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ISOBASES ON THE WISCONSIN MARINE LIMIT IN CANADA

*W. R. Farrand and R. T. Gajda**

ABSTRACT: The pattern of isobases drawn on the maximum extent of postglacial marine submergence, supplemented by isobases on glacial lakes, includes a major dome centred on Hudson Bay and minor cells over late-glacial remnants such as the Keewatin ice divide and Baffin and Ellesmere islands. Radiocarbon dates and uplift curves show that this uplift is truly glacio-isostatic.

RÉSUMÉ: Le réseau d'isanabases qui dessine la limite maximale des mouvements de submersion post-glaciaires, complété par les isanabases qui entourent les lacs glaciaires, comprend un dôme principal qui a pour centre la baie d'Hudson, et quelques ensembles localisés recouvrant les vestiges des dernières phases glaciaires, comme c'est le cas sur les îles Baffin et Ellesmere et dans le système du Keewatin. Les datations obtenues grâce au carbone 14 de même que par les isanabases démontrent qu'il s'agit bien ici d'un exhaussement glacio-isostatique.

INTRODUCTION

This paper presents the results of the first phase of a study initiated in 1948 by the Geographical Branch, and pursued intermittently during the period 1948 to 1959. In 1960 it was enlarged into a combined project with Dr. Farrand and the Lamont Geological Observatory.

The early work involved systematic collection of field data over a wide area of the Arctic by Dr. Gajda; this was followed by an intensive search of the literature and a compilation in the office of all published data. During this phase, J. Warkentin, summer student in 1953, and H. Richard, initially as a summer student and later as permanent member of the Branch, worked on the project. Mr. Richard, in particular, made a most valuable contribution by his compilation and by the production of a lengthy unpublished appraisal of these data. More recently, extensive original additions to the data have been made by several members of the Geographical Branch staff. Finally, Dr. Farrand has added his original research in the north-central United States and has made a major contribution by his interpretation of the accumulated data. This interpretation forms the basis of the present paper and accompanying map.

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MS submitted October, 1961

A preliminary edition of the isobase map was presented to the International Quaternary Association Congress held in Warsaw in 1961. It has now been brought up to date and is presented here with a modified text.

The study of the latest marine transgression of major continental areas, that which occurred in postglacial time following the retreat of the Wisconsin and Weichsel continental ice sheets, is intriguing to many Quaternary scientists. It is especially interesting to geographers and geologists who hope to learn something about the areal extent of the ice sheets and about isostatic depression and recoil of the earth's crust. Before the present work was compiled, however, very few quantitative data were available for North America, although postglacial submergence and rebound have been well documented for a long time in northern Europe. Now owing mainly to field studies during the past decade or so by various Canadian governmental agencies, observations are numerous enough for compilation, and preliminary conclusions can be drawn.

The compilation presented here deals with the altitude of the maximum extent of postglacial marine submergence, i.e., the *marine limit*, throughout that sector of North America covered by the Laurentide-Baffin-Ellesmere ice-sheet complex. All available data have been plotted and isobases have been drawn. With the inclusion of isobases of large glacial lakes in north-central United States and Southern Canada a coherent isobase system for approximately 80 per cent of the perimeter of the Wisconsin Laurentide ice sheet is obtained.

The theory of isostatic depression and recovery due to glacier loading and unloading is now widely accepted, but the arguments pro and con cannot be given here. Suffice it to say that the present writers follow the reasoning outlined by Flint (1957, p. 240) in support of glacio-isostasy. The isobase system presented here is an additional strong argument in its favor for the case of North America.

Earlier compilations and isobase maps have been made by several distinguished workers, but they were severely handicapped by insufficient reliable data, and their work must be judged accordingly. For the area of Canada east of Hudson Bay compilations and isobase maps have been prepared by Cooke (1930) and Daly (1934). For Arctic Canada, Washburn (1947), Prest (1957), Bird (1959), and Sim (1960) have made compilations of data, but they avoided the problem of isobases. Craig and Fyles (1960) present a generalized scheme of marine submergence for the northwestern

Canadian Arctic and draw tentative isobases which are quite similar to those presented here.

SOURCES AND RELIABILITY OF DATA

Numerous observations of raised marine features made during the past decade now permit improvements on previous attempts (e.g., Cooke, 1930) to summarize and interpret the pattern of the postglacial submergence. Most of the recent observations in the Canadian Arctic have been made by members of the Geographical Branch and the Geological Survey of Canada. Most of these have been published, but unpublished observations of R.T. Gajda (1960, 1961), B. Robitaille, and other members of the Geographical Branch have been especially useful in filling gaps.

Limited space in this report does not allow a complete accounting of all features pertinent to the marine limit, but it is planned to include these data in a future paper. In the interim one can consult the summary of Cooke (1930) for almost all data prior to 1930. Important works of more recent date include Mathiassen (1933), Flint (1940), Washburn (1947), Fortier (1948), Blackadar (1956, 1958), Prest (1957), Mackay (1958), J. T. Wilson and others (1958), Bird (1959), Henderson (1959), Lee (1959a), Robitaille (1959, 1961), Craig (1960), Craig and Fyles (1960), Jenness (1960), Lee and others (1960), and Sim (1960).

The reliability of such data may vary considerably with different observers. Very few observations have resulted from systematic studies of marine features; rather, they were incidental to other programs of geological or geographical research. Altitude determinations, most of which have been barometric, are also of variable reliability. They are subject to considerable error in this wilderness country where bench marks and contour maps are rare. However, for the present, compilation accuracy within a few tens of feet is sufficient to show the major isobasic trends.

When all available data were compiled and plotted, a few obvious discrepancies were noted and eliminated on the basis that these features were mistakenly identified or, in some areas, are related to an older system of marine features. These are discussed in detail below. Approximately 250 observations were used here as a basis for the isobase system as drawn; only 26 observations (10 per cent) are anomalous, and most of these can be satisfactorily explained.

Only the highest, or highest reliable, features have been plotted for each area, but these features are of diverse kinds. The most obvious and abundant indications of marine submergence are raised strandlines, which are not proven to be marine, however, unless fossils are associated with them. The second most obvious evidence of marine submergence is accumulations of fossil marine shells not associated with strandlines. These shells, if they occur in clay or sand, are good indicators of the *minimum extent* of submergence because most of them lived in several fathoms of water. However, marine shells have been reported also from deposits of glacial till and other materials such as "stony silt" or stony mud wherein their occurrence is problematical. These occurrences should be held aside until there is some assurance that they are marine deposits *in situ.*

Furthermore, a number of occurrences of so-called "marine deposits" cited in older reports must also be closely evaluated because it is not known whether this label was based on marine fossils or merely the physical resemblance of a certain deposit of sand or clay to known marine sediments.

Another method for determining the extent of marine submergence has been used recently (Bird, 1959; Sim, 1960) that depends on somewhat detailed ground observations and on the use of airphotos. The *limit of wave action*, in the absence of strandlines and fossils, can be established by (a) the upper limit of wave-reworked ground moraine, which is frequently apparent on airphotos, and (b) the lower limit of perched boulders, a somewhat less certain and less easily applied criterion. Sim (1960) in his excellent discussion of northern Melville Peninsula compares the results obtained by four different criteria for establishing the marine limit. Here, as elsewhere in the Canadian Arctic, the mean upper limit of wave action determined by the ground moraine and perched boulder methods commonly lies a few tens of feet above the highest marine fossils and strandlines.

CONSTRUCTION OF THE ISOBASE MAP

A single system of contours on the marine limit has thus been drawn (Figure 1) for the area between Amundsen Gulf in the western Arctic and the Atlantic coast of New England in the United States in order to depict both the extent and pattern of postglacial submergence. The contours were drawn in as simplified a manner as would accord with the data because it is believed that the data are not precise enough to warrant extremely detailed treatment. A contour interval of 100 feet, in general, is the smallest that the

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Figure 1. Map of isobases on marine limit and glacial lakes in eastern and central North America. Isobase interval is 100 feet, supplemented at 50-foot intervals in a few places. In the Great Lakes area, isobases on the Algonquin water planes are shown, as well as the Whittlesey zero isobase. In the Lake Agassiz basin isobases are shown on the highest (Herman) water plane. ➧

ISOBASES ON MARINE LIMIT
AND
GLACIAL LAKES IN CANADA

Observations of Marine Limit plotted from numerous sources.
To accompany "Isobases on the Wisconsin Marine Limit in Canada"
by W.R. Farrand and R.T. Gajda, Geographical Bulletin 17, 1962.

LAMBERT CONFORMAL CONICAL PROJECTION. STANDARD PARALLELS 49° AND 77°.

Geographical Branch, Dept. of M. & T.S. 1961

data justify. However, supplementary 50-foot contours are possible and have been included in a few places.

These contours depict the imaginary surface of the upper limit of marine submergence, the irregular configuration of which is strongly influenced by glacial isostatic compensation upon removal of the load of the continental ice sheet. The contours on this map (Figure 1), therefore, are actually isobases* inasmuch as they connect points of equal elevation on a warped surface.

However, the concept of isobases as used here is somewhat different to most previous usage. Usually isobases are drawn on a single water plane, occupied everywhere at one time, formerly level and now warped. But the *marine limit* is not of the same age at all points. The postglacial sea invaded different areas at different times according to the pattern of deglaciation. Also, sea level was rising gradually throughout this period. The concept of the marine limit, therefore, is very much like that of a transgressive marine littoral sandstone formation, a single unit of rock but portions of it deposited at different times as the sea progressively flooded the land. Thus, just as structure contours may be drawn on the time-transgressive surface of this sandstone formation, so may isobases be drawn on the time-transgressive, imaginary surface defined by the marine limit.

In order to complete the map wherever information on postglacial uplift is available, isobases of warping of glacial lakes in north-central United States have been added (Hough, 1958; Flint, 1957; Farrand, 1960a; Johnston, 1946). Glacial lake isobases cannot yet be directly linked with the marine limit or a sea-level datum of any sort. Their quantitative values, accordingly, cannot be directly compared to the marine limit values. Thus on Figure 1 the isobases of glacial Lake Agassiz and glacial Lake Algonquin are indicated as 100 feet, 200 feet, etc., above their respective zero isobases.†

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* isobase: a topographic or imaginary contour line in a map, drawn through a series of points of equal elevation in a topographic surface or line, formerly level, but at present deformed. (*Glossary of Geology*, Am. Geol. Inst. 2nd. ed., 1960, p. 155).

† An interesting problem arises from the comparison of Agassiz and Algonquin isobases: The "Herman beach" water plane, the highest of Lake Agassiz, is shown on Figure 1. Although older, it has a much lower slope than the Algonquin water plane. The Herman beach pre-dates the Two Creeks interval (Elson, 1959), and Lake Algonquin post-dates Two Creeks time. This age relationship supports the contention that the zero isobase in the Lake Agassiz area should correlate with the Whittlesey zero isobase ("hinge") in the Great Lakes area rather than with the Algonquin zero. On the other hand, the reverse relationship between degree of tilt and age uniformly prevails wherever isobases are studied—younger water planes are tilted less than older ones in the same areas. Perhaps, then, Lake Agassiz and Lake Algonquin must be considered separately, and these disparate slopes may imply that the ice mass was considerably thinner over the Agassiz basin than over the Great Lakes.

These zero isobases separate areas of recognized differential uplift (tilting) of former water planes from areas to the south where no uplift at all is recognized, although uniform vertical movement is not necessarily precluded. The importance of the glacial lake isobases is that they complement the marine isobases and allow the isobasic trend to be extended many miles into the continental interior from the Atlantic coast.

Also, preliminary reports on raised beaches around Great Bear Lake in northwest Canada, although limited, are consistent with the pattern of warping of the marine limit and suggest an extension of the isobase system nearly 200 miles inland from the Arctic coast (Kröger, 1958; Craig, 1960; Lord and others, 1960).

INTERPRETATION OF THE ISOBASES

Concerning the genesis of this isobase system, one should consider the following phenomena.

Firstly, the earth's crust was depressed by the load of the continental ice sheet, and world-wide sea level dropped eustatically more than 300 feet. If isostatic equilibrium was attained at the glacial maximum, then as much as 2,000 to 3,000 feet of crustal depression may have taken place under the central areas (if one may postulate for the Laurentide ice sheet a thickness comparable to the existing ice sheets in Antarctica and Greenland), and proportionately lesser amounts of uplift toward the periphery.

Secondly, retreat of the ice sheet from its maximum position began about 18,000 to 20,000 years ago along the southern border in the U.S.A. and *more* than 12,400 years ago (Craig and Fyles, 1960) in the western Arctic. Glacial retreat in its early stages (prior to about 11,000 years ago) took the form of rather regular withdrawal of the ice margin towards the interior (Flint, 1957; Craig, 1960; Craig and Fyles, 1960). Radiocarbon-dated curves of the eustatic rise of late-glacial sea level (Godwin, and others, 1958) show that the sea was still 120 to 150 feet below its present position as late as 11,000 years ago.

Thirdly, in the later stages of deglaciation the ice sheet apparently became divided into several segments centred on present-day inland areas, such as the Keewatin ice divide, northwest of Hudson Bay (Lee, 1959a) and an ice divide near Schefferville in the centre of the Labrador-Ungava peninsula (Ives, 1960). Similarly, Ellesmere and Baffin islands were probably areas of late-glacial ice masses, on the criterion of their present-day glacierization, which may be a residual of the Wisconsin ice sheet. The Wisconsin age Laurentide-Baffin-Ellesmere ice complex was thus segmented, apparently as sea level rose, flooding the present Arctic waterways (Hudson Bay, Hudson Strait, and the various channels separating the islands of the archipelago), and submerging present-day land areas, causing rapid ablation by calving. There is no necessity to consider that the Keewatin and Schefferville ice divides were in any sense "centres" of the Laurentide ice sheet at its *maximum* extent.

Fourthly, postglacial rebound not only was contemporaneous with deglaciation but certainly began prior to final disappearance of the ice. This conclusion is based, in part, on radiocarbon-dated uplift curves (Farrand, 1960b and in press) for both the Great Lakes and Arctic America which show that for a given locality the rate of uplift (a) was very great at the moment of deglaciation and (b) decreased exponentially to very small values at present. The maximum uplift so recorded (about 900 feet) for central areas is certainly less than one-half the total amount expected if the ice sheet was 10,000 feet thick and in isostatic equilibrium. Thus, at least half of the total rebound must have taken place while the ice sheet was thinning but before it actually melted away. Washburn (1947) reached a similar conclusion from geomorphic evidence on Victoria Island.

Therefore, the isobase map must be interpreted as an integration of these four phenomena: (a) crustal depression (2,000-3,000 feet) and sea level lowering (300 feet or more) at the glacial maximum; (b) regular glacier retreat beginning about 18,000 to 20,000 years ago while sea level was at its minimum level; (c) submergence of wide areas of the Arctic generally concentrated along the present waterways and causing segmentation of the ice sheet; and (d) glacial rebound which began before final deglaciation and proceeded throughout while sea level was rising, even to the present day.

Moreover, the isobases are not drawn on an isochronous surface. Deglaciation, sea-level rise, and rebound are time-transgressive processes. Thus, submergence of a given area cannot occur until that area is deglaciated. The marine limit was attained, accordingly, at later and later times from the periphery of the continent towards the interior. Unfortunately, no radiocarbon dates apply *directly* to the marine limit, although a 12,400-year date from northwestern Victoria Island and a 10,500-year date from Coronation Gulf (Craig and Fyles, 1960) probably followed closely upon deglaciation. Of course, the relatively simple picture of regular submergence following on the heels of regular glacier retreat is complicated not only by a sea level which was rising eustatically at the same time, but also by concomitant crustal uplift. The generalization can be made, however, that isobases in the central areas of the map are younger than those towards the periphery.

With these considerations in mind, it is proposed to discuss the isobase map itself. The most obvious pattern is one of *regularly increasing altitude of the marine* limit from the limit of glaciation *towards the interior* — both in the northwest and along the southern border. This pattern has been previously suggested by Craig and Fyles (1960) for the northwestern Canadian Arctic and has been known for a long time in the north-central and northeastern United States on the basis of warped strandlines of glacial lakes. This pattern persists from the southern limit of Wisconsin age glaciation to the height of land which separates the Great Lakes and Hudson Bay drainages, roughly 300 to 400 miles as measured orthogonally to the isobases. In the western part of the Arctic archipelago this "regular" pattern occupies a belt 500 to 700 miles wide. In addition, a "regular" zone about 350 miles wide crosses the Maritime Provinces.

The second outstanding feature of the isobase pattern is the *central dome over the Hudson Bay area.* A Hudson Bay centre is also proposed by Lee (1959b) on the basis of transport of glacial erratics. Around Richmond Gulf on the southeast coast of Hudson Bay are the highest recorded values for the marine limit (875 feet, Stanley, 1939; 880 feet, Lee and others, 1959). The remainder of the land enclosed by the 600-foot isobase is too low to record such high values. The oldest radiocarbon-dated marine features in this area are marine shells referred to a raised strand 400 to 500 feet above present sea level along the Missinaibi River (7,875 ± 200 years ago) and Opasatika River (7,280 ± 80 years ago) which flow into southern James Bay (Lee, 1960). Deglaciation and marine submergence must have occurred somewhat earlier than these dates, perhaps 8,500 years or more ago (cf. a radiocarbon date of 8,500 years ago for the deglaciation of parts of interior Labrador-Ungava—Grayson, 1956). Thus, it appears that the 600- to 900-foot isobases around Hudson Bay are definitely younger (by 1,000 to 2,000 years) than isobases of comparable values around Coronation Gulf (dated around 10,500 years) or in the Great Lakes-St. Lawrence area (dated around 10,300 to 11,000 years; Hough, 1958). This being the case, the 600- and 700-foot isobases enclosing Hudson Bay imply greater values in terms of *total* glacial rebound than the 600- and 700-foot isobases nearer the periphery of the glaciated area because it is likely that the uplift which raised the marine limit to 600 or 700 feet in the Coronation Gulf and St. Lawrence lowland also raised the Hudson Bay area by a certain amount, which was unrecorded because the Hudson Bay area was still ice-covered.

The third major feature of the isobase map is the group of *relatively small domes and troughs* in the central and northern Canadian Arctic. The *dome* on Ellesmere Island, with maximum values above 500 feet, probably reflects the role of that area as a centre of ice-sheet expansion. Perhaps it also indicates the fusion of the Ellesmere ice sheet with the Greenland ice sheet at the last glacial maximum.

Isobasic values rise above 700 feet in Queen Maud Gulf and Bathurst Inlet, but they are separated from the Hudson Bay dome by a northeast-trending *trough* which coincides closely with the Keewatin ice divide, the site of the last remnant of the Laurentide ice sheet west of Hudson Bay (Lee, 1959a). This ice remnant disappeared between 7,000 and 6,000 years ago, but prior to its final melting it prevented marine waters, which were already making their marks around Hudson Bay (the 600-foot isobase), from transgressing the Thelon River lowland and Wager Bay. In other words, along the Keewatin ice divide *less uplift* has occurred *since the marine transgression* than in adjacent areas, but the marine transgression was not simultaneous in all these areas. It is logical to assume that the thickness of the ice sheet at its maximum extent was nearly uniform over the area between Bathurst Inlet and Hudson Bay, and the *total* crustal depression and uplift, therefore, should be nearly uniform also. On this account, the Keewatin isobasic trough seems to be evidence of a residual ice centre rather than an irregularity in total glacial rebound.

Although the case is not so clear, the isobase trough which lies along the west coast of Baffin Island probably represents a late-glacial ice remnant similar to that which occupied the Keewatin ice divide. Baffin Island was undoubtedly one of the original highland centres of the growing Laurentide ice sheet (Flint, 1957). The extent of the Baffin Island ice sheet was limited on the east by rapid calving into Baffin Bay and Davis Strait, but shallow Foxe Basin on the west was probably drained by eustatic sea-level lowering at an early stage of glacier growth and the dry land so created permitted extensive ice accumulation. Thus, at its maximum extent, the ice sheet was undoubtedly thicker over Foxe Basin than over the crest of the Baffin Island mountains. During deglaciation, the Foxe Basin ice would have melted away more slowly than that on the mountains, restricting the extent of marine transgression around the shores of Foxe Basin. Such a pattern of deglaciation is supported partly by the fact that the residual ice caps (e.g.

Barnes Ice Cap) on Baffin Island are not located on the mountain peaks but on lower terrain *west* of the mountains.

In summary, the main features of the isobase map are: (a) regularly increasing altitude of the marine limit for 300 to 700 miles inland from the limit of glaciation, which coincides with the area of regular withdrawal of the Laurentide-Baffin-Ellesmere ice sheet; (b) a major dome centred on Hudson Bay outlined by isobases younger than those on the periphery and implying greater glacial rebound than nearer the periphery; (c) a subsidiary dome over Ellesmere Island which coincides with a centre of ice-sheet growth and perhaps confluence with the Greenland ice sheet; and (d) isobase troughs centred over the Keewatin ice divide and eastern Foxe Basin apparently coinciding with late-glacial remnants of the ice sheet which locally restricted marine transgression.

ANOMALOUS DATA

The heterogeneity of the data and their variable reliability have been stressed previously. Compilers can only accept or reject observations made in the past on the basis of the original observer's report, and in some cases its agreement with other reports. About 250 observations were used in constructing the map, and an additional 26 were rejected because they have been contradicted by later studies or were not compatible with the isobase system. The incompatible observations can be explained as: (a) features mistakenly identified as marine; (b) truly marine features related to a glaciation earlier than the last (Wisconsin) glacial stage; or (c) features produced during an interglacial high sea stand. Into the first category fall strandlines and deposits of glacial lakes mistakenly interpreted as marine features, such as high shorelines up to 1,425 feet above sea level in Frobisher Bay, Baffin Island (Mercer, 1956; Bird, 1959), and marine shells which were not emplaced by marine processes but which perhaps were reworked by glaciers or dropped by birds, cf. the problematical occurrence of marine shells at 1,998 feet above sea level near Eureka, Ellesmere Island (V. Sim, personal communication, and 1961; Robitaille, 1961, p. 176).

In the western Canadian Arctic some interesting features occur which are considerably higher than the isobases for that area. Although Craig (1960) found no obvious late-Wisconsin marine features along the mainland coast between longitudes 122° and 124° west, O'Neill (1924), Mackay (1958) and others report marine features 200 to 600 feet above sea level along this coast of Amundsen Gulf. The "marine Pleistocene formation" with fossils up to 500 feet above sea level, which O'Neill describes from the Darnley Bay area, has faunal affinities with the Gubik formation of the Arctic coastal plain of Alaska (Dall, p. 30A in O'Neill, 1924). The Gubik formation is Pleistocene in age but whether glacial or interglacial, or both, has not been decided. Radiocarbon dates from the upper Gubik member span the Wisconsin glacial stage and terminate prior to 9,100 years ago (Coulter and others, 1960).

On Banks Island, marine shells and strandlines have been reported at 450, 500, 580, and 600 feet above sea level (Washburn, 1947; Bird, 1959; Manning, 1956). These are widely scattered, however, and signs of *post-Wisconsin* submergence are restricted to quite low elevations —"less than 225 feet" (Craig and Fyles, 1960), and probably less than 100 feet.

On Lougheed Island, marine shells were observed by Stefansson at 300 feet above sea level, and are also reported at 100 feet (Washburn, 1947). The higher value seems incompatible with other observations in the western Queen Elizabeth Islands.

On Prince Patrick Island driftwood, reportedly from a raised strandline 490 feet above sea level, has a radiocarbon age of greater than 38,000 years (Rubin and Alexander, 1958). A possibility exists, however, that this wood is from the Beaufort formation which antedates Wisconsin glaciation (Tozer, 1956).

These three occurrences of high marine features on the westernmost arctic islands which are not compatible with the isobase system of Figure 1, and at least one of which is older than the Wisconsin glacial stage, are possibly equivalents of the "marine Pleistocene formation" of the Darnley Bay area of the mainland coast. All of them together appear to be older than the late-Wisconsin marine transgression represented by the isobase map.

RADIOCARBON-DATING

As discussed above, no available radiocarbon dates apply directly to the marine limit, but numerous slightly younger marine features have been dated (Table 1). These dates range from 12,400 years ago on Victoria Island to less than 1,000 years in several places in the central arctic; many fall between 7,000 and 10,000 years ago, i.e., final glacial time. These dates significantly prove the late-Wisconsin and postglacial age of the marine submergence and uplift.

Moreover, Farrand (1960b and in press) has drawn curves (Figure 2) of uplift *vs.* time for several areas based on these radiocarbon dates. The

Table 1

Radiocarbon-dated Marine Features in Northern Canada

Age	Lab. No.	Feature Dated and Location	Reference*
12,400±320	I (GSC)-18	marine shells, NW Victoria Island	3
10,530±260	I (GSC)-25	marine shells, Dolphin and Union Strait	2
10,215±220	I (GSC)-17	marine shells, Coronation Gulf	2
9,200±160	L-571 B	marine shells, Prince of Wales Island	10
9,100±180	I (GSC)-16	marine shells, Coronation Gulf	2
9,000±200	L-642	marine shells, northern Labrador	7
8,895±220	I (GSC)-20	marine shells, western Victoria Island	3
8,080±160	I-264	marine shells, Schei Peninsula	15
8,500±200	L-643 A	marine shells, Ellef Ringnes Island	12
8,290±330	I (GSC)-13	marine shells, Coronation Gulf	2
8,275±220	I (GSC)-22	marine shells, Coronation Gulf	2
8,275±320	I (GSC)-21	marine shells, Melville Island	3
8,080±160	**unknown	marine shells, Schei Peninsula, Axel Heiberg Island	9
7,875±200	I (GSC)-14	marine shells, Missinaibi River, James Bay	14
7,350±200	L-643 B	marine shells, Ellef Ringnes Island	12
7,280±80	GRO-1698	marine shells, Opasatika River, James Bay	14
7,200±200	L-248 A&B	marine shells. northern Ellesmere Island	4
7,150±350	L-571 A	marine shells, Somerset Island	10
6,975±250	I (GSC)-8	marine shells, Carr Lake, District of Keewatin	5
6,120±150	L-254 C	driftwood, northern Ellesmere Island	1
6,050±200	L-261 C	strandline, northern Ellesmere Island	4
5,750±200	L-254 B	driftwood, northern Ellesmere Island	1
5,600±300	S-13	strandlines, Southampton Island	8
3,958±168	P-207	Eskimo site on strandline, Igloolik, Melville Peninsula	11
3,906±133	P-209	Eskimo site on strandline, Igloolik. Melville Peninsula	11
3,700±150	K-505	Eskimo site, Igloolik	13
3,700±130	L-433 A	wood from stony silt, Ft. George, Quebec	6
3,670±270	S-12	marine shells, Southampton Island	8
3,560±123	P-208	Eskimo site, Igloolik	11
3,400±150	L-254 A	driftwood, northern Ellesmere Island	1
3,150±50	L-441 A	strandline, Great Whale River, Quebec	6
3,000±200	L-254 D	driftwood, northern Ellesmere Island	1
2,910±129	P-213	Eskimo site, Igloolik	11
2,898±136	P-210	Eskimo site, Igloolik	11
2,632±128	P-76	Eskimo site, Southampton Island	11

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*Key to References

1. Broecker, Kulp, and Tucek, 1956
2. Craig, 1960
3. Craig and Fyles, 1960
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5. Lee, 1959a
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14. Terasmae and Hughes, 1960
15. Sim, 1961

** Three additional samples from Axel Heiberg and Ellesmere islands have been tentatively dated in the range 6,500 to 8,000 years ago, but must await further checking (W. S. Broecker, personal communication).

Table 1

Radiocarbon-dated Marine Features in Northern Canada—Concluded

Age	Lab. No.	Feature Dated and Location	Reference
2,508±130	P-75	Eskimo site, Southampton Island..........	11
2,404±137	P-212	Eskimo site, Igloolik....................	11
2,354±135	P-211	Eskimo site, Igloolik....................	11
2,191±120	P-77	Eskimo site, Southampton Island..........	11
2,190±150	L-261 B	strandline, northern Ellesmere Island......	4
2,183±122	P-74	Eskimo site, Southampton Island..........	11
2,060±200	P-62	Eskimo site, Southampton Island..........	11
1,910±130	S-1	raised delta, Lake Melville, Labrador.......	8
980±100	L-261 A	driftwood, northern Ellesmere Island......	4
600±150	K-504	Eskimo site, Igloolik....................	13

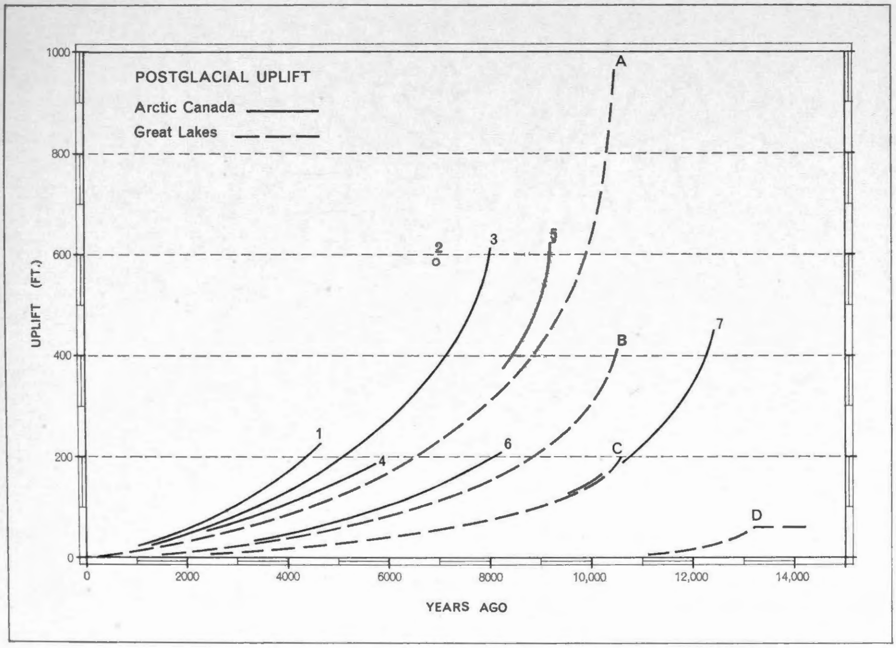


Figure 2. Curves of postglacial uplift versus time in radiocarbon years for the Great Lakes and Arctic Canada.

uplift curves show that the rate of uplift has decreased strongly since the time of local deglaciation. The inference from the curves is very strong that these uplifted marine features are intimately tied to the pattern of deglaciation and isostatic rebound of late-Wisconsin and postglacial age. Interglacial ages seem to be precluded, and evidence favoring an epeirogenic interpretation is very scarce.

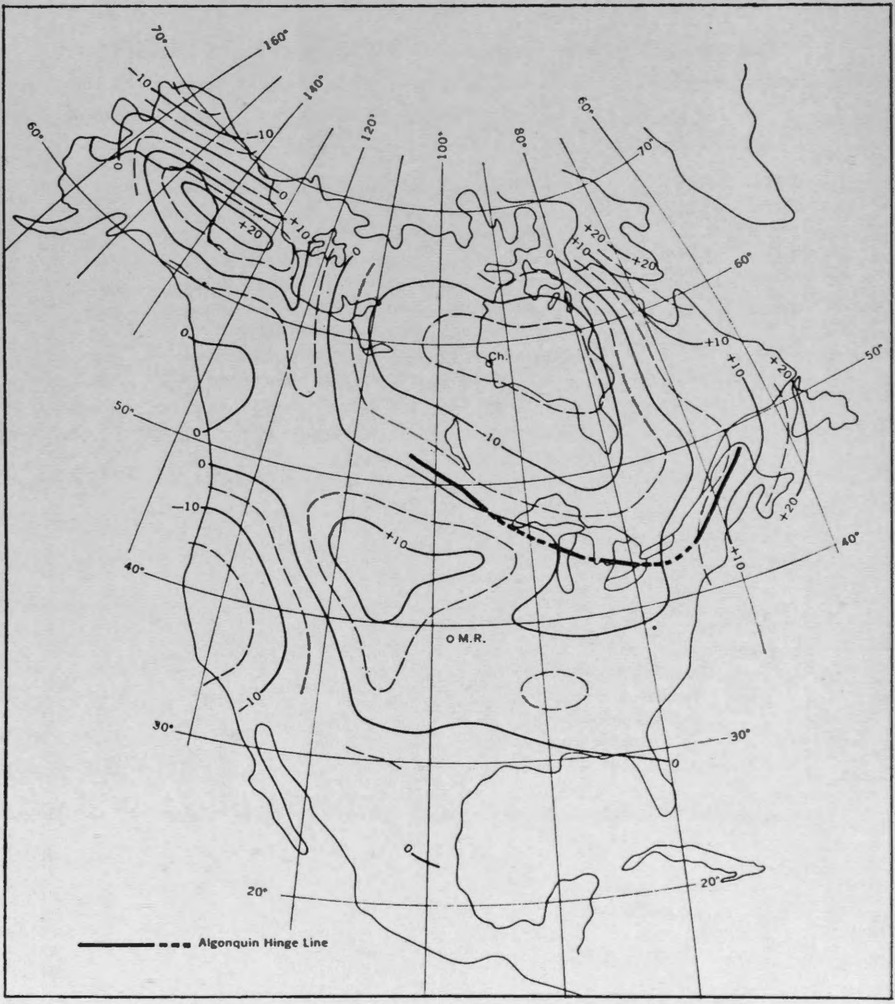
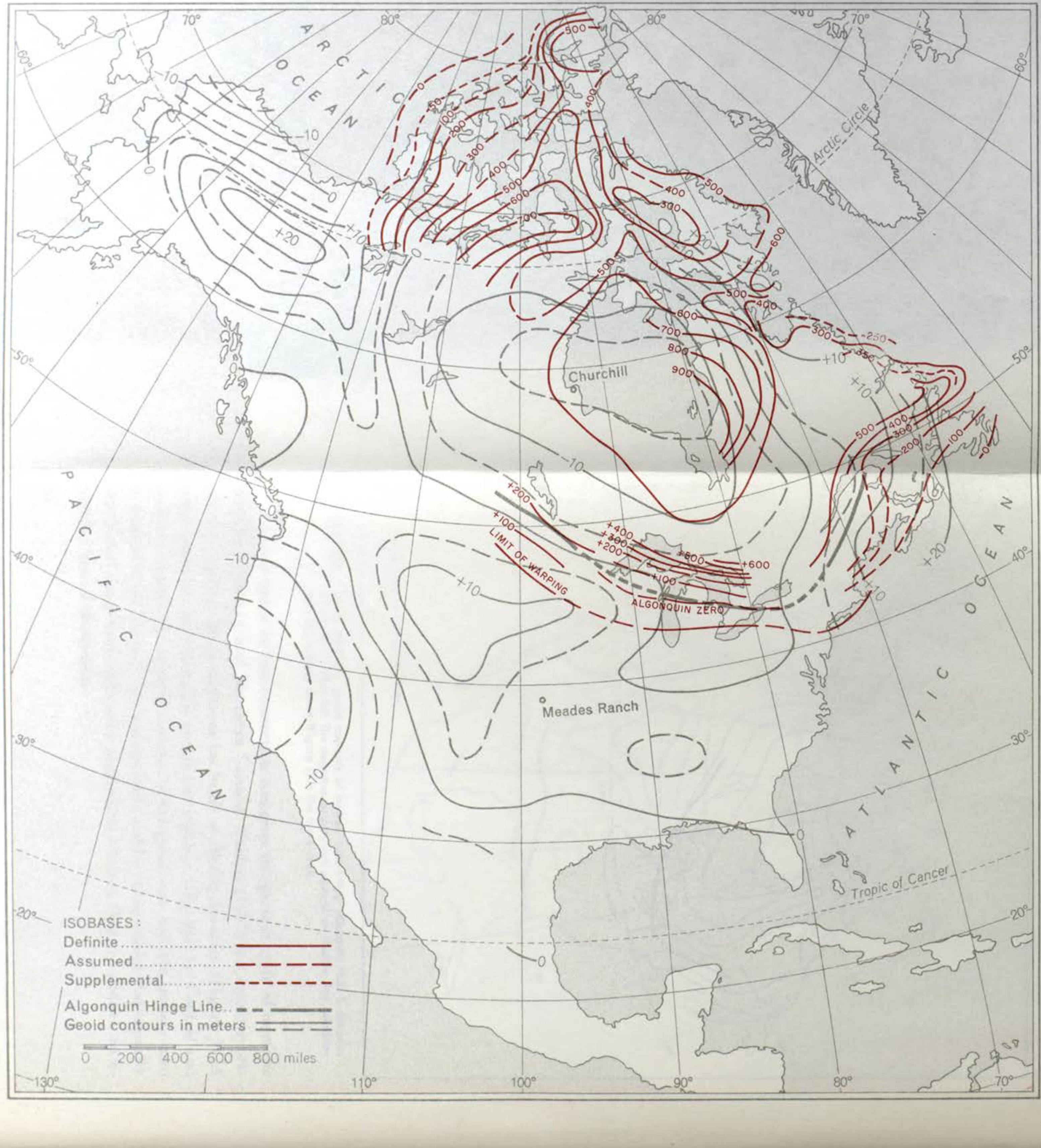


Figure 3. North America, geoid contours in metres, best-fitting ellipsoid; M.R. is Meades Ranch; Ch. is Churchill. The negative gravity cell centred on Hudson Bay coincides with the isobase dome (Figure 1) in the same area.

A final point in this connection concerns the present state of isostatic balance in Central and Northern Canada. Fischer (1959) has recently prepared a map of geoid contours for most of North America (Figure 3). A major negative gravity cell is centred on Hudson Bay, and for Central and Eastern Canada the general outlines of the geoid map and the isobase map presented here (Figure 1) are satisfactorily similar. Miss Fischer has logically attributed the gravity deficiency centred on Hudson Bay to residual, unrecovered glacial depression.


ARCTIC OCEAN
PACIFIC OCEAN
ATLANTIC OCEAN
Arctic Circle
Tropic of Cancer
Churchill
Meades Ranch
LIMIT OF WARPING
ALGONQUIN ZERO
+200
+100
+400
+300
+200
+500
+600
+100
500
400
300
200
100
50
0
600
700
800
900
250
350
+10
+20
-10
0
70°
80°
60°
50°
40°
30°
20°
130°
110°
100°
90°
80°
70°
ISOBASES:
Definite
Assumed
Supplemental
Algonquin Hinge Line
Geoid contours in meters
0 200 400 600 800 miles

In Central Canada observational data for a secular rise of the earth's crust, which could be attributed to residual rebound, are meagre and equivocal. However, at Churchill, Manitoba, — on Hudson Bay and in the central part of the geoidal depression — there is an apparent rise of the land of 1.05 - 0.18 metres per century since 1928 (Gutenberg, 1954) although the precise accuracy of these data are suspect. A similar rate has been suggested for Cambridge Bay, southeastern Victoria Island, for 87 years of record (Washburn, 1947, p. 69-70).

FINAL STATEMENT

Such an attempt to map the marine limit is provisional, of course, being based on only 250 observations over a very wide area. Certainly, future investigations will modify the outline presented here, especially local details, but it is believed that this is a reasonable synthesis which is in agreement with other evidence and ideas of the nature of deglaciation and rebound.

Interpretation of total glacial rebound (and thus a picture of the glacier load itself) from the record of the marine limit must be approached with great caution. Factors other than rebound strongly influence the marine limit, and cannot yet be separately evaluated. Furthermore, some areas were never affected by marine transgression nor contained glacial lakes, such as western interior Canada and the centre of the Labrador-Ungava peninsula. As has been emphasized above, however, the warped surface of the marine limit represents an *integration* of (a) marine transgression, (b) eustatically rising sea level, and (c) crustal uplift as modified by (d) the pattern of deglaciation. Also, the marine limit is time-transgressive. Isolation of any one factor must be based on independent evidence, which is not yet available for most of this area.

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◀ **Figure 4.** Comparison of geoid contours (according to Fischer) with Wisconsin isobases on marine limit.

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THE LATE-GLACIAL AND POSTGLACIAL EMERGENCE AND THE DEGLACIATION OF NORTHERNMOST LABRADOR

Olav Løken[*]

ABSTRACT: Detailed studies of the glacial morphology and raised shore features along the coastal part of the Torngat Mountains permit an appraisal of the late-glacial and postglacial emergence of the area in association with the final retreat of the last ice sheet. Three specific strandlines are identified and found to tilt down NNE; these are in turn truncated by a fourth, younger, horizontal strandline, about 15 m above present sea level. Isobases are drawn for the sea levels represented by two of the strandlines, and the map is the first attempt to show isobases for Northern Canada from essentially contemporaneous shore features. Retreat and readvance phases of the outlet glaciers from the continental ice sheet to the west are identified, and the strandlines have provided a tool by which isolated moraines could be correlated. Finally, a late-glacial chronology of the area is presented, which is, however, mainly a relative one. The only absolute date is provided by a radiocarbon-dating of 9000 ± 200 years[†] for shells found at 29 m above present sea level.

Theoretical and practical studies by Scandinavian workers in this specialized field of physical geography are discussed in terms of their application to similar problems in Canada, and field and laboratory techniques that provide a basis for the present study are described.

RÉSUMÉ: Des études détaillées de la morphologie glaciaire et des caractères des plages soulevées dans la partie côtière de la chaîne Torngat permettent d'estimer l'amplitude du soulèvement qui s'est produit dans cette région au cours de la dernière phase glaciaire et après la régression définitive des glaces. On y a identifié trois anciennes lignes de rivage inclinées en direction NNE, lesquelles sont tronquées par une quatrième ligne horizontale d'âge plus récent; cette dernière est située à environ 15 m au-dessus du niveau actuel de la mer. On a tracé sur la carte au moyen d'isanabases les divers niveaux de la mer; ceux-ci sont représentés par deux des anciennes lignes de rivage. On a ainsi tenté d'indiquer pour la première fois le réseau d'isanabases dans le Nord canadien à partir des caractères actuels de la côte. Cela a permis d'identifier les phases de régression et de récurrence des langues émissaires en provenance de l'inlandsis, situé plus à l'ouest; ces anciennes lignes de rivage ont fourni un indice par lequel les moraines isolées ont pu être mises en corrélation. On a donc pu établir une chronologie plus ou moins précise de la dernière phase glaciaire. Cependant, des essais de datation au radiocarbon, effectués sur des coquilles prélevées à 29 m au-dessus du niveau de la mer, ont fourni la seule date certaine de cette dernière phase glaciaire; elle se situerait dans le temps à 9000 ± 200 ans.

Des études théoriques et appliquées en géographie physique, effectuées par des scientifiques scandinaves, apportent certains renseignements quant à la solution de problèmes analogues au Canada. On y décrit également les techniques utilisées sur le terrain et en laboratoire, lesquelles fournissent la matière à cette étude.

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[†] Dated from the present.

Ms. submitted August, 1961.

INTRODUCTION

Evidence of sea levels higher than the present level is widespread in areas that were covered by Pleistocene ice sheets, and is common along the Labrador coast. From northern Labrador, raised beaches and other evidence of higher sea levels have been reported by Bell (1885), Daly (1902), Coleman (1921), Woodworth (1927), Odell (1933, 1938), Nichols (1936), J.D. Ives (personal communication, 1960) and by B. Robitaille (personal communication 1961). Of these workers only Woodworth, Odell, Nichols and Robitaille have made observations in the area considered in this paper, i.e. the coastal area to the north of Kangalaksiorvik Fiord (Figure 1).

A comprehensive review of observations published prior to 1930 was prepared by Cooke (1930), who also prepared an isobase map covering Eastern Canada. A similar map is found in Daly (1934). Both maps are based on observations of the limits of marine deposits that are usually metachronous features. Isobase maps based on observations of marine features that were formed simultaneously are necessary to obtain a true picture of the deformation of the earth's crust which followed the melting of the last ice sheet. The term "isobase", as originally used by De Geer (1892), had no reference to the time factor, but it has been generally understood in Scandinavian literature that an isobase refers to simultaneously formed features. The term will be used in the Scandinavian context in this paper, although a looser definition is frequently used in Canadian literature. No such isobase map is available for any part of Northern Canada; the isobase map embracing the whole of Canada, published in this bulletin (Farrand and Gajda) relies upon metachronous data.

Detailed studies of the evidence of higher sea levels in a small area where correlations between the different features could be made with greatest possible certainty were believed to be the best way to improve present knowledge of the late-glacial and postglacial emergence of the land. As one area becomes understood it should be possible to extend the study to cover a larger area by small and carefully considered steps. The first part of the paper concerns the late-glacial and postglacial emergence of the area and involves a detailed analysis of the raised shore features.

The second part of the paper is the application of this study of the emergence of the land to an examination of the deglaciation of the area as a whole. In this way it is possible to distinguish between features of marine origin and those formed as lateral terraces, or as glacio-lacustrine features. The study of the emergence would provide in turn a useful tool to obtain a

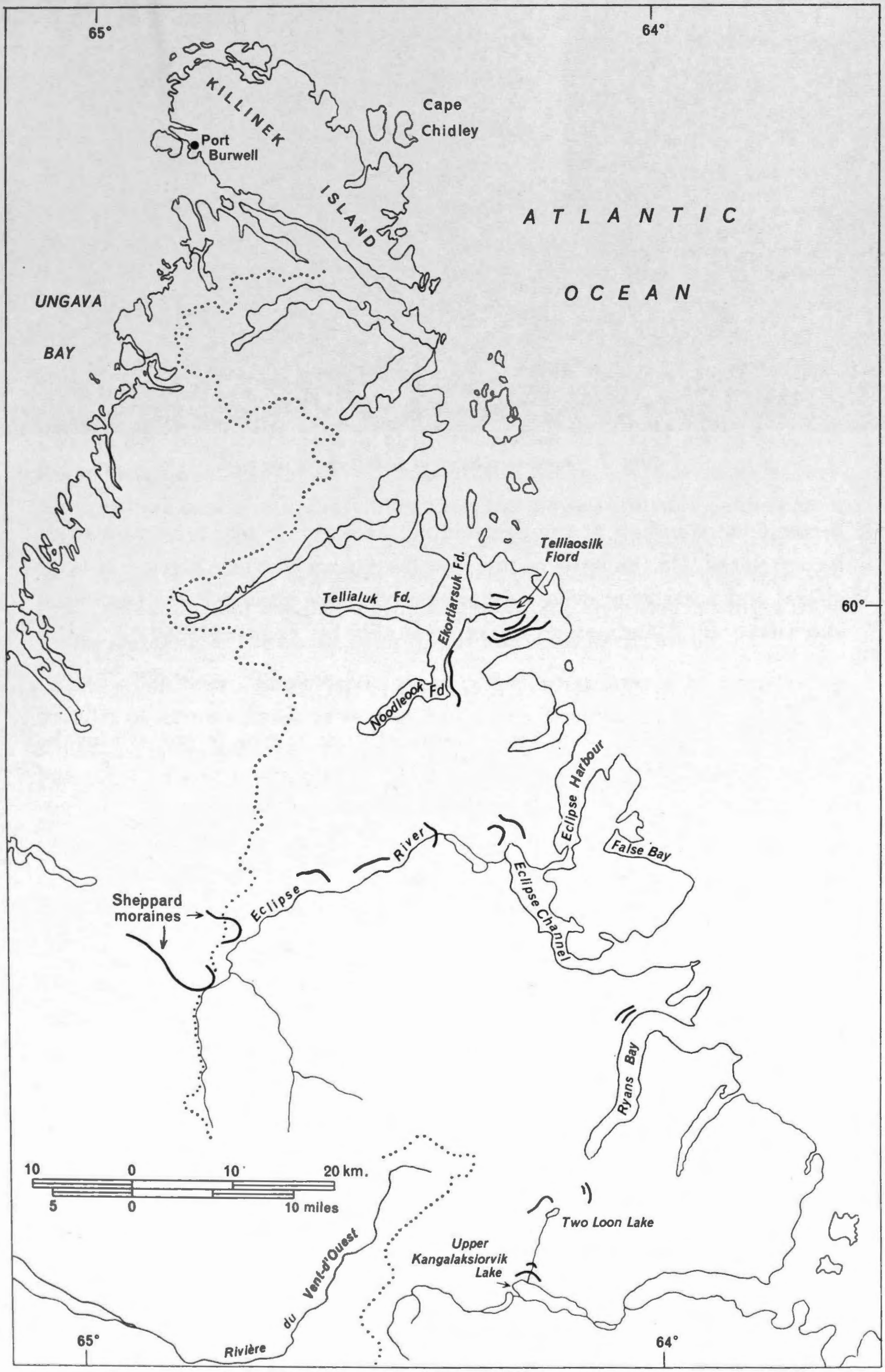

Figure 1. General map of northernmost Labrador, modified after A. Forbes (1938)

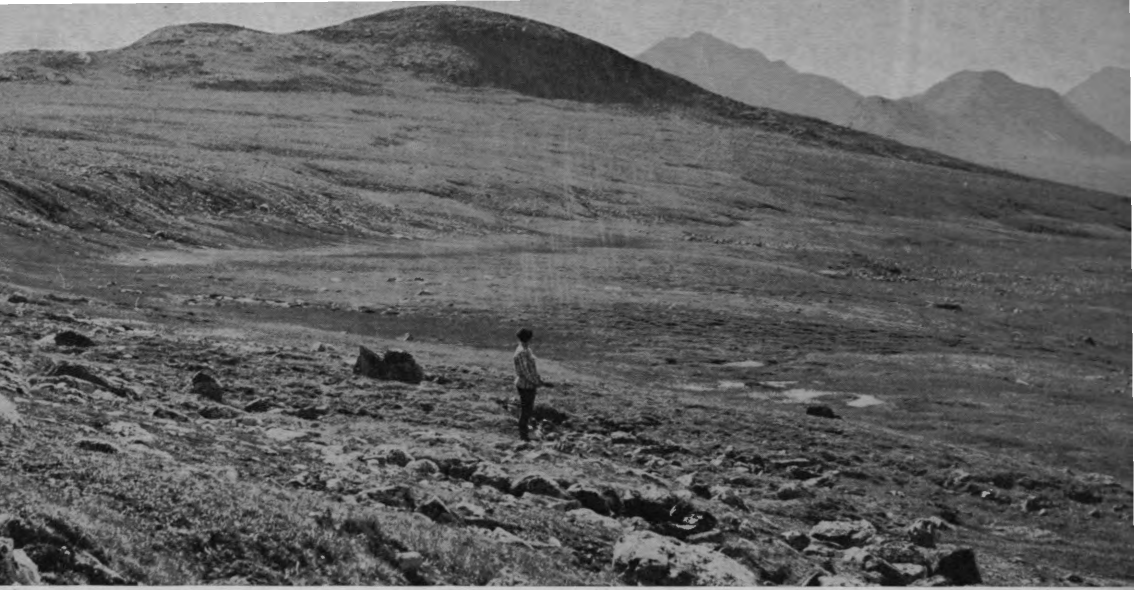

Figure 2. A wave-cut bench at 56.0 m above sea level.

better understanding of the deglaciation as separate marine features can be correlated. On the basis of this information an accurate picture of late-glacial and postglacial events should evolve. This approach has been used extensively by Scandinavian workers, notably by Tanner (1930).

METHODS AND ERRORS

Methods

Only morphological evidence was used to determine former sea levels. Although fossil evidence can give valuable information concerning the age of the submergence of the land and the climatic conditions that prevailed, it is generally considered a poor indicator of the actual sea level (Gilberg, 1952). On the other hand, Feyling-Hansen and Olsson (1959) have been able to trace sloping strata in truncated raised sandspits to the surface and thus relate fossil occurrences to their specific sea level.

Three features have been used to determine former sea levels; (1) wave-cut benches and notches formed in till or other unconsolidated materials (Figure 2); (2) raised delta flats with terminating old river-beds on the surface, and (3), boulder barricades and boulder flats.

(1) The break of slope at the inner (upper) margin of a wave-cut bench (notch) was measured, and this point is believed to lie close to high tide level at the time when the feature was formed (Tanner, 1930, p. 28). Beach ridges and other agglomerations of mainly fine materials have been avoided, since they are often indicators of special local conditions which influence the streamlines and the transportation capacity of the longshore current. Ridges are often built up during storms, and hence are poor indicators of any specific sea level.

The fact that only terraces in unconsolidated material have been measured excludes to a large extent any structural control of their formation. Wave-cut terraces are formed more rapidly in unconsolidated material than in bedrock, thus by excluding rock terraces, a uniformity of observations was obtained.

(2) Dried out river-beds occur on the surface of three delta flats in the area; these can be followed from the higher parts where they are well defined, slightly incised features with stony floors, to the lower areas where they gradually become less distinct, and finally vanish in flats of fine material. The level at which the river-beds vanish is considered to be the base level of erosion, that is the low tide level at the time when the rivers ceased to flow.* River-beds have been observed to continue below low tide level as well developed channels, notably where the river flows in a well defined rock channel. In the cases presented below, the beds vanish on open flats at a level which is believed to be low tide level; this deduction is supported by the observation that the material in and along the river-beds changes from coarse materials in the upper parts to fine materials in the lower.

(3) The term "boulder barricade" refers to strings of boulders lying parallel to many sub-arctic shores, from 2 to 3 metres and up to several hundred metres offshore (Tanner, 1939). Boulder barricades are common along the Labrador coast (Daly, 1902; Wheeler, 1935; Tanner, 1939, 1944). Although Tanner (1930, 1939) and Wenner (1947) were aware of raised boulder barricades, they did not explicitly use them for the purpose of determining sea levels. The present study is believed to be the first in which this has been done.

The origin of boulder barricades is still not clear, although Tanner (1939) points out the significance of (a) regularly forming winter sea-ice, together with (b) a tidal range of 2 to 4 metres. He explains the barricades as having resulted from the pressure exerted by the movement of offshore ice on the stationary icefoot along the shore, and he refutes the idea that the boulders are derived from the adjacent shore.

As pointed out by several workers, for example Daly (1902), Wheeler (1935) and Tanner (1939), the boulder barricades are only found along offshore zones that slope moderately steeply. However, from observations made by the writer along the Labrador coast, it appears that the barricades

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* In order to obtain the high tide level and make these values comparable with those obtained from wave-cut benches, a tidal range of 1.5 m was added to the low tide level based on observations made at the northern end of Eclipse Channel. (Holtedahl, 1924).

Figure 3. A recent boulder flat at the north end of Eclipse Channel.

on gently-sloping offshore zones merge into a wider belt of boulders, and that where the offshore is very shallow, the boulders are scattered over a wide area to form what will be termed a boulder flat in this paper. Such boulder flats can be seen in several of the shallow bays and fiord-heads along the coast, as for example in Ryans Bay, Ramah Bay, and at the northern end of Eclipse Channel (Figure 3) where the boulders seem to be distributed at random. The parallel boulder barricades described by Brochu (1957) were not observed.

It is therefore apparent that boulder barricades and boulder flats are basically related features whose formation is determined by the topography of the offshore zone.

Tanner (1939, p. 157) states that generally the top of the highest boulder is close to the high tide level, although the boulders occasionally rise slightly above this level; the writer has in general verified these observations. Brochu (personal communication, 1961) found boulder barricades lying 3 to 4 m below high tide level in the St. Lawrence estuary where the tidal range is from 5 to 6 m. This factor is believed to be significant. Wheeler, on the basis of experience in the Nain-Okak area, where the tidal range is 1.75 m, states (personal communication, 1961) that the boulder barricades are somewhat below high tide level, and as the waters are safe for canoeing at high tide, he estimates that they are closer to half-tide level. Wheeler also points out that occasional boulders on the boulder flats rise as much as 6 feet above the general level of the flat.* It is considered that under these conditions, boulder barricades and boulder flats can be used to determine

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* In all cases mentioned below, a large number of boulders reached to almost the same level.

former high tide levels, as the error involved does not exceed the errors which occur in determining any other raised shore feature. It is not considered that this method of determining a former sea level can be used generally, and it is suggested that it can only be applied in areas which experience a low tidal range.

Present high tide level has been used as the basis for all height measurements. It was always determined in small bays and coves in which a gravel or sand beach occurred, rocky places being avoided. The break of slope separating an even, smooth beach below an uneven area, often with storm ridges and sea-weed deposits, was taken as the high tide level.

Heights were measured by Paulin altimeter or by Wild level; the heights measured by level are denoted (L). The actual measurements were made in feet and inches, but have been converted into the metric system and rounded off to the nearest half-meter. When the altimeter was used, all the raised shore features were measured twice and the instrument checked against a known level, usually sea level, within an hour of the actual observation. Measurements were corrected for temperature deviations, but not for changing atmospheric pressure.

Errors

Three sources of error occur when heights of raised shore features are to be determined. (1) The errors inherent in the measuring instrument; (2), the error involved in determining the former sea level as it is represented by the morphological feature observed; and (3), the error in determining the base level, i.e. sea level.

(1) In order to determine the accuracy of the altimeter over the small height differences and time intervals involved, six height differences ranging from about 21 m to about 53 m were measured both with the level and the altimeter. In five cases the difference was 0.3 m or less, and in the sixth case it was 2.4 m. The accuracy obtained from these five observations appears to be better than would be expected and thus a somewhat lower accuracy is assumed. For altimeter observations, the probable error in the measuring process itself is estimated to be ±0.7 m. Where the level was used, care was taken to have backsights and foresights of equal length, and the probable error in those measurements is believed to be ±0.1 m.

(2) Solifluction and other forms of mass movement influence shore features raised above sea level and make it difficult to determine the old sea level, at which the feature was formed. The probable error is here believed to be ±0.5 m.

(3) The probable error in determining the base level (high tide level) is believed to be ±0.2 m.

Accordingly, the total probable error in the heights of the raised shore features measured by altimeter is ±1.4 m, and in those measured by level ±0.8 m.

THE LATE-GLACIAL AND POSTGLACIAL EMERGENCE

All the evidence of higher sea levels found during the 1960 field season is plotted on Figure 4 on which the actual point and height of each observation is shown.

The scattered nature of the observations results from the rough topography of the coastal area. In many places, precipitous cliffs are sheer to the sea making it impossible to find evidence of higher sea levels. In some places the slopes are so steep that no loose material has been deposited, and in others active scree had long since obliterated any terrace that might have existed. Finally, in some areas where the slope is favorable, loose material is all but absent, and thus no shore features could be formed. These factors, together with the limitations imposed by shortage of time and the method of travelling, account for the distribution of the observations.

In all localities visited, the land rises to higher elevations than the upper feature that was measured, and consequently higher shore features would have been found if they had ever existed. Only at the western end of Saglarsuk Bay is there an exception to this; here steep cliffs rise just behind the 14.5-m observation.

The methods used are outlined above, but it is stressed again that in all cases the high tide level related to the shore features was determined, and that only features formed in till or other unconsolidated materials were considered. The importance of these factors, which give uniformity to the observations, is reflected in the discussion where the different observations are compared.

Strandlines

The term "strandline" is here defined as the shore feature formed at the intersection between a vertical plane and a former sea surface. The concept may be illustrated by a line drawn through the projection of a series of synchronous marine shore features on to a vertical plane, when these occur along a straight or slightly curved line, or within a distance which does not exceed the error in measurement and plotting of the observations. It is evident that strandlines cannot occur unless the plane of the sea level in

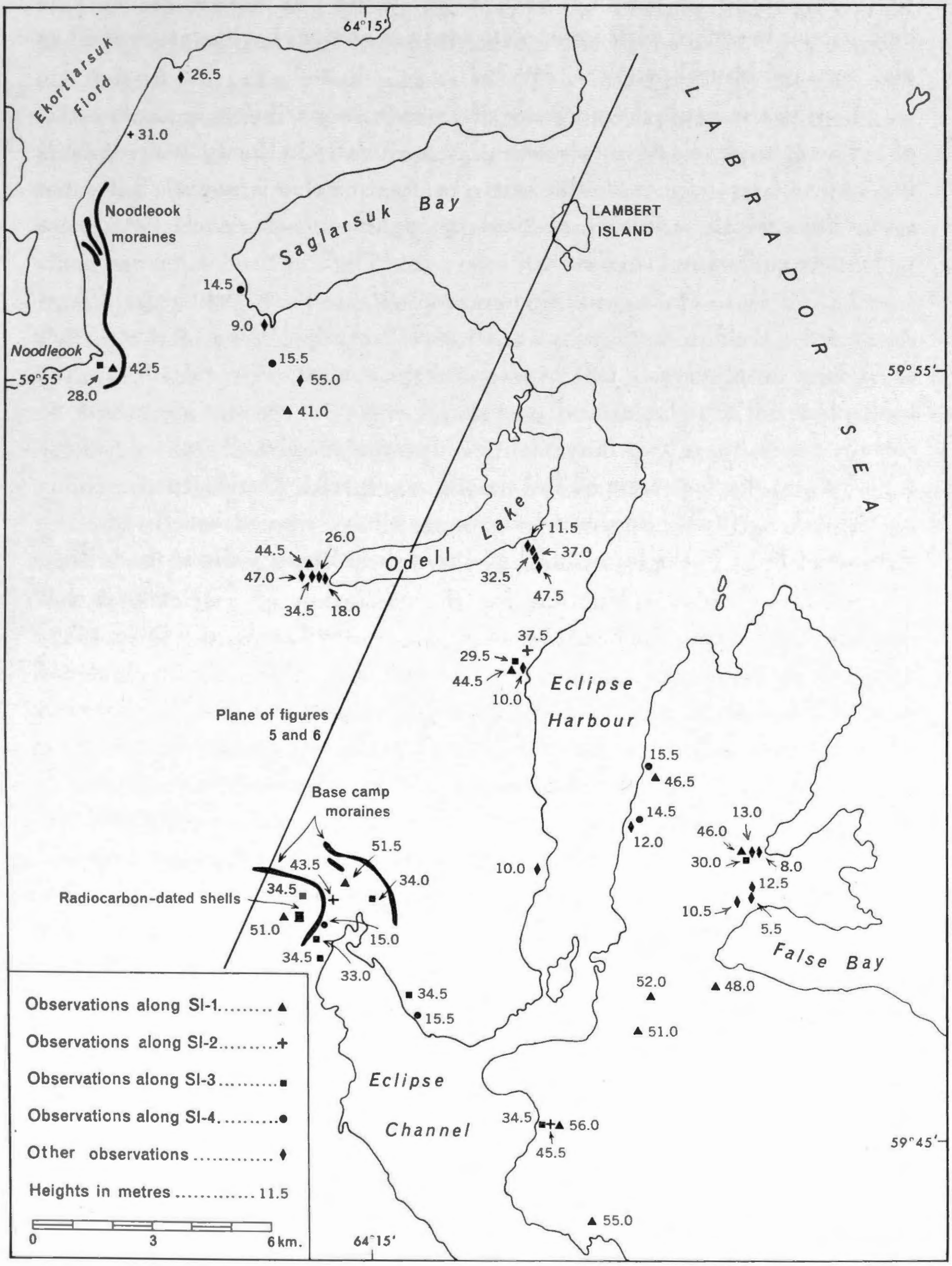

Figure 4. Plot of raised shore features measured during the 1960 field season.

question and the vertical plane are perpendicular to each other, except when the observations lie within a narrow belt along the vertical plane. This definition is in accord with common usage in Scandinavian literature and has also been used by Flint (1957, 240-257).

During the gradual emergence of areas from glaciation, a whole series of different sea levels have existed and consequently in theory a corresponding series of strandlines should exist. In practice this is not so, but some strandlines which represent particularly significant sea levels have been widely recognized in Scandinavia.

According to Holmsen (1918) and Holtedahl (1953, 1960), strandlines result from the interaction between isostatic readjustment of the earth's crust in areas previously ice-covered and the eustatic rise of sea level that took place in late-glacial and postglacial time. In specific areas and at certain times, these two movements counterbalanced each other, and for a period, no displacement of the shoreline occurred. During these periods particularly well defined shore features may have formed which represent significant halts in the late-glacial and postglacial emergence of the area.

An alternative explanation for the formation of particularly well developed shore features has been proposed by De Geer (*in* von Post, 1955) who refers to shore features that were formed very rapidly in regulated lakes in Sweden and which are described as "tempest shorelines". These are shore features that were formed during a particularly violent storm, or a stormy period, and thus do not refer to any halt in the emergence of the land. Ideally, well developed shore features should exist continuously along the shores, but as already noted the topography may prevent the formation and preservation of such long and continuous features; thus the alternative method is to study observations and distributions of smaller shore features from which certain specific levels and strandlines may be fitted together.

In order to do this, all observations have been projected along perpendicular lines into a vertical plane which runs S25°W to N25°E (Figure 4), in a direction which is approximately perpendicular to the isobases in this area. The result is plotted in Figure 5, in which the abscissa is the horizontal distance from an arbitrarily chosen origin and the ordinates are the heights of each observation above present sea level; the diagram is consequently an "equidistant" diagram (Tanner, 1930). The error introduced by the curvature of isobases is considered negligible, as the curvature of isobases is generally low, and no observation which is plotted lies more than 11 km away from the plane.

In studying the characteristics of strandlines, it should be considered that the intersection of a former sea level and a vertical plane must consist of shore features that were formed simultaneously. Holmsen (1918) pointed out that all parts of a continuous terrace were not necessarily formed contemporaneously, and that the process is not strictly synchronous; therefore these features, when plotted, do not necessarily produce a straight line on a vertical profile. However, they are synchronous in a geological sense, and it is in this context that the term is used. Unless the observations are taken along one continous moraine (Andersen, 1960), or can be dated in some other way, it is impossible to prove the synchronous formation of several separate shore features. Usually the best that can be done is to exclude observations that are almost certainly metachronous, and this may be achieved by excluding every observation which represents the marine limit in its locality, as these are usually metachronous.

Further, within a small area, it is to be expected that a sea level that formed well developed shore features in one locality would have had the same effect in other localities, provided that the exposure and the material were similar.

A third consideration is merely geometrical,—a matter of projection. A line that has been projected into a plane will be a line no matter into which plane it is projected, and thus few deductions can be made from points (observations) which lie along a line. Strandlines and their slopes should therefore be studied on the basis of observations that have a wide areal distribution.

To these general considerations may be added another which applies in the present case. No long terrace was found with a measureable tilt, although several shore features could be followed for a distance of up to 1 km. Sights were taken in several compass directions, and thus the result is not dependent on any specific direction. In the above cases a hand level was used, but in one instance a level sight over a distance of about 1 km was made north-northeastwards along a terrace at the southern end of Ryans Bay 49 m (L) above sea level. It was found that any tilt along this terrace was very slight, probably less than 1:1000. The indication was that a slight slope does exist towards the northeast.

Studies in Scandinavia indicate that, if one locality is considered, the slope of the strandlines increases with height. This is correct only where the preserved shore features decrease in age with decreasing height above sea level, and is not correct if strandlines have been drawn on the basis of shore features that have survived an ensuing transgression. It is considered that none of the features covered in this report could have survived a transgression. However, since the marine limit is only some 13 m above the 49-m level, strandlines slightly steeper than those described above could exist, although the difference in slope would not be great.

The slope of strandlines also varies from place to place; these variations are small in an area such as that under consideration, since there is no indication that any late-glacial or postglacial faulting or any other sudden tilting or lifting has taken place. It is concluded that if any strandlines exist in northern Labrador, they have a very slight tilt, possibly towards the north-northeast, and that the tilt probably does not exceed 1:1000. This is an important result, as it excludes the presence of any steeply sloping strandlines.

The above are the necessary features of strandlines but this does not mean that all lines with these characteristics should be termed strandlines.

It has been established that long continuous shore features that have since been elevated and tilted, do occur in previously glaciated areas. If an aligned distribution of the shore features appears when they are projected into a vertical plane, and this is not regarded as part of a strandline, some alternative explanation has to be offered for the distribution. The peculiarities of the projection, as well as the direction of the plane and the distributtion of observations must be considered. Furthermore, the presence of ice tongues in the valleys and fiords, together with the unequal uplift of the landmass, can account for the distribution of the shore features. This is impossible where glaciers were absent, as would normally be the case below the marine limit. Ice tongues conceivably can readvance, destroy, or in other ways interfere with lower marine features without disturbing the higher ones. This can only happen, however, to a very limited extent in an area such as that under study in which the marine limit is generally low.

After all these factors have been considered, without accounting for a linear distribution of the shore features, it can be concluded that they are parts of a strandline. It appears unnecessary to the writer to introduce any new explanation as long as a well known and established development will explain the observed facts; there is no apparent alternative.

With these considerations in mind, four strandlines have been drawn on the profile illustrated in Figure 5; these are Sl-1, Sl-2, Sl-3, and Sl-4 from the highest to the lowest. The upper one and the two lowest are regarded as being confirmed by this study, the fourth is only suggested. The lines are drawn as straight lines, although Holmsen (1918), on theoretical grounds, has observed that this would not be correct over long distances. Marine strandlines have, however, been drawn as straight lines over distances as long as 400 to 500 km (Nilsson, 1953). Andersen (1960), basing his strandlines on features that are definitely synchronous, has drawn curved strandlines, which are in accordance with the theoretical analysis (Holmsen, 1918).

Andersen (1960, Plate 7) illustrates the approximate position of several strandlines in southern Norway, but they are not the only ones that can be drawn on the basis of his observations, and there are some conspicuous breaks of slope which are not justified. However, they give an idea of the curvature of the strandlines in question. This diagram also shows that a straight line connecting two points about 20 km apart on the strandline will deviate from the "true" strandline by 0.5 m at the maximum. The error introduced by drawing the strandlines as straight lines in Figure 5 is therefore small, compared to the possible error in measuring the shore features.

Sl-3 is the best developed of the strandlines, none of the shore features along it being the highest feature found in that locality. There is therefore no reason to assume that the features should be metachronous, although positive evidence for a synchronous formation is not present. All the features are well developed and show a wide areal distribution (Figure 4).

The observations at the right hand side of the diagram in Figure 5 may suggest a more horizontal line than is shown, although the chosen line was drawn on a sound geometrical basis. The northernmost locality is a very well developed delta, at 28 m above sea level, which represents a marked event in the postglacial history of the area, and in itself strongly suggests the existence of a strandline at that level (Løken, 1962).

It is concluded, therefore, that Sl-3 represents an old sea level and has subsequently been elevated and tilted as the land emerged. It now tilts N25°E at a rate of 1:1650 or 0.61 m/km (3.2 ft/mile).

Sl-4 connects a series of points, all of which represent well developed shore features. None of these is the highest shore feature found in its particular locality, and the features show a wide areal distribution (Figure 4). In addition S1-4 is a line separating a higher zone, about 10 m in height, with nearly no observations, from a lower zone, with an abundance of observations in no apparent order. No tilt is apparent and thus the line is plotted as being horizontal. An east-west profile also shows no tilt along this line.

Sl-2 is determined from only four points and thus is not well defined. The two southernmost points are, however, well developed shore features

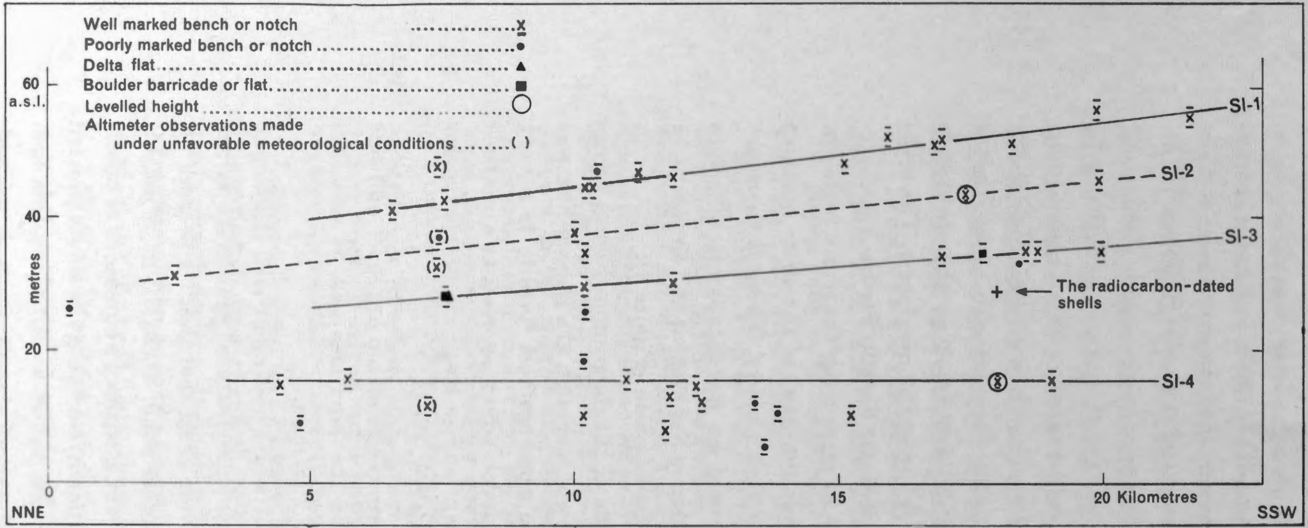

Figure 5. Equal distant diagram from Eclipse Channel to Ekortiarsuk Fiord.

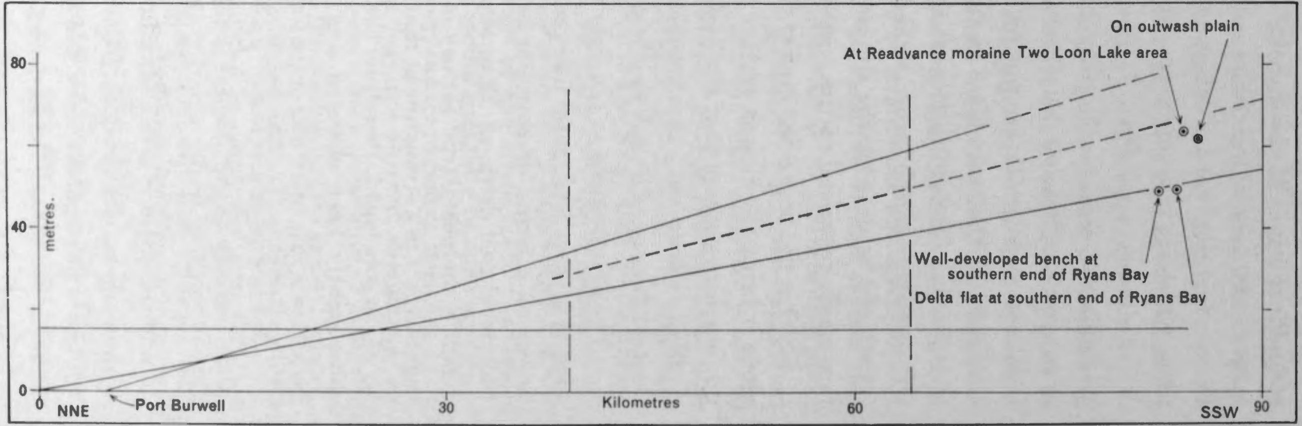

Figure 6. The Extended Diagram. Direction at plane is N25°E, S25°W. Horizontal scale 1:375,000; vertical scale 1:1,250.

suggesting the presence of a line. The areal distribution of these points is not very good as they all lie in a rather narrow belt running north-northwest. No tilt is given for this strandline.

The interpretation of S1-1 is more complicated as many of the points along it represent the highest terrace found in the locality; thus, their marine origin must be shown. The possibility of synchronous formation does exist, although it is not obvious because the shore features are in some cases the marine limit.

The shore features along Sl-1 show a wide areal distribution (Figure 4). There can be no doubt that the line is drawn through a group of measurements that has a very narrow vertical spread, and shows a tilt towards the left hand side of Figure 5. Most of the points lie within the margin of error, but some, notably on the right hand side, show a slightly larger deviation. It is believed that the error in the measurements of these higher points was greater than that estimated. It is pointed out that if the points on the right hand side of Figure 5 are rejected, the line is still justified by the points to the left, although it might not be possible to extend it so far towards the right.

Most of the observations along Sl-1 are of marine origin, but in some cases this could not be ascertained. In all cases, however, the features are related in morphology to the areas below them. Although there are no similar features above, it is reasonable to assume that this change in morphology took place at the marine limit. Thus, it may be concluded that all the observations along Sl-1 are of marine origin, although not necessarily synchronous.

In a previous study in the same general area (Løken, 1962) it was found that the ice which filled Eclipse Channel came through Eclipse Valley, and that the ice front retreated in the opposite direction towards the mouth of Eclipse Valley. Thus, when the lower areas are considered, the southern part of Eclipse Channel and the land along Eclipse Harbour became ice-free before the northern part of the channel. When the points on the right hand side of Figure 5 are examined, the ice recession does not appear to cause any systematic deviation from the line, nor would any other line introduce such a deviation. Of the two observations just south and southwest of False Bay (49 m and 52 m), one is high and the other is low, in spite of the fact that they became ice-free at approximately the same time. Similarly, the point of the 56-m observation is marked higher than the line, whereas the

55-m observation, which locality became free of ice earlier, lies below, as does the point of the 51-m observation, which became ice-free much later. The fact that the 51-m observation does not show any great deviation is important, as it lies behind the Base Camp moraines while all the others are outside it. The marine limit usually shows a marked change of height as one passes from the distal to the proximal side of the moraines (Gillberg, 1952); since this change does not appear in the present case, it strongly supports the contention that the shore features along Sl-1 were formed without interference from the receding ice. There is thus no reason to assume that the features are metachronous, although positive evidence for a synchronous formation is not present. It is concluded from the above that the only explanation that can account for the distribution of the observed shore features is that they represent a former sea level which made a particular imprint on the land; thus Sl-1 is a strandline.

This conclusion is supported by the relationship between Sl-1 and Sl-3. Studies in Scandinavia show that all strandlines in one locality tilt in nearly the same direction, and that their tilt increases with their height. The two strandlines in this study show the same relationship. Sl-1 has been lifted and tilted since it was formed, and today shows a N25°E tilt of 1:1,000 or 1m/km (5.3 ft/mile).

Isobases

All the measured shore features were first plotted on a profile running northeast to southwest; this was done on the basis of techniques developed in Scandinavia which show that the strandlines slope out towards the coast, and that their maximum slope is, in general, towards the centre of the last continental ice sheet. A similar pattern resulted when strandlines from the study area were drawn in a similar manner (Figure 5). In order to determine the isobase directions for the two sea levels represented by Sl-1 and Sl-3, the points along each strandline were grouped in threes; provided that they did not lie along a line, each set would thus determine the plane of the old sea level. The intersection between this plane and present sea level gave the zero isobase for the level. Only the directions of the zero isobases were calculated in this way, their positions being determined from Figure 6. The same method has been applied by Løken (1956), and a similar one by Liestøl (1949) for lakes in southern Norway. The method is based on the assumption that the deformed sea levels can still be regarded as plane surfaces within the area studied.

The discussion on the deformation of the strandlines in a direction perpendicular to the isobases led to the conclusion that they could be regarded as straight lines within the study area. The curvature of the isobases must also be considered. As no isobase map based on contemporaneously formed shore features has been published for any part of Northern Canada, very little is known about their possible trend. Thus information has to be taken from other areas, and results from Scandinavia are cited. Andersen (1960, Plate 3) shows isobases from several localities in southwestern Scandinavia that show a radius of curvature down to about 400 km. An isobase map for southern Sweden by Fromm (1959) indicates isobases with a radius of curvature down to about 350 km.

These references are cited as examples of proved results. It is very difficult to determine whether these can be applied to northern Labrador, as this area forms a pronounced promontory to the whole of Labrador-Ungava, thus being very different from the areas covered by the above two studies. While the coastline in this area has a very definite concave form towards the south, the isobases do not necessarily show the same concavity; this will depend on the distribution of the ice to the north and west. It is well to remember that the isobases over southwestern Scandinavia seem to be only vaguely (if at all) influenced by the deep Norwegian Channel, a feature which in this connection has a position similar to Hudson Strait.

The area studied has a width of some 25 km in a northwest-southeast direction, and this corresponds to an arc of about 3.5° if a radius of curvature of 400 km is assumed. This means that the points farthest away from the plane of projection will have an error of about 200 m in their location on Figure 5, and with the slope of the strandlines as outlined above, this will give an error in height of about 0.2 m, which is small compared to the measuring error. It is consequently concluded that the old sea surface still can be regarded as a plane surface.

In plotting isobases, 39 different combinations were made for Sl-1, 25 for Sl-3, and a similar number of isobase directions were obtained for each sea level (Figure 7). Mean isobase directions for the upper and lower levels are 294° ± 8° and 299° ± 15° respectively.

The estimation of errors is very difficult and complicated, as the error in the direction depends on the size and orientation of the triangle, the position of the corner(s) containing the error(s), as well as the error in the height(s) proper. Compared with these factors, the errors involved in plotting and construction are regarded as negligible. In order to avoid errors,

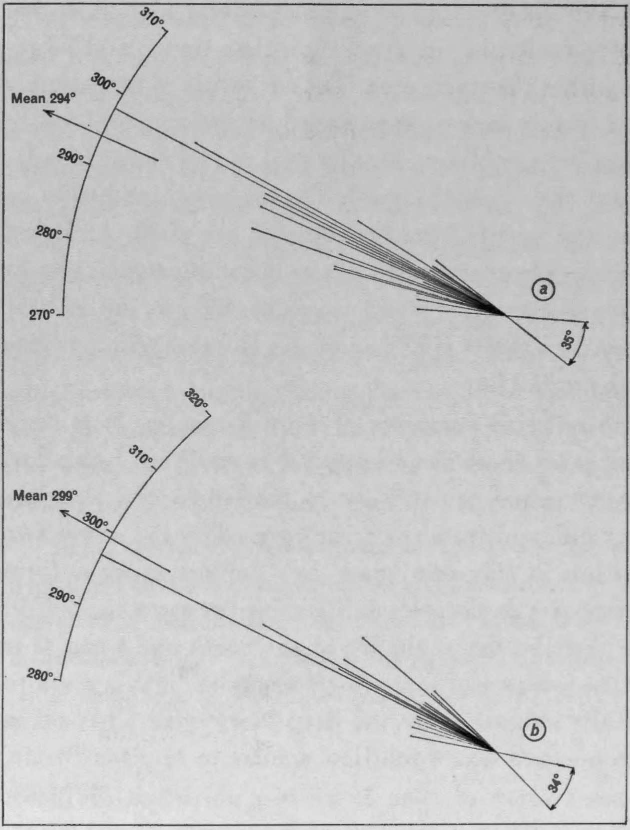

Figure 7.

Isobase directions for SI-1 (a) and SI-3 (b). A line of unit length indicates one isobase direction found in that direction.

the triangles have been made as large and as regular as possible; no side in any triangle is shorter than about 4 km and two triangles with angles of 24-27-129 degrees and 30-44-106 degrees were the largest deviations from the regular form. To be absolutely precise the directions obtained should be weighted in order to find the means, but the accuracy of the ground survey does not seem to warrant this; thus all directions were given the same weight.

An estimation has been made for the errors in two of the smaller triangles, which were nearly identical in shape, size and orientation. In the case of Sl-1, a change in height of 1 m in one corner resulted in a change in isobase direction of 6 and 7 degrees respectively as the corner was lowered or lifted. For the S1-3 sea level, the comparative values were 9 and 14 degrees, illustrating the great need for accurate observations if one is working in areas of low tilt. If there are errors of 1 m in two corners, which act to displace the isobase direction in the same way, a spread of approximately four times the quoted values will ensue. These cannot be considered as the probable errors for the mean directions, as they are taken from two of the smaller triangles in which errors in the observations are especially noticeable; furthermore, it was assumed that the two errors acted in the same direction. Consequently, the probable errors in the mean isobase directions are much less, and are estimated to be ±8 and ±15 degrees respectively for Sl-1 and Sl-3. In light of this, it is rather remarkable that the total spread of directions is only 35 and 34 degrees respectively for the Sl-1 and Sl-3 levels.

Considering the errors involved, the difference of 5 degrees in the mean values can hardly be regarded as significant, and it cannot be stated positively that the two sea levels have different isobase directions. However, the results do suggest that the lower level has a more northwesterly isobase direction, although it cannot be concluded that there was a westward shift of the centre of uplift.

A control has been made from the previous assumption that the curvature of the isobases is so low as to be negligible. Triangles which contain a side from the northern end of Eclipse Channel to the west side of Eclipse Harbour have been chosen for both levels, and the triangles lying to the northwest of this line have been compared with those on the southeast side. The following isobase directions were obtained from the different triangles.

Isobase directions (in degrees)

Sl-1		Sl-3	
NW side	SE side	NW side	SE side
289	289	291	299
296	297	296	301
297	298	297	302
298	299	297	302
	309	297	303
295	298	296	301

The differences are small, but considering the consistent deviations under Sl-3, it is reasonable to consider that the curvature of the isobases is noticeable in the area and will be towards the south. It is not possible, however, to state the radius of the curvature, or any possible change in it that might have occurred in the interval between the formation of the two strandlines.

The Extended Diagram (Figure 6)

The profile in Figure 6 is essentially the same as that in Figure 5 but on a smaller scale. The observations from the Two Loon Lake area (Figure 1) have been plotted, and the strandlines extended north and south. Two errors are involved in such a projection: first, the strandlines are not straight lines over long distances, and second, the strandlines in Figure 5 are drawn arbitrarily as different persons might draw different lines on the basis of the same data. The gradients are therefore only approximately correct.

The first type of error has been discussed previously, and it was found that the lines on Figure 5 could be regarded as straight lines. The problem remains as to how far the average slope over 20 km can be projected along a plane.

Accepting Andersen's (1960) strandlines, but disregarding the break of slope then the average slope of the strandlines over a distance of 15 km can be extended for another 15 km without diverging more than about 1 m from the "true" line. Since the error in the gradient of the strandlines in Figure 5 is not regarded as being larger than 0.5 m/15 km, the extended strandlines in Figure 6 should introduce a maximum error of 1.5 m.

As with all other points, the observations from the Two Loon Lake area are projected onto a plane along lines perpendicular to the plane in Figure 6. The error will be greater in this case than in other cases as the points are farther away from the plane. This error, however, will be offset to some extent by the curvature of the strandlines.

On the basis of the above estimates, it is concluded that two of the observations in the Two Loon Lake area form part of the sea level now represented by Sl-3. A long, well developed terrace at the southern end of Ryans Bay suggests in itself that a strandline exists, but its trend could not be ascertained on the basis of that locality alone (Løken, 1962).

The 64-m observation associated with the readvance moraines at the southern end of Ryans Bay has been plotted, and lies almost on the extension of Sl-2, assuming that this line keeps the same gradient as in Figure 5. Thus, a connection is suggested between this readvance and the strandline.

The strandlines have been extended northwards for a distance greater than 15 km; although this makes them inaccurate in detail, some of the main features appear. The positions of the zero isobases have been derived from this graph, and this information, in conjunction with the isobase direction as obtained above, has been used for the construction of the isobase map

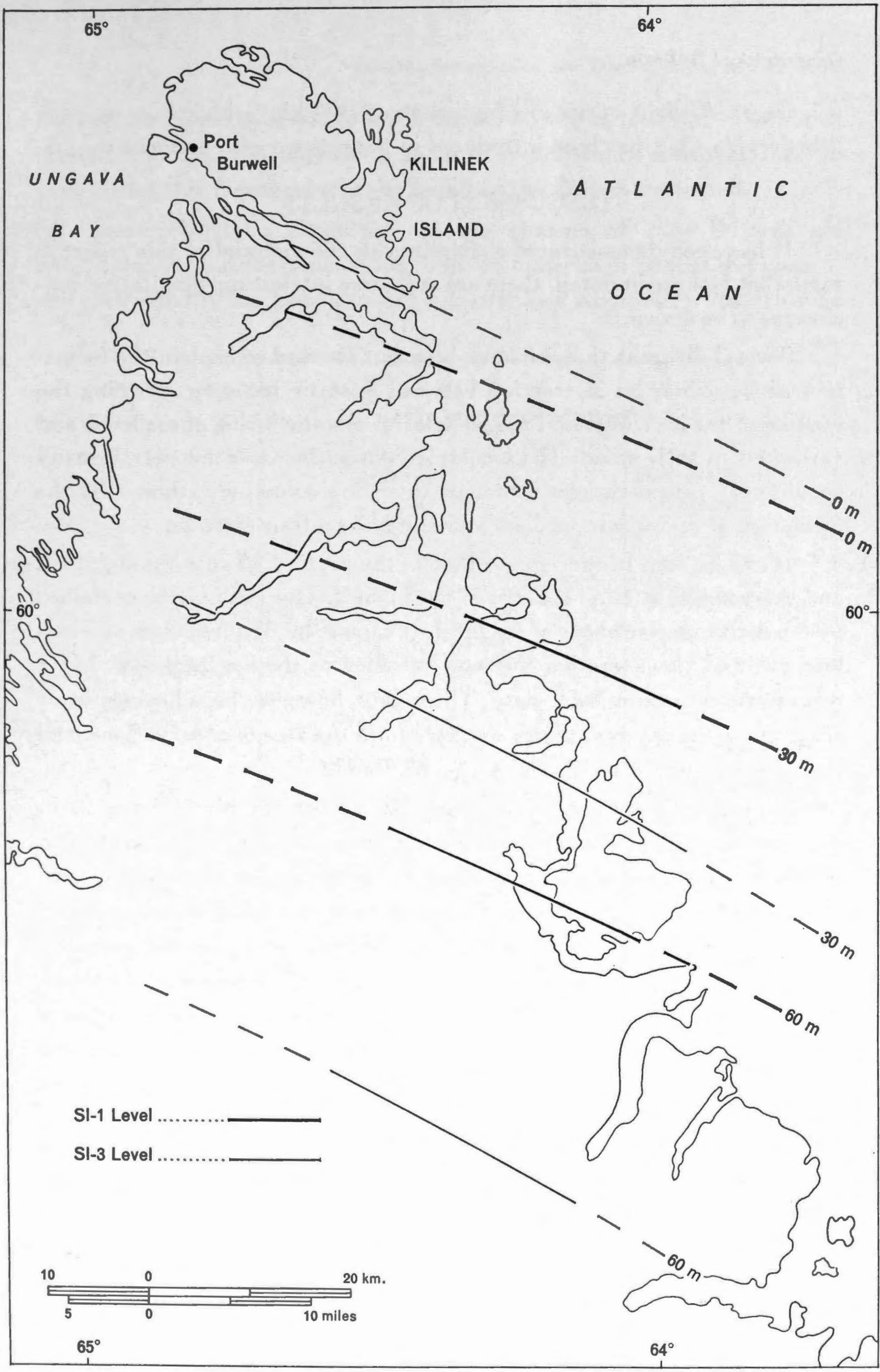

Figure 8. Isobase map for northernmost Labrador, showing approximate positions.

(Figure 8). A slight curvature (radius about 400 km) with its centre near Schefferville, Que. has been introduced in accordance with previous results.

DISCUSSION OF RESULTS

It has been demonstrated that although the material of this report is somewhat lacking in detail, there are still some interesting, qualitative conclusions to be drawn.

Several different theories have been put forward to explain the formation of shorelines by interaction between isostatic recovery following the melting of the ice sheets and the postglacial eustatic lifting of sea level, and variations in their speed. The available information does not permit many geophysical considerations although there are some indications that the formation of Sl-3 was immediately preceded by a transgression.

It can be seen from Figure 6 that in the north, Sl-3 cuts through Sl-1, and the younger strandline becomes the highest. This can only be explained by a positive displacement of sea level. It cannot be decided, from an absolute point of view, whether the land subsided or the sea level rose, but a transgression certainy took place. There may, however, be a low degree of accuracy in the diagram at this distance from the area of observations, and the interpretation given might not be warranted.

A possible transgression is shown by the stratigraphy (Figure 9) in the locality (Figure 4) where sample shells were radiocarbon-dated. The profile shows a layer of clay deposited on top of another layer of clay containing a large number of stones. The stones, well rounded and up to fist-size, occur too frequently to be explained by ice rafting, and thus the following explanation is offered. During a period of negative displacement of the shoreline, the stony layer was in the littoral zone and the finer materials were washed away. At a later period the sea transgressed the former strand, and the water became deep enough to make the locality favorable for deposition of clay. The clay was first deposited between the stones, later on top. During the Sl-3-period the depth of the sea at this locality would have been about 6 m (Figure 5), a depth generally considered to be too shallow for clay deposition, although Antevs (1928) found that clay could be deposited at a depth of 4 m if the locality was well sheltered. Thus, it is indicated that a transgression occurred prior to the formation of Sl-3.

It is evident from Figure 6 that the formation of Sl-4 followed a marked positive displacement of sea level. The transgression in the area around Port

Burwell amounted to about 15 m, as the sea level rose to about 15 m above present sea level. This appears to be far in excess of any possible error. No evidence of this transgression was found in the area investigated.

These predictions about the sea-level changes at Port Burwell are based completely on extrapolations from the material presented in Figure 5, and their validity has been strongly supported by Robitaille's observations at Port Burwell, where he found that the highest raised beach was about 15 m above sea level (personal communication, 1961). This indicates that the 15-m level is an important and significant sea level in that locality, and the evidence supports the extrapolations made above. No indication is available to show how Sl-1 was formed.

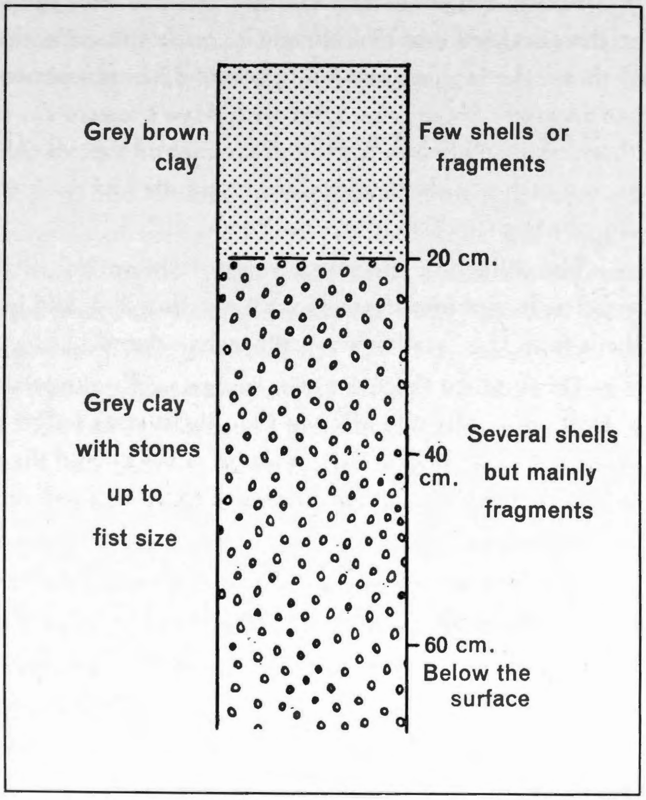

Figure 9.
Stratigraphy of locality 2.

Hinge lines have been widely recognized in the Great Lakes area (Leverett and Taylor, 1915), but no such lines can be identified in this area on the basis of the material studied.

In summary, Sl-4 was formed in association with a marked transgression, and the indications are that the same is true for Sl-3. Neither of these are therefore tempest strandlines, but are associated with two marked events in the postglacial emergence of the area, namely two periods with a positive displacement of the shoreline.

FOSSIL EVIDENCE OF HIGHER SEA LEVELS

Fossils of Pleistocene marine molluscs were found in several localities at the northern end of Eclipse Channel, and collections were made in five of these, the highest at an altitude of 32 m (L) above sea level. The fauna has an arctic-boreal character with *Mya truncata* L., *Hiatella arctica* L. and *Astarte borealis* Schun. as the predominant species. All ten species collected have a rather wide temperature tolerance and no further conclusion about the climatic conditions can be drawn.

The collection and stratigraphy from one locality is described in some detail as it is of importance in interpreting Sl-3, and because a sample of the shells from this locality was radiocarbon-dated.

This locality (Figure 4) lies in a generally sandy area with small pockets of clay, at an altitude of 29 m (L). Shells were found in the clay, but never in the sand. A pit was dug to a depth of 0.6 m, and the stratigraphy is shown in Figure 9. The following species of shells were identified:

Mya truncata L.
Hiatella arctica L.
Chlamus islandicus Muller
Trichotropis borealis Brod. and Sby. (on surface only)
Entomostracan sp. *Balanus* or *Coronula*

The shell sample taken at an elevation of 29 m (L) at the northern end of Eclipse Channel showed a radiocarbon-dating of 9,000 ± 200 years (L-642), but it cannot be related with certainty to any specific sea level, although its significance for the late-glacial and postglacial chronology is discussed below.

SUMMARY

The late-glacial and postglacial emergence of northern Labrador has not been a continuous process as demonstrated by the three strandlines Sl-1, Sl-3 and Sl-4 outlined above. A fourth strandline (Sl-2) below Sl-1 is strongly suggested by the presented material. Sl-3 and Sl-4 are associated with transgressions of former dry land and are therefore not tempest shorelines, but represent significant events in the late-glacial and postglacial history of the area. The strandlines, once horizontal, have been lifted and/or tilted subsequently, and Sl-1 and Sl-3 now slope down N25°E at a rate of 1:1,000 and 1:1,650 respectively. The lowest strandline, Sl-4, is horizontal as far as could be determined. The isobase directions for Sl-1 and Sl-3 have been determined to be 294 ± 8 degrees and 299 ± 15 degrees respectively, a difference in direction not considered significant. The highest occurrence of macrofossils was found around the north end of Eclipse Channel at an elevation of 32 m (L). The marine limit in the locality is 51 m, which illustrates the unreliability of macrofossils in indicating sea level.

THE DEGLACIATION AND THE EMERGENCE OF THE LAND

At the time the edge of the Wisconsin ice sheet had withdrawn to the present coastline, a network of valley glaciers originating on the Ungava Bay side of the mountains filled the valleys and fiords along the Atlantic coast. During the period that followed, when the ice front retreated westwards towards the drainage divide, several halts and readvances occurred as shown by a number of end and lateral moraines (Figure 1). The longest of these moraines can be followed for almost 12 km, but the remainder for less than half this distance. Consequently, large gaps exist between them, and it was not possible to correlate moraine features in one valley with those in another. Following a short resumé of the main moraine deposits (Løken, 1962, Figure 1) it will be illustrated below how the preceding study of the emergence of the land and the recognition of the strandlines provide a useful tool for bridging these gaps.

The northernmost deposits are the Telliaosilk moraines (Figure 10) deposited around the bay of the same name by an ice tongue from the west. There are two distinct moraine ridges that show a readvancing ice body; immediately behind the youngest ridge is found a wide belt of heavy till deposit which indicates a period of very slow retreat of the ice margin.

South of these, along the east side of Noodleook Fiord, lie the Noodleook moraines that were mainly formed by an ice stream flowing northwards in the fiord during a phase of deglaciation, called here the Noodleook phase. The northern part of the oldest moraine, however, was formed by an ice stream the surface of which sloped towards the south, and it is believed that an outlet glacier from Tellialuk Fiord spread out and flowed north *and* south in Ekortiarsuk Fiord. Because of this and the great similarity between

Figure 10. View east-southeast of part of the Telliaosilk moraines.

the Noodleook and the Telliaosilk moraines it is believed that they are from the same phase of deglaciation. (Løken, 1962)

Three distinct sets of moraines deposited by the Eclipse Valley outlet glacier have been recognized from airphotos. The oldest set lies at the northern end of Eclipse Channel, and consists of three closely spaced end moraines, the youngest of which was formed when the sea level was at the 53.5-m (L) level. These are referred to here as the Base Camp moraines. A younger set of well developed lateral moraines reach the valley floor about 7 km upvalley from the southern end of Eclipse Lake. The frontal deposit is poorly developed, and the features were probably formed during a small readvance, or merely during a halt in the recession. The third set of moraines, here called the Sheppard moraines, lies on the west side of the drainage divide towards Ungava Bay, where Eclipse Valley reaches its westernmost point. The outer of several moraines in this set is the longest continuous moraine known in the area and can be followed for about 12 km.

Three sets of moraines, found in the Ryans Bay-Upper Kangalaksiorvik Lake area, were deposited by an arm of the Kangalaksiorvik Valley outlet glacier which flowed northeastwards to Ryans Bay. The oldest set lies on the north side of the northern part of the bay and consists of two, or possibly three moraine ridges which show that readvances took place. Two additional readvance moraines, the youngest of which was formed when sea level was at the 64-m (L) level, lie between the south end of

Ryans Bay and Two Loon Lake. These moraines were deposited during a phase of deglaciation which will be called the Two Loon phase. The third set lies along the north side of upper Kangalaksiorvik Lake, and consists of one, or possibly two readvance moraines. The formation of these moraines is associated with a reversal of the natural drainage from Two Loon Lake which led to the deposition of a large delta flat at the south end of Ryans Bay at an elevation of 49 m (L) above present sea level. The name Kangalaksiorvik phase has been given by the writer to the phase of the deglaciation when these readvances took place.

As seen from Figure 4, the 51-m terrace lies on the proximal side of the Base Camp moraines and is consequently younger than these. The same terrace is synchronous with Sl-1 and the strandline is therefore also younger than the moraines. The last of the Base Camp moraines was abandoned when sea level was at the 53.5-m (L) level, and the age difference between this moraine and Sl-1 therefore corresponds to a change in sea level of 2.5 m, a rather short interval if it is assumed that the emergence was continuous.

Along the southern part of Ekortiarsuk Fiord (Noodleook) the 42.5-m observation, which is synchronous with Sl-1, lies on the proximal side of the Noodleook moraines and is therefore younger than these. A lateral terrace, which is correlated with the final part of the Noodleook phase, was found less than 500 metres away from the 42.5-m observation and only 4 metres above it. These observations provide some information about the age difference between the last of the Noodleook moraines and Sl-1, as the lateral terrace was above sea level when it was formed. Consequently the age difference corresponds to a change in sea level of less than 4 m.

It is seen from the above that both the Noodleook and the Base Camp moraines are slightly older than Sl-1, and it is concluded that they are from the same phase of the deglaciation, i.e. from the Noodleook phase.

Sl-1 extended to the south end of Ryans Bay (Figure 6), would reach an elevation of about 78 m, which is about 14 m above the marine limit in that area. The implication is that this locality was ice-covered at the time Sl-1 was formed, and also during the Noodleook phase. The position of the ice front of the Ryans Bay outlet glacier during this phase has not been determined, but it is considered that some moraine features in this area are associated with it. It is suggested that the moraines along the north side of the outer part of the bay were formed during the Noodleook phase.

It has been stated that the younger moraine of the Two Loon phase was associated with the 64-m sea level at the south end of Ryans Bay. If Sl-2 is extended that far south it reaches the area at approximately that height, and thus Sl-2 is possibly synchronous with that phase.

The connection between the strandline phase and the readvance phase is clear when Sl-3 is considered. The lower delta at 49 m (L) above sea level at the south end of Ryans Bay lies on the extension of this strandline and is at the same time associated with the Kangalaksiorvik phase of the deglaciation. No other observation along Sl-3 was made in association with moraines, and the position of the ice front in any of the other valleys at that time is not known, except for the fact that no tidewater glacier existed in the area investigated by the writer other than the Kangalaksiorvik Valley outlet glacier.

In spite of this, a tentative correlation is made between the Sheppard moraines and the Kangalaksiorvik phase, based on the following considerations; firstly, the moraines at the northern end of the Ryans Bay-Kangalaksiorvik Valley area were formed during the Noodleook phase; secondly, the moraines at Two Loon Lake were formed during the Two Loon phase; and finally, the moraines at the southern end of Two Loon Valley date from the Kangalaksiorvik phase.

The Base Camp moraines were deposited during the Noodleook phase, after which another set of lateral features, believed to represent a significant phase, were formed. At a still later phase, the Sheppard moraines were formed at the water divide towards Ungava Bay. Besides these three distinct phases, no others were found; a parallel to the development in the Ryans Bay-Kangalaksiorvik Valley area is postulated.

It is seen from the above that the three upper strandlines are associated with tidewater glaciers in one or several of the fiords and bays that were investigated, and that they are therefore of late-glacial age. The strandline Sl-4, on the contrary, cannot be related to any glacial phase, and as it is horizontal, it differs noticeably from the others. Studies in Scandinavia (Grönlie, 1940) show that when one area is considered, the slope of the strandlines decreases with decreasing age, and thus it is reasonable to assume that this strandline is much younger than the others, and it is considered to be a postglacial strandline.

The skeleton of a relative chronology has been outlined above; it has been assembled on Table I, which starts with the first extensive moraine system deposited at the ice front which by then had receded to the present land area. These moraines are those formed during the Noodleook phase, at the end of which Sl-1 was formed. A period of ice recession followed until a new, but apparently less marked readvance phase, the Two Loon phase, occurred possibly at the same time that Sl-2 was formed. A new period of melting followed, and was in turn interrupted by the Kangalaksiorvik phase which, judging from the Sheppard moraines, was a major readvance phase contemporaneous with the formation of Sl-3. A long period of further melting presumably followed and in postglacial time the large transgression which culminated along Sl-4 took place.

It is a noticeable feature of the above that the three late-glacial strandlines appear to be related to readvance phases; this suggests that an increasing ice load, which must have caused a retardation of the isostatic recovery at the earth's crust, is an important factor in explaining the formation of the late-glacial strandlines.

The chronology outlined above is a relative chronology, as none of the events have been dated absolutely. Nevertheless, it is of considerable interest that the radiocarbon-dating previously noted is possibly the first dating ever obtained of the Pleistocene on the Labrador coast. It is not possible to determine the depth at which these shells were deposited, and consequently the exact sea level which has been dated is not known. However, the location has been plotted on Figure 5, and two important

Table 1

Part of the late-glacial and postglacial chronology for northernmost Labrador

Phase	Main moraine features	Strandline	Remarks	Absolute age
Noodleook	Telliaosilk, Noodleook, Base Camp moraines. At north end of Ryans Bay ?	Sl-1	Readvance phase	
Two Loon	Lower level in Eclipse Valley, Two Loon Lake	Sl-2(?)	Readvance phase	
Kangalaksiorvik	Two Loon Valley Sheppard	Sl-3	Readvance phase Transgression	 9,000 ± 200
		Sl-4	Transgression	

facts are evident. First, the shells are definitely younger than the Base Camp moraines, as they are deposited on the proximal side of these. As stated above, Sl-1 is only slightly younger than these moraines and it is therefore assumed that the shells are of the same period as Sl-1, or of a later date. Thus, 9,000 ± 200 years is a minimum age for Sl-1. Secondly, the locality in which the shells were collected became dry land shortly after the formation of Sl-3. As clays are not deposited in shallow water, nor in the littoral zone, the shells were thus deposited some time before the locality emerged from the sea. It is considered that the water was possibly deep enough for clay deposition at this locality during the period when Sl-3 was formed, but not later, and thus, 9,000 ± 200 years is considered to be the maximum age for Sl-3.

It can be concluded, therefore, that the radiocarbon-dating gives the age of Sl-1, or Sl-3 or an event in between the formation of these two. At present, this dating is as close as is possible to come with certainty, but it will be seen that if the interpretation of the stratigraphy from locality 2 is correct, then the dating should give the age of Sl-3, although this age requires confirmation by further field evidence.

Strandline Sl-4 is of special interest as it is postglacial and associated with a major transgression. Postglacial transgressions are known from Scandinavian research. The largest of these is the Tapes or Littorinea transgression, and the Sl-4 transgression is tentatively correlated with it. The Tapes transgression reached to elevations of 10 to 30 m above present sea level in western Norway, and only in the outer coastal districts did it reach elevations below these values. It is thus seen that the altitude of Sl-4 is of the right order of magnitude for such a transgression. According to Faegri-(*in* Holtedahl, 1960, p. 455) the maximum transgression took place some 4,700 years ago, and if the dating of Sl-3 is accepted, it means that an interval of about 4,300 years occurred between the formation of these two strandlines; this is considered sufficient to account for the change in slope.

Correlation with other areas

Table 1 can serve, to a large extent, as a summary of the results which emerged from the writer's investigations in northern Labrador. The area is comparatively unknown, and as it is not directly connected with any area in which the glacial morphology is well known, few reliable correlations and extrapolations can be made. This is especially true with regard to chronologies, and it is pointed out that only after the radiocarbon-dating became avaiable, could features which have been previously described as Wisconsin be referred to that period with certainty.

Radiocarbon dates from central Labrador-Ungava for the bottom layers of a bog in the Greenbush area, about 30 km northwest of Schefferville, have been calculated at 5,300 ± 800 years (Ives, 1960b). This bog would thus have existed approximately 3,700 years after the tidewater glaciers in northern Labrador reached the Atlantic. This indicates a very rapid melting especially when it is considered that the bog probably was not formed immediately after the disappearence of the ice, and that the tidewater glaciers were 'fed' by a large ice mass which was maintained even then over the southern part of present-day Ungava Bay (Ives, 1960a; Løken, 1962).

At the present, the moraines described from this area can hardly be correlated with recessional phases along other parts of the fringe of the North American ice sheet. It is pointed out, however, that the Base Camp moraines, which are somewhat older than 9,000 years, possibly might correspond to the Valders readvance of the Great Lakes area and the Fennoscandian moraines in Scandinavia. This correlation is most tentative, as it is not yet known whether this readvance phase had any parallel at all in northern Labrador, or if it had, whether this was contemporaneous with the southern phase. Additional research on these points is certainly needed.

Although parts of moraines cannot alone be correlated with great certainty over large gaps, this is considered possible in conjunction with the study of strandlines especially when the trend of the line has been established and any influence by remaining ice masses can be disregarded. This means that extrapolations of late-glacial strandlines must be made with great care, while a postglacial strandline can be extrapolated with less uncertainty.

Strandline Sl-4 is a postglacial horizontal strandline, and in this connection Wenner's results (1947) from southern Labrador are of interest. On the basis of pollen studies he concludes that the warm period in Labrador occurred while the sea level along the coast was sinking from about 20 metres to a few metres above the present sea level. He further stated, on the basis of Tanner's unpublished results, that the lower strandlines along the coast (under 30 metres) seemed to run nearly parallel with the present surface of the sea, and that below 30 metres above sea level clear strandlines occurred at 25, 20 and 16 metres.

This warm period in Labrador may be correlated with the sub-boreal period of Scandinavia, from the early part of which the Tapes transgression(s) dates (Holtedahl, 1960). The horizontal strandlines along the coast are therefore postglacial, and it is suggested that further research may well prove a correlation between S1-4 and one of the strandlines farther south.

Mercer (1956) reported a number of raised shore features from the west side of Frobisher Bay, and the large number at 65 feet suggest strongly that a strandline exists at this level. As the strandline is found at the same level along the entire west side of the bay it appears to be horizontal. However, as the areal distribution of the observation is poor, very little can be postulated about its slope in other directions. The indications are that an almost horizontal strandline exists on southernmost Baffin Island, and it is tentatively correlated with Sl-4.

It has been suggested above that a horizontal strandline can be traced the entire distance from Hamilton Inlet northwards to the head of Frobisher Bay. An interesting problem raised by this suggestion is whether this postglacial strandline can be traced farther north, and if so, what relationship it bears to tidewater glaciers on the Arctic Islands.

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SOME REGIONAL HEAT BUDGET VALUES FOR NORTHERN CANADA

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ABSTRACT: A regional Bowen ratio is computed from an aerological energy budget approach with both mean monthly and a daily upper air and surface data for Northern Canada. Elsasser radiation computations are made from the mean soundings, the net heat added (or lost) in the column is computed, evaporation is estimated from the change in the precipitable water during the motion along the trajectory, and, finally the Bowen ratio and the complete heat budget are evaluated from the "climatological" soundings and trajectories according to the residual equation,

$$L_0 = R_n - S - E_0.$$

RÉSUMÉ: Une proportion Bowen régionale pour le Nord canadien est calculée à partir des données d'énergie aérologique provenant de la moyenne mensuelle des données d'observation au sein d'une même colonne d'air, une juste à la surface de la terre et l'autre à une altitude plus élevée. Les calculs de radiation d'Elsasser découlent de la moyenne des données obtenues lors de sondages. De plus, l'on calcule la chaleur nette, perdue ou gagnée, dans la colonne d'air de même que l'évaporation en prenant soin d'examiner le changement qui s'effectue dans l'eau en voie de précipitation le long de la trajectoire. En dernier lieu, la proportion Bowen et toutes les données calorifiques sont évaluées au moyen de divers sondages climatologiques et par l'étude des trajectoires parcourus par la colonne d'air; pour ce, on utilise l'équation résiduelle qui suit:

$$L_0 = R_n - S - E_0$$

INTRODUCTION

Heat budget data acquired by the usual methods employing vertical gradients of temperature and moisture and measured radiation and soil storage values are not available for Northern Canada. This paper is devoted to an attempt to estimate these heat budget data for climatological purposes as revealed by modification of a column of air moving over the surface. It is assumed that if the location of these columns in time and space is carefully chosen, the column will remain essentially intact and will cross two aerological stations in succession. If no significant condensation within the column occurs, it is then possible to assign observed moisture and heat changes to measurable or calculable processes, thus obtaining surface fluxes of heat and moisture by difference.

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THEORY

The total heat, H_T, added to a column of air in any prescribed time is given by

$$H_T = I - RI - S - E_0 - B_T, \qquad (1)$$

where I is the insolation, R is the albedo of the surface, S is the subsurface heat storage, E_0 is the evaporation, and B_T is the net outgoing radiation at the top of the column being considered.

Similarly, the energy budget equation for the air-ground or air-water interface is given by

$$L_0 = I - RI - S - E_0 - B_0 \qquad (2)$$

where L_0 is the convective heat transfer at the interface, and B_0 is the net outgoing radiation at the surface.

By substituting (1) in (2) we obtain

$$L_0 = H_T - (B_0 - B_T) \qquad (3)$$

where the term $(B_0 - B_T)$ represents the divergence of radiation throughout the column.

Now the Bowen ratio, β, is given by

$$\beta = L_0/E_0 \qquad (4)$$

And from (3) we have,

$$\beta = (H_T - B_0 + B_T)/(E_0) \qquad (5)$$

The terms on the right in equation (5) may be evaluated in certain cases. If sounding stations are located a reasonable distance apart on the same air trajectory, and if the trajectory changes little with height, and if there is no significant condensation or evaporation within the column proper, then the evaluation of these terms does not meet with insurmountable difficulty. The heating of the column may be computed from the downstream change in the potential temperature of the sounding. The radiation divergence may be computed for the mean of the two soundings with the aid of an Elsasser diagram (1942). The evaporation term may be computed from the downstream change of precipitable water, i.e., $E = \overline{L}\ \overline{\Delta w}$ (6) where L is the latent heat of evaporation and $\overline{\Delta w}$ is the change in precipitable water content.

In general, trajectories vary too much with height for a column of air to be regarded as being translated downstream essentially intact. However, examination of both daily and mean monthly charts for Northern Canada yields a surprising number of cases for which the assumptions listed in the previous paragraph are essentially met. A number of pairs of stations were selected both on the basis of mean monthly conditions and on a daily basis.

Since days with precipitation or rapid cloud changes along the trajectory were eliminated, it was assumed that evaporation and condensation at the surface were solely responsible for changes in precipitable water.

It was, of course, necessary to compute the trajectory distance between the two stations and then determine the time required for the column to pass between stations using the geostrophic wind velocity. This result, expressed as a multiple of three hours was applied to the Elsasser radiation divergence results to furnish the net divergence of radiation during the interval. As mentioned above, it was necessary to choose soundings where the vertical shear in the wind velocity was at a minimum. Fortunately the vertical shear in the mean soundings did not seem prohibitively large and disappeared in some cases.

There remains the justification of the assumed height of the convectively heated or cooled layer. On the average the top (using Lettau's definition of the point *where the temperature difference with height between two soundings becomes constant*) was found to be at 800 mb during the summer and a little lower during the winter. Lettau (1956) found a mean top to the heated layer at 780 mb for the Great Plains Turbulence Field Program.

To test the proposed hypothesis for the evaluation of the Bowen ratio from columnar heat budget considerations comparative data on temperature and vapor pressure gradients would be necessary—but is difficult to find.

REGIONAL HEAT BUDGET VALUES

Monthly mean charts and soundings obtained from Henry and Armstrong (1949) for Northern Canada for a period averaging four and a half years between 1942 and 1949 were used for the monthly regional calculations. Surface and 500-mb charts together with radiosonde data from the Daily Series Synoptic Weather Maps of the U.S. Weather Bureau for July, 1951 were used for the daily calculations. In all, fourteen regional values were computed and are discussed in the following paragraphs.

The first question that comes to mind concerns the accuracy of the surface heat budget components computed from aerological data. Are these values small differences between large values and hence suspect in magnitude to the point where even the direction of the energy flux is questionable? Going through a typical calculation with values of temperature in error by 1°C and humidity in error by 5 per cent suggests that the daily heat budget values given in Table 1 might be accurate to about 50 ly/day. Thus the small values, such as the January values for the Arctic Bay-Churchill trajectory, indicate only that the energy transfers are small, not the direction of the flux. The larger flux values undoubtedly give the correct direction of flux and a reasonable estimate of the magnitude.

Another test that may be applied to the results concerns the maximum reasonable magnitude. Except for the case of trajectories over open water, where there is a large heat source, it is difficult to see how more total heat (sensible plus latent) could be added at the ground than is provided by the sun, especially in the case of mean monthly values. This criterion rules out the July values for the Whitehorse-Fort Nelson trajectory, for the total surface heat flux of 856 ly/day is larger than the maximum reasonable net radiation income. Of course, this trajectory is over mountainous terrain also, and it is not likely that the column leaving Whitehorse arrives intact at Fort Nelson. For this reason it is believed that the values for this trajectory are suspect. The others are in the reasonable range, however.

The Churchill-Port Harrison trajectory is especially interesting. In July the total heat flux is large and directed towards the surface. The monthly mean value of 420 ly/day is the equivalent of somewhat over 5 cm of ice melt, giving a total melt for the month of about one and a half metres. This is in very good agreement with the observed melt during July. During December the mean flux is small and the direction questionable. However the values for December 4-5, 1951 show an enormous flux of heat out of Hudson Bay. The 1300 ly/day heat loss by the water would chill 50 m of water about a quarter of a degree centigrade per day. After chilling the water to near freezing it would produce about 15 cm of ice per day—a value which is too large to be reasonable for more than a very short period. However the data for December 23-24, 1951 show that after the ice forms the heat loss by the bay becomes very small and the large open-water flux is no longer applicable.

Still another way to examine the results of this study is to consider the Bowen ratio values obtained in terms of the type of terrain over which they are found.

MEAN REGIONAL BOWEN RATIO VALUES

The April flow at 700 mb does not quite carry a parcel directly from Churchill to Port Harrison. This improves, however, as we move to 500 mb. Mean charts lower than 700 mb were not available but the value for the Bowen ratio of .93 appears well in line with expected results for an ice surface traversed by warmer air. For comparison, Table 1 lists all the computed Bowen ratios.

Table 1

Summary Heat Budget Components for Northern Canada Computations
(Units are Langley's per Day)

Downward fluxes indicated by negative values.

Trajectory	Date	Total Heat Added to Column	Convective Heat Flux at Surface	Divergence of Radiation	Heat Equiv. of Evap.
Churchill to Port Harrison.....	July	−189	−140	49	−280
Churchill to Port Harrison.....	Dec.	57	74	17	23
Churchill to Port Harrison.....	4/5 Dec.	462	428	34	880
Churchill to Port Harrison.....	23/23 Dec.	− 66	− 40	26	− 5
Churchill to Port Harrison.....	16/17 Jan.	137	157	20	14
Churchill to Port Harrison.....	April	− 74	− 48	26	− 52
Arctic Bay to Churchill........	July	74	145	71	210
Arctic Bay to Churchill........	Jan.	6	54	48	6
Norman Wells to Fort Smith...	Jan.	164	192	28	175
Norman Wells to Fort Smith...	July	60	129	69	438
Whitehorse to Fort Nelson.....	July	14	156	132	700
Whitehorse to Fort Nelson.....	Jan.	− 80	− 51	29	− 46
Aklavik to Norman Wells......	July	44	111	71	210
Aklavik to Norman Wells......	Jan.	51	101	50	46

The July Bowen ratio for the Churchill-to-Port Harrison trajectory, +.50, agrees well with those expected over a relatively cool water surface crossed by air averaging about 8.5°C. In this case the gradient of moisture and heat is from the air to the water, evidence for which exists in the appearance of advection fog east of Churchill over Hudson Bay in the summer months.

Indirect evidence for the late December freeze of Hudson Bay exists in the high (3.20) value for the Bowen ratio determined from December mean data. This point is strikingly evident when the early and late December daily values between Churchill and Port Harrison are considered. The very low vapor pressure of the snow and ice cover and lack of open water appears clearly in the sharp rise of the January Bowen ratio to 9.00; and this in spite of a trajectory from Churchill to Port Harrison nearly across the centre of Hudson Bay.

A lake-studded taiga region resulting in a soggy summer surface and cold, dry winter surface was next analyzed in the region from Norman Wells, NWT to Fort Smith, NWT. The July value of .30 fits the wet surface conditions quite nicely as well as the high value of evaporation equivalent, 438 ly/day, evident in Table 1. However in January, the relative size of the convective and evaporative terms seems incorrect with evaporation being considerably larger than would be expected.

Next a trajectory which crosses mountainous country was analyzed in the region from Whitehorse, Yukon to Fort Nelson, B. C. Here, again, the July monthly value of .20 indicated a moist surface with a great amount of evaporation; but as pointed out above these results are suspect. The mean January Bowen ratio value of 1.10 in which both the convective and evaporative terms are directed to the surface is quite logical when the inflow of warmer and more moist air from the Gulf of Alaska is considered. Condensation would be expected to take place as would downward convective transfer of heat, but this may be another indication that the technique is inapplicable in mountainous country.

Table 2

Regional Bowen Ratios

Period	Trajectory	Bowen Ratio
April	Churchill to Port Harrison	.93
July	Churchill to Port Harrison	.50
December	Churchill to Port Harrison	3.20
January	Churchill to Port Harrison	9.00
July	Norman Wells to Fort Smith	.30
January	Norman Wells to Fort Smith	1.00
July	Whitehorse to Fort Nelson	.20
January	Whitehorse to Fort Nelson	1.10
July	Aklavik to Norman Wells	.86
January	Aklavik to Norman Wells	2.50
July	Arctic Bay to Churchill	.70
January	Arctic Bay to Churchill	9.00
4/5 Dec. 51	Churchill to Port Harrison	.50
23/24 Dec. 51	Churchill to Port Harrison	8.00
15/16 Jan. 52	Churchill to Port Harrison	11.20

In the region from Aklavik, NWT to Norman Wells, NWT, the July evaporation term is less than one-fifth of the value for July from Whitehorse, Yukon to Fort Nelson, B. C., which is more reasonable. However, the convective term L_0 is larger indicating perhaps a drier surface—or possibly failure of the assumptions. The July monthly value of .86 for the Bowen ratio seems appropriate. The mean January ratio of 2.50 in which both the evaporation and convective heat transfer are away from the surface poses an unresolved problem of interpretation.

The concluding mean monthly regional values of the Bowen ratio were computed along the trajectory from Arctic Bay, NWT to Coral Harbour, NWT. The trajectories for all levels available for both January and July from Henry and Armstrong were excellent, with little, if any vertical shear and with Coral Harbour always downstream in the flow from Arctic Bay. The July Bowen ratio of .70 with moderate evaporation is quite reasonable in view of the surface features. The January result of 9.00 indicates a trajectory over a land and ice surface.

DAILY REGIONAL VALUES

Two December 1951 periods, one early and one late, and a January 1951 period were selected for Churchill, Manitoba-Port Harrison, Quebec calculations to verify indirectly the Hudson Bay freeze in late December.

The soundings were twenty-four hours apart (the 4th and 5th of December), the time required for air over Churchill to reach Port Harrison from geostrophic velocity considerations. Of course, such periods had to be chosen carefully from the Weather Bureau Historical Map Series to insure a trajectory continuous over both stations. The 4/5 December 1951 results of .50 for the Bowen ratio indicate open water conditions while the value of 8.00 on 23/24 December 1951 indicates a trajectory over a frozen surface where both the temperature and vapor pressure gradients were directed downward—believed typical of the arctic winter. The 15/16 January 1951 ratio of 11.20 for the Churchill-Port Harrison region is reasonable for this condition and compares with a ratio of 9.00 for the same region on the January mean basis.

CLASSICAL EVALUATON OF BOWEN RATIO

Temperature and vapor pressure data were available for a point in Hudson Bay east of Churchill allowing a computation of the Bowen ratio from Bowen's formula,

$$\beta = (.64)\left(\frac{P}{1000}\right)\left(\frac{\Delta T}{\Delta e}\right),$$

where P is the surface pressure, ΔT is the temperature difference between the sea surface and the air at $2\frac{1}{2}$ metres, and Δe is the vapor pressure difference in millibars between the sea surface and a point $2\frac{1}{2}$ metres above the surface. The value obtained at .72 is generally in good agreement with the July regional value of .60 from Churchill to Port Harrison.

COMPARISON WITH 1/(Δe/ΔT)

A final comparison was made between the calculated values of the regional Bowen ratio and slope of the saturated vapor pressure-temperature curve, i.e., with the quantity [1/(Δe/ΔT)] [.64]. The quantity in brackets [ ] does not refer to the ratio of the temperature and vapor pressure differences with height, but rather to the inverse of the rate of change of saturation vapor pressure, Δe, with a change in temperature, ΔT. This assumes that

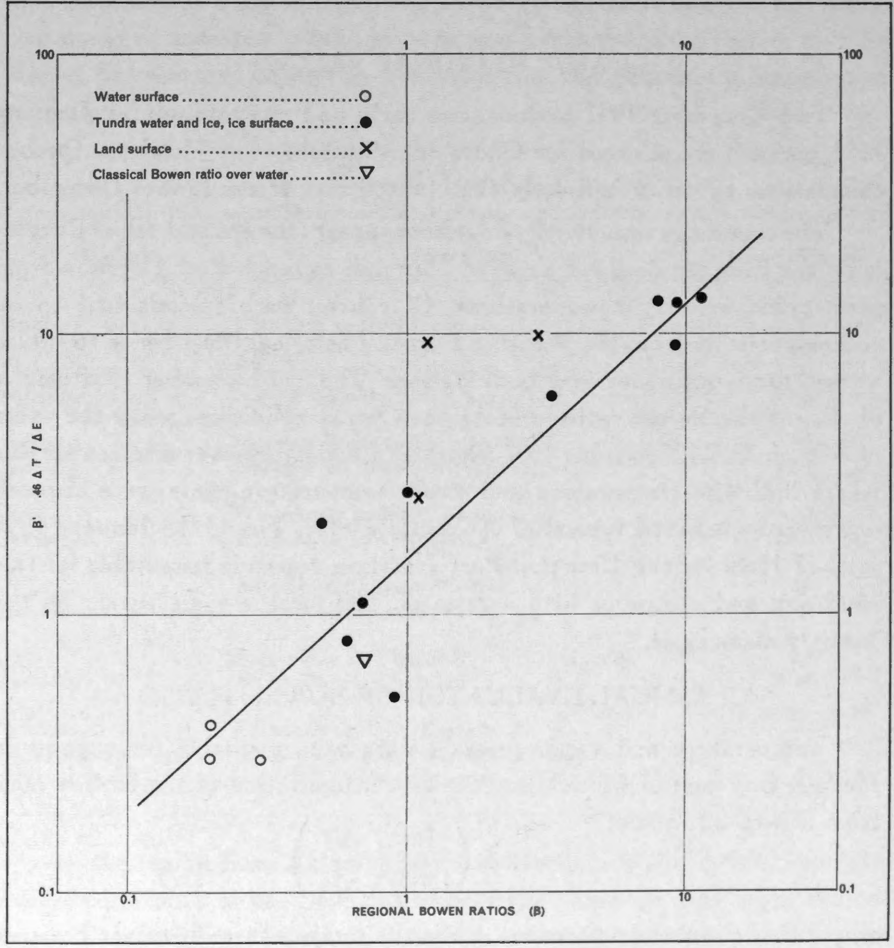

Figure 1. Scatter diagram comparison of the regional Bowen ratios computed from aerological data with Bowen ratios computed from the slope of the temperature-saturation vapor pressure curve.

the vapor pressure fluctuations are in accord with the temperature fluctuation at the surface, and the factor .64 was used simply to make the results comparable to the usual Bowen ratio. It also assumes a wet surface.

The value of (.64) ($\Delta T/\Delta e$) was computed for the mean surface temperature of each pair of soundings. This was plotted versus the aerologically determined Bowen ratio (Figure 1). The correlation of 0.86 suggests that the Bowen ratio can be reasonably estimated from temperature alone for these northern surfaces with much available water.

The position of the scatter values in Figure 1 indicates that the factor by which "$\Delta T/\Delta e$" is multiplied is somewhat too large and perhaps should be on the order of .48 instead of .64.

CONCLUSIONS

It appears from this study that at least some heat budget estimates of regional applicability can be made using only aerological data. From these, regional Bowen ratios may be computed, which compare favorably with estimates by other authors and estimates obtained by the usual method. It was further shown that at least the Bowen ratio values obtained by aerological methods may be reasonably approximated for surfaces with much available water using surface temperatures alone.

While these estimates are probably too inaccurate for engineering purposes, they probably give values useful for the estimation of air-mass modification in Northern Canada.

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IRON MINING IN PERMAFROST, CENTRAL LABRADOR-UNGAVA

A Geographical Review

J. D. Ives[*]

Abstract: The decision to undertake large-scale mining of iron ore in the vicinity of Schefferville was partly based upon the proving of 400 million tons of ore reserves. This essential economic consideration set in motion one of the largest commercial developments of the Canadian northland, and it was based upon the assumption that the ore was "normal", in the sense that it was not permanently frozen. Today it is being realised that a proportion of the initial proven reserves is permanently frozen and that the cost factor in frozen areas is higher than the initial expectation of 1954. This aspect of the economic geography of Labrador-Ungava is discussed and an outline is given of the technical problems involved in mining in permafrost. The extent of permafrost in Labrador-Ungava is obviously a vital factor in economic exploitation. Knowledge of permafrost conditions, however, is inadequate and vague, even in the main ore-producing areas. The paper concludes with a preliminary outline of permafrost distribution in relation to the ore-producing and potential mining areas known today.

INTRODUCTION

Decision to prepare for the exploitation of the Knob Lake iron ore in 1950 set in motion one of the largest commercial developments of the Canadian northland. An analysis of the economic and political considerations behind this decision is beyond the scope of this paper, although it can be assumed that a basic consideration was, that if sufficient reserves could be proven, the immense capital outlay would be justified in terms of relatively cheap, large-scale methods of production. In this sense, the amount of proven ore necessary to provide confidence in a long-term venture is a key figure. This was initially set at 300 million tons of ore with less than 20 per cent silica giving an average grade (dry basis) of about 59 per cent Fe., and was increased to 400 million tons in 1949. Of vital importance to the Iron Ore Company of Canada was the acquisition of a "captive market" of American steel companies who would guarantee a minimum purchase[†],

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[*] The field work referred to in this paper was completed by the writer while he was Field Director of the McGill Sub-Arctic Research Laboratory at Schefferville, 1957–60. It was enlarged to form one of the official laboratory research programs, carried out in liaison with the Iron Ore Company of Canada and the National Research Council.

[†] The critical importance of this factor is clearly seen in the effect on the ore production during the 1958 recession and again during the current year. In each case production amounts to 7½ to 7¾ million tons or about 70 per cent of that of a "normal" year. The favored position of the Schefferville mines is clearly seen when comparing percentage production figures for producing areas in the U.S. Without a "captive market" serious economic disturbance in such isolated areas could be expected.

MS submitted June, 1961.

together with company ownership of the Quebec North Shore and Labrador Railway. A crash exploration program between 1948 and 1950 surpassed the target of 400 million tons of proven reserves (417 m. tons) and the vast machinery of railroad, town and mining plant construction was set in motion.

For the purpose of this paper it is assumed that, with 417 million tons of high-grade reserves, a balance between cost of producing and shipping the ore, and sale price had been set, leaving a safe profit margin. It must also be agreed that, in order to estimate the cost of a ton of ore at tidewater, or blast-furnace, as the case may be, some assumptions were made on the type of ore and the manner of handling it, one of the assumptions being that it was normal with respect to temperature; in other words, that it was not frozen. Iron Ore Company of Canada officials maintain that, based upon Mesabi Range experience, it was closely known in 1950 what it would cost to mine ore with a sufficient profit margin to allow for unknowns such as landslides and washouts on the railroad, and permafrost. However, the fact remains that the extent of permafrost in the mining area was incompletely known in 1950 so that, unless the "margin" was extremely wide, it could hardly be expected to engulf the higher costs of mining in frozen ground in a routine manner.

Ruth Lake mine was the first to be exploited and a token shipment of 1¾ million tons was made in 1954. Full operations were begun in 1955, when French mine, discovered in 1948 beneath the site of the exploration camp at Burnt Creek, and Gagnon mine, were opened up. Production for 1955 reached 10½ million tons, slightly less than 5 million tons below the capacity of the existing installation. During mining operations in 1955 small "pods" of frozen ore were encountered in two of the Gagnon pits and caused some local handling difficulties. Also, the Iron Ore Company of Canada became involved with the technical difficulty of successfully mining and shipping "sticky ores," a problem which later became related to the frozen ore difficulty.

Trenching operations in 1955 in the large Ferriman orebodies led to the discovery of "ground frost" a few feet beneath the surface by H.E. Neal and L. Pituley. Permafrost was suspected, although a shaft driven into the Ferriman orebody to a depth of 50 feet in 1948 encountered frozen ground, and the discovery of "ground frost" in the Kivivic and Sunny orebodies 25 to 30 miles farther north in 1949 and 1950, were the first encounters with what has since proved a problem in mining operations.

Following the 1955 trenching experience at Ferriman, a number of exploration drill holes were utilized by H.E. Neal in 1956 for the installation of thermocouple strings according to National Research Council specifications. This was followed in 1957 by widespread thermocouple installation by B. Bonnlander under Neal's supervision and permitted initial ground temperature exploration of the Ferriman, Rowe and Star Creek orebodies. Almost simultaneously with the acquisition of the first results three pits were opened in the Ferriman area. Many of Bonnlander's thermocouple readings gave results of 30 to 33° F. (Bonnlander, 1957, 1958) and, as the limit of accuracy of the method was possibly greater than ± 1° F., doubt remained as to the extent of permafrost. With the opening up of the Ferriman orebodies much of this doubt was rudely removed. The early cuts pierced frozen ore with a high water content and resulted in production costs considerably higher than those in normal, unfrozen ore.

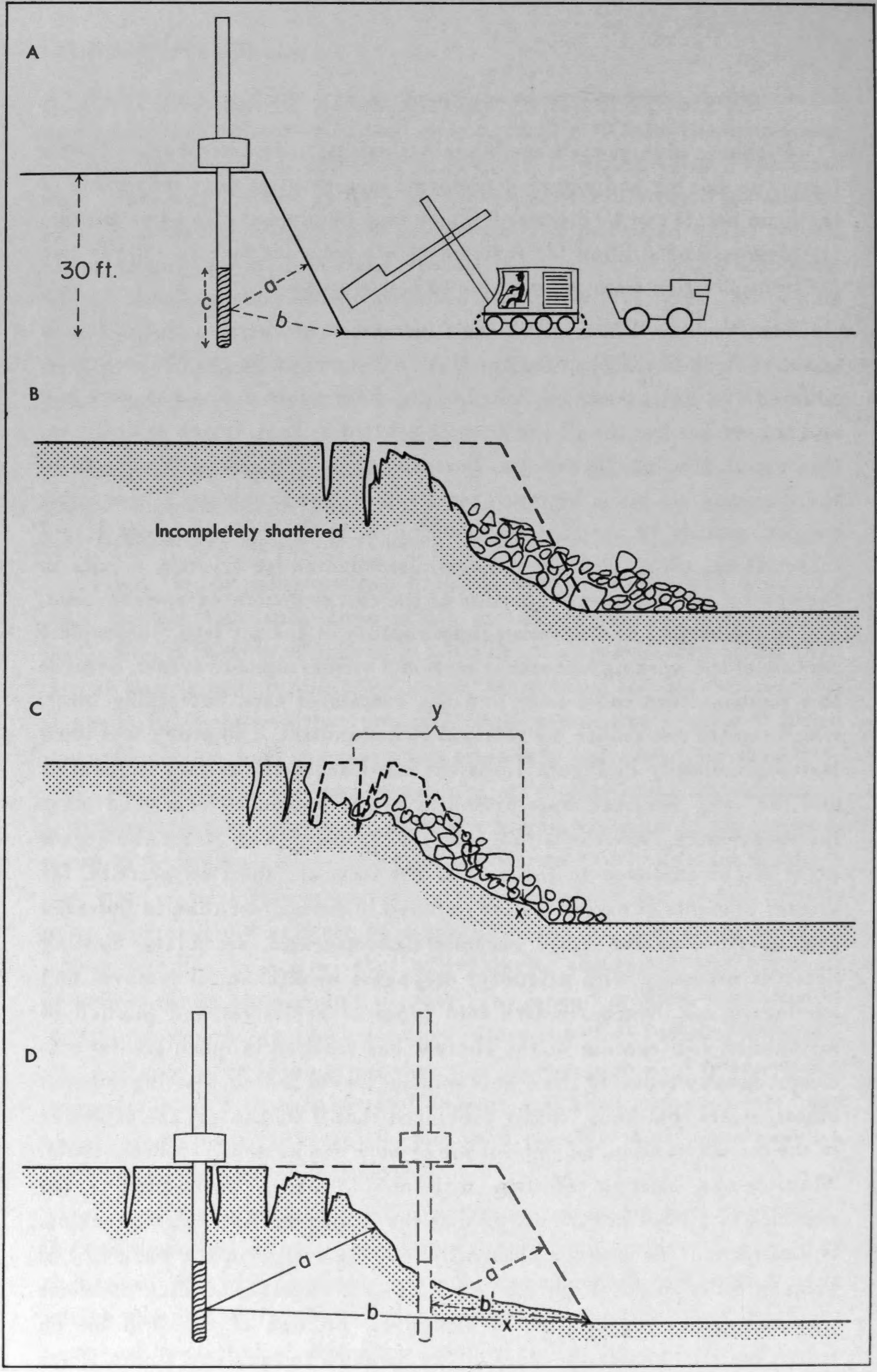
From this introduction two problems emerge which have a bearing upon the economic production of ore in central Labrador-Ungava. The first is that if the cost of mining in permafrost is considerably higher than that of mining in unfrozen areas, other things being equal, what becomes of the initial estimates that profitable exploitation was possible if based upon 400 million tons of proven and essentially unfrozen reserves? Obviously, the proportion of frozen to unfrozen ore (and technical improvements in mining) become significant. Should a large proportion of the reserves prove to be in permafrost, long-term production and production methods may need careful review unless technical advances can greatly reduce costs. There should at least be a pressing need for permafrost research with a technical objective—that of evaluating the extent and thickness of permafrost in an economic manner. The second problem is the *means* of improving production techniques to reduce the cost of mining in permafrost. It should be emphasized that this second problem has received a large amount of attention by the Company and great improvements have already been made, whereas the first, and possibly more basic problem has received only indirect attention.

It has been argued that, since certain orebodies are definitely frozen, the most logical approach is to disregard the academic problem of estimating the over-all area of permafrost occurrence and to concentrate on improving mining techniques. In view of this, an attempt is made to examine the nature of the technical difficulties involved.

OPEN-PIT MINING PROBLEMS IN PERMAFROST

Problems of large-scale mining in permafrost are numerous and closely related to mining and shipping problems in general so that only some of the main points can be discussed. These may be divided into three groups: (1) blasting and drilling (2) removal of ore from pit face to railway car (3) transportation from mining area to blast-furnace.

(1) *Blasting*—Blasting problems increase in proportion to the frozen water content of the ore concerned. An extreme case is the Wabash ores, situated 150 miles south of Schefferville; here water content is very low and the ore has less than 1 per cent ice content so that, frozen or unfrozen, the special Schefferville problem does not occur. Higher water content in the Ferriman ore body, however, results in serious problems. Where water content exceeds 10 per cent, ice segregation, in the form of lenses $\frac{1}{4}$ to 2 inches thick, pipes, and more widely disseminated ice crystals, results in the absorption of a large proportion of the energy generated by each blast, and in incomplete and unsatisfactory rupture of the pit face. Incomplete rupture of the working face sets in motion a vicious circle of events, because this renders much more uncertain the success of each succeeding blast, which in turn can reduce ore removal to a standstill. The problem is illustrated graphically in Figure 1. As the ideal angle of the face is reduced and the "toe" becomes more extended, so the possibility of a good blast becomes remote. Here the critical factor is the distance "b" from the centre point of the explosion to the base of the face, or "toe". In practice, far greater amounts of explosives are required in permafrost than in unfrozen ground. Also, as the "toe" becomes unmanageable, secondary blasting becomes necessary with attendant stoppages in mechanical removal and loading of ore. Much research into types of explosives and method of installation and spacing of the charges has resulted in much greater efficiency, greatly reducing the cost of mining. David Selleck, blasting research officer, states that he is "firmly convinced that if we can get the explosive in the correct location, an efficient job of work can be done" (Selleck, 1961). Multiple-row blasting, starting with an "idealized" face, permits the planning of a blast in such a way that the subsequent face, after mucking, is also ideal. This is accomplished by wasting energy in the back row of holes in order to cut down the "back break". However, drilling problems also complicate the locating of explosives. Friction of the drill bit on frozen material causes the sides of the borehole to melt and slump. Thus


A
30 ft.
a
c
b
B
Incompletely shattered
C
y
x
D
a
b
a
b
x

loss in depth and diameter ensues, rendering correct location of explosives problematical.

(2) *Removal of ore from the pit face*—This problem is intricately associated with the success or failure of the blasting process. A typical blast in frozen ore, as witnessed by the writer, results frequently in the production of large blocks, many of which cannot be handled by the electric shovels and Euclid carriers. The practice in this case has been to bulldoze large blocks to the centre of the pit and (*a*) to await natural thaw and break-down (*b*) to employ secondary blasting or (*c*), to attempt break-down of the blocks by mechanical percussion. If the supply of large blocks is heavy, the pit floor becomes congested, increasing the difficulty of fully effective deployment of large-scale machinery and accordingly reducing production. Another problem is that secondary blasting of the "toe", or only partially successful primary blasting, tends to result in an uneven pit floor. An extreme case is when the shovel cannot approach sufficiently close to reach ore from the upper part of the pit face.

More successful break-down following primary blasting, but still leaving frozen particles exceeding 1 to 2 feet in diameter, permits successful handling from pit to screening plant, but can result in increased wear and tear on the plant, jams, and further reduction of production and increase in cost.

(3) *Transportation to the blast furnace*—During the 360-mile railroad journey to Sept Iles on warm summer days there is a gradual thawing out of at least part of the frozen ore. This can accentuate the problem of "sticky ore" whereby fine-grain ores with a critical level of water content partially stick to the sides and bottom of the rail car during dumping at the Sept Iles terminal. Continued thawing presumably extends this problem to all transport operations until the blast furnace is reached.

Figure 1.

(A) Idealized mining face—(a) and (b) are critical distances between centre of the "charge" (c) and the mining face. (a) is termed the "burden", and (b) the "toe distance".

(B) Moderately successful blast on initial idealized face.

(C) Successive blast leaving extended "toe" at (x). Shattered ore in sector (y) difficult to remove because electric shovel unable to approach over (x).

(D) Actual mining face compared with idealized face showing situation which would result in serious production hold-up. Compare critical distances (a) and (b) with (a′) and (b′). Extensive secondary drilling and blasting of the extended toe (x) would be required here.

THE EXTENT OF PERMAFROST IN RELATION TO IRON ORE RESERVES

As indicated above, the proportion of frozen to unfrozen ore within the 400-million-ton-reserve is a most critical factor in long-term ore production in central Labrador-Ungava, yet so far this proportion is merely a subject for the imagination. Despite this, some comments are in order. Detailed ground temperature measurements and a coordinated research program in permafrost, involving vegetation, climate and meteorology and ground characteristics, were initiated in May 1959 by the writer in liaison with the Iron Ore Company of Canada and the Division of Building Research, N.R.C.

Ground temperature measurements were taken at numerous sites, both in depth and in area, beginning in September, 1959, and were continued until June, 1960. This period was extended to include a full year by the help of Charles McCloughan, senior observer of the McGill Laboratory, who maintained thermocouple readings during the summer of 1960 while the writer was in Scandinavia. A full report of the program has been published elsewhere and acknowledgments are included there. Much more work remains to be done on the data before a complete report of the research findings can be published. However, preliminary consideration of the data has a significant bearing upon the problem at hand.

1. Over wide areas the permafrost is compatible with the climate of recent decades, it exceeds 150 feet in thickness in many places and probably occurs in thicknesses of more than 300 feet.

2. There is a strong relationship between vegetation type, depth of snow cover and development of permafrost. In this sense the writer is tempted to suggest that all areas extending above the tree-line, and especially where the wind prohibits the accumulation of deep snow, are areas of potential permafrost. This is placed against a basic mean annual air temperature of 24° F. for Schefferville.

3. Below the tree-line relic patches of permafrost may be expected to occur across wide areas of central and south-central Labrador-Ungava.

4. The southern boundary of contemporary permafrost* (discontinuous) probably lies as far south as the Laurentide scarp and should

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* Contemporary permafrost is defined as that which is not distinctly relic but which has formed, or has been maintained under the existing climatic regime.

Figure 2. Permafrost distribution and iron-ore reserves in Labrador-Ungava.

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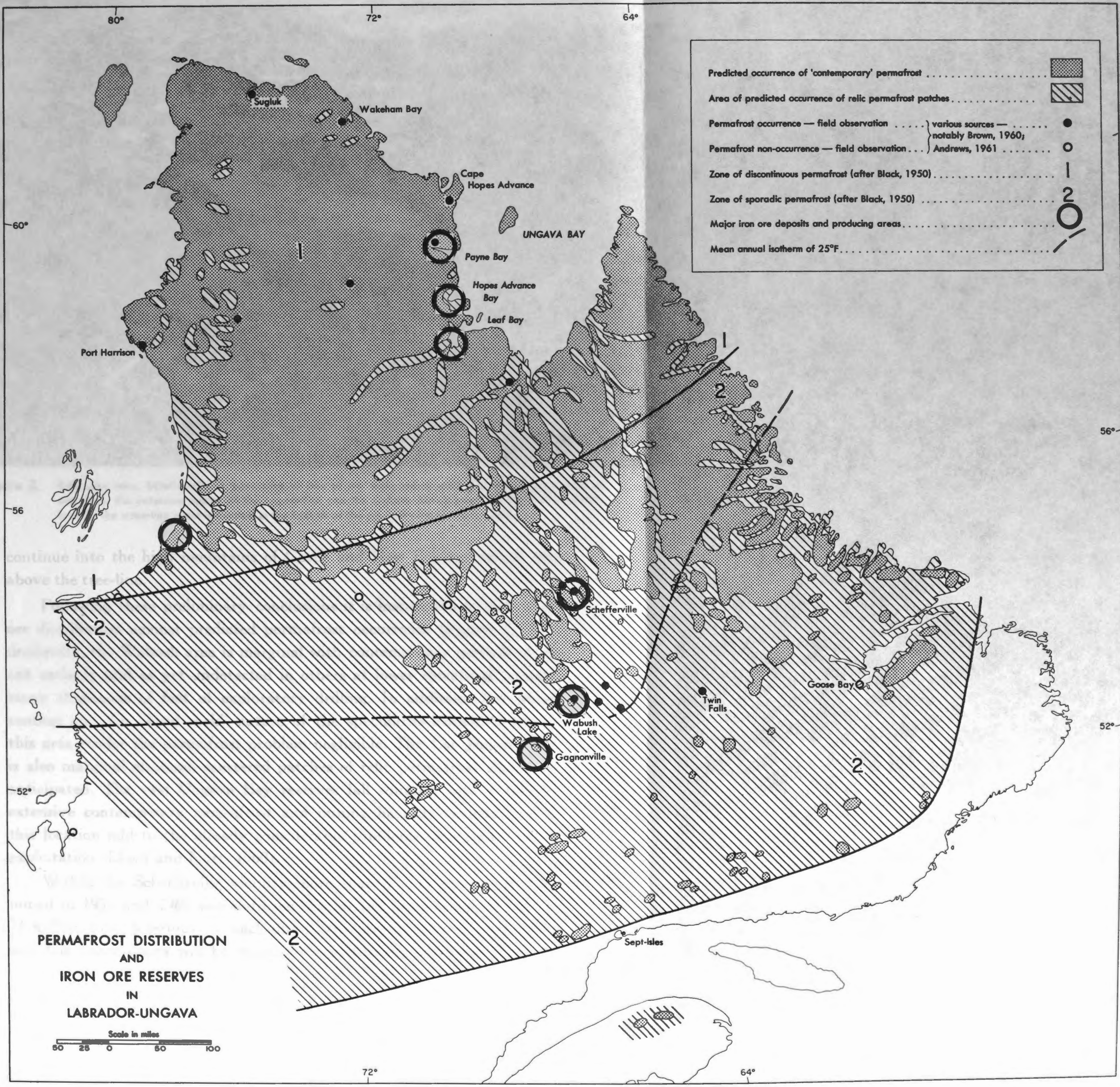

PERMAFROST DISTRIBUTION
AND
IRON ORE RESERVES
IN
LABRADOR-UNGAVA

Figure 3. Ruth Lake mine, Schefferville. A panorama of one of the main ore-producing mines cut into unfrozen ore. Note the extensive nature of the excavation and the orderly development of the burms (mining levels). The screening plant is located in the bottom of the pit (left centre). May, 1960.

continue into the high mountains of Gaspé and New England which rise above the tree-line.

Following these preliminary conclusions it is instructive to plot iron-ore distribution against predicted permafrost occurrence (Figure 2). Undoubtedly, the Wabush area is marginal with contemporary permafrost in one orebody and as yet undetected in others at lower elevations, despite many thousands of feet of exploratory drilling. In addition, low water content and the "hard rock" nature of the specularite-haematite ore in this area render the permafrost problem negligible. The Lac Jeanine area is also marginal although scattered patches of relic permafrost should be anticipated. The vast Ungava Bay reserves fall squarely into a zone of extensive contemporary permafrost and mining hazards associated with this location add to the already considerable problems facing any future exploitation (Lloyd and Nutt, 1960).

Within the Schefferville vicinity more than 85 per cent of the ore mined in 1959 and 1960 was unfrozen. Estimated production for 1961 is 7½ million tons, a serious cut-back due to the present economic situation, and this entire quota will be mined from non-frozen orebodies. Thus no

Figure 4. Ferriman mine, Schefferville, viewed from the high western ridge in the area of thermocouple installations. This orebody is predominantly in permafrost which in places exceeds 200 feet in thickness. Note the barren nature of the landscape. June, 1960.

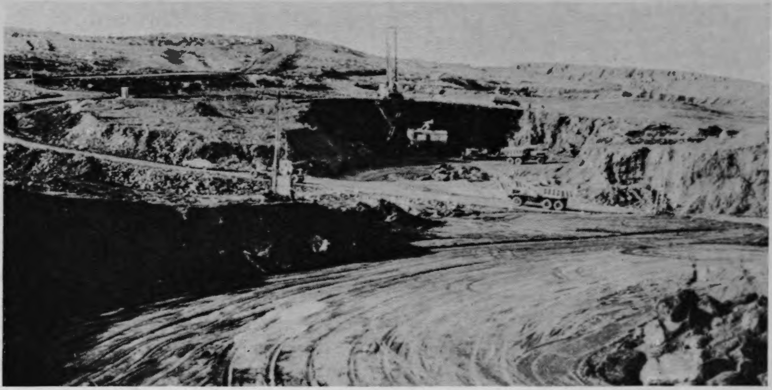

Figure 5. Detail of pit operations at Ferriman mine. Note the accumulations of large blocks of permafrost on the floors of the pits (centre and lower right), and the barren nature of the original land surface behind. September, 1957.

Figure 6. Detail of mining operations at Ferriman mine. Note the large boulders (permafrost) which are up to seven feet across. September, 1957.

Figure 7. Much of the energy of the blast in permafrost is absorbed by the ice segregations. Here a poor blast has resulted in incomplete rupture of the pit back wall. June, 1960.

Figure 8. Lenses of ice can be observed frequently in the new sections resulting from a recent blast. The hammer provides the scale. June, 1960.

permafrost mining is being undertaken during the current year. At this point it is relevant to refer to the problem of the assessment of the proportion of frozen ore to the total known reserves of this general area. Due to incomplete knowledge of permafrost conditions and the need for further research into the relationships between permafrost occurrence and surface factors, only a very subjective estimate of this proportion can be made. It is suggested, therefore, that a considerable amount of the Schefferville reserves, and especially those north of the existing mines, are in permafrost.

The several hundred million tons of unfrozen high-grade ore, plus the huge deposits in the Wabush Lake area that have to be beneficiated before shipment, leave the Iron Ore Company of Canada with a very long-term working reserve. With the passage of time, rising costs and further technical advances might well obliterate the problem. However, it can be maintained that permafrost distribution will prove one of the factors which will influence the pattern of mining development in this area, and the need for detailed permafrost research becomes increasingly apparent.

It is difficult to evaluate the full impact of permafrost occurrence on iron mining, and the purpose of this paper has been restricted to a discussion of some of the theoretical and technical problems. Undoubtedly these are important and it is perhaps correct for the geographer to consider permafrost occurrence as an economic factor in mining operations. It is also hoped that permafrost research in the peninsula, both for its own sake and because of the economic implications, will become one of the applied fields of geomorphology to which the geographer can adapt himself and produce, on the one hand, gratifying pure research results, and on the other, important contributions to the fuller utilization of Canadian resources.

ACKNOWLEDGMENTS

Grateful acknowledgment is made to H. E. Neal, head of the Ore Testing and Research Division, and David J. Selleck, head of the blasting research section, Iron Ore Company of Canada, for many valuable discussions on techniques and problems in mining frozen ore, and for critically reading through the first draft of the manuscript and providing additional data.

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Explanation of Figure 2

An attempt has been made to utilize the scanty direct field data, to combine it with the provisional results from a study of the relationships between ground temperatures and surface conditions, and to compile a map of predicted permafrost occurrence for the entire peninsula. Two categories of permafrost occurrence have been used: "contemporary permafrost" implies that the existing permanently frozen ground so mapped is compatible with the climatic regime of the present half-century; "relic permafrost", the second category, implies permanently frozen ground which is residual of past conditions differing from those of today. It is not implied that these differing conditions are climatic, but rather vegetational; the situation is the result of progressive invasion of the peninsula by aboreal vegetation subsequent to deglaciation some 7,000 to 9,000 years ago (see Ives 1961).

As the relic permafrost occurs in scattered patches throughout a wide area of southern and central Labrador-Ungava, and as, by its nature, it cannot be related to contemporary surface conditions, the only justification of the area shown under this category is that it embraces the remainder of the peninsula which was rapidly deglaciated. For convenience the southern boundary is also made to coincide with the southern limit of Black's zone of sporadic permafrost (Black, 1950).

Contemporary permafrost is predicted for those areas underlain by the lichen heath, tundra and rock desert categories of Hare's cover type classification (Hare, 1959) with minor modifications. The subordination of the importance of snow depth to permafrost occurrence by this method is an inherent weakness, but this is minimized by the scale and generalization of the map. Thicknesses of permafrost within this category vary from 300 feet plus to nil in the Schefferville vicinity. Here, as along the entire southern "edge", topography and thus microclimate, rather than general climate, is the prime control. In more northern areas greater thicknesses of permafrost are to be expected, and with lower mean annual air temperatures and wide tracts of wind-swept terrain, topographical irregularities will exert less influence on permafrost occurrence.

On this base of predicted permafrost occurrence the major localities of iron ore reserves have been superimposed.

COMPETITIVE AND MARKETING ASPECTS OF THE LABRADOR FLOATER CODFISHERY

W. A. Black

ABSTRACT: The development by Newfoundland of traditional markets for the Labrador heavy-salted codfish assured a steady market for this product at least prior to 1930. During the inter-war years, particularly during the 1930s, these markets underwent a major change which resulted from two important and interrelated factors; first, economic measures and controls were used to hasten the growth of national economic self-sufficiency, and secondly, the growth of powerful and sustained foreign competition. The combined result was that heavy-salted codfish became a residual product and an export casualty.

RÉSUMÉ: L'établissement par Terre-Neuve de marchés traditionnels pour la morue très salée du Labrador a, jusqu'en 1930, assuré à cette denrée un débouché très stable. Cependant au cours de la période entre les deux guerres mondiales, tout particulièrement au cours des années trente, ce marché a subi un revirement complet qui a été causé par deux facteurs étroitement liés: tout d'abord l'adoption de mesures économiques et un certain contrôle du gouvernement afin d'accélérer davantage la croissance économique du pays et subvenir à ses besoins; et, en second lieu, l'établissement d'une concurrence vive et soutenue de la part d'autres pays. L'exportation de cette denrée a donc subi une diminution considérable et elle joue de nos jours un rôle très peu important.

INTRODUCTION

The study, *The Labrador Floater Codfishery* (Black, 1960) showed that the floater ship fishery operated on an unprofitable basis and that, in terms of productivity, its yields were submarginal. The method of catching, curing and handling the catch, the crew organization and the financial procedure had altered but little in the course of the industry's history. The unstable domestic setting and the selective and restrictive nature of foreign markets imposed additional burdens on the industry, an aspect of the fishery that was briefly touched upon in the above study. A comparison of the Labrador floater fishery with the Icelandic fishery is presented to emphasize the importance of a nationally oriented policy towards the exploitation of a natural resource. This comparison is suitable as the Icelandic ship fishery was in its earliest stages of development when the floater fishery industry was approaching its zenith. Furthermore, the Icelandic example underscores the drive that is behind nationally oriented policies.

FOREIGN COMPETITION AND MARKETS

Foreign competition for control of the consuming markets was a major factor in the decline of the Labrador floater fishery. The markets for the heavy-salted, soft-cured codfish were expanding during the final quarter of the last century at a time when the floater fishery was developing rapidly. The principal or "traditional" markets that emerged for the Newfoundland product were in Spain, Portugal, Italy, and Greece; after World War I Puerto Rico became an important West Indian market.

Prior to World War I the markets for Labrador heavy-salted cure were not seriously affected by competition. However, after the war, European competition became serious, and in the inter-war period the marketing of Labrador heavy-salted fish was slow. The result was that surplus stocks often accumulated in the hands of the fish exporters, and thus it became increasingly necessary to carry the fish over to the following spring rather than to export it in the autumn after it was landed. The fish thus held over had to be disposed of before the onset of warm weather to prevent spoilage; however, the quality of the fish frequently deteriorated during the long period of storage. Entire cargoes were often spoiled by the time the ships arrived at foreign ports, either because too little salt had been used in curing or because the cure was carried out on the fishing grounds during wet and foggy weather when fungus or "dun" infested the cure.

Until the mid-1930s there was no inspection or control of fish shipments. The greater part of the production was packed in casks and wooden crates and shipped by steamer. It was general practice for the merchant-exporter to have the fish re-graded for export. As there were 5 principal markets, each preferring a particular quality of fish, the grades, by necessity, varied from the standard grades of the fisherman. Large shipments of low-grade fish produced a glut on the market followed by a decline in prices for Labrador cure.

The inter-war period also saw the rise of national European fisheries development policies, the principal goal of which was greater economic self-sufficiency. There were various forms of state subsidies, import quotas and duties, and exchange controls that had the effect of limiting the export of heavy-salted fish from Newfoundland. There was also a strong preference for the products of the Scandinavian countries that were now competing with Newfoundland, and a resistance to the lower quality Labrador product.

Following World War II the growth of restrictive controls further limited the traditional markets for the heavy-salted Labrador codfish (Prowse, 1896; Innis, 1940; Mackay, 1946; Gerhardsen, 1949).

Newfoundland's major European markets were associated with the sterling of the soft-currency area, whereas the Caribbean markets were based on hard currency. This situation accorded a primary advantage to Newfoundland's competitors who were members of the sterling group. Controls on the consuming market for heavy-salted fish varied from country to country and resulted in a major shift in market outlets from the 'traditional' markets.* The lop-sided nature of international exchange controls prevented a return to free-trading in codfish after World War II. The general low quality of the Labrador product together with non-convertibility of currency made the marketing of heavy-salted codfish exceedingly difficult.

Prior to World War I, Spain provided a large market for heavy-salted codfish. In the inter-war period there was a steady decrease in demand for heavy-salted Newfoundland fish and a marked increase for the Icelandic, French and Norwegian products. After 1934, exchange difficulties, the quota system, the Spanish Civil War and World War II created situations that drastically curtailed importation of Labrador cure. In the post-war period Spain emerged with a modern dragger fleet the development of which began in 1927; it supplied the main part of the Spanish market, with the balance imported from Iceland, Norway and Faroe Islands.

In the first decade of the present century, the major supplies of heavy-salted fish for the Italian markets came from Newfoundland. By 1934 Labrador cure represented less than 10 per cent of all imported fish, and Iceland had acquired almost complete control of this market. From 1934 to and including World War II, Italy imposed import quotas and exchange restrictions. Her nationally subsidized industry created an unstable market for the Labrador product. In the post-war period a marked preference for the Icelandic and Danish grades of heavy-salted fish reduced to small amounts the importation of Labrador fish.

The demand by Portugal for Labrador heavy-salted fish reached a maximum in 1920, but thereafter, because of severe competition from

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* For an account of the requirements of the foreign markets, see *Report for Fisheries Post-War Planning Committee*. The Newfoundland Fisheries Board, St. John's, February, 1946. See also, *Newfoundland Fisheries Development Committee Report*, St. John's, Newfoundland, 1953.

Norway and Iceland, exports to Portugal steadily declined,* and by 1939, exports were almost one-quarter of the 1920 figure. Excess production of Newfoundland's heavy-salted fish was normally shipped in bulk and unloaded in Portugal where it was readily absorbed. However, the Icelandic and Norwegian competition severely reduced the amount of fish that might be disposed of in this manner. In 1934 the development of a Portuguese economic self-sufficiency policy led to serious restrictions against the Labrador product. During World War II the heavy-salted fish production in Norway and Iceland ceased, and there resulted a rapid increase in Newfoundland exports to Portugal until 1942. After this date exports were considerably reduced because controls were again imposed under arrangements of the United Nations Combined Food Board. In the post-war period Portugal emerged with a powerful, heavily-subsidized Grand Banks fishing fleet, which supplied a large part of the domestic market with heavy-salted fish, the remainder being imported mainly from Iceland, Norway and Denmark.

Greece was formerly the principal market for Labrador fish, but this market declined in importance rapidly after 1930. The decline was brought about by sustained competition from Iceland and France, and also from increasing domestic production. The larger size and better appearance of the Icelandic and French product resulted in a decline in consumer preference for Labrador cure and the eventual elimination of the Newfoundland product. In the post-war period Greek domestic production was encouraged, but the major imports of heavy-salted fish came mainly from Iceland and from the Faroe Islands.

The importance of Puerto Rico as an outlet for heavy-salted Labrador-style cure began after 1924. From 1934 to 1936 exports to Puerto Rico were on a large scale. With the fall in fish exports to Spain, Portugal, Italy and Greece, a part of the large surplus of Labrador fish was diverted to the Puerto Rican market, the only major market available at the time. In the post-war period Newfoundland hard-dried, light-salted shore cures† have

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* Portuguese fishing vessels have operated on the Grand Banks for centuries. This competition became serious after 1927; subsidies and tariffs were imposed and corporate trading was introduced in 1934. A rapid development of the fishing fleet was undertaken in order to attain the objective of providing 60 per cent of Portugal's fish requirements from the national fleet.

† The Newfoundland hard-dried, light-salted shore cures when graded and in order of quality were as follows: choice, merchantable, Madeira, and West Indian. These grades were again subdivided according to size. The fish must be firm, of even texture, clean, well split, showing no salt and white when hard-dried.

largely replaced Labrador cure in Puerto Rico, because of their better keeping qualities and a change in consumer tastes.

The Labrador-style heavy-salted cure was in the lower price group of Newfoundland cod production, and its consumers were among the low-income groups of the consuming areas; because of the large volume produced, these markets were of special interest to Newfoundland .However, the success of foreign competitors in securing the heavy-salted fish markets resulted in a shift in the traditional markets for the Labrador product followed by a substantially reduced demand for it. There were no marketing agencies to assess the particular requirements of the foreign markets. The superior quality of the Icelandic product, with its attractive appearance and uniform grade, was sufficient to allow Iceland to capture the heavy-salted market without any reduction in prices. As the markets were lost or became limited and restrictive, the heavy-salted fish became a residual product resulting in low returns to the fisherman, and the floater fishery became a highly speculative business after 1925.

GROWTH OF THE ICELANDIC FISHERY

The decline of the Labrador floater fishery to its extinction in 1954 may be suitably compared with the growth of the Icelandic fishery, as each has formed the foundation of the economy of its respective country (Tryggvason, 1946; Christensen, 1946). At the beginning of the Icelandic drive toward modernization, the Labrador floater fishery was a well-organized although individualistic industry. The Icelandic drive resulted in their fisheries becoming one of the world's most efficient and highly competitive industries of its kind.

To meet the competition from the Newfoundland fisheries, Iceland introduced changes in her production, exporting and marketing organizations. Originally, the fishery depended on the efforts of individuals acting for themselves as did the Labrador fishery. In 1911, the Fisheries Association of Iceland was established by legislation, for the purpose of encouraging and advising on various aspects of the fisheries. Then in 1934, the Fish Industry Board was established to investigate markets, fishing and processing methods, and to indicate such measures deemed necessary to benefit the industry. Other organizations such as the Icelandic Freezing Plants Corporation, the Union of Icelandic Cooperative Societies and the Union of Icelandic Fishing Vessel Owners pressed for advancement of the fisheries on a broad front, to provide Iceland with increasing advantages to meet foreign competition. Conversely, the lack of planning and coordination among Labrador fishermen, merchants and government officials led finally to the extinction of this long-established fishery.

In 1876, the Icelandic fishing fleet consisted almost exclusively of rowboats equipped with hand-lines. It was an inshore fishery similar to the Labrador floater and was also carried on during the summer season. By 1905, the Icelandic fishery had become largely ship-based, with 170 motor and sailing vessels using long-lines. Modernization of the inshore fishery and the development of the offshore or deep-sea fishery expanded rapidly. As a result of stable fish prices, and a guaranteed market, Iceland entered the post-war period with a $30,000,000 program for the organization and reconstruction of her fishing industry. The fishery that was formerly carried on from rowboats was replaced by decked vessels utilizing the latest and most up-to-date equipment. Moreover, ship designs were flexible enough to meet new technological and marketing requirements, and to adjust to the seasonal nature of the fisheries.

There were notable changes in fish production. Iceland in 1885 exported under 100,000 quintals of wet-salted codfish, whereas the Newfoundland industry exported 1,300,000 quintals. By 1932, Iceland's codfish exports had reached 1,500,000 quintals compared with Newfoundland's decline to 1,050,000 quintals. The actual Labrador floater production at this time was 220,000 or about one-seventh of the Icelandic fishery although in the first decade of the twentieth century annual production must have exceeded a million quintals. When in 1952 the Labrador floater fishery produced 31,000 quintals, the Icelandic production of codfish was about 2.4 million quintals. In addition, striking changes were taking place in the processing of the products of the Icelandic fishery. Formerly codfish exported to foreign markets consisted of air-cured fish. In the nineteenth century the salting of fish was introduced, and before the close of the century air-cured fish was almost entirely replaced by wet- or heavy-salted codfish similar to the Labrador cure. With the introduction of the steam trawler, Iceland began to export iced fish, and about 1920, with the introduction of artificial drying, the production of dry-salted fish increased. About 1929 quick-frozen fresh filleting was introduced and expanded rapidly thereafter. Prior to 1936 Icelandic fish were mainly fully cured, half-cured, and wet-salted. During World War II almost the entire production consisted of fresh and frozen fish.

In 1952 the leading types of cod exports were iced fish 26.5 per cent, frozen fish 26 per cent and wet-salted fish 39 per cent. These percentages varied widely from year to year and depended mainly on the requirements of the consuming markets. In addition, the Icelandic fishery took a wide variety of fish, particularly haddock, ling, coalfish, herring and others, and processed a wide range of by-products such as fish meal, oil, canned fish and other products.

As the fisheries are the backbone of the Icelandic economy, the government, through the Ministry of Industry and Communications, now has complete supervision over all matters associated with the industry, particularly the means of production, the quality and standards of processing, exports, and marketing. The various organizations associated with the industry and the Icelandic government are thus fully aware of the need for continuing development and experimentation in order to meet the requirements of the consuming markets.

CONCLUSION

The Labrador floater fishery was not supported in modern times as an instrument of national policy as were its major competitors, and it depended on access to a free international fish market. As the industry did not possess the technology or the organization to meet sustained and subsidized national competition, any assessment of its continued operation is irrelevant. As already noted in *The Labrador Floater Codfishery*, (Black, 1960) the industry as it was organized and conducted was doomed.

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NOTES SUR LES MATÉRIAUX TERMINAUX DU GLACIER THOMPSON. CANADA ARCTIQUE*

Benoît Robitaille et Claude Greffard

L'île Axel Heiberg située immédiatement à l'ouest de l'île Ellesmere et après celle-ci, l'île la plus septentrionale du Canada, a une superficie d'environ 16,000 milles carrés (41,440 km carrés) dont un tiers est actuellement couvert de glaciers. On trouve en effet dans la zone montagneuse qui constitue la dorsale Nord-Sud de l'île, entre 3,000 (900 m) et 7,000 (2,100 m) pieds d'altitude**, deux importantes calottes locales. Des langues glaciaires s'écoulent depuis ces deux calottes jusque dans les zones bordières basses par la voie de vallées profondes. Malgré une tendance généralisée à la déglaciation actuellement observable dans l'île Axel Heiberg, il arrive que les pulsations climatiques qui accompagnent cette déglaciation se traduisent en certains cas par l'avancée sporadique des langues glaciaires les mieux alimentées. Ces phénomènes de progression donnent naissance à des formes particulières, comme la zone de matériaux terminaux du glacier "Thompson", dont nous désirons souligner l'originalité géomorphologique.

Le nom *Thompson* n'a pas encore été adopté officiellement par la Commission des noms géographiques du Canada. Cette désignation a été proposée par l'Expédition Jacobsen-Université McGill pour honorer la mémoire de Hugh Thompson, ancien professeur à l'Université McMaster et géomorphologue de la *Baffin Island Expedition, 1953*, décédé en 1958.

DESCRIPTION DE LA LANGUE ET DU FRONT DU GLACIER THOMPSON

Le glacier Thompson est situé dans le centre-Ouest et au coeur de la zone montagneuse de l'île Axel Heiberg (figure 1). Ce glacier s'individualise de la calotte Nord de l'île vers l'atitude de 2,300 pieds (700 m) et se termine à l'altitude de 300 pieds (90 m) après un parcours nord-sud d'une vingtaine

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* Les auteurs ont effectué des travaux sur place, en qualité de géomorphologues de la Direction de la géographie du Canada, dans le cadre de l'Expédition Jacobsen-Université McGill, au cours de l'été 1960. Le présent texte a fait l'objet d'une communication au XXVIIIième congrès de l'ACFAS, tenu à Québec en octobre 1960.

** Les altitudes données dans le texte sont approximatives. La plupart d'entre elles proviennent de lectures faites au moyen d'un altimètre simple, la marge d'erreur pouvant atteindre quelques mètres en certains cas. Les autres proviennent d'une carte préliminaire au 25,000ième préparée par la Section de la photogrammétrie du Conseil national de recherches du Canada.

Figure 1. La langue et le front du glacier Thompson. Noter la zone des matériaux terminaux, très bien délimitée. A gauche, un glacier actuellement en recul et auquel il manque la zone de matériaux terminaux qui caractérise le front du glacier Thompson. Photo Spartan Air Services Ltd. Échelle approximative: 1:60,000.

de milles par l'une des plus profondes et des plus larges vallées de cette région. La largeur moyenne du glacier est de 2 milles (3,2 km) mais, à la hauteur du front glaciaire, elle est de 1.5 milles (2,4 km). En cours de route, le glacier Thompson reçoit l'apport de plusieurs glaciers affluents. Il se termine, à l'aval, par un abrupt vertical d'une hauteur de 150 (45 m) à 260 (80 m) pieds au-dessus de la plaine pro-glaciaire sur le tiers Ouest du front glaciaire, et de 50 (15 m) à 100 (30 m) pieds sur les deux autres tiers. Ici le front glaciaire ne domine pas la plaine pro-glaciaire actuelle mais bien plutôt une zone de matériaux meubles qui eux-mêmes la dominent (figure 2). Notons ici que le glacier Thompson est du type *polaire*, c'est-à-dire que, dans la zone d'accumulation et dans la partie amont de la langue, les températures demeurent constamment négatives au sein de la glace à partir d'une profondeur de quelques pieds depuis la surface, ce qui empêche la pénétration de l'eau de fonte en profondeur rendant impossible la circulation d'eaux sous-glaciaires. L'évacuation de l'eau de fusion de la neige recouvrant la glace à la fin du printemps, de même que de l'eau résultant de l'ablation de la glace durant l'été s'effectue presque exclusivement en bordure de la langue. La plaine pro-glaciaire actuelle du glacier Thompson est donc construite par ces rivières latérales et la zone des matériaux meubles terminaux n'est guère influencée par elles, sauf à sa bordure orientale.

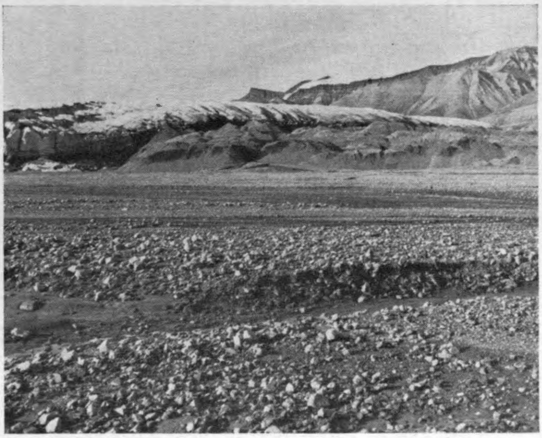

Figure 2.

Vue sur la zone des dépôts terminaux du glacier Thompson, à environ $\frac{3}{4}$ mille (1 km) de distance. La zone des matériaux terminaux se distingue très nettement de la plaine pro-glaciaire actuelle par un abrupt de hauteur variable.

MORPHOLOGIE DE LA ZONE DE MATÉRIAUX TERMINAUX

Les accidents topographiques

La zone de matériaux meubles localisée au front du glacier Thompson a une longueur maximum de 5,900 pieds (1,800 m), une longueur minimum de 2,000 pieds (620 m) et une longueur moyenne de 4,800 pieds (1460 m). Sa largeur maximum est de 2,300 pieds (700 m), sa largeur minimum de 200 pieds (60 m) et sa largeur moyenne de 1,600 pieds (490 m). La hauteur maximum de cette zone au-dessus de la plaine pro-glaciaire actuelle est de 250 pieds (75 m), sa hauteur minimum de 20 pieds (6 m) et sa hauteur moyenne de 80 pieds (25 m), les hauteurs décroissant depuis le front glaciaire jusqu'à la plaine pro-glaciaire. A l'intérieur de la zone des matériaux meubles, on note une topographie de crêtes généralement espacées de 200 (60 m) à 300 (90 m) pieds, et de creux étirés parallèlement au front du glacier, ayant de 30 (9 m) à 100 (30 m) pieds de profondeur et souvent occupés par des étangs (figure 3). A la bordure externe de la zone, on trouve un relief en arches d'escalier où les surfaces, séparées par des abrupts de quelques pieds de hauteur, sont inclinées en direction de la plaine pro-glaciaire. Le contact topographique entre celle-ci et les matériaux meubles terminaux est très nettement marqué par un abrupt. En outre, un réseau de fentes orthogonales de 5 (1,5 m) à 30 (9 m) pieds de profondeur caractérise toute l'étendue de la zone considérée, les fentes transversales élargies par les éboulis donnant souvent lieu à des percées qui recoupent les crêtes.

Le matériel

Contrairement à ce qu'on pourrait croire, les dépôts terminaux du glacier Thompson ne sont ni du till, ni de la moraine d'ablation, ni un mélange des deux. En effet, les grès, les schistes, les calcaires, les gypses et les

Figure 3. Dépression longitudinale à l'intérieur de la zone des matériaux terminaux du glacier Thompson. Le front glaciaire est vers la gauche. De l'observateur à l'étang, la dénivellation est d'environ 75 pieds (22 m). Noter l'inclinaison des surfaces à droite en direction de la plaine pro-glaciaire.

gabbro-diorites qui constituent le matériel des dépôts terminaux sont tous *lités* et présentent une ***stratification entrecroisée.*** Une série de vingt échantillons prélevés à divers niveaux ont livré des pourcentages moyens de 5 p. 100 de blocs, de 65 p. 100 de galets, de 10 p. 100 de granules, de 15 p. 100 de sables et de 5 p. 100 de limons ou d'argiles en lentilles. L'analyse morphométrique des galets a donné un indice d'émoussé moyen de 1,3 et un indice d'aplatissement moyen de 180. Environ 30 p. 100 des galets étaient subanguleux, 50 p. 100 arrondis et 20 p. 100 ovoïdes.

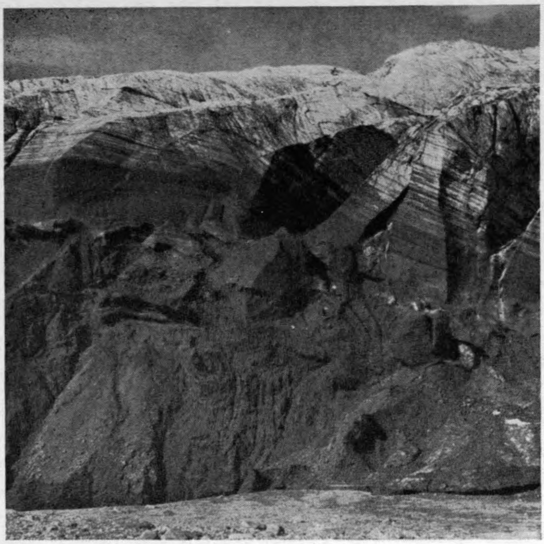

Figure 4.

Contact du front glaciaire du glacier Thompson et des matériaux terminaux, partie Est. Notez les déformations des lits qui ont été plissés et même renversés. Déformations également des bancs de glace qui chevauchent en partie les dépôts terminaux. Hauteur de l'abrupt sédiments terminaux-glacier: 200 pieds (60 m).

Si l'on ajoute à ces caractéristiques granulométriques et morphométriques le fait qu'on trouve, au sein même des sédiments terminaux, de nombreux culots de glace morte, le fait que les surfaces inclinées de la partie externe de la zone de dépôt sont caractérisées par un réseau de chenaux anastomosés encore très bien marqués, et le fait qu'il y a, sur la plaine proglaciaire actuelle, à un mille en aval de la zone de sédiments terminaux, des bosses allongées de 5 (1,5 m) à 10 (3 m) pieds de hauteur et constituées de matériel identique à celui que nous venons de décrire, nous avons là des indications suffisantes pour affirmer que les dépôts terminaux du glacier Thompson sont des ***sédiments fluvio-glaciaires.*** Ces sédiments représentent actuellement les lambeaux d'une ancienne plaine pro-glaciaire construite alors que le front du glacier Thompson était à l'amont de sa position actuelle,

Figure 5. Bloc basculé dans la partie centrale des sédiments terminaux du glacier Thompson, lequel est vers la droite. On distingue très bien le litage et la surface originelle maintenant inclinée en direction de la plaine pro-glaciaire. Absence complète de végétation.

plaine qui a été partiellement entaillée par la suite, soit à cause de l'abaissement du niveau de base consécutif à l'exhaussement glacio-isostatique, soit, et c'est ce qui paraît le plus probable, par suite des changements de position du front glaciaire d'une part, et des modifications dans le débit des rivières glaciaires d'autre part.

Ceci ayant été posé, il faut chercher ailleurs la cause de la hauteur anormale de ces dépôts fluvio-glaciaires au dessus de la plaine pro-glaciaire actuelle, ainsi que la cause de leur modelé très particulier.

Les déformations des lits

En y regardant de plus près, on découvre que les sédiments terminaux du glacier Thompson ont subi des *déformations* récentes dont on trouve les traces un peu partout dans la masse des dépôts. Dans la partie qui est en contact avec le front du glacier, les lits ont été ou bien plissés ou bien complètement renversés (figure 4). Tout à l'est, la glace chevauche même les dépôts stratifiés en leur impliquant des effets de compression remarquables. En dehors de la zone tangente au front glaciaire, les déformations sont essentiellement des cassures délimitant des blocs basculés dont la surface est tantôt inclinée en direction du front glaciaire, tantôt, dans la plupart des cas, en direction de la plaine pro-glaciaire actuelle (figure 5). Dans la partie externe, toutefois, les cassures sont disposées en échelon et les blocs, étagés et légèrement basculés, sont tous inclinés faiblement en direction de la plaine pro-glaciaire (figure 6). Ces accidents sont dus, de toute évidence, aux pressions tangentielles exercées par le glacier Thompson contre ses

Figure 6. Cassure dans les sédiments terminaux du glacier Thompson. Cette cassure recoupe un bloc légèrement basculé en direction de la plaine pro-glaciaire visible à l'arrière-plan. Partie externe de la zone des matériaux terminaux. L'ancien réseau de chenaux anastomosés reste bien marqué.

propres sédiments pro-glaciaires lors d'une recrue probablement très rapide*. Les matériaux terminaux du glacier Thompson nous apparaissent donc comme une véritable *moraine de poussée* mais une moraine de poussée *polaire*, dans laquelle la présence de culots de glace morte et de lentilles de glace de sol au sein des sédiments fluvio-glaciaires rend possible une glacitectonique surtout cassante. Cette morphologie, il est intéressant de le noter, confirme ce que des mesures glaciologiques ont déja révélé pour l'Extrême-Nord canadien à l'effet qu'ici, comme en certaines parties de l'Alaska et du Spitzberg, il existe des zones localisées de recrue glaciaire qui s'opposent au phénomène de décrue glaciaire généralisée qui prévaut actuellement dans l'hémisphère Nord.

RÉPARTITION DES MORAINES DE POUSSÉE POLAIRES DANS L'ARCTIQUE CANADIEN

Nous avons relevé, pour notre part, quinze exemples de moraines de poussée polaires dans l'île Axel Heiberg même et une douzaine d'exemples dans le Nord de l'île Ellesmere (figure 7)†. Quelques-uns ont été rapportés au Spitzberg, mais aucun n'a été signalé, à notre connaissance, ni dans le reste de l'Archipel arctique, ni au Groenland.

Il semble que la rareté au moins apparente de ce type de moraine de poussée et le fait qu'il ne se trouve que dans certaines régions soient reliés aux conditions particulières nécessaires à leur genèse. Ainsi, si on compare la moraine de poussée du glacier Thompson avec les autres moraines de poussée semblables que nous avons observées, on constate qu'elles sont toutes

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* Actuellement, tout le front du glacier Thompson ne se comporte pas de façon uniforme. Dans la partie Est, la glace chevauche les sédiments terminaux et semble en progression, quoiqu'en progression peu rapide. Dans la partie centrale, des matériaux morainiques posés sur les sédiments lités au contact avec le front glaciaire semblent indiquer un léger et récent recul. Dans la partie Ouest, le front glaciaire semble être actuellement en état d'équilibre. En tout état de cause, la fraîcheur des formes de la moraine de poussée implique une avancée récente de tout le front glaciaire.

† Ces moraines de poussée sont facilement repérables sur les photos aériennes. Nous donnons à la suite la localisation et, entre parenthèses, le numéro des photos aériennes consultées par nous à la Photothèque nationale de l'Air, à Ottawa, sur lesquelles apparaissent les exemples considérés:

Ile Axel Heiberg: près de Sherwood Head (A 16836–7), baie du Vendredi-Saint (A 16753–93), fiord des Glaciers (A 16864–54; A 16864–58), fiord Skaare (A 16860–134), fiord Strand (A 16755–114), fiord South (A 16864–36), baie de l'Iceberg (A 16754–105; A 16753–114), fiord Middle (A 16186–99), fiord Li (A 16754–26; A 16754–166; A 16186–95), fiord Bunde (A 16754–22).

Ile Ellesmere: baie Ayles (T409C–13), baie Yelverton (T 405C–214), baie Dobbin (T 495C–32), fiord Canon (T 492C–96), baie Philipps (T 407C–33); T 405C–16), fiord Tanguary (T 408C–65), fiord Hare (T 407C–57), baie Markham (T 491L–149).

localisées dans des vallées profondes de régions fortement plissées, et qu'elles sont toutes situées dans des zones de roches sédimentaires gélives, ce qui rend possible la mise en place sur les planchers de vallées et sur les glaciers eux-mêmes de fortes quantités de matériel de gélifraction. Ainsi, d'abondants matériaux meubles peuvent être pris en charge par les langues glaciaires en progression pour être déposés ensuite sous forme de nappes fluvio-glaciaires à la marge pro-glaciaire. On constate, en outre, que ces moraines de poussée se rencontrent toutes au front de glaciers polaires exclusivement. La préservation des matériaux poussés par le front glaciaire ne serait pas possible, en effet, si, comme dans le cas des glaciers islandais, par exemple, les résurgences d'eaux sous-glaciaires pouvaient se produire au bout des langues et causer ainsi le déblaiement rapide du matériel meuble localisé immédiatement devant le front glaciaire. On constate enfin que ces moraines de poussée sont toutes situées à l'intérieur du domaine périglaciaire actuel. Ceci rend compte du fait que des culots de glace morte et de la glace de sol puissent se trouver en si grande abondance au sein des sédiments.

Soulignons, en conclusion, que la moraine de poussée du glacier Thompson ainsi que les autres du même type sont des formes mixtes où la part de l'influence glaciaire et de l'influence périglaciaire apparaissent toutes deux comme essentielles et non dissociables. Si ces moraines semblent confinées actuellement aux régions des hautes latitudes, il n'est pas exclu qu'il s'en soit formé de semblables dans la zone actuellement tempérée à un moment ou l'autre des glaciations quaternaires. Mais il est peu plausible qu'on en puisse trouver trace aujourd'hui à cause de la vulnérabilité de ces formes à l'érosion.

REMERCIEMENT

Cette étude n'est qu'un préliminaire et en grande partie un compte rendu descriptif d'un type intéressant de moraines terminales qui semblent se limiter aux régions supérieures de l'Arctique. Le travail sur le terrain fut exécuté pour la Direction de la géographie, par nous, les auteurs de cet article, membres de l'expédition Jacobsen-McGill de 1960 à l'île Axel Heiberg. Nous tenons à remercier le Docteur Fritz Müller, chargé de l'expédition, ainsi que tous les autres membres pour leurs très bonnes idées apportées aux discussions sur le terrain. Il est à espérer qu'une interprétation complète de ces formes géographiques attendra les travaux des botanistes, géomorphologues et géologistes qui étaient membres de cette expédition.

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A NOTE ON PERMAFROST IN WESTERN SIBERIA, U.S.S.R.

Robert M. Bone

The phenomenon of permafrost has been more extensively studied in Soviet Russia than in any other country in the world. Over the years, Soviet scientists have gathered considerable data from excavations and borings. As a result, information on the distribution, depth, and thickness of permafrost is much more complete for Russia than for other countries (Brown, 1960).

A recent article on the permafrost of western Siberia provides an insight into Russian permafrost research (Zemtsov, 1960) which is based primarily upon data collected from geological borings in the northern part of the western Siberian lowland (Figure 1 and table).

On the basis of the information collected from these borings two permafrost profiles have been constructed (Figure 1). These profiles reveal the depth of permafrost, and, in the case of one profile, a remnant body of permafrost that is believed to be associated with the beginning of the last ice advance and/or the one preceding it.

Permafrost data obtained from borings in the western Siberian lowland
(in metres)

Place and time of boring	Elevation at top of boring	Depth of boring	Depth of overburden on permafrost	Depth to bottom of permafrost	Thickness of permafrost
Tazov: (May 5–July 5, 1955)	3	270	1–2	217	215
Samburg: (Summer 1954)	5	286	47	228	181
Yanov Stan: (Summer 1951)	20	196	88	*	108
Krasnosel'kup: (Oct. 26, 1954–Jan. 15, 1955)	20	307	108	290	182
Tol'ka: (Sept. 26, 1955 to Jan. 15, 1956)	30	260	140	*	120
Ermakov: (Sept. 1953)	43	245	185.5	*	59.5
Var-Egan (July-Aug. 1953)	57	315	228	*	87
Eutsk: (Summer 1953)	55	250	142	*	108

* Boring did not pass through permafrost body.

MS submitted December, 1960.

Zemtsov, after analyzing the profiles and boring data, recognized three permafrost zones in the northern part of the western Siberian lowland (Figure 2). The areal limits of these zones are based upon two factors, the depth of permafrost and the time of permafrost formation. The latter refers to two types of permafrost formation, relic and present-day. In the past, the relic formation occurred in a temperature regime characterized by colder mean annual temperatures than are experienced today. The present-day formation of permafrost has occurred or is occurring under the influence of current temperature conditions.

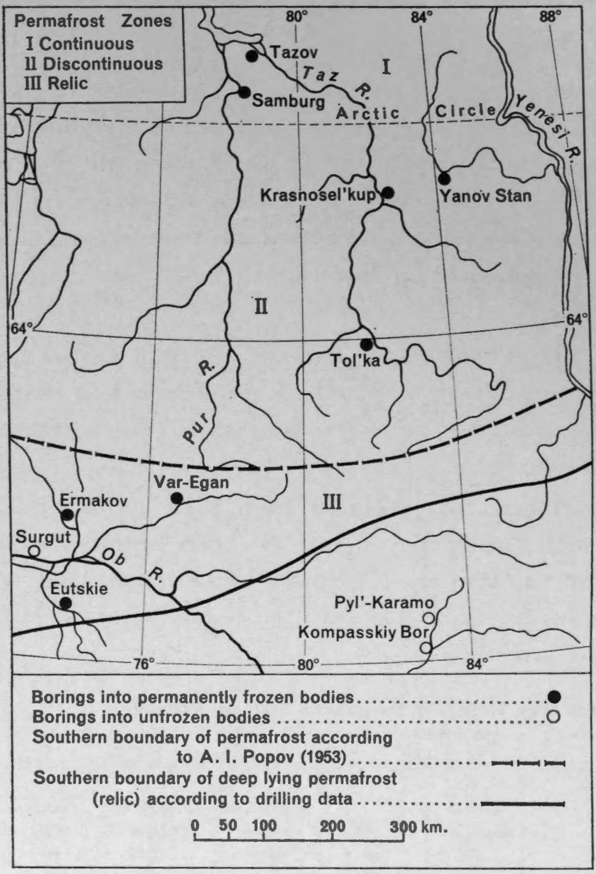

Figure 1.

The three permafrost zones of western Siberia.

The northern zone of permafrost—that of continuous permafrost—lies north of the Arctic circle and is characterized by a shallow active layer, with a maximum thickness of only a few metres, and then by an extensive body of frozen ground often exceeding 300 metres.

The middle zone—that of discontinuous permafrost—is found between the Arctic Circle and the 62nd parallel and is characterized by two distinct bodies of frozen ground. The lower body, lying at a depth of 60 to 100 metres, was formed at the beginning of the last ice advance or in the previous ice advance. Although the exact thickness of the whole of this frozen body is not known, at Krasnosel'kup it is 182 metres thick and extends to a depth of 290 metres (Figure 2).

The upper body of permafrost of the middle zone was formed in the recent past. According to the profiles, it is found within the upper 40 metres of the earth's surface.

The southern zone—that of relic permafrost—lies south of the 62nd parallel and extends to 60°30'N. Generally in this zone, permafrost begins at a depth between 30 and 60 metres beneath the surface of the earth. Its thickness and extent is diminishing owing to the present temperature regime, which has warmer mean annual temperatures than the former regime under which the relic permafrost was formed.

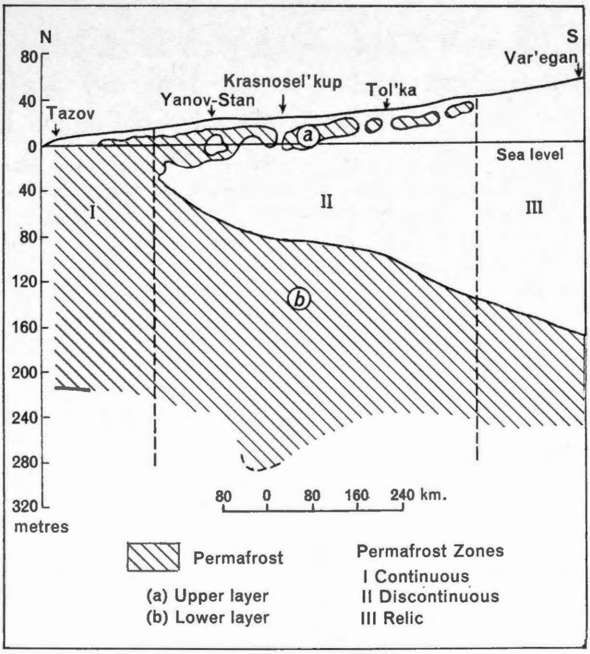

Figure 2.

Profile of permafrost in western Siberia.

From such investigations the Russians expect to learn more about the present state of permafrost as well as about the paleogeography of the time of the last ice age.

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BOOK NOTES—FICHES BIBLIOGRAPHIQUES

ROYAL COMMISSION ON TRANSPORTATION, Vol. I, *Queen's Printer*, Ottawa, 1961. 93 p., app.

This is the first of a 3-volume report of the Royal Commission appointed to inquire into problems pertinent to railway transportation in Canada. The volume deals with the problem as a whole, as the Commission believes that general understanding will lead to adequate treatment of specific problems on which the remaining volumes will concentrate.

Since the end of World War II, a new competitive environment has replaced the monopolistic position the railways enjoyed for almost a century. The development of different modes of transport—trucking, aviation, motor bus, pipelines—has resulted in greater capacity and efficiency of operation, and has been of benefit to the country; however, the railways have been adversely affected. They failed to adjust quickly to a competitive environment because of organization, plant, and services suited to another age. Also, their present rate structure, intended to preserve railway revenues, is leading to self-destruction. The Commission invites adjustments in public policy, and recommends federal financial assistance during the transition period in order to enable railways to find their proper place within a competitive system.

(I.J.)

CANADIAN LAND-USE MAPPING. By N. L. Nicholson, I.H.B. Cornwall and C. W. Raymond, Geog. Br., *Dept. Mines & Tech. Surv.*, Ottawa, Paper 31, 1961, 40 p., maps, illus. Price 75 cents.

A description of the background and purpose of the Canadian land-use mapping program is presented in this paper. The introduction treats the need for land-use mapping and the growth of the awareness of this need in Canada. It is followed by a short section giving the scales of the land-use maps and the reasons for their choice. The body of the paper deals with the legends used in the series, especially regarding the problem of adopting the World Land Use Classification to Canadian conditions. Eight photographs illustrate two land-use categories (open and scrub grassland) that necessitated modification of the World Classification. Three land-use maps are used as examples in the discussion of the legends. The latter part of the paper outlines the methods, time and cartographical procedures involved in the map production. The World Land Use Classification and the published papers on land use written by the staff of the Geographical Branch are contained in two appendices.

(J.H.L.)

WHITE AND RED PINE, ECOLOGY, SYLVICULTURE AND MANAGEMENT. By K. W. Horton and G. H. D. BEDELL, *Dept. Northern Aff. & National Res.*, Forestry Br., Bull. 124, Ottawa, 1960, 185 p.

This monograph provides a summary of fundamental and applied knowledge for further research, and for practical pine forestry. Both white and red pine, and the two species together as a forest type, are the subjects of the study. This review concerns the whole pine range, with emphasis on pine in Canada, and especially in the Great Lakes—St. Lawrence region.

(I.J.)

THE BLUEBERRY IN THE ATLANTIC PROVINCES. *Dept. Agric.*, Res. Br. Pub. 754, Ottawa, April, 1961. 35 p., illus.

This report deals with the mechanics of the culture and propagation of lowbush and highbush blueberries in the Maritime Provinces, and with insect and disease control. The number of "managed" blueberry fields is increasing so steadily in the Atlantic Provinces and Quebec that, among fruit crops, the revenue from blueberries is second only to that from apples.

(P.B.C.)

GEOMORPHOLOGICAL STUDIES IN NORTHEASTERN LABRADOR-UNGAVA. By J. T. Andrews and E. M. Matthew. Geog. Br., *Dept. Mines & Tech. Surv.*, Ottawa. Geographical Paper No. 29, 29 p., maps, illus. Price 50 cents.

The first part of this study is a preliminary discussion of the glacial geomorphology of the northern part of the Nain-Okak section of Labrador-Ungava. The account of the glaciation and deglaciation of the area includes a description of a system of high lateral moraines and kame terraces and mention is made of the later retreat stages of the glaciation, and there is a brief section on the evidence for local corrie glaciation.

The second part of the study is a preliminary account of the complex glaciation and deglaciation of the George River basin of Labrador-Ungava. There is brief mention of the presence and significance of ice-dammed lakes in the field area and suggestions for the future course of field work.

(V.W.S.)

SURFICIAL GEOLOGY OF THE BÉCANCOUR MAP-AREA, QUEBEC. By N. R. Gadd. *Geol. Surv. Canada*, Paper 59-8, 1960. 31 p., maps. Price 50 cents.

The writer presents a preglacial and glacial chronology in the Bécancour area. Initial glaciation in the area is now thought to be pre-Wisconsin rather than Cary, and it is considered that the postglacial St. Pierre Interval was represented by a freshwater fluvial environment. The advance of the Wisconsin glacier blocked the St. Lawrence River somewhere below Donnaconna and impounded an elongate glacial lake, Lake Deschaillons. The Wisconsin ice sheet overode the varved sediments of Lake Deschaillons, and advanced an unknown distance southward. The ice front later retreated to the vicinity of the present St. Lawrence River, and, although there is some evidence of a short period of normal glacio-fluvial and glacio-lacustrine deposition, much of the area was almost immediately inundated by the Champlain Sea. All evidences suggest "a single marine episode, that ended as a result of differential uplift of the land". Doubt is thus cast upon the validity of Antev's proposal of a second marine invasion, the "Ottawa Sea". There are detailed lithologic descriptions of the unconsolidated deposits of the area, and extensive use is made of new radiocarbon data.

(P.B.C.)

NEW GLASGOW ST.-LIN AREA. By F. F. Osborne and T. H. Clark. RAWDON AREA. By R. Béland. CHERTSEY AREA. By P. E. Côté. DONCASTER AREA. By M. A. Klugman. Geological Reports 91-94 incl., *Quebec Dept. Mines*, Geol. Surv. Br., Quebec City, 1960. Maps at 1:63,360, illus.

These four reports cover an area of about 840 square miles on the St. Lawrence Lowlands and the Canadian Shield immediately northeast of Montreal. Prior to publication of the maps accompanying these reports at 1:63,360, the most recent geological maps for this area were those prepared by F. D. Adams of the Geological Survey of Canada, in 1895–96, at a scale of 1:253,440. The Doncaster Area report also includes the results of a magnetometer survey.

(P.B.C.)

SURFICIAL GEOLOGY OF THE OTTAWA AREA. By N. R. Gadd. *Geol. Surv. Canada,* Paper 61–19, 1961. 13 p., diagrams, Price 25 cents.

Preliminary field study fails to reveal any valid evidence of more than one postglacial marine invasion in the Ottawa area. The writer thus repudiates Antev's "Ottawa Sea" theory, arguing that field studies in the adjacent St. Lawrence areas support this stand.

(P.B.C.)

BURIED VALLEYS IN CENTRAL AND SOUTHERN ALBERTA. By A. MacS. Stalker. *Geol. Surv. Canada,* Paper 60–32, 1961. 13 p., map. Price 50 cents.

The writer has plotted the preglacial and interglacial or postglacial valleys of central and southern Alberta on a 1:267,000 map. Preglacial drainage in the area was very similar to the present system. Initial Pleistocene glaciation (Nebraskan?) disrupted this drainage, forcing many rivers on the plains to more southerly courses. In the foothills, diversion was essentially to the north. In postglacial time there has been considerable reversion of drainage to preglacial channels, and, as a result, the modern drainage system consists of segments of preglacial valleys connected by segments of completely new valleys.

From an economic aspect, the preglacial valleys are potential sources of ground water, and also contain good quality gravel.

(P.B.C.)

THE KAMLOOPS REGION—AN ECONOMIC SURVEY. *B.C. Dept. Industrial Development Trade & Commerce,* Bur. of Economics and Statistics, Victoria, B.C., May 1961. 68 p., maps, photos, tables.

This is the third in a series of reports that discusses the economic base of small regions in British Columbia. The "major economic opportunities" of a region are defined and examined; in the case of the Kamloops region, 'opportunities' include transportation, retail and wholesale trade, electric power, recreation, agriculture, oil and natural gas development, mining, forestry, and manufacturing. This study is, however, not strictly an inventory. Recommendations are made for the development of inaccessible areas to increase tourism, to provide additional irrigation, to encourage horticulture, and to employ more intensive utilization practices in forestry. As a result of the rapid economic development of the region, it is shown that the immediate Kamloops district holds promise for the expansion and diversification of secondary industry.

(P.B.C.)

TRANSPORTATION OF MINERALS IN NORTHERN CANADA. By Amil Dubnie. *Dept. Mines & Tech. Surv.,* Min. Res. Div., Min. Info. Bull. MR 50, Ottawa, 1961. 16 p., map. Price 50 cents.

The writer examines the cost of transport of minerals per ton-mile by water, rail, road, air, and pipeline in Canada north of latitude 55°. Although coastal shipping has certain advantages, rail transportation will play an important part in the inland transport system of the Canadian north, supplemented by other forms of transportation. Road construction costs will probably be less than railway construction costs, but ton-mile operating costs on roads will normally be higher than on rails. Air transport is economical for high-value concentrates such as gold, uranium, but for the present, extensive pipeline construction will not be undertaken in the north.

(P.B.C.)

AGE DETERMINATIONS BY THE GEOLOGICAL SURVEY OF CANADA. Report 2, Isotopic Ages. Compiled by J. A. Lowdon. *Geol. Surv. Canada*, Paper 61–17, 127 p., maps, tables, 1961.

This report forms the second annual compilation of potassium-argon age determinations carried out by the Geological Survey of Canada. Part I of the report, in addition to the K-Ar age for 152 samples, gives the numerical values required for the age calculation, the mineral and rock type of the sample, and the precise geographical coordinates of the sample location. A brief comment on the apparent geological significance of the results is also included. In Part II, separate reports dealing with specific problems are presented. Among these is a report on the age determinations made on Cordilleran rocks, and a report on the structural provinces, orogenies and time classification of rocks of the Canadian Shield.

(V.W.S.)

BATHURST INLET, NORTHWEST TERRITORIES. By J. B. Bird and M. B. Bird. Geo. Br., *Dept. Mines & Tech. Surv.*, Ottawa, Mem. 7, 1961, 66 p., maps, illus. Price $2.00.

An account of the physical and human geography of the region around Bathurst Inlet in the Western Canadian Arctic is presented. Following an account of the geology and preglacial evolution of the landscape, the writers discuss the glaciation and deglaciation of the area, and the subsequent postglacial emergence of the land. The physical section of the study concludes with brief descriptions of the physiographic regions. A final chapter covers the past and present distribution of the Eskimo population and discusses the history of European activity in the area.

(V.W.S.)

THE HISTORY AND GEOLOGY OF MEIGHEN ISLAND, ARCTIC ARCHIPELAGO. R. Thorsteinsson. *Geol. Surv. Canada*, Bull. 75, 1961, 19 p. maps, illus., Price 75 cents.

This bulletin is based on a visit to Meighen Island between May 30th and June 3rd, 1957. A lengthy section on the history of exploration describes the discovery of the island by Stefansson in 1916, the possibility of an earlier discovery by Cook in 1908, and the fate of the German explorer H. K. E. Krueger in 1930. This is followed by sections on the geology, the physical features and glaciation, and plants and animals observed.

(K.C.A.)

JACOBSEN-MCGILL ARCTIC RESEARCH EXPEDITION TO AXEL HEIBERG ISLAND, QUEEN ELIZABETH ISLANDS. Prelim. Rept. 1959–1960, McGill University, Montreal, June, 1961, 219 p., tbls., illus.

Following an introduction which describes the objectives and logistics of the 1959 and 1960 expeditions are papers by the participants on the scientific results. These include papers on glaciology, geophysics, meteorology, geology, geomorphology, botany, permafrost, map survey and mountaineering. The report is illustrated by 62 photos, by diagrams and maps.

(J.K.F.)

METEOROLOGICAL OBSERVATIONS IN NORTHERN ELLESMERE ISLAND—1959. J. R. Lotz. *Arctic Inst. N. Am.*, Res. Paper no. 7. Scientific Rept. no. 11, prepared for Geophysics Research Directorate, USAF, Bedford, Mass, 1961. 74 p. tbls.

This report contains meteorological observations taken near Ward Hunt Island from June 1st to September 8th, 1959. An introduction describes the instruments and techniques used. The tables include data from Eureka and Alert weather stations for purposes of comparison. Data on ablation and accumulation are also given.

(K.C.A.)

AN ARCHAEOLOGICAL ANALYSIS OF EASTERN GRANT LAND, ELLESMERE ISLAND, NORTHWEST TERRITORIES. Moreau S. Maxwell. *Dept. Northern Aff. & National Res.*, 1960. Bull. no. 170, Anthropo. ser. no. 49. Price $1.50.

This research, in the summer of 1958, was a contribution to Operation Hazen of the Defence Research Board. Thirty-five sites were investigated and revealed seasonal migrations of small groups beginning 1,000 years ago. While in the area, these people hunted mainly land animals. Five hundred years ago, these migrations stopped, and the region was subsequently forgotten, even in Eskimo legend. It was not visited again by Eskimos until the time of Peary's expeditions. Contrary to earlier theories, it now appears doubtful that early Eskimo migrations passed through the Hazen valley.

(K.C.A.)

A GENERAL INTRODUCTION TO THE CITY OF WHITEHORSE, YUKON TERRITORY. By J. R. Lotz, *Dept. Northern Aff. & National Res.*, Industrial Div., Ottawa; May, 1961; 27 p., maps, biblio.

This publication integrates general information on the physical features of the area, the history of settlement, and recent and present living conditions to give an account of the present-day city of Whitehorse. Climate, vegation, soils and permafrost are discussed, and details of flow and navigation on the Yukon River are given. Industry and employment, community services, and community organizations are described at length in the second half of the publication. Two maps show the location of Whitehorse, and its specific site.

(P.L.H.)

MAP NOTES—FICHES CARTOGRAPHIQUES

CANADIAN LAND-USE SERIES. Various scales. Geog. Br., *Dept. Mines & Tech. Surv.*, Ottawa, 1961.

Four maps in the series, keyed to the maps of the National Topographic Series, have now been published: Dunnville East sheet, in southern Ontario, at 1:50,000; and the Truro, Halifax and Shelburne sheets in Nova Scotia at 1:250,000. The scales of the maps were chosen according to the complexity of land use and population densities in the areas covered. Land-use categories and colors follow closely the classification established by the World Land Use Commission. The boundaries of national and provincial parks, and principal Indian Reserves are shown to assist in the interpretation of the information presented. Although most of the information necessary for the compilation of the maps was obtained by field mapping, airphotos and/or forest inventory maps have been used as supplemental sources. The sheets may be obtained from the Geographical Branch at 25 cents per sheet.

Dunnville East Sheet

The Dunnville East sheet (30 L/13 E) is the first published large-scale (1:50,000) land-use map of southern Ontario. Complexity of land use and a relatively high population density in the area required the use of the present scale. Twenty land-use types are shown—5 urban (industrial, commercial, residential, recreational and associated urban), 7 agricultural (hay, grain, tobacco, horticulture, vineyards, tree and small fruits, and improved pasture), 2 grassland (open and scrub), 4 woodland (dense, open, scrub and cut or burnt over), unproductive land and swamps and marshes. Field mapping and provincial forest inventory maps provided the data necessary for the compilation of the sheet.

Truro, Halifax and Shelburne sheets

The Truro, (11 E), Halifax (11 D), and Shelburne, (20 O.P) sheets, at 1:250,000, are the first of the land-use series maps to be published of Nova Scotia. The scale used for these areas of relatively sparse settlement makes only limited generalization necessary. Land use is shown by 16 categories,—3 urban (industrial and commercial combined, residential, and associated urban), 6 agricultural (hay, grain, orchards, horticulture, improved pasture and blueberries), open and scrub grassland combined, 4 woodland (dense, open, scrub and cut or burnt over), and swamps and marshes and unproductive land. The data necessary for the compilation of these sheets was obtained from field mapping, airphoto interpretation, and provincial forest inventory maps.

(J.H.L.)

MANPOWER AND EMPLOYMENT, 3 maps at 1:8,500,000 in *Proceedings of the Special Committee of the Senate on Manpower and Employment*, No. 7, February, 1961. Compiled by Prof. S. Judek, Univ. Ottawa; drawn by Geog. Br., Dept. Mines and Tech. Surv., Ottawa, 1960.

Map 1. Canada, average monthly registrations, 1953–1959, labor market areas.

The purpose of this choropleth map is to illustrate the statistical data relating to unemployment in the study, "Canada's Persistant Unemployment Problem—Labor Surplus Areas". The criterion used for this map is the average monthly registrations of unemployed as a percentage of total paid workers during the 7-year period 1953–1959 for each of the 109 labor market areas of Canada. A table, inset, ranks the labor markets in descending order within a market area group. The latter, determined by the Department of Labour, includes metropolitan, major industrial, major and minor agricultural areas.

Map 2. Canada, average monthly registrations during winter, 1953–54—1958–59, labor market areas.

This choropleth map illustrates the average monthly registrations of unemployed for each labor market area during the winter months of the period 1953–54—1958–59. The data used for this map are the average monthly registrations as a percentage of total paid workers during the winter months for each of the labor market areas. As in the previous map, a table, inset, ranks the labor markets in descending order within its market area group.

Map. 3. Canada, labor surplus, problem and normal, 1953–59, labor market areas.

The labor market areas in this choropleth map have been classified as depressed problem and normal areas. The criterion for this classification is the average monthly registrations as a percentage of paid workers during the summer months, May to October, for the period 1953 to 1959. As in the previous maps, the table, inset, ranks the labor market areas in descending order within its market area group.

(N.J.S.)

RESSOURCES HYDRAULIQUES—PROVINCE DE QUÉBEC. 1:2,661, 120. *Québec, Ministère de l'Industrie et du Commerce,* 1960.

Cette carte montre la répartition et l'importance relative des centres d'énergie hydro-électrique aménagés et disponibles dans la Province, au sud du 53^{e} parallèle.

Le rang du Québec comme premier producteur d'énergie hydro-électrique au monde *per capita* est bien illustré par ce document.

(V.G.R.)

INDUSTRIES DES PÂTES ET PAPIERS—PROVINCE DE QUÉBEC, 1:1,774,080. *Québec, Ministère de l'Industrie et du Commerce,* 1960.

Cette carte montre la répartition, à travers la Province, des usines de fabrication de pâtes et papiers. Ces usines sont groupées suivant le genre de produit: papier-journal, papiers fins, papiers spéciaux, pâtes, papiers d'emballage, cartons; et suivant leur importance relative exprimée en nombre d'employés: 50–199, 200–499, 500 et plus.

Cette carte met en évidence la concentration de l'industrie des pâtes et papiers dans les régions tributaires du cours moyen du Saint-Laurent.

(V.G.R.)

EXSHAW-GOLDEN AREA (2 sheets)—PHOTOGEOLOGICAL INTERPRETATION AND COMPILATION. 1:126,720. *Hunting Survey Corporation Ltd.*, Calgary, 1960.

These two map sheets show geology, compiled entirely from airphotos, of the Kicking Horse and Bow River valleys from Golden, British Columbia, to Exshaw, Alberta. Three geological sections across the valleys are included. The maps are in 4 colors, with variegated shadings and stipples.

(P.B.C.)

POPULATION BY ENUMERATION AREAS. Various scales. *B.C. Dept. Mines & Petroleum Res.*, Market Res. Br., Bur. Econ. and Stat., Victoria, B.C.

These maps, compiled from Census of Canada data, appear as ozalid photostat copies from compilation sheets based on topographical maps. The planimetric details are restricted to the presentation of railways, highways and roads, as well as lakes and water courses. The population census data of 1951 and 1956 are plotted in absolute numbers. The real value of these maps for the research worker lies, however, in the fact that the maps show boundaries of enumeration areas by census divisions. As such, they supply a base on which a more detailed population distribution can be plotted on a comparatively large scale. The following preliminary maps have been issued, covering the whole province: 1 at 1 inch to 4 miles; 6 at 1 inch to 8 miles; 2 at 1 inch to 16 miles; and 1 at an unidentified scale.

(R.T.G.)

ENERGY SOURCES OF BRITISH COLUMBIA, 1960, AND PRINCIPAL HIGHWAY, RESOURCE DEVELOPMENT ROAD AND RAILWAY REQUIREMENTS—1960–1975. (verso). 1:3,484,000. *B.C. Dept. Mines & Petroleum Res.*, and Dept. Lands and Forests, Victoria, B.C. 1960.

This map shows the principal petroleum, natural gas, coal and hydroelectric resources of British Columbia, and includes oil and gas pipelines. The province's undeveloped power sites have been re-evaluated, most noticeably in the Liard and Peace river areas of northeastern British Columbia.

On the reverse side, the existing pattern of transportation in the province (highways, railways, ferry routes, and resource development roads) has been plotted. Highways are classified as either "presently adequate," "needing reconstruction or paving," "under construction", or "proposed". Most of the "proposed" highway development will take place in the northwest sector of the province, with road outlets to the Pacific along the Taku, Stikine, and Iskut rivers. The proposed Yukon-Alaska railway will run from Prince George to the Teslin Lake area of northern British Columbia.

(P.B.C.)

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