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SIR,

Implications of glacial sculpture on Hans Island, between Greenland and Ellesmere Island (Nares Strait)

Hudson (1983) reported evidence for glacial activity on Hans Island, but discussed two directions of ice movement over the island. In 1988, while studying the Palaeozoic strata in the vicinity of Nares Straight, I observed well-preserved rock sculpturing which indicated a clear direction for glacial movement across the island. The implications of this evidence to the glacial history of the High Arctic are discussed briefly in the following correspondence.

Scours, grooves, and crescent fractures are present near the summit of the island, on dolomitic limestones essentially void of till; yet, erratics are ubiquitous. Striae and plucked bedrock record movement from south-south-west to north-north-east, essentially parallel to the nearby coasts of Nares Strait. Striae occur on relatively smooth dolomitic limestone approximately 160 m a.s.l. (Figs 1 and 2). The highest point on the island, recorded very close to the observed glacial sculpturing, is 168 m as measured by the Geodetic Survey of Canada. Channel bottom, within a 10 km radius of the island centre is between 473 and 264 m below sea-level. The island is cross-cut by numerous normal faults, probably related to early Tertiary tectonism, but stratigraphic offset is less than 10 m. Thick-bedded dolomitic limestone of the island dips 10–15° towards the north-west, following the attitude of contiguous Palaeozoic strata of north Greenland. These strata are in marked contrast to those of northern Ellesmere Island, a tightly folded and faulted carbonate and clastic sequence.

Two ideas pertinent to the present observations are that Nares Strait was a conduit for extensive Innutian and Greenland ice flux (Weidick, 1978; Blake, 1987) until the latest deglaciation which commenced 8–9 ka B.P., or that it was subject to three episodes of glaciation, occurring approximately at 8, 80, and 500 ka to 1 Ma B.P. However, the two latest, areally restricted glacial episodes produced glaciers which probably did not occupy Nares Strait, implying that the strait was glacier-free from perhaps 500 ka to 1 Ma (England, 1987). It is possible that the oldest (500 ka to 1 Ma B.P.) glacial advance of Greenland ice on to Ellesmere Island may have produced the Hans Island glacial features, but this would require that striae be preserved in relatively good condition on carbonates since ice retreat about 500 ka to 1 Ma B.P.

Fig. 1. View of glacial striae observed at 160 m a.s.l. on Hans Island. Note plucking on north-north-east side of outcrop (Geological Survey of Canada (GSC) photograph 204814).

Fig. 2. Detail of striae and well-developed crescent fractures on limestone. Arrow indicates articulate megalodont bivalve, a typical fossil component of Hans Island strata. The notebook at the top of the photograph is 21 cm long (GSC photograph 204815A).

The relationship between striae-preservation potential and weathering is unclear but, if the weathering characteristic of the Hans Island glaciated carbonates is generally comparable to glaciated rocks of Baffin Island (Dyke, 1979), it would indicate that Hans Island striae were inscribed considerably more recently than during a glacial episode about 500 ka to 1 Ma B.P. A similar case was made for glacial striae on Pim Island (Blake, 1978). There, the age of organic sediments in lakes, the occurrence of striae at a high elevation, and the precariously positioned erratics constrain glaciation to within a similar time frame to that hypothesized for Hans Island. Thus, the relative lack of glacial drift at this locality, the occurrence of striae higher than the recorded position of sea-level during the latest "full glacial sea" (120 m according to England (1987)), and the vulnerability of the carbonates to weathering support a relatively recent time of formation. If, indeed, these structures were the result of an earlier glacial event (e.g. >500 ka B.P.), one would expect erosion of the evidence but, until a quantitative study of weathering of these strata is done, the relationship of time and striae preservation is a moot point.

The implication of the observed glacial structure is that Nares Strait was a conduit for a large glacier which moved *from* the south. Additional evidence for contiguous (?) glacial movement is recorded from east-central Ellesmere Island, on Pim Island, and vicinity. There, abundant sculpturing and scouring of granites indicates a southward ice movement. The present data support the theory of a large grounded glacier in Nares Strait. Ice flowing from two source areas, Ellesmere Island and Greenland, perhaps coalesced in Kane Basin and moved north and south between Greenland and Ellesmere Island (the hypothesis of Blake (1978)). The good preservation of striae may indicate a more recent time for Nares Strait glaciation than that previously hypothesized, for example, occurring up to 10 ka B.P., thereby agreeing with similar episodes of Nares Strait glaciation proposed by Blake (1978) and Weidick (1978); but, clearly, more definitive glacial chronostratigraphy and additional field data would facilitate a more accurate interpretation.

I am grateful to W. Blake of the Geological Survey of Canada (GSC) for drawing my attention to the significance of these observations and for proof-reading a draft of this letter.

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SIR,

The origin of waves on rock glaciers

Lowenherz and others (1989) have applied to rock glaciers the well-known theory of incipient folding in layered beds subject to transverse compression (e.g. Lliboutry, 1987, p. 325-28). As they suspect, they have missed an important process, because they could not have read my publications on the subject (Lliboutry, 1955, 1956, 1961, 1965, 1986; the latter being the only one in English and the most complete of all).

Observations on rock glaciers of different ages show that their surfaces evolve from a flat surface of unsorted material to a patterned ground, where most clasts are aggregated in parallel furrows and on edge, the bulges between being mostly silt. It is only when a final stage has been reached that all the fine material has been washed out from the surface, and the rock glacier deserves its name. (The names "rubble glacier", or "glaciar de escombros" in Spanish, used by Corte, would be better.) Moreover, in the average, more sloping parts of rock glaciers, longitudinal furrows are often found, and this could be explained by no compression. Transverse, arcuate furrows are found only near the front, where the surface slope is gentle.

Outwash is due to melt water from winter snow, and this occurs in spring, a period when very few observations (as ours) have been made. This is unfortunate, because it is the time when soils are active. In semi-arid zones, where rock glaciers form, it is only in spring that soils are water-saturated. They thaw at the surface every afternoon. Water drains readily into the furrows without silt, and remains in the intestitial silty bumps. Nocturnal freezing swells the silt, and squeezes the clasts into the furrows. Moreover, over the furrows the snow cover is thicker and disappears from these later. Both effects enhance the development of furrows with coarse material only. Note that streamlets flowing from the rock glacier have clean water. The silt is transferred to a deeper horizon where it remains. Total outwash of the fine material should occur only after a climatic change, when summer rains become frequent.

Therefore, a "cryonival" process triggers the formation of waves on rock glaciers. This should also govern their spacing, rather than the vertical viscosity profile in the creeping material. For the time being, the subject deserves further field studies on *young* rock glaciers and *in spring* rather than mathematics!

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ERRATUM

Vol. 35, No. 121, p. 314, Fig. 4

The author has drawn attention to an error in the left-hand part of Figure 4. The following is the correct illustration.

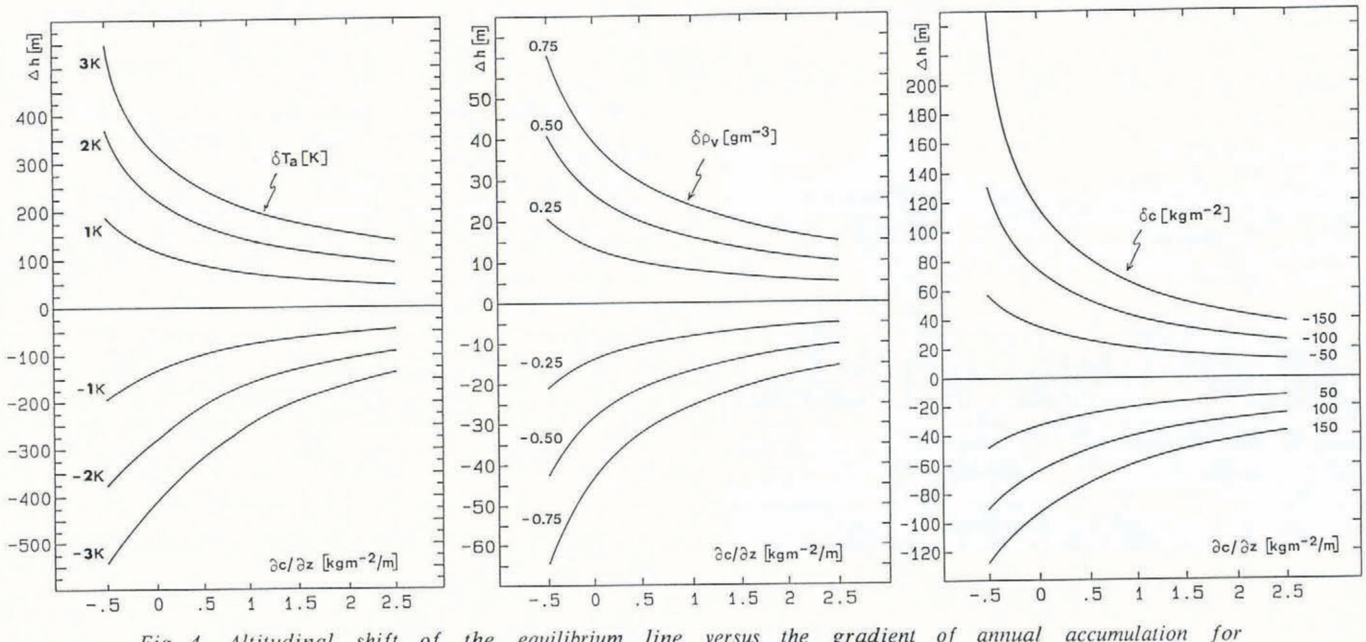

Fig. 4. Altitudinal shift of the equilibrium line versus the gradient of annual accumulation for perturbations of air temperature δT_a (left), absolute humidity $\delta\rho_v$ (center) and annual accumulation δc (right).