Canada

GEOGRAPHICAL PAPER No. 29

Geomorphological Studies in Northeastern Labrador-Ungava

J. T. Andrews
E. M. Matthew

GEOGRAPHICAL BRANCH
Department of Mines and
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P R E F A C E

This paper deals with aspects of the physical geography of a section of northeastern Labrador-Ungava. It represents part of an over-all study of the glaciation and deglaciation of the peninsula initiated in 1955 and contributes to the terrain analysis program of the Geographical Branch. The research described is the preliminary result of field work in 1960 conducted in two widely-spaced, yet interdependent areas, and places particular emphasis upon the successive uncovering of the land from the maximum of the last glaciation.

N. L. Nicholson
Director
Geographical Branch

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INTRODUCTION

Since the days of Dr. A. P. Low, the central tracts of Labrador-Ungava have been recognized as one of the major centres of ice accumulation and dispersal on the North American continent (Low, 1896). Despite this, the paucity, rather than the abundance of field data remains the striking factor to any student of palaeogeography. High calibre research, outstanding in detail and precision, has led to rapid advances in knowledge on the peripheries of glaciation, yet the basic fact remains that there is still little scientific information on the source of origin of many of the glacial pulsations, and certainly on the locus of initiation and final dissipation of successive ice masses. Some of the fundamental reasons for this are to be found in relative inaccessibility, difficulties of terrain and climate, and problems of precise field operations dependent upon accurate maps. Perhaps another reason, springing from the sum of the others, is the widely accepted view that centres of dispersal are difficult areas in which to work because erosive action and transport, predominating over deposition, have resulted in the destruction of a large proportion of field evidence.

Following Low, and with the exception of occasional scattered observations along the Labrador coast, and a handful of adventurers who travelled overland, only E.P. Wheeler 2nd and V. Tanner have made any serious contribution to glacial problems until recent years. The important theoretical discussions of Flint (1943, 1951, 1953), however, by critically examining the existing field data and by providing stimulating suggestions, set the stage for a co-ordinated attack on the palaeogeographical problems of the peninsula.

In 1955 it was possible to view at first hand the centre of ice dispersal on the central plateau north of Schefferville. Many of the assumed problems facing field research were real, but many proved obviously false. In particular, in contrast to a great scarcity of field evidence, the overwhelming abundance of well-preserved forms was so apparent that it more than offset many of the practical difficulties. From this initial experience an over-all field program was evolved, directed primarily towards studying the succession of events from the maximum of the last glaciation to the present. One outstanding problem was to determine from the field evidence the final maximum glacial stand. The controversy arising from this remains unsettled and has proved one of the most fruitful aspects of the work. At least a tentative starting point for the study of the deglaciation was pinpointed in the field evidence, namely the glacial trimline in the northeastern mountains which demarcates the lower altitudinal limit of the mountain-top detritus (Ives 1960a).

So far twenty discrete field areas have been examined by a total of eight geographers. The concentration of research has been in the northeastern quadrant of the peninsula between the Torngat Mountains, which provided the point of departure for the study of the deglaciation, and the central plateau in the vicinity of Schefferville, where evidence of final disintegration of the ice sheet was uncovered. Many institutions and individuals have contributed to carry the work to its present stage. The Geographical Branch and the Arctic Institute of North America provided vital support throughout the entire six-year period (1955-60) and the British Newfoundland Exploration Company and the Iron Ore Company of Canada rendered extensive assistance. Between 1957 and 1960 the program became the major concern of the McGill Sub-Arctic Research Laboratory at Schefferville which provided the primary base of operations and the bulk of the research staff. Equally important have been the stimulating discussions with, and advice received from, a large number of scientists; in particular Professor R. F. Flint, Dr. E. P. Wheeler 2nd and Mr. J. P. Johnson Jr. Similarly, the work of Dr. Eilif Dahl (see Dahl, 1955) in Norway has had a pronounced influence upon the recognition and interpretation of mountain-top detritus and the evaluation of the relationship of its distribution to the former extent of glacial ice. This influence culminated in a combined field excursion with Dr. Dahl in Norway in August, 1960. Consequently, Andrews' discussion of the upper limits of glaciation in his section of this report has been set within the framework of the Norwegian field evidence.

The basic reason for conducting examinations of widely-spaced and discrete field areas was to provide a framework within which more detailed work could be carried out. The major objective was first to locate and describe the vital field evidence in a sufficient number of areas. Preliminary attempts to correlate and interpret this information are necessary if only to provide added stimulus to future field work. Thus many of the conclusions drawn in the preliminary reports (Ives, 1960a) will be, and are now being, modified, a situation which is regarded not as a weakness in the over-all program but a sign of its strength, resulting in the gradual evolution of a more and more realistic picture.

The present paper represents preliminary reports on two complementary studies carried out in 1960 by J. T. Andrews and E. M. Matthew of the 1959-60 staff of the McGill Sub-Arctic Research Laboratory. They were assisted in the field respectively by T. H. W. Fielding and A. Strowger, both students of Cambridge University. Figure 1 gives the location of the field areas and indicates the significance and interdependence of the two studies which provide a time sequence for a large part of the progressive deglaciation of the northeast quadrant of the peninsula. Andrews, working on the east coast, has been able to evaluate deglaciation from what may be the maximum stand of the last glaciation (the high-level lateral moraine phase) to the final withdrawal of ice from the major coastal valleys. The work of Matthew virtually takes up the pattern of deglaciation from where that of Andrews leaves off, and outlines the wastage of ice on the plateau to the west, and the formation of a series of ice-dammed lakes in the basin of the George River. The east-west line of reference represented by these two reports conveniently crosses the northeast-southwest line of reference, ranging from the Torngat Mountains to Schefferville. Thus the data and preliminary conclusions have far-reaching effect; they greatly assist in creating a more realistic picture than that drawn from the earlier work, they give a more closely-knit field coverage, and they provide a vital link with the current work in the Torngat Mountains (Løken 1960 and personal communication).

J. D. Ives
Geographical Branch.

THE GLACIAL GEOMORPHOLOGY OF THE NORTHERN PART OF THE NAIN-OKAK SECTION OF LABRADOR-UNGAVA

by J. T. Andrews

PREVIOUS STUDIES AND OBJECTIVES OF THE FIELD WORK

Although there is no reported work in the actual area of field study, (Figure 1) several investigators have examined neighbouring sections of the Labrador coast. Of these, Wheeler has been most intimately associated with the Nain-Okak section and it was he who first introduced this name (Wheeler, 1935). In addition to geological and topographical studies he has contributed many significant observations on the glaciation of the area (Wheeler, 1958). Tanner examined the coastal sector between Cartwright and Hebron and his monograph contains the greatest single contribution to an understanding of the glacial history of the peninsula as a whole (Tanner, 1944). Tanner concurred with Odell (Odell, 1933) by stating that, at the maximum of the last glaciation, even the highest coastal summits were completely inundated. Following the maximum he proposed rapid down-wasting as the snow line rose above the land surface, kame terraces and marginal lakes being formed between the wasting ice and the emerging land until the final remnants of the ice melted in situ in the valley bottoms. Tanner did consider the possibility of limited halts and re-advances of the ice margin based upon knowledge of the existence of occasional end moraines, although he gives the over-all impression of general absence of these recessional features. His most detailed work was on the marine strandlines and he concluded that the marine limit rose from 227 feet above present sea level near Cape Mugford to 312 feet at Windy Tickle.

Wenner, who worked with Tanner (Wenner, 1947), studied pollen profiles taken from the peat bogs of the coastal area. He postulated that heath layers found within the bogs were contemporaneous with those in northern Europe and, by comparison, concluded that the Labrador coast emerged from the ice in Finniglacial time, that is, about 9,000 B.P. His figures for the marine limit in the Nain-Okak section are more conservative than Tanner's, giving 266 feet as the highest in the area.

Until recent years the work of the Tanner expeditions was the latest attempt to unravel the glacial history of the coast. The one exception is Flint's theoretical consideration of the initiation of glaciation in North America and his direct comparison with the now classical ideas of the development of the Scandinavian

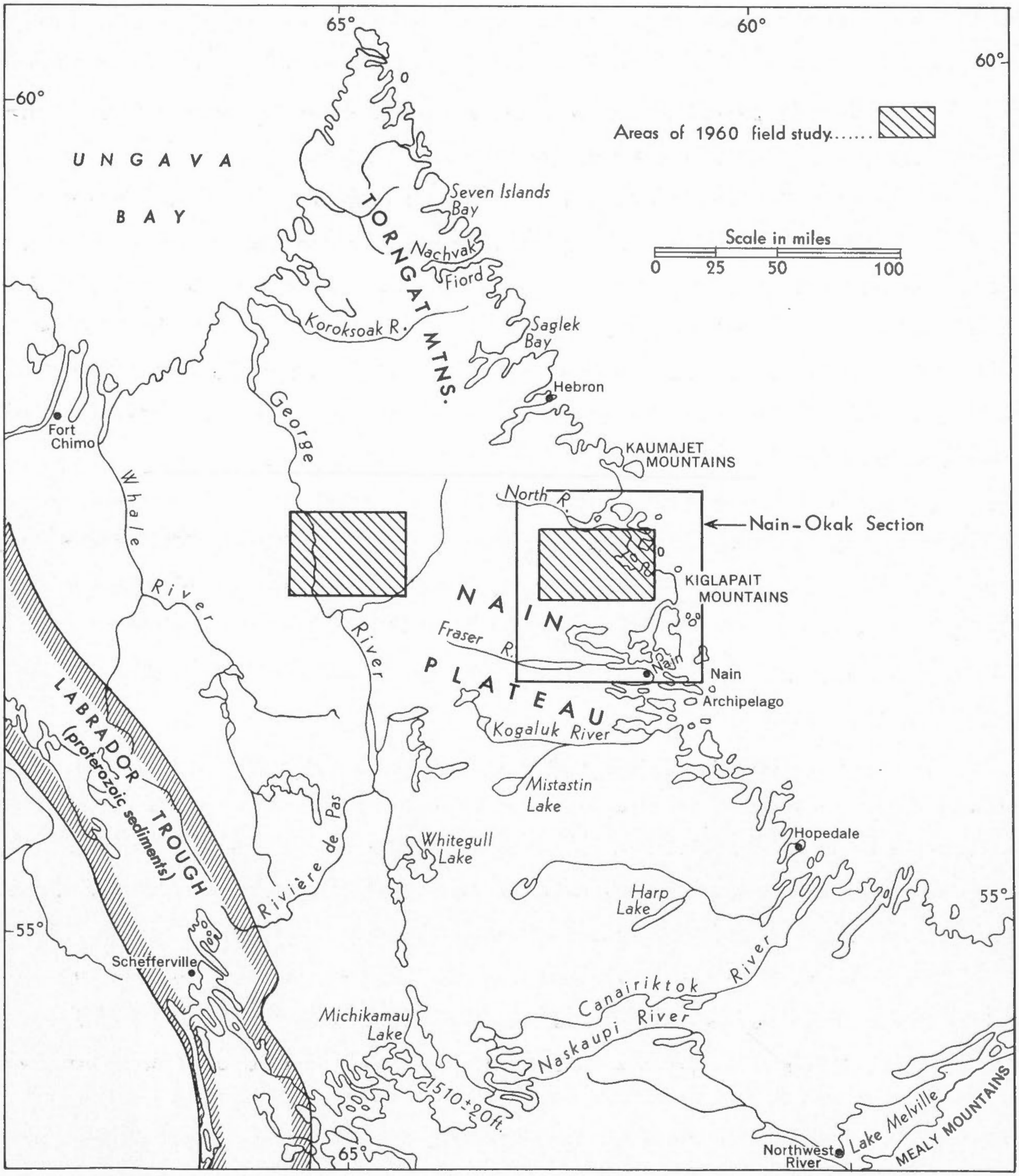

Figure 1. Northeastern Labrador-Ungava and the location of the field areas. The open rectangle denotes the entire area of the Nain-Okak section.

ice sheet (Flint, 1943). Flint envisaged the inception of glaciation on the coastal mountains and the gradual growth of the ice sheet towards the west. Ives (1957) and Wheeler (1958) have not accepted this theory. Ives proposed the concept of instantaneous glacierization across wide areas of the Labrador-Ungava plateau resulting in predominant eastward movement across the coastal mountains. Ice caps and glaciers which formed in the northern coastal mountains were only of local significance, and Wheeler (1958) adds that only corrie glaciers flourished in the Kaumajet and Kiglapait mountains.

Tomlinson, working in the Okak Bay and Cape Mugford areas in 1958 recognized extensive areas of lateral moraines and kame terraces in some of the main valleys leading down to the coast, referring them to an "outlet glacier" phase (Tomlinson, 1959). Finally, Johnson studied the marine and glacial features in the Webb Bay-Port Manvers Run sector in 1956 and 1957. He also recognized a phase when ice moved in streams from the interior through Port Manvers Run and along the east side of South Aulatsivik Island (Johnson, personal communication, 1960). Thus the precise choice of the area of study for 1960 was naturally guided by the recent work of Tomlinson and Johnson.

The main objective of the field work was a detailed study of the significance of a series of high lateral moraines and a complex system of end moraines in the valleys leading out onto the Tasiuyak Tasialua lowland (Figure 2). In particular, a study was to be made of the relationship of the high lateral moraines to the maximum of the last glaciation, and of the successive series of end moraines to the pattern of deglaciation. This report represents a preliminary study of the air photos and the field data, and in no way is to be considered final.

PHYSIOGRAPHICAL AND GEOLOGICAL BACKGROUND

The Nain-Okak section is composed of metamorphic and igneous rocks, mainly Archaean in age, though it should be noted that Wheeler has discovered limited occurrences of sandstone (equivalent to the Double Mer sandstone) lying unconformable to the Archaean basement on the plateau. The main rock types are paragneiss, intermediate and mafic gneiss, anorthosite and adamellite.

In a simplified manner the topography of the Nain-Okak sector can be described as an uplifted plateau block sloping gently westwards and rising to over 3,000 feet on the coast. Following and during uplift the high eastern rim suffered dissection by fluvial action and was later modified by glacial erosion. Tectonic disturbances played a part and the variety of lithology and structure has made itself clearly apparent,

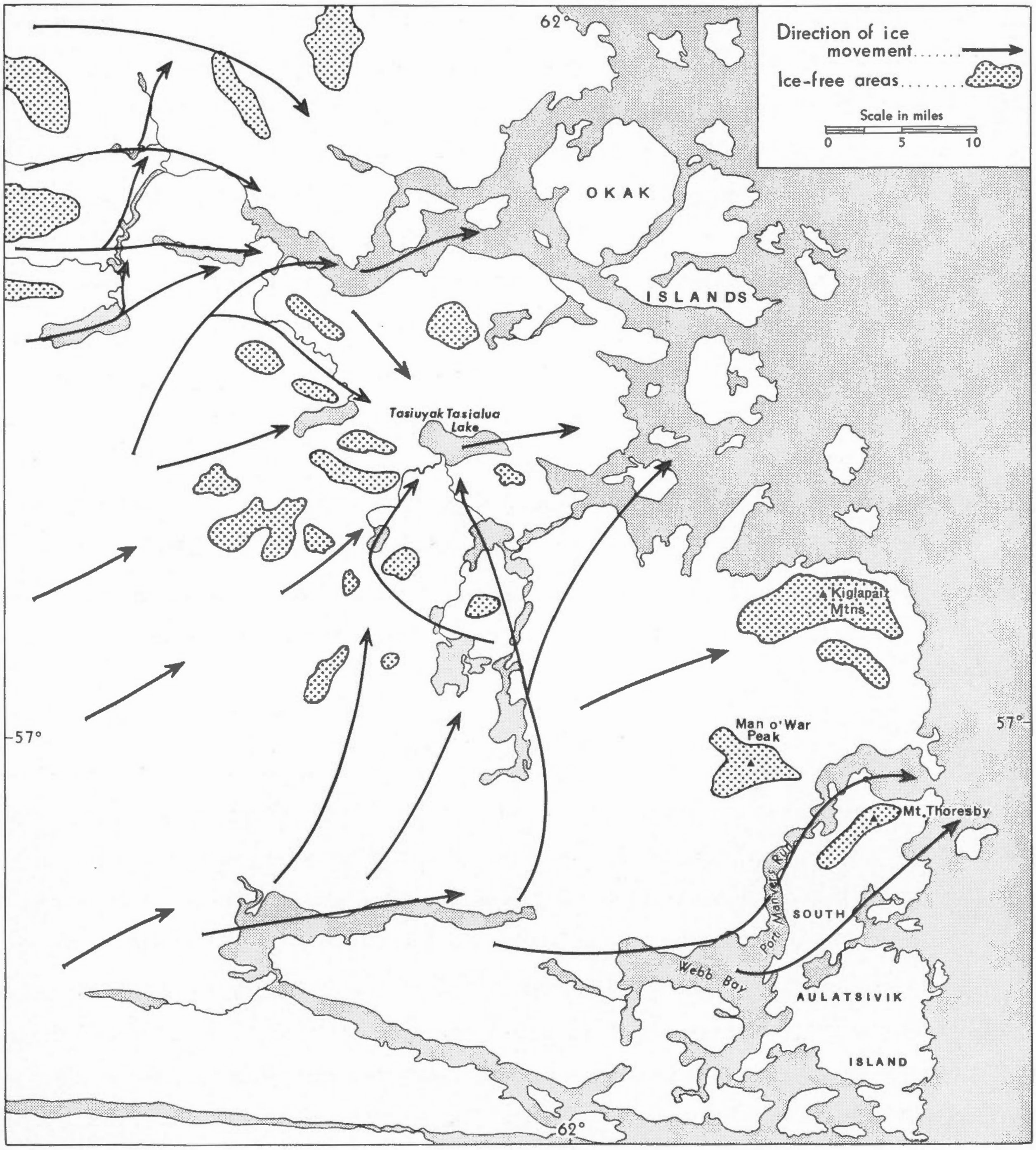

Figure 2. The pattern of ice movement in the Nain-Okak section at the maximum of the last glaciation.

and may, in fact, be more significant than the simplified picture presented here indicates. Wheeler had delineated three morphological regions based upon this description. In the east is the Island and Bay Zone representing the most deeply dissected and drowned portion of the coast. Several of the bays are linked by north-south U-shaped troughs, such as Port Manvers Run and the Webb Brook-Tasiuyak Tasialua trough. The bays cut deeply into the mainland and are often closely associated with the Valley Zone. Here relief is of the order of 2,000 feet and accordant summits close to 3,000 feet suggest the former greater extension of the now dislocated plateau surface. The area is essentially a series of dissected blocks separated by deep U-shaped troughs leading from the plateau towards the sea. Figures 5 and 6 illustrate the character of the zone, showing the deep U-shaped valleys and the steep-sided, often flat-topped, interfluves. Wheeler 1935, gives an average width of 20 miles for the dissected valley zone, although occasional valleys, such as that of the Fraser River, owing to favourable structural conditions, have penetrated the plateau by a much greater distance. At the western limit of the zone the valleys rise abruptly, and often precipitously, into the Interior Zone. Here the relief is generally less than 500 feet with summits not exceeding 2,500 feet. This is the plateau area possibly an uplifted peneplain (or peneplains) of complex origin. In this sense the boundary between the Interior Zone and the Valley Zone represents the head of rejuvenation of the coastal streams.

The three morphological units are most fully developed in the Nain-Okak section, and the deep valleys draining eastwards from an extensive sector of the Labrador-Ungava plateau, together with the actual displacement of plateau, mountain block and sea, have been vital in the pattern of glaciation and deglaciation.

GLACIATION AND DEGLACIATION

With the lowering of the regional snow line, the development of coastal corrie glaciers would be followed by the growth of the ice cap on the plateau. As the ice cap grew outlet glaciers would extend through the existing valley system to the coast. With continued accumulation on the plateau the outlet glaciers would thicken and expand until much of the higher land was inundated, although the maximum thickness attained on the coast remains a controversial subject. Ives (1958b) by extrapolation of his work on mountain-top detritus in the Torngat Mountains to embrace observations by Wheeler, Morse and Johnson,* suggested that one or two nunataks in the Kiglapait Mountains probably remained throughout the final glaciation. This hypothesis has been extended and supported by Løken (1960) in the northern Torngat Mountains, although opposed by

*Personal communications, see Ives 1958b page 29.

Tomlinson (1959) with respect to the Kaumajet Mountains.

During the 1960 field season as many summits as possible were examined and no trace of mature mountain-top detritus, in the sense used by Ives (1958b), was discovered. On all summits above 2,400 feet, however, incipient mountain-top detritus was observed. These summits were all to the west and south of Lake Tasiuyak Tasialua. The attempted ascent of Mount Thoresby (3004 ft.), for examination of reported mature detritus, had to be abandoned because of bad weather. The existence of mature detritus on Mount Thoresby and ManO'War Peak (circa 3,500 feet) can be explained in two ways: either the peaks were nunataks at the maximum of the last glaciation, or else they were covered by slow-moving or stagnant ice which was essentially thin. In either case this gives an indication that in the vicinity of the outer coast (Mount Thoresby) the maximum thickness of the ice was approximately 3,500 feet (3,000 feet above present sea level). This has been taken as the thickness at the maximum of the last glaciation (Ives, 1960a). There is, however, another possible explanation which has been suggested (Ives, personal communication, 1960) and which agrees more fully with observations in the Lake Tasiuyak Tasialua area.

A study of the character of rock weathering above and below the zone of high lateral moraines shows an important difference in the degree of weathering with incipient mountain-top detritus above the moraines and freshly glaciated surfaces below. The important question in this respect is the rate of weathering of the bedrock: the incipient detritus could have formed in the interval between thinning from the maximum stand of the last glaciation and a period of glacial stability represented by the extensive development of lateral moraine systems: or it could represent weathering during the whole of the last glaciation. In the latter case the lateral moraines themselves would mark the upper limit of the last glaciation and the mature mountain-top detritus on Mount Thoresby and Man O'War Peak would represent the nunatak zone of an earlier and more extensive glaciation.

On the air photos, extensive systems of high-level lateral moraines can be traced in most of the main valleys as far north as the southern Torngat Mountains and it is reasonable to suppose approximate contemporainity of formation. As a working hypothesis to form a basis for the present study, it is tentatively concluded that the high lateral moraines, the kame terrace-lateral moraine phase of Ives (1958a) and Løken (1960), mark the upper limit of the last glaciation. If this should be borne out by future work, then the moraines in question would have full stadial significance.

GLACIAL GEOMORPHOLOGY OF THE NAIN-OKAK SECTION

THE HIGH LATERAL MORAINES AND KAME TERRACES

The most complete development of the high lateral moraine-kame terrace system is found on the eastern and southern flanks of Mount Aupalukitak. At its lowest point the lateral moraine descends to 1,735 feet above sea level and consists of a 30-foot high ridge of sands, gravels and sub-rounded boulders sloping up towards the south at 100 feet per mile. The lateral moraine continues as a distinct ridge around the southeast flank of the mountain and eventually assumes the form of a broad kame terrace at 2,045 feet.

A massive lateral moraine was also examined with the same general slope down towards the north on the east flank of a hill farther south (Figure 7). The moraine could be traced for about 2 miles along the valley wall until, at 2,115 feet, it passed above the land surface. A continuation of the gradient of the lateral moraines northwards suggests correlation with similar moraines at a little over 800 feet in the vicinity of lakes Tasiuyak Tasialua and Umiakoviarusek and indicates a time when ice was moving into the Tasiuyak Tasialua lowland from the south, southwest, west, and possibly from the northwest. This would represent an anastomosing system of outlet glaciers in the valley zone draining the ice cap on the plateau to the west and south. Figure 2 shows the main directions of ice movement at this time and the areas that were ice-free. Any end moraines relating to this phase must be beyond the coast and below present sea level.

The pattern of deglaciation following the stand at the high-level lateral moraines was initially one of down-wasting, interspersed with periods of still-stand when additional lateral moraines were built at lower elevations. There is little evidence of accompanying melt-water activity; only one other kame terrace was found, and the moraines themselves are sharp-crested with slopes of up to 26°. It appears that this process of down-wasting was long-continued because on the south side of the valley between lakes Tasiuyak Tasialua and Umiakoviarusek, a minimum thickness of 50 feet of varved clays was found. As the individual varves varied in thickness between 1/4 and ½ inch, and if they are true annual features, they represent an interval of 1,200 to 2,400 years. The length of this period, when it is added to the time required for thinning and retreat from the high-level lateral moraines and that required for the additional retreat to the main end moraine positions, is extremely important. In fact, such a great interval of time is required that it adds appreciable support to the contention that the high-level moraines are of possible full stadial significance.

Continued thinning and retreat eventually brought the glacier termini to the positions shown on figure 3, although it is thought that the end moraines, traced in the field and on the air photos, are not strictly contemporaneous, but were formed at slightly different times due to differential retreat in the various valleys. This might possibly represent the effect of topography on the drainage from the ice cap on the plateau or variations in the source areas. It appears certain, for instance, that the Umiakoviarusek moraine is somewhat younger than the Tasuiyak Tasialua moraine since the outwash from the latter ends to the west in a lobate ice-contact feature which can only be explained by assuming that the Umiakoviarusek glacier stood at this advanced position. It is probable that well-developed end moraines, traced on air photos in the north-south valley north of Lake Umiakovik, date from this time.

The actual moraine system around the north end of Lake Tasiuyak Tasialua is one of great complexity (Figure 8). Two, possibly three, end moraines have been recognized in the field, indicating partial withdrawal and still stand. The pattern of regional ice movement during the time of main end moraine construction makes it likely that the moraines were built into pro-glacial lakes since ice blocked Tasiuyak Bay and partially filled Okak Bay, the normal drainage outlets. Sharp morainic ridges on top of the otherwise broad sand and gravel morainic belts possibly represent accumulation above water level. Further support for this is found in the presence of bedding in the main morainic belts, the water-washed appearance of their crests, and the location of the sharp crested segments exclusively on the southern and higher sections. With the withdrawal of ice from the Tasiuyak Tasialua end moraines the sea would have been able to enter the area, and it is contended that the somewhat younger Umiakoviarusek moraine was built up into the sea.

The marine limit on Tikkigatsiagak Island was measured at 265 feet, on the Tasiuyak Tasialua moraine at 285 feet, and on the upper terrace cut into the Umiakoviarusek moraine at 302 feet. This implies that the strandline of this phase has been tilted up towards the west at 2 feet per mile as a result of subsequent isostatic readjustment. A necessary corollary to the recognized pattern of deglaciation is that wide differences in the height of the marine limit from one point to another is extremely likely, the outer coast, at least in places, having been accessible to marine activity when the sea was still excluded from other areas by the presence of glacier ice.

LATER RETREAT PHASES AND POSSIBLE READVANCE

Broad generalizations on the course of the deglaciation in the area are rendered difficult by the complex conditions found in certain sectors. The most interesting area in this respect is that immediately north of Lake Puttualuk. Here a system of end moraines faces towards the southwest (Figure 3) and can be

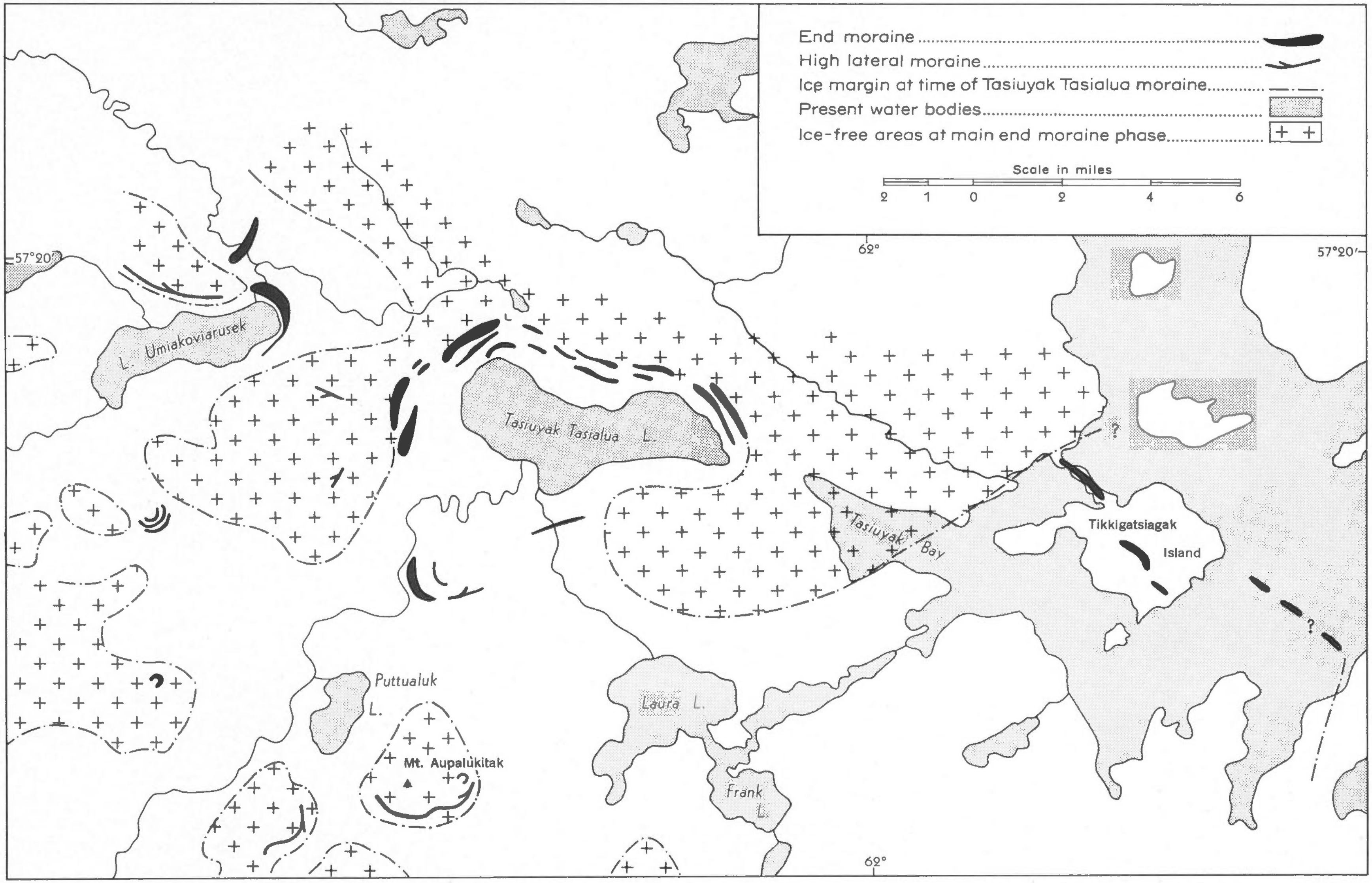

Figure 3. The main end moraine phase and the Tasiuyak Tasialua moraine system.

associated with ice that flowed from the Lake Laura basin around a rock ridge to face southwestwards. North of Lake Puttualuk a series of terraces in the enclosed northern part of the lake basin are equated with an abandoned col and drainage system that cuts through high level outwash deposits in the Puttualuk Valley. The most feasible interpretation is that ice streams from the basins of lakes Laura and Puttualuk retreated and separated from their former position at the Tasiuyak Tasialua end moraine. The retreat continued until the termini lay some distance south of the two lakes and outwash gravels had been laid down. Readvance sent a lobe of the Lake Laura ice around the rock ridge where it finally halted and built up a series of end moraines. At the same time, ice advanced up the Puttualuk valley to a point north of the present exit of the lake. The ensuing lake, dammed up in front of this lobe drained across the col and cut down through the old outwash deposits.

Indications of subsequent halts are to be found farther south again where two lateral moraines were traced to a col 500 feet above present sea level. Southward of this point examination of the air photos indicates continued retreat to a point north of Webb Brook, where ice contact features indicate final stagnation. No extensive areas of dead-ice topography were located except north of Lake Puttualuk where stagnation and melting of ice in situ is postulated as the ultimate phase in the wastage of an ice lobe which pushed over the col from the Lake Laura basin. Well-developed kettle topography is also to be found in sections of the Tasiuyak Tasialua moraines. It is therefore concluded that final recession in this area proceeded as "normal" retreat, rather than massive stagnation and melting of detached pieces of ice in situ.

LOCAL CORRIE GLACIATION

Evidence of extensive corrie glaciation until relatively recent times is abundant in the Torngat Mountains and to a lesser extent in the Kaumajet Mountains. In the 1960 field area four corries were examined and each furnished evidence of former activity with moraines occurring between 1,120 and 1,550 feet. According to methods formulated by Manley (1959) it is thought that when the corrie moraines were being constructed the corrie snow line stood at 1,600 to 1,700 feet. This allows a rough estimation to be made of the contemporary height of the regional snow line, which, allowing for climatic differences between the areas examined by Manley and the present writer, is placed at 2,500 feet. Similar consideration of the evidence afforded by the heights of the lateral moraines gives a minimum figure of 2,200 feet for the regional snow line. It therefore appears that corrie glaciers were active during the initial phase of slow wastage and retreat from the last maximum stand and that the corrie moraines are not recent features in this area. This is further supported by the comparable condition of both corrie moraines and the high level lateral moraines of the outlet glaciers.

SUMMARY AND CONCLUSIONS

From both the field data and the air photo interpretation it is apparent that Tanner's summary of the deglaciation of the coastal sector is an oversimplification. It is tentatively proposed that the upper limit of ice at the maximum of the last glaciation coincided with the lateral moraine-kame terrace level; this statement is largely based, however, on the qualitative study of differences in degree of weathering above and below this level. The ice wasted down slowly from this upper limit and the retreat and thinning was interrupted by periodic halts and possible readvances. The general lack of melt-water forms might be taken to suggest that the initial wastage was the result of decreased accumulation rather than increased air temperatures. With continued wastage the lower sections of the valleys successively emerged from the ice and a phase of end moraine construction occurred which resulted in the deposition of 500 feet of sediments in the Tasiuyak Tasialua moraine system. Only in specialized topographic localities is dead-ice topography to be found, and wastage occurred as "normal" retreat rather than the melting of detached remnants of stagnant ice.

The marine limit on Tikkigatsiagak Island was measured at 265 feet above present sea level and was found to rise up towards the west at 2 feet per mile, although this is not necessarily the direction of maximum tilt.

It is concluded that, within the limits of existing knowledge, there appears to be a marked parallelism of events during deglaciation of both the Nain-Okak and Torngat mountain areas and that the kame-terrace lateral moraine phase can be recognized throughout the coastal sector of northern Labrador. In conclusion the outline of the course of events is tabulated:

1- Formation of mature mountain-top detritus on isolated coastal summits.

2- Formation of incipient mountain-top detritus below the mature forms and above the lateral moraine-kame terrace level.

3- Construction of the high-level lateral moraine-kame terrace systems.

4- Slow wastage of the outlet glaciers and retreat of the termini, accompanied by corrie glacier activity and eventual shrinkage.

5- Readvance, retreat and final disappearance of the ice in the northern part of the area.

6- Withdrawal from the main end moraines and final deglaciation in the south.

The features itemized in points 1 to 3 were, in part, formed contemporaneously.

With the wastage of the final vestiges of ice in the main valleys the coastal sector became virtually ice-free, although the field evidence indicates that an ice sheet of considerable proportions remained on the plateau to the west. Drainage from the residual ice sheet was presumably responsible for the dissection of many of the glacial deposits in the coastal valleys and, with the development of systems of ice-dammed lakes west of the watershed, extensive dissection and deposition may be presumed to have occurred in those valleys running eastwards from the lower sections of the present watershed, although none of the valleys studied in the field appears to fall in this category. Following the deglaciation of the Nain-Okak section, subsequent phases of the deglaciation can be interpreted only from the field evidence on the plateau and in the basins of the George and Whale rivers farther west. Aspects of the subsequent phases therefore are dealt with in the final section of this paper.

DEGLACIATION OF THE GEORGE RIVER BASIN

LABRADOR-UNGAVA

by E. M. Matthew

PREVIOUS WORK

Explorers and scientists have rarely visited the lower reaches of the George River (Figure 4) and no detailed geomorphological or geological work has been carried out north of Indian House Lake. Existing observations are scanty, the product of parties making rapid cross-country traverses. The first recorded journey is that of John McLean of the Hudson's Bay Company who ascended the river in the middle of the last century. Shortly after the turn of the century Mrs. Leonidas Hubbard and Dillon Wallace led separate parties down the river, and it is from Mrs. Hubbard that the earliest valuable descriptions of the river are available. Her observations on the lower reaches of the river are, however, infrequent, and sometimes misleading. More recently, in 1947, Dr. J. Rousseau led a canoe party from the source of the river to its mouth, and although principally interested in botany and vegetation zones, he made a number of comments on the geology and glacial morphology of the valley. In 1958 a party working under contract for the Quebec Department of Hydraulic Resources levelled along the river to within a short distance of tidewater; the establishment of these accurately levelled bench marks at 3 mile intervals has greatly facilitated subsequent geomorphological work. In the same summer Dr. J. D. Ives conducted detailed work on the glacial morphology and deglaciation of the Indian House Lake area. A summary of his conclusions is presented elsewhere in this paper, and for greater detail the reader is referred to the original source (Ives, 1960b).

PHYSIOGRAPHICAL AND GEOLOGICAL BACKGROUND

Little is known of the geology of the George River basin, but it is nevertheless well established that the river lies entirely within the Archaean province of the Canadian Shield. Previous workers have described the bedrock as composed of granite gneisses and schists, with diorite, anorthosite, and diabase intrusions in the extreme south. The Pyramid Hills area is composed largely of gneisses grading on the one hand into granite, and on the other hand into schists. A number of schists invaded by granite magma to varying degrees were observed; these migmatites, however, cover only a small percentage of the area

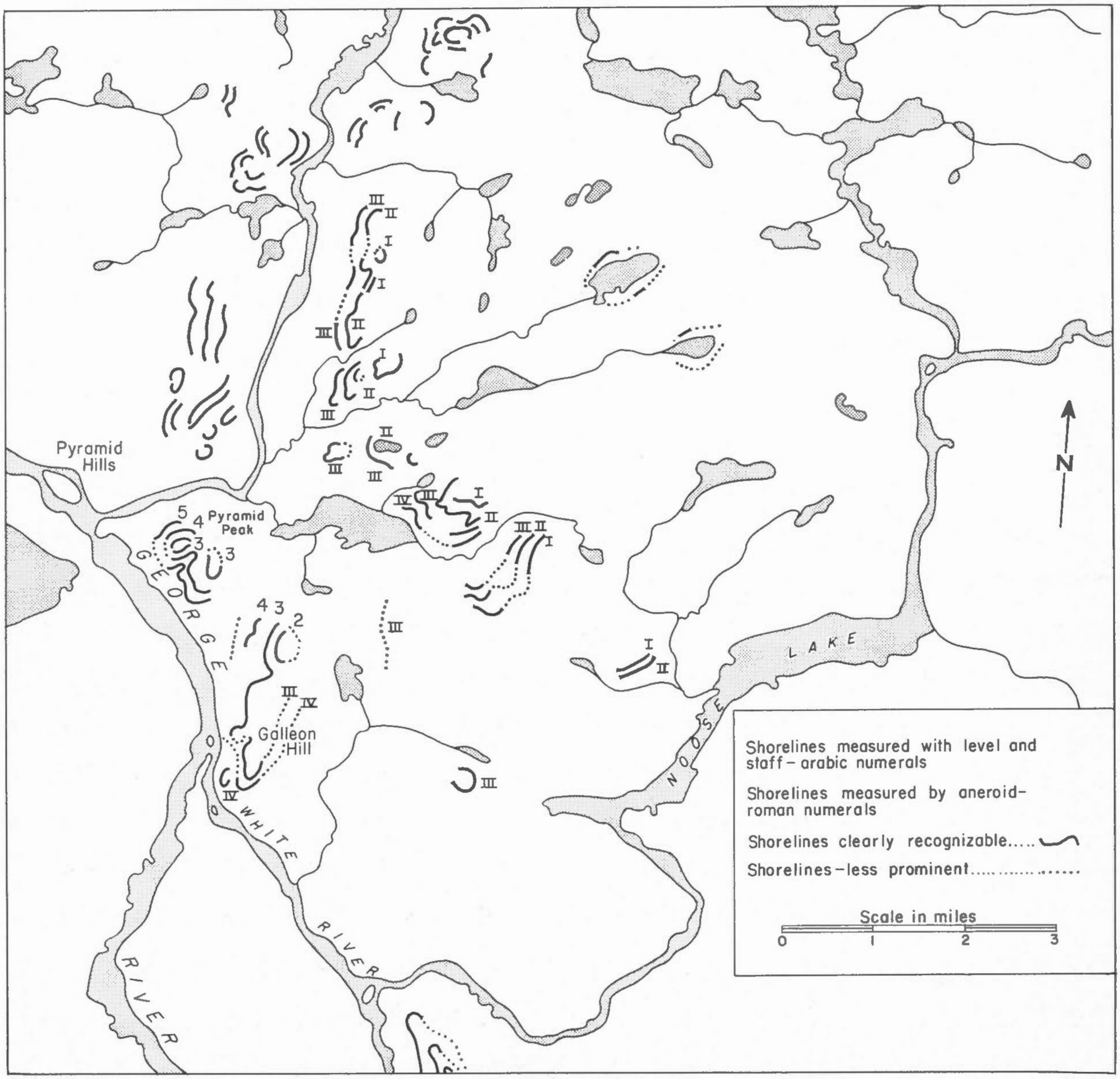

Figure 4. Sketch map of the more prominent Naskaupi glacial lake shorelines in the Pyramid Hills section.

investigated. Finely and extensively foliated schistose rocks are rather uncommon, and most of the area is underlain by coarse-grained granite gneisses, and granites.

A superficial examination of the area suggests that much of the drainage pattern is controlled by faulting, and Cooke (1929) has proposed that the depression of the George River may be tectonically controlled.

Tanner (1944), envisaged a fault scarp in the neighbourhood of the George River, with the surface to the west thrown down in relation to the east. Air photos reveal what appears to be a fault system, aligned NNW-SSE, that is utilized by a number of streams in the Pyramid Hills area. On this evidence it would perhaps be nearer the truth to say that north of Indian House Lake, at least, the George River utilizes a series of these fault lines in echelon pattern.

Rectangular jointing of the bedrock over wide areas is also clearly marked in the field, and small-scale topographical features are obviously influenced by this pattern. Narrow channels with vertical walls cut into the bedrock, and cliff faces up to 20 feet high are common on the higher ground where superficial material is either thin or entirely absent.

The section of the Labrador-Ungava peninsula through which the lower George River drains is composed of three major relief features. In the east is the Nain plateau (Figure 9), the surface of which falls gradually westward into the Whale River depression. The Nain plateau, described by Prichard (1911) as "the roof of the Labrador" is a rolling upland surface, covered with innumerable lakes and marshes connected by a maze of shallow watercourses. Low ridges and flattened hills rise little above the general level. The highest summits in the watershed area to the northeast of the Pyramid Hills reach 2,500 feet, but farther south the elevation of the watershed drops well below 2,000 feet in places. Towards the Labrador coast the plateau is deeply dissected, and its surface can only be recognized in some of the higher islands and peninsulas. Towards the west it falls away gradually towards the second major topographical feature of the region, the Whale River depression (Figure 10). No strict boundary between these two features can be drawn; the major topographical and structural break reported by Tanner in the vicinity of the George River is non-existent in the Pyramid Hills area, and no evidence can be found for it in the Indian House Lake area to the south, nor on the western margin of the Torngat Mountains to the north. Viewed from the summits in the vicinity of the river close to the Pyramid Hills, the general upland surface is seen to fall gradually westward, with no marked break in level, apart from the incision of the George River and its tributaries (Figures 11 and 12). Visual evidence of this sort is subjective, and could be misleading, but a number of east-west profiles drawn across the George River from the spot heights on the radar altimetry profiles support the field evidence. It is seen that the land surface to the east of the river is higher than it is to the west, but the transition is a smooth one, unmarked by any abrupt break in the profile (Figure 12). The lack of detailed knowledge of the topography and geology of much of the Nain plateau makes it impossible to date the surface but it is at least older than the Tertiary, probably very old, and possibly exhumed.

The incision of the George River into the plateau surface forms a local base level for the streams that are tributary to it. These streams have dissected the Nain plateau into numerous isolated and semi-isolated ridges and hills within a zone 10 to 15 miles east of the river. In the Pyramid Hills vicinity the local relief is of the order of 1,500 feet, and while relatively broad areas of the plateau surface are preserved in the ridge summits, the general topography varies from relatively broad, open valleys bounded by isolated hills and discontinuous ridges bordering the George River, to abruptly incised valleys dissecting the plateau surface towards the east. The unbroken plateau surface closely approaches the George River valley in the Pyramid Hills area, and the relative relief is probably greater here than anywhere else in the basin.

The George River is typical of the rivers of the peninsula, particularly in the character of its long profile. Its source lies in a chain of lakes to the north of Lake Michikamau, and over its upper reaches it winds in a broad, open depression over the lake plateau, frequently widening into a series of lake expansions. The mid-section of the river may be said to begin where the river drops over a series of rapids into a distinct valley, and continues its broken and interrupted descent until it reaches the extensive expansion of Indian House Lake. The lower section of the river, from the foot of Indian House Lake to the sea, is composed of a virtually uninterrupted series of rapids and fast flowing water. Hills and ridges hem in the valley closely on both sides, and the inside bends of the river are frequently the sites of low terraces of fluvial material (Figure 10). Over this section from Indian House Lake to the sea, a distance of roughly 140 miles, the river descends 1,000 feet.

GLACIATION

All the evidence from the Pyramid Hills area points to complete inundation by a continental ice sheet of considerable depth. The summits of the hills and ridges are rounded and smoothed, and over limited areas the upland surface is completely bare of superficial material or vegetation. A litter of pebbles and boulders, many of the latter being perched, some precariously, on the bare slabs of bedrock, is found widely distributed on the summit surfaces. On the lower slopes a thin till cover is general, although even at lower elevations considerable areas of bedrock outcrop on the steeper slopes. Erratic boulders are common both amongst the boulder litter covering the bedrock slabs on the upper slopes and summits, and embedded in the till cover in the valleys and on the lower slopes. Paragneisses and metamorphosed sedimentary boulders that could not be related to bedrock outcrops in the area examines were identified. In view of the lack of detailed knowledge of the geology of the greater part of the peninsula, however, and the failure to establish a train of indicator erratics, definite conclusions concerning the direction of ice movement cannot be reached on this evidence alone.

The establishment of the direction of ice movement in the more remote parts of Labrador-Ungava has to be based on less firm evidence than indicator erratics. The coarse-grained nature of the bedrock in the Pyramid Hills area made positive identification of striations impossible. The danger of interpreting ice flow direction from this source was increased by the naturally grooved nature of the weathered surface of foliated gneisses. Roches moutonnées evidence was neither clear nor consistent, and although the majority of these forms indicated a movement of ice from slightly north of west, the exceptions to this rule cast some doubt upon the validity of this interpretation.

Striation and roche moutonnée evidence in the Indian House Lake area indicates that ice movement here was from a direction varying between west and slightly south of west. An examination of air photos reveals striking drumlinoid patterns and well-marked crag-and-tail features in the Lac Brisson area to the east of Indian House Lake, showing that ice movement was from the southwest. Nearer to the Pyramid Hills area, immediately to the north of Wedge Hill, and to the west of the George River, the drumlinoid pattern is orientated WNW-ESE, and this initially was assumed to support the evidence for ice movement from the WNW over the Pyramid Hills area. However, a careful examination of the air photos in this area (Figure 9) has revealed distinct crag-and-tail features which show that ice has moved from the east towards the west. Drumlinoids and a single crag-and-tail feature on the west bank of Indian House Lake opposite Slanting Brook, within 2 miles of field evidence for eastward flowing ice, were noted on the air photos to indicate ice movement towards the west. In view of the rather indecisive evidence for the direction of ice movement in the Pyramid Hills area, and the air photo and field evidence from elsewhere, it seems likely that the ice-divide during the late phases of active flow was a few miles to the west of the Pyramid Hills, and elsewhere in the George River basin closely followed the position marked on the Glacial Map of Canada (Wilson, 1958). It is stressed, however, that the positioning of the ice-divide is still very tentative, based as it is on the streamlining of drumlinoid forms, and on widely scattered crag-and-tail features, together with field observations along a narrow strip flanking Indian House Lake, and in the Pyramid Hills area. The anomaly of distinct flow features occurring within a mile of the proposed divide near Slanting Brook cannot be adequately explained at this stage. Furthermore, the difficulty of explaining the origin of the ice-dammed lakes of the George River basin is increased by the concept of an ice divide lying across the northern end of Indian House Lake.

The existence of a lateral and terminal moraine complex on the Labrador coast in the Torngat area, and in the Nain-Okak region, (Wheeler, 1935; Ives, 1958a) and the evidence for reactivation and re-advance of the ice following the retreat from the maximum stage of inundation is well established (pages 14-16 above). While this may mark a sub-stage in the Koroksoak, or final glaciation, it may, in fact, represent the maximum stand of the Koroksoak ice (see page 11 above), and it is becoming increasingly difficult to ignore the evidence which indicates that relatively large areas of the coastal mountains escaped inundation during this final glacial period. In contrast, the Pyramid Hills area shows no signs of any prolonged still stand and it appears that once the higher summits emerged from the ice, downwasting continued apace until final emergence was effected. In view of the lack of positive evidence to the contrary, all events in the Pyramid Hills area are referred to the final glaciation.

DEGLACIATION

The following is a summary of the views on the sequence of events in the deglaciation of the George River basin based upon work in the Indian House Lake area (Ives, 1960b).

As the ice sheet finally withdrew from the Atlantic Ocean-Ungava Bay divide, the snow line is assumed to have risen well above the land surface. Glacial drainage channels and innumerable abandoned lake shorelines and spillways traced on air photos on the high ground immediately to the west of the watershed indicate that vast amounts of melt-water are released from the ice sheet. The high-level lakes dammed between the ice sheet and the watershed were short-lived features, rapidly draining as the ice uncovered new spillways at lower elevations. It would perhaps be more accurate to suggest that the ice sheet waned and thinned rather than actively retreated, though the combination of lower elevation of the land, and greater thickness of the ice towards the west produced the same result. With continued thinning and accompanying recession of the ice margin successively larger areas west of the watershed became ice-free and melt-water, trapped between the residual ice further west and the rising land to the east, accumulated to form large lakes extending over hundreds of square miles at their maximum. The present drainage towards the north was blocked by a large mass of ice over the lower reaches of the George River and Ungava Bay, and the lakes spilled over the regional divide into the Atlantic.

Three marked stages were recognized in the evolution of the pro-glacial lakes in the Indian House Lake area. These are associated with three prominent shorelines at approximately 1,700, 1,500, and 1,350 feet above present sea level. The lakes which formed these shorelines have been referred to respectively as N-1, N-2 and N-3 (glacial lakes Naskaupi 1, 2 and 3). The most extensive, and the most prominently developed shoreline is N-2, and accordingly much of the field work in the summer of 1958 was confined to this shoreline. Roughly contemporaneous with this lake was another ice-dammed lake situated over the headwaters of the present Whale River, which drained by means of a low col into N-2. It has been named glacial lake McLean. The N-3 shoreline is less prominent than the upper two, and it was thought that this lake was relatively short-lived. The absence of prominent shorelines below this level was interpreted as indicating the rapid collapse of the ice dam over the lower reaches of the George River and in Ungava Bay, and the re-establishment of the natural drainage towards the north. Level and staff measurements over a 40 mile base established that the N-2 shoreline was tilted up towards the south at a rate of 1.57 feet per mile; over a 4-mile base on N-1 the rate of tilt was found to be 2 feet per mile. Raised deltas and shorelines up to 60 feet above the present lake level were found at the southern end of the lake, but are absent from the northern end, implying that continued isostatic uplift has tended to empty the present lake. Evidence from glacial drainage channels in the same area and previous work in the Labrador Trough had indicated that the centre of the ice sheet lay well to the southwest of Indian House Lake. The tilt of abandoned shorelines up towards the north on Julienne Lake and Wabush Lake, due south of Schefferville, does not contradict this view (Henderson, 1959). The line of maximum isostatic recovery was not, therefore, expected to be along the north-south levelled section, but well to the west of south.

WORK IN THE PYRAMID HILLS SECTION

Air photos revealed the existence of a series of abandoned shorelines in the Pyramid Hills Section (Figure 10), and parallax measurements appeared to establish a correllation between the upper two shorelines close to the river and N-1 and 2 in the Indian House Lake area. Field observations showed in addition that an earlier phase could be recognized in the deglaciation of the area. The first signs of disappearance of the ice sheet in the Pyramid Hills Section were found in certain features on the ridge tops. On the summit plateau to the north of Noose Lake are two small basins occupied by lakelets draining to the west. At heights between 50 and 100 feet above the levels of the present lakes there is in each case a small col piercing the eastern wall of the basin, and showing signs of use by considerable quantities of water, with water-washed slabs grading downstream into boulder-strewn channels. Roughly level with the heights of these cols are poorly preserved and in places, slumped terraces. It thus seems probable that, as the ice wasted back, water was trapped between the ice-front and the higher land to the east, with drainage taking place through the cols. These features persisted until the ice had wasted down sufficiently for the present drainage to establish itself. This evidence confirms the assumption from previous work that as the ice sheet, which sloped up towards the west or southwest, continued to thin, more and more land west of the Atlantic-Ungava Bay divide became exposed. It is not possible, however, to establish the direction of this apparent retreat of the ice margin in more than general terms.

A rapid initial reconnaissance of the abandoned shorelines in the field area revealed that, with a few prominent exceptions, the development of the shorelines was insufficiently marked to justify the detailed levelling that had been planned. Fortunately, however, well-marked shorelines existed on the west-facing slopes of the hills immediately bordering the George River, and level and staff work was, therefore, confined to these (Figures 13 and 14). It was established by the initial aneroid reconnaissance that five separate and well-defined shorelines exist in the area, and that the upper three probably correllated with the three Naskaupi shorelines. Remnants of the lower two shorelines are probably present in the Indian House Lake area, but, in comparison with the shorelines of N-1, 2, and 3, they are poorly developed and discontinuous, and were thus largely ignored in the field.

Levelling was conducted from the bench marks established by the Quebec Department of Hydraulic Resources, and thus gave an accurate correllation with the measurements over 100 miles away at the south end of Indian House Lake. The four lower shorelines were levelled from Pyramid Peak to Galleon Hill (Figures 4 and 13). The uppermost shoreline, which does not appear on the lower hills bordering the river, was measured by repeated aneroid checks, and the consistency of the results obtained, together with direct comparison between aneroid estimates and the levelled measurements of the lower beaches, indicated that the accuracy of these observations was within $\pm$ 2 feet. Because of the difficulty of identifying the precise positions of the fore and back slopes of the terraces this order of accuracy is considered more than adequate.

SIGNIFICANCE OF THE FIELD DATA

The results of the levelling, when tied in to the bench marks and levelled sections of the contemporaneous shorelines in the Indian House Lake area, give a first impression of apparent increase in tilt along the section between High Bluff and Pyramid Hills. This is obtained by comparing the calculated tilt of the N-2 shoreline (1.8 feet per mile) in this sector with the average figure of 1.57 feet per mile given by Ives in the Indian House Lake section (Ives, 1960b). Similarly, the tilt of the N-1 shoreline appears to increase from 2 feet per mile near High Bluff to 2.6 feet per mile between High Bluff and Pyramid Hills. This increase in tilt, however, is probably more apparent than real. The four-mile levelled section, upon which the tilt of N-1 was calculated in the Indian House Lake area is too short to provide a completely sound base and, with respect to N-2 a closer examination of the construction of Ives' profile is instructive (Ives, 1960b Figure 6). If the station at Slanting Brook, admittedly an aneroid estimate, is rejected, and if the tilt is re-calculated on the approximate 30-mile base between High Bluff and Weather Station* a figure of 1.7 feet per mile is obtained. All these figures for rate of tilt are so close that they probably fall within the margin of error of estimating the precisely comparative vertical points on the shorelines themselves. Another important factor, of course, is that the straight line drawn between the northern point of the writer's survey and the southern point of that of Ives does not necessarily transect the isobases at a constant angle. Thus, until more precise survey data is available, and in particular, until an east-west survey line has been established to facilitate construction of isobases and determination of the direction of maximum tilt, it must be assumed that the over-all regional tilt is uniform, at least within the limitations of the existing survey.

Certain aspects of the concept of deglaciaition in the George River basin require re-examination in the light of the more recent evidence. In order to provide a dam for the lakes that formerly existed in the George and Whale river basins, and in the western valleys of the Torngat Mountains, Ives envisaged a secondary centre of ice dispersal located over Ungava Bay until a relatively late phase of the final glacial period. He also considered hypothetically the possibility of radial movement outward from the bay but concluded by stating: "It is considered more appropriate to acknowledge the lack of field data and the existence of conflicting evidence, and to leave the drumlin and esker distribution patterns devoid of interpretation until

*Levelled beach cairns established in the Indian House Lake area.

a more opportune moment." (Ives 1960b, p. 67). At the present phase of the work it can be pointed out that the hypothetical pattern of radial outflow from Ungava Bay is not valid. Striation measurements in the vicinity of the George River estuary, indicating presumably late-phase northward motion into the bay, is substantiated by crag-and-tail and streamlined drumlinoid forms which have been interpreted on the air photos between the mouths of the George and Tunulik rivers.

Work on the marine terraces and the terminal moraine complex in the northern Torngat Mountains indicates that the ice retreated from the Atlantic coast first in the extreme north and successively later towards the south. Also, the tilt of the marine terraces in this area is up towards the south-southwest*. Similarly, the tilt on the Naskaupi shorelines is up towards the south or southwest and this trend gives no indication of the existence of a secondary centre of dispersal over Ungava Bay. It is on this basis that the concept of ice dispersal from the bay is rejected.

The rejection of the possibility of ice dispersal from Ungava Bay re-introduces the problem of the form and thickness of an ice barrier sufficient to dam up the extensive glacial lakes in the George and Whale river basins. The only tenable explanation of the shorelines is that they were formed by large masses of water dammed up against ice lying to the north and west. The suggestion that they may mark the level of lateral lakes dammed between extensive stagnant tongues of ice in the valleys and the hillsides is not tenable in this context. The varying development of the individual shorelines, dependent upon the length of fetch to which they were exposed, and the particularly favourable north-westerly aspect are features of both the Indian House Lake and Pyramid Hills areas. Perhaps a more serious objection to the hypothesis, however, lies in the extent and configuration of the valleys themselves which would require tongues of stagnant ice up to 200 miles long lying in them. In many sectors these valleys are broad and open, quite unlike the steep-sided and narrow U-shaped mountain troughs normally associated with the development of such lateral lakes. In contrast, the lake shorelines in the Koroksoak River valley, a trough conforming more closely with the above description, were probably formed by wave action in lateral lakes.

It seems most probable, therefore, that large water bodies existed and that they were dammed up by ice lying to the west and north of the middle sections of the George and Whale rivers. Their former existence appears to be in conflict with the positioning of the late-glacial ice-divide to cut obliquely across

*Løken, O. H., November 1960, personal communication.

the northern end of Indian House Lake. Similarly, there is no correlation between the positioning of this divide and the tilt of the Naskaupi shorelines, as the latter suggests that the maximum thickness of ice lay far to the southwest.

It should be stressed, however, that accumulation conditions during even a single glaciation varied remarkably with time. If the variety of evidence is viewed less as the results of approximately contemporaneous events and more the interaction of changing conditions in time, the evolving picture will become more realistic.

In conclusion it is emphasized that the complexity of the deglaciation sequence in the George River basin is evident and, as yet, no precise interpretation can be made. It is believed, however, that an attempt should be made, albeit tentatively, to interpret the drumlin and esker patterns in terms of a late-glacial ice-divide similar to that depicted on the Glacial Map of Canada (Wilson, 1958). It is apparent that this interpretation leaves much to be desired and that a final solution undoubtedly awaits additional field work, particularly in the George River estuary and around the southeast shores of Ungava Bay.

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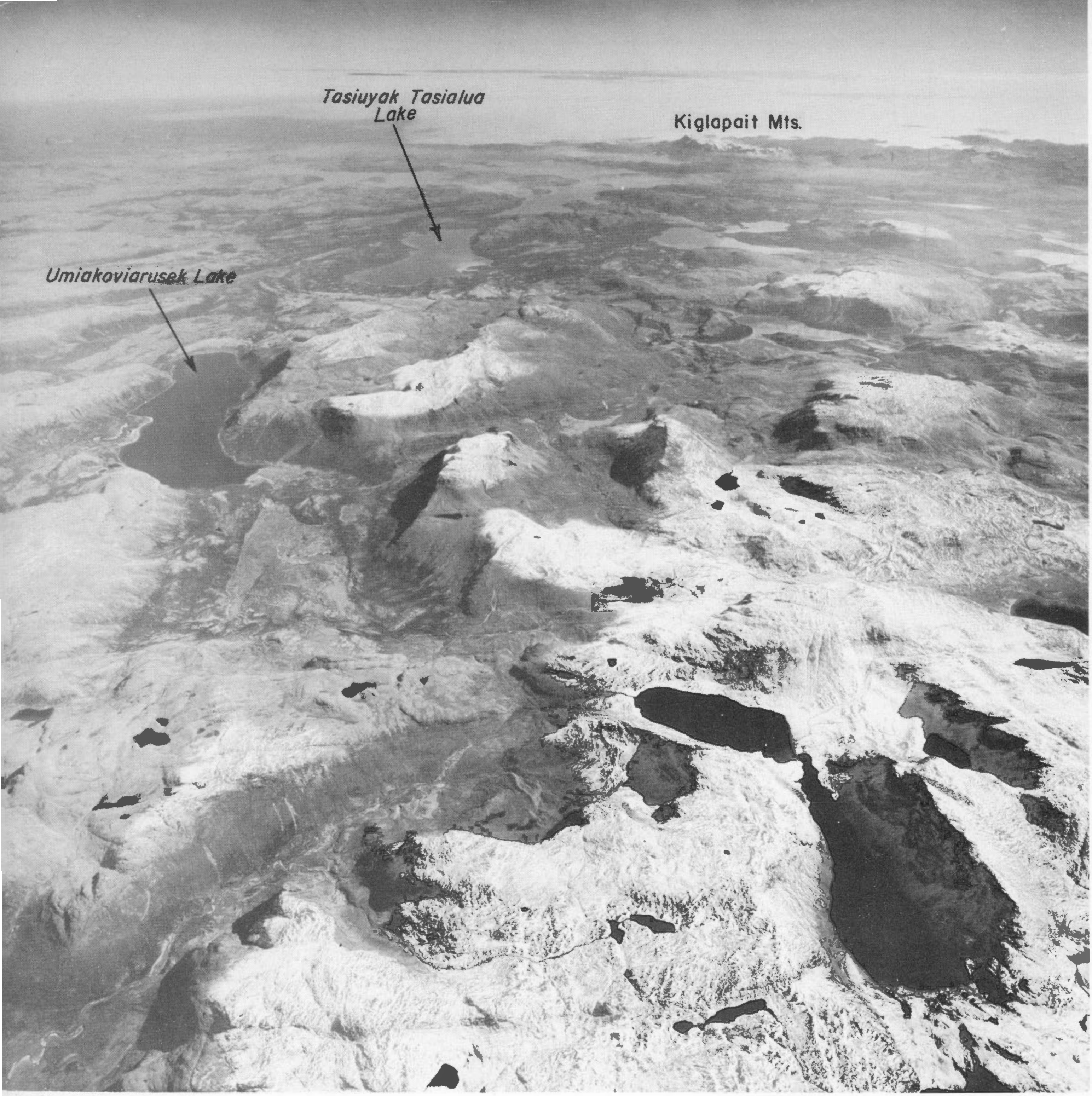

Figure 5. High-level oblique air-photo looking eastwards across the eastern edge of the *Interior Zone*. The *Valley Zone* of the Nain-Okak section is well developed in the middle ground and can be seen merging with the *Island and Bay Zone* beyond. Lake Tasiuyak Tasialua is slightly northwest of centre, and the Kiglapait Mountains form the bold skyline to right of centre (RCAF Photo).

Figure 6. A typical landscape in the *Valley Zone* showing high summits and steep, glaciated valley slopes.

Figure 7. High-level lateral moraine on hillside south of Mount Aupalukitak. The moraine is here 2,045 feet above sea level and slopes down towards the north.

Figure 8. Vertical airphoto showing the western end of Lake Tasiuyak Tasialua from 21,000 feet. Part of the main end moraine system roughly parallels the lake shoreline. Outwash deposits and numerous large kettle holes can be seen. (RCAF Photo).

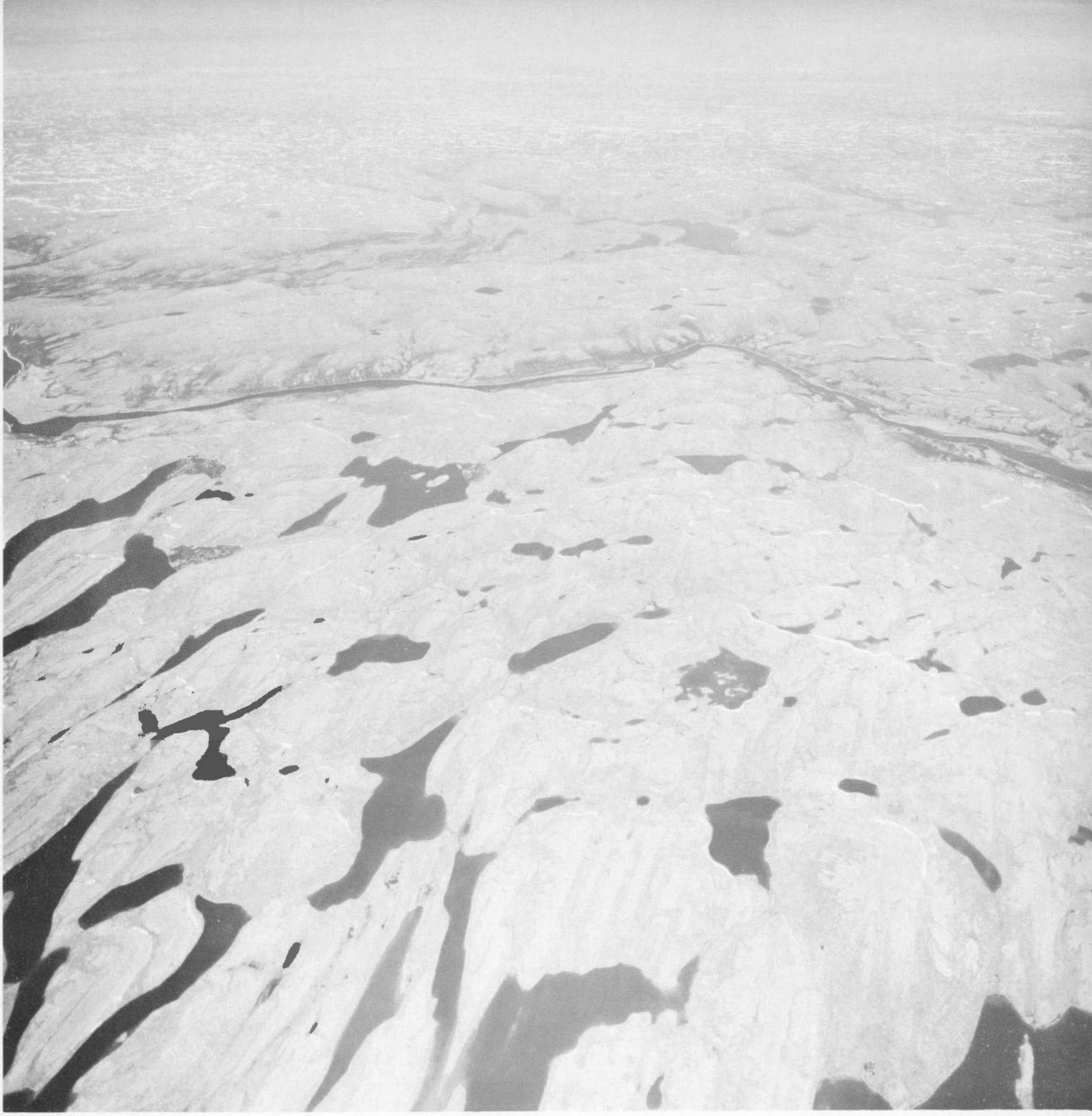

Figure 9. High-level oblique air-photo looking eastwards across the George River onto the Nain plateau. The Nain-Okak section is indistinct in the far distance. Significant crag-and-tail features and drumlinized till are most prominent in the foreground and indicate possible westward movement of ice. The area photographed lies immediately south of the Pyramid Hills section. (RCAF Photo).

Figure 10. High-level oblique air-photo looking westwards from the Pyramid Hills across the George River and into the basin of the Whale River. The prominent shorelines of former glacial lakes Naskaupi 1, 2, 3 and 4 in the left foreground partially encircle Pyramid Peak and Galleon Hill. Ungava Bay lies in the far right distance. (RCAF Photo).

Figure 11. Looking northwestwards down the George River from above the N-5 terrace on the lower slopes of Pyramid Peak. Pyramid Hills, with steep talus slopes, appear on the extreme right. Note the even line of the hills extending on both sides of the valley.

Figure 12. View towards the west-northwest from the uplands east of the George River. Pyramid Peak lies on the left and Pyramid Hills rise above the forested slopes on the right. Note the perfect gradation of the summit line into the hill crests on the far side of the George River.

Figure 13. Pyramid Peak as seen from the George River. The shorelines of glacial lakes Naskaupi 3, 4 and 5 are clearly visible.

Figure 14. The pronounced terrace cut by glacial lake Naskaupi 4 as seen on the northwest face of Pyramid Peak (cf. figure 13).

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