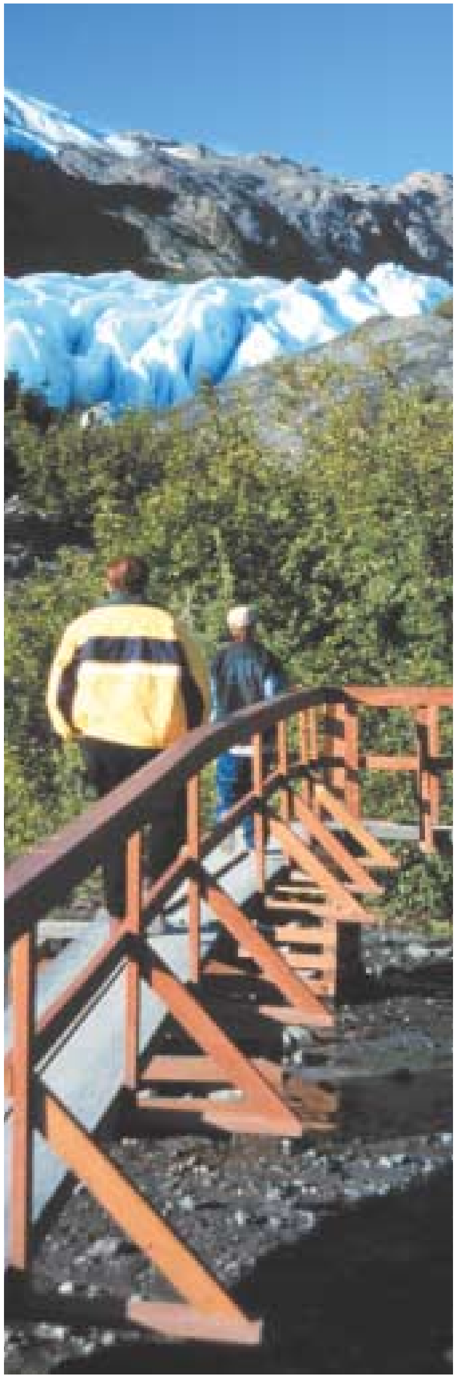
Using Biological Evidence

But what about the glacier prior to 1950? Without aerial photographs researchers had neither identified how far down the valley the glacier extended, nor the shape of the leading edge. Using the series of linear moraines left by the receding glacier, they could determine the shape of the glacier at a particular point in time, corresponding to periods of stagnation. To determine the age of the moraines and reconstruct the history of the glacier, researchers relied on analyzing natural processes that take place in the wake of the glacier.

One of the best methods for aging a moraine is by aging the lichens growing on the rocks. When the glacier first recedes creating the moraine, it is barren. Lichen spores soon settle on the rocks and begin to grow, growing at a constant rate determined by the local climate. To calculate that rate, researchers compare lichen from nearby surfaces they can date. For instance, gravestones are completely clean when they are placed in a cemetery and inscribed on each gravestone is the date it was put there. Or slag piles from the railroad construction in Portage, north of Seward, might be used for determining lichen growth rates. Portage is too far away, however; its climate is less maritime and not adequately representative of the Exit Glacier area. In the end, no useful sources for lichen growth rates were found, since the glacier is in a relatively underdeveloped area. Cusick had to find another method.

Dendrochronology - using tree rings to reconstruct history

A very common biological technique, known as dendrochronology, assigns dates to environmental events in the past by counting tree rings. As a tree grows, its



Right: The hike from the parking lot to Exit Glacier is approximately a half mile long.

National Park Service photograph

Far Right: Exit Glacier is one of 38 glaciers that flow out from the Harding Icefield.

Courtesy of Page Spencer, National Park Service

trunk continually grows outward. In spring and early summer the trees grows a soft light-colored wood with larger cells. As growth slows in late summer and fall, the tree cells are much smaller and darker. It is this difference between the early and later growth rates that creates the characteristic ring pattern within the trunk. By counting the number of rings, researchers can determine the number of years of growth, i.e., a tree's age.

Using the oldest tree, if you subtract its age from the year it was sampled, and then subtract the number of years it took for a tree to establish on the moraine, you have the year the moraine was created by the glacier. Sounds easy, until you get started. To date the moraine using trees, a researcher must first decide how long after a glacier retreats from a moraine does it take for a particular species to start growing there. Does it grow the next day, the next year, the next decade? If the moraine is very old, will the first trees have died already, or is there a species that will live for a hundred years?

Several species of trees and shrubs grow in the Exit Glacier Forelands. Alder establish very quickly on disturbed areas and are typically the first trees to colonize the moraines; however, they do not live long enough to date older moraines. Birch trees are not common enough to use consistently. Therefore, researchers eliminated alder and birch as useful markers. Black cottonwood trees *(Populus balsamifera ssp. trichocarpa)* are prevalent along the moraines, and live long enough to date many of the pre-1950s moraines. Unfortunately the rings of cottonwood can be indistinct, because the wood cells do not vary greatly from spring to fall. Cottonwood centers can also be rotten, losing the earlier rings. Cusick relied on averaging multiple counts for the best estimate of age. Sitka spruce *(Picea sitchensis)* takes much longer to grow on the moraines, but it can live a long time and has distinct rings. Therefore, it was used extensively for dating the older moraines.

When determining the age of a tree, the most accurate method is to simply cut down the tree right at ground level and count the rings on the stump. If you count rings that are above ground level, the tree may have grown a few years before the rings appear at the height you cut. The Exit Glacier Forelands, however, are within a national park where trees are protected. Cusick could not cut down the trees. Instead he used tree cores, drilling out a narrow tube of the trunk and counting the rings on the core.

Cusick visited each moraine and selected trees on the top, distal (farthest from the glacier) and proximal (closest to the glacier) sides. The tree with the widest trunk may not be the oldest, since harsher conditions, such as cold glacier breezes or a rocky substrate, can affect a tree's growth. Its trunk may seem narrower than younger trees that started under more favorable conditions. So, Cusick used a combination of trunk size and trunk appearance to select older trees for coring.

The next step was to determine the number of years it takes for specific species to begin growing on a moraine — this is known as the ecesis interval. This interval depends upon the tree species and upon the local climate conditions. Cottonwoods colonize much sooner than spruce, and therefore have a shorter ecesis interval. Previous research showed a wide range of intervals for spruce, 5 to 60 years. Crossen (1997) calculated an ecesis interval of 5 years for cottonwood and 25 years for spruce for Portage, Alaska. To determine whether Crossen's research would be applicable to Exit Glacier, Cusick compared his cores to moraines that were dated from the photographs. One of the photographs showed a moraine being formed in 1950, and the oldest cottonwood on this moraine dated to 1956, according to the core. Since the moraine was still being

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formed in 1950, Cusick calculated a 5-year lag, corresponding exactly with Crossen. Cusick then sampled spruce on several moraines to calculate an ecesis interval for spruce. With just a small number of trees, he calculated an average interval of 26 years for spruce. Crossen's estimate was similar, but based on a larger sample size, so Cusick used Crossen's estimate of a 25-year ecesis interval for spruce.

The Reconstructed Exit Glacier History

With the moraines mapped and the ecesis intervals determined, Cusick could now visit each moraine, sample the oldest trees and determine the age of each moraine. Using the moraine dates, Cusick could reconstruct the history of Exit Glacier and its dramatic retreat up the valley.

The Little Ice Age (LIA) was a time of global cooling from approximately 1350 to 1870 AD. During this time glaciers expanded in the northern regions, moving down the mountains and scouring the vegetation that had been in the valleys below. Park Service personnel recently discovered evidence of a buried forest dating back to at least 1170 AD high in the Forelands near the current glacier's edge.

Date (Year A.D.)	Distance of Retreat ft (m)	Retreat Rate ft/yr (m/yr)
1815 – 1889	230 (70)	3 (1)
1889 – 1891	299 (91)	151 (46)
1891 – 1894	446 (136)	147 (45)
1894 – 1899	935 (285)	187 (57)
1899 – 1914	630 (192)	43 (13)
1914 – 1917	909 (277)	302 (92)
1917 – 1926	974 (297)	108 (33)
1926 – 1950	469 (143)	23 (7)
1950 – 1961	692 (211)	62 (19)
1961 – 1968	794 (242)	115 (35)
1968 – 1973	171 (52)	33 (10)
Total Retreat		
1815-1999	6549 (1996)	43 (13)

Table 1: Exit Glacier Retreat Distances and rates through Time

Exit Glacier advanced from the Harding Icefield during the Little Ice Age, burying this existing forest and advancing to a maximum marked by the terminal moraine dated to 1815.

With the warming trend of the 1800s, Exit Glacier began to retreat from its 1815 maximum. Very slowly, the glacier retreated 230 feet (70 m) from 1815 to 1889, averaging about 3.1 ft/year (1 m/yr) *(see Table 1)*. The glacier then retreated much more rapidly between 1889-1899, interspersed with periods of stagnation, which are marked by linear moraines (1889, 1891, 1894 and 1899). During this time, the glacier retreated 1680 ft (512 m), about 168 ft/yr (51 m/yr).

The next fifteen years was a period of a slow but steady retreat, as the glacier retreated only 42 ft/yr (13 m/yr). In the years between 1914 and 1917, Exit Glacier experienced its most rapid retreat. In just 3 years, the glacier retreated 908 ft (277 m) or almost a foot per day. From 1917 to 1973, Exit Glacier continued to retreat with periods of slow to moderate retreat. There were five periods of retreat, with the ice melting fastest between 1961 and 1968 (115 ft/yr or 35 m/yr).

During the retreat of Exit Glacier from its Little Ice Age maximum in 1815 until recent times, the glacier has left a series of more than 11 moraines and retreated more than 1.25 miles (2 km). The glacier had an average retreat of roughly 6/10 of a mile each century or one kilometer each century.

Discussion

By identifying the chronology of the Exit Glacier retreat, Cusick has furthered both research and education at Kenai Fjords National Park. Knowing the dates when the valley floor was exposed, researchers have the opportunity to study the processes of vegetative and soil succession. A variety of questions can be explored: How does a rocky, barren expanse slowly become a forested valley? How do soils develop and plants colonize the area? How do insects, birds and mammals move in and an ecosystem evolve?

Visitors to the park can imagine the power of glacial forces by seeing firsthand the effects of the glacier. As visitors proceed up the valley towards the glacier, they are also taking a trip through time. Interpretative signs show when the glacier retreated past points along the way. Similar to hikers in the Grand Canyon, visitors can take a walk through history and experience geologic time in a way no text can ever provide.

More information can be found on the National Park Service website **www.nps.gov/kefj.**

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