Papers

Deglaciation of the Central Nain-Okak Bay Section of Labrador

J. PETER JOHNSON, JR.[1]

ABSTRACT. Glacial erratics on the highest peaks of the Nain-Okak Bay section of Labrador indicate that at one time the entire area was completely glaciated. This complete ice cover is tentatively correlated with the Torngat Glaciation. A subsequent ice advance from the interior of Labrador, during which the higher peaks were nunataks, would appear to correspond to the Koroksoak Glaciation, because distinct moraine systems at lower altitudes are apparently those of the Saglek Glaciation and its phases. Final deglaciation consisted basically of recession accompanying thinning of the ice sheet in the interior of Labrador with isolated masses of stagnant ice still occupying low lying areas when the eustatic rise of sea level began.

RÉSUMÉ. *Déglaciation de la section centrale Nain-baie d'Okak, au Labrador.* Sur les plus hauts sommets de la section Nain-baie d'Okak du Labrador, des erratiques glaciaires indiquent qu'à un certain moment, toute la région était entièrement recouverte de glace. On relie provisoirement cette glaciation à celle de Torngat. Une réavancée subséquente, venue de l'intérieur, au cours de laquelle les plus hauts sommets ont constitué des nunataks, semblerait correspondre à la glaciation de Koroksoak, car les systèmes morainiques des niveaux inférieurs sont apparemment ceux de la glaciation de Saglek et ses différentes phases. La déglaciation finale a consisté surtout en une récession accompagnée d'un amincissement de l'inlandsis intérieur, tandis qu'au début du relèvement eustatique du niveau de la mer, des masses de glace stagnante occupaient encore les régions les plus basses.

РЕЗЮМЕ. *Конец оледенения в районе залива Наин-Окак (Лабрадор).* Наличие ледниковых валунов на самых высоких вершинах в районе залива Наин-Окак указывает на то, что вся территория района в свое время была покрыта льдом, который по предварительным данным причисляется к Торнгатскому оледенению. Считается, что последующее наступление льда из центральных районов Лабрадора, во время которого более высокие вершины представляли собой нунатаки, соответствовало Короксоакскому оледенению, т.к. нижележащие системы морен причисляются к Саглекскому оледенению. К моменту начала эвстатического поднятия морского уровня, отдельные неподвижные ледяные массивы все еще находились на пониженных участках местности.

INTRODUCTION

Many studies of the Labrador coast have been made in which the effects of glaciation have been described. The continental character of Pleistocene glacial activity was clearly established by Bell (1885), Packard (1891), Low (1896), Daly (1902) and Coleman (1920). However, there was little agreement in the development of a conceptual framework which would satisfy findings from widely separated parts of Labrador. The early studies were reexamined by Tanner (1944)

[1]Department of Geography, Carleton University, Ottawa, Canada.

who provided a comprehensive and provocative, if sometimes obscure, account of Labrador's glacial history.

More recently Ives (1957, 1958a, b) and Løken (1959, 1962a, b) have studied parts of the Torngat Mountains in detail. Farther south Tomlinson (1963) has examined the Kaumajet Mountains, and Andrews (1961, 1963, 1965) an area southwest of Okak Bay. Wheeler (1958, 1964) reviewed some of the general problems of Labrador's glaciation on the basis of his work along the central coast, and recently Gray (1969) studied the glacial geomorphology of the Mealy Mountains. Glaciation of the interior of Labrador has been studied, principally by workers from the McGill Sub-Arctic Research Laboratory and the Geological Survey of Canada.

The equivocal nature of much of the field evidence is emphasized by conflicting conclusions drawn by different workers for the same general area. Bell (1885), Daly (1902), Coleman (1921) and Dahl (1946) for instance believed that the continental ice sheet had not covered the higher coastal summits, particularly in the extreme north, while Odell (1938), Tanner (1944) and Flint (1943) argued for complete glacial submergence. The finding of probable glacial erratics on

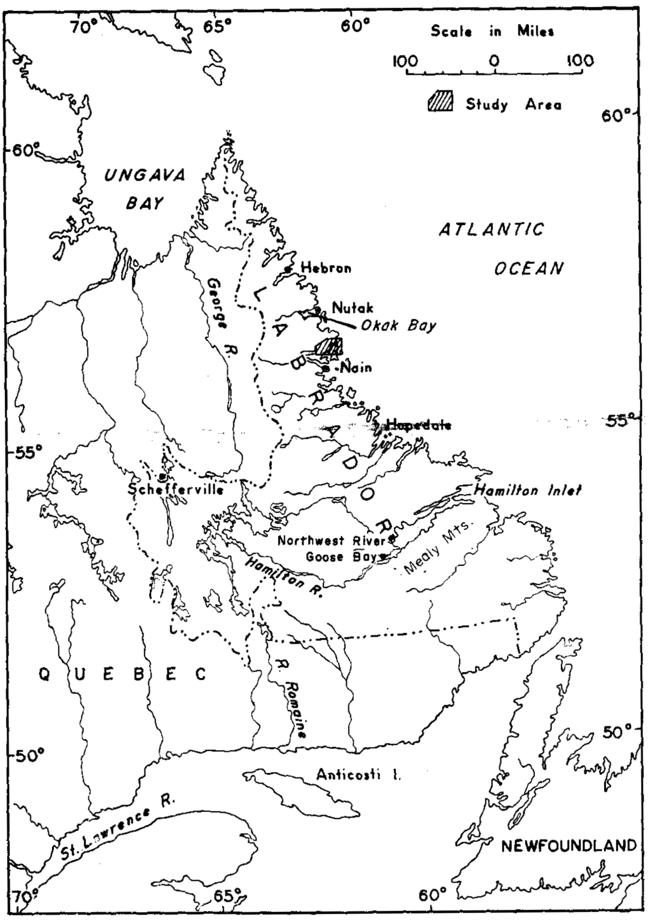

FIG. 1. Location map.

high summits along the coast (Ives 1958a) and an accumulation of circumstantial evidence (Ives 1963) make it seem likely that the highest mountains were once covered by ice, probably prior to the Wisconsin Stage. This glacial event has been called the Torngat Glaciation by Ives (1957). During more recent glacial episodes, however, the presence of both highland and lowland ice-free areas is indicated by the heights and gradients of the upper limits of the Koroksoak (Ives 1957) and Saglek (Andrews 1961, 1963) phases.

The coastal areas became ice-free first; as the ice front retreated westward across the Atlantic-Ungava Bay watershed, a series of ice-dammed lakes formed in the

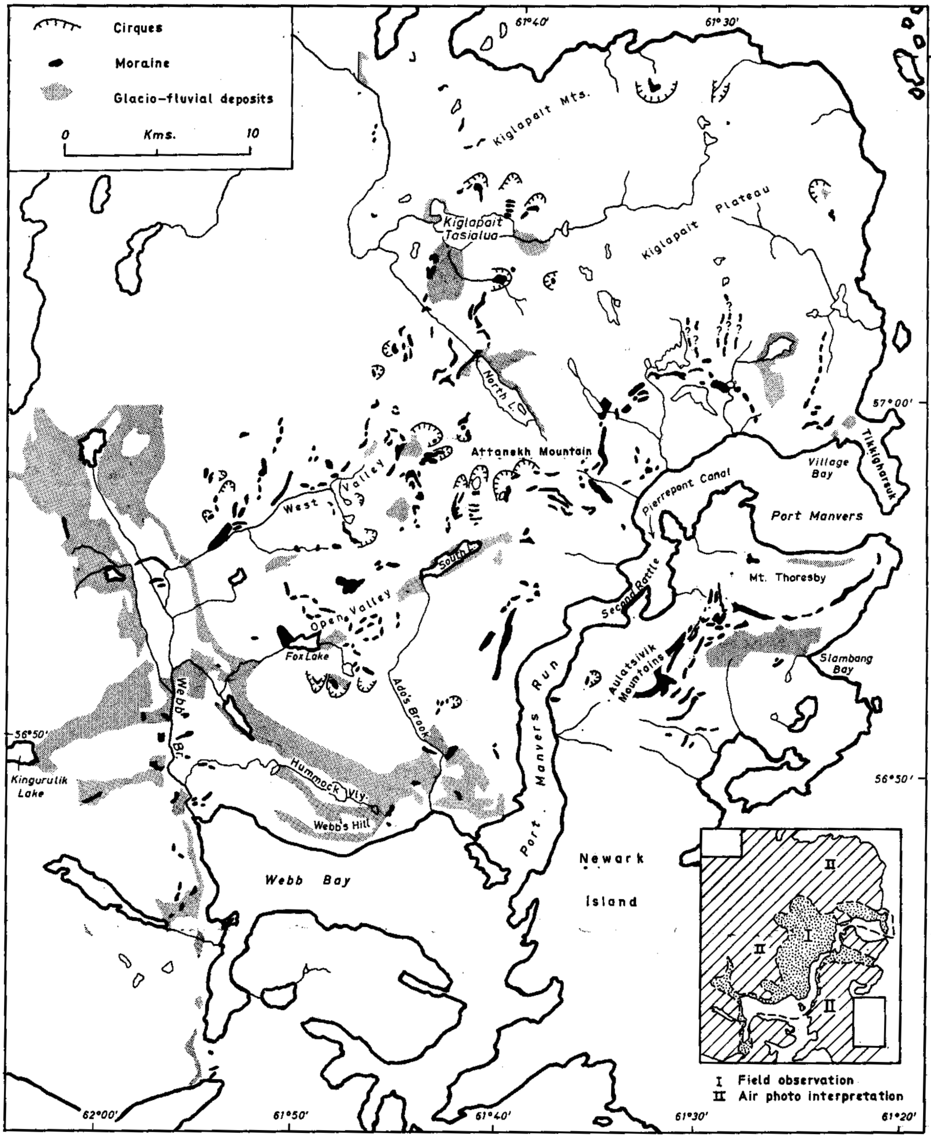

FIG. 2. Central part of Nain-Okak Bay Section of Labrador.

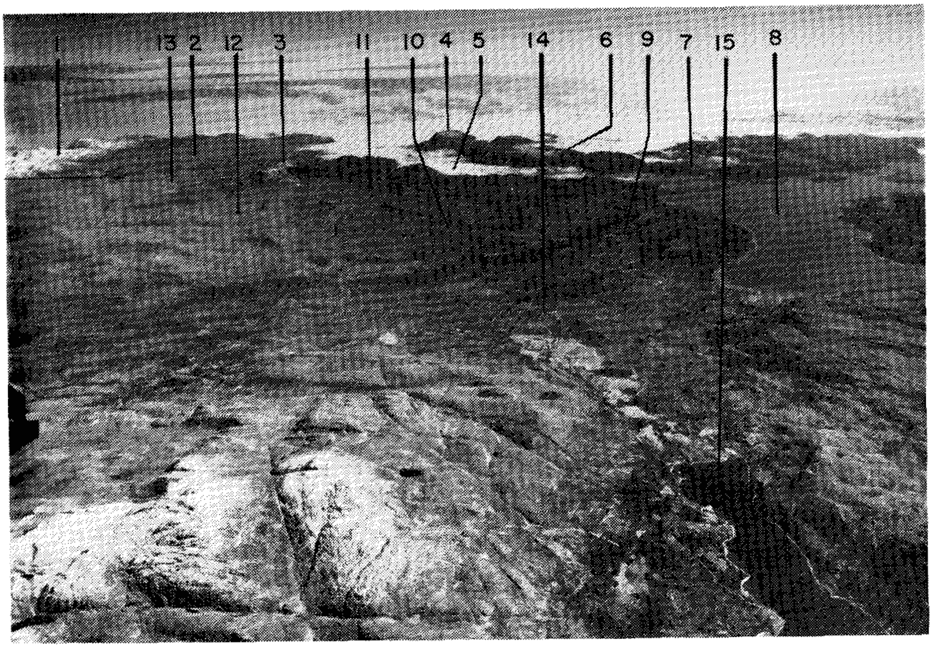

FIG. 3. View east toward coast. (1) Kiglapait Mountains (2) Kiglapait Plateau (3) Attanekh Mountain (4) Mount Thoresby (5) Port Manvers Run (6) South Aulatsivik Highlands (7) Newark Island (8) Webb Bay (9) Hummock Valley (10) Open Valley (11) South Lake (12) West Valley (13) North Lake (14) Webb Brook (15) Kingurutik Lake.

present drainage areas of the George and Whale rivers spilling eastward into the Atlantic (Ives 1960a; Barnett and Peterson 1964). On the interior plateau various lines of evidence, including the tilt of glacial lake shorelines, esker pattern, and the plan of glacial meltwater channel networks, indicate that the locus of final Wisconsin ice sheet disintegration was close to the geographic centre of Labrador-Ungava in the general vicinity of Schefferville (Ives 1959, 1960b; Barnett and Peterson 1964; Harrison 1963; Henderson 1959; Hughes 1964). This more recent work substantiates the early speculations of Low (1896).

CENTRAL PART OF THE NAIN-OKAK BAY SECTION OF LABRADOR

The glacial history of the coastal highland area which lies midway between the village of Nain and Okak Bay (Fig. 1) and is bounded on its northern side by the Kiglapait Mountains (Fig. 2) has received only cursory attention (Tanner 1944; Wenner 1947). A reconstruction of the deglaciation of the southern fringe of the Kiglapait Mountains and nearby coastal areas is offered here, and an attempt is made to show the relationship of these local events to the broader Pleistocene and Recent history of coastal Labrador as it is at present understood.

The study area includes elements of the Island and Bay, Valley, and Interior Upland physiographic zones (Wheeler 1935). The dominant mountains are Attenekh Mountain (1053 m.) and Mount Thoresby (917 m.), which are the highest coastal mountains between the Kaumajet Mountains to the north and

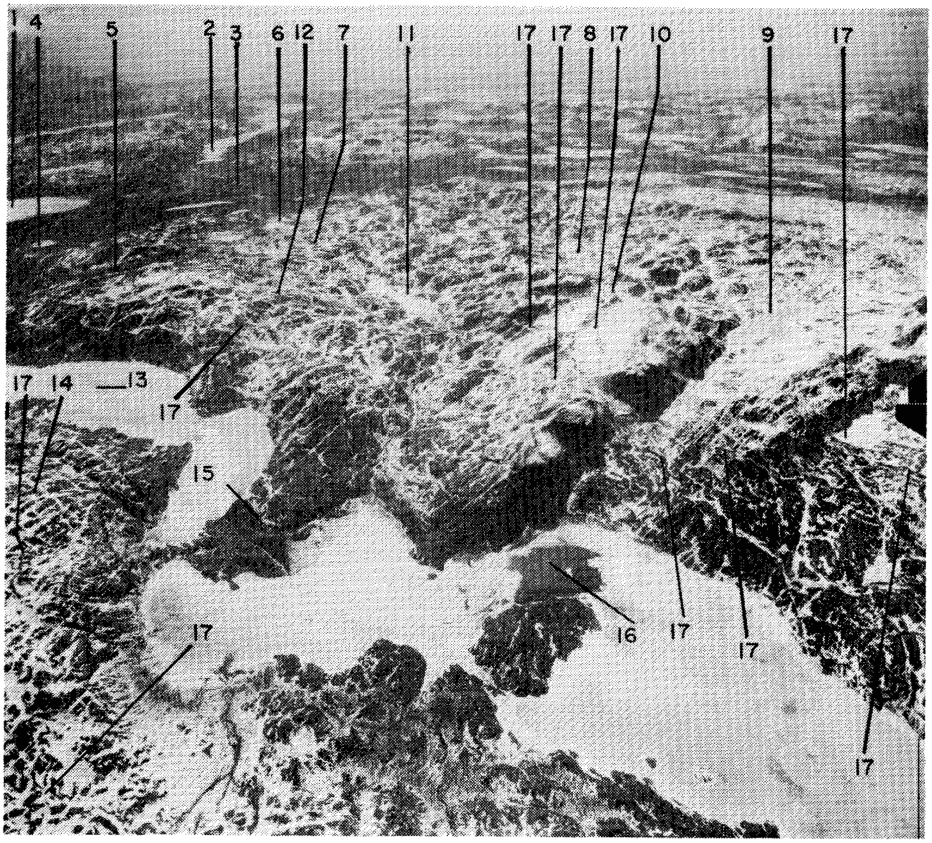

FIG. 4. View west toward Interior Upland Zone. (1) Webb Bay (2) Kingurutik Lake (3) Webb Brook (4) Hummock Valley (5) Ado's Brook (6) Fox Lake (7) Open Valley (8) West Valley (9) North Lake (10) Attenekh Mountain (11) South Lake (12) Port Manvers Run Highlands (13) Port Manvers Run (14) Newark Island (15) Second Rattle (16) Pierrepont Canal (17) Important moraines.

the Mealy Mountains to the south. They rise above a highland portion of the Island and Bay Zone which is separated from the eastern edge of the Interior Upland Zone by a part of the Valley Zone which contains Webb Brook (Figs. 3 and 4).

Geological investigations in this area have been made by Wheeler (1942, 1960), Christie (1952), and Morse (1962, 1964). Certain aspects of the history of glaciation have been reported by Wheeler (1935, 1958), Tanner (1944), Wenner (1947) and Meyer (1954). The deglaciation of an adjoining area northwest of the Kiglapait Mountains has been studied by Andrews (1963, 1965).

PROCEDURE

Except in one area where a low order triangulation survey was made, geomorphic features were mapped directly on aerial photographs, and altitudes were determined by surveying aneroid altimeter. The upper limit of the cirriped

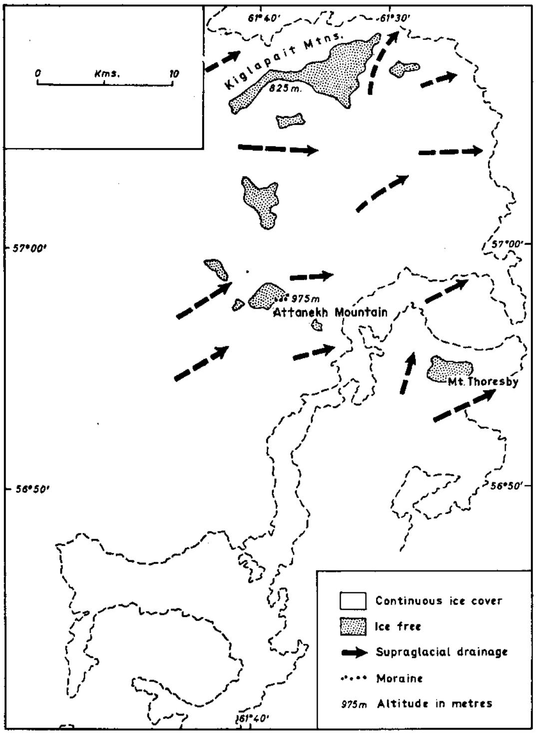

FIG. 5. Deglaciation. Step I.

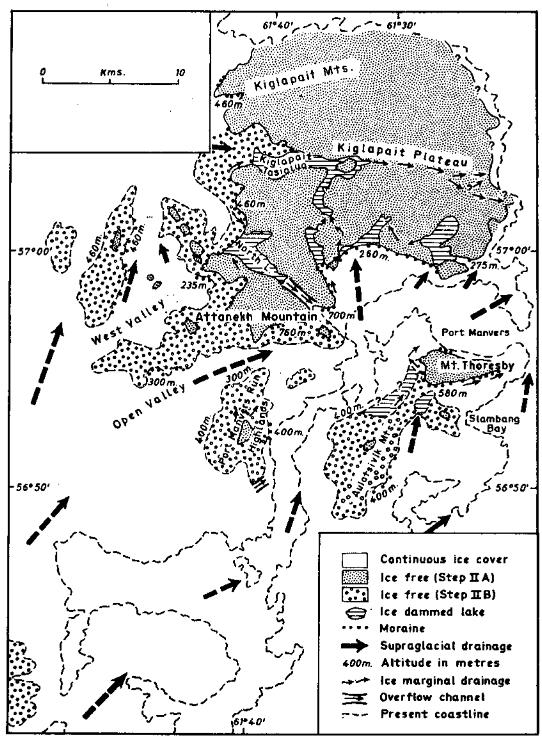

FIG. 6. Deglaciation. Step II.

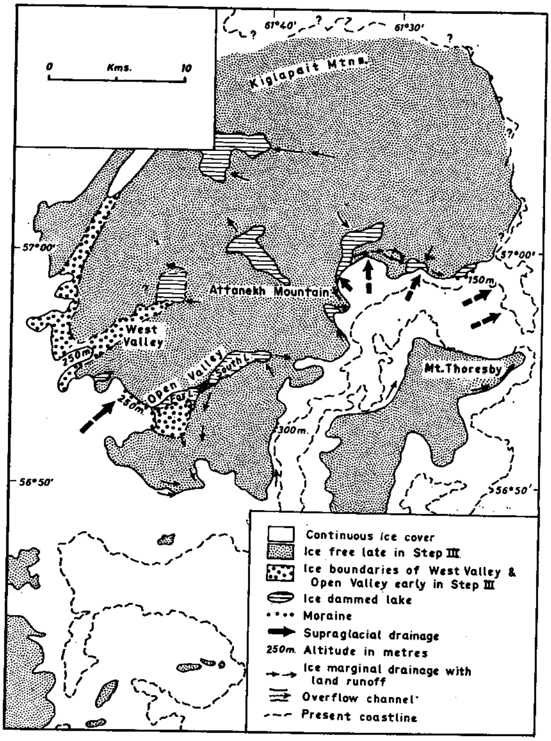

FIG. 7. Deglaciation. Step III.

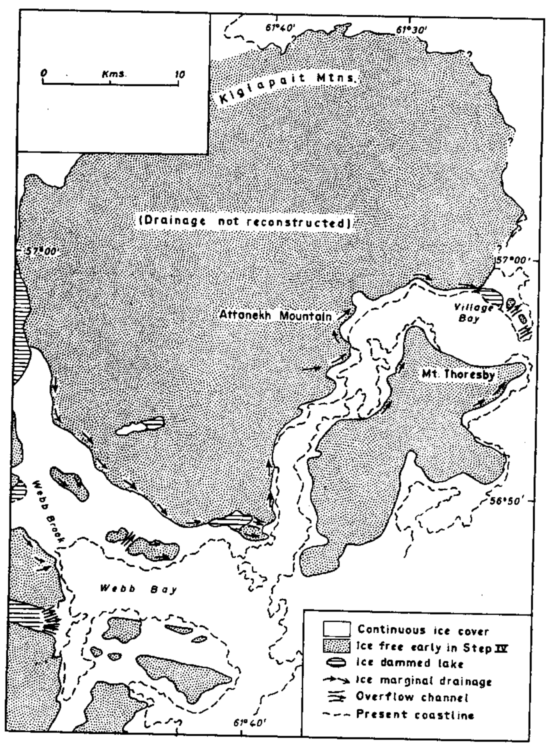

FIG. 8. Deglaciation. Step IV.

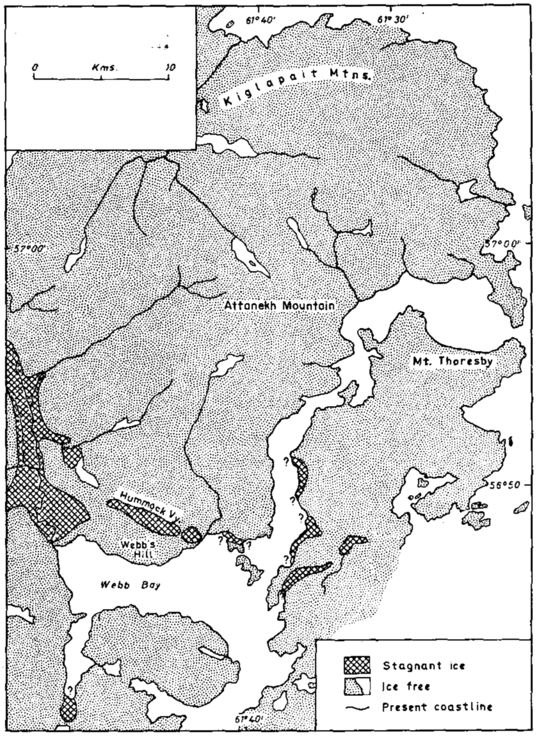

FIG. 9. Deglaciation. Step V.

Balanus balonoides was used as a datum for the aneroid readings which were corrected for temperature and pressure. In the text altitudes are given with respect to present sea level and have been rounded off to the nearest 10 m. unless the sense of the measurements would be lost by so doing. Information from areas adjacent to those visited in the field was obtained by air photo interpretation (Fig. 2). Altitudes in these areas are generalized from parallax bar measurements and unpublished maps of E. P. Wheeler, 2nd, and the Canada Department of Energy, Mines and Resources.

The events leading to complete deglaciation have been reconstructed principally from the distribution of moraines, kame terraces and other ice contact and glaciofluvial features (Fig. 2). The term "step" is used in the text to describe episodes of regional significance which were dominated by advancing ice equilibrium or recession. Because radiometric dates and conclusive stratigraphic evidence are still needed from this area to support the geomorphic evidence of glacial events, it has not been possible to determine if the time differences between glacial advances implied by successively lower moraine systems are of interstadial, let alone, interglacial length. These moraines, therefore, have been interpreted as representing conditions of balance or temporary readvances of a diminishing ice sheet rather than as traces of completely separate glaciations.

The approximate distribution of ice-covered and ice-free land during each step is shown in Figs. 5 to 9. The directions of supraglacial drainage shown in these figures are estimates based on a reconstruction of ice sheet gradients (Johnson

1964). It is worth noting, however, that the ice limits shown in these figures are based principally on the location of ice marginal deposits, and since allowances cannot be made yet for the effect of surges, oscillations and variations in local accumulation centres, their location on the map may not be an exact representation of the entire ice boundary at a particular moment in time. The sequence of glacial events proposed here is necessarily relative and to a degree subjective even though it is based on an abundance of geomorphic evidence.

UPPER LIMITS OF GLACIATION

To determine whether or not glaciation was complete along this section of the coast the highest peak, Attanekh Mountain, was climbed. Approximately 20 m. below the summit is a glacial erratic of garnetiferous gneiss (Fig. 10), the nearest known exposure of which is 15 km. to the west (E. P. Wheeler, 2nd, personal communication). No exposures are known to the east. The underlying bedrock is anorthosite, perched boulders of which were observed even closer to the summit, along with a poorly preserved set of striae bearing N. 10°E. to N. 20°E. Together, these pieces of information are interpreted to be evidence of a former ice sheet which moved toward the east and was of sufficient thickness to cover Attanekh Mountain (Ives 1963). This glaciation is tentatively correlated with the Torngat Glaciation (Ives 1957; see, however, Andrews 1963).

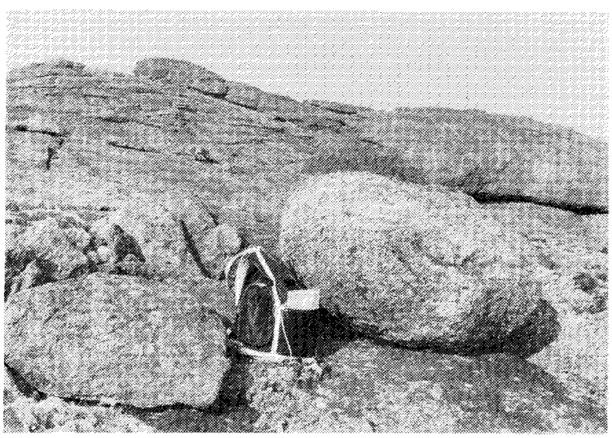

FIG. 10. Erratic boulder of garnetiferous gneiss resting on anorthosite. The summit of Attanekh Mountain (1053 m.), the highest mountain in the central part of the Nain-Okak Bay section of Labrador, can be seen about 20 m. above on the skyline.

DEGLACIATION

STEP I

Less than 100 m. below the summit of Attanekh Mountain there is a general break in slope (*c.* 975 m.) which coincides with the upper limit of a drift sheet. Except on valley floors, and where there are ice marginal deposits, this drift is thin and frequently broken by outcrops of bedrock. Steep surfaces are often bare except for isolated boulders and cobbles which appear to be remnants of drift not removed to lower levels by mass movement and washing.

Above the 975 m. break in slope on Attanekh Mountain, there seems to be an absence of drift. Although erratic boulders remain, fines are rare except for detritus weathered from bedrock or erratics. For lack of any evidence to the contrary it can be surmised that either a proportionally smaller quantity of debris was deposited in the summit area if the region was subjected to only one glaciation, or there was more than one glaciation, the more recent one not reaching the summit of Attanekh Mountain. The second hypothesis is thought to be the stronger; in this event the difference in amounts of debris above and below the 975 m. level could be explained by the different lengths of time available for exposure to eroding processes, by differences in the loads of the two ice sheets, or a combination of both.

Until more satisfactory explanations are provided for the origin of mountain top detritus and other possibly related weathering forms (Ives 1966; Dahl 1966), their value as a means of identifying the limits of glaciation in mountainous areas remains doubtful. However, in northern Labrador and Baffin Island the systematic distribution of mountain top detritus and other weathering features has been used for this purpose in conjunction with other evidence (Ives 1963; Andrews 1963). By applying the same procedure to this part of the Nain-Okak Bay area, the argument for more than one glaciation becomes more plausible. Thus the presence of a large patch of mature mountain top detritus 25 m. below the summit of Attanekh Mountain, and the limiting of this kind of feature to this summit area and that of Mount Thoresby (Ives 1958), make it seem that the processes responsible for them, even if active today, have not had sufficient time to cause comparable features at lower altitudes. Together then, the mountain top detritus, the break in slope and boundary of the drift sheet, seem to mark the upper limit of a glaciation which was more recent than that which covered Attanekh Mountain. This interpretation is strengthened by the presence of poorly preserved moraine remnants along the upper edge of the drift sheet on the eastern ridge of Attanekh Mountain.

An examination of aerial photographs gives the impression of a similar upper limit of glacial activity close to 825 m. along the northern rim of the Kiglapait Mountains. Assuming that the Kiglapait level and that on Attanekh Mountain are contemporaneous, then an ice sheet surface slope between the two of 1.1 per cent is implied. An extension of this gradient eastward (not allowing for differences in sea level or present submarine topography) would place the outer margin of the ice sheet 80 km. beyond the present coastline. The ice-free areas and nunataks at this time are shown in Fig. 5, and the gradients of this and each succeeding step of deglaciation are reconstructed by Johnson (1964).

In addition to the morphologic evidence for nunataks, there is botanic evidence which, although slight, suggests the existence of ice-free refugia along the coast. The nunatak hypothesis (Blytt 1881) was applied to North America by Fernald (1925), whose views were modified by Abbe's work in Labrador (1938). Among other things Abbe proposed that in spite of the geologic evidence (i.e., the complete ice cover advocated by Odell 1938) floral elements might signify ice-free, low lying coastal areas rather than scattered nunataks. Floristic conditions in Greenland, Iceland, and Scandinavia led Dahl (1946) to propose that certain species were characteristic of refuge areas and that their presence in isolated areas with similar site characteristics around the North Atlantic (including parts of coastal Labrador) would mean that these areas might also have been refugia.

Dahl listed 56 plants characteristic of coastal mountain refugia. This list was compared to botanic lists compiled by Bell (1885), Low (1896), Fernald's incomplete list as given by Antevs (1932), Tanner (1944), Wenner (1947), and Johnson (1960). Seventeen items from Dahl's list were collected by one or more of these persons. Three, *Stellaria crassifolia Ehrh., Loiseleuria procumbens (L) Desv.,* and *Veronica alpina L.* are reported from the study area by Johnson (1960). The latter work did not distinguish mosses, lichens or grasses, a number of which were included in Dahl's list.

If ice-free areas did exist, then they must have been there during a glacial maximum more recent than that which covered Attanekh Mountain. It follows that this must have been the one that left its drift up to 975 m. altitude in this area, and that the combined geomorphic and biogeographic evidence supports a hypothesis that there were at least two distinct periods of glaciation. It is for this reason that it has been suggested that the older, higher one be tentatively correlated with the Torngat Glaciation (see above). Assuming that this is not unreasonable at this stage of investigation, it is suggested that the younger glaciation be called Step I here, and that it should be correlated with the Koroksoak Glaciation.

The direction in which the ice moved during Step I is indicated both by the slope of ice-marginal deposits and by quarried features; it was predominantly toward the northeast. The drift associated with this glaciation was, wherever it could be examined, thinner than that of more recent ice activity, and its moraines were smaller. Although this might be explained by Step I being a short period of glacierization followed by rapid withdrawal, it is worth noting that most of the Koroksoak drift is on the Kiglapait Plateau (Morse 1962) where a contributing factor to its sparseness might be the barrier effect of the rim of the mountains around all but the southeastern side of the Plateau. These mountains could have prevented effective replenishment from the ice sheet as soon as the snow line began to rise. This would have caused local ice starvation and a corresponding decrease in ice movement and load.

STEP II

In contrast to the poorly preserved moraines of Step I, a clearly defined and extensive moraine system can be traced from about 760 m. on the south side of Attanekh Mountain to 275 m. at Port Manvers (Figs. 2 and 6). A second set of moraines was built 60 to 300 m. lower than this one. Although the ice sheet was somewhat thinner when this happened, it was still an integral mass, and the principal differences during the two moraine building episodes seems to have been only the larger area of ice-free highlands at the maximum extent of the second set. For this reason these moraine building episodes are considered together as Step II, which for purposes of examination, has been divided into two sub-stages, Step II A and Step II B (Fig. 6).

STEP II A

Step II A ice flowed northward through passes 700 m. high in the mountain range dominated by Attanekh Mountain (Johnson 1964). It left extensive marginal deposits on the western and eastern sides of the mountain as well as on other parts of the Kiglapait Mountains which lay across its path. Some of the moraines can be traced (Fig. 4) onto the edge of the Kiglapait Plateau, and because of the barrier effect of the mountains, they have very steep gradients (Johnson 1964). The ice that flowed through the mountains, out of the gap made by Port Manvers Run, dropped more than 400 m. in a little more than 5 km., and spread in a diffluent manner north and west from the Run onto the southern edge of the Kiglapait Plateau. There, a moraine, 3 m. to 60 m. high, was built at an altitude of approximately 260 m. along a convex front 13 km. long (Figs. 2 and 6). The ice also moved northeast out of Port Manvers Run as shown by striae and quarried faces on the peninsula of Tikkigharsuk. It must, therefore, have continued onward into what is now the ocean east of the Kiglapait Mountains, where it presumably joined ice moving east from the Okak Bay region (Andrews 1963) and diffluent ice spreading north from the Nain Archipelago. South-sloping terraces about 260 m. altitude on the eastern flanks of the Kiglapait rim north of Tikkigharsuk were possibly formed then.

Simultaneously, on the northwestern side of the Plateau, steeply sloping tongues of ice from the west pushed into valleys now occupied by Kiglapait Tasialua and North Lake. The moraines and complex marginal features formed in these localities (Johnson 1964) appear to be related to similar features which extend northward along the high western slopes of the Kiglapait Mountains at approximately 460 m. Considering the slope of the ice sheet surface and the location of all these moraines and their associated deposits, they almost certainly correspond to the massive lateral moraines between 515 m. and 700 m. of the Saglek Glaciation which are reported to the west and north by Andrews (1963).

Runoff from both the Kiglapait Tasialua lobe and the northern edge of the Port Manvers Run ice had to flow onto the Kiglapait Plateau (Johnson 1964). The abandoned bottoms of lakes ancestral to the present ones show that they and other temporary lakes spilled north and east (Fig. 6) and, for a short time, through low passes across the eastern escarpment of the Kiglapait Mountains. In the process an intricate maze of drainage channels, now abandoned, was cut into the surface of the Plateau.

South of the Plateau an ice-dammed lake immediately north of Attanekh Mountain (Fig. 6) overflowed eastward toward Port Manvers Run during Step II A. The discharge from this lake was sufficiently great to cut a gorge more than 1 km. long and up to 60 m. deep. The threshold of this outlet was abandoned when ice to the west receded enough to allow drainage to the northwest to begin. The present lake (North Lake) which is less than one half the area of the glacial lake continues to empty that way, and its outlet has been entrenched 5 m. into bedrock. The detailed histories of this lake and others nearby which were dammed by ice during Step II are effectively recorded by terraces and lacustrine deposits (Johnson 1964).

East of Port Manvers Run, on Newark Island, drift is dominated by a massive lateral moraine complex (Figs. 2 and 4). This was laid down along the southeast side of the South Aulatsivik Highlands. It extends from there across the southern and, to a much lesser extent, along the western slopes of Mount Thoresby. The highest of these deposits marks the upper limit of ice on Mount Thoresby (580 m.) in Step II (Fig. 6). The ice divided against Mount Thoresby and sloped gradually northward on the west side but more steeply on the east side into the eastern end of Port Manvers. The presence of so much ice on the seaward side of the island shows that the ice sheet must have had a distinct northerly as well as easterly slope, a condition which may have been exaggerated here by the topographic differences between the Nain Archipelago and the submarine topography to the north.

A complex, hummocky medial moraine system 1 km. wide with numerous kettles and ponds above 400 m. was left at this time in the saddle between Mount Thoresby and the South Aulatsivik Highlands (Johnson 1964). As the ice thinned, dead ice features formed. Each renewal of wasting was marked by groups of lateral and subglacial drainage features at successively lower levels. These are most strikingly developed east of the divide where they helped to carry or direct water northward.

STEP II B

The ice pressing against the east side of Newark Island separated into two lobes in Step II B. It did this when the ice surface was at 300 m., after which one lobe receded toward Slambang Bay, the other south. Between the two lobes meltwater formed a lake which began to drain northeast through the lateral moraine-kame terrace complex north of Slambang Bay (Fig. 6). However, the regional ice level soon lowered enough, so that it reversed its direction of drainage (Johnson 1964). Continued lowering of the ice surface in Slambang Bay led to the formation of additional marginal and subglacial features which were eventually truncated at the 120 m. level by a series of well-defined kame terraces sometime after Step II B.

At the end of Step II A ice was still pouring through a col (610 m.) at the head of West Valley about 5 km. northwest of Attanekh Mountain. When the ice level dropped from 490 m. to 275 m. during Step II B, the upper part of West Valley (Fig. 2), a major southwest trending valley which extends to the Webb Brook valley, became increasingly ice-free. The progress of ice wasting and deglaciation here is well marked by successively lower concentrations of ice marginal and stagnant ice features on the walls and floor of the valley (Johnson 1964). Moraines show that when there was still 150 m. of ice in West Valley small lobes of ice flowed down into it through passes across the ridge separating it from Open Valley (Johnson 1964). It seems, therefore, that the rate of wasting was more rapid in West Valley (or possibly there was less replenishment) than in either Open Valley or the South Lake basin, both of which run parallel, but south and east of West Valley.

An end moraine in the upper part of West Valley shows that glaciers from two cirques at the head of the valley advanced and coalesced into a lobe that spread onto the floor of the main valley after the upper part of West Valley became free of ice. Later, in Step III, when there was more meltwater, a lake 30 m. deep formed between this lobe and the edge of the ice tongue in the lower part of the valley (Fig. 7). Local advances, probably related in time to West Valley moraines, are also recorded in Open Valley by poorly preserved marginal deposits at altitudes between 300 m. and 460 m. These deposits, in addition to the moraines at approximately the same elevations in West Valley, and the advance of cirque glaciers are tentatively equated with the Tasiuyak phase (Andrews 1963).

The large ice stream flowing through Port Manvers Run also left marginal deposits. In the southern part of the Run, meltwater, some of which may have crossed the Port Manvers Run Highlands, left marginal drainage channels at 640 m. beside ice pressing against the east side of the Highlands. Below these is a poorly preserved moraine system between 540 m. and 590 m., and at 400 m. there is another system of well-developed moraines (Johnson 1964). The latter are also tentatively equated with the Tasiuyak phase, but it is not known with any certainty to which part of Step II the former moraines belong.

The changes in glacial limits that occurred during Step II give a picture of a mountain and upland landscape apparently bounded entirely by ice and consisting of the uplands around the Kiglapait Mountains and Plateau, Newark Island and the neighbouring mainland. Some cirques were active, and isolated glacial remnants still occupied the floors of many high valleys. In addition there were undoubtedly semi-permanent snowfields and the areas of local accumulation which would have given this landscape an appearance very much like parts of coastal Greenland today. However, the incipient decay implied by meltwater responsible for the glacially-dammed lakes suggests that regional deglaciation was imminent.

STEP III

The deglaciation of these landscapes continued with the lowering of the surface of active ice down into the confines of Port Manvers Run, while water from the ice-dammed lake systems of the Kiglapait Plateau formed large rivers along the ice margins (Johnson 1964). One of these breached the Step II moraine to flow east until a route into Port Manvers Run was established down Man o' War Brook. As new outlets to the west were uncovered, Kiglapait Tasialua began to drain in that direction rather than across the Kiglapait Plateau (Figs. 6 and 7).

From the eastern end of what is now South Lake (265 m.) a 1½ km. long pitted outwash plain was built toward Port Manvers Run (Fig. 4). It carried runoff from the south side of Attanekh Mountain, the north side of the Port Manvers Run Highlands and the large ice lobe which was receding down Open Valley. Eventually the ice in Open Valley melted so far down and back from the topographic divide which separated it from the South Lake basin, that its meltwater was diverted subglacially through a gap leading to Ado's Brook valley. By this time the ice in Ado's Brook valley was apparently stagnant and beginning to carry South Lake overflow subglacially (Johnson 1964) as well. The Open Valley meltwater continued to drain this way to Webb Bay until the ice finally receded to the western end of Fox Lake (Step IV) when flow toward Webb Brook could begin.

The deglaciation of West Valley apparently proceeded in much the same way as that of Open Valley. The lake between the valley ice and the cirque glaciers of West Valley remained until the ice occupying the lower part of the valley became so inactive that outlets could develop. The eventual deglaciation at all but the lower reaches of these valleys seems to reflect the inability of the inland ice sheet to maintain ice thickness in marginal areas, and represents conditions sufficiently different from those of Step II to warrant being called Step III.

What glacial movement did occur while this was happening during Step III was concentrated more and more in the major low-lying troughs. In the northern part of Port Manvers Run minor moraines were built at this time to between 110 and 150 m. (Johnson 1964). These may be time equivalents of moraines at 300 m. in the southern part of Port Manvers Run (if the latter are not late Step II B) and the lobate ice tongue from Webb Brook valley which is defined by moraines between 150 m. and 300 m. in the lower part of Open Valley. These moraines represent the last advance for which there seems to be widespread evidence, but it is still not known if they were formed at the same time, nor is there anything to suggest that they are of the same age as the Puttualuk moraine (Andrews 1963) which marked the last advance in the northern Nain-Okak section of the coast.

STEP IV

When the ice sheet had waned sufficiently, the eastern edge of the Interior Upland Zone began to protrude (Figs. 7 and 8), but so long as the western ends of distributary troughs like Kingurutik Valley were enveloped and replenished from the main ice sheet, ice continued to be carried eastward away from this zone. Minor lateral moraines below 100 m. in northeastern and western Webb Bay may have been caused by the last vestiges of regional flow, but it seems more likely that they reflect a shift to flow controlled by the local adjustment to topography of the thinning lowland ice mass. In the Island and Bay Zone to the east the glacial cover, as part of this process, became separate, in a practical sense, from the ice sheet. The formation of features recording the change from regional to local control of ice margins left a strong enough imprint on the landscape to be identified as a major event, Step IV.

The ice on the Interior Upland Zone began to separate from Webb Bay ice when the surface of the latter was between 150 and 180 m. As Step IV continued, the ice became limited more and more to low areas and troughs, and as movement decreased and ablation became predominant, even the low-lying troughs began to be free of ice. Thus, in the southern end of Port Manvers Run the ice margins were about 90 m. above present sea level, and the ice had thinned to approximately 150 m. total thickness. The Second Rattle, Pierrepont Canal and other constrictions or barriers on the floor of Port Manvers Run had already inhibited ice movement and encouraged the development of ice marginal ponds. Kame terrace fragments and fluvially scoured bedrock between 70 and 80 m. formed at this time can be traced along parts of the north shore of the Run to a terrace of 65 m. and an ice marginal delta on the south side of Tikkigharsuk, which had appeared through the ice to separate ice in Port Manvers Run from ice remaining north of

Tikkigharsuk. This was followed by subglacial drainage in Port Manvers Run (Johnson 1964) as ice movement ceased.

While there were still large amounts of stagnant ice in the Valley Zone, extensive ice-dammed lakes (Prichard 1911; Tanner 1944) formed west of the provincial divide (Ives 1960a). Abandoned overflow channels near 520 m. in altitude led from the margins of these former lakes toward the Fraser River Valley (Ives 1960a). North of Lat. 56° N. mountain passes are too high to have carried water at this time. However, they do contain large eskers which lead toward the headwaters of the Kingurutik Brook and North River systems (Johnson 1964), and presumably they were active before the large lakes in the interior formed (i.e., before Ives' Glacial Lake N-1). This subglacial drainage may have begun before the ice became inactive (Carry and Ahmad 1961), although the record of steady downwasting and large volumes of subglacial drainage indicates temperature conditions conducive to climatically dead ice (Ahlmann 1948). If the latter conditions did exist, the eskers preserved in this rugged landscape probably developed beneath disintegrating and immobile ice. Drainage, both surface and subglacial, from this region followed the major valley systems toward the lower areas to the east, and where it came to the surface or the edge of the ice, its heavy load was used to build ice marginal deposits.

The large quantities of meltwater and detritus from both local and Interior Upland Zone sources were responsible during Step IV for the construction of extensive kame terrace systems (Fig. 2) like those in the Kingurutik Lake trough (Fig. 3). These terraces are 8 km. long and end in a delta (95 m.) above Webb Brook. The lake (Fig. 8) into which this kame delta was built was more than 30 m. deep and occupied the northwest corner of the junction of Kingurutik and Webb Brook ice. It confirms that marginal drainage could no longer transport sediment north along the west side of Webb Brook valley (without first filling in the lake cavity with sediment), and so extensive pitted outwash deposits north of the mouth of Kingurutik Valley must have been introduced earlier (Fig. 2) in Step IV. It is also possible that these deposits had their source in the mountains to the west. If this was so, they would not have come from Kingurutik Valley and might have been deposited at the same time as the kame terraces in Kingurutik Valley.

Along the northern side of Webb Bay (Fig. 3) another large complex of ice marginal deposits extends from a few kilometres east of the Kingurutik deposits to Port Manvers Run about 15 km. away (Johnson 1964). Deposits of similar size and disposition are visible on the mainland north of Okak Bay in the Siorak Brook area, and so the extraordinarily large quantities of outwash issuing from the Upland Zone appear to have been quite widespread. Furthermore, the numerous shoals and submerged deposits appearing on Admiralty Chart 265 suggest that the remnants of equally large deposits of possible glacio-fluvial origin may have been submerged along the coast by a rising sea level.

During Step IV enough of the low-lying ice along the outer coast disappeared so that a marine transgression by the eustatically rising sea began to submerge those portions of the ice-free coastal areas which had not yet had time to adjust isostatically to loss of the ice load. The evidence for this is not always distinguishable from glacio-fluvial and glacio-lacustrine features. On the east side of Newark

Island, Slambang Bay deposits below 83 m. appear to be contemporary with similar Port Manvers Run features. Tanner (1944) suggested that two fans located near this level (81 m.) represented the marine limit. Wenner pointed out that these cones may have been laid down against ice, otherwise the exposed position of Slambang Bay to marine erosion would have made their preservation unlikely (Wenner 1947). He suggested too, that the marine limit might be 71 m., but the present writer believes that in Slambang Bay the marine limit (Step IV) may have been located between 52 m. and 40 m. at a level which was largely disrupted when a terrace was cut at 40 m. (Johnson 1964). This is in keeping with evidence elsewhere, particularly that of ice terminal deposits on Tikkigharsuk which in different places show the modifying effects of both glacio-fluvial and glacio-marine action. Thus a bouldery moraine (mentioned by Tanner 1944) is traceable at approximately 52 m. from the mainland to Thalia Point and possibly across the mouth of the Run (Johnson 1964). The north side of it is a nearly level surface (44 m.) which is believed to be the marine limit.

On the south side of Tikkigharsuk (Fig. 8) in the northwest corner of Village Bay is an ice marginal delta of gravelly sand. This delta was built across 5 m. of fissile and crudely banded clayey silts which overlie a thin layer of compacted till on polished bedrock. Wenner (1947) states, "At Port Manvers in the north of the archipelago outside Nain, there are glacio-fluvial sand plains (lateral deltas), about the 67 m. level". The gist of Wenner's general discussion would suggest that this delta was built into the sea, and that this level may have been the marine limit.

Nearby, however, is evidence to suggest that the marine limit was actually lower, as suggested above. A relatively level surface about one km.^{2} rises from an altitude of 49 m. immediately north of this delta to an altitude of 55 m. on the north side of Tikkigharsuk. It has a smooth gravel surface a couple of metres above and distinct from the aeolian and water-laid deposits of other parts of the peninsula. Shallow depressions on its surface have a westward trend and are probably remnants of a short-lived glacio-fluvial system. Several 2 m. deep, non-linear, vegetation-filled depressions believed to be kettles are associated with these features. Their presence, if they are kettles, demonstrates that Tikkigharsuk was never completely submerged by the sea; had it been, they should have been destroyed by marine processes.

STEP V

The disappearance of the last isolated and stagnating ice masses is the final stage of deglaciation and is identified as Step V (Fig. 9).

The existence of unmodified glacio-fluvial deposits at elevations below nearby emerged strandlines shows that in this area eustatic rise of sea level and isostatic adjustment to deglacierization were well advanced before the last remnants of stagnant ice melted completely away. One place where this is recorded is on the northern side of Webb's Hill overlooking Hummock Valley. There an ice marginal terrace approximately 30 m. above sea level slopes eastward with an estimated 10 per cent gradient (see Fig. 11). If subjected to marine inundation, this terrace in its present form would certainly have been destroyed. Similarly, below the top

(45 m.) of a moraine across the eastern mouth of Hummock Valley there are two well-preserved kettle ponds the preservation of which would seem unlikely if they had been submerged by the sea (Johnson 1969).

The floor of Hummock Valley is characterized by poor drainage, large ponds, and hummocks with a relief up to 5 m. (Fig. 11). This mireland does not actually cover the entire floor of the valley. In places deposits of sand, and sometimes coarser materials, which may have been deposited alongside stagnant ice in a shallow marine environment, surround and separate the lower wet areas from the valley walls. It would not have taken long for marine waters in this valley to be decanted out if the land were rising rapidly, and if the water was shallow, it may have required less time than was needed for the melting ice remnants to disappear. It is conceivable, therefore, that the limits of this valley-bottom mireland might represent the margins of stagnant ice just before or at the end of a possible submergence.

FIG. 11. View south across Hummock Valley toward Webb Hill. The floor of the valley is less than 20 m. above sea level, and the maximum relief of the hummocks is about 5 m. An ice marginal terrace may be seen through the trees on the far side of the valley sloping eastward and reaching the floor of the valley slightly left of the centre of the photograph.

There are several square kilometres of similar mireland in Webb Brook valley, the eastern end of Kingurutik Valley and in low valleys crossing Newark Island. All of these examples are near the marine limit. Before the true extent and character of these depositional environments can be established, however, widespread subsurface and stratigraphic investigations are needed along the glacio-marine boundary. Marine fauna and material for absolute dating have not yet been recovered from elevations more than a few metres above sea level. Consequently, it is difficult to determine the relation of the many flights of terraces along the coast to similar-appearing glacio-fluvial and glacio-lacustrine features except as indicated above. This problem and emergence of the coast during the last stages of deglaciation will be considered in a separate paper.

SUMMARY

The highest mountains of the central part of the Nain-Okak Bay section of the Labrador coast must at one time have been completely inundated by northeastward moving ice. This complete ice cover is indicated by glacial erratics, and it

is tentatively correlated with Ives' Torngat Glaciation. Morphologic evidence in the form of mountain top detritus, nunatak forms and drift, plus some botanic evidence suggests that subsequent ice advances did not cover the highest peaks. The last deglaciation was basically a recession accompanying thinning of the ice sheet in the interior of Labrador. In the central Nain-Okak Bay area it occurred in 5 generally coherent "steps".

Step I represents the maximum advance of the most recent glaciation (Koroksoak). The direction of ice movement was northeast, and the ice is believed to have reached 975 m. above present sea level and extended 80 km. east of the coast. The highest peaks in the area rose above its surface as nunataks. By the end of Step I, the volume of ice had decreased until the northeastern part of the Kiglapait Plateau and Kiglapait Mountains was more or less ice-free.

A well defined moraine system (Step II A) locates an ice boundary at 460 m. on the western and 760 m. on the south side of the mountain rim around the Kiglapait Plateau, and at 275 m. on the east side of the Plateau above Port Manvers Run. Steep ice gradients in Port Manvers Run and on Newark Island suggest that the ice did not extend much farther to the northeast. Its deposits appear to be equivalent to those marking the maximum extent of the Saglek Glaciation.

Renewed thinning of the ice was interrupted in Step II B by the construction of moraine systems 60 to 300 m. lower than those of Step II A. The building of these moraines is tentatively equated with Andrews' Tasiuyak phase. At the same time minor moraines were built by glaciers in some of the cirques which had emerged from Step II A ice.

A general recession followed Step II. Replenishment from the inland ice continued, but a negative glacial regime existed, and the ice was waning. Step III ice boundaries show the land mass emerging from the ice. Valleys tributary to the main ice mass contained ice lobes which separated, receded or stagnated as required by the topography. Glacio-fluvial deposits reflected these conditions. Ice in the principal troughs was still active, but local gravity flow may have been responsible for some of the small moraines formed at this time. Andrews' Puttualuk moraine might be synchronous with these events or the late Step II B lower Open Valley moraines, or the 300 m. Port Manvers Run moraine, although there is no proof for any of these suppositions.

Step IV brought an intensification of the ice-wasting conditions of Step III, and in the study area only masses reaching altitudes of 90 m. to 150 m. remained. The ice sheet at higher altitudes in the interior of Labrador must have been climatically dead by this time, because torrents of meltwater left extensive kame terrace systems in all the major troughs. In addition isostatic rebound and coastal submergence of outer areas were well advanced.

The final disintegration of ice in the study area marked Step V. Stagnant ice in low lying areas prevented complete incursion of the eustatically rising sea until isostatic adjustment was well advanced. Thus, the oldest and highest shorelines of submergence are found on the open coast, while in some of the inner bays and troughs the marine limit is marked by lower, younger terraces. Since these are not always found at the same altitudes they may, in fact, be confused with ice marginal terraces.

The history of deglaciation of the central part of the Nain-Okak Bay section of the Labrador coast must remain a relative rather than absolute chronology until accurate dates are available for the episodes recognized. Correlations with more northerly work where absolute chronologies are being constructed are possible, but the distances are so great and the problems sufficiently complex (Falconer *et al.* 1965a, b; Blake 1966) to make such an attempt seem premature.

ACKNOWLEDGEMENTS

The field work for this study was supported by the McGill-Carnegie-Arctic Institute program and the Arctic Institute of North America. Air transport in Labrador was provided by the British Newfoundland Exploration Company, Ltd., and the assistance of Dr. A. P. Beavan and Mr. M. Piloski of that firm is particularly appreciated. Dr. and Mrs. E. P. Wheeler, 2nd, Capt. D. C. Nutt, and Dr. and Mrs. L. C. Graton helped in different but equally important ways. I am especially grateful for their encouragement at the various stages of the study. The Surveys and Mapping Branch of the Department of Energy, Mines and Resources provided preliminary maps of the area, and the Moravian Mission and individuals along the coast were most hospitable; it is a pleasure to acknowledge their assistance. My wife, Eloise V. Johnson, not only served as an able field assistant but did the preliminary cartography. Miss E. A. Crux prepared the maps for publication. Carleton University assisted with the cost of publication.

An early draft of the manuscript was read by Dr. J. T. Andrews, Dr. J. D. Ives and Dr. E. P. Wheeler, 2nd. Their comments proved to be most helpful, and I wish to express my sincere thanks to them.

REFERENCES

ABBE, E. C. 1938. Phytogeographical observations in northernmost Labrador. In: A. Forbes. Northernmost Labrador Mapped from the Air. *American Geographical Society, Special Publication* No. 22. pp. 217-34.

AHLMANN, H. W. 1948. Glaciological research on the North Atlantic coasts. *Geografiska Annaler,* 1: 1-210.

ANDREWS, J. T. 1961. The glacial geomorphology of the northern Nain-Okak Section of Labrador. M.Sc. Thesis, McGill University. 280 pp.

————. 1963. End moraines and late-glacial chronology in the northern Nain-Okak section of the Labrador coast. *Geografiska Annaler,* 45: 158-71.

————. 1965. The corries of the northern Nain-Okak section of Labrador. *Geographical Bulletin,* 19: 49-77.

ANTEVS, E. 1932. *Alpine Zone of Mt. Washington Range.* Auburn, Maine, Merrill & Co. 118 pp.

BELL, R. 1885. Observations on the geology, zoology and botany of Hudson's Strait and Bay, made in 1885. *Geological Survey of Canada, Annual Report 1885.* New Series, Vol. 1, Report DD. 27 pp.

BARNETT, D. M. and J. A. PETERSON. 1964. The significance of glacial Lake Naskaupi in the deglaciation of Labrador-Ungava. *Canadian Geographer,* 8: 173-81.

BLAKE, W. JR. 1966. End moraines and deglaciation chronology in northern Canada with special reference to southern Baffin Island. *Geological Survey of Canada Paper* 66-26. 31 pp.

BLYTT, AXEL. 1881. Die Theorie der wechselden montinentalen und insularen Klimate. *Englers Botanische Jahrbücher,* 2: 1-50.

CARRY, S. W. and N. AHMAD. 1961. Glacial marine sedimentation. In: G. O. Raasch, editor. *Geology of the Arctic*. Vol. 2, University of Toronto Press. pp. 865-94.

CHRISTIE, A. M. 1952. Geology of the northern coast of Labrador, from Grenfell Sound to Port Manvers, Newfoundland. *Geological Survey of Canada Paper* 52-22. 13 pp.

COLEMAN, A. P. 1920. Extent and thickness of the Labrador Ice Sheet. *Geological Society of America Bulletin*, 31: 319-28.

————. 1921. Northeastern part of Labrador and New Quebec. *Geological Survey of Canada Memoir* 124. 68 pp.

DAHL, E. 1946. On different types of unglaciated areas during the ice age and their significance to phytogeography. *New Phytologist*, 45: 225-42.

DAHL, R. 1966. Block fields, weathering pits and tor-like forms in the Narvik Mountains, Nordland, Norway. *Geografiska Annaler*, 48A: 55-85.

DALY, R. A. 1902. The geology of the northeast coast of Labrador. *Bulletin of the Museum of Comparative Zoology at Harvard College, Geological Series*, Vol. V, No. 5, pp. 203-70.

FALCONER, G., J. T. ANDREWS and J. D. IVES. 1965a. Late Wisconsin end moraines in northern Canada. *Science*, 147: 608-10.

FALCONER, G., J. D. IVES, O. H. LØKEN and J. T. ANDREWS. 1965b. Major end moraines in eastern and central Arctic Canada. *Geographical Bulletin*, 7: 137-53.

FERNALD, M. L. 1925. The persistence of plants in unglaciated areas of boreal North America. *American Academy of Arts and Science, Memoirs*, 15: 237-432.

FLINT, R. F. 1943. Growth of North American ice sheet during the Wisconsin Age. *Geological Society of America Bulletin*, 54: 325-62.

GRAY, J. T. 1969. Glacial history of the eastern Mealy Mountains, southern Labrador. *Arctic*, 22: 106-11.

HARRISON, D. A. 1963. The tilt of the abandoned lake shorelines in the Wabash-Shabogama Lake area, Labrador. *McGill Sub-Arctic Research Papers*, No. 15, pp. 14-22.

HENDERSON, E. P. 1959. A glacial study of central Quebec-Labrador. *Geological Survey of Canada Bulletin* 50, 94 pp.

HUGHES, O. L. 1964. Surficial geology, Nichioun-Kaniapiskau Map area, Quebec. *Geological Survey of Canada Bulletin* 106, 20 pp.

IVES, J. D. 1957. Glaciation of the Torngat Mountains, Northern Labrador. *Arctic*, 10: 66-87.

————. 1958a. Mountain-top detritus and the extent of the last glaciation in northeastern Labrador-Ungava. *Canadian Geographer*, 12: 25-31.

————. 1958b. Glacial geomorphology of the Torngat Mountains, northern Labrador. *Geographical Bulletin*, 12: 47-75.

————. 1959. Glacial drainage channels as indicators of late-glacial conditions in Labrador-Ungava. *Cahiers de Géographie de Québec*, 8me. An., No. 5, pp. 57-72.

————. 1960a. Former ice-dammed lakes and the deglaciation of the middle reaches of the George River, Labrador-Ungava. *Geographical Bulletin*, 14: 44-70.

————. 1960b. The deglaciation of Labrador-Ungava — an outline. *Cahiers de Géographie de Québec*, 8: 323-44.

————. 1963. Field problems in determining the maximum extent of Pleistocene glaciation along the eastern Canadian seaboard — a geographer's point of view. In: A. Löve and D. Löve, editors. *North Atlantic Biota and their History*. Pergamon Press. pp. 337-59.

————. 1966. Block fields, associated weathering forms on mountain tops and the nunatak hypothesis. *Geografiska Annaler*, 48A: 220-23.

JOHNSON, E. N. 1960. The phytogeography of a coastal transition zone in northern Labrador. Unpublished, M.A. Thesis, Clark University.

JOHNSON, J. P. JR. 1964. Deglaciation and emergence of the Webb Bay-Port Manvers Run area of Labrador. Unpublished Ph.D. Thesis, McGill University.

———. 1969. Late glacial origin of the Sandbanks, Webb Bay, Labrador. *Canadian Geographer,* 13: 99-112.

LOW, A. P. 1896. Report on Explorations in the Labrador Peninsula along the East Main, Koksoak, Hamilton, Manicuagan, and portions of other Rivers in 1892-93-94-95. *Geological Survey of Canada, Annual Report, 1895,* Vol. 8, New Series. Part L. Ottawa, 387 pp.

LØKEN, O. 1959. Geomorphological studies in the Torngat Mountains, Northern Labrador. *Arctic,* 12: 243.

———. 1962a. The Late-Glacial and Postglacial emergence and the deglaciation of northernmost Labrador. *Geographical Bulletin,* 17: 23-55.

———. 1962b. On the vertical extent of glaciation in northeastern Labrador-Ungava. *Canadian Geographer,* 6: 106-19.

MEYER, K. 1954. Report on the preliminary survey of raised beaches in Northern Labrador. Blue Dolphin Expedition, Report No. 12, 1954. Typewritten.

MORSE, S. A. 1962. The Kiglapait layered intrusion, coast of Labrador, Canada. (Lithographed preprint of a paper delivered before the Mineralogical Association of Canada, Ottawa, Ontario, April 24, 1962.)

———. 1964. Age of Labrador anorthosites. *Nature,* 203: 509-10.

ODELL, N. E. 1938. The geology and physiography of northernmost Labrador. In: A. Forbes. *Northernmost Labrador Mapped from the Air.* American Geographical Society Special Publication No. 22.

PACKARD, A. S. 1891. *The Labrador coast. A journal of two summer cruises to that region. With notes on its early discovery, on the eskimo, on its physical geography, geology, and natural history.* New York: Hodges.

PRICHARD, H. H. 1911. *Through Trackless Labrador.* New York: Sturgis and Walton. 244 pp.

TANNER, V. 1944. Outlines of the geography, life and customs of Newfoundland-Labrador (the eastern part of the Labrador Peninsula). *Acta Geographica Fennias,* 8: 1-909.

TOMLINSON, R. F. 1963. Pleistocene evidence related to glacial theory in northeastern Labrador. *Canadian Geographer,* 7: 83-90.

WENNER, C. G. 1947. Pollen diagrams from Labrador. A contribution to the Quaternary Geology of Newfoundland-Labrador, with comparisons between North America and Europe. *Geografiska Annaler,* 29: 137-373.

WHEELER, E. P. 2nd. 1935. The Nain-Okak section of Labrador. *The Geographical Review,* 25: 240-54.

———. 1942. Anorthosite and associated rocks about Nain, Labrador. *Journal of Geology,* 50: 611-42.

———. 1958. Pleistocene glaciation in northern Labrador. *Geological Society of America Bulletin,* 69: 343-44.

———. 1960. Anorthosite-Adamellite complex of Nain, Labrador. *Geological Society of America Bulletin,* 71: 1755-62.

———. 1964. Unmetamorphosed sandstone in northern Labrador. *Geological Society of America Bulletin,* 75: 569-70.