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METHOD OF DEGLACIATION, AGE OF SUBMERGENCE, AND RATE OF UPLIFT WEST AND EAST OF HUDSON BAY, CANADA **

Abstract

Directions of ice movement during the maximum stage of Wisconsin (last) glaciation are deduced only from the transport of erratics, from the positions of the outer terminal moraines, and from the area of greatest isostatic readjustment.

The successive positions of the ice margins during deglaciation are made clear with the help of De Geer moraines below the marine limit and by another type of minor moraine in the supra-aquatic area.

The continental ice-sheet split into 2 parts at the time Hudson Bay Basin became free of the last ice--sheet. The final positions of the ice margins west of Hudson Bay are made clear by minor moraines, ice--dammed lakes, glaciofluvial channels, and shifts in directions of striae. This position of the last ice west of Hudson Bay has been named the "Keewatin ice divide".

Geological investigations, archaeological studies and radiocarbon dates indicate a similarity of events around Hudson Bay, commencing at the time Hudson Bay Basin was freed of the continental ice-sheet. The sea that then spread around Hudson Bay 5 000 to 6 000 years B. C. is named "Tyrrell Sea". The subsequent rate of land emergence has been measured by dating organic, shell, and bone materials related to strand lines. The rate of uplift decreased from an initial rapid uplift of about 600 cms per century to later a much decreased rate of 30 to 90 cms per century.

A slightly warmer climate than present took place about 3 000 years B. C. as indicated by the radiocarbon age on buried plants having now a more southerly distribution.

This report was presented as a lecture to the Abisko-symposium of the XIX International Geographical Congress, 1960. The history of the Quaternary west and east of Hudson Bay is reviewed.

Recent studies of Pleistocene deposits around Hudson Bay, including ice recession and marine overlap studies by Bird (1953), archeological studies by Rainey and Ralph (1958), and ice recession and stratigraphic studies by Fyles (1955) and by Lee (1959a, 1960a), suggest a correlation of events.

Field coverage of such an immense area was made possible for Fyles and myself by the employment of helicopters for transportation, by the extensive use of air photographs and the advantages of large tracts of land without trees. For a discussion of the use of helicopters for geological work, see Officers of the Geological Survey of Canada (1959).

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This region is within the central zone of the maximum Wisconsin ice sheet. It was greatly downwarped during occupation by the ice, was flooded during ice recession, and later partly emerged as upwarping progressed. The dominant marker in these events is the marine submergence, to which the name "Tyrrell Sea" has been given (Lee 1960b).

The Tyrrell Sea reached its maximum extent 5 000 to 6 000 years B.C., as indicated by radiocarbon ages obtained on shells collected from near the highest strand lines west and south of the bay. The age of 6 975 ± ± 250 years (5 015 B.C.) was obtained on shells from west of Hudson Bay (Lee 1959a; site 1 in fig. 2), and south of the bay ages of 7 875 ± 200 and 7 280 ± 50 years (5 915 B.C. and 5 420 B.C.) were obtained on shells collected by O. L. Hughes from sites 2 and 3 in fig. 2 (the various laboratories engaged in this work are listed in the figure legend). Dates are not yet available for the east coast of Hudson Bay. Comparative ages on other Pleistocene seas outside of the central zone of the maximum Wisconsin glaciation are: about 10 000 to 11 000 before the present (8 000 to 9 000 B.C.) for the Champlain Sea episode (Terasmae 1959) and 13 325 years (11 365 B.C.) for the marine overlap along the Atlantic Coast, near Saint John, New Brunswick [dating index I (GSC) 7]. The latter date is on shells I collected from beds of marine clay which were overlain by deltaic gravels.

The advance of the Tyrrell Sea into the Hudson basin split the ice sheet into 2 parts and shaped the direction of the last ice recession. These shifts of glacier flow are recorded both west and east of Hudson Bay in the distribution of erratics and the orientations of drumlins and striae (Lee 1959a, 1960a). The former positions of the ice-sea contacts are recorded in distinctive drift ridges, termed by me straight-ridged minor moraines for the region west of the bay (Lee 1959a) and washboard moraines for the region east of the bay (Lee 1960a). I have since studied the classical area of washboard moraines in the Chibougamau region of Quebec (Mawdsley 1936), and they all appear to have had a similar origin. These shifts of flow and washboard moraines indicate similar ice-sea conditions both west and east of the bay.

The washboard moraines (pl. 1) sometimes called "annual" or "De Geer" moraines are similar to those described originally by De Geer (1889) from the Stockholm region, and more recently described by Hoppe (1948) from the province of Norbotten in northern Sweden. The mechanics of their deposition is not yet fully understood. Hoppe (1957) has suggested that seepage pressure, caused by a hydraulic gradient of streams from the upper to the lower surfaces of the ice sheet, can cause movement of drift towards the ice-margin. Mawdsley (1936) has suggested that deposition was in crevasses near the margin of the ice sheet. On the other hand my findings from extensive diggings and bulldozer cuts (Lee, *in press*) show that the material below the ridge crests is not always till, but may be sand, and the sand contains primary pollen. This suggests some transport from the surface to the base of the ice sheet. Despite differences in interpretation as to how all ridges formed, there is general agreement that they were formed parallel to the ice-margin and hence good indicators of the trends of the former ice-margins.

Another type of minor cyclic moraine records the former shifts in ice-flow in those supra-aquatic areas west of Hudson Bay where the terrain is flat. I have called these "ribbed minor moraines" (Lee 1959a). No

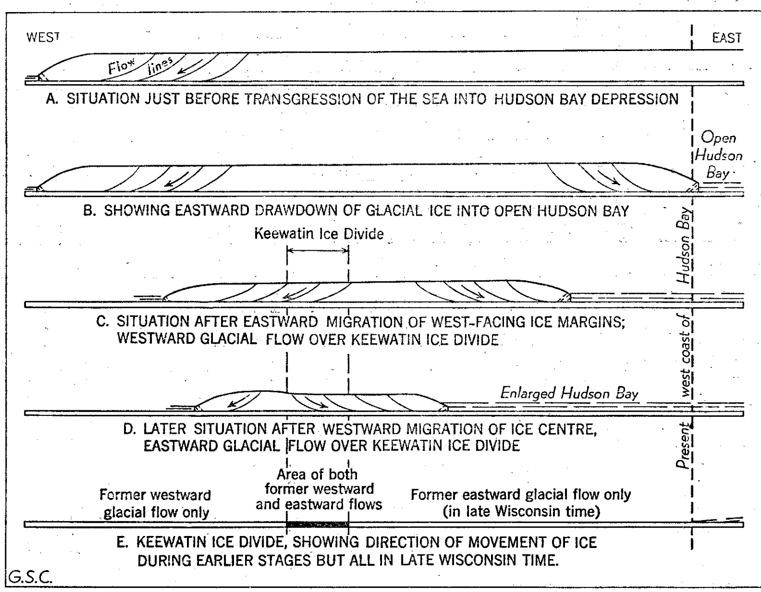

Fig. 1. Cross-section of an ice-sheet illustrating ideally the late glacial history west of Hudson Bay leading to the development of the Keewatin Ice Divide

equivalents have been found in the rougher terrain east of Hudson Bay or in Sweden. The ridges are a few hundred metres in length and up to 15 metres high. Trend is generally transverse to former ice movement. The proximal sides of some ridges are marked by a striated boulder pavement with the striae parallel to the direction of the last ice flow. The ridges are thought to have been formed subglacially near the ice-margin where the glacier rode up and over an inverted V of heavily loaded basal drift. The extensive area of flat terrain, the thickness of the ice sheet, and the rate of its ablation were favourable for the formation of ribbed minor moraines west of Hudson Bay, whereas elsewhere, the more broken relief and the condition of the ice sheet seems to have been generally unfavourable.

The sequence of events during deglaciation (fig. 1) is deduced from both "ribbed minor moraines" and "De Geer moraines", and from frontal channels, successions of ice-dammed lakes and outlets, and by trends of drumlins, striae and crag-and-tail hills.

Upwarping of the land began upon removal of the load of the ice sheet, and caused a regression of the Tyrrell Sea. Radiocarbon dates on shells, wood, and bones collected from the marine deposits at known elevations around Hudson Bay give information on the rates of this land emergence. The highest shore lines, about 250 to 275 metres above present sea level, are recorded east of Hudson Bay (Lee 1960a), in contrast to about 120- to 180-metre elevations west of the bay (Fyles 1955; Lee 1959). This difference in elevation is due either to greater rebound east of Hudson Bay, where the ice sheet had been thicker, or to greater, unrecorded uplift having taken place west of Hudson Bay before the highest shore lines were formed. The information on emergence is summarized in fig. 2, and a comparative curve is shown for changes of sea level through post-glacial time in the stable areas of the world. The rate of emergence around Hudson Bay follows an exponential curve with an initial rapid uplift of the order of 600 centimeters per century, and later a much decreased rate of the order of 30 to 90 centimeters per century. The samples dated are not all equally reliable, for they are of different materials from many regions, and correlation of material to a stand of the sea cannot be precise. Hence, the graph gives only the relative rates of emergence.

The similarity of events around Hudson Bay is also recorded in a section through the soil strata. The composite section valid for either side of the bay has bedrock at the base, overlain by glacial till and sand, then by marine — usually fossiliferous — clay, silt, and sand, and then by beds of organic, alluvial, or dune deposits of peat and sand. Lake beds can be expected below the marine or glacial deposits south of Hudson Bay. In the Fort George — Great Whale region the many sections I examined (Lee 1960a) show thick beds of dark, odoriferous clay with shells, overlain by thick beds of stony silt with shells and wood, and with beds of alluvial sand overlying the silt. A bore hole at Fort George traversed 5 metres of alluvial sand, then 62 metres of the dark, odoriferous clay before encountering bedrock.

A former climate warmer than present is indicated by fossil *Ceratophyllum demersum* L. that was discovered west of Hudson Bay. Te-

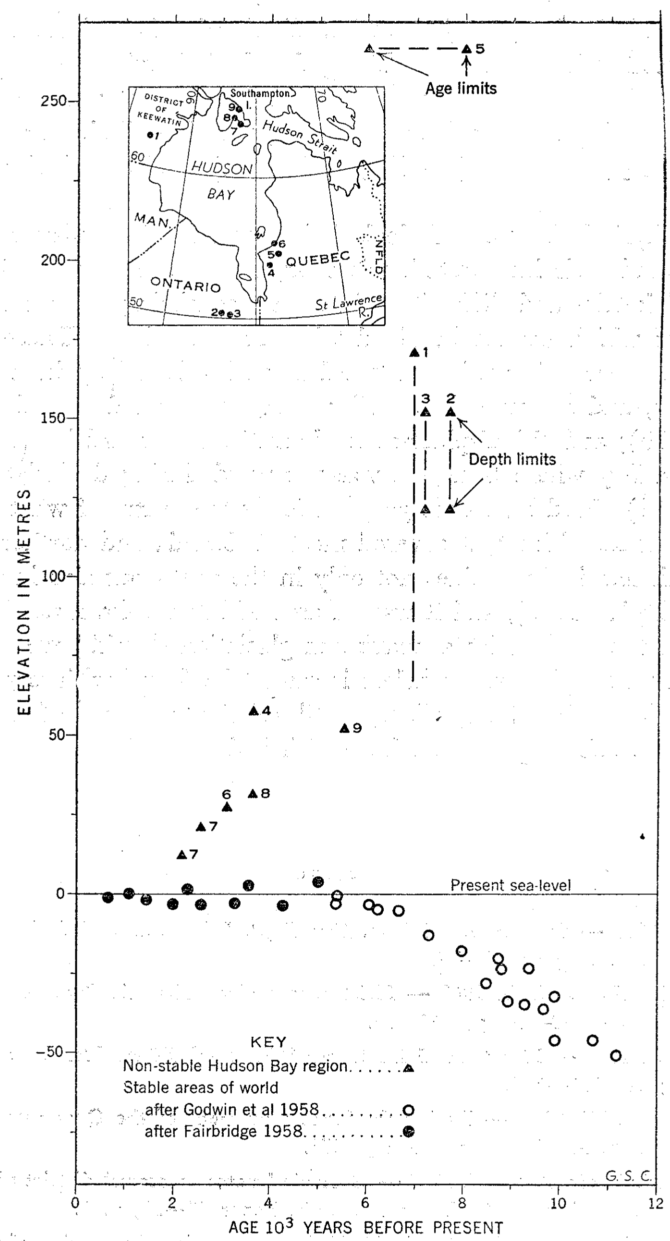

Fig. 2. Radiocarbon ages relative to elevations above and below present sea level (index map inset)

Site 1 — carbon dating index I (GSC) 8, shells (Lee 1959a); site 2 — I (GSC) 14, shells; site 3 — Gro. 1698, shells; site 4 — L433A, wood (Lee 1960a); site 5 — estimated age 6 000 to 8 000 years; site 6 — L441A, wood (Lee 1960a); site 7 — P76, P77, burned bone (Rainey & Ralph 1958); site 8 — S12, shells (Mc Callum 1955); site 9 — S13, shells (Mc Callum 1955)

Dating stations referred to above: I (GSC) — isotopes (Geological Survey of Canada); Gro. — Groningen; L — Lamont; S — University of Saskatchewan; P — University of Pennsylvania rasmae and Craig (1958) state: "... distribution is both north and east of its presently known range. The palynological evidence supports the conclusion that climate was warmer than the present when the silt, in which the fossil plant remains were found, was deposited. A radiocarbon age of 5 400 $\pm$ 230 years (L—428; 3 440 B.C.) has been obtained for the sample."

The physical features of deglaciation and marine submergence are abundant and their interpretation is clear, whereas those of earlier glacial flows are sketchy and difficult to interpret, consisting in part of erratics the age of which cannot be fixed with any certainty. These include: (a) displacement of erratics eastward from Hudson Bay in a direction opposed to, and at some time earlier than, transport during deglaciation (Lee 1959b); and (b) displacement of erratics southward in an area west of Hudson Bay where transport was westward during deglaciation (Lee 1959a, p. 11). Hudson Bay is geographically the centre of what was once a large pancake of ice that covered most of Canada and northern United States with terminal moraines not only in the south but also in the north (Craig & Fyles 1960), and it was an area of intense downwarping. That area under the thickest ice at maximum glaciation should have undergone greatest downwarping, nevertheless it cannot be found with any certainty by measuring uplifted shorelines, until relative amounts of unrecorded uplift before submergence can be established.

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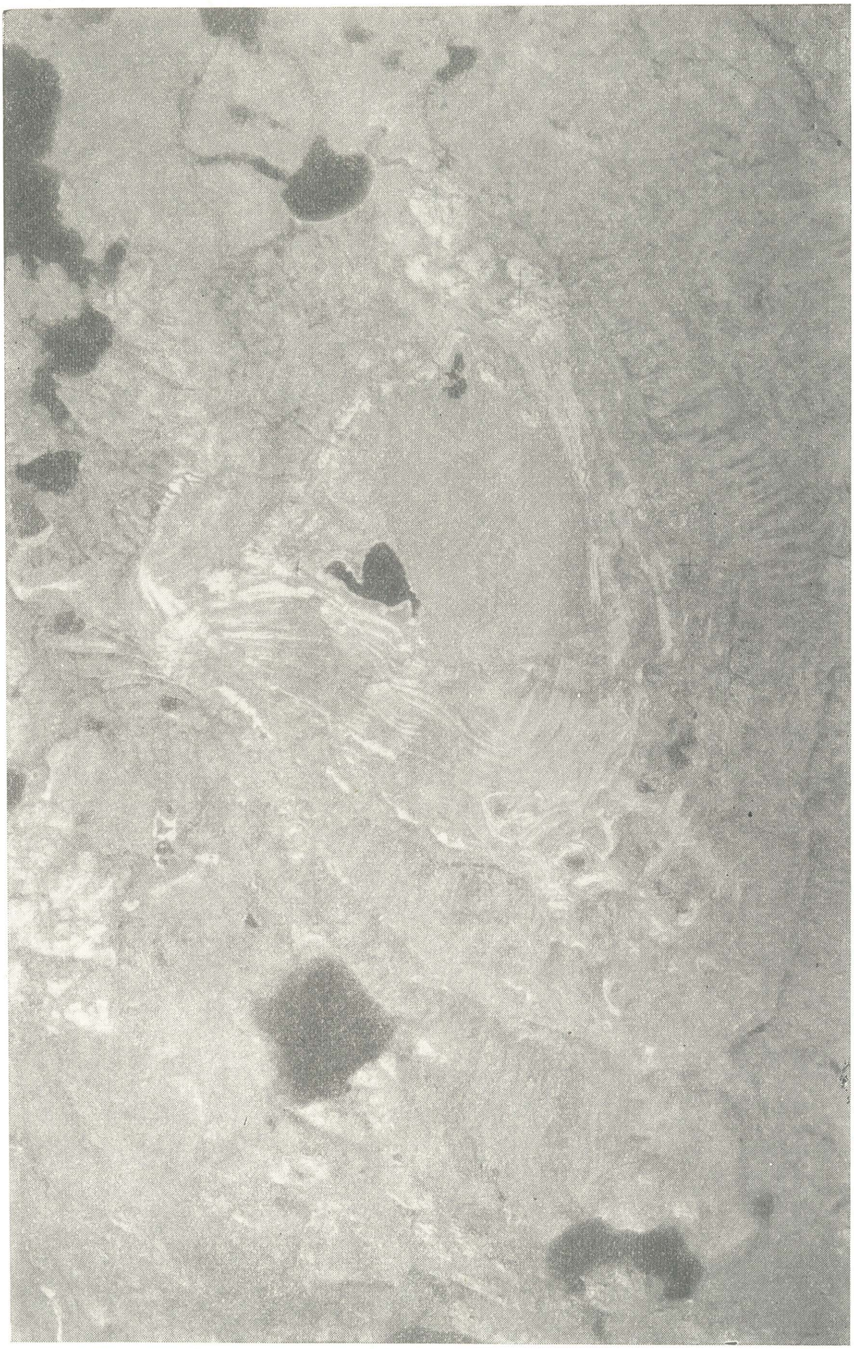
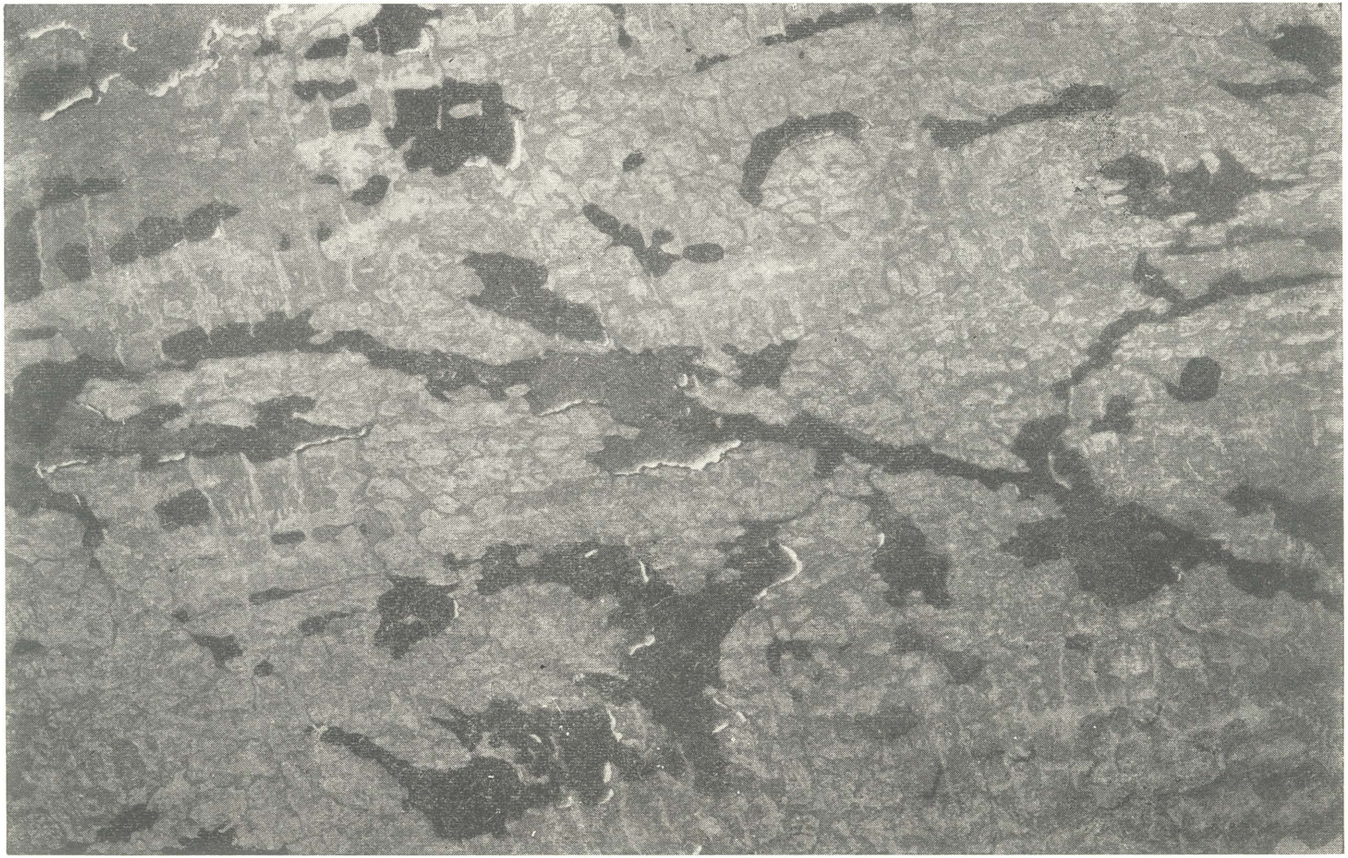


Pl. 1. Air photo of De Geer moraines from east of Hudson Bay. They trend from top to bottom across the photo and shows as short, light coloured succession of lines
Scale is approximately 1 : 60 000. Top is north



Pl. 2. „Kalottberg" hill surrounded by boulder beaches and marking the highest marine limit west of Hudson Bay
Scale is approximately 1 : 40 000. Top is north