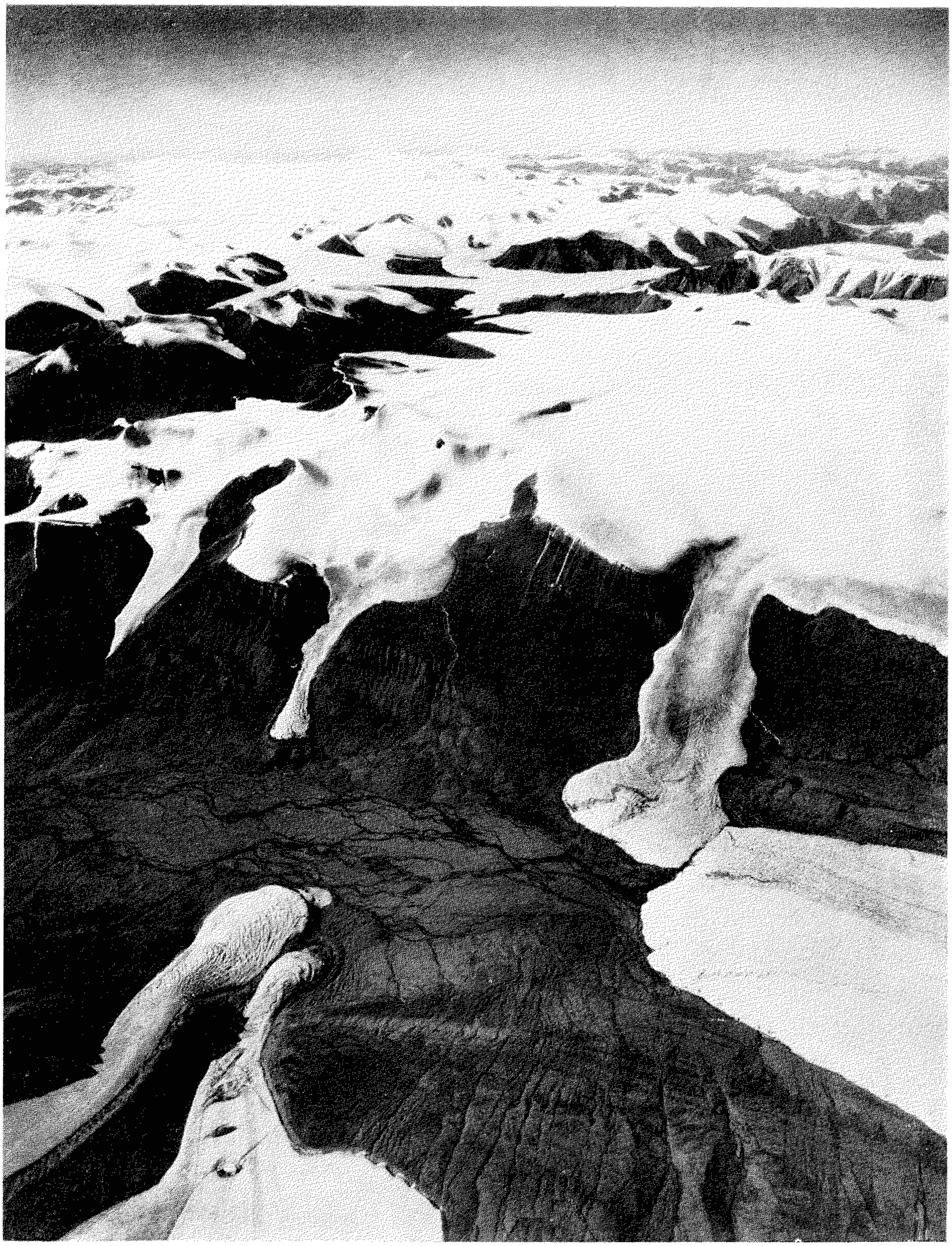

Photo: R.C.A.F.

Fig. 1. Small ice cap, Conger Range, Ellesmere Island. View looking west towards the United States Range.

THE ICE AGE IN THE NORTH AMERICAN ARCTIC

Richard Foster Flint*

Significance of glacial and interglacial ages

ARCTIC North America[1], in common with the rest of the world, is now emerging from the latest of the series of glacial ages which, as a group, have characterized the last million years or more of geological time. During the glacial ages, each of which was a hundred thousand years or more in length, the mean temperatures at the earth's surface were markedly lower than today. In consequence the proportion of snowfall to rainfall increased, melting diminished, and the accumulated snow formed glaciers. These great ice masses spread outward, slowly flowing under their own weight, until they covered one quarter to nearly one third of the land area of the world, principally of course in high and middle latitudes. In North America and Greenland alone, the area covered by ice amounted to seven million square miles.

Between the cold glacial ages, warmer times intervened. The record of the soils formed in temperate latitudes during the warmer, interglacial ages shows that those ages were longer than the glacial ages—one of them probably lasted 300,000 years. The record of the fossil animals and plants entombed in the deposits of interglacial times establishes that one or more of those times was warmer than today; from this the inference follows that the interglacial ages probably witnessed a more extensive disappearance of ice from the arctic regions than is now the case. In fact for the world as a whole the present is a time transitional from glacial to interglacial. The great ice sheets that formerly blanketed much of North America and Eurasia have disappeared, but more than ten per cent of the world's land area still remains covered by glacier ice.

The glacial and interglacial ages together constitute the Pleistocene epoch, the latest epoch in the scale of geological time. Although this epoch is also known as the "Ice Age", the latter term is not a good one; it is too simple. It does not imply that it includes the interglacial ages, whose combined length was greater than that of the combined glacial ages.

Most of the information on which we have formed our concepts of Pleistocene conditions comes from temperate regions. Knowledge of the

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[1]Throughout this paper "Arctic North America" is used in the broad sense and includes both arctic and subarctic regions.

former glaciation of arctic regions is scanty and is based in part on inferences from research carried on in lower latitudes. At present our reconstruction of glacial and interglacial events in the Arctic consists of broad generalizations, meagrely supported at one place or another by detailed data. As exploration and research fill in the wide blanks in our knowledge much will be learned that will modify our concepts concerning the extent of the former glaciers, their growth and decay, and the paths they made possible for large mammals and for early man emigrating from northeast Asia into North America.

Evidence of glaciation[1]

Today only a minor proportion of the arctic and subarctic regions is covered with glacier ice. But it is now well known that during the glacial ages a very large proportion of the land areas of these regions was overspread by glaciers, while the seas were largely covered with ice consisting of frozen sea water plus icebergs broken off from the glaciers along the coasts.

This knowledge is based on evidence of various kinds. Direct evidence of former sea ice is little known as yet, but it is unmistakable. In 1936 the Western Union Telegraph Company's ship *Lord Kelvin* made a cable-repairing voyage from Canada to Britain. On board was Dr. C. S. Piggot, who had invented a device for taking a 10-foot core sample of the soft sediments beneath the sea floor. A study of the series of cores he made from the region between Newfoundland and Ireland showed that the sea floor in that region is underlain by alternating layers of foraminiferal ooze and pebbly grit (Bradley and others, 1940). The single-celled foraminifera contained in the ooze are characteristic of the warm surface waters of the Gulf Stream. The pebbly grit likewise contains some foraminifera, but they are of types peculiar to colder northern waters.

There can be no reasonable doubt that the layers of pebbly grit were deposited by sea ice as it floated southward and melted during glacial times. The layers of foraminiferal ooze, on the other hand, were deposited under warmer conditions much like those of the present day. Hence there is firm ground for the belief that in the glacial ages the northern seas yielded sea ice that was far more abundant and that extended much farther south than at present.

On the lands of Arctic North America the glacial ages left a more evident impress. In the alpine mountains of British Columbia and Alaska in the west, and of Labrador, Baffin and Ellesmere islands, and Greenland in the east, the shattering action of frost, accompanying the glacial climates, sculptured typical jagged peaks and serrate ridges and, at slightly lower altitudes, excavated the capacious, half-bowl-like corries that characterize the heads of most glaciated valleys. The larger valleys were converted into fiords and, in Alaska and British Columbia, where the rate of flow of the glaciers was rapid owing to abundant snowfall, some valleys were deepened at least 2,000 feet by glacial erosion. Now partly filled with sea water, these trough-like valleys are the familiar fiords characteristic of the mountainous coastal regions of high latitudes.

[1]Systematically discussed in Flint, 1947.

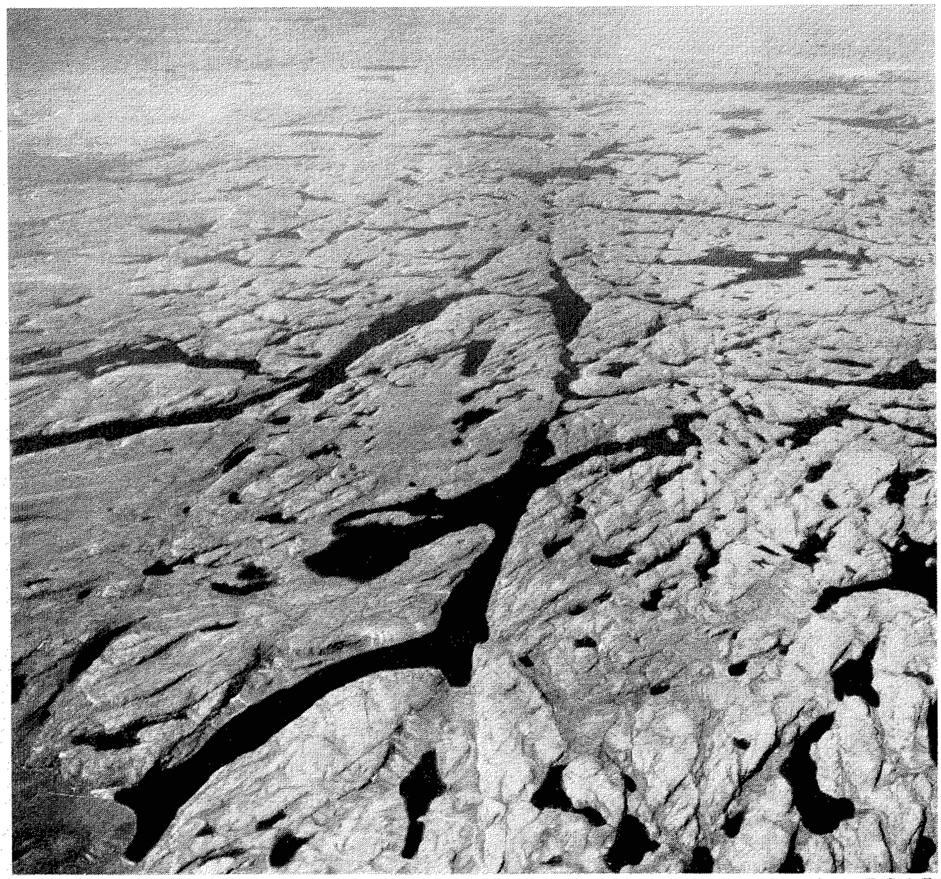

Photo: R.C.A.F.

Fig. 2. Nearly bare glaciated bedrock, Rae Isthmus, Melville Peninsula. View looking west.

On the lowlands the slow grinding action of thick glaciers almost entirely removed the mantle of preglacial soil and subsoil, and grooved, scratched, polished, and generally smoothed the surface bedrock underneath. In places where the rock is cut by closely spaced fractures and other planes of weakness, the glaciers quarried out blocks of many sizes, creating roughened surfaces, as well as many rock basins that now contain lakes.

The depth of glacial erosion of the lowlands was small, as is indicated by the preservation of preglacial topographic features and of chemically altered bedrock that could only have been formed close to the surface during preglacial time. Most estimates place the layer of soil and rock removed by glacial action at a few tens of feet at most. The small figure is the result chiefly of the lowland character of the country; there were no deep valleys to channel and concentrate the flow of the ice, nor were there mountains to provide steep gradients.

Here and there throughout the lowland region, irregular deposits of earth and stones (the *glacial drift*) left on the surface, chiefly during the melting of

Photo: R.C.A.F.

Fig. 3. Drumlins. View looking east on Barren Grounds near Artillery Lake.

the glaciers, created obstructions to the natural drainage, forming many lakes in addition to those occupying bedrock basins.

The glacial drift is generally thin and is distributed in patches. In the regions surrounding Hudson Bay and lying immediately east of the Mackenzie Great Lakes, where the ancient bedrock is strong and not easily eroded, bare, ice-smoothed outcrops are much in evidence and drift is scanty. Farther west, in the plains region, where the weaker bedrock yields more readily to erosion the covering of drift is more general. It is also thick in the central region between Hudson Bay and the Mackenzie River.

Much of the drift is a variety of *till*—a tough, compact, nonstratified stony clay plastered bit by bit on to the ground from the load of rock fragments carried in the base of the slowly flowing glacier. The till is usually only a few feet in thickness, although in the plains region it may be much thicker. In some areas where the till is comparatively thick the flow of the overriding ice has molded it into the whaleback hills known as *drumlins*. Commonly these occur in broad groups, the individual drumlins ranging in length up to three miles. Thus far drumlins have been reported principally from the region

Photo: R.C.A.F.
Fig. 4. Esker on Barren Grounds between Back River and Contwoyto Lake.

west of Hudson Bay, as far west as northern Saskatchewan. Undoubtedly further exploration will bring to light many more than are now known. The value of drumlin study lies in the fact that the long axes of these hills record the general direction of flow of the glacier ice at the time when they were built.

The *esker*, another type of drift accumulation, is also useful in reconstructing the movements of glaciers. Eskers are long and usually winding ridges, several tens of feet in height, and in some cases more than one hundred miles in length. Some of them branch like streams, and all are built of stratified glacial sediments. They are believed to be the deposits made by streams of meltwater that flowed in tunnels beneath the ice or in channels in the surface of thin ice, in the marginal part of an ice sheet. They were built during the period of decay, just before the ice melted away, and are generally aligned at right angles to the trend of the glacier margin at the time they were built. Thus they may record successive positions of the edge of the ice sheet during its shrinkage. Eskers are numerous in Arctic North America, but as yet they have been mapped in two regions only: east of Great Slave and Great Bear lakes (Wilson, 1939, 1945) and in central Quebec and Labrador.

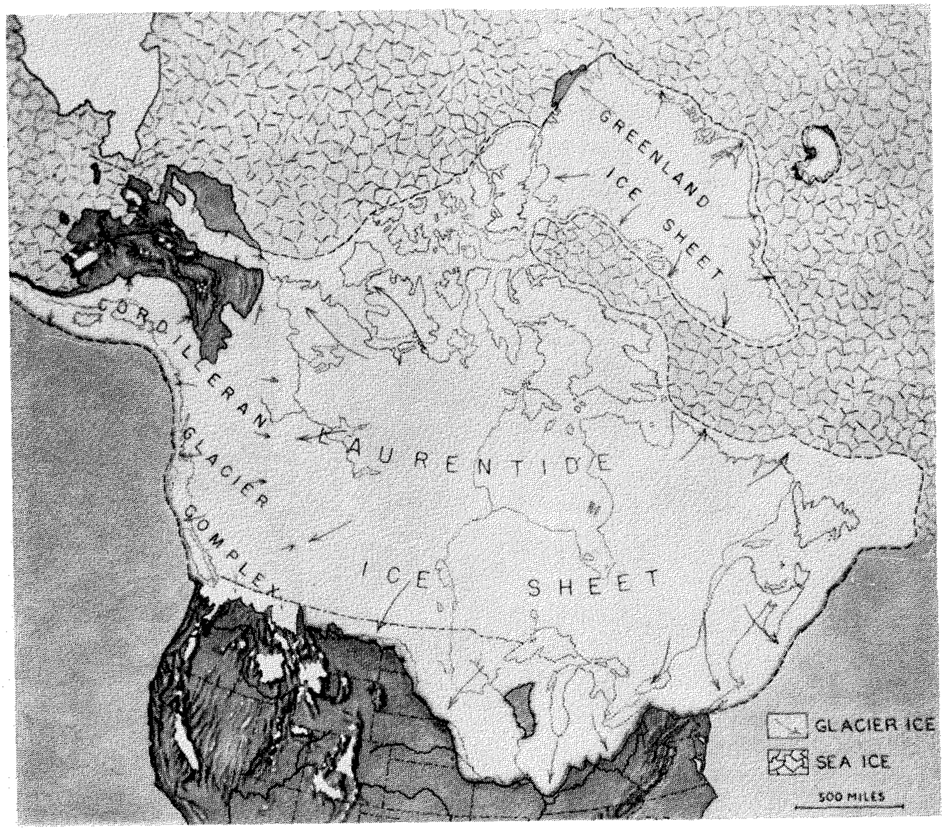

Fig. 5. Glaciated areas in North America, generalized to show the maximum area covered regardless of date of glaciation. (Reproduced by permission from 'Textbook of Geology', Part 1, by Longwell, Knopf, and Flint, published by John Wiley and Sons).

End moraines—ridges of drift heaped along the margin of the ice sheet—occur here and there. Except in a few localities, however, no systematic attempt has been made to map them. When fully mapped these features too, like the drumlins and eskers, will constitute a valuable clue to the successive positions of the retreating margin of the ice sheet.

Distribution and types of former glaciers

Figure 5, adapted from the Glacial Map of North America (Flint and others, 1945), shows the areas at present believed to have been covered by former glaciers in North America. Excepting in the region of the Arctic Ocean, the limits of the highland glaciated regions are fairly well known, though many details remain to be filled in. Of the vast lowland area west, north, and east of Hudson Bay, our knowledge is hardly even elementary.

The distribution and directions of flow recorded by the former glaciers show that the two great groups of highlands in Arctic North America—the western or Pacific and the eastern or Atlantic—were glaciated and that glaciers originated in these highlands. Data of the same kind show that the vast lowland region between these highland groups was also glaciated–evidently by a thick and extensive ice sheet. It was long believed that this ice sheet was built up by the accumulation of fallen snow on the lowlands themselves. However, I have put forward reasons for believing that the great lowland ice sheet grew up through the coalescence and expansion of glaciers from the Atlantic highlands (Flint, 1943, 1947; Demorest, 1943). According to this view the ice sheet was in a sense an immigrant into the lowland country rather than being indigenous. The manner in which the ice sheet developed is not entirely settled, nor can it be until much more has been learned about the glacial geology of the vast region surrounding Hudson Bay. The discussion that follows is based on the view that the broad ice sheet invaded the lowland from the east, with the reservation that this view is not yet fully proved and is therefore subject to whatever modifications may be made necessary by further study.

The Cordilleran Glacier Complex. The Cordilleran or high-mountainous region of western North America, from Alaska to Mexico, is dotted with glaciers today. The colder climates of the glacial ages brought about so great an expansion of glaciers in this region that from southern Washington northwestward to the Bering Sea a complex of coalescent valley glaciers, piedmont glaciers, and ice sheets covered a combined area of more than 950,000 square miles[1]. On the west this ice entered the Pacific and probably formed a floating shelf similar to the shelf floating on the Ross Sea off the Antarctic Continent today. On the east the ice descended to the plains where, along a 1,700-mile front stretching from Glacier National Park in Montana to the mouth of the Mackenzie at the Arctic Ocean, it coalesced with the great lowland ice sheet.

The distribution of the Cordilleran glaciers was controlled then, as today, by two principal factors: high land and atmospheric moisture. These controls are clearly evident in Alaska. There the thickest and most extensive glaciers formed on the coastal mountains, which not only are the highest and most massive mountains in western North America but also stand directly in the path of warm moist air masses coming in from the Gulf of Alaska. The Brooks Range in northern Alaska is lower, less massive, and faces the cold Arctic Ocean rather than the warm Gulf of Alaska. In that range the glaciers were correspondingly less extensive, thinner, and less active. Between the coastal mountains and the Brooks Range the lowlands drained by the Yukon River had no glaciers at all; this intermontane country, although cold, was too low and too dry to support them.

In southern Yukon and northern British Columbia, where coastal mountains are lower, enough moisture was carried across the coastal barrier to build up a thick ice sheet in the rough but lower country between the Coast Ranges on the west and the Rocky Mountains on the east.

The Laurentide Ice Sheet. Most of North America east of the Rocky Mountains was overspread during the glacial ages by a vast, coalescent mass of ice to which the name Laurentide Ice Sheet has been given (G. M. Dawson, 1890,

[1]For descriptions of the glaciation of representative districts see Kerr, 1934; Capps, 1932.

p. 162)[1]. The area of this glacial carapace at its maximum probably exceeded five million square miles. Its exact eastern limits are not known because the ice extended to seaward of the present coast and the evidence is therefore submerged. To the north the vast glacier covered the southern and eastern islands of the Canadian Arctic Archipelago and overspread the network of narrow straits that separated them. Whether the most northerly and westerly islands were ever wholly buried beneath ice is not known, simply because the geology of much of the region has never been investigated.

The ice grew thick enough to overtop most or all of the highlands in northeastern North America, and may possibly have reached an extreme thickness of 10,000 feet, although this figure is a matter of conjecture.

Greenland Ice Sheet[2]. Eastward across Baffin Bay and Davis Strait the Greenland Ice Sheet, during the glacial ages, was thicker and more extensive than it is today, as is clearly shown by the ubiquitous signs of glaciation both vertically above and outward beyond the existing ice sheet. It can hardly be doubted that the Greenland and Laurentide ice bodies were firmly coalescent across the narrow straits that separate northwest Greenland from Ellesmere Island. It is even possible that the two ice sheets, partly aground and partly afloat, were coalescent across Baffin Bay and Davis Strait.

Despite its great area, the Greenland Ice Sheet failed to cover the extreme northeastern tip of Greenland, just as it fails to do today. The explanation lies in lack of nourishment. In that region the precipitation is now very small, and during the glacial ages it must have been as small or smaller, literally starving the northeastern tip of the Greenland Ice Sheet.

Growth and disappearance of the glaciers

The hypothesis that best fits the facts now known is that each of the glacial ages began with a world-wide gradual reduction of temperature. In consequence the proportion of snowfall to rainfall increased, and the melting of fallen snow during the summer diminished. All of this, quite understandably, resulted in the enlargement of glaciers existing in the higher mountains and in the appearance of many new glaciers in mountainous districts. There can be little doubt that in Arctic North America the first crop of glaciers took form in the two great mountain regions: the Alaska–Yukon region and the Greenland–Ellesmere Island–Baffin Island–Labrador–Quebec region.

The probable growth of the glaciers in the Alaska–Yukon region is not difficult to trace. Individual mountain glaciers enlarged, thickened, and coalesced. Many of them spread out beyond the bases of the mountains as piedmont glaciers. In southern Yukon and northern British Columbia the ice bodies flowing eastward from the Coast Ranges and those flowing westward from the Rocky Mountains coalesced over the rough but somewhat lower country between them, and the combined mass thickened and grew into an ice sheet that nearly overtopped the high mountains themselves. Geological

[1]For good descriptions of some of the glacial features see Bell, 1890; J. W. Dawson, 1893; Tanner, 1944, pp. 173–253.

[2]Systematically discussed in Kayser, 1928.

evidence shows clearly that the ice, when near its maximum extent, flowed from the lower interior country westward *across* the higher coastal mountains to the Pacific.

The growth of the glacier ice in the eastern part of the continent is less clearly evident, but the probable course of events was similar. Through the use of what scanty direct evidence we have, and by analogy with better-known regions, we can conjecture that on each of the highlands along the northeastern border of the continent proper, and in Greenland, the new crop of glaciers expanded until they coalesced, as did those in the far west. Recent seismic measurements on the Expéditions Polaires Françaises have suggested the possibility that the land mass of Greenland consists of three separate islands which have been buried beneath the Greenland Ice Sheet.

Glaciers descending the western slopes of the mountains of Ellesmere and Baffin islands, and of Labrador and Quebec, formed a piedmont apron of ice that chilled the air above it and thus drew snowfall from the comparatively moist air masses that approached it from the south and southwest. The added snowfall increased the thickness of the ice, which thereby gradually became a topographic barrier to the southerly and southwesterly winds, as well as a cold-air barrier or polar front. Snowfall was thereby still further increased, which in turn thickened the ice and increased its outward spread.

The high cold front of the combined glacier crept slowly westward and southward, fed by moisture brought to it by the winds it intercepted. At the same time the ice thickened until it buried, or nearly buried, the highlands along the northeast coast on which the earliest glaciers had formed. The ice, now the full-fledged Laurentide Ice Sheet, flowed across the broad shallow Hudson Bay depression and up the long gentle slope of the plains country to the west. Its uphill course was made possible by its great thickness. Ultimately it met the piedmont glaciers flowing eastward from the Rocky Mountains and merged with them to form a continuous glacial mantle that stretched from the Labrador Sea to the Gulf of Alaska, broken only by high mountain peaks. The line along which the two ice masses merged shifted its position from time to time, but it was never far east of the Rocky Mountain front. This line lay along the general course of the Mackenzie and Liard rivers, through the vicinities of Fort Nelson and Dawson Creek, and passed west of Calgary and Lethbridge, to the southern limit of the ice at the International Boundary. That rock debris was brought to this line by both glaciers is shown by exposures of overlapping glacial deposits, one layer containing Rocky Mountain stones, another containing stones brought from the region west of Hudson Bay, and still another layer containing a mixture of both.

The transport of stones to western Alberta from the country immediately west of Hudson Bay involved not only a journey of many hundreds of miles but also a vertical lift amounting to more than 4,000 feet. In order to accomplish the lift, the ice sheet must have had a thickness considerably in excess of this value. It is not probable, however, that the ice sheet, when at its maximum, was thickest at its geographical centre and thinner elsewhere. The probability is that the ice was thickest at its eastern and southern marginal areas—the areas that intercepted the largest amounts of atmospheric moisture—and that elsewhere the ice was thinner. The glacial striations and other geologic evidence of direction of flow of the ice are still too scanty to justify definite conclusions, but such facts as we have are consistent with this concept.

If this was the case, then the flow of the spreading ice was most active in the southern peripheral zone and was least active in the vast interior and northern areas. Furthermore, most of the ice markings left on the bedrock and the localized accumulations of glacial drift deposited on the surface must have been made during the waning of the ice sheet; for the majority of the markings and accumulations made earlier would have been erased or reshaped by later movement.

Floating shelves of glacier ice, like the shelf off northern Ellesmere Island today, undoubtedly fringed many coasts. Beyond the shelves the sea ice was far more extensive and more nearly continuous than it is today. Pack ice filled not only the Arctic Ocean but also the Bering Sea and the Greenland and Labrador seas, and reached into the North Atlantic beyond the southern coasts of Greenland and Iceland.

The state of exploration of Arctic North America permits us as yet to sketch only the general outlines of the deglaciation—the shrinkage of the glaciers from their former great extent. As recorded by a variety of features, chiefly in the glacial drift, the shrinkage seems to have been generally concentric, inward toward a "last stand" of the shrunken main body of the ice sheet in the regions of Hudson Bay and the Quebec–Labrador highlands. But wherever there were conspicuous highlands their cold and moist climates favoured the persistence of glacier ice upon them. Thus southeastern Quebec, Labrador, and Baffin and Ellesmere islands and their high-standing neighbours, as well as Greenland, continued to nourish glaciers of various kinds separate from the main residual ice body. Some of these separate glaciers, notably the Greenland Ice Sheet, persist today despite a somewhat unfavourable climate and conspicuous contemporary shrinkage.

Evidence of repeated glacial ages

Most of the evidence that glaciation was repeated comes from the temperate region, where the southern margins of the great glaciers piled up at least four overlapping layers of drift, each separated from the one below it by a zone of deep weathering-decomposition that indicates a lapse of perhaps hundreds of thousands of years. During each glacial age most of the arctic region lay beneath ice, and in the mountainous areas the intensity of glacial erosion favoured the destruction of earlier-formed drifts. Hence, as yet, the Arctic has contributed little to our growing knowledge of the succession of glacial ages. In no arctic locality has clear evidence of more than two glacial ages yet come to light. If the Arctic alone were considered, this fact might be taken to mean that glaciers continued to cover much of the arctic region during the interglacial ages proved to exist in lower latitudes. But when the whole glaciated region is examined, such a condition is seen to be very improbable, for the fossil plants and animals contained in some of the interglacial deposits imply arctic climates as warm as, or warmer than, those of today. This in turn implies very widespread deglaciation.

Within the arctic region perhaps the best evidence of repeated glaciation is a series of exposures in the district south and west of James Bay (McLearn, 1927, pp. 30C–31C). Here, between two sheets of till, is a layer of peat, the compressed remains of a spruce–pine–birch–fir forest. Clearly there were two glaciations of this district and, although the length of the intervening time is not evident, it is probable that both glaciations are of very late date.

In the Carmacks district, Yukon, there are present two till sheets of which the younger contains firm, fresh stones while the stones in the older are thoroughly decomposed. A long interglacial process of soil formation is indicated (Bostock, 1936, p. 48).

In the sea cliffs of Herschel Island, in the Beaufort Sea west of the mouth of the Mackenzie River, extensive beds of soil and clay containing twigs and at least one log are exposed (O'Neill, 1924, p. 12). Again, near the mouth of the Ikpikpuk River, on the arctic coast of Alaska east of Point Barrow, spruce logs occur in the sediments of the coastal plain (Smith and Mertie, 1930, p. 254). Large logs are found in the superficial deposits of the Kuzitrin lowland north of Nome, Alaska (Collier and others, 1908, pp. 89, 91). Little is known about these deposits but, as their localities lie beyond the present poleward limit of trees, the material may be interglacial. We cannot state the inference more strongly than this, because the possibility that the twigs and logs were simply driftwood, perhaps from distant points of origin, has not been eliminated.

There is clear evidence of at least two glacial ages in the frozen ground in the Yukon River basin in central Alaska, although the region was never glaciated because it is low, dry, and subject to warm summers. This country is underlain by thick beds of silt, deposited mainly by the Yukon and other rivers. As it lies within the arctic belt of perennially frozen ground, most of the silt is frozen to depths reaching hundreds of feet. Mining operations have exposed extensive sections of the silt, overlain by thick mudflow deposits consisting of thawed silt, now refrozen. Such sections furnish evidence of an episode of deep thaw that intervened between two episodes of deep freezing (Taber, 1943). As freezing and thawing well below the surface take place slowly, a long interval of warmth is indicated. These events, however, have not yet been firmly dated.

In northern British Columbia and also on the east coast of Greenland the forms of major valleys seem to indicate a period of deep stream trenching that occurred between two periods of glaciation.

These are the scattered pieces of evidence of repeated glaciation derived from the arctic region. Many more will be discovered, but they are not likely to approach either in quantity or quality the records from the southern margin of the glaciated region.

A great variety of evidence has established the belief that since the latest of the glacial ages reached its peak several tens of thousands of years ago and began to wane, the climate has not become continuously milder. The record shows that in northern Europe and temperate North America, at least, climates attained a maximum of warmth and dryness roughly 5,000 years ago; since when, conditions have become appreciably cooler and wetter. It has been shown that some of the glaciers in western United States had dwindled away or disappeared entirely during the period of warmth and were later reborn. Arctic America is not likely to have undergone so drastic a change because of its cooler climate, but nevertheless it is likely that all the arctic glaciers underwent at least some reduction in size during the warm period. Future research is likely to bring forth evidence that this reduction occurred.

Glacial lakes

The great deglaciation that has been in very irregular progress throughout the last few tens of thousands of years was accompanied by the appearance of many temporary lakes, held in between glacier ice on one side and sloping ground on the other. Most of the lakes were localized in preglacial stream valleys, depressions that could be converted into basins by glacial erosion, or damming by ice, or both. Some of the most conspicuous preglacial valleys had developed along the contact between the igneous and metamorphic Precambrian rocks of the Canadian Shield and the surrounding Paleozoic sedimentary rocks. Major lakes of today, such as Great Bear and Great Slave lakes and Lake Winnipeg, consist of segments of these valleys converted into lake basins by glacial action. These, together with other lakes in the region west of Hudson Bay (notably Lake Athabaska and Wollaston, Reindeer, Cree, and Lesser Slave lakes), show by the abundance of lake deposits and abandoned strandlines in the terrain surrounding them that they were considerably larger during the shrinkage of the ice sheet than they are at present.

The two larger lakes formed partly within the arctic region during the deglaciation have almost entirely disappeared. *Lake Agassiz* extended from latitude 46°N., in Minnesota, nearly to latitude 58°N., in northern Manitoba, and had an area equal to that of the existing Great Lakes combined. It was held in the north and east by the edge of the ice sheet, and when this melted away the water drained off to Hudson Bay, leaving a few basins, lakes Winnipeg and Winnipegosis, to contain residual pools. *Lake Ojibway-Barlow*, south of James Bay, was held in in the same manner. It stretched from the 76th meridian to the 88th, and when glacial melting destroyed its northern shore it drained away, leaving upon the bedrock surface a veneer of silt and clay to mark its former extent. This is the well known "clay belt" which has made a wide region possible for agriculture, in contrast with the rocky country surrounding it.

The postglacial sea and rise of the land

The greater part of the coastline of Arctic North America is fringed with superficial deposits of sand and silt, in places containing the fossil shells and bones of marine animals. Throughout great distances these deposits are fashioned into beaches, bars, and other shore features sweeping along the contour of gently sloping terrain. Shore and sea-floor deposits of this kind form a discontinuous belt that varies greatly in width. Along steep coasts,

Photo: R.C.A.F.

Fig. 6. Successive shorelines lifted above sea level by upwarping accompanying deglaciation. West coast of Hudson Bay at mouth of Shell Brook, south of Fort Severn.

such as those of Labrador and British Columbia, the deposits are narrow and very discontinuous, consisting of hardly more than local patches. Along gently sloping coasts, such as the coast of Hudson Bay, they increase to form a belt more than 150 miles wide, and in the Thelon River basin, northwest of Hudson Bay, the width of the belt exceeds 400 miles. The greatest height of the marine features above present sea level likewise varies from one part of the coast to another. This height commonly reaches 500 feet; and, at a few points, it has been observed to reach as much as 900 feet. In contrast, in northwestern Alaska it is not certain that marine deposits extend above the present level of the sea. In general the height increases with increasing proximity to the Hudson Bay region, which lies near the geographical centre of the area covered by the former ice sheet.

In the few places where exposed sections of these deposits have been examined, they are seen to rest upon the glacial drift. Hence the marine sediments postdate the glaciation. The phenomenon of marine deposits overlying glacial drift is known also in southeastern Canada and New England, and is still better known along the Baltic Sea coasts of Sweden and Finland. The explanation now widely accepted is that the weight of an ice sheet causes the earth's crust beneath it to subside slowly. As the great glacier shrinks, the sea inundates the subsided crust, which is slowly rising (though with a considerable time lag) owing to reduction of the glacial load. At first the sea rests against shores of glacier ice. But as the ice sheet shrinks and as the crust rises, the shoreline is transferred to the ground vacated by the ice and is forced to retreat little by little. Thus are explained the marine cover and the successive shorelines at ever-decreasing levels. Evidently, then, during an earlier phase of the process of postglacial uplift, Hudson Bay was very much larger than it is now.

There are indications of various kinds that the upheaval is still in progress. Prominent among these are the occurrence at several localities of Eskimo dwellings, built near the shoreline, and fish traps, built between high and low tide, now 30 to 80 feet above sea level (cf. Bell, 1884, p. 37; Washburn, 1947, pp. 69–71). Calculations based on the probable amount of depression of the crust under the ice sheet, and on the uplift already accomplished, indicate that in the region of Hudson Bay some additional hundreds of feet of uplift are to be expected before the crustal equilibrium that prevailed before glaciation will have been restored. From this it follows that Hudson Bay will gradually become still smaller. In fact it is probable that by the time the movement has ended, the Bay will have become once more a broad plain drained by a master stream flowing north. There is reason to believe that in preglacial time this master stream included the drainage of the Missouri River in North Dakota and Montana, but that that drainage was diverted toward the south by the expanding ice sheet.

The absence of highly elevated marine features from the western and northern coasts of Alaska results probably from the fact that western and northern Alaska were but scantily covered with ice, so that disturbance of crustal equilibrium there was small. Postglacial emergence of the Pacific coast of Alaska and British Columbia has been conspicuous; this is in keeping with the known thick cover of glacier ice in that coastal region.

Chronology and causes of glaciation

The North American Arctic yields very little direct information either on the actual dates of events in the glacial past or on the probable causes of the glacial climates. Our knowledge of these matters, still very scanty at best, comes chiefly from the glacial drift sheets in the temperate zones of North America and Europe. Until the use of the radiocarbon method of dating, developed by Libby (1952), it was assumed that the time elapsed since the shrinking ice sheet began to uncover the very young Mankato drift was 25,000 years. Radiocarbon measurements of wood from the Two Creeks peat, immediately underlying the Mankato drift, has shown that the age of the wood is only about 11,000 years (Flint and Deevey, 1951). As yet the radiocarbon method is directly applicable only to organic matter less than 30,000 years old. Therefore the degree of chemical alteration of each of the several drift sheets still furnishes the best chronology, inaccurate though it is. At present the lengths of the glacial ages can only be guessed at, but they are widely regarded as having been much shorter than the interglacial ages. The whole group of four glacial and three interglacial ages together is believed to have lasted roughly one million years.

Because the interglacial times are believed to have been longer than the glacial times, the Arctic has been largely free of a glacier-ice covering during the greater part of the Pleistocene epoch. However, whatever thin soils may have been developed over the surface of the bedrock during the ice-free interglacial ages were almost wholly swept away by the intervening glaciations.

The fluctuations in the mean annual temperatures of temperate latitudes during the Pleistocene epoch seem to have been no more than 10°C—roughly 8° colder than now during the glacial ages and 2° warmer than now during the interglacial ages. The causes of these repeated fluctuations constitute a much-debated question to which various answers have been given. To me the cause appears to have been twofold (Flint, 1947). The first factor was a conspicuous world-wide elevation of the lands in general and of many mountain ranges in particular, during the epoch immediately preceding the Pleistocene and continuing into the Pleistocene epoch itself. This elevation in itself reduced surface temperatures in several ways, though alone it cannot explain repeated temperature fluctuation. The second factor is an assumed fluctuation in the rate at which radiant energy is emitted by the sun. Small present-day fluctuations are currently observed, but the larger fluctuations necessary to form glaciers on the highlands must be assumed. These two factors constitute a reasonable and, it seems, probable explanation of the glacial and interglacial ages, though the second factor is not at present capable of proof.

Effect of glaciation on life

The present-day flora of the North American Arctic includes few endemic forms. There can be little doubt that glacial-age conditions in the glaciated regions almost wholly extinguished the plant cover, which was renewed after each glacial age by immigration from the nonglaciated territory. Probably the principal arctic refuge within which plants with sufficient hardihood survived the glacial ages lay in nonglaciated areas in central Alaska and the adjacent parts of the Yukon. In addition, repopulation of the arctic flora must have taken place to a considerable extent from the belt of country lying south of the southern limits of glaciation.

If, during the glacial times, there was a conspicuous belt of tundra at the southern margin of the ice sheet, there is little evidence of its former presence. Most of the comparatively few exposures of plant-bearing deposits immediately overlying the drift sheets yield floras, dominated by spruce and fir, such as characterize the subarctic forest of the present day. It seems likely, therefore, that the subarctic forest generally reached close to the margin of the ice sheet and that the intervening belt of tundra was narrow. Along the arctic coast between Point Barrow and the Mackenzie River, as already noted, there are suggestions of tree growth, presumably during some interglacial time (unless the wood in question is merely driftwood).

Evidence of the effect of the glacial ages on animal life in the far north is very slight, chiefly because there has been little systematic search for fossils.

We can be quite sure that in the glacier-covered areas animal life was completely extinguished. The change was gradual, and took place through slow migration, generally towards the south, as each glacial age developed. During the interglacial ages the glaciated tracts were repopulated with at least some of their former inhabitants. In the arctic regions, as elsewhere, the Pleistocene record is one of repeated wholesale shifts of faunal assemblages rather than one of conspicuous evolutionary changes in the animals themselves. On the other hand, cold-climate adaptations did appear in such Pleistocene mammals as the woolly mammoth and the muskox—adaptations that are unknown in the fauna of the preceding Pliocene epoch.

The only extensive Pleistocene mammal fauna thus far collected in Arctic North America comes from the nonglaciated interior region of Alaska and western Yukon. Here, in frozen muck and silt, has been found a rich collection (Frick, 1930; Stock, 1942; Quackenbush, 1908), that includes mammal types both extinct and still living. Among the extinct forms are the short-face bear (*Arctotherium yukonensis*), dire wolf (*Aenocyon dirus*), great cat (*Panthera atrox*), ground sloths (*Megalonyx* and *Nothrotherium*), camel (*Camelops*), great bison (*Bison crassicornis*), oviboids (*Symbos tyrrelli* and *Boötherium sargenti*), horse (*Equus alaskae*), woolly mammoth (*Mammonteus primigenius*), and mastodon (*Mammut americanum*). Forms still living include lion, peccary, reindeer, moose, bighorn sheep, saiga antelope, Rocky Mountain goat, and the muskox. The deposits from which the bones are taken have been thought to be of interglacial age, but the assemblage of fossil animals implies such different habitats that both glacial and interglacial faunas are suggested. The ground sloths, peccary, camel, and lion suggest a warmer climate than do the woolly mammoth, muskox, and reindeer[1]. More extensive study of the deposits may reveal that they are of more than one Pleistocene date.

Elephant bones and ivory are widespread in northwestern Alaska, together with fossil horse, muskox, and beaver (Smith and Mertie, 1930, p. 252). Fossil elephant remains, not generically identified, have been found in the Aleutian and Pribilof islands (G. M. Dawson, 1894; Bell, 1898, p. 374). Teeth ascribed to the Columbian elephant have been found near Edmonton and on an island in James Bay (Bell, 1898, pp. 370, 372). Mastodon bones have been collected from the Moose River near Moose Factory on James Bay and from the district west of Lake Winnipegosis (Bell, 1898, pp. 383, 387; Hay, 1923, p. 166). Fossil muskox, reindeer, and seal occur in the younger deposits of Ellesmere Island (Hay, 1923, p. 244).

These scattered bits of information hardly provide a firm basis for reconstructing a picture of the arctic plants and animals of the various Pleistocene ages. All we can say with probability is that during the glacial ages the transition zone between tundra and subarctic forest was pushed far south of the Great Lakes region and that during interglacial ages it reached

[1]Even the Columbian elephant (*Mammuthus columbi*) has been reported from Alaska (Bell, 1898, p. 371). If correctly identified, this form would suggest a warmer-than-glacial climate.

somewhat farther north than it does at present. This particular zone is recorded not only by fossil plants but by the distribution of the woolly mammoth, outstandingly an inhabitant of this zone. The various muskoxen generally preferred the open tundra; in contrast, the mastodon and moose inhabited the subarctic forest.

It is well known that many of the large mammals that inhabited northern North America during Pleistocene ages were immigrants from northern Asia via the Bering Strait bridge. The strait is both narrow and shallow. It could have become land at one or more times as a result of a moderate lowering of sea level, such as is known to have occurred during each glacial age when water was abstracted from the sea to build the great terrestrial glaciers. A slight warping of the earth's crust in the Alaska–Siberia region could also have converted this shallow strait into land. However the land bridge may have been made, there is little doubt that it existed and that over it moved a varied fauna into Arctic North America. The arctic region therefore was the corridor through which Asiatic mammals entered the New World.

In contrast with mammals on the lands, the vertebrate life in North American Arctic waters does not seem to have undergone conspicuous changes, probably because temperatures were fairly low during the interglacial as well as the glacial ages. The chief differences thus far noted consist of slight changes in postglacial faunal assemblages. These changes are attributable to increased salinity of the sea water, as dilution with glacial meltwater diminished, and to decreased depth, as continuing crustal uplift elevated the sea floors (Richards, 1937).

Among the mammals that crossed from Asia into North America via the Bering Strait bridge was man. He came in several, perhaps many, groups, over a considerable period of time. Very likely he followed some of the migrating game animals as a hunter.

Just where, or through how long a time, the diffusion of people from Asia into Arctic North America took place, is not known. It has been established that man was well settled in southern North America at the time when the Mankato expansion of the Laurentide Ice Sheet reached its maximum, roughly 10,000 years ago. But how long he had been there is still a question. When that question is answered, and when the climatic and ecological circumstances of the whole immigration become known, the arctic region will undoubtedly assume a new and important perspective in the history of man in America.

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