Significance of Labrador Sea and Baffin Bay Waters for growth of the Laurentide Ice Sheet

THOMAS B. KELLOGG

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Thomas B. Kellogg, Department of Geological Sciences and Institute for Quaternary Studies, University of Maine, Orono ME 04469, U.S.A.

Global ice-sheet growth from interglacial stage 5e to last glacial maximum stage 2 occurred in two major steps, at the isotope stage 5e/5d and 5a/4 transitions (e.g., Ruddiman et al. 1980). Although we do not know where ice accumulated during these times of increasing oceanic $\delta^{18}O$, one likely location is the Laurentide Ice Sheet (LIS). This paper describes a hypothesis forwarding the possibility that Baffin Bay and the Labrador Sea acted as moisture sources for LIS growth. Then competing interpretations of oceanic sediment cores are evaluated with regard to the potential of these areas as precipitation sources for ice growth at the stage 5a/4 transition. Finally, modelling of the global atmosphere at the stage 2 maximum suggests constraints on the location and timing of ice sheet growth.

The argument has been made that ice-free conditions in the Labrador Sea and Baffin Bay are a necessary condition for growth in the LIS, because these areas might be important moisture sources (e.g., Andrews & Mahaffy 1976; Johnson & Andrews 1979). If this is correct, winter precipitation on the ice sheet, and therefore winter evaporation from the marginal seas, is most important for continued ice-sheet growth. Open water in winters facilitates precipitation heavy enough to survive in part through the cool summers. Calculated orbital parameters for appropriate northern latitudes support this concept, showing lower-than-modern insolation during summers, and higher winter insolation (e.g., Ruddiman & McIntyre 1981, Fig. 2).

It is difficult to envision conditions under which Baffin Bay and the Labrador Sea could have had seasonal sea-ice cover with open conditions existing only in winters during glacials. Therefore, year-around open conditions are called for at times of ice growth, if these marginal seas really were important moisture sources. If convincing evidence of year-around open water in these areas is lacking, we must turn our attention elsewhere in search of possible moisture sources for LIS growth.

Record from marine sediment cores

North Atlantic. – Ruddiman et al. (1980) studied the isotope stage 5a/4 transition in North Atlantic cores in order to determine oceanic conditions during this ice-growth phase, and concluded that the "strong thermal gradient off the east coast of North America (an 'interglacial' ocean alongside a 'glacial' land mass) . . . should have directed low-pressure storms from warm southern latitudes northward toward the Laurentide Ice Sheet" (p. 33). While these results appear to support the contention that warm surface water, with at most seasonal ice cover, persisted in the Labrador Sea during stage 5a/4, at least two inconsistencies are present in the way these data are presented. First, contoured sea-surface temperature (SST) data show isotherms trending northward into the Labrador Sea, implying the presence there of warm waters, yet no data were presented to support this contouring. Second, hypothetical storm tracks, which should parallel steep thermal gradients, are shown turning perpendicular to SST isotherms off the coast of Labrador.

Labrador Sea. – Fillon & Duplessy (1980) analysed a series of cores collected in the northeastern Labrador Sea from beneath the West Greenland Current which transports warm water into the Labrador Sea and Baffin Bay. These cores should be sensitive to the warmest inflow from the North Atlantic. Core HU75-42 was found to penetrate into isotope stage 5b. Small specimens of subpolar foraminifera, in stage 2 and in southern cores at the stage 5a/4 transition, were cited as evidence for seasonally open water. However, the small (62–150 μm) planktonic specimens analysed by Fillon & Duplessy may actually record geochemical changes in the deep water, causing carbonate dissolution, rather than indicating sea surface temperatures (Kellogg 1984).

If data based on small planktonic foraminiferal specimens are ignored, foraminiferal analyses of HU75-42 show only one sample with significant (>5%) subpolar species (Kellogg 1986, Fig. 2). This sample, at 896 cm, probably represents relatively warm surface water at the 5a/4 transition. The remainder of the core contains planktonic faunas dominated by sinistral *N. pachyderma*, suggesting cold surface temperatures and year-round ice cover. Sedimentation rates in HU75-42 were calculated using the ages of isotopic boundaries. The maximum duration of the 'pulse' of warm water, determined using these rates, was between 500 and 647 yr, but was possibly much less because little evidence was found for biotic mixing into overlying and underlying samples.

Data for the stage 5a/4 transition in HU75-42 can be used to resolve the uncertainties of the Ruddiman et al. (1980) reconstruction of North Atlantic SST and inferred storm tracks, and to achieve a parsimonious correlation of Labrador Sea/ Baffin Bay oceanographic events with those determined for the North Atlantic. The warmest conditions in the North Atlantic at 5a/4 were centered at about 75,000 B.P. (Ruddiman et al. 1980). The duration and intensity of this event, as recorded by the percentage of sinistral *N. pachyderma*, were greatest in cores located at some distance from the Labrador Sea, and decrease systematically to the north and west to HU75-42. This gradient is precisely what one would expect, based on the similar modern and 5a/4 SST patterns, but only for the warmest interval during the 5a/4 transition.

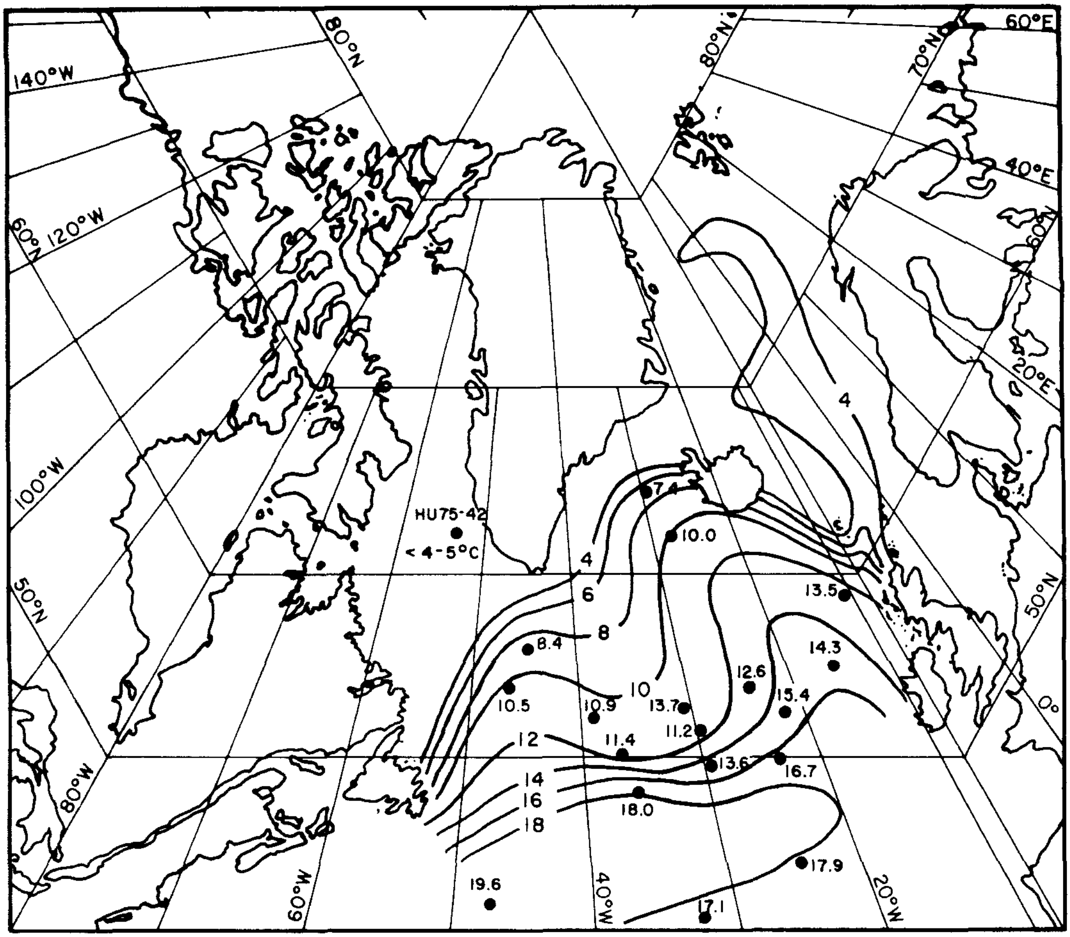

Fig. 1. August sea-surface temperature for the northern North Atlantic during isotope stage 5a/4 (modified from Ruddiman et al. 1980, Fig. 6C). Note (1) the strong thermal gradient across the mouth of the Labrador Sea should direct cyclonic storms past the Labrador Sea, and (2) isotherms south of Iceland suggest a counterclockwise surface gyre.

Because the warm 'pulse' in HU75-42 was of such short duration, it appears that the warm ocean adjacent to growing ice sheets was restricted to the open North Atlantic for most of the 5a/4 transition and did not include open water in the Labrador Sea and Baffin Bay. For this reason, the revised SST map for the North Atlantic (Fig. 1) prepared by recontouring the Ruddiman et al. (1980) data, illustrates oceanic SST conditions for the majority of the 5a/4 transition, but not the warm 'pulse' at ~75,000 B.P. This revised isotherm pattern (1) suggests the presence of a counterclockwise surface gyre in the region south of Iceland, and (2) emphasizes a strong thermal gradient across the mouth of the Labrador Sea from Newfoundland to southern Greenland. This gradient is of particular significance because of the steering effect strong thermal gradients have on storm tracks (Blackmon et al. 1977). Cyclonic storms probably tended to bypass the Labrador Sea throughout the 5a/4 transition, except possibly during the warm 'pulse' at ~75,000 B.P.

Atmosphere-ocean interactions during ice growth

Manabe & Broccoli (1985) used CLIMAP Project (1981) data on surface albedo and ice extent ('maximum' reconstruction of Hughes et al. 1981) as boundary conditions for modelling with a General Circulation Model of the atmosphere-mixed layer ocean system. Thus, they were able to determine the influence of various ice-age boundary conditions, especially continental ice, upon the SST distribution. CLIMAP SST data (CLIMAP 1981) were used to evaluate model results. Output parameters included winter and summer sea-ice extents, SST, surface and 515 mb flow fields, and precipitation. The model results show a split jet-stream flow, with a high velocity branch along the southern and especially southeastern margin of the LIS, and weaker flow across the northern margin and southward through Baffin Bay and the Labrador Sea. Surface winds display a similar pattern and probably caused the low SSTs and extensive ice cover predicted by the model for seas off eastern Canada and much of the North Atlantic region north of ~45°N, in good agreement with CLIMAP (1981) results. These data suggest that the likelihood of major storms travelling northward along the east coast of North America to deliver precipitation to northern Labrador and Baffin Island was small during the glacial maximum. Precipitation predicted by the model supports this observation, showing negative net annual accretion in parts of these areas and in southern Greenland.

Discussion and conclusions

It is not clear if a threshold ice elevation or extent exists during ice-sheet growth, beyond which the split-jet configuration dominates upper atmospheric flow as it did during the glacial maximum. However, because of model dependence on albedo and ice sheet extent, it would appear that ice growth progressively intensified the split jet stream, leading to decreasing SST and increasing sea-ice extent in adjacent downstream seas. This scenario is consistent with the low SST and ice cover interpretations for stage 5a/4 at HU75-42. The short duration of the 'pulse' of subpolar water at 5a/4 suggests that the ocean-atmosphere system reached a threshold rather early in this ice-growth phase. Thereafter, continued ice-sheet advance and thickening in the northern and eastern Canadian Arctic must have depended primarily on moisture derived from the Pacific. Earlier ice-sheet growth, presumably at stage 5e/5d, may have involved moisture derived from the Labrador Sea.

Other areas of agreement between the Manabe & Broccoli (1985) model results and the oceanic record are (1) the very strong thermal gradient, directed west-east, off the coast of southern Labrador, and (2) surface wind vectors in the area south of Iceland, consistent with the predicted counterclockwise gyre. While the model results apply strictly only to the stage 2 maximum, the reconstructed circulation for stage 5a/4 suggests that these elements of the glacial atmospheric circulation may have developed early during ice-sheet growth, perhaps during the 5e/5d transition.

Apparent agreement between the Manabe & Broccoli (1985) model results and reinterpreted data from Labrador Sea and Baffin Bay sediment cores spanning the 5a/4 transition, combined with the parsimonious correlation of the 5a/4 North Atlantic and Labrador Sea records, appear to support the revised Labrador Sea model (Kellogg 1986). This work suggests that seasonally open water persisted for at most ~600 yr during this ~10,000-year interval, and seems to rule out eastern Canadian waters as significant moisture sources for LIS growth during the stage 5a/4 transition. The Manabe & Broccoli (1985) model results suggest that the Pacific was the major moisture source for northern parts of the LIS.

References

Andrews, J. T. & Mahaffy, M. A. 1976: Growth rates of the Laurentide Ice Sheet and sea level lowering (with emphasis on the 115,000 B.P. sea level low). *Quaternary Research 6*, 167–183.

Blackmon, M. L., Wallace, J. M., Lau, N.-C. & Mullen, S. L. 1977: An observational study of the northern hemisphere winter circulation. *J. Atmos. Sci. 34*, 1040–1053.

CLIMAP Project Members 1981: Seasonal reconstructions of the earth's surface at the last glacial maximum. *Geol. Soc. America, Map & Chart Series, MC-36.*

Fillon, R. H. & Duplessy, J. C. 1980: Labrador Sea bio-, tephro-, oxygen isotopic stratigraphy and Late Quaternary paleoceanographic trends. *Canadian J. Earth Sci. 17*, 831–854.

Hughes, T. J., Denton, G. H., Andersen, B. G., Schilling, D. H., Fastook, J. L. & Lingle, C. S. 1981: The last great ice sheets: A global view. In Denton, G. H. & Hughes, T. J. (eds.): *The Last Great Ice Sheets.* John Wiley, N.Y.

Johnson, R. G. & Andrews, J. T. 1979: Rapid ice-sheet growth and initiation of the last glaciation. *Quaternary Research 12*, 119–134.

Kellogg, T. B. 1984: Paleoclimatic significance of subpolar foraminifera in high-latitude marine sediments. *Canadian J. Earth Sci. 21*, 189–193.

Kellogg, T. B. 1986: Late Quaternary paleoclimatology and paleo-oceanography of the Labrador Sea and Baffin Bay: an alternative viewpoint. *Boreas 15*, 331–343.

Manabe, S. & Broccoli, A. J. 1985: The influence of continental ice sheets on the climate of an Ice Age. *J. Geophys. Res. 90(C2)*, 2167–2190.

Ruddiman, W. F. & McIntyre, A. 1981: Oceanic mechanisms for amplification of the 23,000-year ice-volume cycle. *Science 212*, 617–627.

Ruddiman, W. F., McIntyre, A., Niebler-Hunt, V. & Durazzi, J. T. 1980: Oceanic evidence for the mechanism for rapid northern hemisphere glaciation. *Quaternary Research 13*, 33–64.