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NALED ICE IN FRONT OF SOME SPITSBERGEN GLACIERS

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ABSTRACT. Ice of naled type, in the form of sheets up to 4 m thick and covering areas of 0.5–2.5 km^2, is a frequent feature in front of some of the large Spitsbergen glaciers. Observations from the marginal outwash plain of Werenskioldbreen and the extra-marginal outwash plain of Gåsbreen are presented. The morphological role of this type of ice, on which forms similar to glacial eskers and kames may develop, is indicated.

RÉSUMÉ. *Glace de type "naled" devant quelques glaciers du Spitsbergen.* De la glace de type "naled" (glace de regel de l'eau de fusion) en forme de feuilles allant jusqu'à 4 m d'épaisseur, couvrant des surfaces de 0,5 à 2,5 km^2, se rencontre assez fréquemment à l'avant de quelques grands glaciers du Spitsbergen. Quelques observations provenant de la plaine de lavage marginale du Werenskioldbreen et de la plaine de lavage extra-marginale du Gåsbreen sont présentées. Le rôle morphologique de ce type de glace, dans lequel peuvent se développer des formes analogues à des "eskers" ou à des "kames" glaciaires, est mis en évidence.

ZUSAMMENFASSUNG. *Festeis vor einigen Gletschern Spitsbergens.* Festeis in Schollen von bis zu 4 m Dicke und einer Ausdehnung von 0,5 bis 2,5 km^2 ist eine häufige Erscheinung vor einigen grossen Gletschern Spitsbergens. Beobachtungen im Gebiet der randlichen Auswaschungsebene des Werenskioldbreen und der Auswaschungsebene ausserhalb des Randes des Gåsbreen werden wiedergegeben. Die morphologische Bedeutung dieser Eisart, auf der sich Formen ähnlich den glazialen Eskern und Kames entwickeln könnten, wird herausgestellt.

TYPICAL regions in which naled ice develops are those of permafrost in Siberia and the Arctic zone of North America, where sheets of this type of ice located in river valleys sometimes attain areas up to 26 km^2 (Velmina, 1970, p. 290). It is known, however, that under favourable hydrogeological and atmospheric conditions ice of this type can also develop outside the zone of a cold continental climate.

It appears that naled ice develops quite frequently in the forefields of contemporary glaciers, mainly those of sub-polar type, but so far it has been seldom reported from this particular environment. Spitsbergen is a specific example, to which Liestøl (1969) referred in his remark "the occurrence of refrozen meltwater is a common phenomenon". The Spitsbergen glaciers are ones from beneath which streams of water flow throughout the winter, most probably as a result of subglacial melting due to the geothermal heat flux and friction at the glacier bed. The streams flowing from these glaciers re-freeze in low winter temperatures, thus forming sheets of typical naled ice.

The author had the opportunity of observing naled ice on the outwash plains of several large Spitsbergen glaciers in the period 1957–71. Werenskioldbreen was systematically investigated during that time and each year it produced naled ice covering at least 0.5 km^2. When wintering in 1957–58, the author (Baranowski, 1973) observed at this locality the actual process of subglacial water outflow, its spreading over the sheet of ice that had been formed previously, and its freezing to form a new sheet of naled ice. At the end of the winter season this sheet of ice reached a thickness of 2–4 m. In the southern part of the glacier forefield, at the beginning of July 1958, the naled ice cover was already in an advanced state of thawing and the columnar structure of the ice was clearly visible. By the end of August the ice cover had been cut by several glacial streams but even so its maximum thickness was still considerable. In some places, where the ice had already completely melted, small elongated ridges of sand and gravel, and oval mounds, had appeared. This material had been deposited in tunnels cut in the naled ice cover. These forms were, however, ephemeral ones as the vigorous action of the melt water destroyed them easily. At the end of the 1958 summer, naled ice disappeared from the forefield of Werenskioldbreen, but in the succeeding summer seasons small patches of this ice sometimes survived until the following summer when it eventually melted out.

The author also observed naled ice on the surface of the broad outwash plain of Gåsbreen (Sørkappland) in 1970 and 1971; Norwegian hunters had observed it there in 1969. It is interesting to note that in the years 1957–60 this phenomenon had not been reported from this area, although the original description of small eskers and kames observed on the outwash plain (Gåshamnøyra) (Jewtuchowicz,

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Fig. 1. Sheet of naled ice on the outwash plain of Gåsbreen (Gåshamnøyra) at the end of June 1971.

Fig. 2. A small kame on Gåshammøyra August 1971. This feature still has the naled ice core.

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Fig. 3. Fragment of a small esker on Gåshamnøyra partly destroyed by melt water; August 1971.

1962, 1965) dates from that time. According to Szupryczyński (1963), the presence of these features confirmed the hypothesis that not long ago Gåsbreen had advanced beyond the zone of its terminal moraine and had deposited these eskers and kames.

In 1970, at the beginning of the summer, naled ice covered almost the whole of Gåshamnøyra (2.5 km^2) and reached a thickness of 4 m. The naled ice disappeared at the end of August, leaving a few small ridges (some of which still had iced cores) remaining as true eskers.

A similar situation was observed in 1971. Figure 1 shows naled ice on the outwash plain of Gåsbreen on 30 June. In the central part the thickness of the ice reached 4 m but towards the edges it was only 1.5–2 m. At this time the sheet of ice had already been cut by some of the larger streams flowing out from the glacier front. Thawing of the ice was well advanced.

It it tempting to evaluate the discharge of subglacial streams that build up this ice. If we assume that the ice was deposited during the period 1 September 1970 to 1 May 1971, then, taking the density of naled ice as 0.75 $Mg\ m^{-3}$, the average water discharge during the winter from beneath Gåsbreen was 0.3 $m^3\ s^{-3}$.

In the early days of August 1970 the author revisited the forefield of Gåsbreen. Naled ice had disappeared from almost the whole extra-marginal outwash area; only in its central part there remained a patch of ice about 0.5 m thick but this was in an advanced state of thawing. At several localities, however, where tunnels and canyons had been cut in the naled ice sheet described above, esker- and kame-like forms were observed (Figs 2 and 3). Most of these features had ice in their cores and this was distinctly of naled type.

Eskers and kames, which were observed on the outwash plains of Werenskioldbreen and Gåsbreen, resembled both in their shape and internal structure original forms which were developing

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contemporaneously at the snouts of Spitsbergen glaciers. The forms described here are probably more common than one might judge from previous reports, because the morphological role of the naled ice has generally not been noticed. It could be that some of the previously reported features might have been mistaken for eskers and kames of a true glacial origin.

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