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TAKU GLACIER ADVANCE - PRELIMINARY ANALYSIS

By

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An interagency report prepared for the Alaska Department of Fish & Game and the Alaska Department of Transportation and Public Facilities

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ABSTRACT

The Taku Glacier has advanced 7.25 km (4.5 mi) since 1890 in contrast to neighboring glaciers which have all retreated. Continued advance of the glacier threatens closure of the Taku River with potentially serious socio-economic impacts. Results of this study, based on analysis of vertical air photos and USC&GS charts, are in general agreement with previous estimates of historic linear rates of glacier advance but our estimate of the current rate of advance, 15 m/a (50 ft/yr), is substantially lower than estimates that were recently reported in the local press (100 to 200 ft/yr). We consider the Taku Glacier to be a tidewater-type glacier and that its advance is linked to the periodic rapid retreat and gradual advance cycle documented at other Alaska tidewater glaciers and that climatic effects are secondary. The high accumulation zone to total area ratio (0.86) and the large positive net mass balance documented by JIRP for the glacier over the last four decades insure the Taku Glacier will continue to advance. For rates of advance of 15 to 30 m/a (50 to 100 ft/yr) the glacier can be expected to seriously impact the Taku River in 30 to 60 years. Effects of climate change and a general thickening of ice in the accumulation zone could alter the future rate of advance.

1.0 INTRODUCTION

Located in the Coast Mountains 32 km (20 mi) NNE of Juneau, the Taku Glacier, a temperate, maritime valley glacier with an area of 670 km^2 (260 mi^2), is the largest glacier draining the Juneau Icefields (fig. 1). The Taku Glacier has advanced 7.25 km (4.5 mi) since 1890 in contrast to neighboring valley glaciers which have all retreated during the same period. The Taku Glacier terminus currently lies about 1.5 km (1 mi) across the Taku River from Taku Point. Continued advance of the Taku Glacier threatens closure of the Taku River with potentially serious socio-economic impacts.

The Taku River is the major producer of king and coho salmon in the northern panhandle and is a leading producer of sockeye and the local commercial and sport salmon fisheries rely heavily on the river system's continued productivity. The Alaska Department of Fish & Game is currently negotiating with Canada regarding Taku River salmon allocation and general enhancement. The Taku River valley is also being considered as a possible road corridor into Canada by the Alaska Department of Transportation and Public Facilities. A number of promising mining prospects are located off the Taku River in the

Tulsequah River valley near the US-Canada border. Future development of these sites may well be dependent on Taku River transportation corridors. Taku Glacier Lodge and a number of summer residences, located upstream of the terminus, would also be imperiled by flooding should the glacier dam the river.

The Juneau Icefields and the Taku Glacier have been under long term study by the Juneau Icefields Research Project (JIRP), with the data base, particularly for the accumulation zone, now extending over a forty year period (Pelto and Miller, 1989). Maynard Miller, director of JIRP, has been monitoring the Taku Glacier advance and recently predicted that the glacier would seriously impact the Taku River within a decade.

Because of the concerns associated with the potential glacier damming of the Taku River, the Alaska Division of Geological & Geophysical Surveys (ADGGS) undertook an independent evaluation of the Taku Glacier advance. The study entailed detailed examination of vertical aerial photography and U.S. Coast and Geodetic Survey (USC&GS) charts with the objectives of estimating historic and current rates of advance and of producing a map showing the historic positions of the Taku Glacier terminus. The results and discussion of this preliminary study are the subjects of this report. Delays in funding and inclement weather prevented field survey of the terminus during fall, 1988 and has been postponed until late May, 1989. A proposal for continued monitoring of the glacier advance and acquisition and analyses of photogrammetric and field data to aid in addressing the broader questions of the causes and the glacier's future behavior are outlined in Appendix A.

2.0 BACKGROUND

The Taku Glacier has attracted considerable scientific attention because its advance is anomalous in contrast to most other temperate glaciers in the world which are in a state of retreat. Taku Glacier investigators appear to generally agree that the glacier will continue to advance but opinions differ regarding the cause of the advance, the current and future rates of advance, and the duration of the advance.

Geologic evidence discussed by Lawrence (1950) indicates that the Taku Glacier dammed the Taku River as recently as 1750 - 1775 A.D., creating an extensive lake in the Taku River valley. Tree dates and scour marks above Taku Point indicate that lake overflow reached at least as high as 30 to 45 m (100-150 ft) above sea-level. Tree growth on moraines upstream from Taku Point show that lake level had dropped at least 15 m (50 ft) by 1775 A.D. indicating glacier retreat had begun by that time.

Although the rate of retreat and the furthest retracted position are not documented, an intriguing passage in Vancouver's (1801) journals during his August, 1794 exploration of southeast Alaska suggests the glacier may have retreated quite rapidly. He reported large numbers of floating icebergs in Taku Inlet especially at the entrance, through which "passage was with difficulty effected". At a point about 21 km (13 mi) up the inlet (the approximate vicinity of Taku Point) he describes "the shores spread to the east and west, and formed a basin about a league broad, and 2 leagues across, in a N.W. and S.E. direction, with a small island lying nearly at its north-east extremity" (1 league = 3 miles = 4.83 km), and further describes "immense bodies of ice, that reached perpendicularly to the surface of the water in the basin". This description fits the tidal basin that existed in front of the Taku Glacier terminus when it was first charted in 1890 by the USC&GS (fig. 2) and would place the terminus well up-fjord but still fronting in tidewater in 1794 as icebergs were apparently quite common.

This first charting of Taku Inlet by the USC&GS in 1890 shows the Taku Glacier terminating at the head of a deep tidal basin about 8.85 km (5.5 mi) from Taku Point measured along the valley centerline (fig. 2). Because of its proximity to Juneau and its magnificent scenery, the basin became a popular tourist attraction during the early part of this century (Tarr and Martin, 1914; Wentworth and Ray, 1936). Steam ships would anchor a short distance from the glacier front to observe ice-calving.

The current advance is estimated to have begun in 1900 (Lawrence, 1950). By 1937 the glacier had advanced about 4 km (2.5 mi), center line distance, and the once-deep tidal basin had largely filled in with glacial sediments. Water depths immediately in front of the glacier terminus which were reported to be 102 m (336 ft) on the USC&GS 1890 chart were reduced to a maximum of 6.7 m (22 ft) according to the 1937 USC&GS chart (Post and Motyka, in preparation). By 1960, the tidal basin had become completely filled by ice and sediment.

3.0 PREVIOUS WORK

Estimates of historic rates of advance have been made by Lawrence (1950), Field (1954), Miller (1963), Post and Mayo (1971), and Pelto and Miller (1989) and are summarized in table 1. Maps showing previous historic positions of the Taku Glacier based on USCGS charts, ground surveys and vertical aerial photography have appeared in articles by Lawrence (1950), Miller (1963), Miller (1985) and Pelto and Miller (1989). The methods used in plotting the terminus positions and their accuracy were not discussed in these articles. Another map, prepared by Hans Arnett with the engineering firm Peratrovich and others, appeared in a Juneau Empire (Sept. 15, 1988) newspaper article. Arnett (pers. comm., 1988) used earth Landsat imagery to determine and plot the 1986 terminus position and estimated the accuracy of his terminus positions at no better than 0.16 km (0.1 mi).

In articles appearing in the Juneau Empire (August 3, 1988 and Sept. 15, 1988) Maynard Miller, director of the Juneau Icefields Research Project (JIRP), at first estimated the current rate of advance at 180 m/a (600 ft/yr) then subsequently revised his estimate to 60 m/a (200 ft/yr) when reading errors were found in his survey data. In the second article the engineering firm of Peratrovich and others relying on their photogrammetric evidence estimated the current rate of advance at about 30 m/a (100 ft/yr).

In 1963, Miller (1963) suggested that, depending on climate, the advancing Taku Glacier could block Taku Inlet as early as 1980. More recently, based on his estimate of the current rate of advance, Miller

(Juneau Empire, Sept. 15, 1988) suggested the Taku Glacier would seriously impact the Taku River in ten years. Post and Mayo (1971) estimated closure of the Taku Inlet could take place by 2025 ± 25 A.D.

Heusser and others (1954) using geobotanical and geomorphic evidence documented a significant lowering of ice (120 - 180 m)(400 - 600 ft) in the Taku Glacier accumulation zone which they suggested had occurred since the mid-18th century maximum. They attributed the current advance of the Taku Glacier to an ice wave that was generated during a previous period of increased mass balance in the accumulation zone and which has now travelled down to the ablation zone. Miller (1963; 1985) believed the advance of the Taku Glacier was related to climate and has attributed the advance to ice waves from two periods of "excessive accumulation gain" in the upper part of the accumulation zone during the early part of the last century and to increased accumulation in the lower part of the accumulation zone during the mid-19th century. Post (pers. comm., 1988; also Post and Motyka, in preparation) believes that the current advance is more likely linked to the periodic rapid retreat and gradual advance cycle documented at other tidewater glaciers (eg. Columbia and Hubbard Glaciers; cf. Meier and Post, 1987) and that climatic effects have been secondary. Pelto and Miller (1989) recently also attributed the current advance to the "advance stage of the Alaska tidewater glacier advance-retreat cycle" and state that the advance "is comparatively insensitive to climate at present".

4.0 METHODS

This investigation relied extensively on USC&GS charts and vertical aerial photography for determining the historic positions of the Taku Glacier terminus (table 2). The principal tool used was a Bausch and Lomb stereo zoom transfer scope. This instrument enables an operator to view two objects, such as a photo and map, in superimposition. Differences in scale and distortion can be compensated by using different lens combinations and zoom and stretch adjustments. In practice, identifiable geographic features common to both objects are located and the adjustments are made until the features coincide.

The zoom transfer scope was used to plot the termini for the years 1963, 1973, and 1988 directly onto the 1979 photo base. The 1986 terminus was plotted onto the 1987 photos and the 1987 terminus onto the 1988 photos. Except for 1986 and 1987, glacier positions on air photos or USC&GS charts listed in table 1 were also all superimposed and plotted onto a 1:63,360 (inch-to-the-mile) mylar base map. The 1986 and 1987 terminus positions were not plotted because of their proximity to the 1988 position. A compensating polar planimeter was used to measure both the combined increase in lateral and frontal planar ice area and the increase in frontal ice area alone. The advances between 1979-88, 1973-79, and 1963-1979 were measured from the 1979 photo base, 1986-87 advance from the 1986 photo base, and the 1987-88 advance from the 1987 photo base. All other advances were measured from the base mylar. The smoothed terminus lengths for each year were measured by planimeter, then averaged and divided into the increase in frontal area to provide an average advance per unit length between dates.

As a cross-check, vernier calipers were used to measure distances between the termini of the superimposed photo images 1963-79, 1973-79, 1979-88. 1986-87, and 1987-88 along equally spaced lines perpendicular to the glacier fronts. The average advance calculated from these measurements agreed well with determinations made with the planimeter method.

5.0 SOURCES OF ERROR

Factors limiting measurement accuracy include photo or chart quality, scale, observer perception of the terminus, and imprecision in superimposing images. Observer error is usually random in nature and can be compensated to some extent by repeating measurements. The planimeter measurement process itself tends to average out random error. In practice, measurements were generally repeated three to six times to insure reproducibility with the average value accepted as the result.

Imprecision in superimposing images is probably the most important source of systematic error and the most difficult to evaluate. Extreme care was therefore taken to insure the best possible registry of identifiable conjugate points. Assessments were then made regarding photo or chart quality, the quality of photo control points, and the precision of registry. These estimates of accuracies of the measured advances are included in the tables of results. Because of the constantly changing nature of terrain in front of an advancing glacier, finding suitable conjugate image points was especially a problem when using large scale photographs of the central portion of the glacier terminus (1986, 1987, and 1988).

6.0 RESULTS

Historic positions of the Taku Glacier terminus as determined in this study are shown in fig. 3. The terminal region consists of the main lobe located near the mouth of Taku River and a smaller upstream distributary tongue called Hole-in-the-Wall Glacier. The results of zoom transfer scope - planimeter measurements of the advance (or retreat) for periods between 1929 and 1988 are given in table 3 for the main Taku terminus and in table 4 for the Hole-in-the-Wall and Norris Glaciers. Information on valley boundaries for 1890 - 1929 was inadequate to perform an analysis of the increase in ice area. The rate of advance, measured along the centerline, is about 63 m/a (210 ft/yr) to 85 m/a (280 ft/yr) depending on whether the advance is assumed to have begun in 1890 or 1900.

Results of analyses of changes in terminus positions between 1986-87 and 1987-88 are given in table 5. Photos used were large scale and analysis was restricted to locations where adequate photo control was available, namely near the peripheries of the terminus and at the center where a moraine provided geographic control.

7.0 DISCUSSION

7.1 Rates of Advance

7.1.1 Historic Advances

Table 4 presents several different measures of the Taku Glacier advance: A_t, the total increase in ice area (lateral and frontal); A_f, the increase in down glacier or frontal area; A_t/yr and A_f/yr, the average rates of total and frontal areal advance, respectively; and Adv/yr, the average linear rate of advance. Our results for the linear rate of advance generally agree with previous estimates (cf. Table 2) with differences probably attributable to measurement methods and base periods used.

The rate of advance (or retreat) of a glacier is a function of (1) incoming ice flux, i.e., the rate at which ice is being transported into the terminal region by glacier flow, and of (2) ablation, the rate at which ice is being melted or calved from the terminal region. The linear rate of advance is also a function of basin geometry. If the volume of advance can be determined then the effects of basin geometry on linear rates of advance can be ascertained and the relative dependence of the advance on ice flux vs ablation can be more easily assessed. Although the thickness of the advancing terminus is not known the area of advance is easily measured. If the assumption is made that the thickness is roughly similar for each period of advance under consideration then area measurements provide a parameter for assessing the total amount of ice being added to the terminus. No previous attempts have been made to areally quantify the advance and the results provide insights on the factors controlling the rate of advance.

The linear rate of advance of the main lobe of the terminus initially at 63 to 85 m/a (210 to 280 ft/yr), increased to about 150 m/a (500 ft/yr) during 1929-37 but an increase in ice flux as suggested by Miller (1963) may not necessarily have been responsible for this increase. Although measurement of the areal increase between 1890 and 1929 was not possible it is evident from fig. 3 that much of the ice flux during this period must have gone to filling in the broad upper tidal basin. By 1929, basin geometry would have caused the linear rate of advance to increase without any increase in ice flux since the glacier had by then advanced to the constriction in the valley. A second factor which could explain the increased rate of linear advance is that glacier calving, a very effective and efficient means of ablating ice, had diminished considerably by 1929 because of sediment in-filling of the basin.

Similarities in areal rates of advance suggest ice flux and ablation rates remained approximately constant during the period 1929 to 1973. The significant decreases in linear rates of advance after 1937, to 91 m/a (300 ft/yr) and 1952, to 52 m/a (170 ft/yr) appear to be largely attributable to the broadening of the terminus as the glacier advanced down valley (cf. L_{ave}, table 3). Although terminus length remained approximately constant after 1973, both the areal and linear rates of advance declined significantly after 1973, to 33.5 m/a (110 ft/yr) and again after 1979, to 15 m/a (50 ft/yr). These declines apparently cannot be attributed to decreased ice flux from the accumulation zone as Pelto (pers. comm. 1989) reports that equilibrium line ice velocities have remained nearly constant over the last forty years. Perhaps a larger proportion of the ice flux is now thickening the ablation zone. Future photogrammetric analyses outlined in Appendix A should determine whether or not has thickening has taken place. Alternatively, a warming that began abruptly in 1977 could have significantly increased the rate of ablation, reducing the rate of Taku Glacier advance and simultaneously accelerating the rate of retreat of adjacent Norris Glacier (table 4).

7.1.2 Recent Advances

The average linear rate of advance of 15 m/a (50 ft/yr) for the period 1979-88 determined in study is considerably lower then either Miller's or Arnett's estimates of current rate of advance, 60 m/a (200 ft/yr) and 30 m/a (100 ft/yr), respectively. To determine the most recent changes in terminus positions, large scale (approximately 1:15,000) vertical aerial photographs of the termini taken on May 27, 1988, August

24, 1987, and September 12, 1986 were compared using the zoom transfer scope. Lack of adequate photo control points restricted the analyses to certain sections of the terminus. For the period 9/12/86 to 8/24/87, advance was visible along the entire section of the terminus examined and exceeded 60 m (200 ft) in at least two locations. The average linear advances along the terminus were 35 m/a (115 ft/yr), 22 m/a (72 ft/yr), and 40 m/a (130 ft/yr) for the northeast, central, and southwest parts of the terminus, respectively, rates that are substantially above the 1979-1988 average. The areal rate of advance was at least 0.26 km^2 (0.10 mi^2).

In contrast, changes between 8/24/87 and 5/27/88 terminus positions were nearly imperceptible along the southwest part of the terminus and much of the remainder of the terminus. Glacier advances averaging about 23 m (75 ft) and 35 m (115 ft) did take place along two short sections of the terminus but the total areal advance was about 0.057 km^2 (0.022 mi^2). A push moraine lying in front of sections of the 8/24/87 terminus marks the furthest advanced position of the terminus during 1987 from which the 8/24/87 face had ablated back during the 1987 summer. The 5/27/88 advance is halved when measured to this presumed furthest 1987 position.

The reasons for these recent short term variations remain unclear. Perhaps advance of the glacier takes place only during early summer months when ice velocities are higher and the effects of seasonal ablation are still minimal. Alternatively, the differences may be due to meteorologically induced variations in annual net ablation. Apparently, the Taku Glacier terminus has even undergone slight retreats in previous years (A. Post, USGS, pers. comm.). These fluctuations underscore the need to exercise caution in predicting future behavior based on short term activity.

7.2 Causes of Retreat and Advance

It has become increasingly apparent that the progressive advance of the Taku Glacier is linked to the periodic rapid retreat and gradual advance cycle that has been documented for many other Alaska tidewater glaciers (Meier and Post, 1987) and that climatic effects have been secondary. Objections to Miller's hypothesis (Miller, 1963; Miller, 1985) that the Taku glacier advance is climatically induced will be detailed in a future report (Post and Motyka, in preparation).

Tidewater glaciers, i.e., glaciers that end in saltwater, characteristically advance down their fjords by pushing an anchoring moraine or shoal ahead of them (Post, 1975). This anchoring moraine is crucial because it isolates the terminus from deeper tidal water where the iceberg calving rate can be very rapid. In fact, should some event (such as a minor climate change) cause a small retreat off the shoal or moraine, the glacier, now in deeper water behind the moraine, will start to calve rapidly, and may disintegrate all the way up to dry land. Once on dry land, calving stops and the glacier is able to construct a new anchoring moraine from material eroded from its bed. The glacier can then start re-advancing down fjord, typically slowly, because of the time required to continually transport and reestablish the anchoring moraine or shoal ahead of itself.

The cause of the Taku Glacier 1755-75 A.D. retreat is unknown. Miller (1963) suggested that the retreat was climatically induced but other temperate glaciers in southeast Alaska, particularly in Glacier Bay, are thought to have not begun receding until about 1790 (Pewe, 1975). Post (written communication, 1988) speculates that glacier outburst floods may have caused collapse of the terminal ice region abutting Taku Point exposing the entire terminus to tidal fluctuations. Whatever the cause, once the terminus receded from Taku Point, Post suggests that tidewater-induced glacier calving could have resulted in rapid retreat of the Taku Glacier.

Vancouver's (1801) description suggests the glacier had retreated on the order of 10 km (6 mi) by 1794 A.D. If retreat began sometime between 1750 and 1775 A.D. as indicated by Lawrence (1950) then the rate of retreat would have been 0.2 to 0.4 km/a, which is within the range of rates of retreat documented at historically rapidly retreating tidewater glaciers in Alaska (Meier and Post, 1987). Increase in glacier calving is accompanied by an increase in ice flux to the terminal region with the speed-up apparently caused by the release of back pressure due to the loss of ice at the front and to the decrease in the effective pressure at the glacier bed (Meier and Post, 1987). The increased ice flux causes thinning of ice in the accumulation zone, and the lowering of the Taku accumulation zone surface, documented by Huesser and others (1954), is consistent with this fast-velocity mode tongues of calving glaciers undergo while in retreat.

As the shoaling moraine gradually developed and the tidal basin filled in, calving diminished and the Taku terminus became increasingly more grounded. The increased back pressure on the glacier would have reduce ice flow causing the accumulation zone to thicken once again. That this was already happening by the late 1940's is evident from Neilsen (1957) who found that the glacier had a significant net positive mass balance and that "much more snow was accumulating in the upper regions of the glacier than was melting below the firn line". Pelto and Miller (1989) documented the continuation of this trend through 1986 and Pelto (pers. comm., 1989) estimated that the accumulation zone has thickened by 10 % between 1946 and 1986 while ice velocities measured at the equilibrium line showed little change since 1950.

Inherent in this scenario is that the Taku did not undergo an advance-retreat cycle during the 100 year period between late 18th and 19th centuries. In view of the size and depth of the 1890 tidal basin charted by the USC&GS it seems unlikely any such advance-retreat could have occurred during this period but evidence verifying this conclusion should be sought.

7.3 Future Behavior

The Taku Glacier has an extremely high accumulation area ratio (AAR) (percentage of accumulation area to total glacier area) of 0.86; in contrast, the adjoining retreating Norris Glacier, typical of most other glaciers in the area, has an AAR of about 0.66 (Post and Motyka, in preparation). In the absence of significant calving, this high AAR and the strongly positive net mass balance virtually insure that the Taku

Glacier will continue to advance. At present the terminus lies about 880 m (2,900 ft) from the main channel of the Taku River and about 1,550 m (5,100 ft) from Taku Point on the opposite bank. If the rate of advance persists at 15 m/a (50 ft/yr) to 30 m/a (100 ft/yr), it would take the glacier 30 to 60 years just to reach the Taku River. The increase in ablation area and the continued spreading of the terminus as the glacier advances towards the Taku River will help reduce the linear rate of advance. If the glacier does advance to the Taku River, the river itself will become very effective in controlling further advance by increasing melting and glacier calving.

The most immediate effect of changing climatic conditions will be on ablation, with increasing temperatures and rain obviously favoring a reduction in the rate of advance. Significant increases in accumulation during recent years, particularly 1984-88, have been reported for higher elevations (Pelto, pers. comm, 1989). This recent increase in accumulation and the longer-term gradual thickening of ice in the accumulation zone in general could eventually result in an increase of ice flux into the ablation zone. The magnitude and timing of such an increase and its potential effect on increasing the rate of advance have not as yet been analyzed. Monitoring of the glacier's activity through the program outlined in Appendix A will provide data that should help to answer these and other questions regarding the Taku Glacier's past, present, and future history.

8.0 ACKNOWLEDGEMENTS

I wish to express appreciation to J. Olsen (U.S. National Marine Fisheries Service) for providing the 1988 vertical aerial photos; D. Swanston (U.S. Forest Service) for loan of the zoom transfer scope used in this study; to A. Post (U.S. Geological Survey) and M. Pelto (U. of Maine, Orno) for helpful discussions regarding the Taku Glacier; to R. Jeric for assistance in report preparation; and to J. Szarzi, for assistance in photogrammetric measurements.

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APPENDIX A. Proposal submitted to state legislature at the request of Senator Jim Duncan.

TAKU GLACIER STUDY

PROJECT DESCRIPTION:

Background: Located in the Coast Mountains, 20 mi NNE of Juneau, the Taku Glacier is about 20 mi long, with an accumulation zone of 300 sq mi principally at 3,000 to 5,000 ft elevation in the Juneau Icefield. The terminus is located at the head of Taku Inlet near the mouth of the Taku River.

Geologic evidence indicates that the Taku Glacier crossed the Taku River as recently as 1750, creating an extensive glacier-dammed lake in the Taku River Valley. Glacier retreat began sometime between 1750 and 1775. The first charting of Taku Inlet by the U.S. Coast and Geodetic Survey in 1890 shows the Taku Glacier terminating at the head of a deep tidal basin. Since 1900 the Taku Glacier has re-advanced about 4.5 miles although all other valley glaciers in the immediate area have been retreating. Present location of the terminus is about 1 mi across the Taku River from Taku Point.

Dr. Maynard Miller of the Juneau Icefields Project estimates the present rate of advance at 200 feet per year and predicts that within a decade the advancing terminus will narrow the Taku River channel to 2,000 feet. Using photogrammetric evidence the engineering firm Peratrovich et al estimated current rate of advance at about 100 feet per year. Because of the socio-economic impacts that would be associated with the damming of the Taku River DGGS was requested to do an independent evaluation of the Taku Glacier advance in cooperation with the U.S. Geological Survey.

Miller has attributed the advance of the Taku Glacier to climatic effects. We believe that the Taku Glacier is a tidewater-type glacier and that the current advance is more likely linked to the periodic rapid retreat and gradual advance cycle documented at other tidewater glaciers (eg. Columbia and Hubbard Glaciers) and that climatic effects have been secondary. However, the large increases in accumulation that have been documented at higher elevations over the past 10 to 15 years may eventually affect the terminal region and may compound the rate of advance sometime in the future.

First Year Work Plan:

1. Obtain available aerial photos and charts and make qualitative analyses of terminus positions and rates of advance between photo or observation dates.
2. Establish photo-control network using panels and geodetic survey. Survey present location of terminus and periodically re-survey position.
3. Obtain new vertical aerial photographs of ablation zone, twice the first year at least four months apart which allows photogrammetric determination of ice velocities.
4. Conduct on-glacier measurements of accumulation and ablation.
5. Search for field evidence of prior glacier advances and retreats and glacier-dammed lakes.
6. Reduce and analyze survey and field data.
7. Photogrammetrically locate terminus and construct surface-altitude profiles from available photos to document ice thickening or thinning. Photogrammetrically estimate ice velocities.
8. Prepare progress report on preliminary findings.

Second Year Work Plan:

1. Recheck photo-panels and re-survey if necessary. Re-survey terminus position.
2. Obtain new vertical aerial photographs of ablation zone (one flight).
3. Conduct on-glacier measurements of accumulation and ablation.
4. Conduct radio-echo sounding of glacier ice thickness.
5. Obtain updated bathymetry of Taku Inlet.
6. Reduce and analyze field data.

7. Photogrammetrically locate terminus and construct surface-altitude profiles and compare to previous profiles to document ice thickening or thinning.

8. Construct bathymetric map of Taku Inlet and compare to older charts. Estimate sedimentary filling of inlet since 1890.

9. Prepare and publish final report with derivative maps and figures documenting findings of study and evaluating the potential for continued advance of the Taku Glacier and possible closure of the Taku River.

Third, Fourth, and Fifth Year Work Plan:

Continue monitoring activity of Taku Glacier through photogrammetry and direct observations.

PERFORMANCE OBJECTIVES:

1. Document historic rate of advance.
2. Determine current rate of advance.
3. Evaluate the potential for continued advance of the Taku Glacier and possible closure of the Taku River.

SOCIO-ECONOMIC CONCERNS

1. Salmon Fishery: the Taku River is the major producer of king and coho salmon in northern Southeast and is a leading producer of sockeye.
2. Salmon Treaty: the ADF&G is negotiating with Canada regarding Taku River salmon allocation and general enhancement.
3. Road Corridor: the Taku River valley is under consideration as a possible road corridor into Canada.
4. Land and lodges: Taku Glacier Lodge and a number of summer residences are located upstream of the terminus.

5. Mining: A number of promising mining prospects are located off the Taku River near the US-Canada border.

FIGURE CAPTIONS

Figure 1. Location map, Juneau Icefields and Taku Glacier, modified from Miller (1977).

Figure 2. Tidal basin bathymetry and position of Taku Glacier terminus in 1890 as determined from USC&GS charts (Post and Motyka, in preparation).

Figure 3. Historic positions of the Taku Glacier terminus as determined from vertical aerial photography and USC&GS charts.

THE NORTHERN BOUNDARY RANGE

ALASKA - CANADA

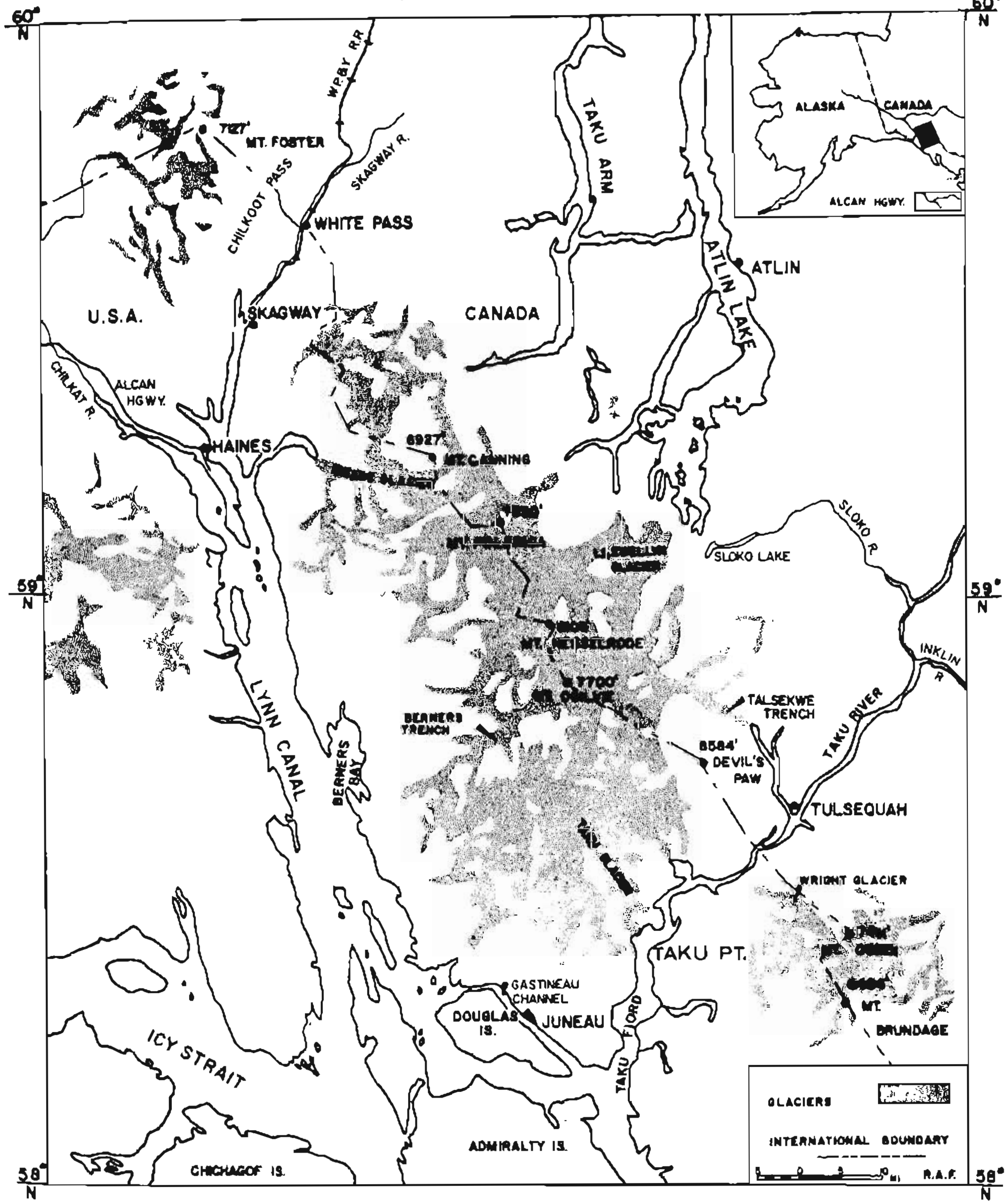
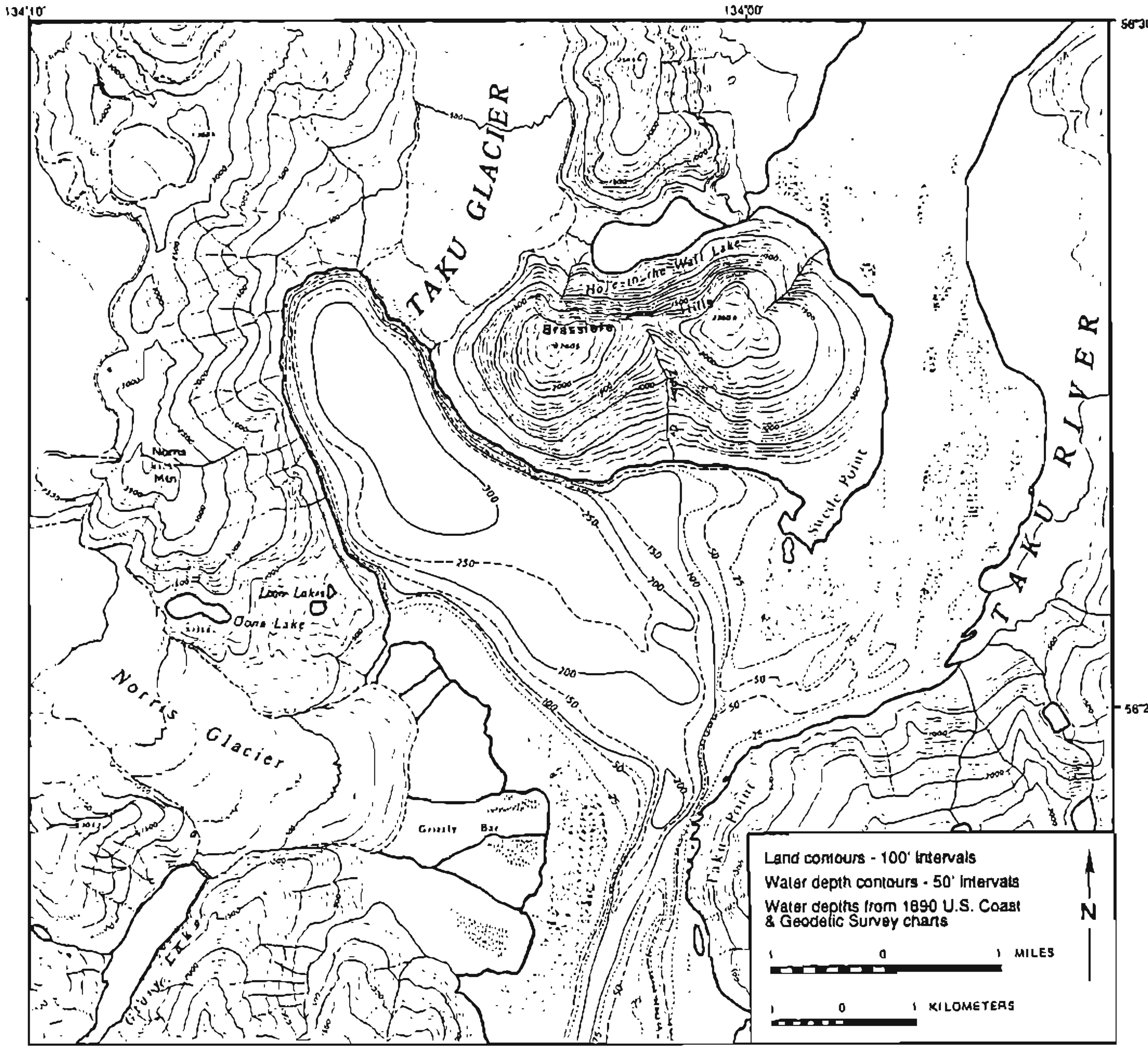


Fig. 1



134°10'
134°00'
56°30'
56°25'
TAKU GLACIER
Hole-in-the-Wall Lake
Hills
Brassiere
Norris Mtn
Loon Lakes
Ooms Lake
Norris Glacier
Grizzly Bar
Taku Point
Taku Inlet
TAKU RIVER
Land contours - 100' intervals
Water depth contours - 50' intervals
Water depths from 1890 U.S. Coast & Geodetic Survey charts
MILES
KILOMETERS
N

Fig. 2

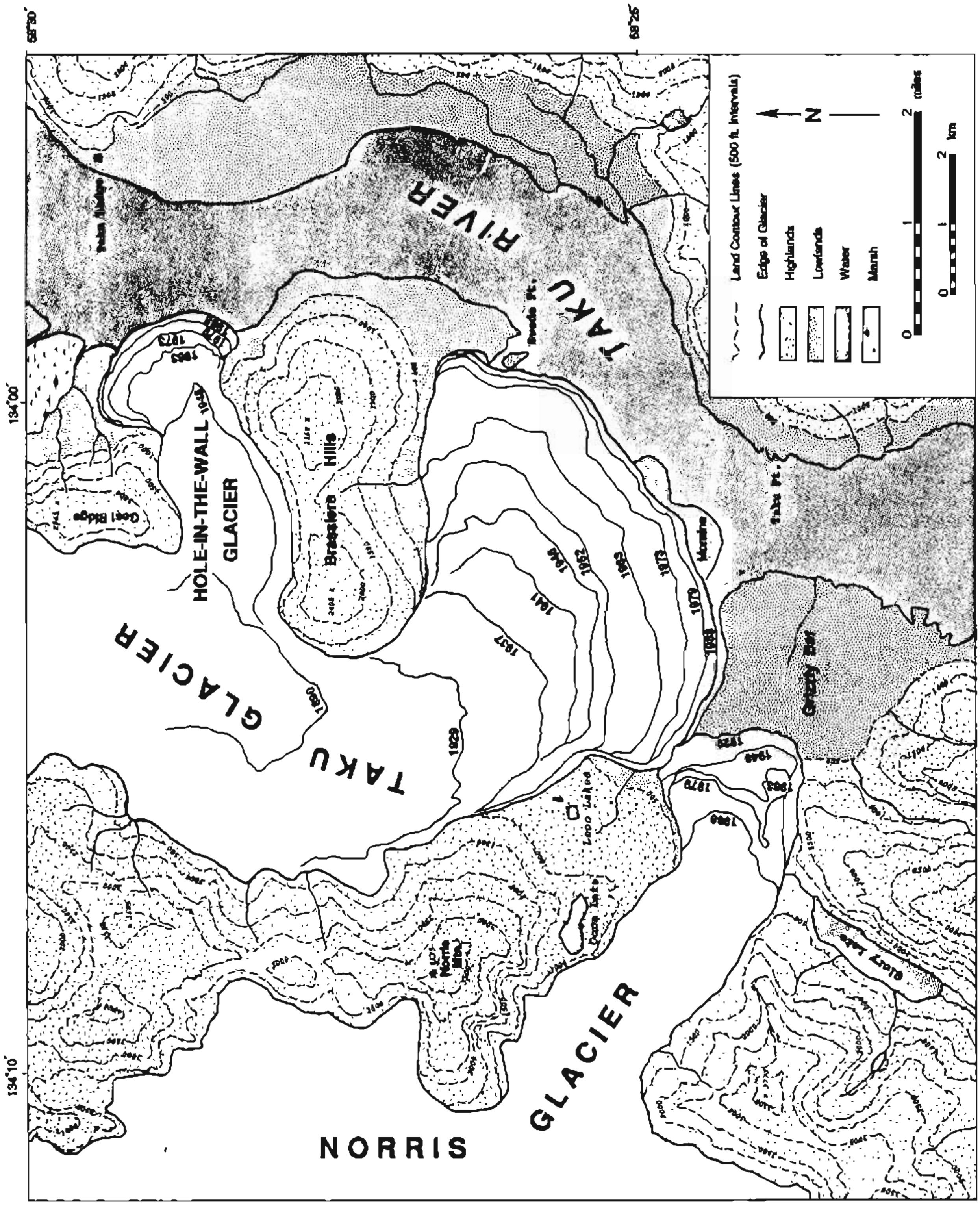

TAKU RIVER
TAKU GLACIER
NORRIS GLACIER
HOLE-IN-THE-WALL GLACIER
Brassiere Hills
Goat Ridge
Grizzly Bar
Moraine
Land Contour Lines (500 ft. intervals)
Edge of Glacier
Highlands
Lowlands
Water
Marsh
N
miles
km

Fig. 3

Table 1. Previous estimates of Taku Glacier historic rates of advance.

Wentworth and Ray (1936):

Period	1909-31
Rate, ft/yr	340

Field (1954):

Period	1900-09	1909-29	1929-31	1931-37
Rate, ft/yr	385	272	600	522
Period	1937-41	1941-48	1948-50	1950-52
Rate, ft/yr	325	271	167	300

Miller (1963):

Period	1900-29	1929-48	1948-55
Rate, ft/yr	250	500	300

Miller and Pelto (1989):

Period	1900-48	1948-80
Rate, ft/yr	290	120

Table 2. Vertical aerial photo and USC&GS charts used in this study to determine position of the Taku Glacier terminus.

Date	Agency	Type	Scale	Quality
Summer, 1890	USC&GS	chart	1:200,000	Fair
Summer, 1929	USN	photo	1:24,000	Good
Apr-Jul, 1937	USC&GS	chart	1:10,000	Excellent
Summer, 1941	unknown	photo	1:42,000	Poor
Aug 13, 1948	USGS	photo	1:47,000	Very Good
Jun-Jul, 1952	USC&GS	chart	1:10,000	Excellent
Aug 24, 1963	UW	photo	1:29,400	Very Good
Aug 21, 1973	USAF	photo	1:54,300	Very Good
Aug, 1979	USGS	photo	1:65,000	Excellent
Sept 12, 1986	USGS-ICP	photo	1:14,800	Excellent
Aug 24, 1987	USGS-ICP	photo	1:16,140	Very Good
Aug 13, 1987	USFS	photo	1:65,000	Fair
May 26, 1988	NOAA	photo	1:15,800	Excellent

USN = U. S. Navy
USC&GS = U.S. Coast & Geodetic Survey
UW = University of Washington
USGS = U. S. Geological Survey
USGS-ICP = U. S. Geological Survey, Ice and Climate Project
USAF = U. S. Air Force
USFS = U. S. Forest Service
NOAA = National Oceanic and Atmospheric Administration

Table 3a. Advance of the Taku Glacier as determined from vertical aerial photography and USC&GS charts (metric units).

Period	yrs	A_t km^2	Δ	A_f km^2	Δ	L_{ave} km	A_t/yr km^2/yr	Δ	A_f/yr km^2/yr	Δ	Adv m/yr	Δ
1979-1988	8.8	0.96	0.12	0.96	0.12	8.01	0.110	0.014	0.110	0.014	13.7	1.7
(1979-87)	8.0	0.96	0.12	0.96	0.12	7.84	0.120	0.015	0.120	0.015	15.3	1.9
1973-1979	6.0	1.57	0.12	1.57	0.12	7.76	0.261	0.019	0.261	0.019	33.6	2.5
1963-1973	10.0	3.92	0.11	3.84	0.11	7.27	0.392	0.011	0.384	0.011	52.8	1.5
1952-1963	11.1	-	-	3.73	0.10	6.43	-	-	0.335	0.009	52.2	1.3
1948-1952	3.9	-	-	1.79	0.07	4.91	-	-	0.461	0.019	94.0	3.9
1937-1948	11.2	4.20	0.10	3.99	0.06	3.95	0.375	0.009	0.356	0.005	90.2	1.3
1929-1937	7.8	3.60	0.14	3.42	0.07	2.78	0.462	0.018	0.438	0.009	158.0	3.2
1948-1963	15.0	6.41	0.20	5.64	0.18	5.85	0.428	0.014	0.376	0.012	64.3	2.0
1929-1948	19.0	7.89	0.25	7.44	0.15	3.67	0.415	0.013	0.392	0.008	106.9	2.1

A_t = Total area of advance between photo dates.
A_f = Area of advance between photo dates minus lateral increases in ice area.
L_{ave} = Length of terminus, average of beginning and ending year.
Adv = Average rate of advance per length of terminus per year.
Δ = estimated uncertainty.

Table 3b. Advance of the Taku Glacier as determined from vertical aerial photography and USC&GS charts (English units).

Period	yrs	A_t mi^2	Δ	A_f mi^2	Δ	L_{ave} mi	A_t/yr mi^2/yr	Δ	A_f/yr mi^2/yr	Δ	Adv ft/yr	Δ
1979-1988	8.8	0.37	0.05	0.37	0.05	4.98	0.042	0.005	0.042	0.005	45	6
(1979-87)	8.0	0.37	0.09	0.37	0.05	4.87	0.046	0.011	0.046	0.006	50	6
1973-1979	6.0	0.61	0.09	0.61	0.04	4.82	0.101	0.015	0.101	0.007	110	8
1963-1973	10.0	1.51	0.08	1.48	0.04	4.52	0.151	0.008	0.148	0.004	173	5
1952-1963	11.1	-	-	1.44	0.04	3.99	-	-	0.129	0.003	171	4
1948-1952	3.9	-	-	0.69	0.03	3.05	-	-	0.178	0.007	308	13
1937-1948	11.2	1.62	0.08	1.54	0.02	2.45	0.145	0.007	0.137	0.002	296	4
1929-1937	7.8	1.39	0.11	1.32	0.03	1.72	0.178	0.014	0.169	0.003	518	11
1948-1963	15.0	2.48	0.16	2.18	0.07	3.63	0.165	0.011	0.145	0.005	211	7
1929-1948	19.0	3.05	0.19	2.87	0.06	2.28	0.160	0.010	0.151	0.003	351	7

A_t = Total area of advance between photo dates.
A_f = Area of advance between photo dates minus lateral increases in ice area.
L_{ave} = Length of terminus, average of beginning and ending year.
Adv = Average rate of advance per length of terminus per year.
Δ = estimated uncertainty.

Table 4a. Advance of the Hole-In-the-Wall Glacier as determined from vertical aerial photography and USC&GS charts (metric units).

Period	yrs	A km^2	Δ	L_{ave} km	A/yr km^2/yr	Δ	Adv m/yr	Δ
1979-88[a]	8.8	0.29	0.07	2.48	0.033	0.008	13.5	3.4
1973-79	6.0	0.45	0.10	3.30	0.075	0.016	22.6	5.0
1963-73	10.0	0.63	0.10	3.26	0.063	0.010	19.4	3.0
1948-63	15.0	0.93	0.07	2.22	0.062	0.004	28.0	2.0

[a] Values do not include north end of terminus because of incomplete photo coverage for 1988.

A = Area of advance between photo dates minus lateral increases in ice area.
L_{ave} = Length of terminus, average of beginning and ending year.
Adv = Average rate of advance per length of terminus per year.
Δ = Estimated uncertainty.

Table 4b. Retreat of the Norris Glacier as determined from vertical aerial photography and USC&GS charts (metric units).

Period	yrs	R km^2	Δ	L_{ave} km	R/yr km^2/yr	Δ	Ret m/yr	Δ
1979-88	8.8	1.054	0.073	2.43	0.120	0.008	49.6	3.4
1963-79	16.0	0.305	0.072	2.41	0.019	0.005	7.9	1.9
1948-63	15.0	0.590	0.073	2.43	0.039	0.005	16.1	2.0
1929-48	19.0	0.768	0.102	2.55	0.040	0.005	15.8	2.1

R = Area of retreat between photo dates minus lateral increases in ice area.
L_{ave} = Length of terminus, average of beginning and ending year.
Ret = Average rate of retreat per length of terminus per year.
Δ = estimated uncertainty.

Table 4c. Advance of the Hole-in-the-Wall Glacier as determined from vertical aerial photography and USC&GS charts (English units).

Period	yrs	A mi^2	Δ	L_{ave} mi	A/yr mi^2/yr	Δ	Adv ft/yr	Δ
1979-88	8.8	0.11	0.03	1.54	0.013	0.003	44	11
1973-79	6.0	0.17	0.04	2.05	0.029	0.006	74	16
1963-73	10.0	0.25	0.04	2.03	0.024	0.004	64	10
1948-63	15.0	0.36	0.03	1.38	0.024	0.002	92	7

[a] Values do not include north end of terminus because of incomplete photo coverage for 1988.

A = Area of advance between photo dates minus lateral increases in ice area.
L_{ave} = Length of terminus, average of beginning and ending year.
Adv = Average rate of advance per length of terminus per year.
Δ = estimated uncertainty.

Table 4d. Retreat of the Norris Glacier as determined from vertical aerial photography and USC&GS charts (English units).

Period	yrs	R mi^2	Δ	L_{ave} mi	R/yr mi^2/yr	Δ	Ret ft/yr	Δ
1979-88	8.8	0.41	0.03	1.51	0.047	0.003	163	11
1963-79	16.0	0.12	0.03	1.50	0.007	0.002	26	6
1948-63	15.0	0.23	0.03	1.51	0.015	0.002	53	7
1929-48	19.0	0.30	0.04	1.59	0.016	0.002	52	7

R = Area of retreat between photo dates minus lateral increases in ice area.
L_{ave} = Length of terminus, average of beginning and ending year.
Ret = Average rate of retreat per length of terminus per year.
Δ = estimated uncertainty.

Table 5a. Advance of the Taku Glacier along selected portions of the terminus as determined from vertical aerial photography for 1986-87-88 (metric units).

Period	yrs	A km^2	Δ	L_{ave} km	A/yr km^2/yr	Δ	Adv m/yr	Δ
1987-88	0.85							
A		0.0	0.01	3.0	0.0	0.01	0	3
B		0.0	0.01	1.9	0.0	0.01	0	5
C		0.02	0.01	2.9	0.03	0.01	9	3
1986-87	0.95							
A		0.12	0.01	3.0	0.13	0.01	42	3
B		0.04	0.01	1.9	0.04	0.01	23	5
C		0.10	0.01	2.8	0.10	0.01	37	3

Table 5b. Advance of the Taku Glacier along selected portions of the terminus as determined from vertical aerial photography for 1986-87-88 (English units).

Period	yrs	A mi^2	Δ	L_{ave} mi	A/yr mi^2/yr	Δ	Adv ft/yr	Δ
1987-88	0.85							
A		0.0	0.004	1.9	0.0	0.004	0	10
B		0.0	0.004	1.2	0.0	0.004	0	16
C		0.008	0.004	1.8	0.010	0.004	30	10
1986-87	0.95							
A		0.046	0.004	1.9	0.048	0.004	133	10
B		0.016	0.004	1.2	0.017	0.004	75	16
C		0.038	0.004	1.7	0.040	0.004	121	10

A = Area of advance between photo dates minus lateral increases in ice area.
L_{ave} = Length of terminus, average of beginning and ending year.
Adv = Average rate of advance per length of terminus per year.
Δ = estimated uncertainty