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The development of the marginal zone of the Hörbyebreen Petuniabukta, central Spitsbergen

ABSTRACT: The largest glacier of the Petuniabukta area is the Hörbyebreen. It is among the few on Spitsbergen whose marginal zones undergo areal decay. What has made in this type of glacier is a rich supra-glacial moraine cover that was formed as a result of a deformation of debris bands in the frontal part following a surge. In the marginal zone three subzones were distinguished differing in the degree of degradation of passive ice that covers almost all its area. They also differ in the stability of deposits and in the relief.

Key words: Arctic, Spitsbergen, Billefjorden, Hörbyebreen, glacial morphology.

General characteristics of the glacier

The Hörbyebreen is the largest in the Petuniabukta area, which is the northern end of Billefjorden. It is a valley glacier filling the extension of the bay. Its marginal zone extends between the slope of Birger Jonsonfjellet in the west and the slope of Gizehfjellet in the east. The Hörbyebreen is located in the border zone between Dickson Land and Olav V Land.

Obliquely across the Hörbyedalen, roughly in the north-south direction, runs the fault line of Billefjorden forming a escarpment in the subglacial surface. Almost the whole of the valley was cut in Palaeozoic deposit series, marine and continental, of the Carboniferous and Permian periods. It is only near the faults of Birger Johnsonfjellet and Faraofjellet that metamorphic rocks of the Hecla Hoek formation occur (Lamor, Reed and Douglass 1986).

The glacier is fed mainly by two firn fields situated at an altitude of some 450 m above sea-level; its front reaches an elevation of roughly 100 m above sea-level and its length is 8 km. The width of the zone between the slopes

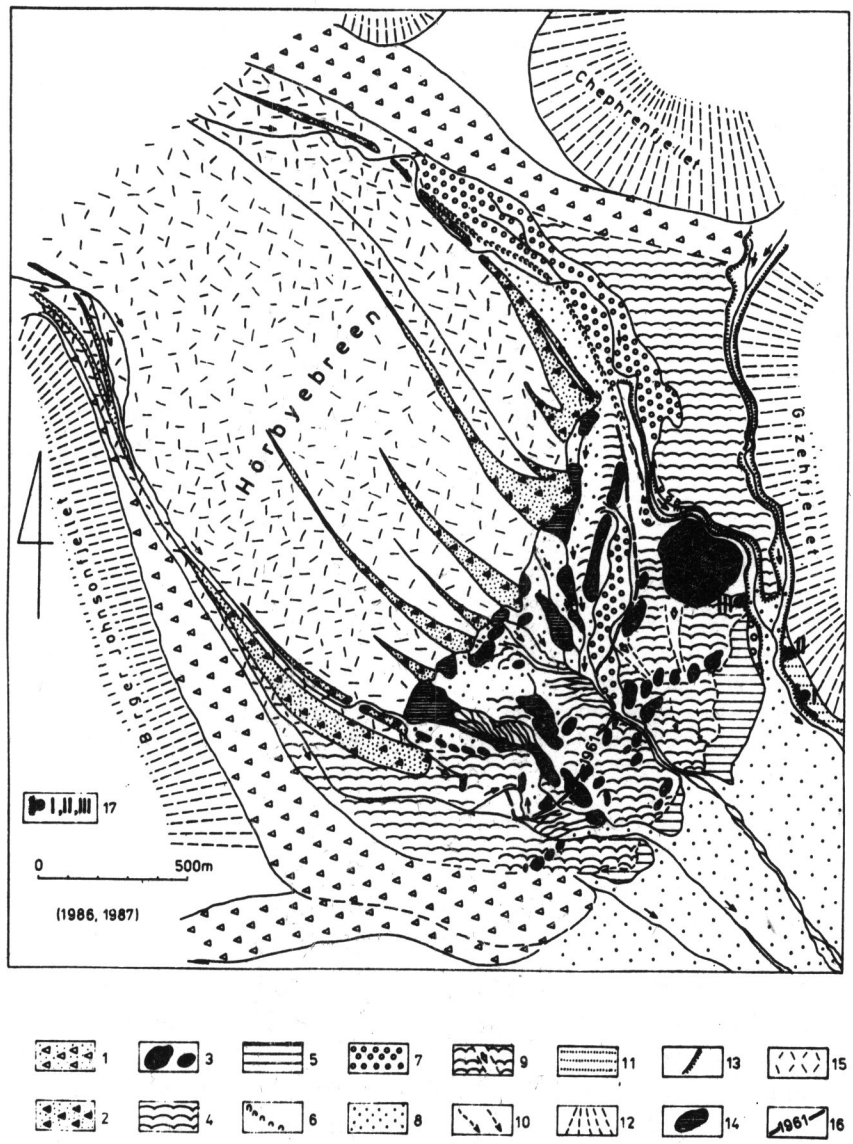


Fig. 1. The marginal zones of the Hörbyebreen.
1 — ramparts of lateral moraines, 2 — debris bands, 3 — ice-morainic hills or their complexes, 4 — a flat or undulating moraine (supra-glacial) cover on stagnant or dead relict ice, 5 — a flat ground moraine, 6 — a crevasse form with an ice core, 7 — higher levels of marginal outwash plains, 8 — the surface of younger outwash plains, 9 — large channels of proglacial waters, 10 — small channels of proglacial waters, 11 — an uplifted marine terrace, 45 m above sea-level, 12 — talus slopes of mountain massifs, 13 — erosion undercuttings, 14 proglacial lakelets, 15 — the glacier, 16 — the 1961 glacier limit as shown in Norwegian aerial photos, 17 — three lithological profiles (*see* the article by A. Karczewski and W. Rygielski)

mentioned amounts to 1.200 m and the length from the contemporary front of the glacier to the southern edge of the moraine surface is some 800 m (Fig. 1).

A feature that distinguishes this glacier from the rest is its way of decay. It decays areally across its whole width, in a belt of a few hundred metres, which results in the development in its foreland of a number of still unstable, ephemeral forms undergoing deformations due to the melting of the relict glacier ice.

The type and causes of glacier decay

This type of decay of the Hörbyebreen was mentioned in Karczewski *et al.* (1987). In its front, concave and active part the glacier has a diversified supra-glacial cover: stony clayey gravel and sandy which keeps the active zone decaying to the advantage of the expanding flat zone of passive ice. This ice is covered with a supra-glacial cover of varying thickness.

When analysing Norwegian aerial photos of 1961, one can discern, especially in the frontal zone of the glacier, clearly deformed debris bands and ice foliation. These phenomena are typical of glaciers that have gone through the stage of surging (Jania 1989 *in press*). In the foreland with passive or dead ice still as the substrate, under the cover of supra-glacial deposits, there are a number of ice-core morainic hills or their complexes suggesting recession sequences. This is not a result of recession, but an indication of the course of ice-core debris bands deformed by a surge and undergoing advanced degradation. The covers of the supra-glacial moraine are composed of weathered material coming principally from the formation of Palaeozoic sedimentary rocks and, to a small extent crystalline rocks of the metamorphic formation. Other indications that the Hörbyebreen has gone through a surge, apart from the deformation of the debris bands, the medial moraine and the foliation, are a loss in the ice mass and a marked lowering of its surface in the longitudinal profile in the middle part near the tectonic fault of the substrate. Numerous transverse crevasses developed there, as well as glacial pits and supra-glacial streams flowing transversely to the foot of the Faraofjellet slope. This situation may lead eventually to the cutting off of the frontal part of the glacier.

The marginal-moraine zone

The marginal zone constituting the immediate foreland of the Hörbyebreen is an area of typical areal decay. Within it, there clear sub-zones can be

distinguished differing in the degree of decay of relict ice, which is the principal constituent of the zone. It also causes morphodynamic differences in processes.

The southern part of the zone, where it borders on the extra-marginal outwash plain, is occupied by a flat moraine. This is the only sub-zone in the substrate of which glacier (relict) ice does not occur. Hence, it is astabilised surface and its sediments do not undergo redeposition. The slight irregularities of the surface are due to shallowly cut channels of melt water which extend into the outwash plain. There are no kettle holes. The glacial till is composed of macroclastic sediment with an insubstantial clay content and a few large boulders. (Pl. 1).

The second, middle sub-zone, the broadest, is an undulating and hilly area. The relief is characterised by numerous hollows and isolated, though sequence--forming, ice-morainic hills as well as a complex of such hills occurring under Gizehfjellet. The ice cores of the hills have their extension in almost the whole-zone in the form of the "floor" of stagnant or dead ice. It is covered with a layer of morainic, supra-glacial deposits. The only places in which relict ice does not occur are the lines of three gorges of proglacial streams draining the Hörbyebreen. At the bottoms of hollows with no outlet glacier ice can frequently be found. There is a permanent redeposition of sediment of the ice-morainic hills. The whole subzone with its relief and deposit layer is not stabilised and ephemeral. (Pl. 2). By comparing 1961 aerial photos of the sequences of debris bands (Fig. 2) with those of the ice-morainic hills of the sub-zone, one can trace a continuation. Hence, it was with deliberation that in 1987 the author called the hill sequences the effect of recession taking in stages. The hills reach a height of from several to 50 m. This continuation and the sharp turn of the debris bands in the sequence of hills are the results of the surge mentioned earlier. Roughly along the middle of the sub-zone runs the limit line of the 1961 glacier as reconstructed from the aerial photos (Fig. 1).

The third sub-zone, closest to the glacier and being in direct contact with the convex, active part of the ice, is the youngest area of stagnant ice. In many places, under a thin ablation cover there occurs passive ice with a visible internal structure, a joint pattern. A great number of very shallow proglacial lakelets with streams flowing through them contributed to the transfer of the finest fractions from the supra-glacial cover of the nearest foreland to the extra-marginal outwash plain and the tidal flat. There is a considerable variability of the surfaces of marginal outwash plains and moraine patches with fluid limits. In the substrate of the deposits building the forms mentioned glacier ice can be found. Here, the lability of deposits is considerable, too.

The three sub-zone of the marginal zone of the Hörbye glacier differ in the degree of degradation of glacier ice in its areal decay, as well as in the stability of deposits and the relief.

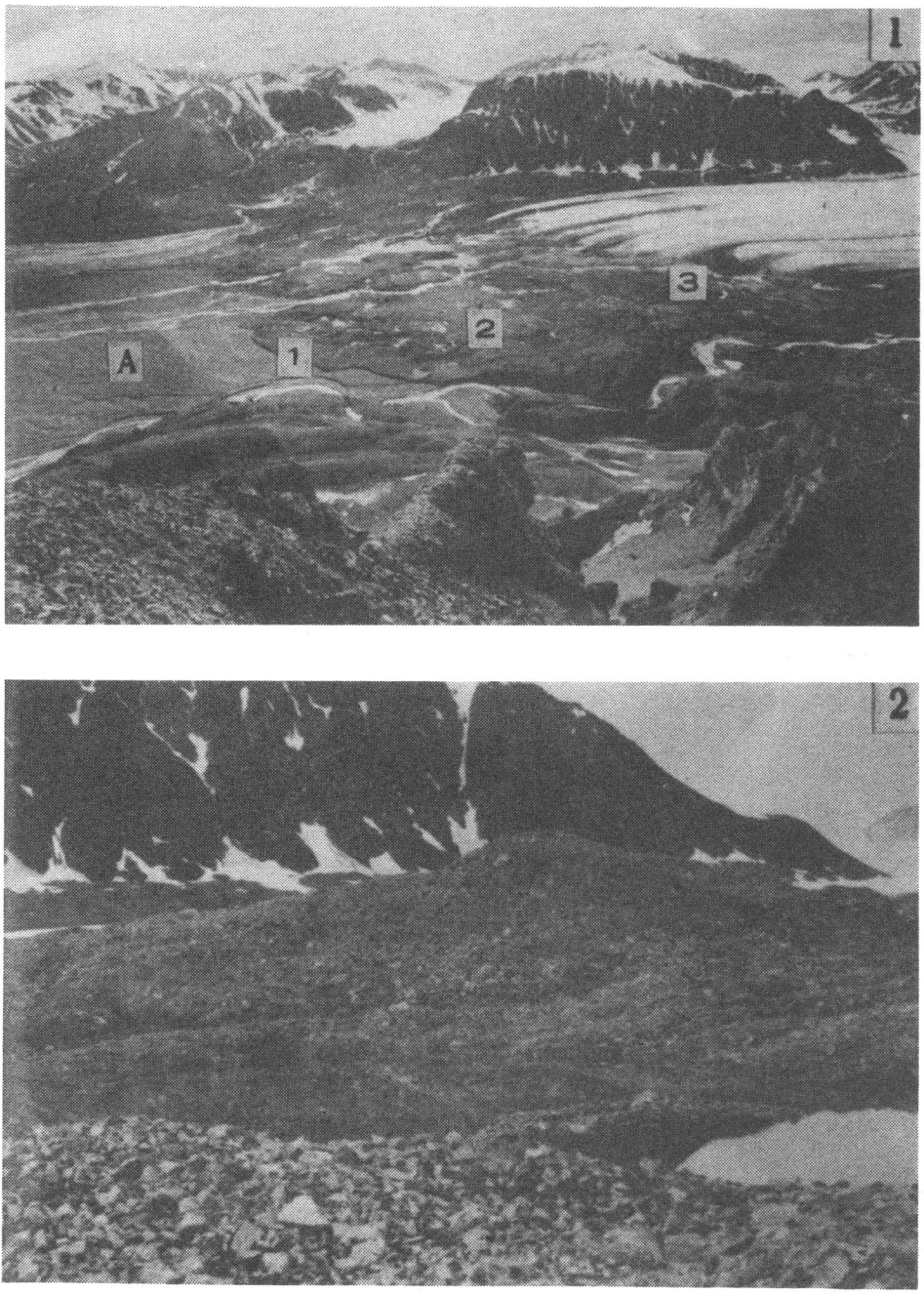
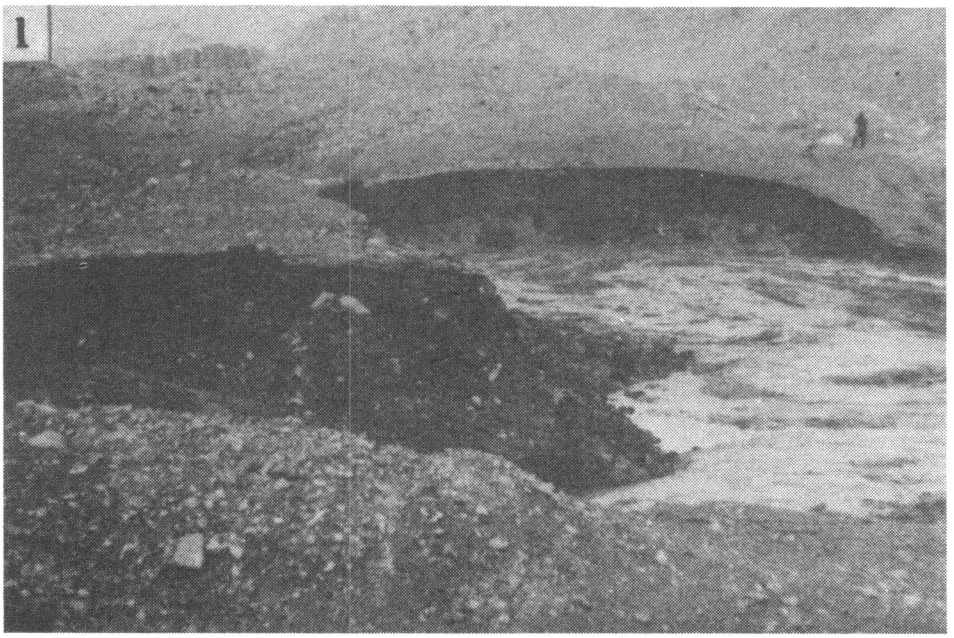


PLATE 1

1. The marginal zone of the Hörbyebreen (1987). 1 — the sub-zone of a flat moraine, 2 — the sub-zone of an undulating moraine and ice-moraine hills, 3 — the sub-zone of unstable surfaces of marginal outwash plains and moraine patches on the surface of passive ice, A — the extra-marginal outwash plain

2. A fragment of the sub-zone with cave-in lakes and hills



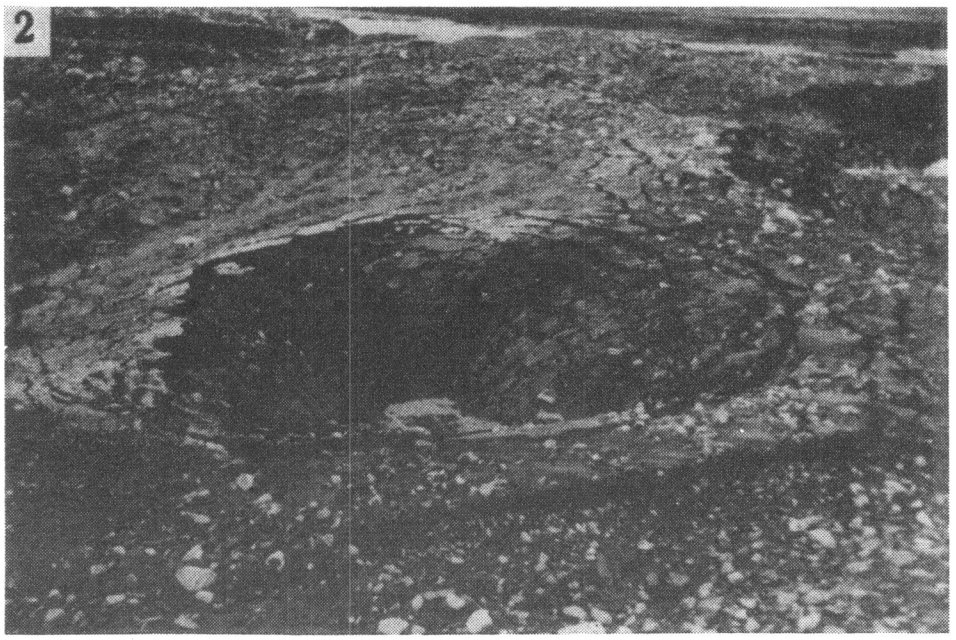


PLATE 2

1. Ice degradation and redeposition of the supra-glacial moraine cover (relict ice in the substrate)

2. The melting of relict ice under the cover of glacio-fluvial deposits

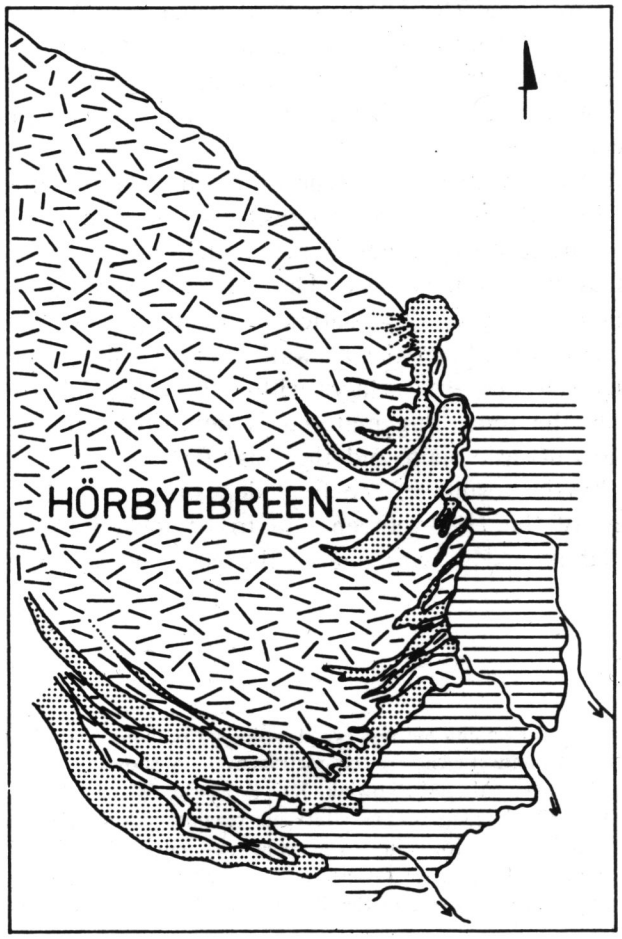


Fig. 2. The pattern of debris bands in the frontal part of the Hörbyebreen in 1961 (on the basis of Norwegian aerial photos)

Proglacial runoff (marginal, extra-marginal, tidal flat)

Owing to the changing position of the Hörbyebreen front during the Vistulian and Holocene, and hence to changes in the glacial and marine morphogenesis of the outlet part of the valley, proglacial runoff developed in different forms. It is also connected with aggradation and erosion in the valley floor. From the Vistulian aggradation, for instance, comes the huge series of deposits visible in the pedestal of the uplifted marine terrace near Gizehfjellet.

Four stages can be distinguished in the Holocene evolution of the runoff network and glacio-fluvial deposition connected with the position of the

active glacier front and the adjustment of waters to the Petuniabukta level (Karczewski *et al.* 1988). In this way four levels of extra-marginal outwash plains were formed, while the degraded and widening zone of stagnant ice and the receding front of active ice produced a system of marginal outwash plains as well.

The contemporary proglacial runoff, usually via the proglacial lakelets, takes place along three principal routes, eastern, medial and western. The water flowing along these routes is active thermally due to which it leads to the degradation of stagnant ice. The marginal outwash plains on the ice pedestal, which undergoes degradation in many places, often modify their surfaces. As a result of proglacial water runoff, dissolved and suspended material is deposited on the surfaces within the marginal zone of the glacier ($\pm 50\%$), while the remaining material is deposited on the surface of the extra-marginal outwash plain and the tidal flat.

That is why the results of the final deposition of sediments leaving the marginal zone of the Hörbyebreen had to be locked for on the tidal flat of the Petuniabukta. This was one of the goals of the expedition.

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Streszczenie

Hörbyebreen jest największym z otoczenia zatoki Petuniabukta — północnego zakończenia Billefjorden. Cechą, którą omawiany lodowiec różni się spośród pozostałych jest jego sposób zaniku. O takim typie zdecydowała bogata morenowa pokrywa supraglacjalna powstała w wyniku deformacji w części czołowej wstęg gruzowych po przebytym surge (porównując norweskie

mapy lotnicze z 1961 roku). Na całej swej szerokości, w pasie kilkusetmetrowym lodowiec zamiera arealnie dając w efekcie szereg form na powierzchni przedpola jeszcze nieustabilizowanych, efemerycznych podlegających deformacjom. W strefie marginalnej wydzielono trzy podstrefy różniące się zaawansowaniem degradacji lodu pasywnego występującego na prawie całej jej przestrzeni. Skraj południowej strefy, na kontakcie z powierzchnią sandru ekstramarginalnego, zajmuje powierzchnia moreny płaskiej. Jest to jedyna podstrefa, w której podłożu nie występuje lód lodowcowy. Podstrefa środkowa, najszersza, to obszar falisty i pagórkowaty. Występuje duża ilość zagłębień oraz izolowanych pagórków lodowo-morenowych. Pagórki nie są wynikiem etapowej recesji (jak błędnie zaklasyfikowano w 1987 r.) ale ciągami zdeformowanych wstęg gruzowych. W jądrach pagórków lód podlega powolnej degradacji. W trzeciej, najbliższej lodowca podstrefie pod cienką pokrywą supraglacjalną występuje lód pasywny ukazujący swą wewnętrzną strukturę. W podstrefie zachodzi przemienność powierzchni sandrów marginalnych i płatów morenowych o granicach nieostrych i dużej labilności.

Trzy wspomniane podstrefy wchodzące w skład strefy marginalnej Hörbyebreen różnią się zaawansowaniem degradacji lodu lodowcowego w jego arealnym rozpadzie oraz zróżnicowaną stabilnością osadów i rzeźby.