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GLACIATION IN ALASKA

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INTRODUCTION

The history of glaciation in Alaska offers a fascinating field for study. Because of the remarkable development and easy accessibility of valley and piedmont glaciers in the coastal mountains, Alaska has long been popularly conceived as a land of ice and snow, a concept that is only slowly being corrected. To the student of glaciation, however, Alaska affords a unique opportunity to observe the formation, movement, and dissipation of the many living glaciers, to examine the results of glacial erosion on a gigantic scale, and to discover and work out the sequence of Pleistocene events as shown by the topographic forms in both glaciated and unglaciated areas and by the deposits left by ice and water during earlier stages of glaciation.

The evidence for successive glacial advances in many parts of the world during Pleistocene time has been largely obtained in regions not far from the outer margin reached by the glaciers during the different stages. This is necessarily so, for that evidence consists mainly of the superposition of till deposits and their relations to one another, to preglacial, interglacial, and postglacial deposits, and to outwash materials laid down beyond the ice edge. Morainal deposits are best developed near the margins of glaciated areas, and it is therefore in such areas that observations having a significant bearing on recurrent glaciation are most likely to be made.

Alaska would thus seem to be a promising region for the study of the events of Pleistocene time. The Territory lies just west of the border of the great continental ice sheet, and although it was never itself overridden by glaciers of the continental type, its climate so closely approached that necessary for continental glaciation that all the higher mountain masses were severely glaciated. From the coastal mountains along the entire Pacific littoral of Alaska [1] glaciers descended to the sea. There, unfortunately, the evidence of the limits reached by the ice edge, as displayed by moraines, is submerged and not available for direct examination. Interior Alaska, on the other hand, presents a great driftless area, in the basins of the Yukon, Tanana, and Kuskokwim Rivers, where low relief and dry climate prohibited the formation of glaciers. This unglaciated region was encroached upon by the continental ice sheets from the east and by mountain glaciers from the north and south. Along its margins at several localities there have already been found evidences of glacial advances preceding the last great glaciation, and it seems certain that future studies will bring additional observations that will shed much light on the glacial history of the continent.

There is an extensive literature on glaciation in Alaska, yet in view of the great area of the Territory, the number and size of its living glaciers, and the extensive area covered by ice during Pleistocene time, it must be confessed that little more than a beginning has been made toward an adequate understanding of its glacial history. Each year since 1898 there have been a number of Geological Survey parties in the field, engaged for the most part in reconnaissance or exploratory surveys, with the result that about half the Territory has been mapped, and a fair knowledge of the extent of glaciation in the surveyed areas has been obtained. Many descriptions of living glaciers have also been published, and Tarr and Martin, as the result of three years of study under the auspices of the National Geographic Society, prepared an imposing volume [1a] that deals largely with the living glaciers along the Pacific coast and the lower Copper River. The literature is widely scattered, however, and it seems worth while to review our present knowledge of the subject. The details of mapping, as shown in the illustrations presented herewith, are in large part taken from the observations of members of the Alaskan branch of the Geological Survey.

EXISTING GLACIERS

Existing glaciers in Alaska cover an area of less than 20,000 square miles, or slightly more than 3 per cent

[1] As used in this paper the term "Pacific" does not include Bering Sea.

[1a] Tarr, R. S., and Martin, Lawrence, Alaskan glacier studies, 498 pp., Nat. Geog. Soc., 1914.

of the total area of the Territory. Plate 1 shows the largest of these glaciers, but there are probably several thousand small glaciers, from a fraction of a mile to several miles in length, that lie in unsurveyed areas or are too small to be shown on a map of this scale. The glaciers are almost exclusively confined to the coastal mountains, the Wrangell Mountains, and the Alaska Range. This distribution is in large part a response to high topographic relief but in part also to heavy precipitation. The coastal mountains reach altitudes of 15,300 feet at Mount Fairweather, 18,008 and 19,850 feet at Mounts St. Elias and Logan, and 6,000 feet in the southern part of Kenai Peninsula. The Wrangell Mountains have many peaks of 12,000 to 14,000 feet, and the more heavily glaciated portions of the Alaska Range reach 10,000 to 11,050 feet near Mount Spurr, 13,740 feet at Mount Hayes, and 20,300 feet at Mount McKinley. In the Brooks Range few peaks reach altitudes of more than 8,000 feet, with a possible maximum of 10,000 feet. The most active centers of glaciation to-day are therefore in places where high mountains lie within areas of heavy rainfall, as along the coast. High mountain areas of moderate rainfall are represented by the Wrangell and Talkeetna Mountains, which carry less extensive glaciers, and by the Alaska Range. The fairly high mountains of the Brooks Range, lying in a belt of scanty precipitation, have only a few small glaciers. That the extent of glaciation in past times was strongly influenced by the amount of rainfall, as it is to-day, is certain, and a realization of that fact is important to the understanding of the peculiarities of ice distribution during the last great ice advance in Pleistocene time.

For size, accessibility, and beauty the coastal glaciers of Alaska are in many ways unique. They have been studied by many competent geologists, and much has been written about them. Data concerning their movements are rapidly accumulating, and during the summer of 1929 the lower portions of nearly all the larger glaciers of southeastern Alaska were photographed from the air. These photographs will prove invaluable for the purpose of checking future changes in the positions of the ice fronts. Any adequate description of the hundreds of imposing glaciers of Alaska is far beyond the scope of this paper, but it should be kept in mind that the glaciers of to-day are but the shrunken remnants of the much greater glaciers of the past, that they have probably existed continuously from Wisconsin time to the present, and that many high valleys may have been continuously occupied by ice since early Pleistocene time.

FORMER GLACIAL ADVANCES

Plate 1 shows the areas in Alaska covered by glacial ice during the last great ice advance. During the time of maximum glaciation there were in Alaska two major areas of glaciation and many smaller ones. The largest area includes the Pacific coastal region and embraces all of southeastern Alaska, the Chugach, Wrangell, Talkeetna, and Kenai Mountains, the Alaska Range and its southern extension into the Alaska Peninsula, and the great basins of the Copper and Susitna Rivers and upper Cook Inlet. Next in size was the great glacier that occupied the entire Brooks Range, in northern Alaska. The other areas in which glaciers occurred are scattered throughout central and southwestern Alaska and Seward Peninsula, and all are small.

The great ice mass that occupied southern and southeastern Alaska, though connected toward the east with the continental ice sheet, was entirely independent of that sheet as to its source of ice supply, the directions of ice movement, and its persistence. It was fed solely by glaciers that had their origin within its own area, and its lines of flow were directed by the mountain topography within that area. Throughout Alaska as a whole the balance between temperature and precipitation was such that glaciers could form and grow only in the higher mountains, and even there the size and vigor of the glaciers depended in large degree upon the abundance of precipitation. The distinction, therefore, between the Alaska glaciers and the contemporary continental glaciers in former stages of ice expansion was that in Alaska each of the larger glaciers was formed by the coalescing of a great number of individual valley glaciers, each of which responded to the accretion of ice within its own basin and moved down its own mountain valley in a way that was largely independent of the movement of its neighboring ice streams. It was only because these adjoining mountain glaciers grew to so large a size that they coalesced to form nearly continuous ice caps. Even at their maximum, however, there were high peaks and dividing ridges that separated them from one another, and it was only in those places where the individual ice streams emerged from the mountains onto the lowlands that they joined and lost their individuality.

In Plate 2 an attempt has been made to show the lines of flow in the two larger glaciated areas. The arrows indicate the direction of flow of various threads of ice within the areas where the ice formed a practically continuous cap, with only the highest peaks and ridges projecting above its surface. The dotted lines indicate the divides between the glaciers that moved south and those that moved north and west.

In southeastern Alaska, south of Cross Sound, the threads of flow had in general a southerly direction, being influenced by the preglacial topography, which in turn was determined by the trend of the rock structure. I know of few more striking physiographic features than the great fiord formed by Chatham Straits and Lynn Canal, cutting obliquely across a rugged mountain region in a straight line for 250 miles. The riddle of this great fiord has not yet been entirely solved, but it is known that a great preglacial structural valley was widened, deepened, and straightened by ice scour and that faulting had much to do with the establishment of the preglacial drainage lines.

On the southern slope of the St. Elias, Chugach, and Kenai Mountains the ice threads in general followed direct courses to the sea. On the inland slopes more complex flow patterns were developed. Between the arc of the Chugach Mountains, which form a barrier along the coast, and the great curve of the Alaska Range, farther north, there is a region of milder relief containing the basins of the Susitna and Copper Rivers but broken by two separate mountain groups, the Wrangell and Talkeetna Mountains. Into these basins ice poured down from all the surrounding highlands and from the Wrangell and Talkeetna Mountains as well, until the lowland was filled with ice that sought outlets through the gaps that offered themselves. The lowest outlet to the coast was by way of the Susitna Basin, toward which most of the threads of flow converged, but at the time of maximum ice development lobes spilled over the basin margins into the valleys now occupied by the Copper, Nenana, and Delta Rivers, through Mentasta and Suslota Passes, and probably also into the valley of the Nabesna River by way of Jack and Platinum Creeks. Through the rim of the intermontane basin these overflow lobes eroded deep valleys, which were later utilized by the draining streams of the glaciers as the ice shrank in retreat. This eventually resulted in the capture, by the Copper, Nenana, and Delta Rivers, of drainage areas within the intermontane basin, and we now have the unusual condition of rivers draining mature headward basins through youthful canyons carved directly across high mountain ranges. Although the Copper River now drains a large area between the Chugach and Alaska Ranges, it is quite evident, from the topographic youth of the part of its valley cut through the Chugach Mountains as compared with the maturity of the part north of the coastal range, that the drainage discharge from the upper basin of the river formerly found some other course to the sea. That course doubtless was by way of the Susitna Basin and probably lay north of the Talkeetna Mountains. The working out of this great change of drainage has been complicated by Pleistocene or post-Pleistocene warping, and the details are not yet known.

Another anomaly occurs at the head of the Delta River, which has its origin in a large glacier. That glacier lies on the south slope of the Alaska Range and would normally be expected to drain to the Copper River. The Delta River has built up a gravel train that splits, a part sloping southward toward the Copper River and a part draining into the Delta, which flows northward through a narrow glacial valley directly across the Alaska Range to empty into the Tanana River. The waters from the melting Delta Glacier therefore flow at times by way of the Copper River to the Pacific and at times by way of the Yukon tributaries to Bering Sea. On occasion the stream splits, part flowing one way and part the other, so that a salmon could conceivably ascend the Copper and Gulkana Rivers, enter the head of the Delta, and descend to Bering Sea, crossing a great mountain range on the way.

In Plate 2 the dotted line indicates the divide between the ice streams that drained to Bering Sea and those that sent their waters to the Pacific. In a general way this divide follows the crest of the Alaska Range. As plotted it ignores the ice spillways through the range at the passes noted above, as it is impossible to estimate how large an area of the ice in Copper and Susitna Basins drained northward through these passes. For a part of the way the ice divide follows the crest of the Wrangell Mountains, whose northward-flowing glaciers crossed the Nutzotin Mountains through the canyons of the Nabesna and Chisana Rivers.

A striking fact is the meager development of the Pleistocene glaciers on the north side of the Alaska Range between the Tonzona River and Mentasta Pass as compared with those on its south side. This same discrepancy is shown by the glaciers of to-day. It is due in part to the asymmetrical position of the crest of the range. On the north slope the mountains rise steeply from the lowlands to the summit peaks, and the belt of high mountains in which ice accumulation can take place is narrow. Furthermore, the mountain glaciers within a few miles of their source move out into a relatively low, arid lowland, where dissipation is rapid. By contrast, the mountain belt on the south side of the range is wider from the divide to the lowlands, there is a greater area for ice accumulation, and the basins into which the glaciers emerge are higher and less arid. A second fact, perhaps of equal importance, is the difference in the amount of precipitation on the two slopes. No accurate records are available for points on the mountain slopes, but throughout the Susitna Basin as a whole the average precipitation is several times as great as in the Tanana Basin. The winds that strike the Alaska Range from the west have already passed over several hundred miles of dry, rolling country and have lost a considerable part of their moisture content. The moist winds from the Pacific, on the other hand, blowing up Cook Inlet, are trapped between high surrounding mountains and drop much of their moisture on them.

The great ice cap that covered the Brooks Range was likewise independent of the continental ice sheet in supply and in direction of movement. It may or may not have been connected with the continental sheet near the mouth of the Mackenzie River. The Brooks Range lies in a difficultly accessible part of

Alaska, and the geologic studies made there have all been of reconnaissance or exploratory character, so that many details of its glacial history are yet unknown. The outline of the glaciated area as shown on Plate 2, however, is believed to approximate the truth. Like the great ice cap to the south, this one was composed of numerous valley glaciers which flowed out radially from the mountains but which at the time of their greatest extent filled adjoining valleys and coalesced to form a nearly continuous ice cap, above whose surface only the highest summits projected. In general, the southward-flowing ice threads appear to have been longer than those that flowed to the north. The direction of flow of each thread was entirely controlled by the topography of its mountain valley.

Between the northern and the southern ice caps have been found about a score of localities in which glaciers of minor extent existed during the time of the last great ice advance. All but one or two of these places consist of a high mountain or group of mountains upon which one or two small valley glaciers were able to form during the period of maximum glaciation. These glaciers were comparatively short-lived and have now disappeared entirely. A single area of considerable size is that lying between Bristol Bay and the lower Kuskokwim River, where such scanty information as is at hand indicates a center of notable mountain glaciation.

Plates 1 and 2 portray the distribution of glaciers in Alaska during the Wisconsin glacial stage in so far as they covered land areas. An interesting but more difficult problem is that of determining how far the ice of southern and southeastern Alaska pushed out to sea at that time. An examination of maps of the Antarctic ice cap and the adjacent ocean basins shows that the ice barrier there, in places where its face is 50 to 80 feet high and its thickness therefore not more than 400 to 600 feet, projects out into oceans that are as much as 2,000 feet or more deep. The glacial ice therefore projects as an overhanging shelf far out over deep water, although still firmly attached to the landward portion of the glacier.

On the Pacific coast of Alaska there is abundant evidence that during Wisconsin time glaciers pushed out to the open sea at many places. Even now the great piedmont lobes of Malaspina and Bering Glaciers extend close to the open coast, and very little expansion would be necessary for them to advance to the sea. Similarly many glaciers between Cross Sound and Yakutat Bay, as well as many ice tongues in southeastern Alaska, Prince William Sound, and Kenai Peninsula now extend almost or quite to tidewater. Any increase in size of the glaciers along the coast comparable to that which took place elsewhere in Alaska in Wisconsin time would have caused hundreds of glaciers to push their snouts out to sea and there to expand and coalesce into an ice barrier comparable to that now found along the borders of the Antarctic Continent. It seems to me very likely that such a barrier did exist. Plate 2 indicates the position of the 100-fathom contour along this coast. At most localities where large valleys emerge at the coast there are deep channels across the continental shelf, such as those between Afognak Island and the mainland of Kenai Peninsula; at the entrance to Prince William Sound between Hinchinbrook and Montague Islands; and at Yakutat Bay, Cross Sound, Christian Sound. Iphigenia Bay, and Dixon Entrance. The formation of these channels seems to demand some strong erosive force, and glacial ice is known to have moved out from shore at many if not all of these places. Tarr and Martin [2] concluded that no ice more than 400 feet thick issued out to sea between Hinchinbrook and Montague Islands, basing this conclusion upon the height to which they found erratic boulders on the south end of Hinchinbrook Island. They also concluded that ice passing southward along the west shore of Montague Island barely issued into the open sea. I am inclined to doubt the validity of their conclusions on these points. A study of the glacial smoothing on the south end of Hinchinbrook Island, as seen from a ship passing into Prince William Sound, seems to indicate rather distinctly that ice scoured the south end of that island to a height of several times 400 feet, at least. The 100-fathom channel extending southward from that entrance certainly suggests glacial erosion of the bottom, and reported deposits of glacial till and boulders on Middleton Island indicate the possibility that ice pushed out some 60 miles to sea across the shoal within the 50-fathom line, shown on Plate 2.

At a great number of places within the glaciated areas of Alaska observations have been made as to the thickness reached by the ice during the time of maximum Pleistocene glaciation. This information is difficult to show on maps of the small scale necessary for publication here, but the glaciated mountain forms, hanging valleys, erratic boulders, and many other accepted types of evidence indicate convincingly that valleys now free of ice held in Wisconsin time glaciers 5,000 feet and more in thickness, and it seems reasonable to believe that over the entire glaciated area, as shown in Plate 1, the Wisconsin ice had an average thickness of half a mile.

EVIDENCE OF WISCONSIN AGE OF LAST GREAT ICE ADVANCE

It has been assumed in the foregoing pages that the last great ice advance in Alaska was contemporaneous with the Wisconsin stage of glaciation in the northern United States. There is evidence of several kinds to support this assumption. The uneroded character of morainal deposits, which still show kettle and hummock topography little modified by postglacial ero-

[2] Tarr, R. S., and Martin, Lawrence, Alaskan glacier studies, p. 469, 1914.

sion; the abundance of polished and striated rock surfaces and erratic boulders in a region where exfoliation and weathering are rapid; and the unoxidized character of the glacial till all point to a relatively recent date for the last great glaciation. All such evidence indicates comparative youth but is not sufficient to assign to these phenomena an age stated in years.

In the basin of the White River, near the international boundary, however, excellent exposures along a newly cut river bluff reveal evidence that makes it possible to date rather accurately the time of the glacial retreat past that place.[3] The locality is not far from the source of the river in Russell Glacier. This glacier is a large and vigorous ice stream that draws its ice supply from the high mountains of the Wrangell and St. Elias group. It may fairly be considered an average example of the glaciers of that region, and its history must have been much the same as that of similar glaciers in that part of Alaska.

About 8 miles below Russell Glacier, on the north bank of the White River, that stream has cut a bluff over a mile long and 50 to 70 feet high. A typical section there exposed is shown in Figure 1. At the base of the bluff is 30 feet of unconsolidated and unoxidized glacial till, with an uneven, rolling surface. Above the till and extending to the top of the bluff is 39 feet of fibrous, peaty vegetable material, full of spruce stumps and roots but composed for the most part of the remains of sphagnum moss. This heavy deposit of peat is interrupted, some 7 feet below the top of the bluff, by a 2-foot layer of white volcanic ash. The surface of the bench, back from the bluff, is covered with living sphagnum moss and a dense forest of spruce trees. At the time of visit, in July, till, peat, and ash were frozen within a few inches of the surface along the face of the bluff, and in the forest permanent ground frost was found 6 inches

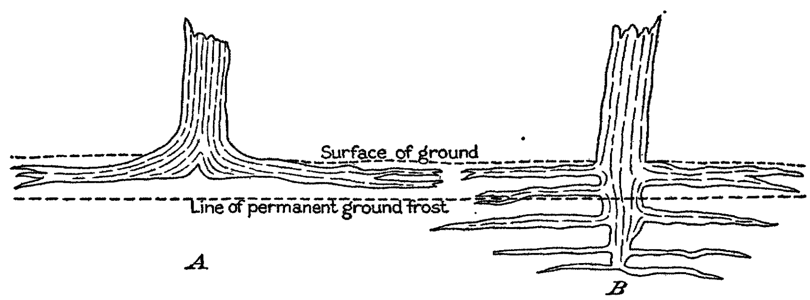

FIGURE 2.—Diagrams showing the character of the roots of a spruce tree (*A*) growing normally on solid ground and (*B*) growing on rapidly forming peat, White River, Alaska

beneath the surface of the growing moss. The cut bank has a vertical to overhanging face, and erosion takes place by the formation of great, clean vertical cracks through the frozen peat and the falling outward of large tree-covered blocks, which tumble down to the stream level and are gradually thawed and removed.

The peculiar appearance of the roots of the spruce trees that grow on the edge of the bluff and of the stumps that occur through the peat deposit suggested that it might be possible to determine approximately

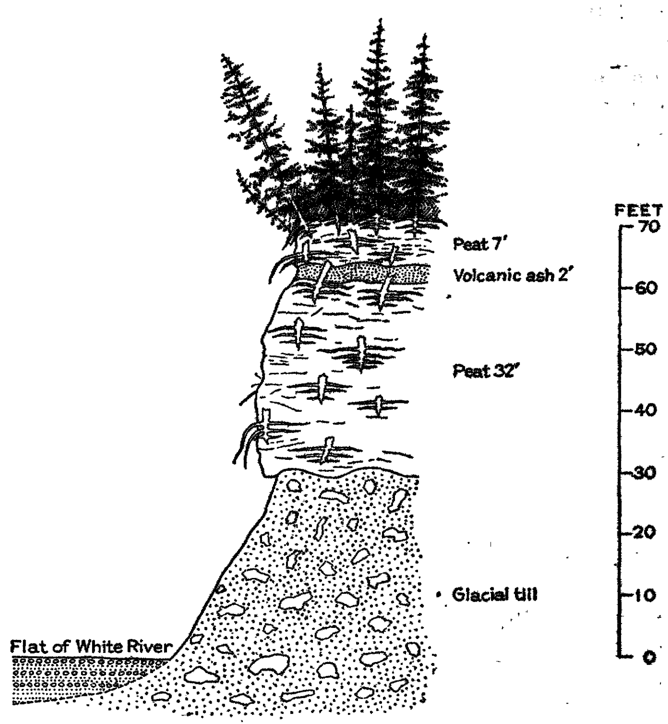

FIGURE 1.—Typical section of peat and glacial till on the White River, Alaska, 8 miles below the terminus of Russell Glacier

the rate of accumulation of peat at this place and so determine the time that has elapsed since the ice withdrew from its moraine here and thus permitted reforestation. The ordinary spruce tree, growing on solid ground, either frozen or unfrozen, sends its roots out radially, parallel with the surface of the ground and only a few inches below the surface. (See fig. 2.) Uprooted stumps of this kind are a familiar sight. In the White River locality here described, however, the roots of the spruce trees, both those growing at the edge of the bluff, or recently overturned, and those deeply buried within the peat mass, show quite different characteristics. Instead of a single, flat-based set of radial roots, each of these trees shows a central stem, a sort of taproot, from which radial roots branch off at irregular intervals, with an upper set of roots near the surface corresponding to those of the normal tree. Around the living trees the ground was frozen 6 inches below the top of the moss. Below the frost line the roots were sound and undecayed, but they were of a darker color than the live surface roots and were apparently not functioning. It is evident that the living tree derives its nourishment from the ground only

[3] Capps, S. R., The Chisana-White River district, Alaska: U. S. Geol. Survey Bull. 630, pp. 69–75, 1916.

through the roots in unfrozen ground near the surface, and that the lower roots cease to function as soon as the line of permanent frost rises above them.

From the facts stated above it appears that a seedling spruce, having established itself on the mossy soil of this area of rapidly accumulating vegetable material, sent out a set of radial, flat-based roots in the ordinary way, but the constantly thickening moss and the consequent rise in the level of ground frost cut off the food supply from the lowest roots and forced the tree, in its efforts to survive, periodically to throw out new sets of roots into the unfrozen surface soil. If these premises are correct, then the vertical distance between the lowest set of horizontal roots of a living tree and the surface of the ground represents the thickness of the peaty accumulation during the lifetime of the tree, and the rate of accumulation can be determined by ascertaining the age of the tree, as shown by the annual rings.

Any figures for the rate of accumulation of the peaty deposit that were obtained in the way outlined are subject to a number of uncertainties. Most of the qualifying factors, however, fall on the side of conservatism and result in a minimum rather than a maximum figure. Among the unweighed factors is the possibility that the peaty material is compressed after burial. The amount of such compression, however, is probably very small, for the peat is permanently frozen within a foot or less of the surface and has remained so since its formation. Another factor that might affect the rate of accumulation is the quantity of wind-blown sand, which is noticeably present near the edge of the timbered bench. Throughout the deposit as a whole, however, the percentage of wind-blown material seems to be fairly uniform. Other elements of uncertainty appear to be of so small importance as to affect the calculation but little.

From ring counts on a number of trees and from measurements of the distance between the lowest and uppermost radial roots on the same trees, it was determined that the peaty material is now accumulating at a rate of about 1 foot in 200 years. It seems that this factor may be safely applied to the whole thickness of 39 feet of peat, from which we arrive at a figure of 7,800, or, in round figures, 8,000 years since the ice of Russell Glacier withdrew beyond this point. Even if this figure is admitted to be 50 per cent in error, it still gives a basis for calculation.

At the time of its maximum extension Russell Glacier, according to Hayes, extended northeastward about 130 miles beyond its present terminus. Its retreat to the peat deposits described above, which lie about 8 miles below the end of the present glacier, was therefore 94 per cent of its total retreat. So far as time is concerned, it is quite possible that the glacier retreated much more rapidly during the earlier stages of shrinking than during the later stages. For the last 35 years the ice edge has remained practically stationary.

Various estimates have been made of the length of time since the Wisconsin continental ice sheet began its retreat, but the consensus of opinion seems to place that time as somewhere between 30,000 and 60,000 years. The determination made in the White River Valley, at a point that was not bared until a large part of the retreat had been accomplished, is of the same order of magnitude, and it seems safe to say that the last great ice advance in Alaska was contemporaneous with the late Wisconsin continental glaciation.

PRE-WISCONSIN GLACIATION

As the last great glaciation in Alaska is thus regarded as of late Wisconsin age, the question arises as to what were the conditions in this region during the earlier stages of Pleistocene glaciation elsewhere on the continent. Information on that question must be sought mainly in the superposition of glacial and interglacial deposits, and in a frontier country where road, railroad, and other extensive excavations are few and where little more than a beginning has been made in the study of such subjects, facts that bear on this problem come to light only infrequently. Furthermore, there is evidence in Alaska, where the Pleistocene glaciation was almost entirely mountain glaciation, that the last ice advance was more vigorous than the earlier ones, with the result that the last glaciers destroyed much of the evidence of the work that may have been done by their predecessors. Nevertheless, at several localities evidence has been found of Pleistocene glaciation that antedated the ice of the Wisconsin stage. (See pl. 1.)

On the southern flanks of the St. Elias Mountain mass there occurs in the Chaix Hills, as described by Russell,[4] and in the Robinson Mountains, as described by Maddren,[5] a thickness of 2,000 to 5,000 feet of beds that are, in part, at least, of glacial origin, and that carry Pleistocene marine fossils. These beds are now uplifted to altitudes as great as 5,000 feet and are interesting in showing the active growth of the St. Elias Mountain mass. As evidence of a glacial stage earlier than the Wisconsin, however, they have less significance, and unless a more accurate determination of the age of the inclosed fossils can be made, their correlation must be vague. Both these ranges of hills lie within an area that is even now severely glaciated, and they are at least partly surrounded by the great piedmont ice lobes of Bering and Malaspina Glaciers. In other words, that area of high mountains is even now in a glacial period and may well have endured glacial conditions continuously since the beginning of the

[4] Russell, I. C., Second expedition to Mount St. Elias, in 1891: U. S. Geol. Survey Thirteenth Ann. Rpt., pt. 2, pp. 24–26, 1893.

[5] Maddren, A. G., Mineral deposits of the Yakataga district: U. S. Geol. Survey Bull. 592, pp. 131–132, 1914.

Pleistocene epoch or even longer. The glacial beds of the Robinson and Chaix Hills are therefore as likely to have been laid down during a time of small ice development as during a time of ice expansion and thus can not be correlated with any definite stage of Pleistocene glaciation.

Another locality at which evidence of glaciation antedating the Wisconsin has been found [6] is in the valley of the White River, 5 miles north of the snout of Russell Glacier. Foothills adjoining the main mountain mass of Carboniferous lavas and sediments show a section of more than 3,000 feet of tilted beds of glacial and glacio-fluvial origin. Ten distinct beds of tillite or of till were recognized, separated by beds of gravel and of finer clastic sediments. Most of the beds of till have been indurated to form hard tillite and have been etched into high relief by erosion. They contain abundant beautifully striated and faceted boulders, cobbles, and pebbles. In places the tillite was overridden and smoothed by glacial ice during the Wisconsin ice advance. It is, therefore, old enough to have been indurated, uplifted, and eroded before Wisconsin time. It is impossible, with the information now at hand, to correlate this older glacial material with any definite stage of Pleistocene glaciation. Indeed, there is no positive evidence that it is of Pleistocene age, though I am inclined so to assign it. Certainly it greatly antedates the Wisconsin stage. In view of the known activity of mountain growth in this part of Alaska, the uptilting could have occurred in Pleistocene time, and comparatively recent volcanism in this region, together with the stresses of tilting, may have resulted in the induration of some of the beds.

As regards the evidence from this locality in respect to the extent of the glaciation represented by those beds, no great extension of the ice from its present stand would be required to reach the localities where the older tillite occurs. Indeed, the whole aspect of this deposit suggests that it may have been formed near the oscillating edge of a glacier, repeated advances being represented by layers of till and retreats by deposits of gravel, sand, and silt. The deposit can be said to show only that glacial conditions existed in that part of Alaska at some time long before the Wisconsin advance.

A third area in which older glacial deposits have been found occurs along the valley of the Nenana River, some distance beyond the point where that river leaves the mountains but where it is still bordered by foothills. High ridges of Tertiary gravel, standing 2,600 feet above the level of the Nenana River, contain on their surface numerous large boulders and erratic blocks that many geologists agree are of glacial origin. These boulders are found as far as 25 miles north of the recognized moraines of Wisconsin age and indicate that during some pre-Wisconsin glacial stage a vigorous ice tongue pushed northward from the range at least 25 miles farther than the Wisconsin ice and that at the point where the Wisconsin ice terminated the older glacier had a thickness of at least 2,600 feet. Although the erratic boulders left by this earlier glacier have suffered somewhat from weathering and are less fresh in appearance than glacial boulders of Wisconsin age, they are nevertheless still firm and little decayed and are more likely to belong to a late pre-Wisconsin stage than to an early one.

Still another locality at which evidences of pre-Wisconsin glaciation have been found is on the west flank of the Alaska Range, in the basin of the Mulchatna River. During the summer of 1929 the writer found there a deposit of deeply oxidized and weathered material that in composition, lack of assortment, and shape of included boulders and blocks seems certainly to represent a glacial moraine. The included boulders and rock fragments, however, are all so weathered and decomposed that their original surfaces have been lost. No striae were found, but few of the rocks were firm enough to retain striae. I believe this deposit to be a remnant of an ancient glacial moraine. It is now overlain by several hundred feet of fresh, unoxidized glacial till that forms a lateral moraine left by the Wisconsin glacier. This weathered deposit also, though certainly representing a stage of Pleistocene glaciation older than the Wisconsin, can not be definitely correlated with any particular glacial stage.

SUMMARY OF KNOWN FACTS CONCERNING PRE-WISCONSIN GLACIATION IN ALASKA

The main purpose of this paper is a discussion of Pleistocene glaciation in Alaska, but it seems well to mention briefly here reported occurrences of pre-Pleistocene ice invasions.

Cairnes [7] in 1914 described a conglomerate, thought by him to be of Carboniferous age, occurring at a locality on the Alaska side of the international boundary just north of the Yukon River. He thought that this formation might be of glacial origin, though he admitted that the question was still open. Mertie,[8] after later studies of the same formation, determined its age to be Cambrian or pre-Cambrian and concluded that its glacial origin was not yet established. If this material is glacial, it represents the oldest glaciation of which evidence has so far been found in Alaska.

Unpublished manuscript notes by Eliot Blackwelder refer to a body of tillite, containing polished and scratched pebbles, on the Yukon River near Woodchopper Creek and to an unbedded clay slate, studded with chunks and pebbles of other rock, on Beaver

[6] Capps, S. R., The Chisana-White River district, Alaska: U. S. Geol. Survey Bull. 630, pp. 63-69, 1916.

[7] Cairnes, D. D., The Yukon-Alaska international boundary, between Porcupine and Yukon Rivers: Canada Geol. Survey Mem. 67, pp. 91-93, 1914.

[8] Mertie, J. B., jr., Geology of the Eagle-Circle district, Alaska: U. S. Geol. Survey Bull. 816, pp. 24-28, 1930.

Creek. He thought that both these occurrences represented glacial deposits and tentatively guessed their age to be Cambrian. Mertie,[9] thinks that the first of these formations is of Devonian age and the other late Silurian, and he doubts the validity of Blackwelder's conclusion as to their glacial origin.

Kirk[10] describes a Silurian conglomerate occupying a considerable area on Prince of Wales Island and neighboring islands in southeastern Alaska which has locally a thickness of 1,000 to 1,500 feet and in which he found abundant faceted and striated boulders. He entertained no doubt that this is a glacial deposit.

Kirk further describes faceted pebbles in a limestone of Middle Devonian age on Prince of Wales Island and rounded boulders in Lower or Middle Devonian sediments near the north end of Chichagof Island, to which he doubtfully attributes a glacial origin.

At still other localities in southeastern Alaska, as at Pybus Bay, on Admiralty Island, and on the Screen Islands, off the west shore of Etolin Island, Kirk found faceted but no striated pebbles in beds of Permian age that he thinks may be glacial.

Blackwelder[11] considers certain conglomerates of the Yakutat series, in the mountains east of Yakutat Bay, to be glacial deposits, and the boulders in associated shales to have been dropped by icebergs. These rocks, according to Blackwelder, have been assigned to the Jurassic by Ulrich, though C. W. Wright thought they were probably of late Carboniferous age.

It will thus be seen that the evidence of pre-Pleistocene glaciation in Alaska includes a questionable tillite of Cambrian age near the international boundary in Yukon Basin; one fairly well established occurrence of tillite in the Silurian of southeastern Alaska, and a less certain one in the late Silurian of the Yukon Basin; questionable occurrences of Devonian age in the Yukon region and in southeastern Alaska; a doubtful occurrence of glacial material near Yakutat that may be of Carboniferous or of Jurassic age; and a possible glacial deposit of Permian age in southeastern Alaska.

To summarize the evidences of glaciation in Pleistocene time before the Wisconsin stage, we now know of tillite, indurated and uplifted to a height of 5,000 feet above sea level, on the south flank of the St. Elias Mountains, but occurring in the midst of great present-day glaciers and so having no certain correlation with early great ice transgression; of an uplifted and tilted succession of tillite, gravel, and silt beds in the White River Basin, at a locality that lies close to the terminus of an active glacier and therefore does not prove an ice expansion much beyond that of present glaciers; of glacial boulders in the Nenana Valley that lie many miles north of the limit reached there by Wisconsin glaciers; and of an old till in the Mulchatna Basin that was deeply oxidized before the Wisconsin advance but that lies well back within the area covered by ice in Wisconsin time.

CONCLUSION

It is probable that in Alaska, as in other parts of the world, there have been recurrent glacial periods from mid-Paleozoic time to the present. This was to have been expected, for unless the earth's poles have wandered much farther than has been determined, the high latitude of Alaska would always have favored glaciation there as compared with more temperate lands. Furthermore, for much of geologic time there have probably been high mountain areas in Alaska, and in these areas local glaciers might have been fostered even when glaciers could not exist in the lowlands.

Pleistocene glaciation in Alaska was severe, probably during several stages but certainly during Wisconsin time. The surprising fact is that so large an area in subarctic and arctic Alaska should have remained unglaciated while the remainder of northern North America was submerged beneath successive continental ice sheets. The restriction of Pleistocene glaciation in Alaska to mountainous areas was due mainly to a semiarid climate in the lower country.

If the climate of to-day may be considered to be as mild as the average climate during the several Pleistocene interglacial stages, then there is every likelihood that mountain glaciers have survived continuously in the higher mountains of Alaska from the beginning of Pleistocene time to the present and that the Pleistocene ice advances were merely expansions and the interglacial stages contractions of continuously existing glaciers. In other words, in Alaska glaciation has been continuous since the beginning of the Pleistocene epoch.

If the conclusions set forth above are justified, it follows that the present time of restricted glaciation is possibly only an interglacial stage. The time that has elapsed since the Wisconsin ice invasion is probably shorter than half the average duration of the Pleistocene interglacial stages. Whether or not the maximum stage of deglaciation has been reached is not known, but it is entirely possible that sometime within the next 50,000 or 100,000 years or so the northern part of the continent may again be subjected to submergence beneath a continental ice sheet.

[9] Mertie, J. B., jr., oral communication.

[10] Kirk, Edwin, Paleozoic glaciation in southeastern Alaska: Am. Jour. Sci., 4th ser., vol. 46, pp. 511–515, 1918.

[11] Blackwelder, Eliot, The probable glacial origin of certain folded slates in southeastern Alaska: Jour. Geology, vol. 15, pp. 11–14, 1907.