

RECENT GLACIER ACTIVITY IN THE TAKU INLET AREA, SOUTHEASTERN ALASKA

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RECENT studies have shown that in the middle of the eighteenth century the Norris and Taku glaciers, together with others issuing from the Juneau Ice Field, had advanced considerably beyond their present positions, and were, presumably, even farther beyond the positions of the termini during the thermal maximum (Lawrence, 1950a). A similar pattern of advance and retreat has been noted for certain glaciers elsewhere in Alaska and in many other parts of the world, and the period during which the advance occurred has been termed "the little ice-age" (Matthes, 1939, p. 520). Evidence for increased glacier activity in a late postglacial maximum seems abundant and clear, but details of the fluctuations of individual glaciers are frequently lacking, although such information is essential if the causes of the glacial changes are to be understood.

This paper discusses the significant features of recent fluctuations of the lower Norris and Taku glaciers, including their maximum extent, date of important phases, and the relationship of the glaciers to other physical features of the area. The glacier variations in the Taku valley are of particular interest because observations are now being made on the regimen of these glaciers, and on the effect of changes in the regimen at higher levels on the position of the ice in the valley. The resultant information should be of value in providing a better understanding of glaciation.

Present conditions

The Juneau Ice Field occupies an area of approximately 700 square miles in the Alaskan Coast Mountains, north of Juneau and east of the Lynn Canal. From it flow a number of valley glaciers, five of which emerge on the southeastern side and reach the broad trench of the Taku Inlet and River. These are the Norris, Taku, Hole-in-the-Wall, Twin, and Tulsequah glaciers. Except for the Taku and its distributary, Hole-in-the-Wall, all the glaciers appear to be retreating. The apparently anomalous advance of the Taku has received much attention, particularly since the organization of the Juneau Ice Field Research Project by the American Geographical Society in 1948, and some progress has been made towards an understanding of the present advance (Heusser, Schuster, and Gilkey, 1954). The Norris Glacier, which terminates less than a mile from the Taku and emanates from the same group of interconnected névés, appears to be retreating and is thinning rapidly.

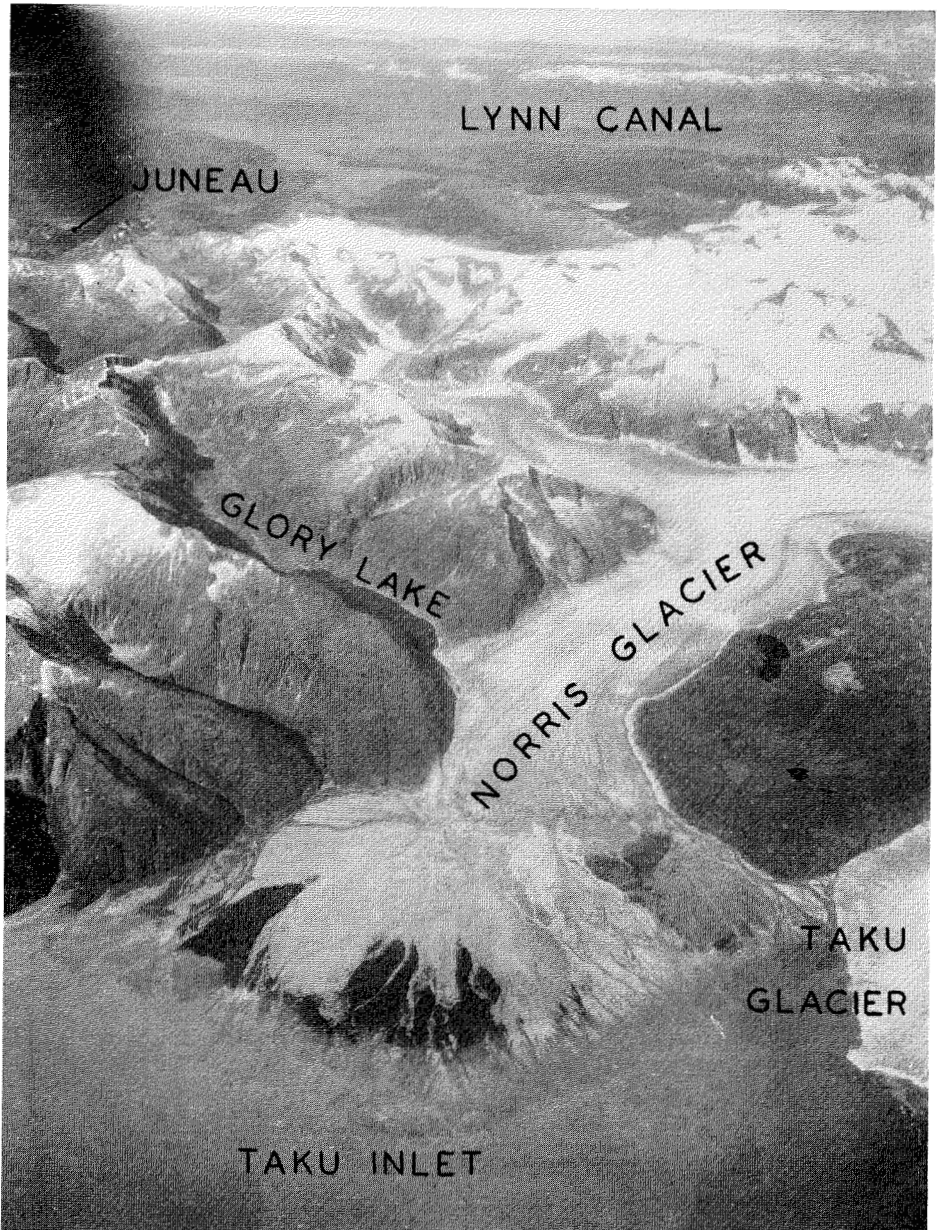


Fig. 1. View northwest along Norris Glacier. 1942.

Photo: U.S.A.F.

Past conditions

Different methods may be used to determine the condition of glaciers in the past, and to date major advances and recessions. Historical records may provide information, but unfortunately early detailed descriptions of glaciers are rare. Geological evidence is invaluable in most respects, but does not

generally permit accurate dating of events. Radiocarbon dating of organic material less than 500 years old is not sufficiently accurate for meaningful results. Botanical studies, particularly pollen and tree ring analysis, have been of great significance and recently geobotany, the union of geological and botanical approaches, has provided a fairly reliable means of dating recent events.

Very little of the information thus far compiled concerning the recent maximum of the Norris and Taku glaciers has been based on historical records. Written descriptions of these glaciers before the 1800's are unknown, although the glaciers of Taku Inlet in general are mentioned by Vancouver (1801, p. 25-7) who charted the area in 1794. He describes a basin, about 13 miles within the inlet, and Lawrence (1950a, p. 208) cites a reference by Vancouver in which he suggests that "the Norris still had a vertical tidal icefront in 1794". The reliability of Vancouver's description is doubtful, and it is impossible to base final conclusions on the scanty data he gives. There is, at present, no basin visible; however, if his description of the Taku Inlet is compared with maps made around 1900, a strong correlation exists. At that time the terminus of the Taku Glacier was more than 3 miles farther up its valley than at present, and this exposed part of the inlet was approximately the same as the basin Vancouver described more than 100 years earlier. In 1890 I. C. Russell visited the Taku Glacier and reported that it was retreating. Since the beginning of the present century the glacier has been advancing rapidly, and in 1949 Lawrence (1950a, p. 209) estimated that it had advanced $3\frac{1}{2}$ miles in 48 years.

The Norris Glacier has had a somewhat different history during the present century. Since about 1915 it has been retreating, and although the recession of the ice itself has not been great, the amount of thinning that has occurred near the terminus is considerable. Before 1915 the ice stood at a high level for at least several decades, for early photographs show that in the 1880's the ice was "close to or in contact with the trees along the margins" (Lawrence, 1950a, p. 208). Evidence obtained by the writer indicates that this high level was maintained for a very long period.

Although a period of increased glacier activity in the recent past has been recognised, it was not until 1949 that any significant attempt was made to determine the extent to which the glaciers in the vicinity of Juneau and the Taku Inlet had been affected. During July and August 1949, Lawrence studied the termini of several glaciers of the Juneau Ice Field, and the data he obtained are of great value, especially as they demonstrate the effectiveness of the geobotanical approach to the study of recent glaciation. By comparing the annual growth rings of trees on both sides of the line of recent maximum advance Lawrence was able to estimate not only the approximate date at which the ice began to retreat from its maximum position, but also the minimum length of time that had elapsed since the ice last advanced beyond that position. He concluded that all the glaciers studied had advanced to a maximum that culminated during the early or middle eighteenth century, and that retreat began around 1765 (Lawrence, 1950a). The writer carried out detailed

investigations in the Taku Inlet area in 1953 in an attempt to determine the extent of the late postglacial maximum of the Taku and Norris glaciers in terms of farthest advance and greatest thickness at or near the termini, and to date the maximum as closely as possible. The conclusions, in part, support those of Lawrence, although evidence for a mid-eighteenth century maximum was not found on the lower Norris, but the writer has interpreted certain other phenomena associated with recent glaciation in this area differently.

Research methods

The methods employed were essentially those used and described by Lawrence (1950b). The forest trimlines of the Norris and Taku glaciers were studied carefully both on air photographs and in the field. Trimlines are formed by a glacier advancing down a forested valley and destroying all the trees in its path, creating a sharp line between the forest untouched by ice and that sheared off. Trimlines are frequently associated with lateral or terminal moraines, but whereas trimlines are invariably formed by a glacier advancing through forests, various factors may prevent the formation and survival of moraines. When the glacier retreats or thins, the trimline is left above and beyond the existing ice. Normally reforestation soon begins on the area cleared and abandoned by the ice, but the time required for seedlings to become established on freshly deglaciated terrain varies with local conditions. Lawrence determined that 3 to 7 years were necessary for Sitka spruce to become established on land from which the Mendenhall Glacier has recently retreated (1950a, p. 202) and it is reasonable to assume that a similar period is required in the Taku-Norris area. The number of years necessary for the re-establishment of seedlings plus the age of the oldest trees below or inside a trimline, indicates the number of years that an area has been deglaciated. From an examination of forest conditions and an analysis of sections and cores from trees growing on the outer side of a trimline, it is possible to estimate the time that has elapsed since ice last advanced over the area. Differences between forest conditions on either side of a trimline gradually become less marked and may eventually be obscured, but they can still be observed after more than 200 years.

In this study, trimlines were recognized and traced on the basis of both geological and botanical evidence, and cores or sections were taken from trees which were believed to be of a significant age. Equipment used included Swedish increment borers, capable of extracting a core of 15 to 20 inches, and a small hand saw for obtaining sections from small trees.

In order to make a reliable estimate of the age of a tree, the total number of annual growth rings must be counted, and the core must, therefore, be taken from the exact centre and the very base of the tree. This was frequently impossible, and in such cases it was decided to add one year for each foot of height between the base of the tree and the point of extraction. If the centre of the tree could not be reached with the coring device, the number of rings remaining was estimated by multiplying the number of rings in the most central inch of the core by the number of additional inches required



Fig. 2. Trimline of Norris Glacier, on slopes above southern end of the present terminus. Narrow belt of spruces adjacent to trim follows lateral moraine. August 1953.

to reach the centre. For example, if a 14 inch core containing 100 rings was extracted 3 feet above the base of a tree 36 inches in diameter at the point of extraction, and if the innermost inch of the core contained 4 rings, then the age of the tree was estimated at 119 years—the additional 19 years being the sum of the height in feet of the core above the base (3) and the product of the number of rings in the innermost inch (4) by the number of additional inches required to reach the centre of the tree (4). In the following discussion the exact number of rings counted is given, and the computed addition is in parentheses when necessary.

Norris Glacier

Casual observation shows that the lower Norris Glacier formerly filled the valley it occupies to a much greater extent. The rocky walls which confine the ice and tower above it show with remarkable clarity the recent fluctuations in height of the ice. Less obvious, but nevertheless apparent, are the indications of the time which has elapsed since the higher levels were abandoned by the shrinking glacier. Clearly defined zones of vegetation, in different stages of development, are the most easily seen indices of the age of the various levels, although they are frequently complicated by factors other than those directly associated with the ice. The vegetation zones range from bare rock and rock flour containing occasional masses of ice immediately

above the present surface of the glacier, to an ancient forest high on the upper slopes, and where slope conditions permit, the progression from tiny pioneer plants to large alders and spruces is readily observable (Fig. 2).

Conditions on both the south and north walls of the lower Norris gorge are similar, and on both, the highest level attained by the glacier in the recent past is marked by a striking trimline, accompanied, where slopes are not prohibitively steep, by a well-defined lateral moraine. The youthful forest immediately below the trimline is very different from that above, and smashed and broken stumps and trunks are still well preserved along the line of trim. These observations suggest that the ice stood at this high level recently, probably within the present century. Subsequent investigations support this idea. Cores and, in the case of small trees, sections were taken from trees on both sides of the trim on the slopes above the northern and southern sides of the glacier. The results were essentially the same. Below the trimline, the oldest tree discovered, growing on the lateral moraine 400 feet above the present ice level, was 40(2) years old. If this age plus five, to permit establishment as a seedling, is the number of years that has elapsed since the ice retreated from the trimline, the ice must have stood at the level of the trim as recently as 1906.

More accurate dating of the maximum represented by the trimline was made possible by the discovery, on the slopes overlooking the southern edge of the present glacier terminus, of a living Alaska yellow cedar, within 10 feet of the trimline, that had been pushed by the ice and/or morainic material and tilted to an angle approximately 80° from the vertical. The fact that this cedar was lying between two logs still partially embedded in the moraine precluded the possibility that some other agent could have tilted the tree. A section from this yellow cedar showed that it had been severely damaged in 1910, and that differential growth as a result of tilting began in 1920. As descriptions of the Norris mention a high ice level in the late 1800's and early 1900's, the trimline evidence merely confirms the historical record. Analysis of cores from trees growing on the outer side of the trimline, however, revealed an additional and highly significant fact—that the 1910 maximum was probably higher than any the glacier attained since approximately 1200 A.D. This is deduced from the age, 473(300) years, of a huge spruce growing within 10 feet of the tilted yellow cedar, and from the advanced ages of other spruces and hemlocks growing adjacent to the trim that were also cored.

This early twentieth century maximum of the Norris is apparently unique among the glaciers of the Juneau Ice Field which have so far been studied, although relatively minor advances at this period have been noted elsewhere. It is possible that the Norris had a mid-eighteenth century maximum and that instead of retreating rapidly the ice maintained its high level until approximately 1900, when a relatively minor advance and/or thickening formed the trimline described. Little evidence for this exists, with the possible exception of a trimline in a tributary valley occupied by "Glory Lake" (Fig. 1). The slope between the lake and the trimline, 310 feet above, is covered with shrubby willows and alders. The complete lack of tree stumps or trunks shows that no



Photo: W. O. Field

Fig. 3. "Glory Lake" 1926. View southwest from point above the lake outlet, close to Norris Glacier.



Fig. 4. "Glory Lake" 1953. Trimline above the western shore is less clearly defined and shrubs are growing on moraine in foreground.

forest has existed here for hundreds of years. A possible explanation is that the lake was dammed by the ice of the Norris Glacier when it advanced into the mouth of the tributary valley during the 1910 maximum. It is, however, impossible to be sure that the 1910 ice dammed the lake to the height of the apparent trimline as a wall of ice could have entered the valley mouth without raising the level of the lake. A photograph of the outlet of "Glory Lake" by William O. Field proves that the lake was not ice-dammed in 1926 and the treeless zone above the western shore of the lake was even more clearly defined than at present (Figs. 3 and 4); this suggests that the lake covered the treeless area only a few years before this photograph was taken.

If one accepts this theory of an ice-dam raising the level of the lake to the height of the apparent trimline, the complete absence of water-killed forest must still be accounted for. One answer is that the ice-dam persisted long enough to complete the destruction of the drowned forest. It seems unlikely that the trimline was formed by Norris ice advancing far up the valley, since the trim of the 1910 maximum is accompanied by a lateral moraine which can be traced into the mouth of the tributary valley, crossing it within a few feet of the northern extremity of the lake.

The alternative, that the absence of forest and forest remnants from the treeless zone is due to a high lake level maintained by an ice-dam for a very long period supports the theory that the Norris Glacier stood at or near the line of the 1910 trim for a great length of time. If valid, this introduces many problems, among which is the question of why the Norris Glacier was not affected by a major recession in the nineteenth century. Further investigations of "Glory Lake" and its trimlines may contribute significant information on the recent behaviour of the Norris.

Since the location of the termini of the Taku Valley glaciers at different periods has been a matter of considerable speculation, an attempt was made to determine the position of the Norris terminus during the recent maximum. The lateral moraines which accompany the trimline of the 1910 maximum were traced down to the well-defined terminal moraine a short distance beyond the present terminus. They show that although the ice then stood more than 400 feet higher less than a mile from the present ice front, the terminus was only $\frac{1}{4}$ to $\frac{1}{2}$ mile farther advanced than today. The abrupt descent of the lateral moraine indicates that the gradient of the ice surface near the terminus, during the maximum, must have been steep.

Taku Glacier

The lower Taku was not investigated as thoroughly as the Norris, although several important details concerning its recent maximum were established. Particularly significant was the determination of the height of the maximum near the present terminus, and confirmation that the maximum occurred in the mid-1700's.

Forest conditions above the lower Taku ice contrast strongly with those adjacent to the Norris. Instead of recently deglaciated terrain, with vegetation ranging from a few pioneer species upwards to substantial but never-

theless youthful trees, the southeastern slopes of lower Norris Ridge are mainly covered by a forest of trees so big that cursory examination alone suggests they are very old. Actually this is a first generation forest, in spite of the great size of the trees (Lawrence, 1950a, p. 209).

In a preliminary reconnaissance, the writer observed an old lateral moraine more than 500 feet above the Taku terminus with similar large trees on and below it. Subsequent measurements revealed that the forest below the moraine was also first generation and that none of the trees exceeded 250 years in age in spite of their massive girth. The moraine was, therefore, formed during the recent maximum of the Taku.

The lateral moraine is for the most part prominent and well-defined, and so large that the ice must have remained at that height for a great length of time (Fig. 5). The moraine can be traced for a considerable distance, but on the slopes above the present terminus of the Norris it becomes inconspicuous and can no longer be recognized, and attempts to trace it as far as the 1910 trimline of the Norris failed. Why the moraine disappears at this point is not known, although the increasing steepness of the slope may be one cause.

The moraine descends slowly towards sea level; for the distance it was followed it declined at roughly 100 feet per mile. At its southernmost extremity, where it was last recognized, it is approximately 400 feet above the outwash plain of the Norris. If the line of the moraine is projected farther south, allowing for a decrease in elevation at the observed rate, it should reappear at an altitude of approximately 275 feet on the slopes above the Norris outwash, south of the Norris terminus. Careful investigation of this area disclosed no moraine at or near this elevation, nor was there any trace of a trimline, although cores from the largest trees growing on the lower slopes indicated they were less than 200 years old.

The age of these trees, however, cannot be considered conclusive evidence that the Taku reached these slopes during its maximum, nor can a uniform descent of the line of the moraine be assumed. In fact, conditions on the Norris, where lateral moraines descend abruptly and precipitously near the terminus, suggest that the opposite might have been true, and that the gradient of the swollen mid-eighteenth century Taku near its terminus might have been extremely steep. It is, therefore, possible that although the ice of the Taku stood more than 500 feet above the present terminus approximately two centuries ago, the glacier might have been only slightly farther advanced than it is today. This is contrary to the opinion expressed by Lawrence (1950a, p. 209).

The eastern shore of Taku Inlet was visited both above and below Taku Point to collect additional information and to examine the evidence cited by Lawrence for a mid-eighteenth century advance to Taku Point. This evidence consisted of "two fragments of what appear to be moraine ridges south of Taku Point, a forest trimline that stands 100 to 150 feet above tidewater on Taku Point, against which Norris Glacier must have pushed, and a heavily scoured region between that trimline and the inlet, over which the Taku River must have flowed when the tip of the ice dam rested there" (Lawrence, 1950a, p. 208).

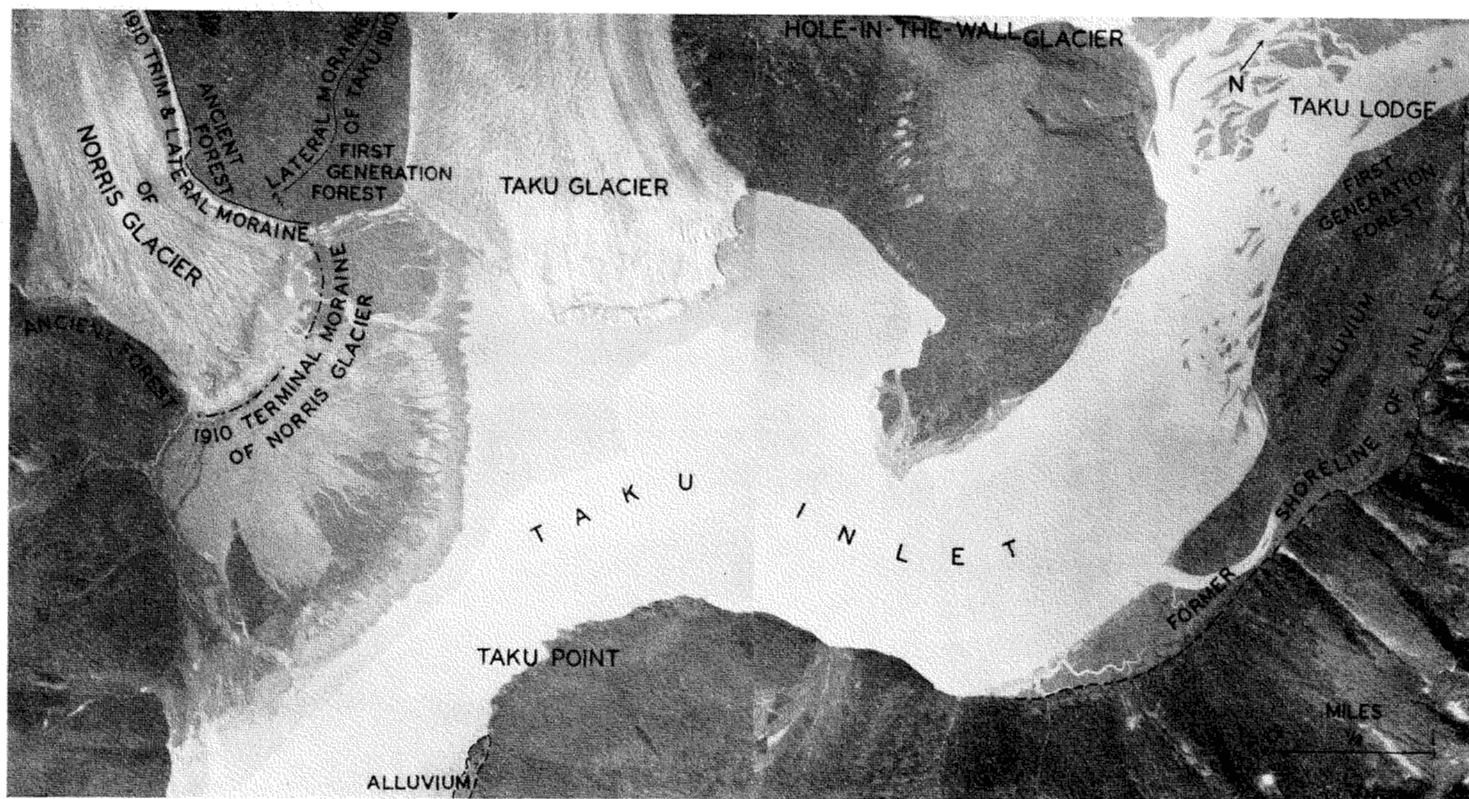


Fig. 5. Norris and Taku termini, Taku Inlet. 14 August 1948.

Photo: U.S.N.

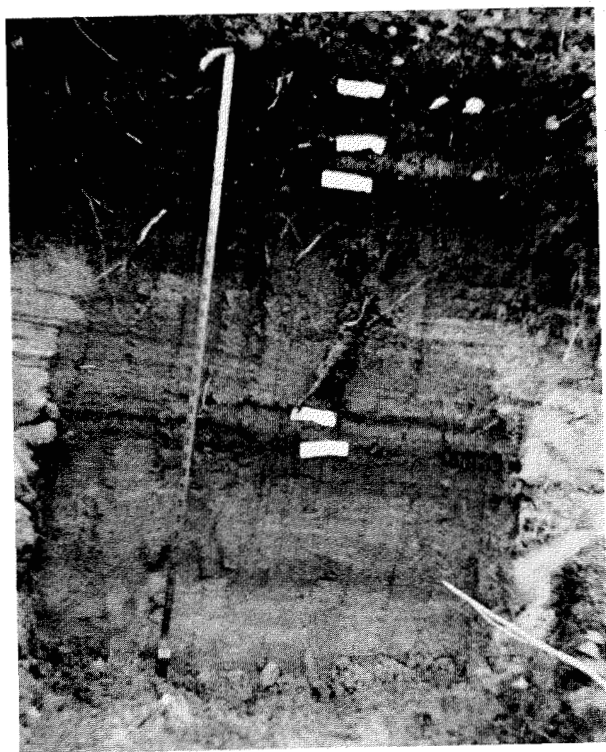


Fig. 6. Fresh profile in alluvium on east shore of Taku Inlet, south of Taku Point. Layers of organic material are indicated, and rule is extended approximately 3 feet.

The two forested areas south of Taku Point—the apparent moraine fragments mentioned by Lawrence—were found to be alluvial or marine deposits apparently laid down when sea level was considerably higher than at present (Fig. 5). The material is well stratified, with the individual layers ranging from extremely fine sand to coarse gravel. Five distinct strata containing much organic material also occur within 2 feet of the surface (Fig. 6). The deposits are covered by a youthful forest in which most of the trees are less than 100 years old, and the oldest cored contained only 104 annual rings.

These forested flats south of Taku Point are remarkably similar, in both stratigraphy and topography, to the much more extensive level area on the eastern shore of the inlet south of Taku Lodge (Fig. 5), where currents and storm waves are actively cutting back the shoreline. There are many excellent exposures showing clearly defined strata of sand and gravel of varying coarseness, with individual pebbles up to 2 inches in diameter. The area is not as level as a view from the air or from the inlet suggests; very low ridges and winding depressions are numerous, particularly in the southern portion of the plain. The surface is generally sandy, in some places so much so that tree growth is prohibited or severely limited. A dense but youthful forest covers most of the northern part and counts of growth rings on cut stumps indicate that most of the trees are less than 100 years old; the largest tree observed contained only 115(30) rings. The trees on the flats both north and south of Taku Point are, therefore, similar in age.

According to Lawrence, a lake, formed when a dam of glacial ice blocked the inlet at Taku Point, covered the flats south of Taku Lodge near the middle of the eighteenth century (1950a, pp. 209–11). No evidence for such a lake was found, and the lack of identifiable lake silts or clays in or above the deposits described, and the irregular topographic features, indicates flood plain deposition.

The similarity of the deposits north and south of Taku Point suggests a common origin, and the uniformity in the age of the tree cover of each indicates that they were formed at the same time. Although the evidence is not conclusive, the deposits are apparently remnants of alluvium which formerly choked the upper part of the present inlet. As the sea level was lowered relative to the land deposition ceased and erosion has since removed most of the material.

Higher sea levels in the past might also account for the scoured appearance of the rocky slopes up to 150 feet above present sea level, which are especially conspicuous above the western shore of the inlet. Lawrence ascribes the relative barrenness of the lower slopes of Taku Point to glacial scour, but since these conditions are evident along the shores of the inlet far south of Taku Point, the writer considers that some other factor is responsible. Abundant evidence has been obtained indicating that much higher sea levels have occurred in postglacial time along the coasts of southeastern Alaska (Twenhofel, 1952, p. 523–48) and a lowering of 150 feet is by no means improbable.

It is difficult to estimate when the lower, "scoured" slopes emerged, and the alluvial deposits first stood above high tide. The age of trees on the lower slopes cannot provide significant data, since the time required for tree growth to be established after emergence is not known. A section from a stunted spruce growing in a rock chimney less than 100 feet above present high tide, showed the tree to be 222 years old; this is a minimum figure, and the actual time since emergence must be greatly in excess of this. On the alluvial flats, once the water table was sufficiently lowered, conditions would be much more favourable for a relatively rapid establishment of seedlings, and therefore, here the age of trees can be considered a more reliable index of the date of emergence. The oldest tree discovered on the alluvial flats on the eastern shore of the inlet contained 115(30) rings, which suggests that the sea covered the flats until recently—perhaps as little as 200 years ago.

All the evidence discussed so far indicates that Taku Glacier failed to reach the eastern shore of the inlet during its recent maximum, and that changes in sea levels are responsible for features formerly attributed to glaciation. This conclusion is particularly important in attempting to forecast the limit of the present advance of the Taku. The rapid advance of the glacier since 1900 suggests that it might, in a few years, reach Taku Point, a circumstance which would obviously be of considerable significance to any future developments in the Taku Valley.

In the mid-eighteenth century Taku had not reached the eastern shore of the inlet, although it then stood more than 400 feet higher on Norris Ridge

than it does at present. If the assumptions presented above concerning the location of the 1750 terminus are correct, it is probable that the ice front has already reached its maximum position, and that an enormous thickening of the entire system would be necessary before the ice could advance across the inlet.

The field work on which this paper is mainly based was carried out under the auspices of the Juneau Ice Field Research Project, directed by the American Geographical Society and sponsored by the Office of Naval Research. The author wishes to express his appreciation to these and other cooperating organizations, to the members of the 1953 J.I.R.P. party, and to Professor Kirk H. Stone, Department of Geography, University of Wisconsin. Special thanks are due to Richard Pierce, field associate of the writer, who analysed all the tree sections and cores obtained in the field.

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