POLISH POLAR RESEARCH	10	3	419—427	1989

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The main stages of development of glacier margin morphology in the region between Billefjorden and Austfjorden, central Spitsbergen

ABSTRACT: The main relief features of glacier marginal zones in the region between the Billefjorden and Austfjorden comprise ice-cored moraines, outwash plains and glacial lakes. Characteristics of various types of ice-morainic ridges are given. This article presents examples of outwash fan relief. The results of palaeogeographical analysis serve as the basis for distinguishing between three principal stages of development of glacier morphology and meltwater outflow in the region between the Billefjorden and Austfjorden.

Key words: Arctic, Spitsbergen, Quaternary palaeogeography, ice-cored moraine, glacial lake.

Introduction

The morphology of the region between the Billefjorden and Austfjorden is affected by ice streams flowing from the east and west. The Lomonosovfonna from where glaciers belonging to the Mittag-Lefflerbreen system flow on the east side is the main area of supply to glaciers of the region between the fjords. To the west the Cambridgebreen and Balliolbreen enter the region. An unnamed small glacier feeds the southwestern portion of the region. Ice streams responded variably to changes in the ice mass balance in the areas of supply. From the preliminary geomorphological research conducted during the summer months of 1987, it follows that their responses was not identical everywhere. Consequently, considerable local defferences in marginal

relief resulted, depending on the dynamics of the ice streams. The major landforms that indicate changes in glacier extent in the region between the fjords include ice-cored moraines and outwash fans, some of which bear imprints of remodelling by the spread of glacial lakes.

Ice-cored morainic ridges

Throughout fieldwork a few types of marginal ridges marking positions reached by glaciers were recognized in the region between the Billefjorden and Austfjorden. One of them is associated with the exits of debris bands along which increased delivery of morainic material takes place, thereby encouraging ice conservation. Its particular characteristic is an increase in relative heights towards the glacier terminus. Best developed ridges of this type are reported from the west side of Ålandvatnet in the marginal zone of the Cambridgebreen. The thickness of a debris mantle that preserves dead ice is not great as it does not exceed 1 m in the centre of ridge slopes. Strikingly peculiar is a relatively large quantity of discoidal pebbles present in the morainic material of the Cambridgebreen-Balliolbreen ice stream. Because of typical flattening the pebbles provide evidence for abrasion in the marine environment (Stankowski 1989, *this volume*).

Impressive ice-cored morainic ridges also occur in the centre of Ålandvatnet. As compared with the ridges reported from the marginal zone of the Cambridgebreen, they are blanketed with a thicker supraglacial cover, which seems to indicate a prolonged period of ice-core ablation. The trend of a ridge train follows the maximum advances of the Mittag-Lefflerbreen. However, it cannot be excluded that the ridges were formed in the area of contact between the Cambridgebreen-Balliolbreen and Mittag-Lefflerbreen ice streams.

Another type of ice-cored morainic ridges is associated with geomorphologic settings in which the Mittag-Lefflerbreen abutted against the Trikolorfjellet slope to the east, thereby inducing compression and local pushing. The ridges lie at considerably higher altitudes than those reported from the Ålandvatnet. High location indicates that marginal ridges found on the Trikolorfjellet slopes were left behing due to a local advance of the glacier, resulting from intense snow accumulation over the Lomonosovfonna from which glaciers of the Mittag-Lefflerbreen system travelled. Part of the marginal zone under investigation is also characterized by distinctive morphology. Despite the existence of fairly diversified relief the ridge surface displays distinctive characteristics of sediment stability demonstrated by a high degree of compaction and dryness of deposits. In addition, the supraglacial covers reach many metres in thickness. Till contains marine shells dated by the radiocarbon method to 8.120± 60 yr BP (Gd-1900: Marks and Wysokiński 1987).

The shells are not only encountered on the ridge surface but in deep parts of morainic material as well.

In general the evidence suggests that three generations of ice-cored marainic ridges of different ages, the youngest occuring in the marginal zone of the Cambridgebreen and the presently shaped marginal zone of the Mittag--Lefflerbreen, the older presumbly relating to the Little Ice Age in the centre of Ålandvatnet and the earliest high-lying ridges on the Trikolorfjellet slopes between lakes Ålandvatnet and Hoglandvatnet, can be recognized in the region between the Billefjorden and Austfjorden. The latter ridges are thought to have occured prior to ca. 8.000 years BP.

The southern portion of the region between the fjords does not contain prominent ice-cored ridges. Those found in the southern part of Trikolorfjellet massif have the remains of dead ice. A distinctive characteristic of marginal landforms of this region is their remodelling by active lacustrine processes. This implication is illustrated in Fig. 1 which shows an example of marginal landform remodelling by the waters of a glacial lake. Note should be made here of the fact that the number of lake terraces shown in the figure is not constant across the region between the fjords but ranges from 6—8 in the vicinity of Hoglandvatnet to 2—3 to the north of Ålandvatnet and on the Odelfjellet slopes.

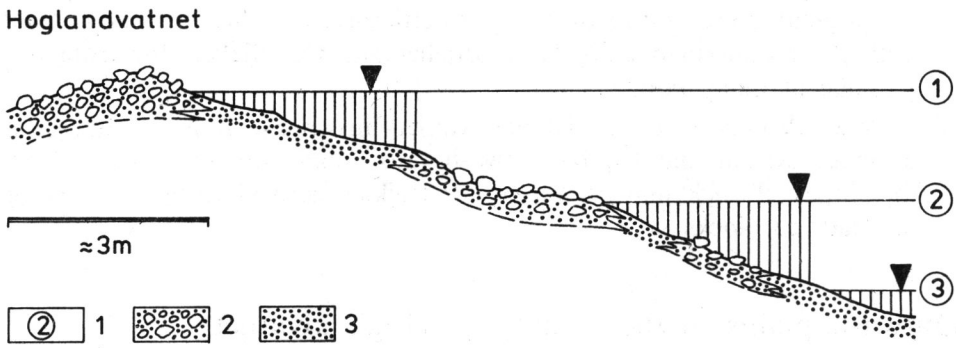

Fig. 1. Profile of Hoglandvatnet shore zone
1 — former upper lake terraces, 2 — debris mantle, 3 — clay mantle

Particulary significant is a marked northward increase in marginal relief energy levels with a fall in the number of lake terraces. Thus, it can be presumed that the glacial relief becomes younger with increasing distance towards the Austfjorden. The times interval between the formation of marginal landforms present near Hoglandvatnet and the production of landforms adjacent to the Austfjorden has been estimated to ca. 8.000—10.000 years. However, these figures are not conclusive. There is a suggestion that an earlier phase of glaciation which left poorly defined imprints in the relief may have occured in the study area.

Ridges of different origin have been recorded in the marginal zones of glaciers belonging to the Mittag-Lefflerbreen system. These are build-up of supraglacial material fallen from hanging steep ice walls. This distinctly angular material has accumulated at the base to form ridges that follow the trend of the glacier margin. In places where deposition occurs on icings produced at the sites of expulsion of a marginal river, ice-cored ridges are formed. The resemble classic ice-cored morainic ridges produced at the exits of debris bands.

Outwash deposits

Other major features of glacier marginal zones in the region between the Billefjorden and Austfjorden include landforms produced by active and spatially changing processes of erosion and accumulation by meltwater. They can be grouped into four morphologic units:

— outwash fans which are variably distributed and coincide with successive steady-state positions of retreating glaciers,
— intramarginal outwash plains within ice-morainic ridge sets, to which material derived from the melting of dead ice blocks is transported by water,
— a marginal outlet along the Mittag-Lefflerbreen in the area of contact with the mountain massifs Trikolorfjellet and Odellfjellet; the trough is gap-like at many points,
— through Alandvatnet and Hoglandvatnet incorporated in the marginal drainage system and fed by outwash fans, small streams flowing over the slopes of rock massifs and water trickles derived from the melting of dead ice blocks.

Outwash plains in the vicinity of Hoglandvatnet

The presence of two outwash plains, one occurring in the southern portion of the lake and the other in the southeastern portion, has been inferred from direct field observations. They are embedded landforms. As one morphologic unit, they drain two different glaciers.

The southern outwash plain drains the unnamed small glacier on the west side and the McWhaebreen on the east side (Fig. 2). In both cases four outwash terraces are conspicuous in the relief. The highest outwash terrace in front of McWhaebreen contains numerous, partially oriented melt-out kettles which make it pitted. Terraces 4 and 1 are most expanded in the outwash plain in front of the unnamed glacier (Fig. 2). The imprints of lake abrasion, occuring as benches and ridges which presumably mark sites of

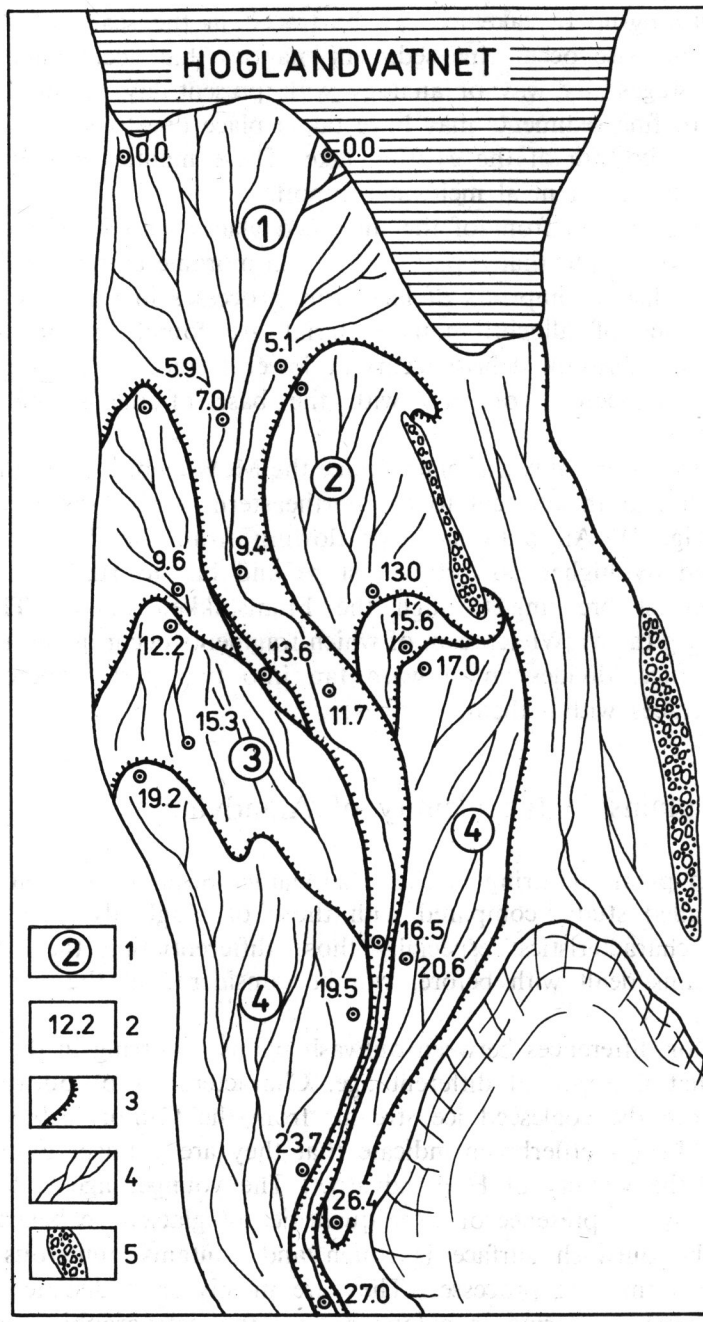

Fig. 2. Morphological sketch-map of an outwash plain in front of the unnamed and McWhaebreen glaciers

1 — outwash terraces, 2 — heights above present-day lake level, 3 — scarps, 4 — braided channel fragments, 5 — till spur

material pushing-up by lake ice can be traced in the scarp of the second terrace. At its base occur fine sediment mantles that accumulated at high lake water stages. By way of analogy with present-day accumulation, the deposition of fine sediments may have taken place due to lodgement on ice frozen to the bottom of the existing lake. These mantles are dissected by gullies resulting from nival meltwater runoff.

Outwash plains in front of the unnamed glacier and McWhaebreen are separated by a till spur that is part of a lateral moraine along McWhaebreen. It also bears distinct imprints of lacustrine processes in the form of shorelines. Build-ups of allochthonous material are found at the uppermost terraces, while abrasion debris occurs at lower terraces. The height of the lowermost lake bench coincides with the base of the second outwash terrace scar.

The south-eastern outwash plain draine the McWhaebreen and the Mittag-Lefflerbreen margin adjacent to the northeastern side of the Framstakken nunatak (Fig. 3). An outwash river flowing from the McWhaebreen is characterized by higher downstream slope and has to run over a longer distance whilest breaking through the Framstakken massif. The lateral moraine along the McWhaebreen, of which fragments occur at the uppermost outwash terrace, divides an outwash fan into two parts. There are two outwash terraces within them.

Outwash plains in the vicinity of Ålandvatnet

Outwash plains occuring in the Ålandvatnet basin have been subjected to less detailed study, compared with those of Hoglandvatnet. Therefore only main characteristics, especially those differentiating them from the outwash plains dealt with before, can be considered at the present stage of research.

The major differences between outwash plains occurring in the two lake basins is that they are of different age. Characteristics of outwash plains resulting from the coalesced ice streams from the Cambridgebreen-Balliolbreen and Mittag-Lefflerbreen indicate that they are younger than outwash material in the vicinity of Hoglandvatnet. The younger age is largely demonstrated by the presence of large quantities of glacier ice beneath gravel mentles. The outwash surface is rough and contains numerous imprints of present-day melting processes. They are mostly short-distance transport outwash deposits differing in colour due to the petrographic composition of glacial bedrock.

To the east Ålandvatnet is surrounded by the marginal zone of the Mittag-Lefflerbreen. Dinstinct meltwater outflow routes extend there at few terraces.

The Ålanddalen occupies an exceptional position in the study area. It is larger than the Cambridgedalen and is now glaciated in the short upper reach only. Its slope is uniform. A braided river cutting through many terraces flows over its floor. Overlying the terraces occur layers of deltaic--stratified fine sediments covering the icings with distinctive crystals. The icings penetrate the valley far inwards. At the mouth the valley is joined by lateral small valleys with embedded terrace sets at steep slopes. Their deep incision is indicative of considerable lowering in the local baselevel of erosion. Because of the above morphologic setting, traces of the former farther-reaching extent lines of Ålandvatnet ought to be searched for in the Ålanddalen.

Conclusions

Conclusions from the analysis of the marginal zone morphology in the region between the Billefjorden and Austfjorden support the establishment of three main stages of relief and marginal outflow development. A schematic illustration of these stages is given in Fig. 3.

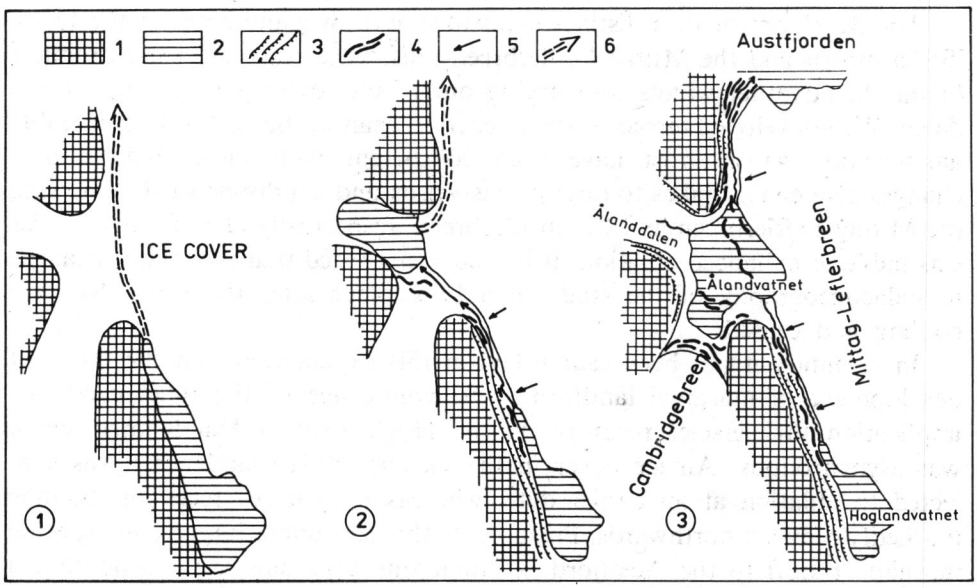

Fig. 3. The main stages of morphology development in the region between the Billefjorden and Austfjorden

1 — rock massifs, 2 — lakes, 3 — former lake shoreline, 4 — ice-morainic ridges, 5 — meltwater gap section, 6 — subglacial outflow

Hoglandvatnet should be regarded as the oldest feature of the marginal relief in the study area. It was formed after the climax of glaciation referred to in the literature as the Billefjorden Stage (Mangerud and Salvigsen 1984). This concept is lergely supported by well-stabilized old outwash plains and high-lying shorelines. It has been presumed that Ålandvatnet still remained inactive then and meltwater runoff from the Hoglandvatnet become subglacial or occured in the area of contact the Mittag-Lefflerbreen and the Trikolorfjellet and Odellfjellet massif, partly over ice. That may have taken place at about 8.000 years BP. The timing of these events is based on dates recorded on marine shells from the ice-morainic ridges (Marks and Wysokiński 1987). Lake water level often fluctuated but the tendency that dominated was that towards lowering. This is implied by well-developed shorelines and outwash terraces.

The second stage of relief shaping in the region between the fjords commenced when Ålandvatnet was formed. Originally it occupied the interior of the Ålanddalen but afterwards it migrated eastwards, following the retreating Mittag-Lefflerbreen terminus. The water level was by several metres higher than nowdays. Considerable marginal runoff to the Austfjorden was then initiated. It occurred at a considerably higher level. Because of exceptionally new relief features found over a distance between Ålandvatnet and the Austfjorden, the implication is that the northernmost part of marginal runoff still occurred at least partially over ice or become subglacial.

The development of a distinct meltwater outflow route between the Odellfjellet massif and the Mittag-Lefflerbreen must have resulted in the drainage of the Ålandvatnet waters and drying out of the lower parts of the Ålanddalen. Well-developed terrace system occurred than in the valley. Considerable amelioration which must have been concurrent with these hydrographic changes also caused lakes to migrate eastwards and southwestwards following the Mittag-Lafflerbreen and Cambridgebreen, respectively. The former glacier was liable to enhanced ablation. It has been suggested that this major changes in palaeogeography of the study area took place after the Little Ice Age cooling had ceased.

In summary it has been established in this explanation that the mode of development of marginal landforms and young age of the relief carry the implication that glacier recession in the Hoglandvatnet-Ålandvatnet region was asynchronous. An ice cover in the vicinity of Hoglandvatnet was subjected to ablation at an earlier date, whereas the rate of recession become markedly reduced northwards. Presumably this accounted largerly for specific marginal runoff to the Austfjorden. Numerous gaps and terraces developed as the glaciers receded, new flows travelled northwards and new meltwater outflow routes were followed.

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Received December 15, 1988
Revised and accepted May 24, 1989

Streszczenie

W trakcie badań terenowych prowadzonych latem 1987 na międzyfiordziu Billefjorden i Austfjorden rozpoznano trzy różnowiekowe generacje wałów lodowo-morenowych: najmłodsze, w strefie marginalnej lodowca Cambridge (Cambridgebreen) oraz we współcześnie kształtowanej strefie marginalnej lodowca Mittag-Leffler (Mittag-Lefflerbreen), starsze, prawdopodobnie pochodzące z okresu Małej Epoki Lodowej, występujące w środkowej części jeziora Åland (Ålandvatnet); oraz najstarsze wysoko położone wały marginalne na zboczach Trikolorfjellet, na odcinku pomiędzy jeziorami Åland i Hogland (Hoglandvatnet), które można określić jako starsze od ok. 8.000 lat BP. Ponadto wyróżniono cztery typy jednostek morfologicznych zawdzięczających swoje powstanie aktywnym i silnie zróżnicowanym przestrzennie procesom erozji i akumulacji wód roztopowych: stożki sandrowe, sandry intramarginalne w obrębie kompleksów wałów lodowo-morenowych, rynnę odpływu marginalnego wzdłuż lodowca Mittag-Leffler, na kontakcie z masywami górskimi Trikolorfjellet i Odellfjellet oraz jeziora przepływowe Åland i Hogland włączone w system hydrologiczny odpływu marginalnego.

Wnioski płynące z analizy rzeźby marginalnej międzyfiordzia Bille-Aust (Billefjorden-Austfjorden) umożliwiają wydzielenie trzech zasadniczych etapów kształtowania rzeźby i odpływu marginalnego. Etapy te pokazano schematycznie na fig. 3. Zapoczątkowało je utworzenie jeziora Hogland, które należy uznać za najstarszy element rzeźby marginalnej a zakończyło ukształtowanie wyraźnego odpływu marginalnego do Austfjorden. Zasadniczą przyczyną takiego stanu rzeczy była asynchroniczność recesji lodowców w rejonie Hoglandvatnet-Ålandvatnet. Wcześniej uległa ablacji pokrywa lodowca w otoczeniu jeziora Hogland, natomiast w kierunku północnym tempo recesji wyraźnie słabło. W konsekwencji powstał specyficzny odpływ marginalny z licznymi przełomami i terasami kształtowanymi w miarę recesji lodowców i otwierania się ku północy coraz młodszych szlaków odpływu.