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# Sedimentation in small proglacial lakes in the Hörbyebreen marginal zone, central Spitsbergen

ABSTRACT: A rich network of bodies of water fed by supraglacial streams has developed in the Hörbyebreen marginal zone due to intensive deglaciation. Most of them are lakelets of 0.1 to 1.0 ha in area and a mean depth of 0.3 to 1.3 m. They developed mainly after 1961. Studies were made of suspended and dissolved sediment concentration, and the ionic composition of the waters of proglacial streams and lakes, followed by an estimate of the balance of the proglacial transport of material. The calculation showed that the total net deposition of mineral material in the marginal zone amounts to 58.45 t per day, which constitutes 56.07 per cent of the total volume transported by proglacial streams. Borings proved sediments deposited in lakes at present to be of little thickness, ranging from 3 to 19 cm. As to litholology, there in a dominance of light-grey silty-clay deposits with a mean grain-size of 5.70 to 6.21 phi, sometimes with thin intercalations of coarse-grained sands and gravels. Chemical analyses shovedthat these deposits contain mostly silicates with small admixtures of Ca and Mg, and that they reflect the geological structure of the area.

## Introduction

Contemporary glacio-limnic sedimentation is one of the major problems that have been drawing scholars' attention for years (*e.g.* Bradbury and Whiteside 1980, Gilbert and Shaw 1981, Liverman 1987, Østrem and Olsen 1987, Smith 1978, Weirich 1985). While the very character and processes of sedimentation in proglacial bodies of water are generally well know, their variability due to changes in the intensity of material transport still calls for all-round and penetrating studies.

An interesting area that offers material for this kind of studies is the contemporary marginal zone of the Hörbyebreen, in which a rich network of bodies of water fed by supraglacial streams has developed due to intensive deglaciation. Such studies were undertaken in 1986. Preliminary results of this research were presented in Karczewski *et al.* (1987). In the present work analysis is made of the intensity and balance of proglacial transport and the magnitude of present-day sedimentation in lakes on the foreland of the Hörbyebreen.

## Study area

The Hörbyebreen, the largest one in the Petuniabukta area, is the northern end of Billefjorden (Fig. 1B). It attains about 10 km in length and 1 km in width in the marginal zone. It is one of the few which decay areally, which results in a number of unstabilized relief forms undergoing deformations due to the melting of dead and passive ice (Karczewski *et al.* 1987).

The contemporary glacial relief covers closely an older one resulting from a complicated geological structure. The oldest metamorphic rocks of the pre-Silurian Hecla Hoek Succesion occur in the western part of the surroundings of the glacier, in a large tectonic structure of the Billefjorden Fault Zone (Lamar, Reed and Douglass 1986). Taking the form of shists, gneisses and amphibolites they build the massifs of Birger Johnsonfjellet and Faraofjellet. The eastern part is mostly occupied by lower-Carboniferous sandstones and conglomerates covered by thicker dolomite and limestone series with intercalations of gypsums and anhydrites of the Ebbadalen, Nordenskjöldbreen and Gipshuken Formations (Lauritzen 1985).

The morphology of the contemporary marginal zone of the Hörbyebreen is a results of a fairly quick recession, as evidenced by several sequences of ice-core morainic hills with relative heights of a few to 50 metres. Between them, under a thin ablation cover, lies passive and dead ice forming an extensive zone with numerous kettle holes (Karczewski, *this volume*). There are also numerous bodies of water there. They are usually connected by means of several proglacial streams forming thus a rich hydrographic network. The lakes are fed by small supraglacial streams and drained by three streams carrying waters onto the outwash plain and the tidal flat (Fig. 1C).

An analysis of Norwegian aerial photos has shown that the majority of lakes occurring on the Hörbyebreen foreland at present developed after 1961 as a result of advancing degradation of blocks of dead ice. Only those few lakes that lie beyond the line of the 1961 maximum extent of the ice margin are much older.

Detailed studies were made of seven lakes in different morphological situations relative to the ice margin. Their location is shown in Figs 1 and 2,

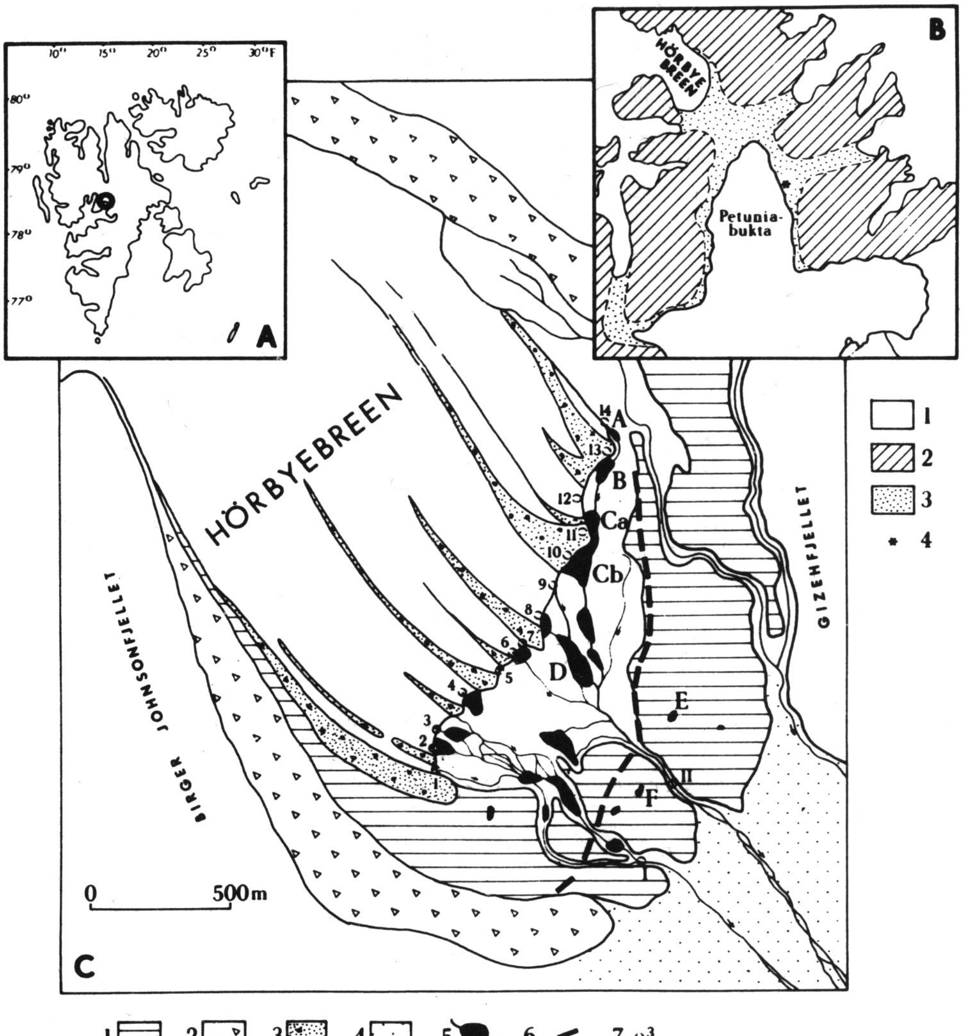


Fig. 1 Location of study area. B. 1 — glaciers, 2 — non-glaciated mountain areas, 3 — Quaternary; mainly outwash plains and marine terraces, 4 — Skottehytta. C. 1 — moraine zone with ice-cored hillocks, 2 — lateral moraine, 3 — supraglacial debris bands, 4 — outwash plain, 5 — lakes and proglacial streams, 6 — extent of glacier in 1961 (based on Norwegian air-photos), 7 — sampling sites. Geomorphology after Karczewski (1989), simplified

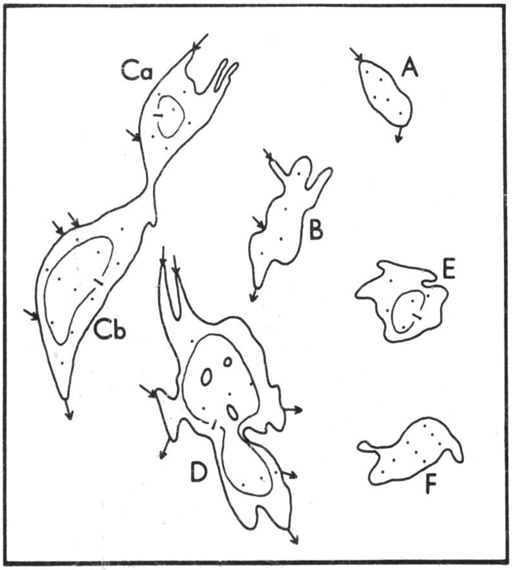


Fig. 2 Bathymetry and location of boreholes in selected lakes of the Hörbyebreen marginal zone

while Table 1 presents their detailed characteristics, including selected bathymetric elements, water temperature and the thickness of sediments. Because the lakes have no names, they were denoted by successive letters of the alphabet.

Table 1

Some characteristics of selected lakes in the Hörbyebreen marginal zone. The location of the lakes is indicated in Fig. 1

| Lake | Area [1] (ha) | Mean depth (m) | Max. depth (m) | Water temperature (°C) | Thickness of deposits (cm) | Age |
|---|---|---|---|---|---|---|
| A | 0.20 | 0.3 | 0.8 | 3.8 | 3—6 | post 1961 |
| B | 0.35 | 0.8 | 1.1 | 7.4 | 3—7 | post 1961 |
| Ca | 0.50 | 0.4 | 1.2 | 4.9 | 5—12 | post 1961 |
| Cb | 0.80 | 0.5 | 1.5 | 6.1 | 4—8 | post 1961 |
| D | 1.00 | ~1.3 | >1.5 | 6.3 | 8—13 | post 1961 |
| E | 0.30 | 0.8 | 1.1 | 4.6 | 5—18 | pre 1961 |
| F | 0.25 | 0.3 | 0.9 | 7.8 | 7—19 | pre 1961 |

[1] estimates based on measurements from an oblique photograph

## Methods

Field studies were carried out from 28 June to 2 August 1986. Water temperature and flow velocity were measured using a hydrometric current meter in selected points located in the profiles of proglacial streams and lakes (Fig. 1). Water was sampled using a bottle bathometer of 1 $dm^3$ in volume. The content of suspended sediment was determined using the filtration method, and the ionic composition using the titrimetric method, after Markowicz and Pulina (1979).

Lake deposits were sampled using a light piston corer with an internal pipe diameter of 50 mm. When the thickness of deposits did not exceed 3—7 cm, only one sample per core was taken for analysis. Otherwise samples were taken from each layer.

The grain-size distribution of the deposits was determine using the sieve method and a Sartorius sedimentation balance. Losses on ignition were established by incinerating the samples in a muffle furnace at 550°C. The ignition residue was treated with concentrated $HNO_3$ and concentrated HCl in a water bath, and then put through filter papers. The main components of the deposits in the solution (Ca, Mg, Na, K) were determined on an AAS-1N spectrophotometer using the atomic absorption method. A total of 38 samples was analysed.

## Sediment transport

### Suspended and dissolved load

Hydrological observations were made during the main ablation season, from the end of June till the beginning of August 1986. This was a period of the stabilization of the ablation runoff regime with regularly recurring diurnal extreme discharges. The discharge registered in the profiles of supraglacial streams ranged from 0.008 $m^3 s^{-1}$ to 0.370 $m^3 s^{-1}$, and in the profiles of two streams carrying waters into the extra-marginal outwash plain, from 0.390 $m^3 s^{-1}$ to 0.920 $m^3 s^{-1}$.

Suspended sediment concentration showed much spatial variation. In the profiles of the supraglacial streams it ranged from 82.34 $mgdm^{-3}$ to as much as 2951.55 $mgdm^{-3}$. The lakes displayed a relatively low variation in suspended sediment concentration, from 75.86 $mgdm^{-3}$ to 364.79 $mgdm^{-3}$ for lakes E and F, and from 151.28 $mgdm^{-3}$ to 540.47 $mgdm^{-3}$ for lakes A, B, Ca, Cb and D (Tab. 2).

In the longitudinal profile from the glacier margin to the moraine zone two kind of changes in suspended sediment concentration were observed: 1 — a regular decrease in its magnitude down the course of the runoff route, 2 — fluctuations.

The first tendency was characteristics of the western part of the foreland, in which the amount of material transported down the stream was no doubt determined by the accumulation of suspended sediment in the lakes along the runoff route. The middle runoff route displayed a different distribution

Table 2

Suspended sediment concentration and ionic composition for lakes and proglacial streams (mean values for season)

| Lake | Suspended sediment concentration ($mgdm^{-3}$) | | Ionic composition ($mvdm^{-3}$) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | range | mean | $Ca^{2+}$ | $Mg^{2+}$ | $(Na^{+}+K^{+})$ | $(HCO_3^{-})$ | $(SO_4^{2-})$ | $Cl^{-}$ |
| A | 398.21- 507.83 | 433.14 | 0.62 | 0.14 | 0.13 | 0.55 | 0.06 | 0.28 |
| B | 151.28- 392.11 | 238.92 | 0.72 | 0.12 | 0.20 | 0.78 | 0.08 | 0.18 |
| Ca | 222.68- 405.64 | 275.42 | 0.68 | 0.18 | 0.27 | 0.75 | 0.16 | 0.22 |
| Cb | 218.13- 540.47 | 353.28 | 0.92 | 0.16 | 0.13 | 0.84 | 0.12 | 0.25 |
| D | 190.02- 507.30 | 364.79 | 0.72 | 0.12 | 0.46 | 1.10 | 0.08 | 0.12 |
| E | 75.86- 247.52 | 192.83 | 0.98 | 0.28 | 0.35 | 1.20 | 0.18 | 0.23 |
| F | 98.62- 364.79 | 184.36 | 1.10 | 0.36 | 0.40 | 1.35 | 0.24 | 0.27 |
| inlet streams (sites 1—14) | 82.34-2951.77 | 541.23 | 0.55 | 0.10 | 0.30 | 0.72 | 0.08 | 0.15 |
| outlet streams (sites I—II) | 236.46- 829.17 | 349.52 | 1.07 | 0.26 | 0.38 | 1.20 | 0.20 | 0.31 |

Table 3

Proglacial sediment transport balance for the Hörbyebreen marginal zone (mean values for season). The location of measured sites is indicated in Fig. 1

| | Site | | | | | | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A. INFLOW | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | |
| discharge ($m^3s^{-1}$) | 0.330 | 0.300 | 0.053 | 0.038 | 0.051 | 0.036 | 0.056 | 0.011 | 0.087 | 0.012 | 0.015 | 0.014 | 0.013 | 0.021 | |
| suspended concentration ($mgdm^{-3}$) | 2763.90 | 390.59 | 82.56 | 126.17 | 161.45 | 96.65 | 300.75 | 188.47 | 162.63 | 269.18 | 303.65 | 319.39 | 457.83 | 347.99 | |
| dissolved concentration ($mgdm^{-3}$) | 105.00 | 95.00 | 98.00 | 85.00 | 63.00 | 80.00 | 95.00 | 70.00 | 68.00 | 75.00 | 67.00 | 102.50 | 107.50 | 75.00 | |
| total sediment concentration ($mgdm^{-3}$) | 2868.90 | 485.59 | 180.56 | 211.17 | 224.45 | 176.65 | 395.75 | 258.47 | 230.63 | 344.18 | 370.65 | 421.89 | 565.33 | 422.99 | |
| suspended load ($gs^{-1}$) | 912.09 | 117.18 | 4.33 | 4.77 | 8.14 | 3.51 | 16.78 | 1.98 | 14.15 | 3.23 | 4.55 | 4.27 | 5.68 | 7.31 | |
| dissolved load ($gs^{-1}$) | 34.65 | 28.50 | 5.15 | 3.21 | 3.18 | 2.90 | 5.30 | 0.74 | 5.92 | 0.90 | 1.01 | 1.39 | 1.34 | 1.58 | |
| total sediment load ($gs^{-1}$) | 946.74 | 145.68 | 9.48 | 7.98 | 11.32 | 6.41 | 22.08 | 2.72 | 20.07 | 4.13 | 5.56 | 5.56 | 7.01 | 8.89 | |
| total load/day (tons) | 81.80 | 12.59 | 0.82 | 0.69 | 0.98 | 0.55 | 2.13 | 0.24 | 1.73 | 0.36 | 0.48 | 0.49 | 0.61 | 0.77 | 104.24 |
| | Site | | | | | | | | | | | | | | |
| B. OUTFLOW | I | II | | | | | | | | | | | | | |
| discharge ($m^3s^{-1}$) | 0.819 | 0.420 | | | | | | | | | | | | | |
| suspended concentration ($mgdm^{-3}$) | 352.99 | 342.50 | | | | | | | | | | | | | |
| dissolved concentration ($mgdm^{-3}$) | 80.00 | 75.00 | | | | | | | | | | | | | |
| total sediment concentration ($mgdm^{-3}$) | 432.99 | 417.50 | | | | | | | | | | | | | |
| suspended load ($gs^{-1}$) | 289.10 | 143.85 | | | | | | | | | | | | | |
| dissolved load ($gs^{-1}$) | 65.52 | 31.50 | | | | | | | | | | | | | |
| total sediment load ($gs^{-1}$) | 354.62 | 175.35 | | | | | | | | | | | | | |
| total load/day (tons) | 30.64 | 15.15 | | | | | | | | | | | | | 45.79 |
| C. NET DEPOSITION (tons/day) | | | | | | | | | | | | | | | 58.45 |

of transported material. Maximum magnitudes were recorded both in river beds and in their outlets into the lakes due to decreasing slope and enrichment with material coming from lateral erosion. Low concentration levels were registered below thresholds as a results of the accumulation of material in hollows connected with the break of slope and the material (debris) building the thresholds.

The waters of the lakes and proglacial streams were found to have a fairly constant ionic composition independent of the mineralization level and the sampling site (Tab. 2). The dominant types of solutions were $HCO_3$—$Ca^{2+}$—$(Na^+ + K^+)$ as well as $HCO_3^-$—$Ca^{2+}$ and $Ca^{2+}$—$HCO_3$. In some sites located in the eastern part of the ice margin solutions of the $Ca^{2+}$—$SO_4^{2-}$ type were recorded resulting from the solution of gypsum occuring on the eastern side of the Hörbyebreen valley.

The concentration of material dissolved in the lakes and proglacial streams ranged from 42.80 $mgdm^{-3}$ to 124.18 $mgdm^{-3}$ and did not show any major spatial variation. Only the waters of small supraglacial streams have a relatively low mineralization level, about 51.02 $mgdm^{-3}$ on average.

There was a much greater variation in dissolved loads than in concentration. Their spatial changeability was similar to that of suspended sediment. Small loads, of 0.58—1.60 $gs^{-1}$, were found in the profiles of small supraglacial streams, while the greatest (32.58 $gs^{-1}$ on average) were registered at the outlets of large streams in the western part of the glacier.

## Sediment balance

On the basis of hydrological and hydrochemical studies conducted estimates were made of the balance of the proglacial sediment transport. As can be seen in Tab. 3, the total daily load of suspended and dissolved material brought by supraglacial streams into the foreland of the Hörbyebreen amounts to 104.24 tons. 45.79 tons of suspended and dissolved sediment are carried beyond the marginal zone, into the outwash plain and the tidal flat. Thus, the total net deposition within the marginal zone amounts to 58.45 tons per day. This is 56.07 per cent of the total volume of material transported by proglacial streams. Suspended sediment makes up about 90 per cent of this total volume of material deposited on the foreland of the glacier, mostly in lakes.

The above-presented magnitude of contemporary sedimentation is certainly underestimated because bed transport has not been included. However, it reflects the general proportions of proglacial sediment deposition in other regions, ranging from 64% for a shallow lake in the Purcell Mountains (Weirich 1985) to 70—80% for the catchments of Norwegian glaciers (Kjeldsen 1983, *see* Weirich 1985).

## Lake deposits

### Lithology

On the basis of borings (*see* Fig. 2) it was found that the thickness of presently deposited sediments in the lakes is slight and does not exceed 20 cm. It is the slightest (3—12 cm) in the ice-marginal lakes: A, B, Ca and Cb, and the greatest in lakes E and F situated in the southern part of the foreland. The thickness of deposits is thus a function of the distance of a lake from the ice margin and, indirectly of their age.

Three facies of deposits filling the lakes were distinguished:

— coarse sands and gravels (Gm),

— massive, grey clays and silts (Fm), and

— planar-bedded and massive fine sands (Spm).

The facies of coarse sands and gravels is the substrate of the majority of the lakes: it also forms thin, 3—5 cm intercalations of clay deposits in lakes E and F (Fig. 4). They are largely fluvio-glacial deposits connected with the drainage of the frontal zone of the glacier. In most of the samples

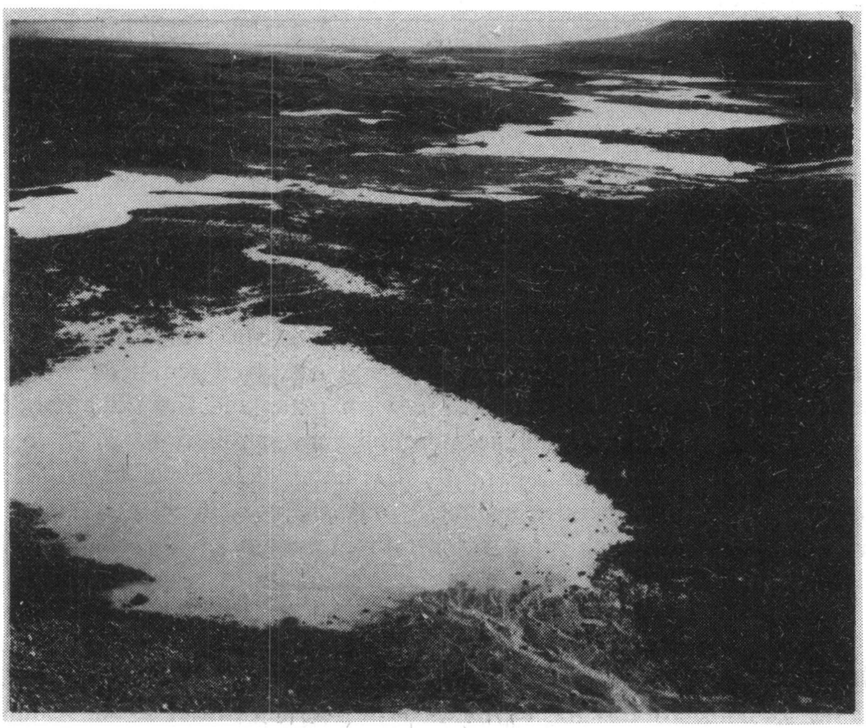

Fig. 3. Lakes in the Hörbyebreen foreland. Lake A in the foregrounded, ice-cored hillocks marking the 1961 glacier extent in the background (Photo by A. Wojciechowski. July 1986)

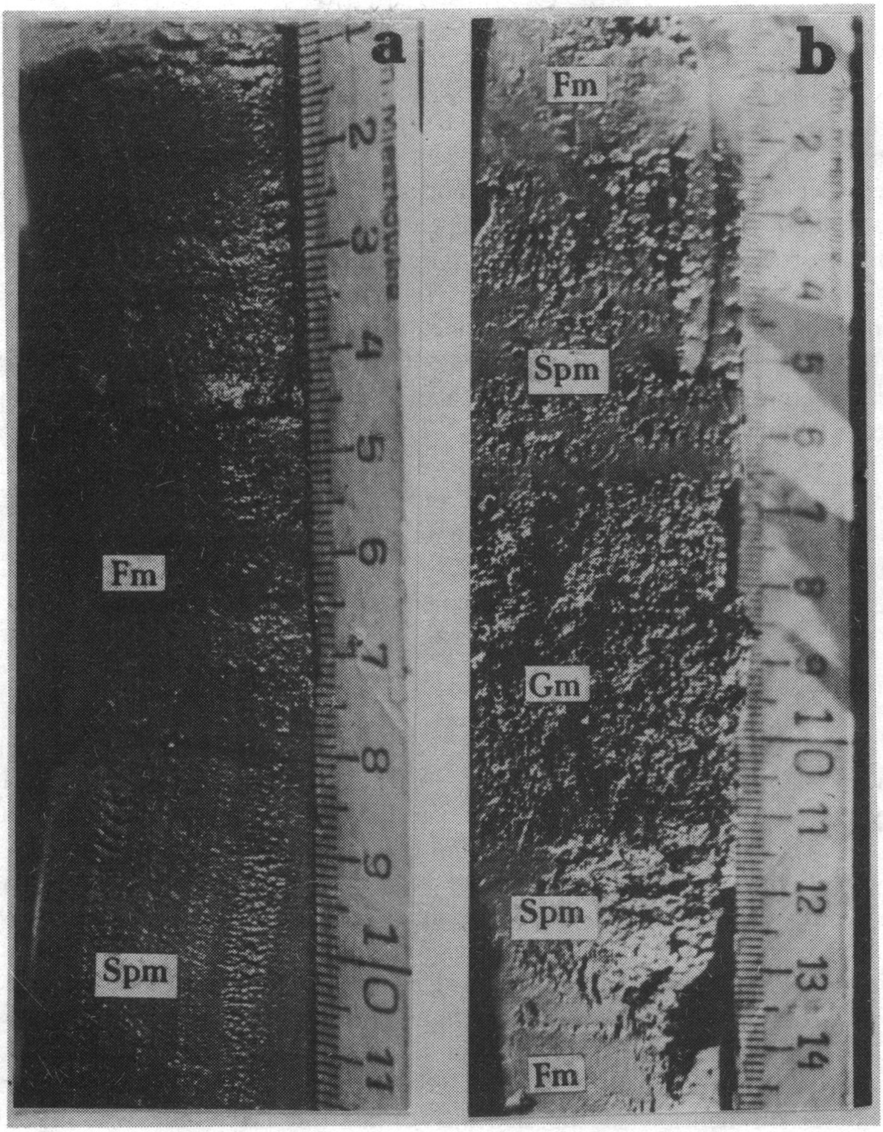


Fig. 4. Representative cores from lake D (a) and lake F (b). Sediment facies: Fm — massive gray clays and silts, Spm — planar-bedded and massive fine sands, Gm — coarse sands and gravels

analysed the mean grain-size ranges from 0 to $-2$ phi, but not infrequently clasts of 3—5 cm in diameter can be found in the deposits.

A dominant facies occuring in all the lakes irrespective of their location and size are clay-silt deposits. In lakes A and Cb they lie directly on stagnant glacier ice, while in lakes B, Ca and D on a sharp-edged ice pavement.

The dominant fraction in these deposits is silt (4—8 phi) with its share of 68.6 per cent, and clay (over 8 phi) whose share ranges from 10.5 to 24.7 per cent (13.8% on the average). There is a sand admixture, mainly of fine sand, ranging from 2.2 to 31.8 per cent, with the coarsest material (under 3 phi) not exceeding 5 per cent as a rule. The mean grain-size of these deposits varies between 5.70 and 6.21 phi (6.09 phi on the average). No spatial variation in the textural features of the deposits of this facies can be observed. In all the lakes differences in grain-size indices are slight, and the decrease in the Mz value is related with the increase in the sand admixture, mainly in the littoral zones of the lakes.

The facies of fine sands as a rule forms small deltaic fans situated at the outlets of the streams into the lakes (Fig. 3), and delicate, several-millimetre laminae in silty-clay deposits. These deposits are poorly and fairly well sorted ($\delta_I = 1.13$) as well as positively skewed ($Sk_I = 0.13$), and their mean grain-size varies between 2.89 and 3.62 phi (3.21 phi on the average).

In the lakes under study no rhythmically stratified deposits (varves) were found. Their absence should probably be attributed to the little depth of the lakes and a fairly intensive sedimentation of suspended material.

## Chemical characteristics

In the analysed samples silicates are the principal component. Their content ranges from 754.75 mg $g^{-1}$ to 803.72 mg $g^{-1}$ and does not show any major spatial and stratigraphic variation. A slightly higher percentage of $SiO_2$ is found in deposits containing sand and gravel admixture.

In all the samples the content of losses on ignition, which can roughly be identified with the content of organic matter, is low and varies between 25.81 to 77.37 mg $g^{-1}$ (Tab. 4, Fig. 5). Similar figures for the content of this substance in the deposits of proglacial lakes are quoted by Österholm (1986) from the Nordaustlandet region, and as well as Bradbury and Whiteside (1980) for some lakes and ponds in the foreland of the Klutlan Glacier. A distinct tendency can be noticed in the spatial variation of the content of losses on ignition in the deposits of all the lakes, namely a gradual increase in the share of this substance with the growing distance of the lakes from the ice margin. In the deposits of the ice-marginal lakes (A, B, Ca, Cb) the losses on ignition attain the lowest values averaging 26—36 mg $g^{-1}$, to increase to 65—77 mg $g^{-1}$ in those situated in the southern part of the foreland, *i.e.* the "oldest". This marked increase can be put down primarily to the enrichment of deposits with organic matter, which can be an indication of the age of the deposits.

The Ca content displays the greatest variation and its determined values range from 2.89 to 12.71 mg $g^{-1}$. The lowest content of Ca is in samples with a substantial admixture of sands and gravels, while the highest Ca

Table 4

Chemical characteristics of the sediments in selected lakes (mean, min. and max. values)

| Lake | Loss on ignition mg $g^{-1}$ | Silicates mg $g^{-1}$ | Ca mg $g^{-1}$ | Mg mg $g^{-1}$ | Na mg $g^{-1}$ | K mg $g^{-1}$ |
|---|---|---|---|---|---|---|
| A | 32.16<br>25.81-36.04 | 789.89<br>775.46-803.72 | 9.03<br>6.60-11.02 | 12.70<br>11.88-14.17 | 0.55<br>0.47-0.62 | 5.75<br>5.25-6.73 |
| B | 30.62<br>26.47-34.48 | 789.74<br>774.72-795.86 | 11.59<br>10.38-12.71 | 13.95<br>13.63-14.41 | 0.54<br>0.48-0.58 | 5.14<br>4.36-6.08 |
| Ca | 27.84<br>25.88-31.12 | 775.06<br>770.22-794.15 | 6.13<br>5.31-8.04 | 13.87<br>12.96-14.63 | 0.34<br>0.29-0.38 | 5.24<br>5.04-6.12 |
| Cb | 31.03<br>27.12-36.80 | 781.20<br>769.99-796.15 | 7.11<br>6.11-9.85 | 12.29<br>10.28-14.01 | 0.49<br>0.30-0.57 | 5.07<br>4.20-6.38 |
| D | 48.83<br>39.30-57.12 | 776.21<br>775.02-790.18 | 8.18<br>6.33-10.80 | 11.43<br>10.93-13.20 | 0.46<br>0.39-0.60 | 5.80<br>4.92-6.81 |

Chemical composition of sediments in lakes E andF is presented in fig. 5.

concentration is registered in presently deposited silt sediment of the lakes near the ice margin (Tab. 4).

In all the samples the Mg content is slightly higher than that of Ca, which can indicate that the suspended sediment deposited in the lakes is dolomitic in character. As in the case of calcium, the concentration of magnesium is closely connected with the content of clay. The Mg content increase

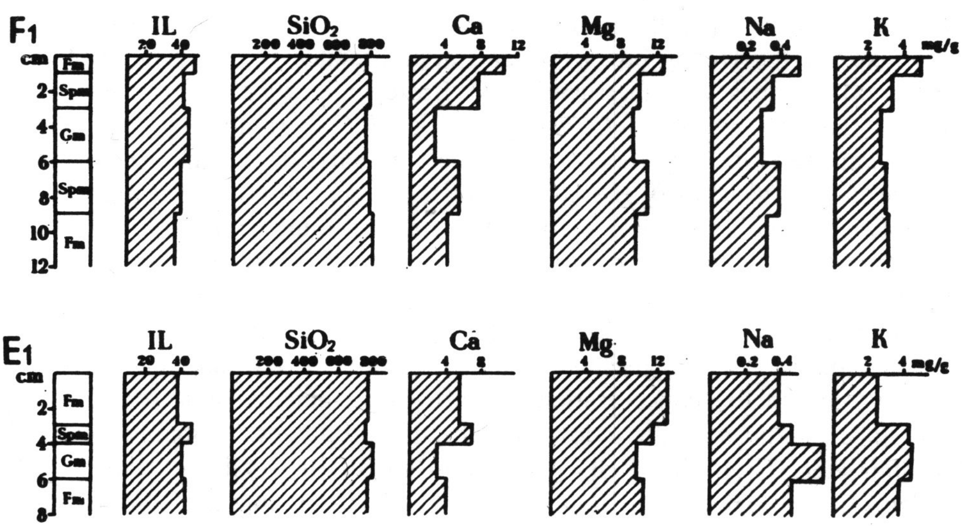


Fig. 5. Chemical characteristics of sedimentsin lake E (profile E1) and lake F (profile F1) Lithology: Fm — massive gray clays and silts, Spm — planar-bedded and massive fine sands, Gm — coarse gravel and sands

in deposits with the highest share of the finest fraction and it drops in those with a sand admixture.

In all the samples the content of sodium is the lowest and varies from 0.28 to 0.69 mg g $^{-1}$ (Tab. 4). It does not show a major spatial and stratigraphic variation. Potassium is a component strongly sorbed by a colloidal substance, hence its concentration exceeds that of sodium 10 times. The highest figures for the K content (5.07—5.80 mg g $^{-1}$) are registered in the presently deposited sediment of the lakes near the ice margin that also has the highest content of the clay fraction. In the deposits of lakes E and F its content drops to 2—4 mg g $^{-1}$, which is connected with the increase in the content of silicates and the sand fraction.

## Conclusions

The lakes occurring in the foreland of the Hörbyebreen developed mainly after 1961 as a result of an intensive deglaciation and areal decay of the marginal zone. For the most part the lakes are small and their origin and size correspond to those occuring in the foreland of the Klutlan Glacier (Whiteside, Bradbury and Tarapchak 1980). Their evolution is closely connected with the Hörbyebreen retreat and the magnitude of mineral material transport. The most significant component in the proglacial transport balance is suspended sediment amounting to almost 90 per cent of the material supplied to the lakes. While the ionic composition of water and the concentration of dissolved material do not very much, the concentration and loads of suspended sediment determine the magnitude of present-day glacio-limnic sedimentation. Suspended sediment concentration in proglacial streams and the lakes of the Hörbyebreen foreland approximates to the values recorded from other areas (*cf.* Pietrucień and Szczepanik 1982, Szczepanik 1982, Gilbert and Shaw 1981; *cf. also* the table in Gilbert and Desloges 1987).

It can be stated on the basis of analyses carried out that the deposits of the proglacial lakes of the Hörbyebreen foreland display very high homogeneity, both with respect to textural features and ionic composition. In those resulting from an intensive deposition of suspended sediment the dominant fraction is clay-silt, averaging 75—85 per cent of the whole of a deposit. Disregarding organic matter, the elements that open the migration series are silicate followed by magnesium, calcium, potassium and sodium. This type of variation in the concentration of particular elements indicates that they are silicate deposits with a low content of carbonates, probably dolomitic in character. Thus, the chemical composition of the analysed lake deposits reflects the geological structure of the glacier's surroundings and also resembles the mineralogical composition of the glacial deposits of this area, in which silicates and carbonates dominate in similar proportions as well (Stankowska 1987).

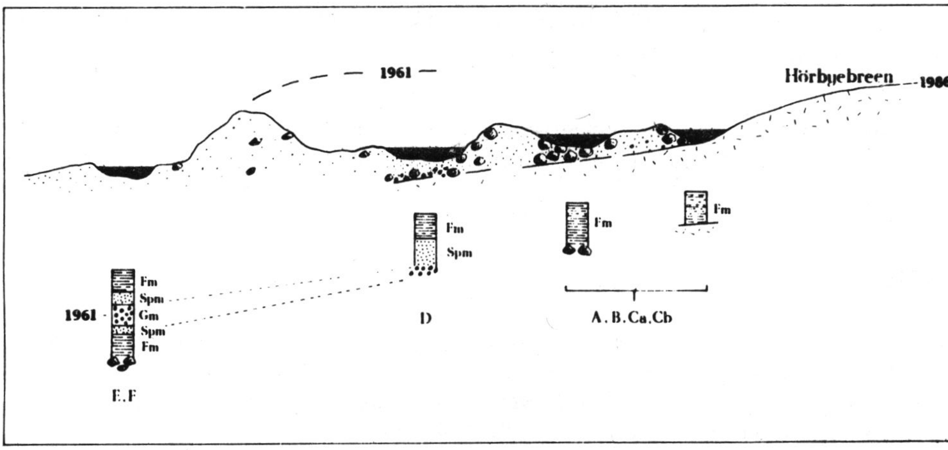


Fig. 6. Schematic cross-section of the Hörbyebreen marginal zone and interpretation of a sedimentary sequence (no scale). For facies names see Fig. 4

A clear relationship can be noticed between the sequence of the facies of lake deposits, in spits of their thinness, and the glacial retreat and the formationof the proglacial runoff (Fig. 6). The sequence is composed of both, deposits of vertical accretion (facies Fm) produced by glacio-limnic sedimentation and deposits of lateral accretion (Spm, Gm) connected with the migration of braided channels (Shaw 1975). Another type of sequence is best illustrated by the cores of deposits sampled from lakes E and F, in which clay deposits are interbedded with a thin coarse-grained series. Deposits of the Gm and Spm facies occurring in these profiles (Fig. 6) are interpreted as fluvio-glacial ones, connected with the drainage of the frontal zone of the glacier along its 1961 extent line. The coarse-grained deposits in the substrate of lake D probably correspond to this layer. The presently accumulated deposits in the ice-marginal lakes (A, B, Ca and Cb) are exclusively those of vertical accretion of the Fm facies. They lie either on a sharp-edged ice pavement or on stagnant glacier ice (Fig. 6). At the outlets of proglacial streams into the lakes they often mix with sand deposits of small deltaic fans of the Spm facies.

The sedimentation rate of clay-silt deposits (of the Fm facies) in the proglacial lakes under study, calculated on the basis of suspended sediment concentration, depends primarily on the magnitude of the present-day supply of material and also on the rate of retreat of the Hörbyebreen. In lakes E and F, situated beyand the 1961 maximum extent line of the glacier, it ranges from 0.8 to 1.6 mm/year, in lake D it averages 2.4 mm/year, and in the lakes near the margin (A, B, Ca and Cb) it exceeds 5 mm/year. The higher sedimentation rate in comparison with other proglacial lakes (*cf.* Gilbert and Desloges 1987, Liverman 1987, Osterholm 1986, Weirich 1985) results from larger supplies of clastic material in proportion to the areas of the lakes, though it is not unlikely that the figures quoted cover also the part of deposits coming from the melting of ice substrats.

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# Streszczenie

W obrębie strefy marginalnej Hörbyebreen, na skutek intensywnej deglacjacji rozwinęła się bogata sieć zbiorników wodnych zasilanych strumieniami supraglacjalnymi (fig. 1, 3). Większość z nich stanowią niewielkie jeziora o powierzchni od 0,1 do 1,0 ha i głębokości średniej od 0,3 do 1,3 metra, powstałe głównie po 1961 roku (fig. 2, tab. 1). Przeprowadzono badania koncentracji zawiesiny, substancji rozpuszczonych, składu jonowego wód potoków proglacjalnych oraz jezior (tab. 2) obliczając szacunkowy bilans transportu proglacjalnego materiału. Z obliczeń wynika, że całkowity ładunek dobowy materiału zawieszonego i rozpuszczonego, dostarczanego przez potoki proglacjalne na przedpole lodowca wynosi 104,24 tony, z czego poza obręb strefy marginalnej, na obszar sandru i równi pływowej, wynoszone jest 45,79 ton materiału na dobę. Łączna zatem depozycja netto materiału mineralnego w obrębie strefy marginalnej wynosi 58,45 ton na dobę, co stanowi 56,07 procent ogólnej masy transportowanej przez potoki proglacjalne (tab. 3).

Wiercenia wykazały niewielkie miąższości współcześnie deponowanych osadów w jeziorach, wynoszące od 3 do 19 cm. Pod względem litologicznym dominują jasno-szare osady ilasto-mułkowe o średniej średnicy ziarna 5,70—6,21 phi, przewarstwione niekiedy cienkimi wkładkami piasków gruboziarnistych i żwirów (fig. 6). Analizy chemiczne wykazały, że osady te zawierają głównie krzemiany z niewielkim udziałem węglanów Ca i Mg (fig. 4, tab. 4) i odzwierciedlają budowę geologiczną obszaru.