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CLIMATE CHANGE AND RELATED PROBLEMS IN
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by

G.F. Hattersley-Smith

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A B S T R A C T

This paper draws inferences on climatic trends in the Arctic from work done over the decade previous to 1970 on a number of long lived climate dependent Arctic features. Dating of material found at the Ward Hunt Ice Shelf, and measurements of oceanographic parameters in Disraeli Fiord behind the shelf as well as on glacial lakes have helped establish the lifetime of these features and contributed to an understanding of long-term climatic variations since. Measurements on the Gilman Glacier, the plug of ice at the mouth of Nansen Sound, together with those of mass balance on the Ward Hunt Ice Shelf have led to predictions of onset of a shorter termed cooling cycle.

R É S U M É

Le présent rapport fait état, à la suite d'études s'échelonnant de 1960 à 1970, de conclusions abtenues sur les variations climatiques de l'Arctique. Ces conclusions sont dérivées de l'observation des caractéristiques qui rendent compte des lentes fluctuations de température qui se produisent dans l'Arctique. La détermination de l'âge de la glace dans le "Ward Hunt Ice Shelf" ainsi que les mesures océanographiques dans le fjord Disraeli et les lacs glaciaires permettent d'établir la durée de vie de la glace fournissant ainsi une indication des variations à long terme du climat. Des mesures sur le Glacier Gilman et sur la lanque de glace à l'entrée du Détroit Nansen combinées à celles de la balance de masse sur le "Ward Hunt Ice Shelf" laissent prévoir, pour un avenir rapproché, le début d'une période plus froide.

CLIMATIC CHANGE AND RELATED PROBLEMS IN NORTHERN ELLESMERE ISLAND, N.W.T., CANADA

INTRODUCTION

The Defence Research Board has supported interdisciplinary studies in northern Ellesmere Island since 1953. Firstly this paper uses some of the results of this work to summarize the limited knowledge of the times of onset of (i) the climatic warming leading to general deglaciation and (ii) the subsequent fluctuation towards cooler conditions that led to the growth of ice shelves off the north coast of Ellesmere Island. Secondly this paper reviews the present status of the Ward Hunt Ice Shelf and describes the unusual oceanographic conditions in Disraeli Fiord that result from the presence of the ice shelf and, looks briefly at the peculiar structure of certain glacial lakes in the same area. All these phenomena are directly or indirectly related to climatic change. It will be seen that present climatic cooling appears to be affecting the Ward Hunt Ice Shelf, and evidence will be provided of the same trend affecting the Gilman Glacier and adjoining ice cap and of a parallel deterioration in sea ice conditions in Nansen Sound. Finally, a brief examination of the possible information on past climate that could be obtained from deep coring on one of the main ice caps of northern Ellesmere Island will be made.

INFERENCES ON CLIMATE IN THE LAST 10,000 YEARS

Glacial geological studies indicate that Tanquary Fiord became free of glacial ice at least 6,500 years ago. The evidence comes from radiocarbon dating of marine shells from the highest level at the head of the fiord ($6,320 \pm 140$ BP; GSC-373) and of a sample from a nearby peat deposit ($6,480 \pm 200$ BP; SI-468). The climatic amelioration that caused deglaciation led to subsequent isostatic uplift at the rate of about 3.5 m/100 yr. in the period from 6,500 to 5000 BP, as against an uplift of about 0.25 m/100 yr. in the period since 5,000 BP (1). A long period of river erosion followed the recession of the ice, but after a climatic deterioration within the last 4,000 years glaciers advanced to reoccupy V-shaped valleys (2). One such advance was responsible for the damming of Lake Tuborg (Fig.1). Sometime after 3,000 BP ice shelves started to form off the north coast of Ellesmere Island; this approximate date is set by the radiocarbon age of the youngest driftwood so far discovered on beaches behind the Ward Hunt Ice Shelf

(3,000 \pm 200 BP; L-254D;) (3). In the last 900 years the climate appears to have been relatively stable in so far as there has been little change in the terminal positions of most of the major glaciers, as shown for example by radiocarbon dating of plant material from deposits near the margins of the Air Force Glacier (Tanquary Fiord) and the Gilman Glacier. Both these main glaciers are advancing slightly, although many of the side glaciers have receded from well-marked terminal moraines, probably as a result of the climatic warming centred around 1930 (4).

THE WARD HUNT ICE SHELF

The ice shelves off the north coast of Ellesmere Island are important as climatic indicators. (5), as well as being the source area of the floating ice islands of the Arctic Ocean. DRB has analysed the results of ten years' (1958-68) record of accumulation and ablation on the Ward Hunt ice rise and of three years' (1965-68) on the Ward Hunt Ice Shelf (Fig.21;) (6). The net mass balances on the ice rise for the three years 1962-65 were positive, while the net mass balances for the other years on both ice rise and ice shelf were all negative. The records for the ice shelf started only in 1965-66 and refer to surface mass balance; we do not know what is happening on the underside, although in 1969 Dr. J.B. Lyons of Dartmouth College drilled through the ice shelf between Ward Hunt Island and the mainland in 47 m and found salt rather than fresh water beneath. While there is no close correlation between seasonal melt and mean monthly temperatures at Alert, the weather station about 200 km to the east-north-east, quite small deviations from mean summer temperatures appear to determine whether the mass balance is positive or negative. For this reason neither ice rise nor ice shelf should be considered as a relic glacial feature. It is suggested, on rather meagre evidence perhaps, that the beginning of a period of renewed surface build-up following a period of net surface ablation at least since 1906 is being observed. This date of 1906 is known because of finding on the surface of the ice shelf in 1954 the debris of one of Peary's camp sites (7). Because of the warm summer of 1954 when the net ablation was more than 600 mm H₂O, the tendency was to assume that the ice shelf is thinning rapidly as a result of climatic warming and that this is the reason for massive calving in recent decades, as for example in 1961-62 (8). In fact the calving should much more appropriately be related to unusual tidal effects (9). To summarize, the ice about Ward Hunt Island has been ablating at an average rate of only about 60 mm/yr since 1958, and has actually been accreting at a rate of about 30 mm/yr since 1963.

Other investigations that may have an important bearing on the genesis and maintenance of the Ward Hunt Ice Shelf were made. These concern the oceanography of Disraeli Fiord and the limnology of small lakes near the coast to the south of the ice shelf (Fig.2).

DISRAELI FIORD

The oceanographic data from Disraeli Fiord are of particular interest, for the near-surface waters of this fiord are blocked from the ocean by the Ward Hunt Ice Shelf, which occupies the outer 25 km of the fiord (10). South of the ice shelf there is perennial fiord ice or (in summer) limited open water up to the Disraeli Glacier front, a further 25 km. The freeboard of the ice shelf indicates that it is about 40 m thick across the mouth of the fiord. The fiord water was found to be virtually fresh to a depth of 44m; this layer rests with sharp discontinuity on typical Arctic Ocean water to the bottom in depths of 200 to 300 m. There is a temperature minimum of about -1.7°C below the freshwater-saltwater interface. By contrast, observations in M'Clintock Fiord showed that since the disruption of the ice shelf in this fiord (11) the surface water layer had been flushed out, so that temperature and salinity curves were similar to those for Arctic Ocean water off the coast. The situation in Disraeli Fiord raises the question of whether a flow of fresh water to the ocean just beneath the ice shelf, as the fiord receives seasonal melt water from the land, may have enabled the ice shelf to grow by bottom accretion of ice during the 3,000 years (maximum) of its existence (10). A number of measurements indicate that tidal currents exist from the bottom up to 50 m depth, but that no measurable motion occurs above this level. The fresh water at 44 m is within 0.1°C of its freezing point, which makes it very likely that, locally at least, ice is accreting at the base of the ice shelf.

GLACIAL LAKES

In 1963 old sea water was discovered near the bottom of Lake Tuborg (Fig.1) beneath 50 m of freshwater, and it was concluded that the lake had been cut off from Greely Fiord by advance of the glacier that now dams the western end of the lake (12). The radiocarbon age of the seawater indicated that the lake was cut off about 3,000 years ago (13). This suggested the possibility that other lakes in the area might contain old seawater trapped either by glaciers or by post-glacial rise of land. For this reason, in 1969, lakes near the north coast of Ellesmere Island were investigated. Three of the lakes visited (lakes "A", "B", and "C" in Fig.2) showed density stratification similar to that observed in Lake Tuborg, with temperature maxima as high as $+10^{\circ}\text{C}$ at depths of 15 m. It was concluded that seawater was trapped in these lakes by post-glacial rise of land, and the warm layer was due to the trapping of solar radiation beneath a permanent ice cover (14). It is hoped to obtain a radiocarbon age for the seawater in one of these lakes ("B" in Fig.2) which is at an elevation of 23 m above sea level. In this way a rate for the post-glacial uplift on this coast and effect it had on the development of the ice shelves may be deduced.

GILMAN GLACIER AND ADJOINING ICE CAP

The results of studies on the Gilman Glacier and adjoining ice cap will be examined briefly to determine if they support the idea that northern Ellesmere Island has entered a period of cooler summers. (Fig.2) After work there in the spring of 1967, following previous work (15) the following was postulated: the four summers 1963-66 were the coldest sequence of summers since before 1925; the former percolation facies of the ice cap above 1,800 m had been changed to an almost dry-snow facies; and the equilibrium line on the glaciers had been lowered to an elevation of about 900 m from a mean of about 1,200 m above sea level for the years 1957-63. Further work by R. B. Sagar in 1968 indicated highly positive net budgets for the period 1962-67 (c. $+230 \times 10^6 \text{ m}^3 \text{ H}_2\text{O}$) and for the year 1966-67 (c. $+50 \times 10^6 \text{ m}^3 \text{ H}_2\text{O}$). It is of interest to note that cool summers in 1963, 1964 and 1965 resulted in sharply positive mass balances on the ice cap of Devon Island (16).

NANSEN SOUND

One might expect the recent cooler summers off the north coast of Ellesmere Island to have caused build-up of fast ice, as for example in Nansen Sound (Fig.1). A good deal of information has been obtained by DRB field parties on sea ice thicknesses in the Nansen Sound fiord system. First-year ice, which covers most of the inner parts of the fiords, ranges in thickness from 2 to 2.5 m in Tanquary and Greely fiords. However, in Hare and Otto fiords first-year ice as thin as 1.15 m can occur, probably because of deeper snow cover in these fiords. Second-year ice, which is frequently found in the outer parts of the fiords and is common in Nansen Sound, reaches thicknesses of 3 to 3.5 m. Much older sea ice is also encountered, and near the mouth of Nansen Sound there is a plug of multi-year ice that is believed not to have broken up for a considerable period of time. From field work in May 1969, H. Serson concluded that the ice plug reaches a thickness of 6 m or more over an area of about 1,000 km², from a line joining Krueger Island to Cape Stallworthy southward to a line running southwestward from Emma Fiord to the coast of Axel Heiberg Island (Fig.1). Detailed investigations of this interesting feature, which we suggest relates to cooler summers since 1962, following the warmer post-1925 period that was recognized in previous earlier glaciological work (15) are continuing and the photographs taken during a survey flight over the ice plug in August 1971 showed a number of features which are evident, at the same location, as in the July 1950 aerial photography. These are ice shelf fragments and piles of ice rafted rock debris. The ice plug therefore dates back to at least 1950.

It seems that ice conditions at the northern end of Nansen Sound are getting back to what they were in the early part of this century, when travellers reported very old unbroken floes. Indeed R.E. Peary's description in 1906 suggests that an ice shelf covered the mouth of Nansen Sound at that time, (17). By contrast, in 1932, H.W. Stallworthy reported new pressure ice over this area (18).

It is clear therefore that present climatic conditions off the north coast of Ellesmere Island allow very thick, landfast sea ice to form up to the point where it may be regarded as incipient ice shelf. On the one hand, the ice plug in Nansen Sound could improve ice conditions in the channel to the south by barring the drift of ice from the Arctic Ocean. On the other hand, the ice plug should favour the build-up of a surface layer of freshwater from runoff, and this could lead to a thickening of the ice to the south. In this connection it is worth noting that studies of relict plankton fauna in the glacially dammed Lake Tuborg lead to the likely conclusion that the waters of the Arctic Archipelago were of generally lower salinity 3,000 years ago than today (19), a condition that could have been caused by blockage of channels leading from the Arctic Ocean by ice shelves.

It is perhaps not unreasonable to suggest that there may well be a period of worsening sea ice conditions in the Canadian Arctic Islands of which shipping authorities should be aware. It is well known that ice conditions off Iceland have deteriorated in the last few years (20), and ice conditions off east Greenland in 1969 were the worst in more than a hundred years (B. Fristrup, personal communication). At the same time, if the ice plug in Nansen Sound does reach the status of an ice shelf, defined as landfast ice with a freeboard of more than 2 m, it might acquire some legal significance from an extension of practice in Antarctica where ice shelves are "assimilated to land".

POSSIBLE FUTURE INVESTIGATIONS

It would certainly be of interest to know more about the climatic history of northern Ellesmere Island over the last few thousand years. A promising way of doing this would be to put down a deep corehole on the large ice cap northwest of Tanquary Fiord, although there are no present plans for undertaking such work. Radar sounding in 1966 showed that this ice cap is up to 800 m thick; to the west it feeds the Otto Glacier which is a rare example of a high Arctic glacier that is known to have surged (Hattersley-Smith and others, 1969). Deep pit studies on the ice cap in 1970 showed that the mean annual accumulation over the last 20 years is about 140 mm H₂O. This means that a core through the deepest part of the ice cap might represent a time span of 5,000 to 6,000 years, extending well back into the Climatic Optimum. The information on climatic fluctuations to be gained from a deep ice core in northern Ellesmere Island might be far more detailed and relevant to areas bordering the Arctic Ocean than the information gained so brilliantly from the deep core at Camp Century, Greenland (21). The higher elevations of the ice cap in Ellesmere Island are within the zone where the greatest variations

of surface melting between cold and warm summers are likely. The stratigraphy is therefore typified by layers of bubbly ice, representing cool periods, and layers of clear or less bubbly ice, representing warmer periods. These features should facilitate climatic deductions from core analysis and confirm results from oxygen isotope analysis. There is the further possibility that radar sounding can be used to correlate reflecting horizons within the ice over wide areas. It is suggested that the effect of minor climatic fluctuations on ice stratigraphy is more marked in Ellesmere Island than in Greenland where the ice sheet by its very size must act as a damper on climatic change. The recent work in Greenland (21) shows a cyclicity in climatic oscillations and leads to the prediction of a continued cooling trend over the next 10 to 20 years, which agrees well with the trend that we see in northern Ellesmere Island. It is likely that similar work in northern Ellesmere Island would uncover valuable new data bearing on climatic cycles and relevant to the present status of both land and sea ice in this area bordering the Arctic Ocean.

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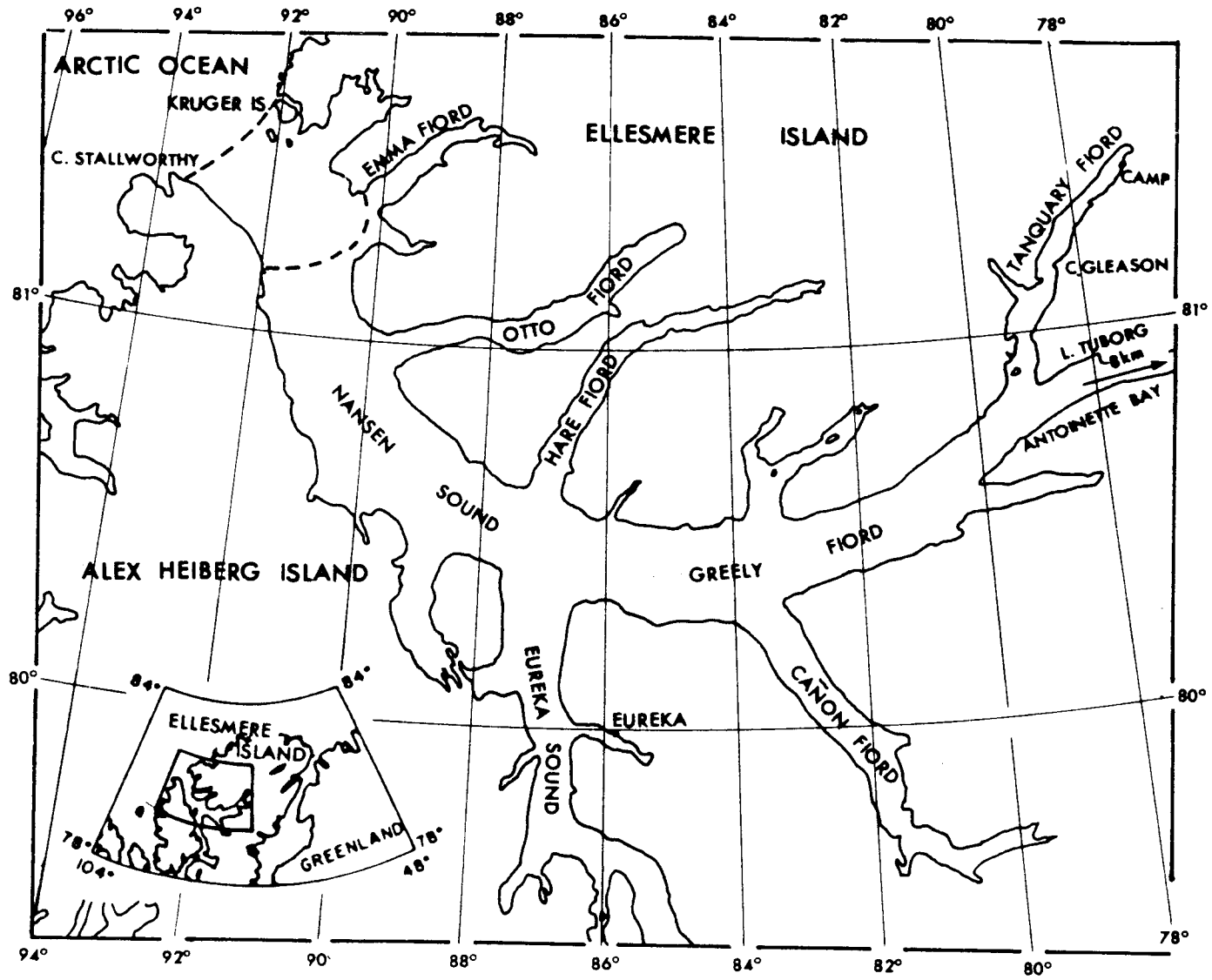


Fig. 1

----- LIMIT OF THICK, LANDFAST SEA ICE

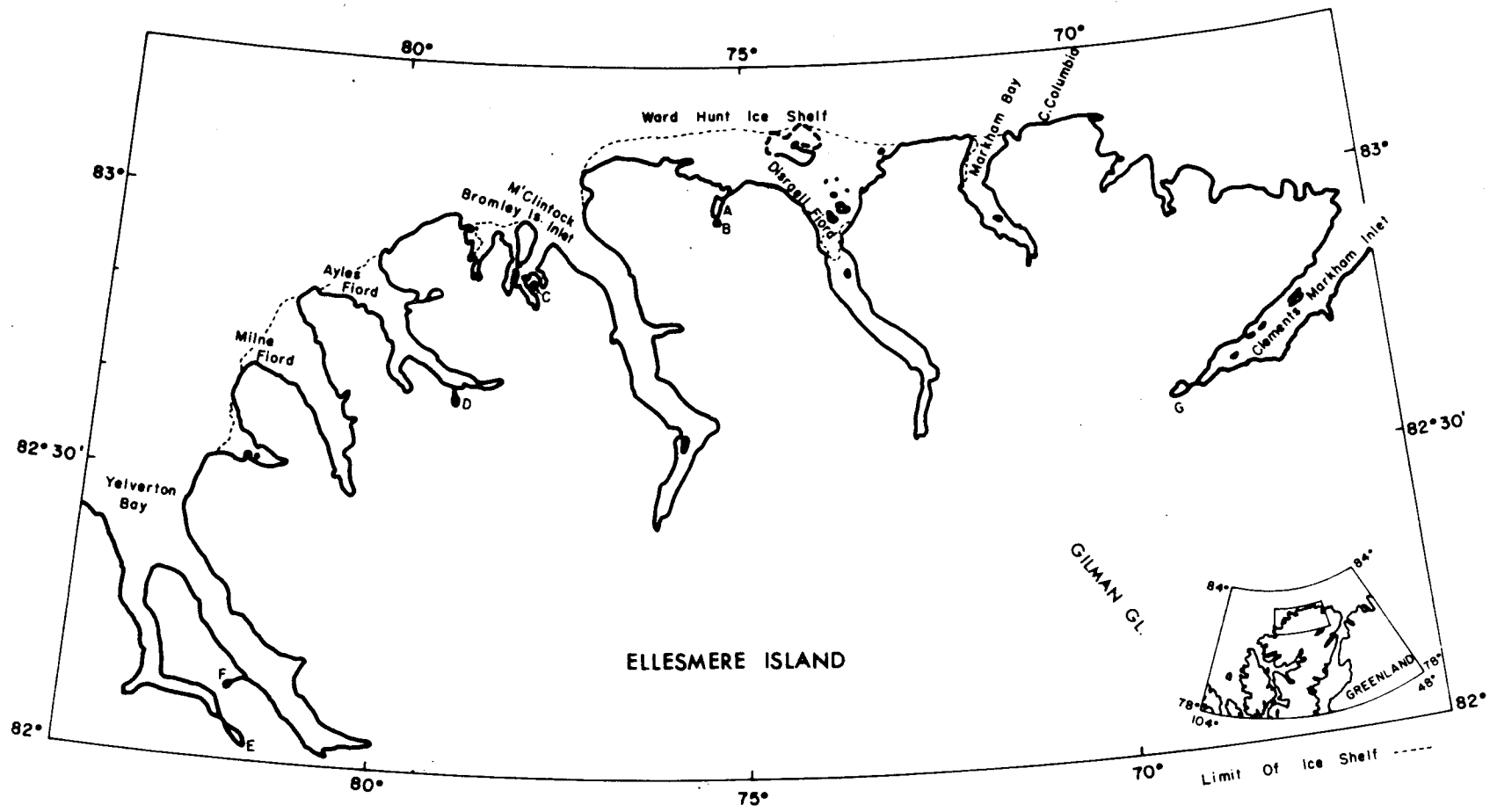


Fig. 2

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KEY WORDS

Climatic trends, Arctic dating material, Ward Hunt Ice Shelf, Disraeli Fiord, glaciers, glacial lakes, Nansen sound, ice plug mass balance.

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