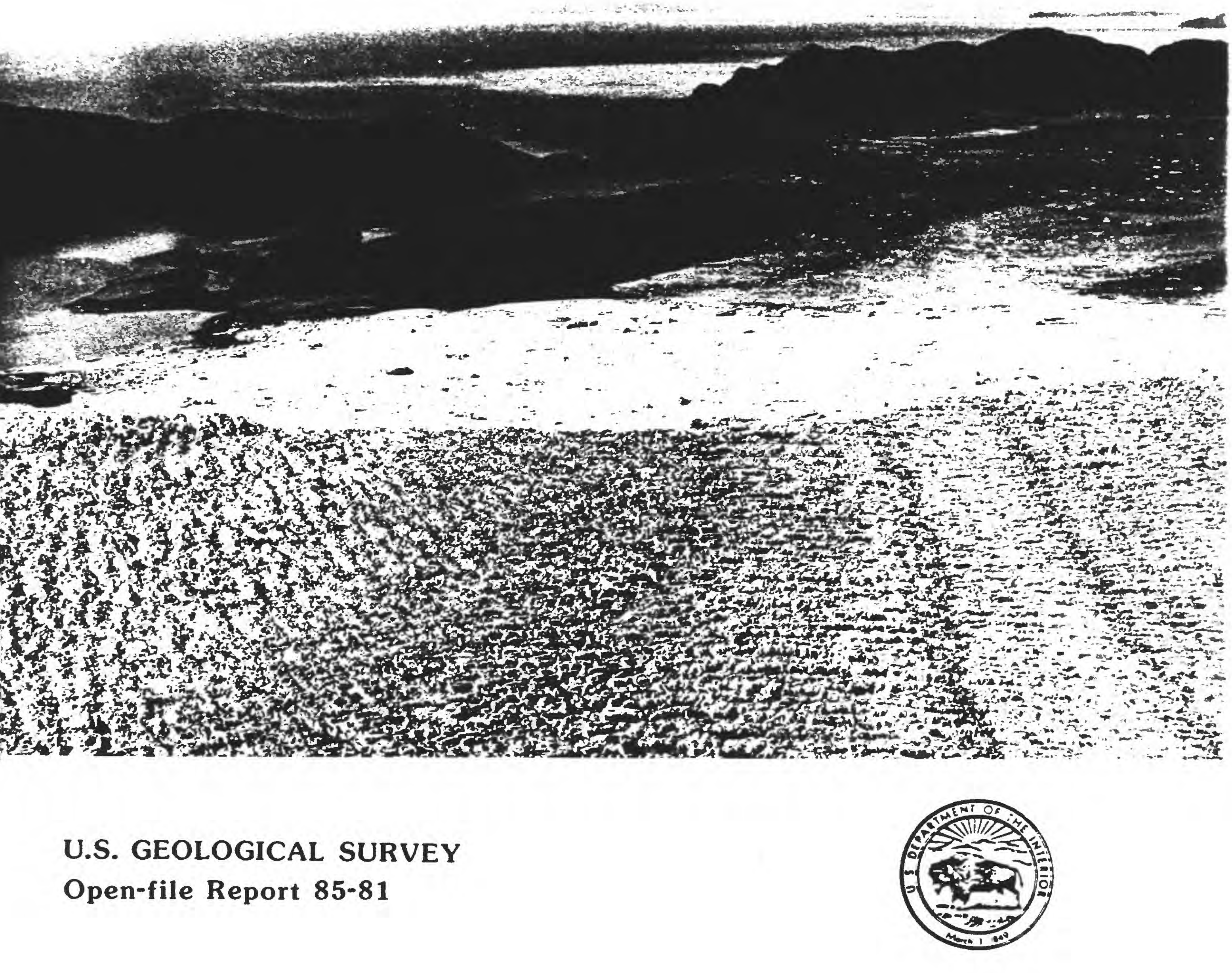
Columbia Glacier in 1984: Disintegration Underway



U.S. GEOLOGICAL SURVEY
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Cover -----Aerial view of the 6-kilometer wide terminus of Columbia Glacier, taken on August 14, 1984. In front of the glacier trapped icebergs and smaller ice blocks are confined by a submerged moraine shoal. Beyond this, icebergs drift south along the west side of Heather Island (left center), and then sometimes to the east into Valdez Arm and Prince William Sound (left distance). USGS photo by M. F. Meier.

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DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

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Columbia Glacier is a large, iceberg-calving glacier (fig. 1) near Valdez, Alaska. The terminus of this glacier was relatively stable from the time of the first scientific studies in 1899 until 1978. During this period the glacier terminated partly on Heather Island and partly on a submerged moraine shoal. Post (1975) suggested that if it were to retreat from the stabilizing moraine shoal, a period of drastic retreat would ensue. Detailed studies were made during 1977-78, and monitoring has continued through 1984. In June, 1980, a prediction of drastic retreat was issued (Meier and others, 1980).

In December, 1978, the glacier terminus retreated from Heather Island, and retreat has accelerated each year since then, except during a period of anomalously low calving in 1980. Although the glacier has not terminated on Heather Island since 1978, a portion of the terminus remained on the crest of the moraine shoal until the fall of 1983. By December 8, 1983, that feature had receded more than 300 m from the crest of the shoal, and by December 14, 1984, had disappeared completely, leaving most of the terminus more than 2,000 meters behind the crest of the shoal.

Recession of the glacier from the shoal has placed the terminus in deeper water, although the glacier does not float. The active calving face of the glacier now terminates in seawater that is about 300 meters deep at the glacier centerline. Rapid calving appears to be associated with buoyancy effects due to deep water at the terminus (Post, 1975; Brown and others, 1982; Sikonia, 1982) and subglacial runoff (Sikonia, 1982).

Columbia Glacier has shown a seasonal pattern of fluctuation superimposed on a long-term trend of accelerating retreat since 1976 (fig. 2). These seasonal changes in length, due to seasonal changes in iceberg calving, are also displayed in figure 3. The 1,100 meter retreat during 1984 (through December 14) was far greater than in any previous year, the next greatest was 600 meters in 1983.

The observed long-term retreat is compared with that predicted by a continuity-equation model (Rasmussen and Meier, 1982), a finite-element dynamic model (Sikonia, 1982), and a finite-difference dynamic model (Bindschadler and Rasmussen, 1983) in figure 2. The acceleration of the observed retreat is roughly consistent with results of predictive models although the models all predicted that rapid retreat would occur somewhat sooner than observed. It should be noted, however, that the timing of the retreat determined by models was expressed only to the nearest one or two years.

The retreat is shown in map view in figure 4; positions of the terminus are shown at the end of the summer retreat period for the years 1974 and from 1978 through 1984. Deep embayments in the terminus occurred in most earlier years, but since 1982 the terminus has been approximately straight.

The positions of markers set out on the glacier surface in August 1984 to measure the rate of flow are shown in figure 4. These markers were set (by use of a helicopter) on top of seracs (ice pinnacles) on the extremely rough glacier surface (fig. 5). The markers were surveyed frequently, from two survey stations on ridges to the east of the glacier, over a period of about three weeks. One marker (number 11) was tracked by an automated distance-measuring device from Heather Island every 15 minutes during the same period.

Changes in the surface altitude are examined by plotting the altitude change since July 27, 1974 for each of 17 markers. Topographic maps exist for that date and for September 1, 1981 and, for only the lower part of the region, for

September 10, 1983. A detailed surface topography analysis (Rasmussen and Meier, 1985), based on photogrammetrically determined altitudes, gives the altitude at the position of each of 6 markers between June 2, 1977 and September 1, 1981, and for 11 other markers between July 24, 1976 and September 1, 1981. A preliminary analysis of the photography from two more flights, on August 2, 1982 and October 15, 1982, and surveys on August 13, 1984 yielded additional altitude data. The altitude change since July 27, 1974 is shown (fig. 7) in terms of the average for 6 upper markers and the average for 11 lower markers. A strong acceleration of surface lowering (thinning) occurred in 1981.

The bed topography has recently been estimated (Brown and others, in preparation) for the lower part of the region, thus enabling estimation of the glacier thickness at the positions of 6 markers (numbers 7-11 and 17) forming a progression down the centerline of the glacier. By using the ratio of seawater density to ice density, it is possible to determine the part of the thickness unsupported by buoyancy. This is shown in figure 8 as a function of time since 1977 for each of the 6 markers. The seasonal variation has been removed by choosing maps or other surface topography analyses on or near September 1 of each of the five years for which data are shown, and by correcting to that date any altitude values that were not exactly on September 1. For each marker, a curve is drawn through the five points and is extrapolated for about a year into the future. Although this graph suggests that the lowest kilometer or two along the centerline will float within about a year, ice has generally calved before this occurs; this calving increase as the unsupported thickness becomes small is what forms the basis of a calving law (Sikonia, 1982) used in modeling Columbia Glacier. The ice thickness unsupported by buoyancy at marker 17 in 1984 is very close to that predicted at the terminus by Sikonia (1982, p. B24).

During late winter and spring of 1984, the ice cliff at the terminus was abnormally low and irregular. In one segment, where the water depth is 100 to 170 m, a portion of the glacier flowed out as a tongue about 500 m long and 500 m wide (fig. 9). This tongue had a freeboard (height above sea level) as low as a few meters, indicating that it was floating. Such a phenomenon has not been observed before at Columbia Glacier, and indicates that the thickness unsupported by buoyancy had, for a short time, locally diminished to zero.

The velocity trend over the past several years is shown in figure 10 for a point fixed in space near the position of 1984 marker number 17; the trend of glacier thickness is shown as well. As with the unsupported thickness data (fig. 8), the seasonal variation has been removed from these two curves. Because the transverse variation of velocity is known (Fountain, 1982; Meier and others, 1985), it is possible to estimate the total volumetric flux through the glacier cross-section containing this point by using the estimated bed topography. The flux values corresponding to the five points on the curves in figure 10 are, from 1977 to 1984: 1.34, 1.36, 1.40, 2.56, and 3.95 km^3/year. The sharp increase in flux is caused by the sharp increase in velocity and is only slightly tempered by the mild decline in thickness.

The volumetric discharge of icebergs from Columbia Glacier is increasing. The iceberg calving flux from June 17, 1983 to October 4, 1984 is shown in figure 11. During the 1977-78 measurement year the calving flux averaged about 1.4 km^3/year; in the second half of 1983 the average value was about 3 km^3/year and from January 1 through October 4, 1984, almost 4 km^3/year. The iceberg discharge on September 1, 1984 (about 5 km^3/year) was appreciably greater than the volumetric flow of the glacier near marker 17 (3.95 km^3/year) on that date. Thus glacier flow, although it has increased markedly, is not keeping up with the discharge of icebergs.

All the evidence indicates that Columbia Glacier is now in a phase of rapid and accelerating disintegration. The rate of terminus retreat is increasing (fig. 2, 3). The glacier is thinning at an ever more rapid rate (fig. 7). Because of this thinning, a condition of flotation is being approached (fig. 8) and has been attained briefly in at least one local area (fig. 9). Although the glacier is thinning, the velocity is increasing rapidly so that the volumetric flow rate is accelerating, especially since early 1982 (fig. 10). The rate of discharge of icebergs is also accelerating (fig. 11) and is appreciably larger than the glacier flow rate. Thus the glacier, in spite of a rapid drawdown of its ice reserves, is unable to balance the increasing losses by iceberg discharge. Clearly, disintegration is now underway.

There is no evidence that disintegration and iceberg discharge will decelerate soon. The rate of change of almost all pertinent variables is toward ever faster breakup, which is consistent with the predictions based on numerical modeling. It should not be assumed, however, that the increasing iceberg discharge will cause greatly increased iceberg problems with shipping in Valdez Arm. The moraine shoal, which had a maximum sill depth of 23 m below lower low water in the late 1970's, prevents the escape of large icebergs into open water, and thus acts as a filter to prevent large outbreaks of ice.

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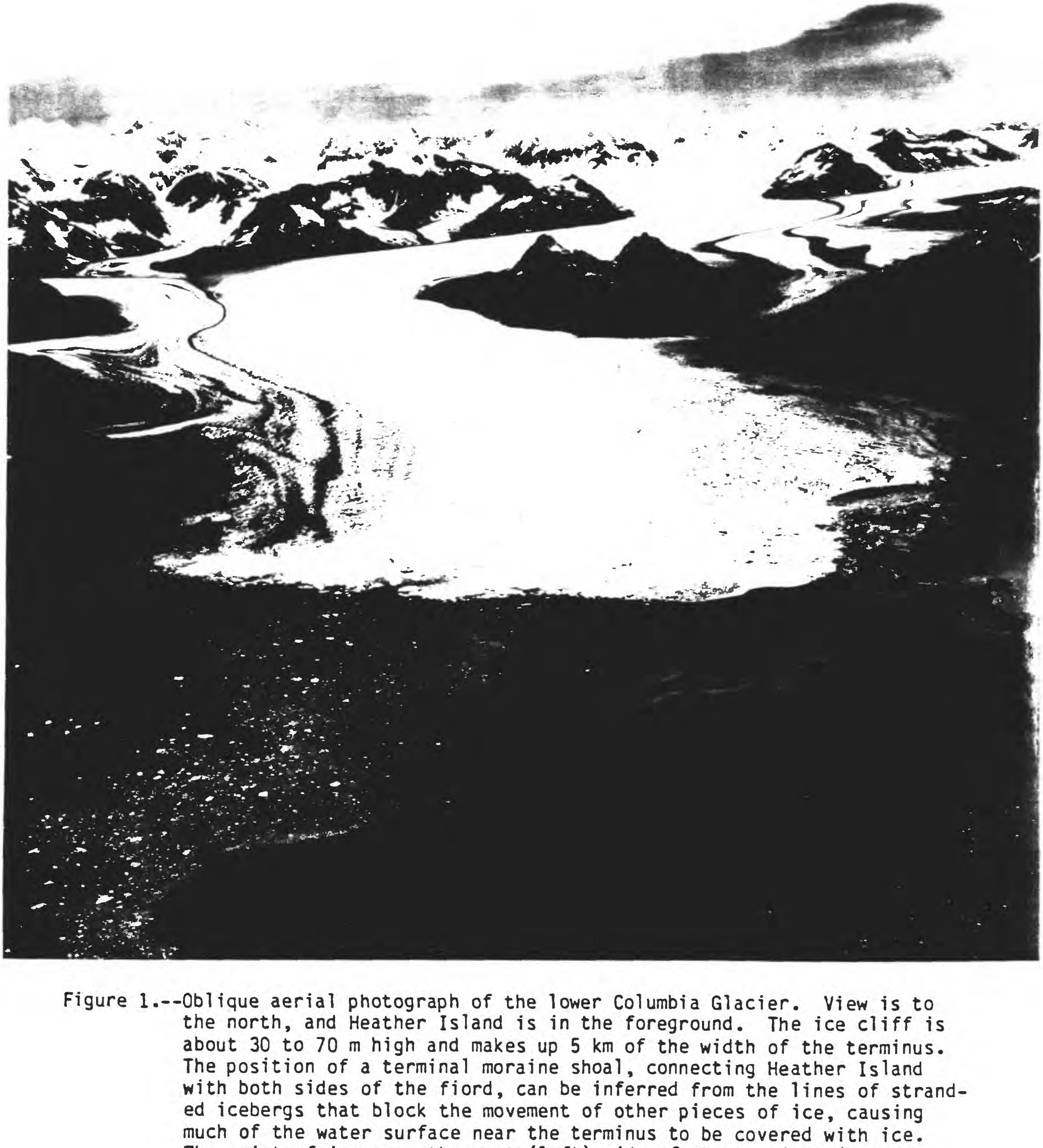

Figure 1.--Oblique aerial photograph of the lower Columbia Glacier. View is to the north, and Heather Island is in the foreground. The ice cliff is about 30 to 70 m high and makes up 5 km of the width of the terminus. The position of a terminal moraine shoal, connecting Heather Island with both sides of the fiord, can be inferred from the lines of stranded icebergs that block the movement of other pieces of ice, causing much of the water surface near the terminus to be covered with ice. The point of ice near the west (left) side of the terminus (marked with streaks of debris) disappeared completely by December 14, 1984. USGS photograph by Robert M. Krimmel, August 29, 1984.

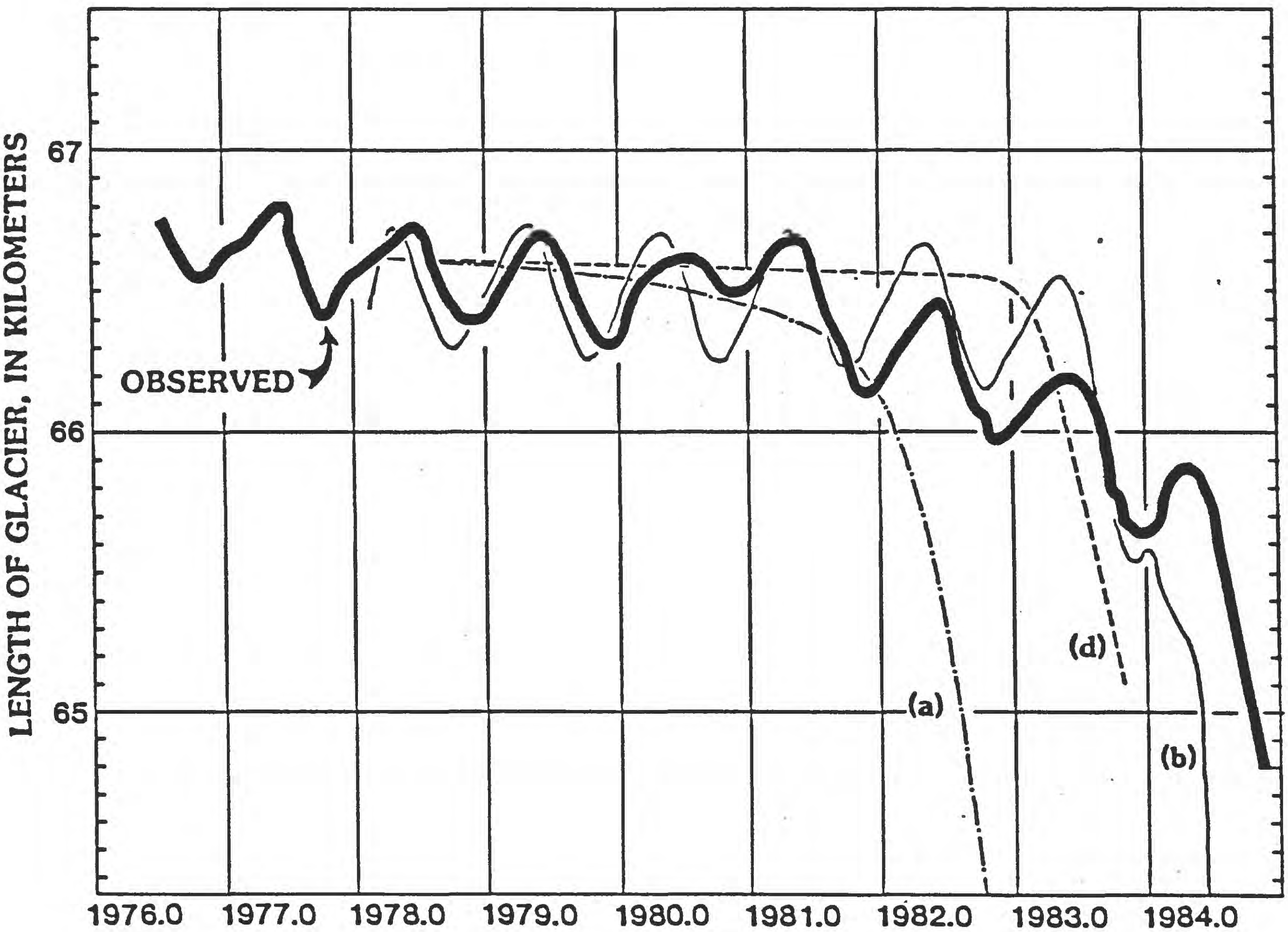

Figure 2.--Changes in the length of Columbia Glacier since 1976. Upwards trend represents advance, downwards trend represents retreat. Heavy line is observed behavior of the terminus, averaged over the width. Light lines labeled (a), (b), and (d) show published predictions using different kinds of numerical models: a, Rasmussen and Meier (1982); b, Sikonia (1982); d, Bindschadler and Rasmussen (1983).

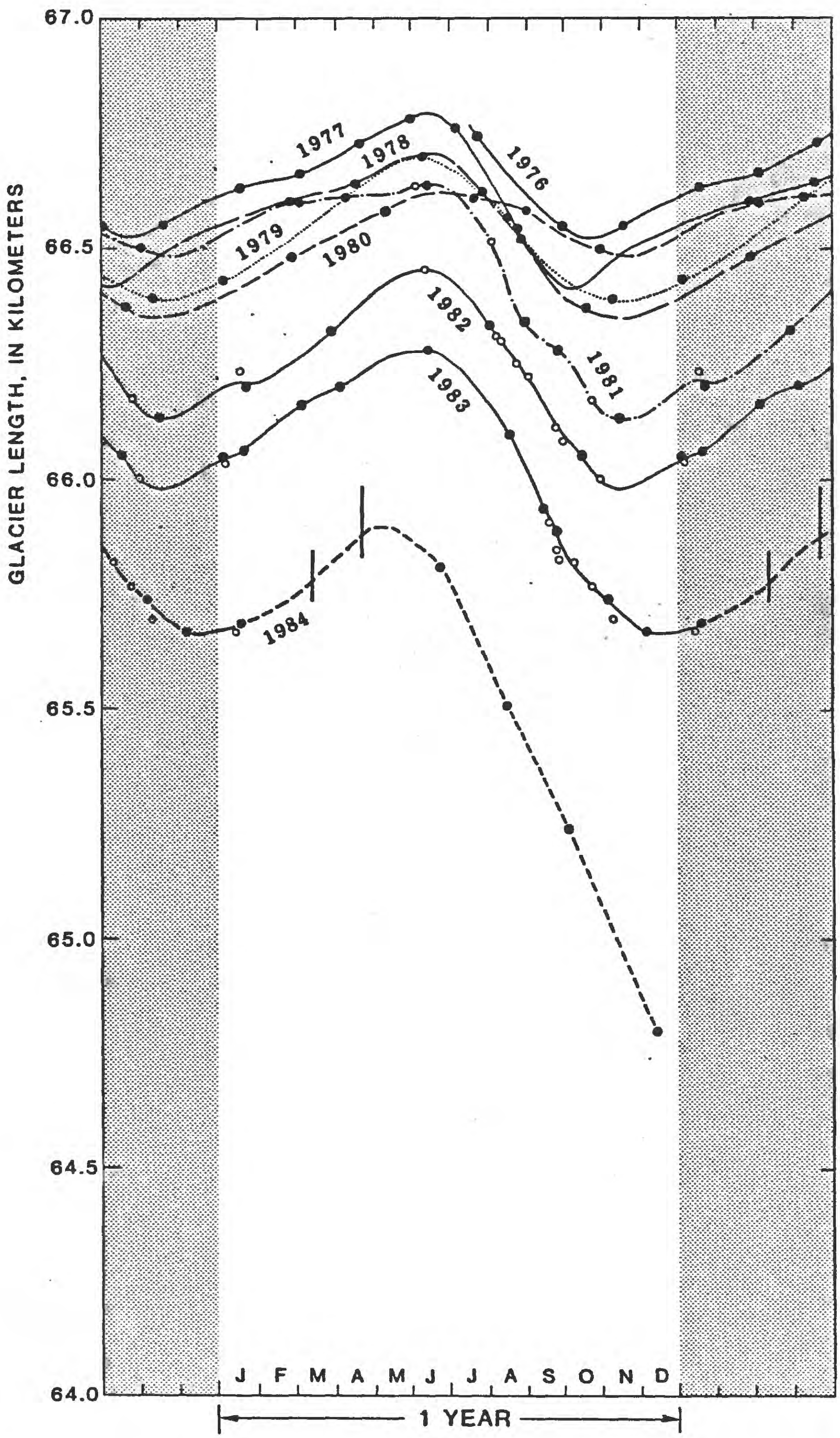

Figure 3.--Seasonal advance and retreat of Columbia Glacier for the years 1976-84, superimposed onto one year for comparison. The curves are repeated in the gray areas to either side to help visualize trends. Solid dots are data points obtained by photogrammetry (error is about 10 m), open circles are observations by less-accurate methods (ship-borne radar, ground surveys), and smooth curves are drawn through data points. Data from aerial photographs taken on March 12 and April 24, 1984, are plotted as vertical lines because of the difficulty in differentiating the low, irregular ice cliff from floating ice. Values are averaged over the width of the active terminus.

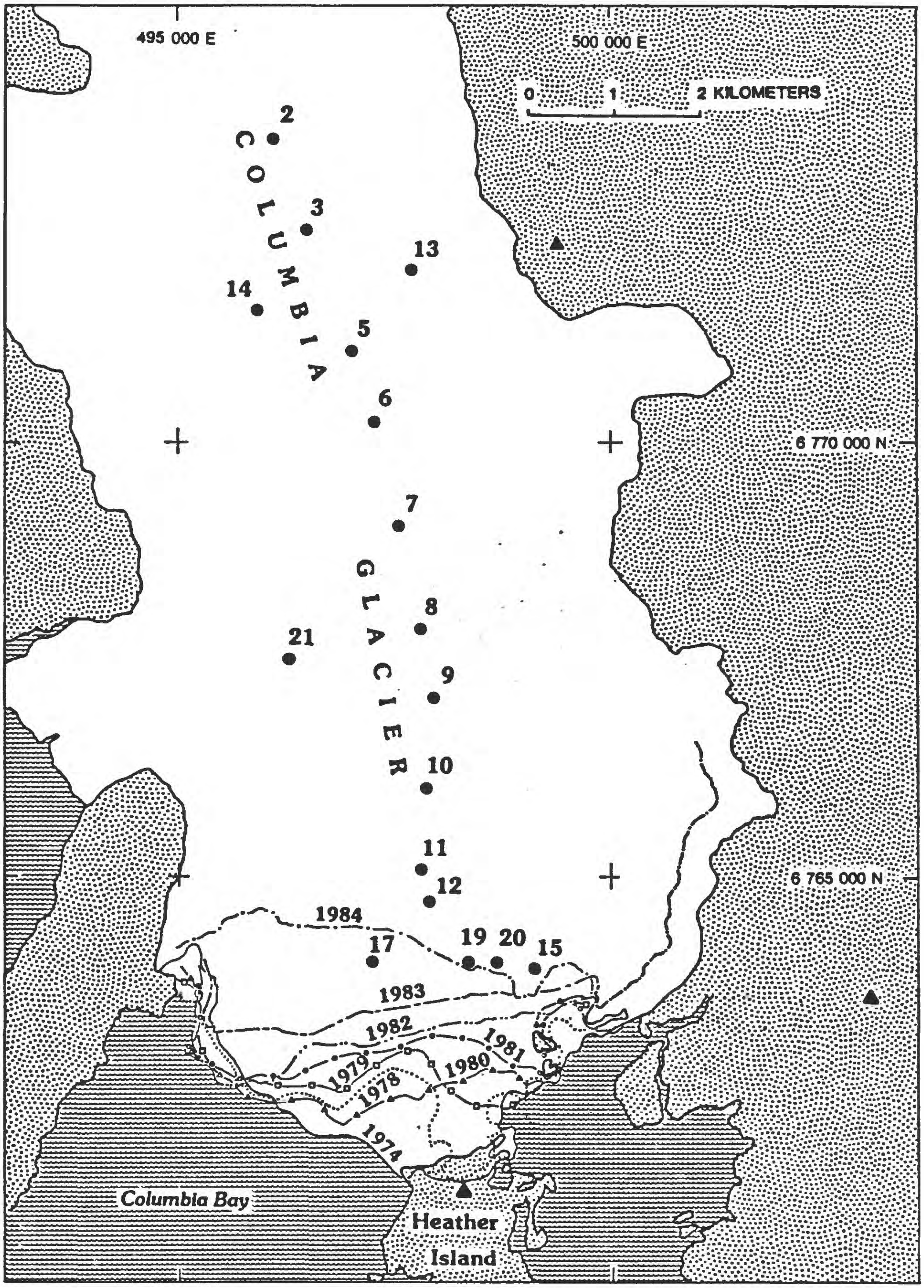

Figure 4.--Map showing the configuration of the terminus of Columbia Glacier after summer retreat, for the years 1974 and 1978-84. Small crosses represent the Universal Transverse Mercator coordinates in meters. Also indicated are the marker locations (dots) and survey stations (triangles) used during the August, 1984 field program. Markers numbers 2, 3, 5-11 and 17 are on or near the main stream of the glacier flow. Marker 17 was on the glacier in August but the terminus subsequently retreated back from that location.

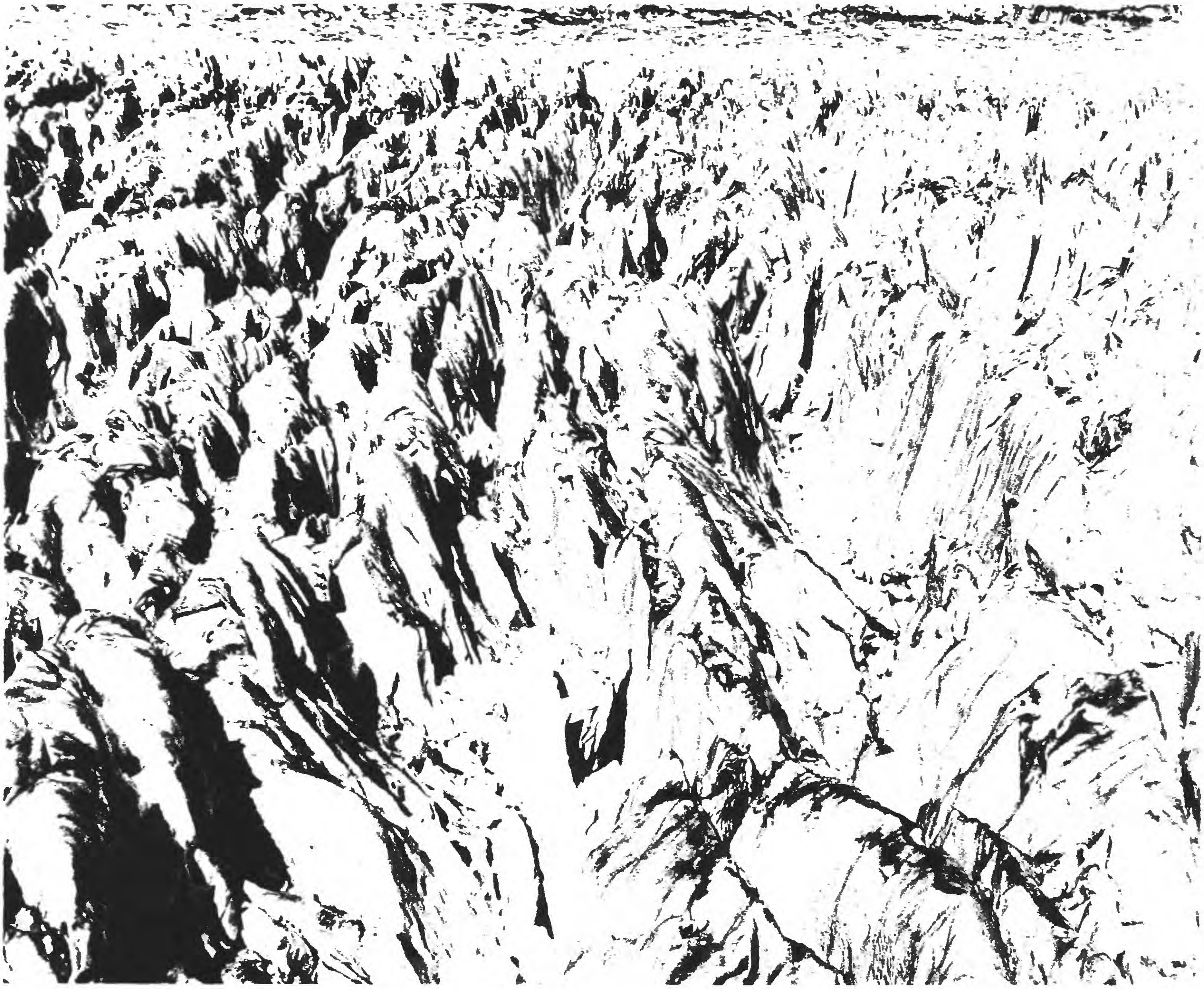

Figure 5.--Oblique aerial photograph showing the roughness of the glacier surface. View is to the west, about 2 km above the terminus. Average relief from summits to valleys is about 25 m; local relief may range up to 40-50 m. USGS photograph by M. F. Meier, August 14, 1984.

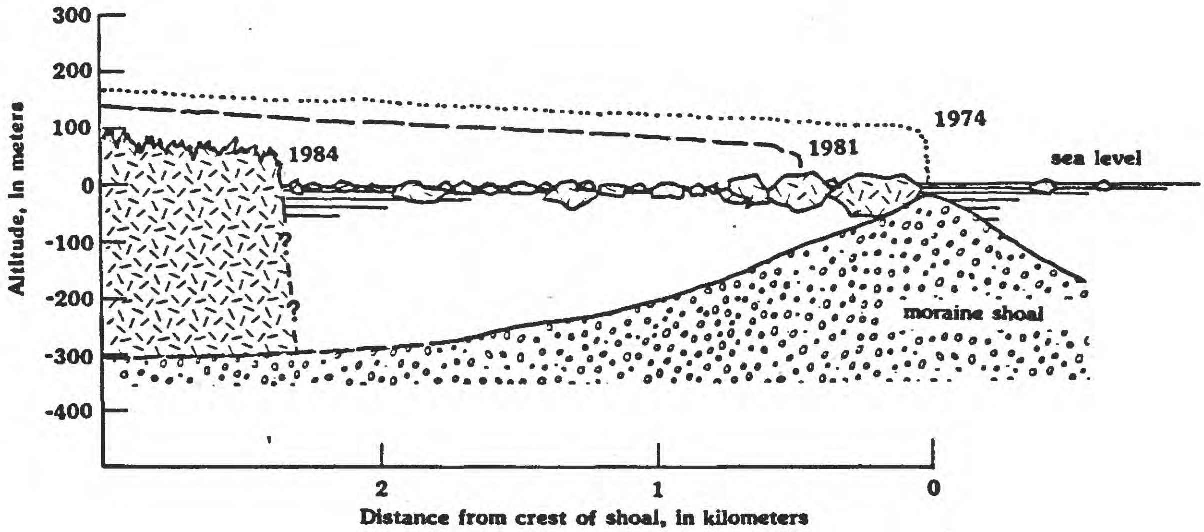

Figure 6.--Longitudinal section of the terminus of Columbia Glacier, as of August, 1984. The 1981 and 1974 profiles are also shown. Note that the terminus of the glacier has retreated into water about 300 meters deep, but that the ice is not floating. Also, large icebergs are grounded against the moraine shoal, trapping other floating ice blocks and delaying their release to navigable waters.

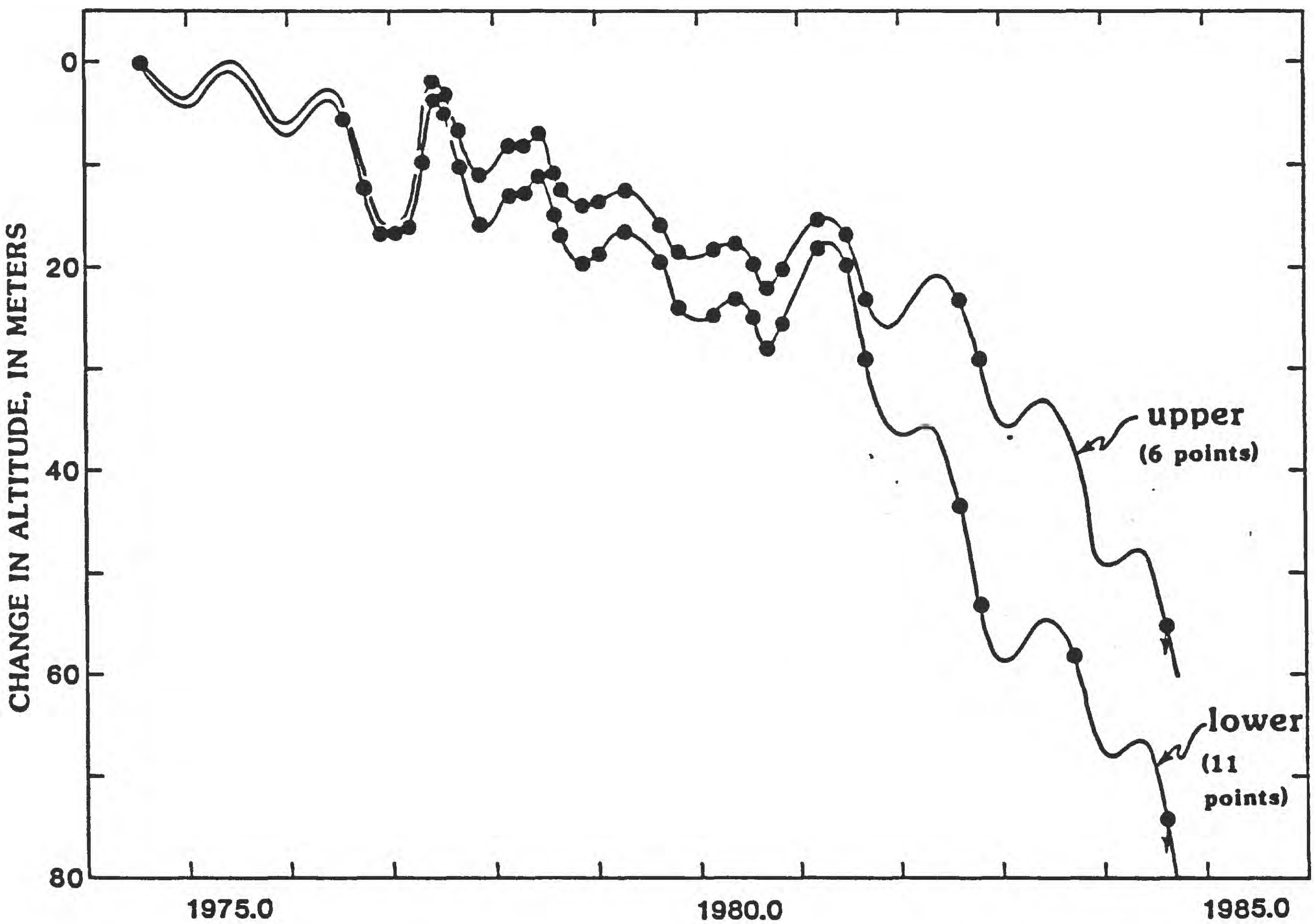

Figure 7.--Altitude decline since July 27, 1974 for the average of 6 markers (numbers 2, 3, 5, 6, 13 and 14) in the upper part of the region and for 11 markers (numbers 7-12, 15, 17, 19-21) in the lower part. The 1984 values are probably high compared with the other values (as indicated by the arrows): in 1984 markers on serac tops were surveyed, whereas the other values were determined photogrammetrically at points usually at the lips of crevasses.

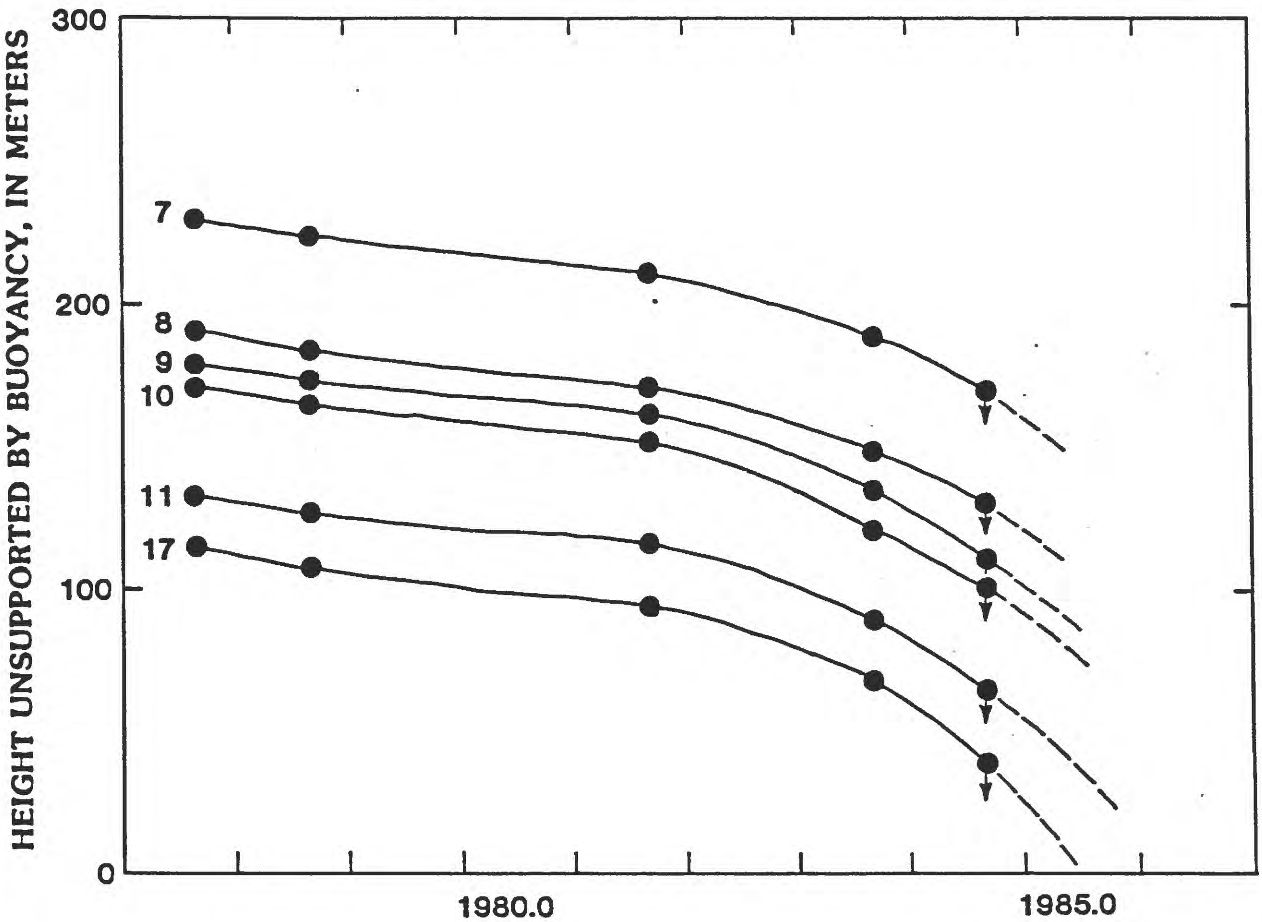

Figure 8.--Part of glacier thickness unsupported by the buoyant effect of the seawater. Marker numbers 7-11 and 17 form a progression downglacier approximately along the centerline (fig. 4). Arrows indicate that the 1984 values are probably high compared with the other values because surveys were to serac tops.

Figure 9.--Oblique aerial photograph showing the glacier terminus on March 29, 1984. The water in front of the glacier (foreground and left) is choked with iceblocks. Note that the ice cliff is low, indistinct, and irregular, and that a tongue of ice (arrow) has flowed out in advance of the ice cliff. The freeboard of this tongue is very low, indicating that it is floating. USGS photograph by R. M. Krimmel.

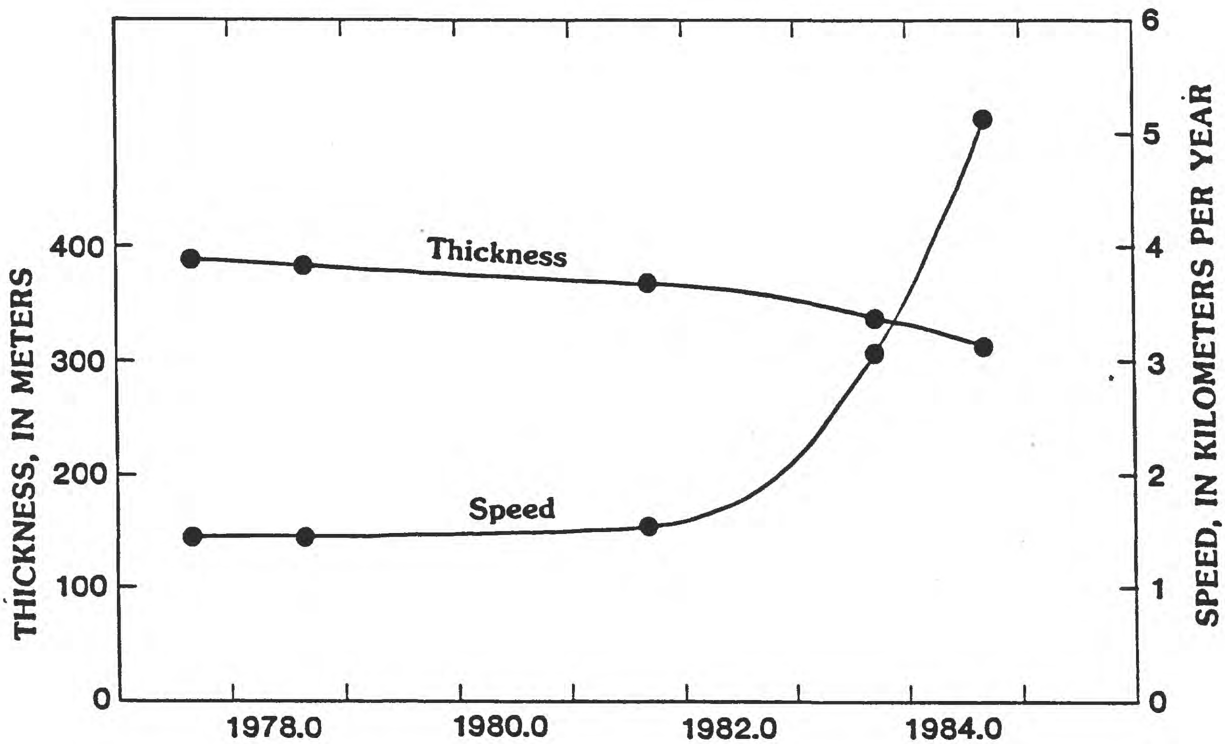

Figure 10.--Surface speed (component to the south) and glacier thickness for a point fixed in space near the 1984 position of marker number 17 (fig. 4).

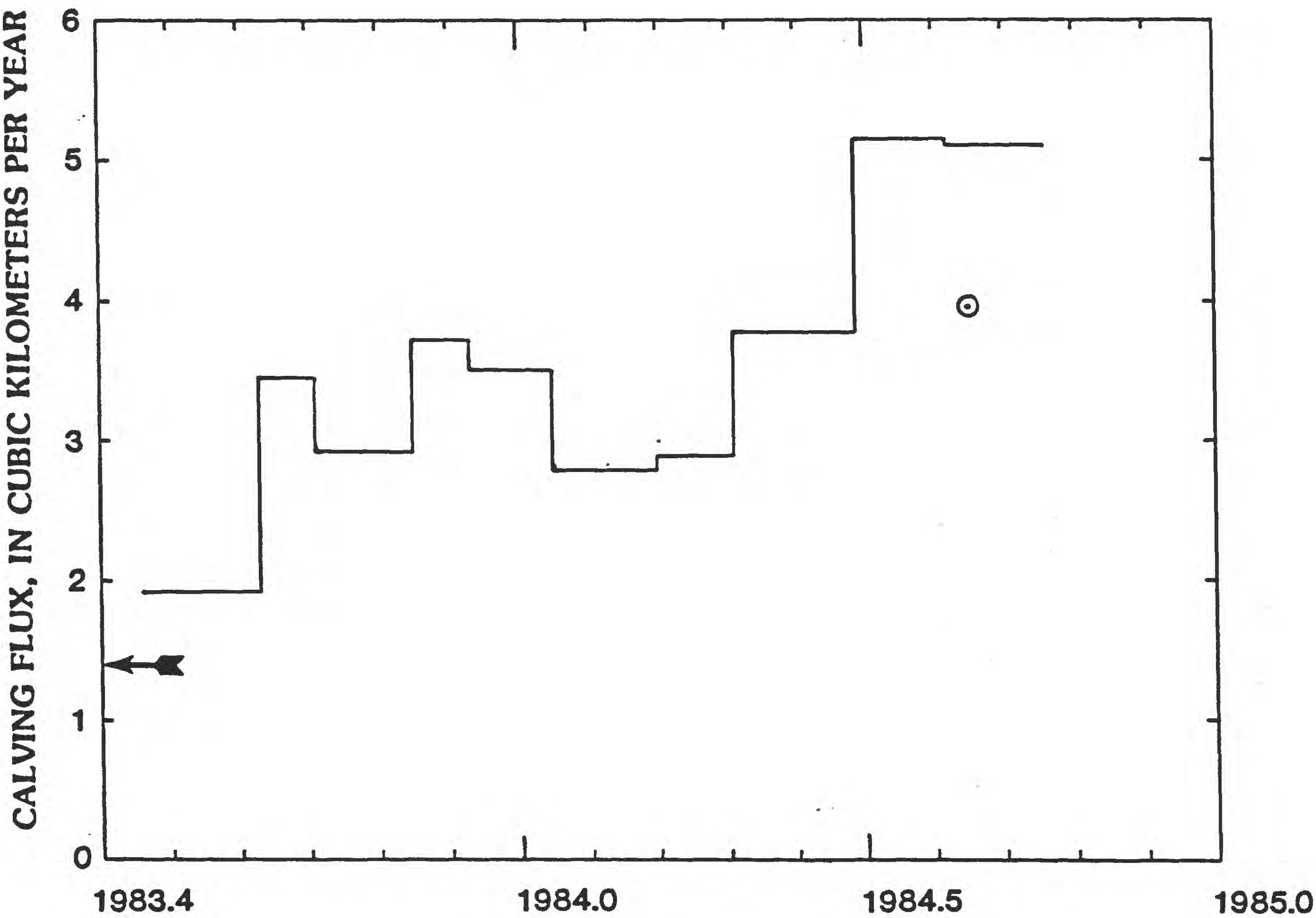

Figure 11.--Calving flux from June 17, 1983 through October 4, 1984. The values are averages between times of aerial photography, and thus are plotted as a histogram. The arrow indicates the average value for the year September 1, 1977 to August 31, 1978. The circle indicates the flux of ice towards the terminus on September 1, 1984.