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TOPOGRAPHIC AND GLACIOLOGICAL CONTROLS ON HOLOCENE ICE-SHEET MARGIN DYNAMICS, CENTRAL WEST GREENLAND

by

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ABSTRACT

The retreat of the West Greenland ice sheet from its Sisimiut (Wisconsinan) glacial maximum, was punctuated by a series of stillstands or small readvances that formed numerous moraines. These landforms have been interpreted in the past as the result of short-term, regional falls in ablation-season temperatures. However, mapping of the geomorphological evidence south of Ilulissat (Jakobshavn) suggests that retreat behaviour was not primarily governed by climate, and therefore that the former ice margins are not palaeoclimatically significant. During warm climate ice-sheet wastage, the successive quasi-stable positions adopted by the ice margin were largely governed by topography. The retreat of the inherently unstable calving glaciers was arrested only at topographically-determined locations where stability could be achieved.

INTRODUCTION

The West Greenland ice sheet retreated from a marine glacial maximum position to become predominantly terrestrial during the Holocene; this study examines the influence of topography and ice/water interactions on the nature of this transitional retreat. There is a close link between topographic influences, marginal environmental conditions, and total ice-sheet stability (Mercer, 1961; Brown and others 1982; Payne and others, 1989). The areal extent of an ice sheet is controlled primarily by changes in equilibrium line altitude (ELA), sea level, and calving rate, and the relative dominance of these depends on the terminal environment (Hughes, 1987). Iceberg calving appears to play a key role in the collapse of ice sheets (Denton and Hughes, 1981; Pollard, 1983) and during this process topography can exercise a powerful control on the ice margin (Mercer, 1961); narrowings, bends, bifurcations, and changes in the sideslope gradient are places where the terminus of a fjord glacier can achieve greater stability. Apparently anomalous behaviour can result from the intersection of the ELA by a thickening glacier, and thus terminus behaviour may be unrepresentative, or even contrary to climatic trend.

Work on the calving tidewater glaciers of Alaska (Meier and Post, 1987) has extended Mercer's original ideas. It has shown that retreat rates of grounded calving glaciers are controlled by channel shape and water depth, that the calving rate increases almost linearly with water depth, and consequently that the climatic significance of grounded tidewater glacier fluctuations is problematic. According to Mann (1986), the fjord glaciers most susceptible to anomalous responses to climate are those which occupy complex fjord systems, lie in areas of low (ELA), or terminate at fjord mouths adjoining the open sea. Existing work therefore suggests that the key variables determining the extent of topographic control of an ice-sheet margin are trough geometry, relative sea/lake level, and resulting water depth.

WEST GREENLAND: CONFLICTING HYPOTHESES

Weidick (1968, 1985) was the first to attempt an overall chronological interpretation of the glacial deposits of West Greenland. Major uncertainty exists concerning their origins, and two hypotheses can be advanced to account for them:

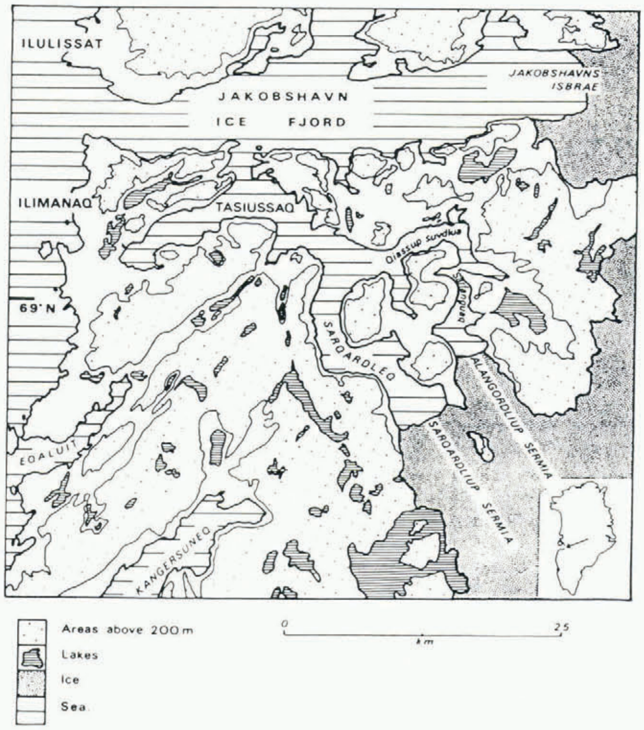

Fig. 1. Jakobshavns Ice Fjord and the Tasiussaq Fjord system.

" ...They may represent either significant readvance of the ice sheet margin in response to regional positive changes in ice mass balance, albeit during periods of overall deglaciation, or alternatively, local stillstands or readvances caused by topographic influences or by shifts in the ice-sheet streamline patterns during deglaciation" (Kelly, 1985, p.477).

Weidick proposed the former, interpreting the moraine systems as evidence of short periods of colder summer temperatures during the collapse of the ice sheet, consequently suggesting that the ice margin features are the product of climatically-controlled changes in mass balance. The alternative possibility, that the characteristics of the marginal environment may themselves influence the stability of the Greenland ice sheet, has seldom been considered. In this second scenario, halts or readvances during ice-sheet retreat are caused by a sequence of changing ablation mechanisms at the margin. Thus Funder (1989) has noted that the location of moraines along the fjords indicates that they were formed by interaction between the glaciers and bed topography, rather than by climatic change.

THE STUDY AREA

The research area (Fig. 1) lies in a 15–30 km wide coastal strip of plateaux and hills below about 550 m, separated by long, structurally aligned glacial troughs in Precambrian gneiss. The Tasiussaq Fjord system averages 100–200 m in depth (Engell, 1905). Formation and/or preservation of glacial deposits was often impossible along the main glacial troughs, because of steep slopes and cliffs up to 500 m high. It is an area of retreat-stage transition from the maximum, marine-based state of the inland ice to its current, predominantly terrestrial condition. The inland ice retreated from a Sisimiut glacial maximum position in Disko Bugt at some time between 14 000 and 10 000 B.P., reaching a position close to the present margin around 7000 B.P. (Weidick, 1985; Kelly, 1985). Two major phases of stillstand were identified by Weidick (1968) and proposed as contiguous margin positions between the three valleys of Tasiussaq, Eqaluit and Kangersuneq (Fig. 1), the younger dating from 7500 to 8500 B.P., the older phase antedating it by an unknown amount. Large depositional features forming the western shore of Tasiussaq (Weidick, 1968) are the only West Greenland example of a definite Holocene readvance (Kelly, 1985).

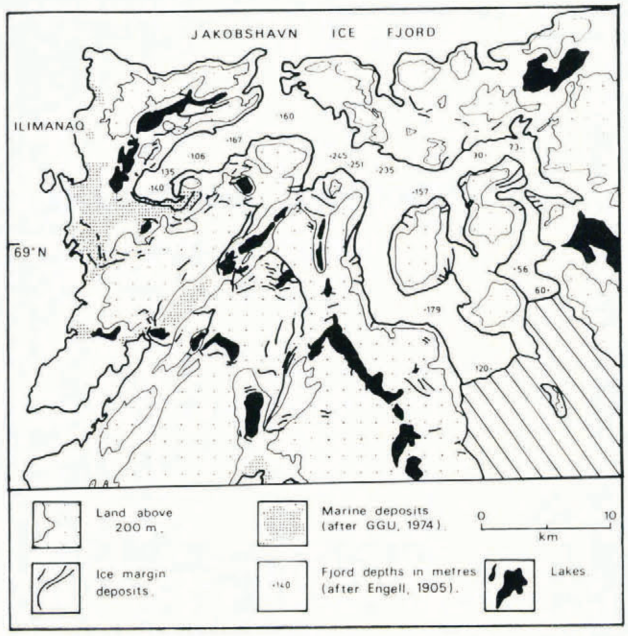

Fig. 2. Tasiussaq Fjord system: glacial geomorphology and bathymetry.

RESULTS

The main geomorphological elements of the landscape were mapped onto aerial photographs at a scale of 1 : 40 000, glacial landforms being identified on the basis of morphology and sedimentology, and used to delimit former ice margins (Fig. 2). Large accumulations of glacial debris are commonly found at topographic narrowings or bifurcations. In the Sarqardleq trough, for example, the main lateral moraines indicate terminus positions at successive narrowing points up the fjord (Fig. 3). South of the narrowing point of the bay Igdlup qingua, a continuous mantle of morainic debris, buries the bedrock but is absent where the bay opens out into the main Tasiussaq trough. On the west side of the valley of Akiamiut tasserssua, moraines coincide with prominent bedrock ridges projecting into the lake. Similarly, a moraine 3 m high occurs on a narrow rock ridge which separates the two lakes at the north end of Qivdlertup valley, and in this valley the large glacial deposits are concentrated where the valley bifurcates around an isolated hill 230 m high. Between such points, lateral moraines tend to be smaller, less continuous, and show a diverging spatial pattern; moraine ridges in close association diverge as they are traced down-slope, down-fjord, and down towards present or past water bodies. On the western flanks of Sarqardleq, for example, where the fjord is narrowing southwards, 10 m of elevation separates lateral moraines which relate to terminus positions 1.5 km apart.

DISCUSSION

The spatial pattern of the glacial deposits indicates that the ice margin retreated in episodic fashion, alternating between rapid retreat and relative stability, and that parts of the margin were stable when other parts were unstable. Since variation in ablation is likely to have controlled ice-margin oscillations, episodic retreat was probably caused by variation in the factors controlling ablation rates.

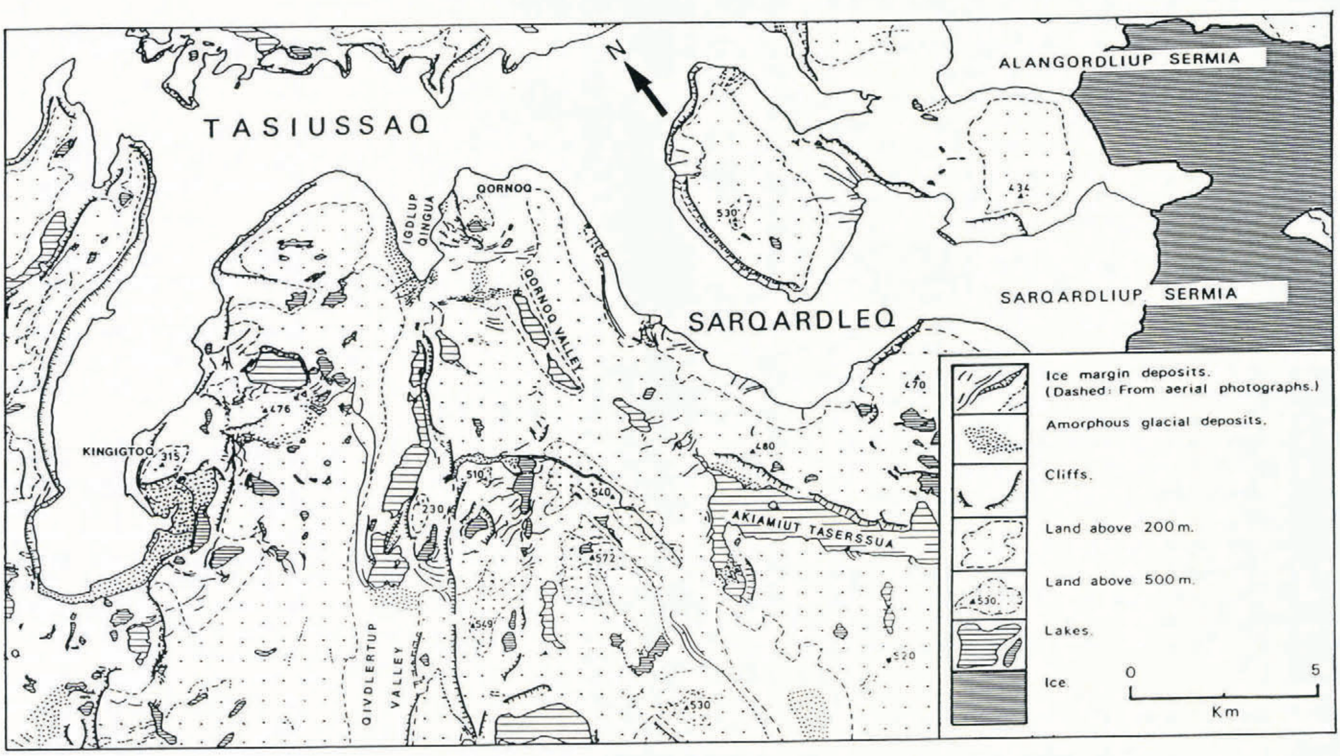

Fig. 3. Detailed glacial geomorphology of the central area.

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Climatic control

Weidick (1968, 1985) proposes that cooler summers during the Early Holocene warming caused the stillstands. According to Weidick, some of the larger moraines extend over long distances, and are of similar morphology; although the continuity over the high ground is not always clear, the connection between the large deposits in the neighbouring troughs is obvious. If the moraines *are* the result of climatically controlled changes in regional mass balance, then this must be the case. However, palaeontological and palynological evidence (Donner and Jungner, 1975; Fredskild, 1985) suggests that the Early Holocene in West Greenland was a period of uninterrupted warming and drying, reaching a peak warmer and drier than today sometime between 7000 and 6500 B.P. The sub-Arctic West Greenland Current was established from 9100 B.P., and there was intrusion of water warmer than at present from 7300 B.P. until after 5000 B.P. (Kelly, 1985). For the rapidly wasting ice sheet to halt, or readvance slightly in positions far in advance of today's margin (which is in quasi-equilibrium with the existing climate), marked falls in summer temperatures for substantial periods of time would be necessary, yet neither the fauna of the time nor the ice core evidence (Hammer and others, 1986) indicate anything more than minor cooling episodes in this period. In historical times, even slight temperature decreases have led to minor advances of the Inland Ice, but this effect is only known to have occurred recently, involving an ice sheet in quasi-equilibrium; it is not known whether such responses would occur in the context of rapid ice-sheet retreat. It is questionable, therefore, whether the retreat stages of the ice-sheet margin were controlled climatically. Indeed, Weidick in his more recent paper states that the recession was "often locally determined by topography rather than by changes in mass balance" (Weidick, 1985, p.306).

Topographic control

The glaciers appear to have halted only at places where the topographic configuration gave them an increased degree of stability. Retreat beyond such points into wider and/or deeper parts of the fjord led to increased rates of iceberg calving, and continuous, rapid retreat until the next topographic "pinning point" was reached. Using the ideas of Mercer (1961), Figure 4 presents a hypothetical reconstruction of the ice-sheet retreat in the Tasiussaq Fjord system c. 9000–7000 B.P., showing only the *present* coastline, and also possible contemporary positions of Jakobshavns Isbræ as dashed lines.

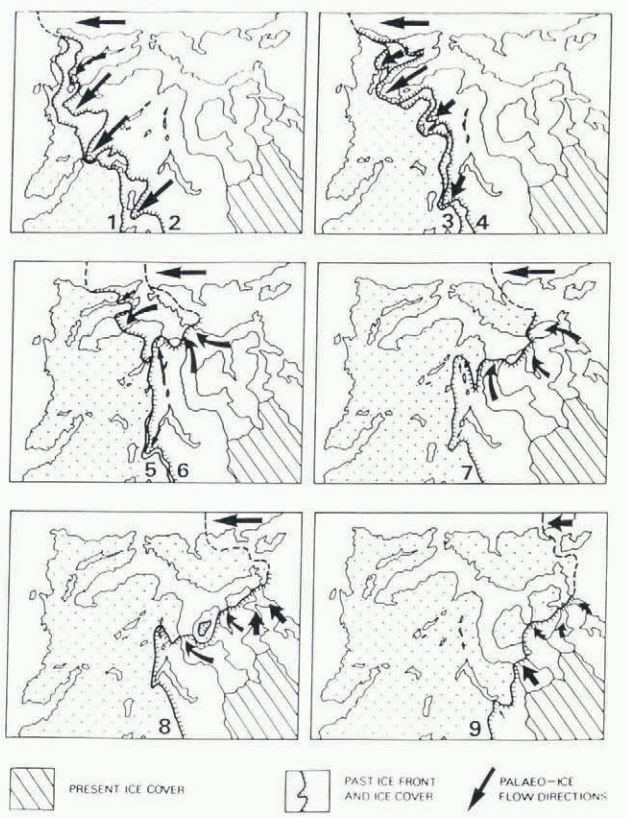

Fig. 4. Reconstruction of ice-margin configurations during retreat, c. 9000–7000 B.P.

The outermost moraine systems may be an example of the hypothetical sequence of evolving marginal dynamics envisaged by Hughes (1987, fig. 9, p.189). The warming climatic conditions and rising sea levels of the Early Holocene are thought to have caused catastrophic calving and dramatic retreat of this marine-based sector (personal communication from S. Funder). The transition from a marine-based to a predominantly land-based ice sheet would have led to greatly reduced ablation rates due to the fall in iceberg production. Furthermore, isostatic rebound was rapid at this time (Donner and Jungner, 1975) so that the length of the transition period would have been shortened and the dynamic impact consequently heightened. Just as glacio-isostatic sinking compels the grounding line to retreat (Hughes, 1988), so glacio-isostatic emergence enables it to advance. Under such circumstances a halt or a readvance would be expected.

Two distinct states of this transition can be recognised. The first was the time when the ice-sheet margin initially reached a grounding position at or near the contemporary coastline, and the second when the rapidly-calving outlet glaciers retreated either to stable, grounded calving locations or ceased calving altogether. The outermost moraines south-west of Tasiussaq show that the margin closely paralleled the coast, strongly suggesting that here, as in many parts of West Greenland, "the sea/land transition formed a major glacio-dynamic obstacle in the deglaciation process" (Funder, 1985, p.140). The readvance of the Tasiussaq ice lobe relates to the second of these transition phases. Initially, rapid calving probably led to retreat to the narrows of the fjord at Kingigtoq hill, a very sudden topographic constriction relative to the unconfined plain to the west. Dynamic adjustment to the much reduced ablation area and continuing isostatic rebound then caused a readvance, followed by adoption of a stable, grounded position. The complex glaciomarine sedimentology of these large deposits suggests that this readvance occurred on a morainic shoal as observed in many fjords in Alaska (Meier and Post, 1987). The marine clay plain to the west represents a contemporary sea level at 50–55 m a.s.l., suggesting a date for this readvance of 7250–7500 B.P. from the emergence curve of Donner and Jungner (1975).

It is therefore proposed that the dominant outer moraines of the area relate to this period of adjusting ice dynamics following retreat out of the sea. The topography of the coastal zone and the relative altitudes of these parts of the glacial troughs (45–55 m a.s.l.) are such that this transition happened at almost the same time in each of the major valleys, as shown by Weidick's (1968) ^{14}C dates. Thus these ice-margin deposits may be divided broadly into an outer and an inner phase, as originally proposed by Weidick (1968), but the primary causal link is a dynamic response to topography rather than climate.

CONCLUSION

The nature of the episodic retreat here is governed by the influence of topographic configurations on marginal ice dynamics, particularly iceberg calving dynamics. The evidence indicates that stepwise retreat occurred as envisaged by Hughes (1987, 1988). The contemporary warm climate was the dominant forcing function causing ice-sheet retreat, and led to destabilisation from pinning points, but the geomorphological evidence shows that the stillstands were topographically induced. An implication is that palaeoclimatic significance should not automatically be attached to the Late Glacial and Holocene stillstands of tidewater outlet glaciers of ice sheets, especially stillstands resulting from the sea/land transition.

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