U.S. Department of the Interior
U.S. Geological Survey

Columbia Glacier, Alaska Research on Tidewater Glaciers

Figure 1. Columbia Glacier, January 10, 1993.

Columbia Glacier (fig. 1) is one of North America's most dynamic glaciers. It has retreated nearly 10 kilometers (6 miles) in the past 12 years, while producing large numbers of icebergs that are a hazard to ships approaching and departing the port of Valdez, Alaska (fig. 2). During the past century, Columbia and other glaciers have been the subject of continuous research by the U.S. Geological Survey, Department of the Interior. The goals of this research are an improved understanding of glacier processes, assessment of glaciers as a water resource, documentation of glacier fluctuations, and assessment of glacier hazards.

BACKGROUND

Columbia Glacier flows southward from the Chugach Mountains and enters the north side of Prince William Sound about 150 kilometers (93 miles) east of Anchorage and 40 kilometers (25 miles) west of Valdez (fig. 3). Prior to 1980, it had a long history of stability, with a length of 66 kilometers (41 miles), and small, short-lived advances or retreats. During the early part of the 1980 decade, it began a rapid retreat that has continued into the mid-1990 decade, with no indication that it will stop soon. In 1995, it was about 57 kilometers (35 miles) long and had an area of about 1,000 square kilometers (384 square miles).

The retreat of Columbia Glacier was anticipated. During aerial glacier reconnaissance flights during the 1960's and 70's, USGS employee Austin Post realized that Columbia Glacier was the only tidewater glacier in southern Alaska that was in an extended position, that is, it had not recently retreated. All other major tidewater glaciers had made major retreats in the last century or two. Post's observations inspired a team of USGS scientists, led by Mark Meier, to begin intensive studies at Columbia Glacier in 1977. This work would have practical application because a rapid retreat would increase the rate at which icebergs calved from the glacier. These icebergs could then enter shipping lanes near Valdez, through which oil tankers travel.

MEASUREMENTS

The rate at which ice breaks from a tidewater glacier terminus, or the calving rate, was measured at many glaciers, and related to water depth at the terminus. Ice thickness was measured using a newly developed method of low-frequency ice-penetrating radar. Ice speed was measured with surveyed surface markers and with sequential aerial photography. Snow accumulation and ice melt were measured to determine the glacier's change in volume (mass balance). When all available information was put into a numerical model, the results were clear—rapid retreat would soon begin.

RETREAT

The prediction that Meier's team released in 1980 said that "the rate of retreat will accelerate during the next two or three years, and the annual discharge of icebergs will increase to a peak of about 8 to 11 cubic kilometers (about 2.5 cubic miles) per year (6 to 8 times the 1978 value) in the period 1982 to 1985. It is expected that the glacier will have retreated about 8 kilometers (5 miles) by 1986, and that retreat will continue for several decades." Continued direct observations show that the prediction was impressively correct in some ways, but inaccurate in other ways. Rapid retreat in fact began in about 1982. Although the retreat has not been as fast as predicted, the glacier has

Figure 2. Damage to the bow of the oil tanker *Overseas Ohio* after hitting an iceberg in shipping lanes near Columbia Glacier.

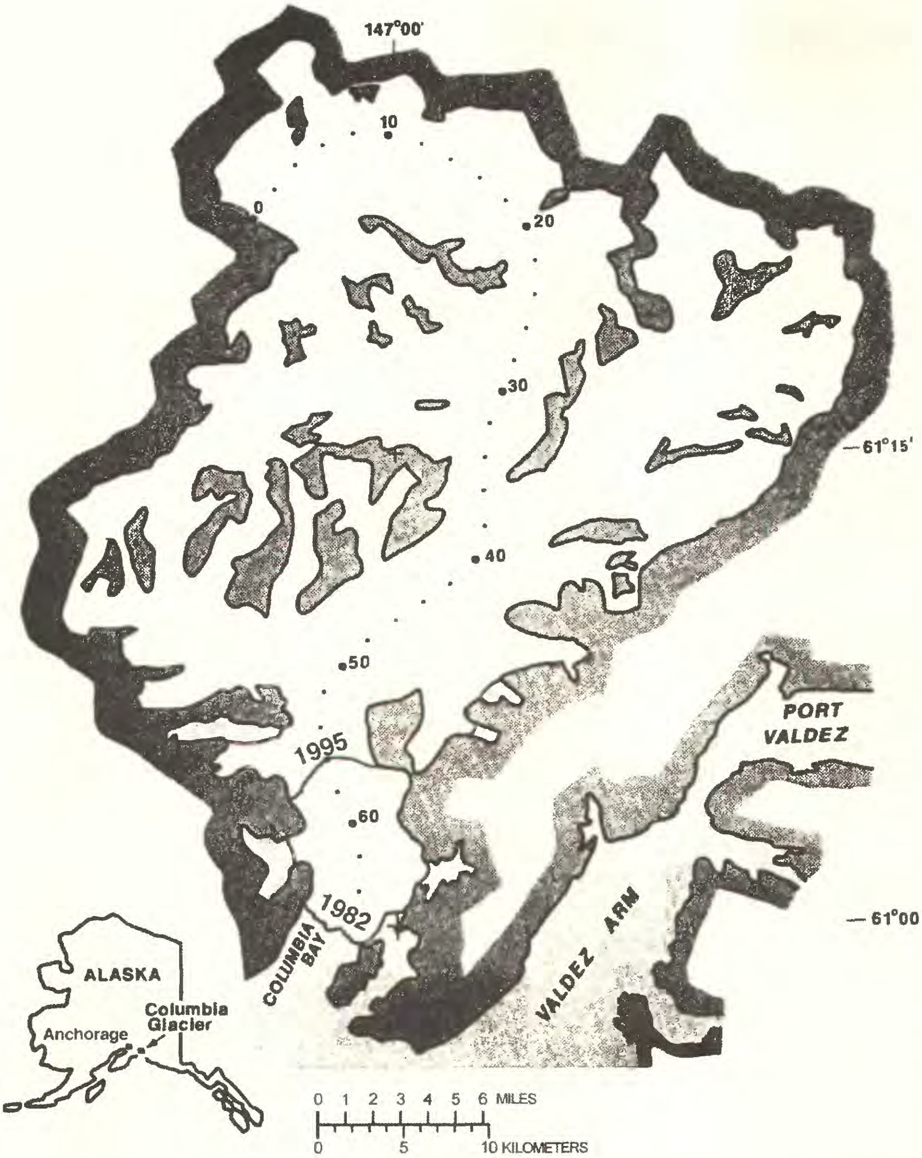

Figure 3. Columbia Glacier and vicinity. The terminus positions for 1982 and 1995 are shown. The numbers indicate the distance from the head of the glacier, in kilometers.

continued to retreat at a rate that has averaged 0.8 kilometer (0.5 mile) per year since 1982 (fig. 4). The rate of retreat, however, is not constant. Instead, it changes seasonally: during the winter, the terminus advances several hundred meters (up to 0.2 miles) and in the summer and fall, it retreats more than a kilometer (0.6 mile).

CALVING AND ICEBERGS

Nearly all of the retreat is a result of icebergs calving into Columbia Bay. The calving is episodic. For long periods—sometimes lasting for several days—little or no calving occurs, followed by a few minutes or hours of frequent large calving. Thus, even at a very active calving glacier, an observer is lucky to see a calving event. The exact mechanism of calving is not understood, but calving rates appear to relate to the water depth, ice speed near the terminus, local flotation, and fresh water flowing from underneath the glacier.

The largest icebergs exceed several million tons, but break into smaller pieces within a few days. The floating mass of packed icebergs in upper Columbia Bay is restrained by the shallow water over the submerged terminal moraine, a rounded ridge that marks the position of the terminus prior to the beginning of the retreat (fig. 5). The iceberg pack is fairly coherent, and moves at the rate of 100 to 200 meters (300 to 600 feet) per day through the bay. Maximum water depth over the terminal moraine is 27 meters (90 feet), limiting the size of icebergs that can escape into the navigable waters of Prince William Sound. Once clear of the moraine shoal, icebergs may travel several tens of kilometers per day, and usually disintegrate within a few days. Even so, icebergs are commonly seen in the shipping lanes traversed by oil tankers enroute to or from Valdez, Alaska—the terminal of the trans-Alaska oil pipeline (fig. 6).

ICE SPEED AND VOLUME

Ice speed is measurement of the speed at which glacier ice moves, rather than the change in terminus position. A general increase in the ice speed is associated with the retreat of Columbia Glacier (fig. 7). Prior to the beginning of the retreat, ice near the terminus moved about 5 meters (16 feet) per day. During the winter of 1994, ice speed near the terminus (now 8 kilometers [13 miles] up the glacier relative to its pre-retreat position), was about 30 meters (98 feet) per day. In addition to the general, long-term speed increase, speed during winter is typically 20 to 30 percent faster than it is during summer and fall. Furthermore, speed is typically 5 to 10 percent greater during late evening than during mid-morning. Speed also increases during times of high rates of water input, whether from rain or melting of the surface ice by strong, warm winds (fig. 8). These short-term speed fluctuations are a result of water-storage changes at the bed of the glacier, with high speeds simultaneous with high basal water storage. A semi-diurnal speed fluctuation also occurs near the terminus where higher speed occurs with low tide, and lower speed with high tide. The pressure exerted by high tide slows the speed of the glacier (fig. 8).

Columbia Glacier is now losing far more ice volume by calving and melting than it is receiving from snowfall. Because of this, the ice is thinning by about 20 meters (66 feet) per year in the lower glacier area (fig. 9). The total volume of ice lost from the glacier between 1982 and 1994 is estimated to be 40 cubic kilometers (10 cubic miles).

CHARACTERISTICS OF TIDEWATER GLACIERS

The cause of this retreat is an inherent instability in tidewater glaciers. When an advancing glacier reaches tidewater, normal melt continues at the terminus, and in addition, ice begins to be lost by calving.

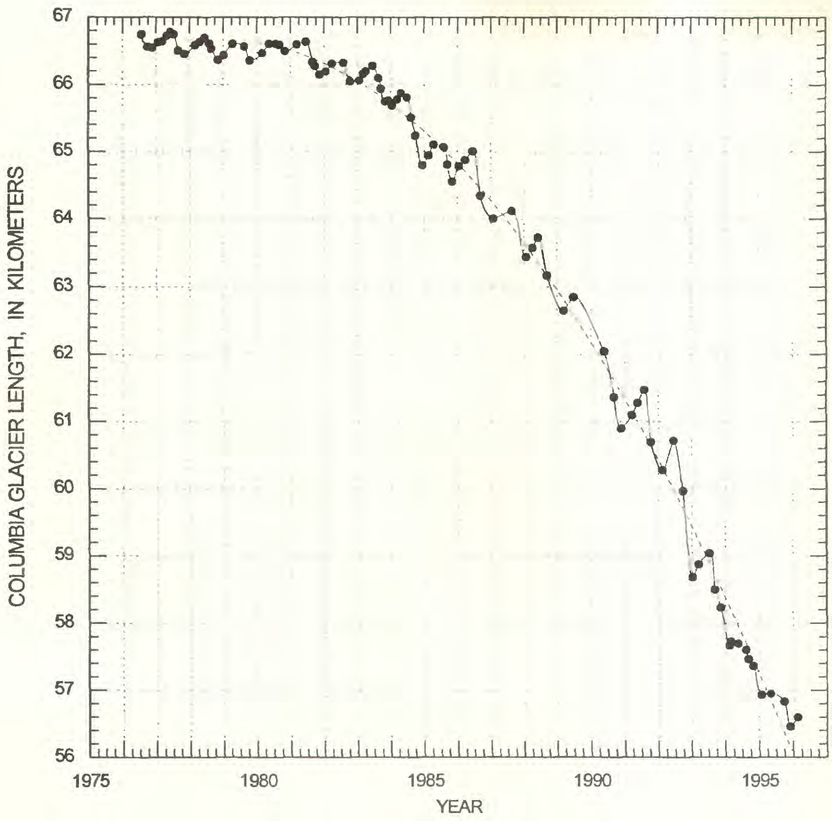

Figure 4. Length of Columbia Glacier, 1976 to 1995.

As the glacier tries to advance into water of increasing depth, the calving rate increases, thus making advance more difficult. However, the glacier also is moving earth material on its surface (moraines) and at its bed. This material is deposited in front of the glacier, reducing the water depth, which retards calving. The glacier is able to slowly advance by the process of moving earth material ahead of its terminus. Ultimately, a balance is achieved where the snow accumulation on the upper glacier replaces the ice melt and calving on the lower glacier and at the terminus. The glacier terminus rests on the terminal moraine in shallow water. Water deepens rapidly seaward of the terminus, and the lower glacier fills a valley that may be several hundred meters deep. The position of the terminus is unstable because if the supply of ice is disrupted by a minor climate change, retreat begins, and that places the terminus in deeper water. The deeper water allows more calving, which results in more retreat. Soon the glacier ends in very deep water, and the rapid retreat is under way.

ALASKA'S TIDEWATER GLACIERS

Columbia Glacier is but one of numerous Alaska examples of this advance/retreat cycle for tidewater glaciers. Glacier Bay, about 150 kilometers (93 miles) west of Juneau, was still ice filled when mapped by Vancouver in 1794, although retreat had already begun. By the late 19th century, there had been about 80 kilometers (50 miles) of retreat, opening the fiord as we now know it. By the early 20th century, some of the glaciers had begun a slow re-advance. Hubbard Glacier, about 60 kilometers (37 miles) northwest of Yakutat, completed a 60-kilometer (37-mile) retreat near the end of the 19th century, and since then has slowly advanced to a position about 2 kilometers (1.2 miles) ahead of its 1900 position. In Prince William Sound within 50 kilometers (31 miles) of Columbia Glacier, Harvard and Meares Glaciers are slowly advancing, and Yale Glacier has recently ended a rapid retreat. In each of these examples, major glacier changes have occurred within decades or less, and local communities often have been affected. The advance of Hubbard

Figure 5. Vertical photograph of Columbia Glacier, January 25, 1995. The forebay is about 4 kilometers (2.5 miles) wide.

Glacier temporarily closed a major fiord, and the nearby town of Yakutat was overrun with scientists and news reporters. Another closure is expected, and it will probably change an important fishery.

Prior to its retreat, the terminus of Columbia Glacier could be viewed from tour boats. Now boats can approach no

Figure 6. Oil tanker passing near icebergs in Prince William Sound.

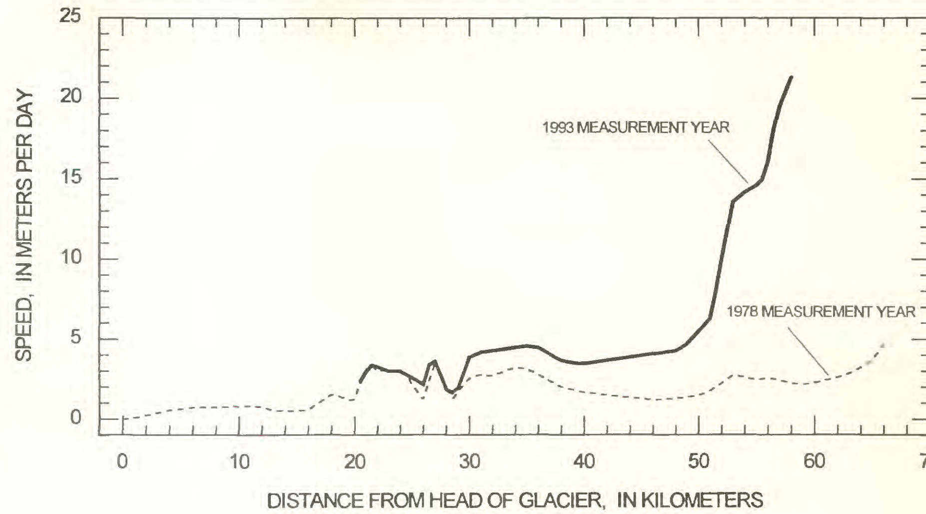

Figure 7. Ice speed of Columbia Glacier in 1978 and 1993.

closer than about 8 kilometers (5 miles), but still cruise very close to icebergs from the glacier. Oil tankers must follow special procedures because of iceberg hazard. The retreat of Columbia Glacier is expected to continue until the calving face is in shallow water at the head of the fiord. The new fiord will be about 40 kilometers (25 miles) long, extending well up the present east branch. As the retreat continues and the new fiord becomes larger or the calving diminishes, the new fiord will become progressively more ice free. Several calving glaciers will still enter the fiord, and scientists and tourists will have a spectacular new fiord to explore.

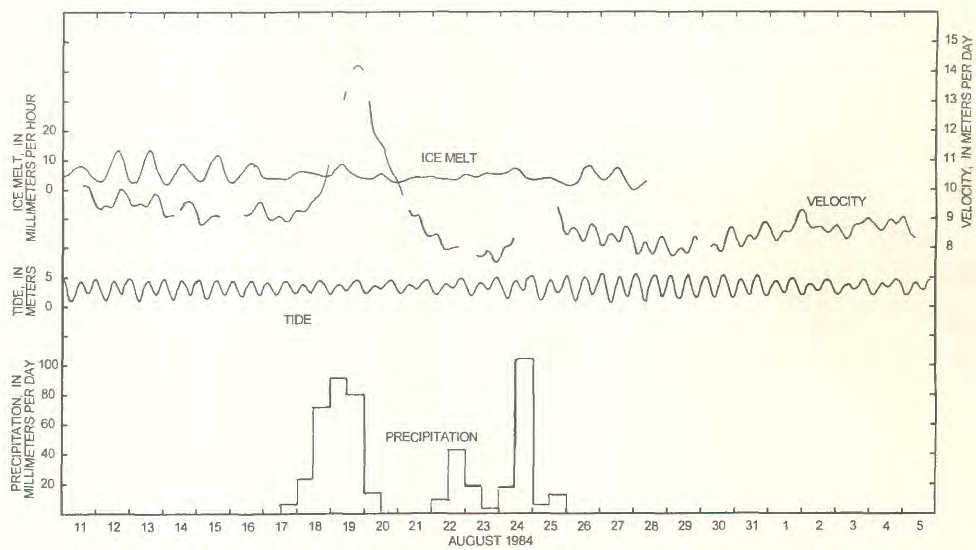

Figure 8. Short-term variation in speed of Columbia Glacier, shown with precipitation, tide, and ice melt rate.

Research at Columbia and other Alaska glaciers can be applied to the Antarctic, where most of the world's ice exists. The West Antarctic Ice Sheet is also a tidewater glacier, but more than a thousand times the size of Columbia Glacier. A similar instability may exist there, and scientists say a rapid retreat could cause a rise of sea level of several meters in a few centuries.

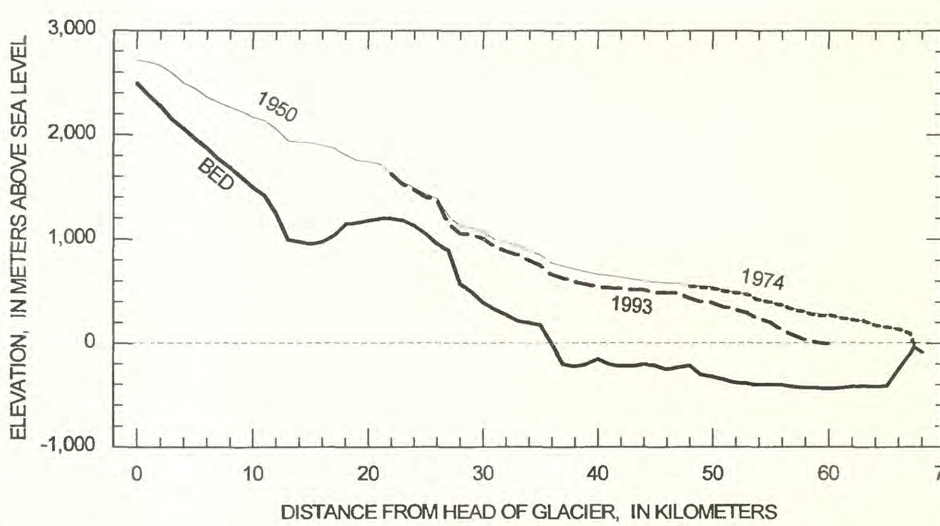

Figure 9. Changes in the surface elevation and bed profile of Columbia Glacier.

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Suggested reading:
U.S. Geological Survey Professional Papers 1258 A-H

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