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GLACIAL DRAINAGE CHANNELS AS INDICATORS OF LATE-GLACIAL CONDITIONS IN LABRADOR-UNGAVA : A DISCUSSION

by

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During the four summer seasons, 1955 to 1958, the author was engaged in a study of the deglaciation of the northeast quadrant of Labrador-Ungava. Field investigations were conducted in the Torngat Mountains, at scattered localities along the Labrador coast, on the upper George River, and within a 50 to 70-mile range of the McGill Sub-Arctic Research Laboratory situated in the central « lake plateau » area at Schefferville (Knob Lake). These areas were selected to provide an opportunity for studying the progressive thinning of the last continental ice sheet from a coastal mountain area in the northeast, where some of the first indications of thinning were expected, and inland and southwards from here eventually to the vicinity of Schefferville where a reconnaissance in 1955 suggested that the final stages of wastage could be recognised.

This paper is submitted as an initial report on data accruing from a broad regional study of the glacial drainage features insofar as they provide intelligence of conditions prevailing during deglaciation. The field work has been supplemented by an extensive study of the air photographs in the Canadian National Air Photograph Library in Ottawa during the intervening winters, and the disposition and direction of slope of glacial drainage channels were plotted on the Topographical Survey maps, on a scale of 1:506,880, for most of the area of Labrador-Ungava. In figure 2 a small section of this investigation is reproduced to depict the distribution and direction of slope of the channels in the central part of the « lake plateau ».

With a few notable exceptions (Tarr, 1909), only recent studies in glaciology and glacial geomorphology consider the problems as three dimensional ones. The Scandinavian work, and particularly that of Ahlmann (1933), Ahlmann and Thorarinsson, (1937), Mannerfelt (1945, 1949), Hoppe (1950, 1957), and Strøm (1956), is invaluable to the few investigators who are just beginning to study similar problems in the vast areas of Canada. Labrador-Ungava, an area the size of Western Europe, has played a vital role in the glaciation of North America and yet knowledge of glacial conditions in this area is negligible. It is natural, therefore, to utilise the Scandinavian research, and it is not too much to acknowledge that the present study would have been impossible without reference to this work in an area which has so many similarities to Labrador-Ungava.

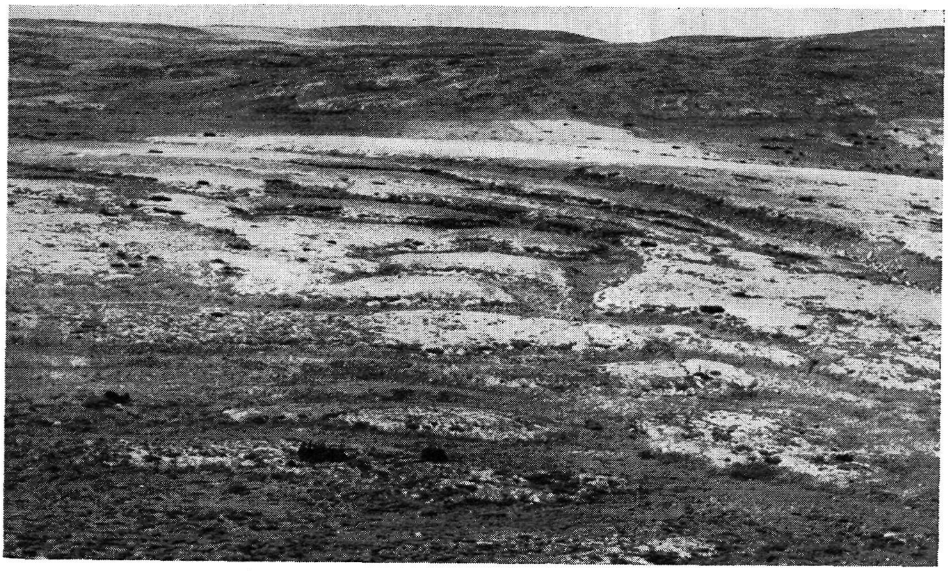
Glacial drainage channels are frequently formed during the final stages of glacial wastage. Their precise form, size and disposition in relation to one another, to the co-existing ice mass, and to the topography, are controlled by a number of factors. If a simple case is considered, that of the melting down of a distinct lobe of ice in a well defined valley, it will be seen that melt-water will tend to flow along the notch between the ice lobe and the hillside. If the ice is cold and unbroken then the melt-water, resulting from melting snow in late-spring and early-summer, will course down this notch and eventually discharge onto the sandur, or out-wash train, at the ice front. As the season progresses and the body of the ice approaches the pressure-melting point, the melt-water will tend more and more to undercut the ice margin. Finally, if the ice is broken or crevassed, the melt-water stream will eventually find its way beneath the ice and will tend to flow down the greatest gradient. Mannerfelt (1949, pp. 197-198) has described channels formed in this manner as « sub-glacial chutes ».

The morphology of the channels of such melt-water streams will depend upon the slope of the hillside and of the ice mass, the depth and character of the surface mantle and, as indicated above, upon the temperature regime of the wasting ice. Another factor is whether or not the ice is moving. A rapidly moving glacier, especially if its snout is advancing, would be expected to destroy the melt-water channel almost as soon as they are formed, but a stagnant lobe of ice, gradually wasting down *in situ*, will tend to leave a record of its progressive shrinkage in the form of its melt-water channels and fluvio-glacial accumulations.

In Öræfi, southeast Iceland, where a study was made of a number of valley and outlet glaciers (Ives & King, 1954, 1955 ; King & Ives, 1955, 1956), it was observed that glacial melt-water rarely maintained a course strictly lateral to the ice tongue for more than a few yards. Here the waters soon penetrated beneath the ice, the operative factors being the steepness of slope of the mountain side, the temperature of the glacier, which was at the pressure-melting point even in the spring, and the crevassed nature of the ice. In high arctic areas, on the other hand, where the ice usually remains below the pressure-melting point throughout the year, except for the upper few feet during the ablation season, melt-water streams are generally entirely lateral or supra-glacial in position. Sub-lateral channels may be formed when the stream undercuts the ice margin, but true sub-glacial drainage is rare. It follows, therefore, that a study of the existing glacial drainage channels in an area long since uncovered by the melting ice sheets, will yield information bearing upon conditions during the final melting of the ice.

One of the problems closely associated with this study is the differentiation, both in the field and on the air photograph, of the various types of channel. This problem is further complicated by the widespread existence of various forms of overflow channels from former ice-dammed water bodies, features which are essentially similar to the lateral and sub-lateral forms, for they also have been cut by a large volume of water flowing for a relatively short time, and producing the characteristic broad, steep-sided U-shaped cross section and gently sloping floor. Usually it is a fairly simple matter to isolate the extra-glacial channels by considering the existing topography and the inferred position

PHOTO I



Sub-Glacial Drainage Channels Northwest of Helluva Lake.

PHOTO II

Part of a system of huge glacial drainage Channels Northeast of Helluva Lake. Some of these Channels exceed 60 feet in depth. Note the irregular, interconnecting form of the Channels and the field assistant in the first Channel.

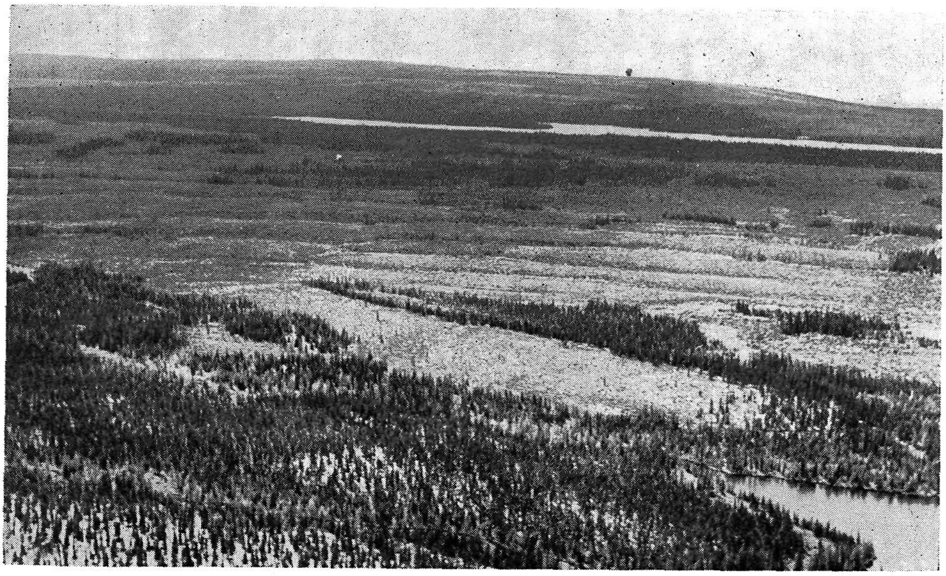
of the ice mass at the time of formation. Both Peel and Mannerfelt have shown, however, that sub-glacial channels may well be confused with direct overflow channels (Peel, 1956 ; Mannerfelt, 1945). Perhaps the greatest difficulty is to differentiate between the strictly lateral, sub-lateral, and sub-glacial types, which are frequently found as a progressive series with sections of the same channel falling into each of the three categories.

Mannerfelt (1949) has argued that regular spacing, gentle long profiles (1:50 to 1:100) and vertical interval (3.5 to 5 meters) of the lateral channels suggest an annual rhythm of formation and give a good indication of the marginal gradient of the free ice surface. Schytt advocates that more than one channel may be formed in each ablation season (Schytt, 1956). Despite this controversy it is stressed that only channels of the strictly lateral variety can be used to evaluate precise conditions of wastage and slope of the ice mass. On the other hand, it is believed that the direction of slope of the channels will generally conform to the direction, if not the degree of slope of the ice mass. A few exceptions, where channels are formed under special conditions, will be considered below.

The map, figure 2, shows the distribution of all channels, sub-lateral, sub-glacial, extra-glacial, and the strictly lateral type, although this final type is much less frequently found in the central « lake plateau » area.

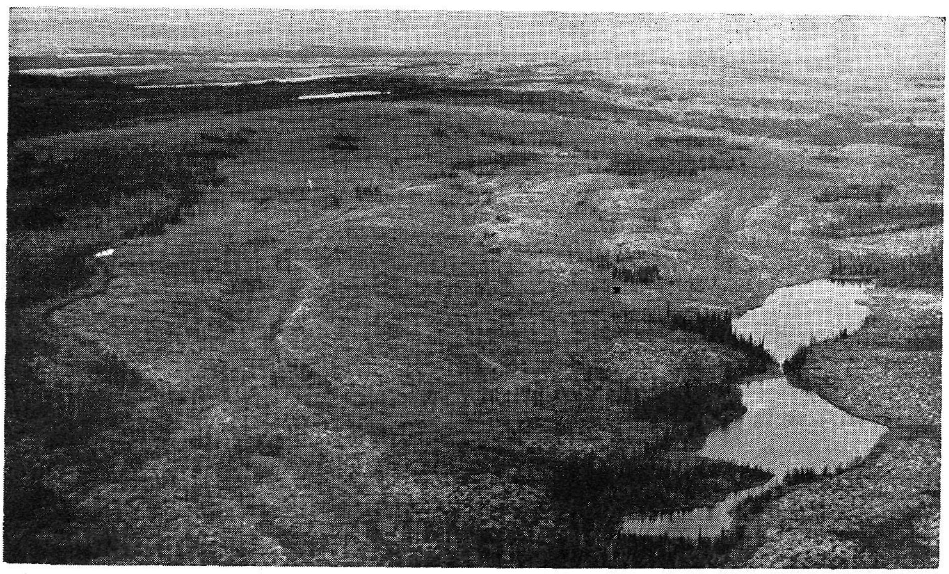
As a detailed study of the morphology and classification of the glacial drainage channels in the vicinity of Schefferville has been carried out by several students of the McGill Sub-Arctic Research Laboratory, this aspect of the study of the channels found in the area will not be considered in detail here. It is suggested, however, that morphology alone is not a reliable guide for differentiation, and in some cases the disposition and form of the channels, although strongly suggestive of a lateral mode of origin, leads to a false identification. To illustrate this point, one particular group of channels which were studied in the field will be described. The channels were thirteen in number and curved gently around the northern flank of an ironstone ridge some 12 miles northwest of Helluva Lake (see figure 1). These channels sloped down towards the north as a sub-parallel series and with an average gradient of 1:32. The average vertical interval was measured by hand level to be 21.8 feet. Apart from the relatively steep slope and large vertical interval, the regularity of form, sub-parallel nature, and comparative lack of tributary development strongly suggested that these channels had been formed laterally to the ice margin. Detailed examination revealed an interesting feature which mitigated against this interpretation. One of the channels was completely blocked by an erratic boulder some 10 feet in diameter. Had this erratic been part of the original till mantle the stream would have deviated around it, or at least formed a scoop on either side. From the field conditions, however, it was apparent that the boulder has been emplaced after the completion of the channel. Two possible methods of emplacement were then considered ; that the boulder had slipped down the hillside into the channel, a hypothesis which was rejected on account of the very gentle hillslope into which the channels had been cut and the total

Photo III



Glacial drainage Channels on the east side of Dolly Ridge, 5 miles S.E. of Schefferville. View looking southwest from the air. These Channels slope down towards the south-southwest.

Photo IV



Part of the same series of Channels shown in plate III, but looking northwest. Scherfferville on top left (hidden).

absence of a slip scar in the soft till which formed the sides of the channel ; and that the boulder had been part of the ablation moraine of supra- or en-glacial disposition lying immediately above the channel and had been lowered into it as the ice finally melted and collapsed. Further examination revealed the presence of extensive ablation moraîne scattered irregularly in and between the channels, although the size of the material was generally too small to allow any definite conclusion concerning its origin and temporal relation to the channels. In several other localities large erratic blocks were found in positions suggesting that they had been emplaced after the formation of the channels. It was concluded, therefore, that many channels which had every appearance of being strictly lateral in mode of origin were in fact sub-lateral, or sub-glacial.

It is generally concluded that the majority of glacial drainage channels in the vicinity of Schefferville were formed in sub-lateral or sub-glacial positions. This is based not only upon the isolated examples cited above but on the overall morphology and disposition of the majority of the channels which show a strong tendency towards tributary development, the steepness of the gradients (excepting a single channel with a gradient of 1:112, all of the 104 channels surveyed had gradients of 1:40 or more with an average of 1:20 to 1:35), and the extreme irregularity of the vertical intervals between the successive channels. More than 100 channels were measured, either by level and staff or hand level, giving an average vertical interval of 19.8 feet. Other things being equal, this vertical interval of 19.8 feet might be described as a reasonable figure for the annual ablation of the ice mass (see Mannerfelt, 1949). When it is considered, however, that this average conceals a range of from 0.5 to 76.0 feet, the statistical inadequacy of the average is clearly demonstrated. It is suggested, therefore, that one method of resolving difficult cases of differentiation between lateral and sub-lateral types of channel is a careful statistical study of the vertical interval and gradient. One exceedingly regular series of channels along the northeast shore of Helluva Lake appeared in plan view as an ideal group of the lateral variety. The level and staff quickly threw doubt upon this, however, when it was seen that the average vertical interval was 22.3 feet with a range of from 5.8 to 34.8 feet, and that the depth of individual channels was as much as 22 feet, and this was controlled by bedrock. It is suggested that these channels were neither lateral nor annual.

It is thought prudent, therefore, not to attempt an evaluation of any hypothetical annual ablation cycle, nor to estimate a hypothetical surface gradient of an ice sheet because the channels in the central area of the « lake plateau » are largely sub-lateral and sub-glacial in origin and do not lend themselves to such practices. On the other hand, the study of these channels can lead to an evaluation of the conditions prevailing during the final phase of wastage of the ice mass despite these limitations.

As stated above, glacial drainage channels of all types are shown in figure 2. It must be pointed out, however, that the scale of this map makes it impossible to show every single channel. Because of the scale and the importance of covering an area sufficiently large to illustrate the broad pattern of distribu-

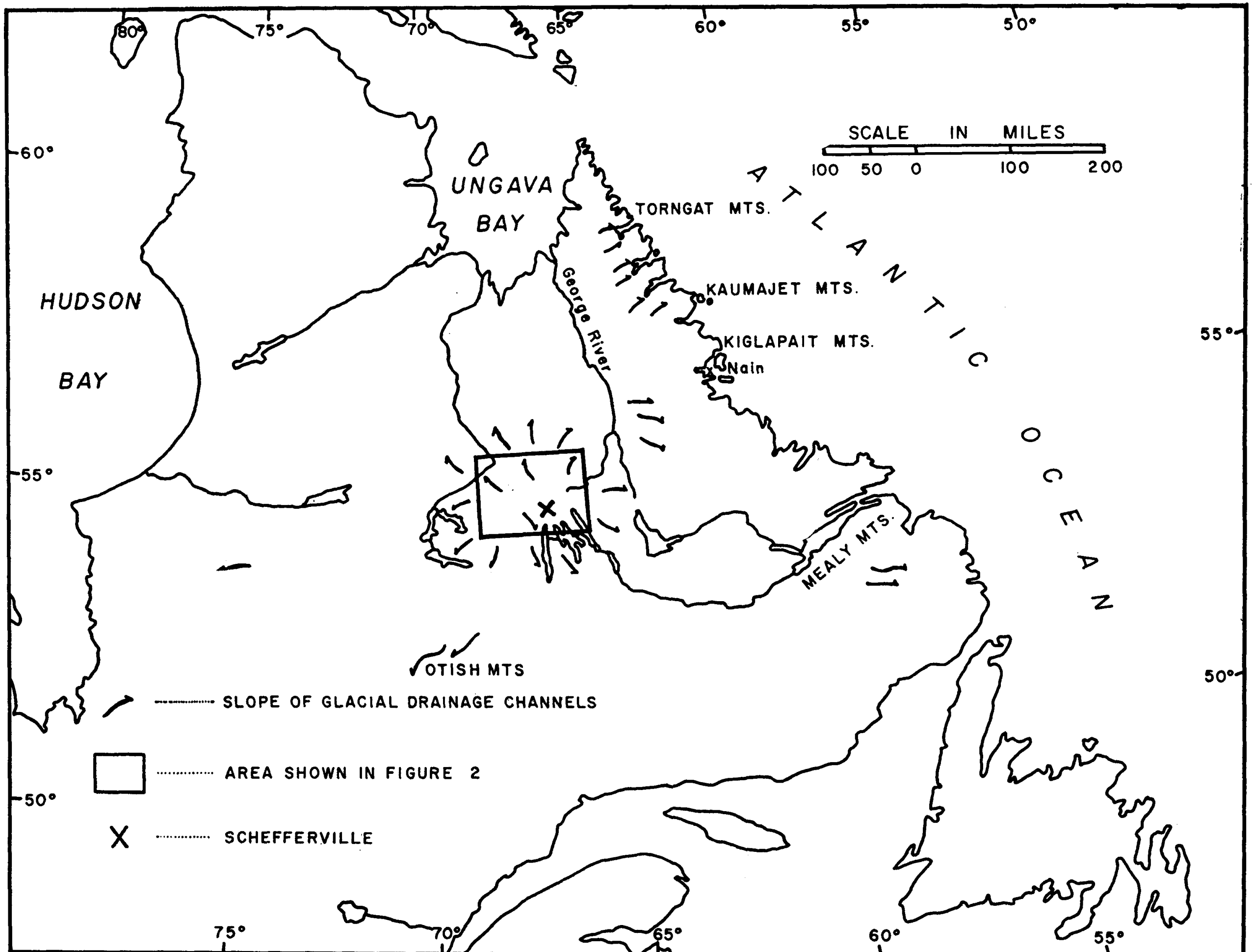


FIGURE I LOCATION MAP

tion of the channels, the map is somewhat schematic. The individual channels are shown slightly larger than true scale, and many have been omitted for the sake of clarity. On the other hand, every effort has been made to include any channel which does not conform with the regional pattern. An examination of the map will show immediately that there is a remarkable accordance in direction of slope of the channels over wide areas. North and west of the line drawn through the south end of Kivivic Lake all the channels have a strong northerly component in their direction of slope, whereas south and east of this line the prodominant direction of slope is southerly. Several factors affect the direction of slope of such channels ; first, the sub-glacial topography, second, the overall regional slope of the ice, and finally, the thickness and physical condition of the ice. The north-northwest to south-southeast alignment of many of the channels shown in figure 2 indicates the importance of the first factor. It is possible to delimit the area of the so-called Labrador Trough, where the Proterozoic meta-sedimentaries have a marked N.N.W. to S.S.E. trend, from the area to the west, which is underlain by Archean granitic gneisses, merely from this alignment of the channels. The western boundary of the Labrador Trough clearly approximates the course of the upper Goodwood and Howells rivers. It is possibly the factor of topographic control alone which makes it feasible to draw a line demarcating the northerly sloping channels from those sloping towards the south. It is stressed, therefore, that although this line is referred to on the map as the « theoretical ice divide » it is not intended to suggest that the last remaining ice was necessarily a single body with its main diameter coincident with this line. On the contrary, as the relief in this area is of the order of 1,000 feet, it is envisaged that the final remnants were detached masses melting *in situ* with the intervening ridges projecting as ice-free areas. Thus the vicinity of Kivivic Lake is recognized as one such site which was occupied by stagnant ice after glacier ice had generally wasted from the « lake plateau » area. Other sites are situated in the valley bottoms along the dividing line, both to the east-northeast and west-southwest. It is noted that as the altitude of the Swampy Bay River valley is somewhat lower than that of Kivivic Lake, ice may have remained there longer than in the latter valley because its original thickness was that much greater. This suggestion is supported by the field evidence. Some 12 miles north of Kivivic Lake and immediately east of the south end of Partington Lake there occurs a broad col in one of the main structural ridges. This col overlooks the Swampy Bay River and carries a series of glacial drainage channels which first slope down towards the north on the Swampy Bay River side of the ridge. The channels have been deflected through the col and as they emerge from it they curve round the south side and slope down towards the south into the Lespinay Valley. Although they are sub-glacial channels, at least where they emerge from the col, they indicate that at the time of their formation the ice was somewhat thicker in the Swampy Bay River valley than towards the southwest.

These general considerations are supported by an attempt to extend the « ice divide » beyong the area of the Labrador Trough. In the areas underlain by Archaean rocks, which occupy the greater part of the « lake plateau » no

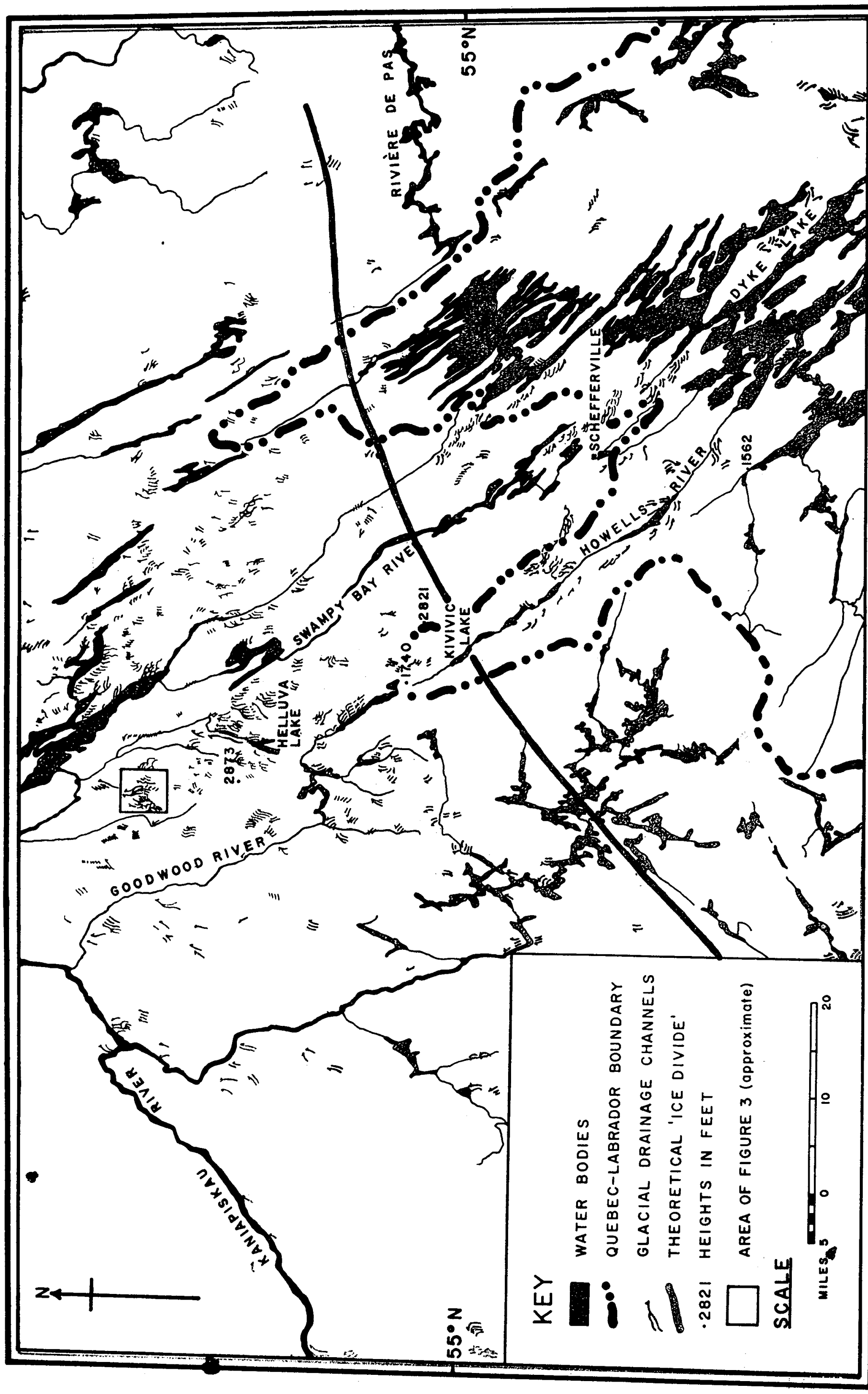


FIGURE 2. GLACIAL DRAINAGE CHANNELS IN CENTRAL LABRADOR-UNGAVA

clearly defined alignment can be detected because there is no regular topographic alignment. Passing eastwards and westwards from the Labrador Trough to beyond the area covered by the map the channels become fewer in number and less regular in alignment. The density of the channels also clearly indicates the topographic conditions and, more particularly, the depth of the till. Till is more uniformly spread and of greater depth in the Labrador Trough than on granitic gneiss areas, which are frequently bare over great distances. Despite this, however, it was established from a study of the air photographs that the flow of melt-water has been generally outward in all directions from the Kivivic Lake – Swampy Bay River area, although the scarcity of the channels renders this conclusion not particularly satisfactory. At least it can be said that there is no evidence at present available which contradicts this.

The Otish Mountains, some 200 miles southwest of Schefferville, rise to almost 4,000 feet above present sea level and stand over 1,500 feet above the surrounding country. It appears that they projected through the ice sheet relatively early in the waning stage and that melt-water channels, formed subsequently about their flanks, have a southwesterly direction of slope. Similarly, the few channels located to the south of the Mealy Mountains have a slope towards the southeast, while those on the highlands to the east of the junction of the George River with the Rivière de Pas slope down towards the east and southeast. The only other area where a high density of glacial drainage channels was recorded is the coastal area from Nain northwards, and particularly in the Torngat Mountains where flights of 100 and 130 channels were investigated in the great east-sloping troughs. Here the channels invariably slope down towards the east, and immediately west of the present watershed none is to be found, an understandable condition for this is the area of the ice-dammed lakes (Ives, 1957, p. 80 ; 1959).

The regional direction of slope of the glacial drainage channels across Labrador-Ungava, despite the paucity in number of the channels over wide areas, forms a pattern sufficiently striking to suggest that the regional slope of the ice sheet was comparable in direction with that of the channels and that the progressive « down-melting » and concomitant recession of the ice-front proceeded inwards from the east coast towards the west, and ultimately towards the final centre of wastage some 25 miles north of Schefferville. A parallel study of the position and altitude of former ice-dammed lakes (now being prepared for publication) fortifies this conclusion to a considerable extent.

The type of channel, the degree of slope, and the position in relation to topography and pre-existing ice mass, remain to be examined from the point of view of their value as indicators of late-glacial conditions.

The channels in the coastal area of the northeast are predominantly lateral and sub-lateral in type. It is suggested that rapid ablation of the order of 15 feet per year is indicated. The channels are generally confined below the 2,200 foot contour, and even the « col gully » of Mannerfelt (1949, p. 194) is rarely found above this level. This would suggest that the initial emergence of these mountains, which exceed 5,000 feet in height, was the result of decreased

FIGURE 3: Glacial drainage channels north of Helluva Lake

Contour interval 50 feet; Scale in miles 3/4 1/2 1/4 0 accumulation rather than rising temperatures, and that the snowline did not rise much above 2,200 feet, above which melt-water features are absent. Conditions were much more complicated than this simple explanation would indicate for it has been suggested that during the final glaciation continental ice did not exceed the general altitude of 2,200 feet in the mountains, and that the erratics found on some of the highest summits were emplaced during an earlier glaciation (Ives, 1959). From the foregoing it is only possible to conclude that the snowline was higher than the existing ice mass, that is, higher than 2,200 feet, but it is extremely unlikely that it rose above the summits. This is supported by the fact that the snowline today (approximately 3,500 fet.) is beneath the highest summits and in late-glacial time there was certainly more active ice in the Torngat Mountains, in the form of cirque glaciers and possibly small local ice caps, than there is today.

In considering a later stage of this process of wastage the area to the east of Indian House Lake on the George River is significant. On the higher land col gullies and lateral and sub-lateral drainage channels indicate that melt-water drained eastwards and that the entire area, rising to more than 2,500 feet, lay below the snowline. These features, taken in conjunction with an extensive system of ice-dammed lakes, indicate that westwards the ice was sufficiently thick and massive to prevent sub-glacial drainage along the natural slope of the George River depression. Sub-glacial channels are virtually absent and the ice is believed to have been active at this stage.

The final stage of wastage, represented by the glacial drainage channels in the vicinity of Schefferville, is characterised by an abundance of sub-lateral and sub-glacial types which indicate that at this time the ice was relatively rotten and also probably at the pressure-melting point. Figure 3 shows a good example of channels formed by the extensive undercutting of the ice mass 12 miles north-northwest of Helluva Lake. The vertical interval of these channels ranges from 0.5 to 76 feet, and the largest exceed 100 feet in depth. The larger ones acted as major channels for sub-glacial drainage for an appreciable number of years. Other general characteristics of the Schefferville channels are ; a tendency towards an anastomosing pattern, extensive development of tributary channels, and the absence of deltaic accumulations at the lower ends of most of the channels. These points all indicate the sub-glacial nature of the channels, and the general absence of deltaic accumulations implies that drainage proceeded beneath the ice, to, or below, the water-table of that time. This resulted in the relatively long-distant transport of the finer material eroded from the channels, a conclusion corroborated by the widespread and irregular occurrence of fluvio-glacial sands.

The sub-glacial nature of most of the channels suggests that the ice was sufficiently impervious and that its slope was sufficiently great to give a general direction to the slope of the channels, as is shown in figure 2, and so to resist complete sub-glacial topographic control of the slope of the channels. In a few limited instances, however, the direction of slope of the channels is the reverse of that of the inferred slope of the ice surface. A large group of sub-lateral and sub-glacial drainage channels is situated 15 miles north-northwest of Schefferville in the vicinity of a small lake known locally as « Snowy Lake ». The overall direction of slope is southerly, that is, accordant with the inferred slope of the ice surface in this area. Eight hundred yards west of the main series is a broad shallow valley which slopes down towards the north. Several channels on the lower slopes and floor of this valley slope downstream towards the north for several hundred yards to where the valley opens out and terminates. Here the channels swing around the spurs to west and east respectively, eventually falling into the southerly sloping channels on the east side of the Howells River Valley and into those of the « Snowy Lake » series. This instance of almost complete topographic control on the direction of slope of glacial drainage channels is important in that it supports the contention that these particular channels were formed sub-glacially, and it also indicates the degree to which sub-glacial melt-water was able to penetrate beneath the ice mass.

The study of a series of glacial lake shorelines to the west of Helluva Lake also emphasised the extent of the sub-glacial penetration of melt-waters during the final stages of deglaciation. One particular lake was damned at successively lower levers in a south-facing valley in this area where the regional slope of the ice was down towards the north. The overflow from the uppermost level was across a bedrock col towards the northeast, and thence further north-east beneath the ice still remaining in the lower part of the valley. The ice at this time dammed possible outlets to the south and west. The westerly outlet was next exposed and the lake level fell by 45 feet. The overflow channel then formed was directly across a plug of till near the upper end of the valley which sloped down towards the west, and the channel was cut along the floor of the valley, despite the fact that its lower section was still choked with ice to a depth of at least 200 feet. In other words the drainage was sub-glacial once the actual col had been breached. At this point it is worth nothing that ice-dammed lakes in the general Schefferville area were few and far between and were invariably of small extent, a condition compatible with the statement that this area contained the final mass of wasting ice and that drainage was generally outwards from it in all directions.

Enough has been said of the disposition of the channels to permit the conclusion that, in the vicinity of Schefferville, the ice, at least during the final stages of wastage, was at the pressure-melting point, that the snowline was well above the land surface, which reaches a maximum height of 2,875 feet, and that large volumes of melt-water formed annually. It may also be concluded that the ice was stagnant and melted as detached pieces *in situ*. Today, despite the relatively heavy accumulation of winter snow, and despite the frequent vigour of the initial melting phase in the late-spring, melt-waters are not at present modifying the form of the glacial drainage channels. The present mean annual temperature, based upon a ten year period of observation, is 23.9°F. This is only a few degrees higher than that compatible with the active development of permafrost (i.e. 21.0°F.) Similarly, if large masses of ice existed at a time when the annual mean temperature was only slightly below that of today, it is reasonable to postulate that the temperature regime of the ice would have been negative. The conclusion, put forward here for discussion, is that the mean annual temperature (and particularly the summer temperature), during the period of final melting of the ice sheet on the « lake plateau » was comparable with, if not higher, than that of today.

Such a conclusion is hardly compatible with the present line of thought of the botanist and pollen analyst in this area. Grayson, using radiocarbon dating methods, proposed a date of 5,300 $\pm$ 800 years B.P. for the bottom layers of a bog in the Greenbush area some 20 miles north-northwest of Schefferville, and an extrapolated date to 5,600 to 5,750 years for the initial uncovering of the area by the melting ice. He also suggested on palynological grounds that the climate of the immediate post-glacial period was cold and dry and that the general temperature trend since has been one of increasing warmth (Grayson, 1956, pp. 198-205). It is interesting to note that this bog lies only a few miles south of Kivivic Lake and its locality is suggested by Grayson (see pages 205 to 209) as the final area to emerge from the ice. Such a late date for final deglaciation falls well within the « Thermal Maximum » dated by Flint and Deevey (1951) as 6,000 to 7,000 years ago. Although Grayson sees no reason to suppose that temperatures in the past ever exceeded those of the present in this area, perhaps it could be suggested that long range wind transport of pollen, the effectiveness of which has been ably demonstrated by him, was not sufficient to allow rapid vegetational development to a climax in relation to the temperatures prevailing at that time and upon raw till immediately uncovered by the melting ice. It is suggested, therefore, that the temperature was warmer than the vegetation indicates, there being a lag between rate of climatic amelioration and development of vegetation. That this postulated warm period was followed by one of falling temperatures is readily demonstrated by the pollen profiles of Grayson and by Henderson's study of the nivation hollows (Henderson, 1956).

Finally, it is interesting to quote Grayson's dates for the deglaciation of three localities situated approximately along the Schefferville meridian. These dates are all based upon radiocarbon countings to which is added an allowance for the formation of the bottom few inches of each bog which could not be sampled. The date for the deglaciation of the Greenbush area has already been given as 5,600 to 5,750 years before present. Grayson calculated that the ice left the Marymac Lake area, some 170 miles north-northwest of Schefferville, about 8,000 years ago, and a date of 8,500 years ago is suggested for the deglaciation of a site 130 miles south of Schefferville. It is from these dates that Grayson postulates that the Greenbush area was the last area of the « lake plateau » to emerge from the ice sheet. Whether these dates be absolute or relative does not affect the comparison with the essentially similar conclusion drawn from the study of the glacial drainage channels. The valley bottoms in the Kivivic Lake and Swampy Bay River areas are very close to Greenbush and the close accordance of the conclusions of a botanist and a geomorphologist from two independent pieces of research is yet another illustration of the value of studying essentially one problem by utilising the methods and accumulated knowledge of two disciplines. It is only to be hoped that the detailed evaluation of the deglaciation across Labrador-Ungava, which this introductory paper indicates as a problem for the future, will be undertaken by a close field combination of botanist and geomorphologist.

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