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Quaternary landforms, sediments and morphogenetic evolution of Hansbreen-Sofiekammen region, Wedel Jarlsberg Land, Spitsbergen

ABSTRACT: Mapping and analysis of air photos enabled preparation of a photogeological map of the Hansbreen-Sofiekammen region in a scale of 1 : 10,000. Glacial, slope and marine landforms and sediments were distinguished. Supplied with thermoluminescence and radiocarbon data, a morphogenetic evolution of the area could be presented. Four Pleistocene and Holocene glacier advances were distinguished. Seven raised marine beaches result from the Pleistocene and the Holocene uplift of the land.

K e y w o r d s: Arctic, Spitsbergen, photogeological mapping.

Introduction

The paper presents Quaternary landforms and sediments of mid-northern seashore in Hornsund, Wedel Jarlsberg Land, Spitsbergen (Fig. 1). This area comprises a tidewater part of the Hans Glacier (Hansbreen) (Pls 1–2), fragments of mountain massifs Fugleberget and Tuva to the west of this glacier, mountain massifs Fannytoppen and Flatryggen to the east, and the massif Sofiekammen (Pl. 3) which occurs slightly eastwards – with snow-mantled glaciers Sofie (Sofiebreen) (Pl. 4) and Wiener (Wienerbreen). In Burgerbukta there is the tidewater Paierl Glacier (Paierlbreen) and the cape Luciapynten, being a southern tip of the mountain massif Luciakammen (Fig. 1).

The region has been previously many a time but usually only generally examined (Birkenmajer 1958a, 1959, 1960a; Jahn 1959; Pulina 1974, 1975, 1977; Bieroński and Pulina 1975; Pękala 1975, 1980a, b; Baranowski 1977; Karczewski, Kostrzewski and Marks 1981; Baranowski and Pękala 1982; Kozarski 1982; Kłysz 1983a, b; Karczewski *et al.* 1984). Other papers dealt with dynamics of

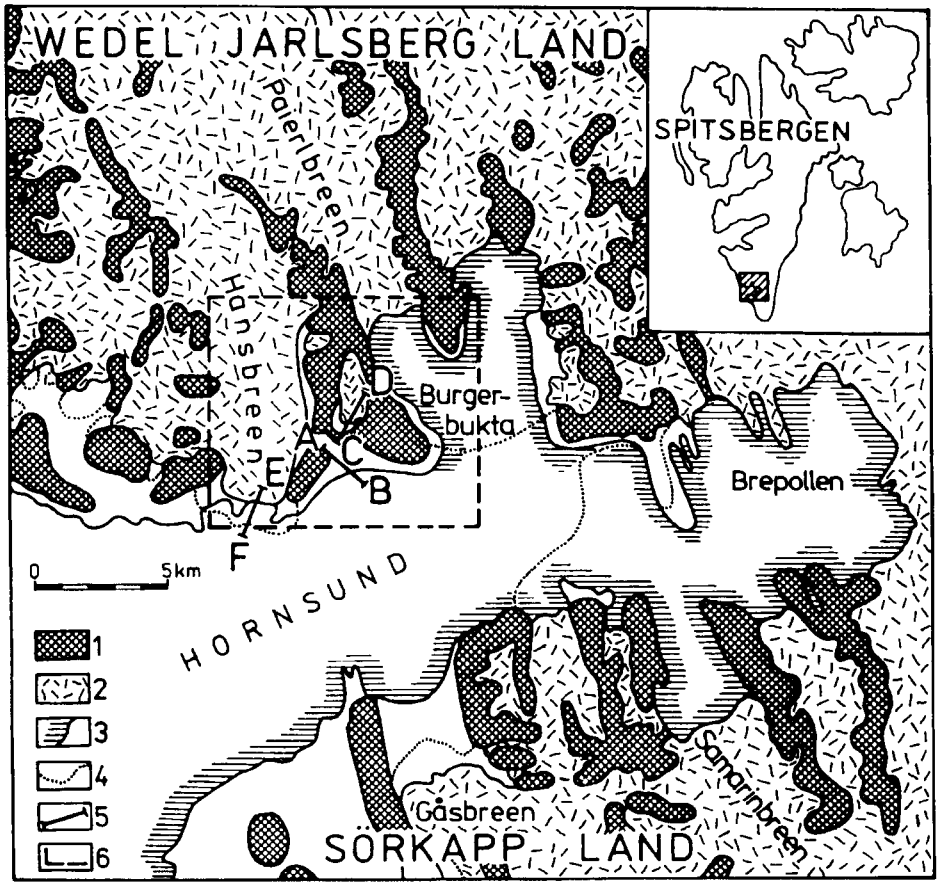
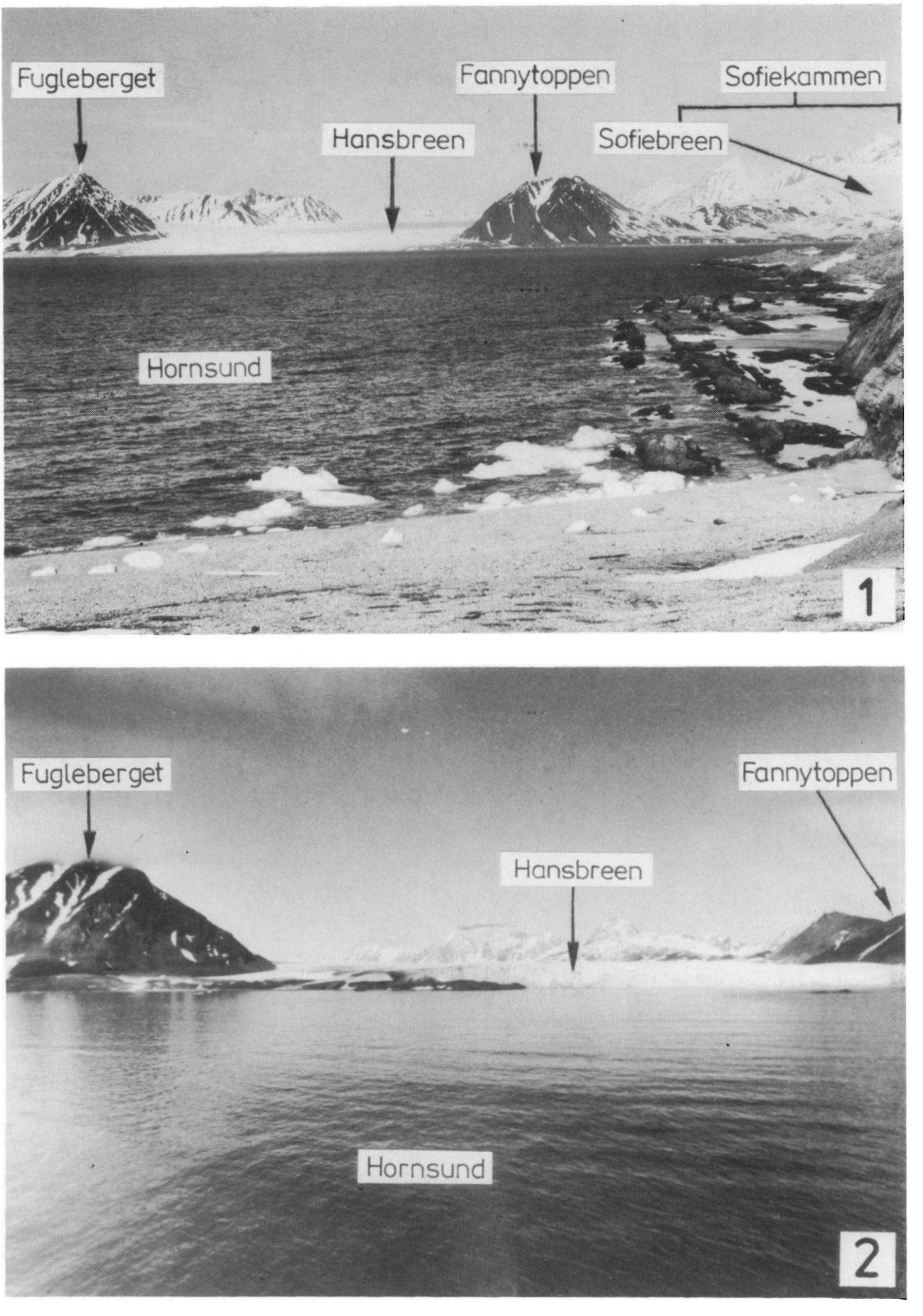


Fig. 1. Location sketch of the studied area
1 — mountains, 2 — glaciers, 3 — shoreline, 4 — maximum glacier extent during the Little Ice Age, 5 — schematic geologic section (*cf.* Figs 2 and 3), 6 — borders of the photogeological map of Hansbreen-Sofiekammen region (*cf.* Szczęsny, Lindner and Marks 1991)

the Hans Glacier (*e.g.* Jania 1982, 1988; Jania, Kolondra and Bukowska-Jania 1983; Kolondra 1985), its hydrological regime (Różkowski 1980) and physical properties (Czajkowski 1980).

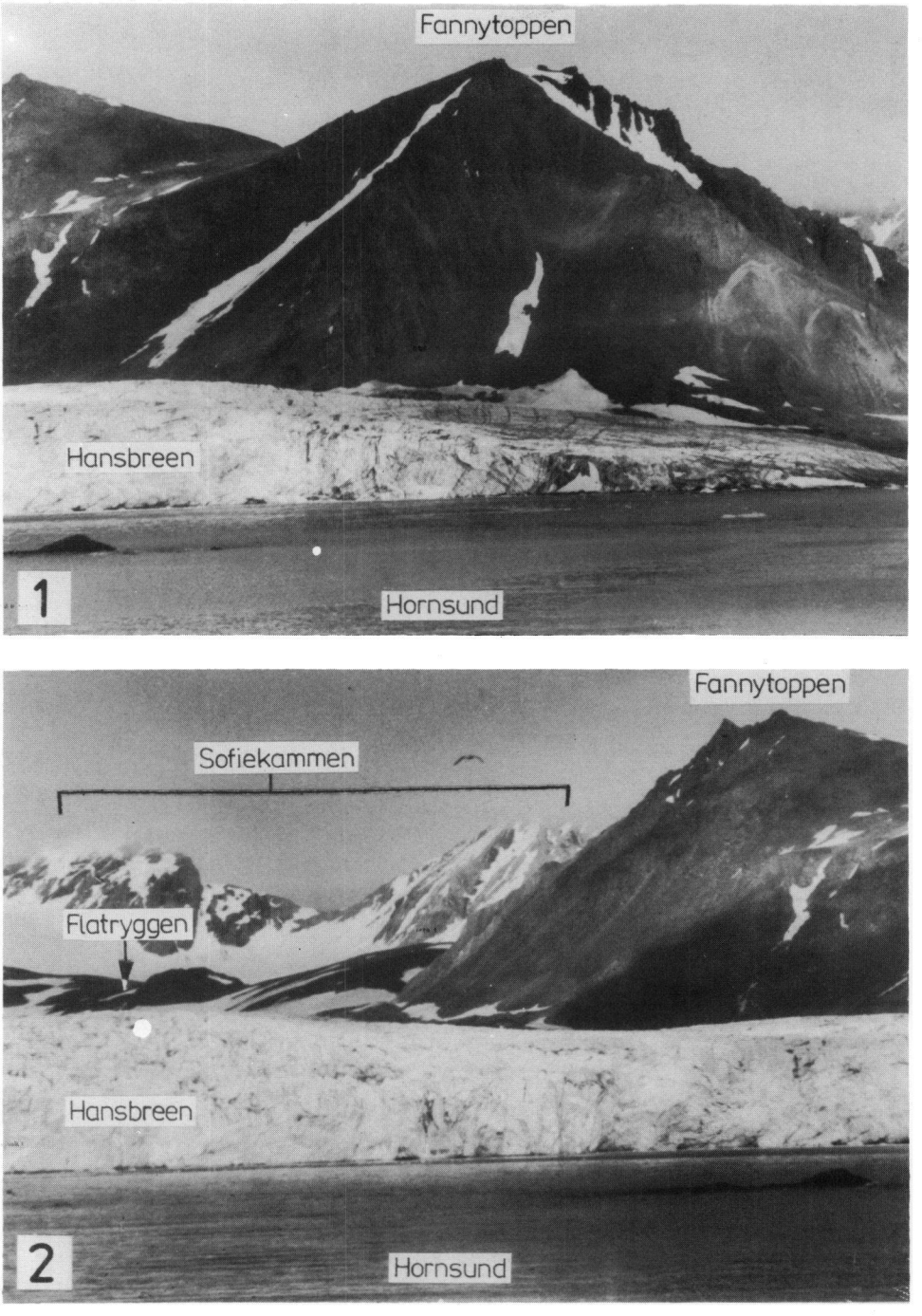
Marine sediments of the Hornsund fiord, also in the very forefield of the Hans Glacier, have been preliminarily examined (Florczyk *et al.* 1981, Kowalewski *et al.* 1987). A chronostratigraphy of Quaternary inland sediments of this area was presented too (Marks and Pękala 1986, Pękala 1989).

Analysis of Norwegian air photos of 1961 and the authors' fieldworks in 1979 and 1980 during the expeditions organized by the Institute of Geophysics Polish Academy of Sciences, and in 1985 — by the Jagiellonian University, Cracow, enabled to prepare a photogeological map of the described area (*App.*)



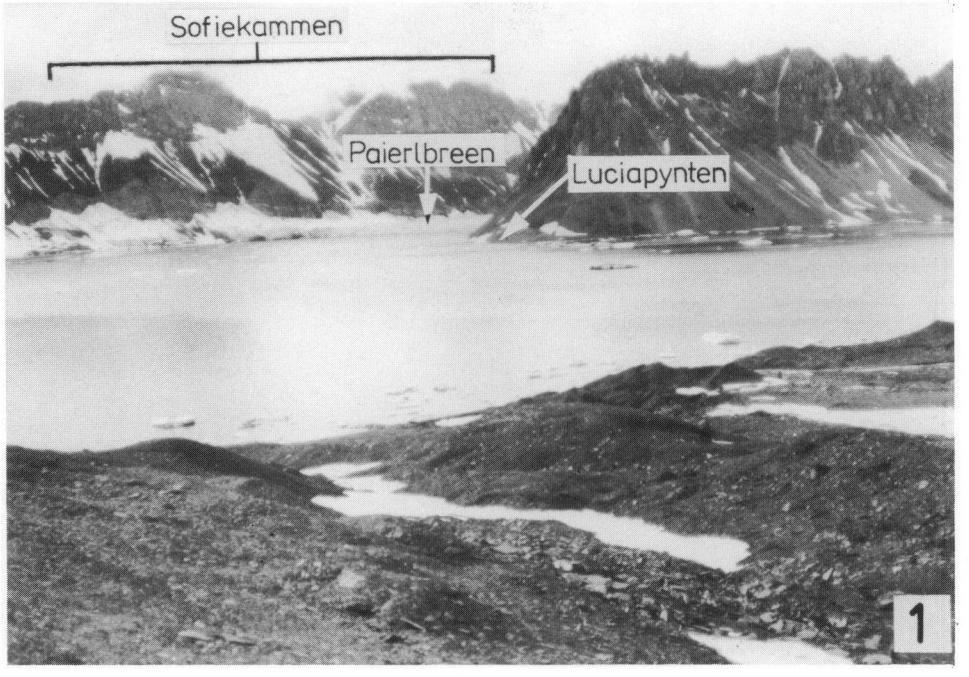
1 – Hansbreen-Sofiekammen region from the southern coast of Hornsund, July 1985; photo R. Szczęsny

2 – Hans Glacier, view from Hornsund, July 1980; photo L. Lindner



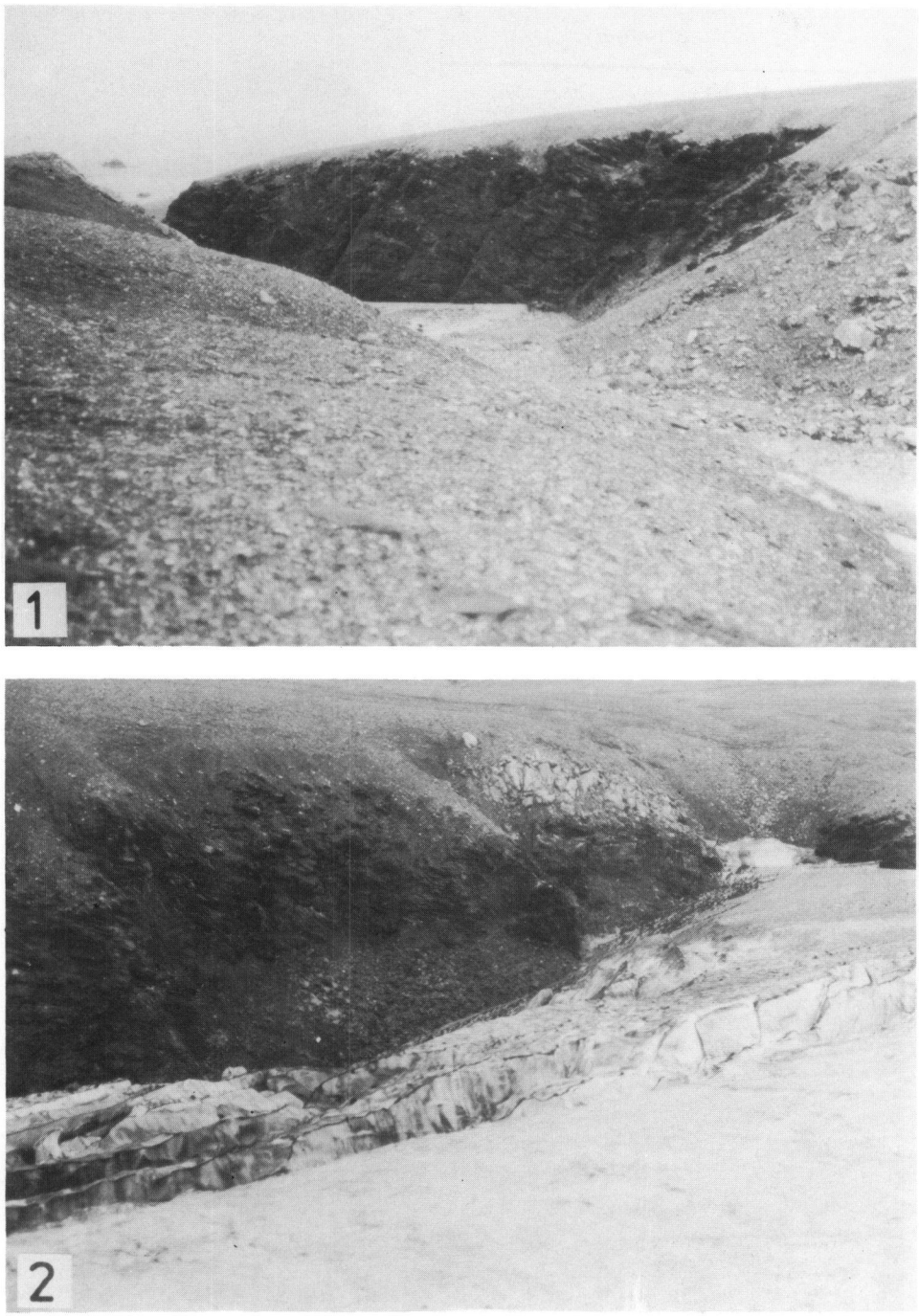
1 – Eastern part of an ice cliff of the Hans Glacier, with southern fragment of Fannytoppen in the background, July 1980; photo L. Lindner

2 – Central part of an ice cliff of the Hans Glacier, with western fragment of Fannytoppen as well as culminations of Flatryggen and Sofiekammen in the background, July 1980; photo L. Lindner



1 – Eastern slope of Sofiekammen, ice cliff of the Paierl Glacier and Luciapynten, view from Burgerbukta, August 1979; photo L. Marks

2 – Alluvial fan at southern foot of Gnålberget, with the raised marine beach 3-6 m a.s.l., trapper hut and meteorological cage in the foreground, July 1988; photo W. Roszczynko



1 – Outwash valley from the Sofie Glacier into Hornsund, cut in a seashore cliff of Bogstranda, August 1979; photo L. Marks

2 – Filled with snow the outwash valley from the Sofie Glacier into Hornsund, cut in raised marine beaches of Bogstranda, August 1979; photo L. Marks

in scale of 1 : 10,000 (Szczęsny, Lindner and Marks 1991). The methodology presented elsewhere (Lindner *et al.* 1990) was applied.

Outline of pre-Quaternary geology

Pre-Quaternary rocks of the described area were examined mainly by Birkenmajer (1958b, 1960b, 1964, 1978a, b) as well as by Flood, Nagy and Winsnes (1971). They are represented by intensively folded and partly overthrust rocks of the Hecla Hoek Formation (Precambrian and Lower Palaeozoic). They form the Fold Belt of Birkenmajer (1972). In this area the oldest rocks of the Lower Hecla Hoek Formation occur in the southwest (Fugleberget), exposed in a core of a complex anticline as the Isbjörnhamna Formation (gneisses and crystalline shales with inserts of marbles) and as the younger Eimfjellet Formation (quartzites with shale interbeds and inserts of diabase-like rocks, also basalt-like *i.e.* greenstone rocks interbedded with quartzites and gneissic-granitic rocks).

The Middle Hecla Hoek Formation is represented by rocks of the Deilegga Formation, formed of phyllites and shales with interbeds of dolomites and inserts of quartzites. They build the mountain massif Tuva to the west and the massif Fannytoppen to the east of the Hans Glacier.

The oldest part of the Upper Hecla Hoek Formation is composed of rocks of the Sofiebogen (Eocambrian), Sofiekammen (Cambrian) and Sörkapp Land (Ordovician) formations. The first one is represented by methamorphosed conglomerates with inserts of sandstones and shales, and by younger limestones and dolomites of Bogstranda and Flatryggen. Rocks of the Sofiekammen Formation occur in a mountain massif of the same name and are composed of limestone breccia, shales and limestones that pass upwards into dolomites, dolomitic limestones and marly dolomites. The Sörkapp Land Formation is represented by dolomitic limestones and dolomites that pass into limestones of the mountain massif Luciakammen.

Quaternary landforms and sediments

Fieldworks and photogeological analysis of the Hansbreen-Sofiekammen region enabled to distinguish 24 geomorphologic-geological features (*App.*). On the map they are grouped in three main genetic assemblages: (*i*) slope landforms (5 symbols), (*ii*) glacial and nival landforms and sediments (9 symbols), and (*iii*) raised marine beaches (8 symbols). The map is supplemented also with some topographic (nos 23 and 24) and geodetic symbols.

Slope landforms with structural features. Central part of the area is occupied by the mountain massif Sofiekammen that rises in the east above Burgerbukta

and the Paierl Glacier. Starting from the south, the Sofiekammen ridge is composed of the summits Gnålberget (780 m a.s.l), Karnkrona (767 m a.s.l.), Prinsessetoppen (763 m a.s.l.) and Wienertinden (925 m a.s.l.). Close to the latter, the Sofiekammen massif contacts with a considerably lower (250–500 m a.s.l.) ridge of Flatryggen that in turn, touches in the south the bi-summit (412 and 391 m a.s.l.) massif of Fannytoppen. Flatryggen and Fannytoppen contact with the Hans Glacier in the west. All these mountain massifs are mantled with a weathering waste (symbol 1) which is also present on southern tip of Luciakammen (528 m a.s.l.). In the west a weathering waste mantles the eastern slope of Fugleberget. Weathering waste on the northeastern slope of Fannytoppen was TL dated 143 ± 21 ka (*cf.* Marks and Pękala 1986; Fig. 2).

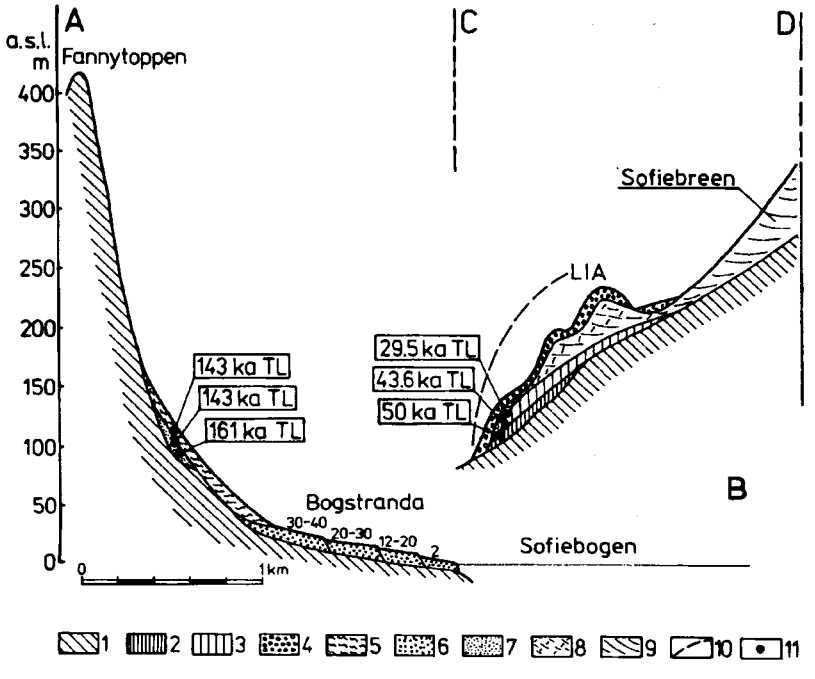


Fig. 2. Schematic geologic section of the Bogstranda area (*after* Marks and Pękala, 1986)
1 – bedrock, 2 – older till, 3 – younger till, 4 – ice-cored moraine deposits, 5 – boulders, clays and sands of alluvial fans, 6 – shingle (raised beach altitudes are given in metres a.s.l.), 7 – outwash sand, 8 – buried glacial ice, 9 – compact glacial ice, 10 – glacial extent (LIA – Little Ice Age), 11 – TL dating site

Bare outcrops of pre-Quaternary rocks (symbol 2) occur in a limited area only, especially on mountain slopes facing the fiord and close to the seashore. They are common in sea skerries near Gnålodden and Fannytoppen, at edges of lower raised marine beaches in Bogstranda, on marine beaches at Fannypyn-

ten and eastern slope of the nunatak Tuva (*cf.* Pękala 1975, 1980a, b). Bare rock is commonly subjected to karst processes (Pulina 1974, 1975, 1977; Bieroński and Pulina 1975).

Slopes of Luciakammen, Fannytoppen and Fugleberget are cut by numerous chutes (symbol 3). They occur in southern part of Flatryggen, on steep southern slopes of Sofiekammen and on Tuva. Deeply incised chutes cut also steep edges of raised marine beaches in Bogstranda.

Taluses (symbol 4) are common especially on easterly-exposed slopes of mountain massifs, presumably because of more favourable conditions for frost weathering there. They are common on slopes of Luciakammen, Sofiekammen, Fannytoppen and Fugleberget, and extremely rare on slopes of Flatryggen.

Alluvial fans (symbol 5) occur at foot of mountain slopes on Bogstranda, and at foot of Gnålberget. They are located mostly on raised marine beaches, at outlets of chutes or gorges that provide meltwaters from infilling snow patches.

Glacial and nival landforms and sediments. The described area is heavily glaciated but, besides recent glacial sediments and landforms, there are also

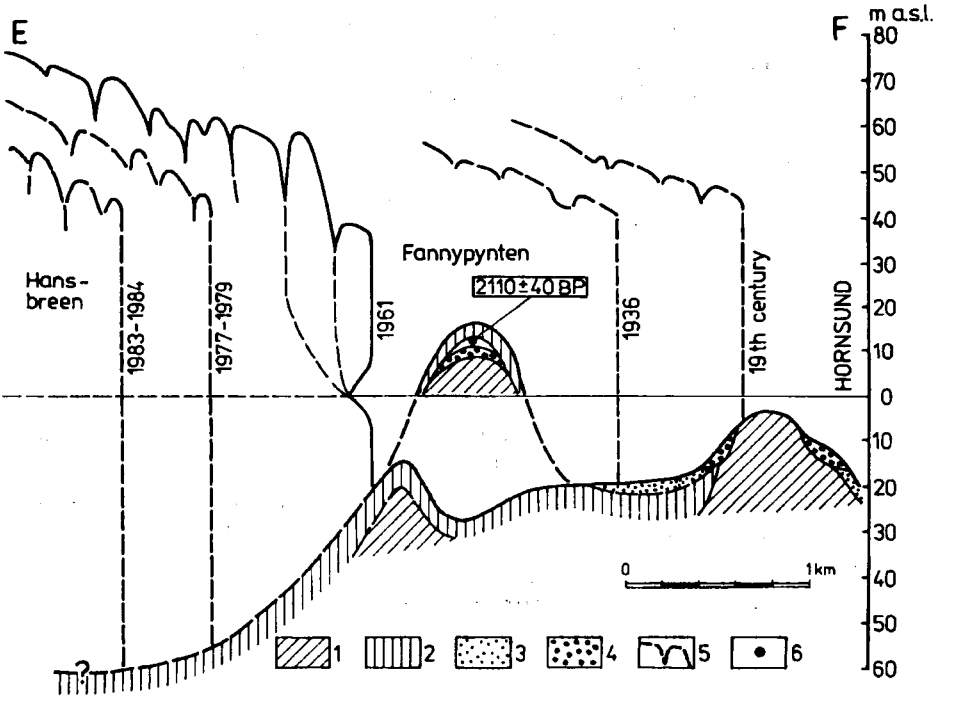


Fig. 3. Schematic geologic section across the Hansbreen forefield
1 — bedrock, 2 — till, 3 — glaciofluvial(?) sands, 4 — shingle, 5 — ice cliff of the Hans Glacier, 6 — radiocarbon dating site

ancient ones that indicate greater extents of the glaciers in the past. Ancient lateral moraines (symbol 6) occur along Burgerbukta at foot of Sofiekammen as isolated hummocks, several metres high. The ancient lateral moraine, about 30 m high, is noted on Luciapynten. Small patches of till from a ground moraine (symbol 7) are exposed on bedrock capes in front of the Hans Glacier where they locally overlie palaeosols and plant remains, radiocarbon dated at 230 ± 70 BP to 2110 ± 40 BP (Pękala 1989; Fig. 3). Tills form also small patches on slopes of Fugleberget and Fannytoppen. On slopes of Fugleberget they were TL dated at 63 ± 9 ka (at 80 m a.s.l.) and at 36–45 ka (at 40–45 m a.s.l.). On slopes of Fannytoppen tills were noted under solifluction covers at 100 m and about 60 m a.s.l.; they were TL dated at 91 ± 11 ka and 56 ± 6.7 ka respectively (Pękala 1989).

Almost one third of the area is covered with compact glacier ice (symbol 8). It forms two tidewater glaciers: the Hans Glacier in the west and the Paierl Glacier in the northeast. Both these glaciers have intensively fissured surface, especially closely to the cliffs. Most crevasses run parallel to glacier fronts and have been formed due to tension caused by more intensive ice flow in result of calving. More rare are longitudinal crevasses (mainly in southeastern part of the Hans Glacier but also in the eastern part of the Paierl Glacier. The Hans Glacier at its axis is about 100 m thick near the cliff but gets thicker upglacier, reaching at least 220 m (Czajkowski 1980). There are also several much smaller glaciers that do not reach a sea. The largest of them is the Sofie Glacier (Sofiebreen) which occurs in a triangular depression at foot of Wienertinden. Close to the Sofie Glacier – at foot of Prinsesstoppen – there is a small glacieret, almost completely covered with snow but occasionally compact ice is also exposed. Another glacieret occurs on western slope of Flatryggen, hanging above the Hans Glacier. Presumably, a compact glacier ice of a small glacieret on the western slope of Luciakammen is mantled with snow.

Ablation moraine (symbol 9) mantles locally the Hans Glacier. It forms an almost continuous strip along the eastern margin (at foot of Fannytoppen and Flatryggen) but also smaller and more irregular patches near the southeastern slope of Fugleberget. Along the glacier margin there are usually terminal (symbol 10a) and lateral (symbol 10b) ice-cored moraines. Lateral ones run along both margins of the Hans Glacier, either at foot of Fugleberget in the west or Fannytoppen and Flatryggen in the east. More or less complex systems of terminal and lateral ice-cored moraines encircle the snouts of all the glacierets in this area. On the other hand, ice-cored moraines of the Paierl Glacier are presumably hidden under a snow. Two tills of the ice-cored moraines of the Sofie Glacier were TL dated: the older one at 50 ± 6 ka and 43.6 ± 5.2 ka, and the younger one at 29.5 ± 3.5 ka (*cf.* Marks and Pękala 1986; Fig.2). Tills that mantle lateral ice-cored moraines of the Hans Glacier at foot of Fugleberget were TL dated at 10 ± 1.2 ka (Pękala 1986).

Due to melting of a buried ice core, such terminal and lateral features are intensively fissured. Ice-cored moraines of the Sofie Glacier and theneighbouring glacieret have been already partly transformed into moraine rock glaciers (*cf.* Lindner and Marks 1985). A solifluction mantle (symbol 11) is present locally on the terminal ice-cored moraine of the Sofie Glacier and on the western ice-cored moraine of the Hans Glacier.

Patches of stagnant or dead ice (symbol 12) are noted on the northeastern slope of Sofiekammen. They represent fragments of a previous marginal part of the Paierl Glacier and could be preserved until the recent times due to poor insolation.

Small sandurs (symbol 13) occur only in outer morainal zones of the Hans Glacier. They are only partly used at present by small meltwater streams, running along or across lateral ice-cored moraines. At Fannypynten they are in general dead features, cut into the raised marine beach 12–20 m a.s.l. Outwash sands on the northeastern slope of Fannytoppen were TL dated at 161 ± 24 ka and contained a paleosol, TL dated at 143 ± 21 ka (*cf.* Marks and Pękala 1986; Fig. 2).

High elevation and isolation makes most of the described area be mantled with snow (symbol 14). On glaciers a discontinuous snow cover starts at about 120–150 m a.s.l. and becomes continuous above 250 m a.s.l. In the mountains a snow covers almost entirely the elevations above 450 m a.s.l., with the only exceptions of steep slopes and zones exposed to insolation.

Raised marine beaches with structural features. Seven raised marine beaches and the present beach were distinguished (*App.*) but generally, due to mountainous character of the described region, raised marine features occupy a limited area only. Higher beaches occur mainly in Bogstranda but they are considerably mantled with slope sediments and their marine origin cannot be therefore proved easily. The lower raised marine beaches occur at Fannypynten and Gnålodden. Inner-fiord location of the region, shallow bedrock and obliteration by slope processes result in absence of storm ridges – features that are so common on seashores of Spitsbergen. Carbonate bedrock makes karst features occur commonly in cliffs of raised marine beaches and in skerries (Pulina 1974). Thermal waters (11.6–12.6°C) form the „Orvin" spring at southern foot of Gnålodden (Pulina 1977).

Raised marine beaches 42–70 m (symbol 15) and 30–40 m (symbol 16) occur exclusively, whereas the beaches 20–30 m (symbol 17) and 12–20 m (symbol 18) a.s.l. – mainly in Bogstranda. The highest beach (42–70 m a.s.l.) adheres to the slopes of Flatryggen and Gnålberget and is mantled with slope deposits. All the beaches in Bogstranda are deeply dissected (to 25–20 m) by gorges that provide meltwaters from the Hans Glacier (between Fannytoppen and Flatryggen) in the west, the Sofie Glacier in the centre and snow patches on Gnålberget in the east. Most of the gorges are all the year round filled with

snow (water flows underneath) due to local severe climatic conditions in this isolated part of the Hornsund area. Both western and central gorges act as valley trains for the outwash.

The raised marine beach 12–20 m a.s.l. (symbol 18) in Bogstranda is present only close to the mouth of the valley train running from the Hans Glacier. It occurs also at Fannypynten where it is considerably dissected by ancient outwash in front of a lateral ice-cored moraine of the Hans Glacier, hanging above the surface of the raised marine beach 2 m a.s.l.

Small fragments of the raised marine beaches 20–30 m a.s.l. and 8–10 m a.s.l. (symbol 19) occur at foot of Gnålberget between Gnålodden and Löynodden. The raised marine beach 3–6 m a.s.l. forms a narrow strip on seashore from Gnålodden to Löynodden, but a small fragment is present also at Fannypynten. The lowest raised marine beach 2 m a.s.l. (symbol 21) runs almost continuously along Bogstranda and occurs at Fannypynten.

The present beach (symbol 22) forms a narrow strip (maximum to 30 m) along a seashore from Fannypynten to Löynodden, interrupted with zones where steep cliffs of Precambrian rocks (*e.g.* at foot of Fannytoppen and Gnålodden) make presence of the beach impossible.

Morphogenetic evolution of the area

The Hansbreen-Sofiekammen region has been in general the subject of more detailed and complex chronostratigraphical studies. Only selected landforms and sediments were described (*e.g.* Birkenmajer 1959, Jahn 1959, Marks and Pękala 1986). A little more is known about recent changes of a cliff of the Hans Glacier (Jania 1982, Jania, Kolondra and Bukowska-Jania 1983, Kolondra 1985).

The oldest are outwash sediments of the Hans Glacier, located in a pass between Fannytoppen and Flatryggen. They were TL dated at 161 ka and correspond therefore to the final part of the Wedel Jarlsberg Land Glaciation (*cf.* Lindner and Marks 1991). The overlapping palaeosol, TL dated at 143 ka, was correlated to the Bogstranda (Eemian) Interglacial, similarly as the overlying slope sediments of the same age (Marks and Pękala 1986). Only two glacial episodes during the Sörkapp Land Glaciation (*cf.* Lindner and Marks 1991) were distinguished. They are represented by two tills in front of the Sofie Glacier, dated at 43.6–50 ka and 29.5 ka respectively. During this glaciation the Sofie Glacier occupied a slightly greater area than recently. On the other hand nothing is known about the Hans and Paierl glaciers during the Sörkapp Land Glaciation. Assuming that both glaciers remained tidewater, in spite of changes of a sea level due to glacioisostatic subsidence, they had to occupy a considerably greater extent during advances in that time but should have also extensively retreated during climatic ameliorations.

Very little is known about glacier extens in this area during the Early and Middle Holocene (*App.*). More information comes from the last glacier advance during the Little Ice Age, especially if the Hans Glacier is concerned (Fig. 3).

The two highest raised marine beaches (*i.e.* 42–70 and 30–40 m a.s.l.) were formed during the Sörkapp Land Glaciation (*cf.* Lindner, Marks and Pękala 1987). All the other beaches are already of the Holocene age, although the two at 20–30 and 12–20 m a.s.l. seem to have been formed rapidly at the turn of the Pleistocene and the Holocene during a sudden glacioisostatic rebound. The beach 8–10 m a.s.l. is connected with the Middle Holocene warming whereas the beach 3–6 m a.s.l. is much younger and was formed probably after the Revdalen Stage of Hornsund (*cf.* Lindner and Marks 1991). The beach 2 m a.s.l. is to be correlated to the Little Ice Age.

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Streszczenie

Na podstawie badań terenowych oraz norweskich zdjęć lotniczych opracowano mapę fotogeologiczną rejonu lodowca Hansa i Sofiekammen w południowym Spitsbergenie w skali 1 : 10 000 (fig. 1 i zał. mapa). Przedstawiono na niej, jak również na przekrojach geologicznych (fig. 2 i 3) rozmieszczenie osadów i form lodowcowych i zboczowych oraz wyniesionych tarasów morskich (pl. 1–4).

Na podstawie rozprzestrzenienia osadów lodowcowych i wyniesionych tarasów morskich oraz w oparciu o datowania osadów metodą termoluminescencji i radiowęgla, przedstawiono próbę rekonstrukcji rozwoju morfogenetycznego opracowanego rejonu. Najstarszymi są osady sandrowe zlodowacenia Wedel Jarlsberg Land (Saalian), datowane na 161 ka. W stropie zawierają one słabo wykształconą glebę kopalna, korelowaną z interglacjałem Bogstranda (eemskim), przykrytą osadami stokowymi datowanymi na 143 ka. Zlodowacenie Sörkapp Land (Wisły) jest reprezentowane w opracowanym rejonie przez dwie transgresje lodowców, około 43,6–50 ka oraz 29,5 ka. Dla holocenu, w odróżnieniu od innych rejonów południowego Spitsbergenu, stwierdzono w opracowanym obszarze występowanie osadów i form lodowcowych jedynie z okresu Małej Epoki Lodowej.

Na podstawie relacji do zjawisk lodowcowych i korelacji z innymi rejonami Hornsundu, powiązano powstawanie wyniesionych tarasów morskich 42–70 oraz 30–40 m n.p.m. z okresem zlodowacenia Sörkapp Land, zaś tarasów 20–30 i 12–20 m n.p.m. z przełomem plejstocenu i holocenu. Taras 8–10 m n.p.m. powstał podczas ocieplenia środkowoholoceńskiego, natomiast taras 3–6 m n.p.m. prawdopodobnie w okresie fazy Revdalen, datowanej na około 2,5 ka. W Małej Epoce Lodowej powstał taras 2 m n.p.m.

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