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Middle and Late Quaternary evolution of the Hornsund Region, South Spitsbergen

ABSTRACT: Studies of the Quaternary evolution of the Hornsund Region in Spitsbergen focused in nine key areas, in which detailed fieldworks with mapping and sampling to radiocarbon and thermoluminescence analyses have been done. Glacial history of the Hornsund Region is known from the Torellkjegla (Holsteinian) Interglacial up to the recent times. The Wedel Jarlsberg Land (Saalian) Glaciation was the most widespread in this part of Spitsbergen and consisted of two stades(?). It was followed by considerable glacier retreat during the Bogstranda (Eemian) Interglacial, the latter being represented by development of soils. Four glacier advances (the two younger ones are the Lisbetdalen and the Slaklidalen stages) occurred during the Sörkapp Land (Vistulian) Glaciation. Three glacier advances (Grönfjorden and Revdalen stages, followed by the Little Ice Age) were recognized for the Holocene. The oldest and highest (although somewhat questionable) raised marine beaches come presumably from the Wedel Jarlsberg Land Glaciation. The beaches 80-100 m a.s.l. were formed during the Bogstranda (Eemian) Interglacial. The beaches 20-60 m a.s.l. are correlated with the Sörkapp Land Glaciation. All the lower marine beaches were formed during the Holocene.

K e y w o r d s: Arctic, Spitsbergen, Hornsund, Quaternary stratigraphy and morphogenesis.

Introduction

First remarks on the Late Quaternary evolution of the Hornsund Region are presented in papers on raised marine beaches, subslope ramparts and glacial sediments of this area (among others Birkenmajer 1958, 1959, Jahn 1959a, b, 1968, Szupryczyński 1963, 1968, Birkenmajer and Olsson 1970, Baranowski 1977). But the subrecent Little Ice Age, also older and more extensive glacier advances during the Holocene (*cf.* Jahn 1959a, Szupryczyński 1968) or even earlier (*cf.* Birkenmajer 1959) were distinguished.

New approach was possible to the Late Quaternary evolution of the Hornsund Region recently, firstly due to complex mapping of the area (Birkenmajer

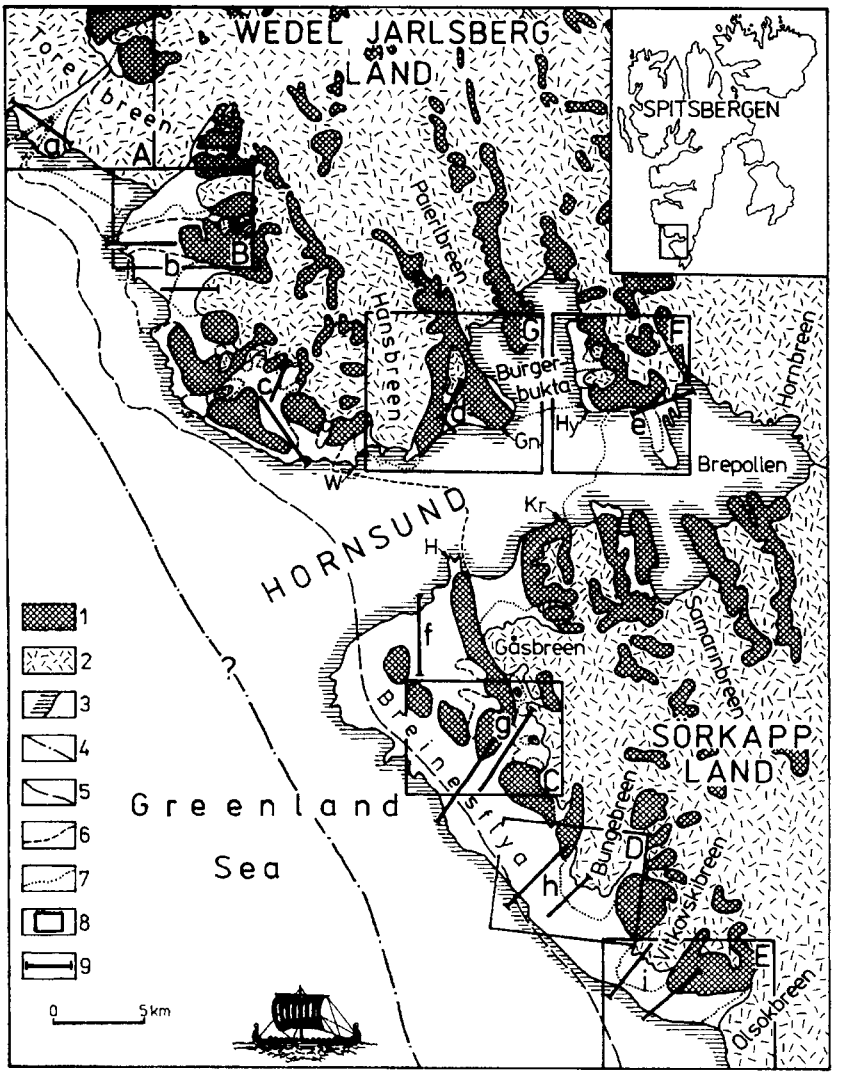

Fig. 1. Location sketch of the Hornsund Region

1 - mountains, 2 - glaciers, 3 - shoreline, maximum extents of glaciers during: 4 - Wedel Jarlsberg Land Glaciation, 5 - Lisbetdalen Stage of the Sörkapp Land Glaciation, 6 - Holocene, 7 - Little Ice Age, 8 - published photogeological maps: A - interlobal zone of the Torell Glacier (Szczęsny *et al.* 1985), B - forefield of Torell and Nann glaciers (Ostaficzuk, Marks and Lindner 1980), C - Slaklidalen area (Ostaficzuk, Lindner and Marks 1986), D - forefield of the Bunge Glacier (Ostaficzuk, Lindner and Marks 1982), E - Hilmarfjellet area (Szczęsny, Lindner and Marks 1987), F - Treskelen-Hyrnefjellet-Kruseryggen area (Szczęsny, Lindner and Marks 1989), G - Hansbreen-Sofiekammen area (Szczęsny, Lindner and Marks 1991), 9 - schematic geological sections in: a - Torellkjegla (Fig. 2), b - Elveflya (Fig. 3), c - Revdalen and Fuglebergsletta (Fig. 4), d - Bogstranda (Fig. 5), e - Treskelen (Fig. 6), f - Lisbetdalen and Kulmstranda (Fig. 7), g - Slaklidalen (Fig. 8), h - Bungeleira (Fig. 9), i - Hilmarfjellet (Fig. 10). W - Wilczekodden, H - Höferpynten, Gn - Gnålodden, Hy - Hyrneodden, Kr - Krykkjestupet

1960, 1964, Szupryczyński 1963, Pulina 1977, Ostaficzuk, Marks and Lindner 1980, Marks 1981, 1983, Ostaficzuk, Lindner and Marks 1982, 1986, Karczewski *et al.* 1984, Pękala *et al.* 1985, Szczęsny *et al.* 1985, Szczęsny, Lindner and Marks 1987, 1989, 1991, Szczęsny 1986, 1991, Czeppe and Ziaja 1989, Ziaja 1989). Many radiocarbon (Blake, Olsson and Środoń 1965, Grosswald *et al.* 1967, Birkenmajer and Olsson 1970, Baranowski and Karlén 1976, Pękala 1980, 1989, Chmal 1984, 1987, 1988, Lindner, Marks and Pękala 1986) and thermoluminescence (Lindner, Marks and Pękala 1983, 1984, 1987, Pękala *et al.* 1985, Marks and Pękala 1986, Butrym *et al.* 1987, Pękala 1989, Lindner *et al.* 1991) data have been already available to a new scheme of Quaternary glaciations (*cf.* Lindner, Marks and Pękala 1983, 1984, 1986, 1987). Two Pleistocene glaciations *i.e.* Wedel Jarlsberg Land (Saalian) and Sörkapp Land (Vistulian), and two interglacials *i.e.* Torellkjegla (Holsteinian) and Bogstranda (Eemian), followed by two or three glacier advances during the Holocene were distinguished.

Considerable glacioisostatic movements of Spitsbergen (among others Feyling-Hanssen 1955, Jahn 1959a, b, Birkenmajer 1960, Punning *et al.* 1982, Lindner, Marks and Szczęsny 1986) made correlation of raised marine beaches to the south and to the north of Hornsund highly controversial. For this reason the Quaternary stratigraphy in this region should be based on absolute datings of sediments in selected key areas.

Key areas

Stratigraphy of Quaternary sediments in the Hornsund Region is based on examination in nine key areas (Fig. 1).

Torellkjegla area. Numerous datings of the Pleistocene and the Holocene sediments (Lindner, Marks and Pękala 1983, 1984, Chmal 1987), supplemented with detailed field and photogeological studies (Pękala *et al.* 1985, Szczęsny *et al.* 1985), provided evidence on the Middle Pleistocene glaciations in the Hornsund Region (Lindner, Marks and Pękala 1983, 1984, 1986, 1987; Figs 1 and 2). The oldest Quaternary sediments are the glaciotectonicly deformed marine clays, tills, glaciofluvial gravels and sands (Fig. 2). They form an immense ridge in central part of the area and push moraines of the Austre Torell Glacier. Marine clays were TL-dated at 413-383 ka, being referred to the Torellkjegla Interglacial (Lindner, Marks and Pękala 1983, 1984, 1986, 1987). The overlying older till was TL-dated at 313-284 ka whereas the younger till - at 229-189 ka. Sands and gravels between these tills were TL-dated at 222-182 ka. Both tills and separating sands with gravels represent two glacier advances during the Wedel Jarlsberg Land Glaciation (Lindner, Marks and Pękala 1983, 1984, 1986, 1987). These sediments are locally covered with a till of the Sörkapp Land (Vistulian) Glaciation, TL-dated at 73-209 ka (Fig. 2), and with glacial and glaciofluvial sediments of the Little Ice Age. On the other hand in western Torellkjegla there are

the Early Holocene aeolian sands, TL-dated at 8.6 ka. Buried with recent aeolian sediments, remains of fossil flora on the raised marine beach 10-18 m a.s.l. were radiocarbon-dated at 1.83 ka, whereas driftwood - at 1.63 ka.

Elveflya area. Sediments of the marine beach 8-12 m a.s.l. at Vimsodden were TL-dated at 16+2.5 ka and of the marine beach 4.5-6 m a.s.l. - at 4.1±0.6 ka and 3.7±0.5 ka (Fig. 3; Lindner *et al.* 1991). Laminaria from pushed beach sediments inside an ice-cored moraine of the Werenskiold Glacier were radiocarbon-dated at 0.86 -0.75 ka (Chmal 1984), the ones from sediments of the marine

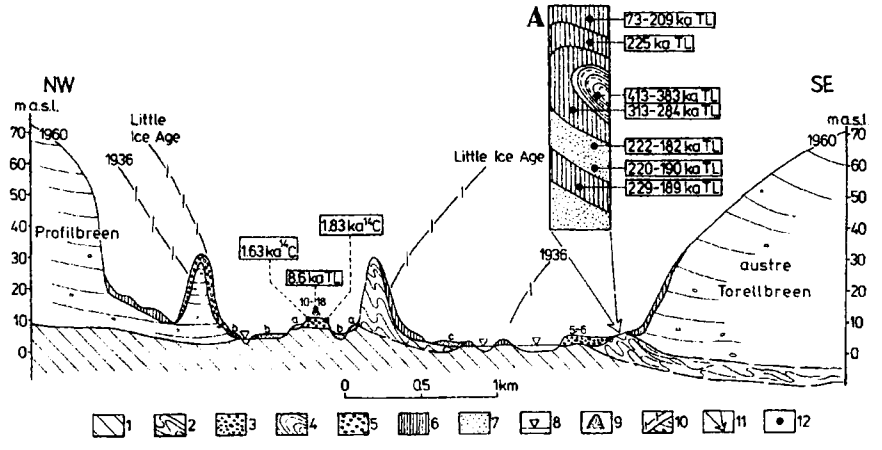

Fig. 2. Schematic geological section in Torellkjegla (after Pękala *et al.* 1985, supplemented)
1 - bedrock, 2 - glaciotectonicly deformed sediments, 3 - marine shingle (altitudes of raised beaches are in metres a.s.l.), 4 - marine clays, 5 - sediments of ice-cored moraines, 6 - till, 7 - gravels and sands of older (a) and younger (b) extramorainal outwash, and of intramorainal outwash (c), intratill in section A, 8 - water level, 9 - aeolian sands, 10 - glaciers and their extents, 11 - exposure (section A), 12 - dating site

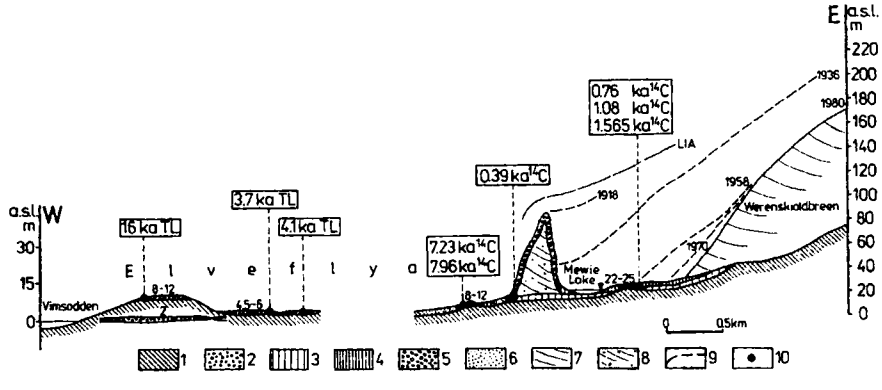

Fig. 3. Schematic geological section in Elveflya (after Lindner, Marks and Pękala 1984, modified)
1 - bedrock, 2 - marine shingle (altitudes of raised beaches are in metres a.s.l.), 3 - older till, 4 - younger till, 5 - sediments of ice-cored moraines, 6 - outwash sands and gravels, 7 - active glacier ice, 8 - dead glacier ice, 9 - glacier extents (LIA - Little Ice Age), 10 - dating site

beach 8-12 m a.s.l. - at 7.96 ka whereas shells of *Mya truncata* - at 7.23 ka (Chmal 1987). Remains of tundra plants under an ice-cored moraine of the Werenskiold Glacier were radiocarbon-dated at 0.39 ka (Chmal 1987). In an intramorainal zone of this glacier, an intratill fossil flora was radiocarbon-dated at 1.565-0.76 ka (*cf.* Baranowski and Karlén 1976, Lindner, Marks and Pękala 1984).

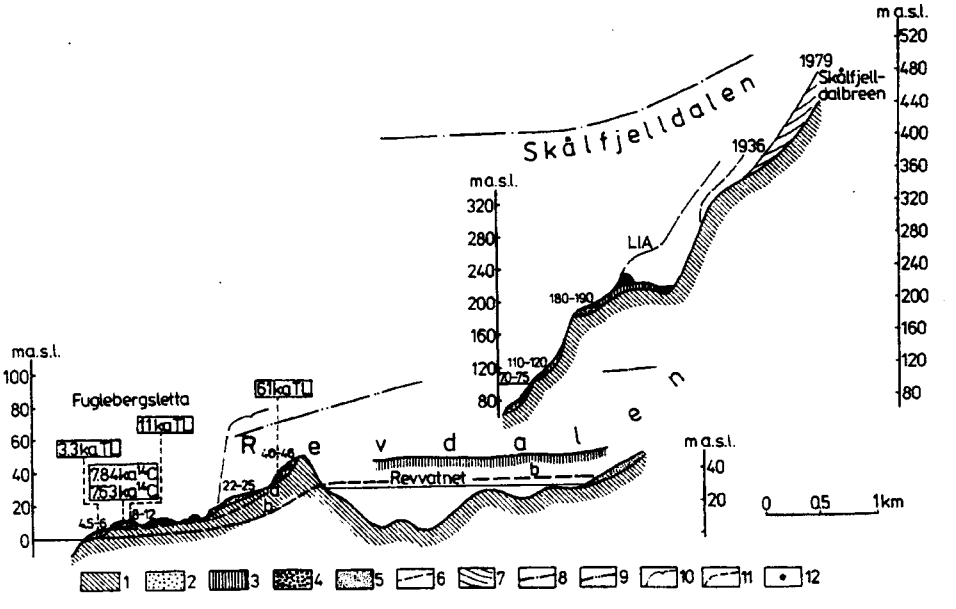

Fig. 4. Schematic geological section in Revdalen and Fuglebergsletta (after Lindner, Marks and Pękala 1984, modified)

1 - bedrock, 2 - marine shingle (altitudes of raised beaches are in metres a.s.l.), 3 - till, 4 - sediments of ice-cored moraines, 5 - outwash gravels and sands, 6 - older (a) and younger (b) outwash, 7 - glacier ice, 8 - older trimline, 9 - younger trimline, 10 - maximum extent of glaciers during the Holocene, 11 - younger extent of glaciers (LIA - Little Ice Age), 12 - dating site

Revdalen and Fuglebergsletta area. Quaternary deposits in this area were studied by Birkenmajer and Olsson (1970), Karczewski, Kostrzewski and Marks (1981a), Lindner, Marks and Pękala (1984), Pękala (1989) and Lindner *et al.* (1991). There are many radiocarbon datings of marine molluscs, whale–bones and driftwood from sediments of the marine beaches 8-12 and 4.5-6 m a.s.l. (Birkenmajer and Olsson 1970). The higher beach (Fig. 4) was radiocarbon-dated at 7.63-10.13 ka and the lower one at 0.8-1.16 ka; TL dates are 10.2 ka and 4.3-3.3 ka respectively (Lindner *et al.* 1991).

Relic sediments of the marine beach 100-120 m a.s.l. on southern slope of Fugleberget were TL-dated at 163±24 ka (Pękala 1989). The lower marine beach 70-75 m a.s.l. occurs on eastern slope of Revdalen whereas relics of the raised marine beaches 50-60 m (TL-dated at 56±8 ka; Pękala 1989) and 40-46 m

a.s.l. are on southern slope of Fugleberget. The beach 40-46 m a.s.l. to the south and southeast of Revvatnet (Fig. 4) was TL-dated at 61±9 ka (Pękala 1989) *i.e.* its surface has been eroded in sediments of the older beach (Lindner *et al.* 1991).

A till in the tributary hanging valley Ariedalen was TL-dated at 45 ka (Lindner, Marks and Pękala 1983, 1984), thus indicating glacier advance during the Sörkapp Land Glaciation. In Revdalen a till and outwash sands of the Little Ice Age and of the earlier Holocene glacier advance were noted (Karczewski, Kostrzewski and Marks 1981a, Lindner, Marks and Pękala 1984; Fig. 4).

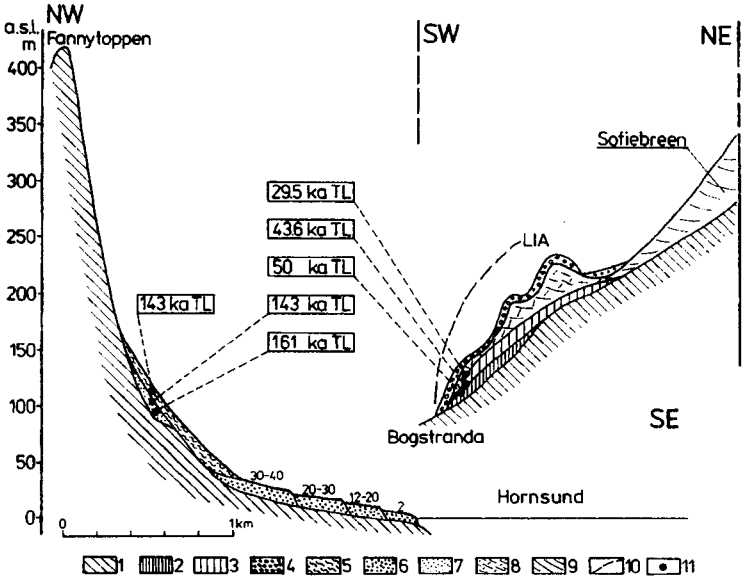

Fig. 5. Schematic geological sections in Bogstranda (after Marks and Pękala 1986, modified)
1 - bedrock, 2 - older till, 3 - younger till, 4 - sediments of ice-cored moraines, 5 - solifluction clay, 6 - marine shingle (altitudes of raised beaches are in metres a.s.l.), 7 - outwash sand, 8 - dead glacier ice, 9 - active glacier ice, 10 -glacier extent (LIA - Little Ice Age), 11 - dating site

Bogstranda area. Late Quaternary evolution of this area was based on fieldworks, TL-data (Lindner, Marks and Pękala 1983, 1984, Marks and Pękala 1986) and photogeological analysis (Szczęsny, Lindner and Marks 1991, Lindner, Marks and Szczęsny 1992). Outwash sands, TL-dated at 161-143 ka and capped with palaeosol of the Bogstranda (Eemian) Interglacial, were overlain with solifluction clay, TL-dated at 143 ka (Marks and Pękala 1986; Fig. 5).

Two tills beneath an ice-cored moraine of the Sofie Glacier are separated with a palaeosol. The older till was TL-dated at 50-43.6 ka, whereas the younger one at 29.5 ka. The palaeosol proves glacier retreat during a younger part of the Sörkapp Land Glaciation (Lindner, Marks and Pękala 1983, 1984, Marks and Pękala 1986).

The two highest raised marine beaches (42-70 and 30-40 m a.s.l.) were formed during the Sörkapp Land Glaciation (Fig. 5) whereas the beaches 20-30 and 12-

20 m a.s.l. during a sudden glacioisostatic rebound at the turn of the Pleistocene and the Holocene. The beach 8-10 m a.s.l. is connected with the Middle Holocene warming whereas the beach 3-6 m a.s.l. was formed probably after the Revdalen Stage (*cf.* Lindner *et al.* 1991). The beach 2 m a.s.l. is to be correlated to the Little Ice Age.

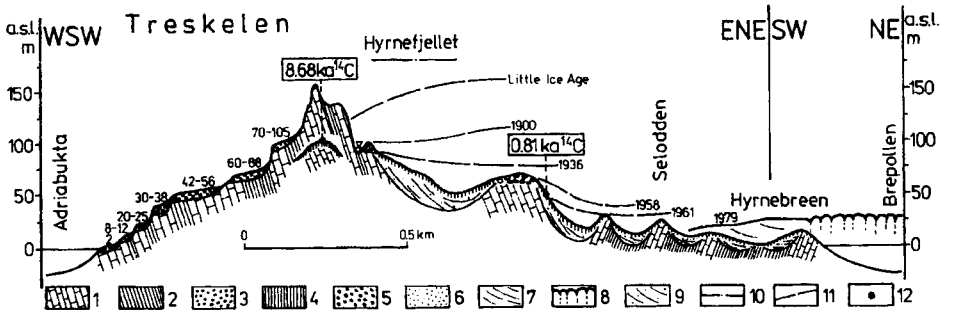

Fig. 6. Schematic geological section in Treskelen (after Marks and Pękala 1986, modified)
1 - rocks more resistant to weathering, 2 - rocks less resistant to weathering, 3 - marine shingle (altitudes of raised beaches are in metres a.s.l.), 4 - till, 5 - sediments of ice-cored moraines, 6 - outwash gravels and sands, 7 - active glacier ice, 8 - ice cliff, 9 - dead glacier ice, 10 - trimline, 11 - extent of a glacier, 12 - dating site

Treskelen area. The Late Quaternary evolution of this area was studied by Heintz (1953), Birkenmajer (1964), Grosswald *et al.* (1967), Marks (1981, 1983), Marks and Pękala (1986). Eastern and southern parts of the Treskelen Peninsula are mantled with glacial sediments, mainly by till with abundant mollusc shells (Fig. 6), transported by glaciers from the Brepollen and radiocarbon-dated at 8.68 ka (Marks and Pękala 1986). A driftwood transported by a glacier to about 38 m a.s.l. was radiocarbon-dated at 0.81 ka (Grosswald *et al.* 1967). The younger date corresponds to the Little Ice Age, but the older one indicates the Early Holocene glacier advance in this area.

Western shore of the Treskelen Peninsula is occupied by raised marine beaches (Szczęsny, Lindner and Marks 1989). The highest ones (70-105, 60-68, 42-56 and 30-38 m a.s.l.) are preserved in the northwestern part of the peninsula only. The highest beach (70-105 m a.s.l.) adheres to the peninsula crest and is mantled to the south with lateral moraines of the Hyrne Glacier (Hyrnebreen), marking its maximum extent during the Little Ice Age (*cf.* Heintz 1953, Birkenmajer 1964, Marks 1981, 1983). The beaches 42-56 and 30-38 m a.s.l. occupy a very limited area. The beach 20-25 m a.s.l. is the most widespread one on the peninsula and at Hyrneodden, being the highest beach at eastern side of Treskelen and mantled with a till of the Little Ice Age to the south.

A driftwood from sediments of the raised marine beach 8-12 m a.s.l. in the adjacent Burgerbukta was radiocarbon-dated at 5.05 ka (Chmal 1987).

Lisbetdalen and Kulmstranda area. Six raised marine beaches with a till of the Sörkapp Land Glaciation in substrate, the latter being locally replaced by

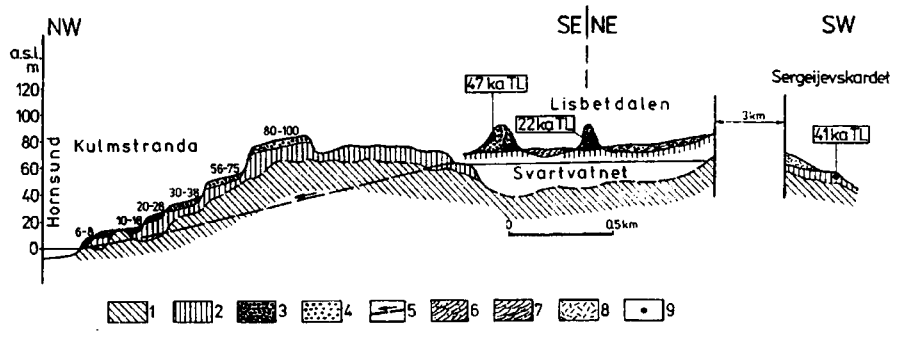

Fig. 7. Schematic geological section in Lisbetdalen and Kulmstranda (after Butrym *et al.* 1987)
1 - bedrock, 2 - till, 3 - gravels and sands of lateral moraines, 4 - marine shingle (altitudes of raised beaches are in metres a.s.l.), 5 - bed of Lisbetelva, 6 - outwash gravels and sands, 7 - talus debris, 8 - solifluction mantle, 9 - dating site

glacially-eroded rubble of Carboniferous sandstones, were distinguished in the downstream Lisbetdalen and in the Kulmstranda (Kłysz and Lindner 1981, 1983a; Fig. 7). The highest beach (80-100 m a.s.l.) is preserved to the east of the Lisbetelva gorge only. In the south it is cut by an edge, formed due to deposition at snout of a tidewater glacier during the Sörkapp Land Glaciation. Three lower marine beaches (56-75, 30-38 and 20-28 m a.s.l. are presumably connected with decline of this glaciation whereas the lowest beaches (10-18 and 6-8 m a.s.l.) were formed during the Holocene.

Glacial sediments in central and upstream part of the Lisbetdalen (Fig. 7) were formed by advancing valley and pass glaciers of the middle and late Sörkapp Land Glaciation. They were TL-dated at 47 ka and 22 ka, respectively (Butrym *et al.* 1987). Similar age (41 ka) was ascribed to a till at Sergeijevskardet (Fig. 7). These sediments are certainly younger than the ones in inner part of the valley, found on rocky shelves at about 100 to 560 m a.s.l. and origin of which was connected incorrectly by Stankowski (1981) with the Late Pleistocene sea abrasion.

Slaklidalen area. Inside the Slakli valley and in the northern Breinesflya (Fig. 8), the oldest glaciation is indicated by a till in substrate of raised marine beaches on slopes of Gavrilovfjellet. This till was TL-dated at 141±21 ka *i.e.* the end of the Sörkapp Land Glaciation (Butrym *et al.* 1987). Overlying sediments of raised marine beaches 42-56 and 30-38 m a.s.l. were TL-dated at 87±13 ka and 88±13 ka, respectively. All these marine sediments come from the early and middle Sörkapp Land Glaciation (Butrym *et al.* 1987). Younger part of this glaciation is recorded by two trimlines (*cf.* Ostaficzuk, Lindner and Marks 1986) and a till in the upstream Slaklidalen, TL-dated at 28±4 ka (Fig. 8). This till was deposited during glacier retreat of the Sörkapp Land Glaciation. At maximum, the glacier filled the valley and its cliff entered a sea in the present Breinesflya (Kłysz and Lindner 1983b).

Development of glaciers during the Holocene resulted in deposition of end moraines in the middle and upstream Slaklidalen (Fig. 8). Moraines in a middle

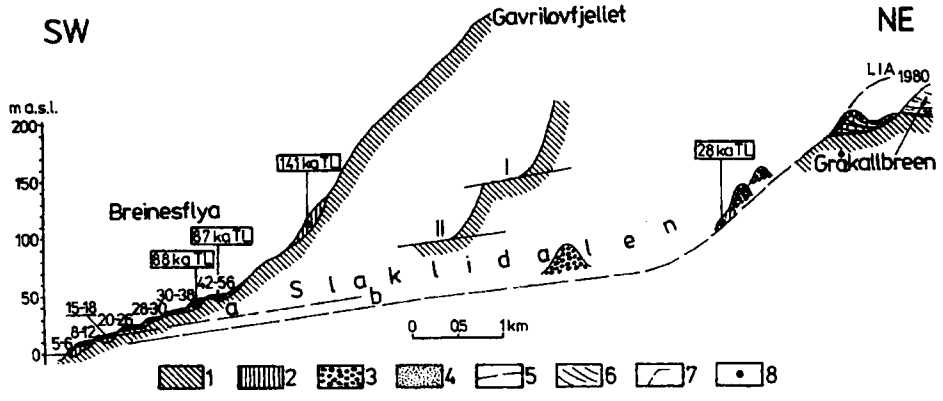

Fig. 8. Schematic geological sections in Slaklidalen, with marked ancient glacial valley beds I and II (after Lindner, Marks and Ostaficzuk 1986, modified)
1 - bedrock, 2 - till, 3 - gravels and boulders of lateral moraines and ice-cored moraines, 4 - marine shingle (altitudes of raised beaches are in metres a.s.l.), 5 - older (a) and younger (b) outwash, 6 - glacier ice, 7 - glacier extent (LIA - Little Ice Age), 8 - dating site

part of the valley delimit presumably glacier extent during the Early Holocene whereas the ones upstream - extent of the Late Holocene glacier (Lindner, Marks and Ostaficzuk 1986). Ice-cored moraines of the Gråkall Glacier and rock glaciers on southern slope of the Slaklidalen were formed during the Little Ice Age (Lindner and Marks 1985).

Bungeleira area. The Wedel Jarlsberg Land Glaciation is indicated by a till on slopes of Stupryggen and TL-dated at 217±22 ka (Fig. 9). A younger till is exposed commonly from under sediments of raised marine beaches in Breine-

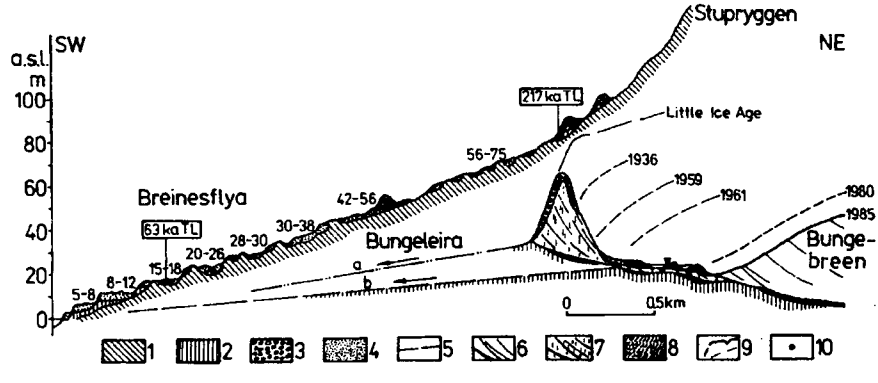

Fig. 9. Schematic geological sections in Bungeleira (after Lindner, Marks and Ostaficzuk 1986, modified)
1 - bedrock, 2 - till, 3 - gravels and boulders of lateral and ice-cored moraines, 4 - marine shingle (altitudes of raised beaches are in metres a.s.l.), 5 - older (a) and younger (b) extramorainal outwash, 6 - active glacier ice, 7 - dead glacier ice, 8 - gravels and sands of intramorainal outwash, 9 - glacier extents, 10 - dating site

sflya and from under outwash sediments in the Bungeleira, suggesting that glaciers reached at least as far as the present coastline (Ostaficzuk, Lindner and Marks 1982). Deposition of this till is to be correlated to a younger part of the Wedel Jarlsberg Land Glaciation rather, than to a maximum advance of glaciers during the Sörkapp Land Glaciation (*cf.* Kłysz and Lindner 1982).

During a younger part of the Sörkapp Land Glaciation a renewed advance of glaciers occurred in this area, indicated among others by lateral moraines in front of the Bunge Glacier (Bungebreen), up to 100 m a.s.l. on southern slope of Stupryggen (Fig. 9). In a pass between Stupryggen and Kulmrabben glacier melting resulted in deposition of glacial sediments that delimit glacier extent during development of the marine beach 30-38 m a.s.l. (Kłysz and Lindner 1982, Lindner, Marks and Ostaficzuk 1984).

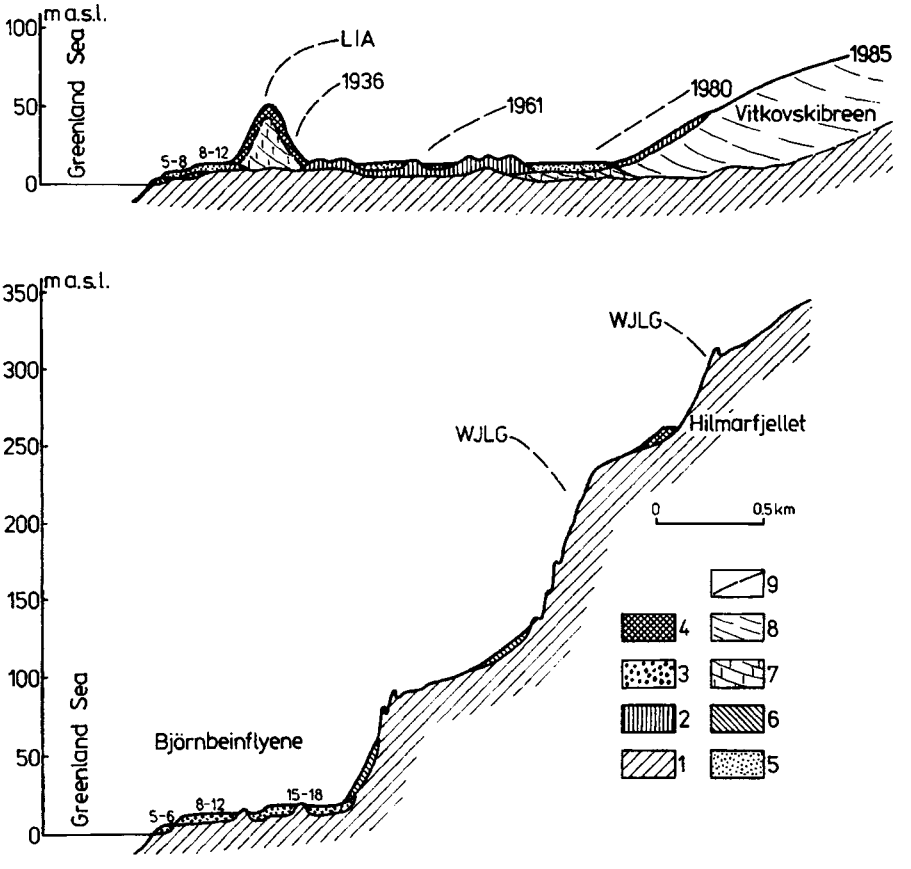

Fig. 10. Schematic geological sections in Hilmarfjellet area (after Lindner, Marks and Szczęsny 1989)
1 - bedrock, 2 - till, 3 - marine shingle (altitudes of raised beaches are in metres a.s.l.), 4 - sediments of lateral and ice-cored moraines, 5 - outwash gravels and sands, 6 - deluvia, 7 - dead glacier ice, 8 - active glacier ice, 9 - glacier extents (WJLG - Wedel Jarlsberg Land Glaciation, LIA - Little Ice Age)

During the Early and Middle Holocene a glacier retreat was accompanied by sea ingression, what favoured development of the marine beach 15-18 m a.s.l. The latter contained however older marine sediments, TL-dated at 63±9 ka (Fig. 9). Renewed glacier advance occurred during the Little Ice Age and is indicated among others by immense ice-cored moraines of the Bunge Glacier and a higher extramorainal outwash (Fig. 9). The last retreat of this glacier started at the end of the previous century (Szczęsny 1986).

Hilmarfjellet area. Glaciers of the Wedel Jarlsberg Land Glaciation seem to have formed the two highest trimlines on southern slope of Hilmarfjellet (Fig. 10); their development was partly dependent on fault systems WNW-ESE and NE-SW - they also favoured cutting of rock shelves at 250-270 m and 100-140 m a.s.l. (Szczęsny 1988), accompanied by ancient lateral moraines formed during the Wedel Jarlsberg Land Glaciation (Lindner, Marks and Szczęsny 1989).

During the Sörkapp Land Glaciation and the Early Holocene the area was occupied by glaciers as indicated by trimlines on the Hilmarfjellet slopes at 50-90 m a.s.l. (Szczęsny, Lindner and Marks 1987). At the end of the Sörkapp Land Glaciation or at the beginning of the Holocene the highest marine beach 20-26 m a.s.l. was formed. Three lower marine beaches (15-18, 8-12 and 5-8 m a.s.l; Fig. 10) were formed during the Middle and Late Holocene (Szczęsny 1988, 1991, Lindner, Marks and Szczęsny 1987, 1989). During the Little Ice Age all these beaches were occupied partly by the Vitkovski (Andrzejewski and Stankowski 1981, 1985) and Olsok glaciers. The former deposited an ice-cored moraine on the marine beach 8-12 m a.s.l. (Fig. 10), and the latter was a tidewater glacier (Fig. 1).

Morphogenesis

Examination of key areas (among others Jahn 1959a, b, Karczewski, Kostrzewski and Marks 1981a-c, Kłysz and Lindner 1981, 1982, Lindner, Marks and Ostaficzuk 1982, 1984, 1986, Marks 1983, Pękala *et al.* 1985, Lindner, Marks and Szczęsny 1989, 1990, 1992, Lindner *et al.* 1991, Szczęsny 1991), stimulated studies of the Quaternary morphogenetic evolution of the Hornsund Region.

Marine clays of the **Torellkjegla Interglacial**, dated at 413-383 ka, are the oldest Quaternary sediments in this area (Lindner, Marks and Pękala 1983). At present they occur inland and form a fold structure, glaciotectonicly deformed together with younger glacial sediments (Fig. 2) but they must have been deposited at lower altitude - when glaciers occupied considerably smaller area in the western Wedel Jarlsberg Land. These clays correspond in age to marine sediments of the Holstein (Likhvin, Mazovian) Interglacial in Europe and are to be correlated to the ^{18}O stage 11 in deep-sea sediments (Fig. 11).

During the following **Wedel Jarlsberg Land Glaciation** a bipartite glacier advance occurred in the Hornsund Region (Lindner, Marks and Pękala 1983).

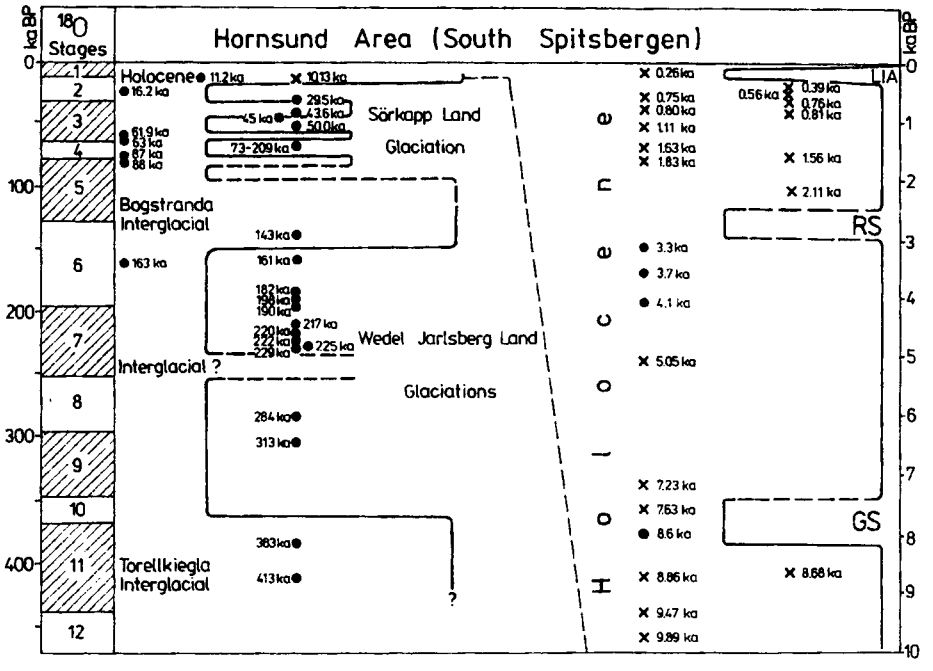

Fig. 11. Chronostratigraphical scheme of Quaternary glaciations in the Hornsund Region (after Lindner, Marks and Pękala 1987, supplemented); ^{18}O stages after Shackleton and Opdyke 1973), black dots - TL age, crosses - radiocarbon age, GS - Grönfjorden Stage, RS - Revdalen Stage, LIA - Little Ice Age

The older advance is dated at 313-284 ka *i.e.* corresponds to the ^{18}O stage 8 in deep-sea sediments (Fig. 11). It delimits maximum extent of the Middle Quaternary glaciers in this part of Spitsbergen (Fig. 1).

During the following interval, dated at 222-182 ka (Fig. 2), the glaciers had more limited extents, presumably due to global warming, identified in deep-sea sediments as the ^{18}O stage 7. In the northern Hornsund Region the three highest, although questionable marine beaches 220-230, 200-205 and 180-190 m a.s.l. could be formed in this time. They are certainly older than sediments of the beach 100-120 m a.s.l., dated at 163 ka (Pękala 1989, Lindner *et al.* 1991). A younger glacial episode (stade or glaciation) of the Wedel Jarlsberg Land Glaciation, is dated at 229-189 ka in forefield of the Torell Glacier (Fig. 2) or at 217-141 ka in the western Sörkapp Land (Figs 8-9). It corresponds to a cooling, recorded in deep-sea sediments as the ^{18}O stage 6. The Wedel Jarlsberg Land Glaciation correlates in general to the episodes C and D, identified in northwestern Spitsbergen (Miller 1982). In the northern Hornsund Region marine sediments of the beach 100-120 m a.s.l., dated at 163 ka, were deposited during a younger part of this glaciation (Pękala 1989, Lindner *et al.* 1991).

During the following **Bogstranda Interglacial** a considerable glacier retreat occurred, represented to the north of Hornsund by a palaeosol on outwash sands

of the Wedel Jarlsberg Land Glaciation, dated at 161-143 ka and overlain with a solifluction clay, TL-dated at 143 ka (Fig. 5). Taking into consideration a dating error (Marks and Pękala 1986), the Bogstranda Interglacial is to be correlated to the Eemian Interglacial and the oldest part of the ^{18}O stage 5 in deep-sea sediments (Fig. 11). Raising sea-level of this time is recorded by the marine beach 80-95 m a.s.l. in the northern Hornsund Region (Lindner *et al.* 1991) and probably also by the high marine beaches 80-100 and 56-75 m a.s.l. in the northwestern Sörkapp Land (Figs 7 and 9).

The younger, **Sörkapp Land Glaciation** is indicated with three or four glacier advances. The first one seems possible at 110-100 ka, if referred to central Spitsbergen (Troitsky *et al.* 1979, Boulton *et al.* 1982, Lindner, Marks and Pękala 1984). The following interstadial was associated with glacier melting and rise of sea-level, indicated in the northwestern Sörkapp Land by the marine beaches 42-56 and 30-38 m a.s.l., dated at 88-87 ka (Fig. 8). The beach 70-75 m a.s.l. in the northern Hornsund Region can be also of similar age (Lindner *et al.* 1991).

A younger stade during this glaciation is indicated in forefield of the Torell Glacier by a till, dated at 73 ka (Fig. 2). It corresponds probably to a cooling, recorded in deep-sea sediments as the ^{18}O stage 4 (Fig. 11). The following interstadial resulted in glacier retreat and favoured marine deposition of the beaches 50-60 m a.s.l., dated at 56 ka (Pękala 1989), and 40-46 m a.s.l., dated at 61 ka (Lindner *et al.* 1991) in the northern Hornsund area. In the Breinesflya this part of the Sörkapp Land Glaciation is connected with deposition of marine sediments of the beach 15-18 m a.s.l., dated in the Breinesflya at 63 ka (Fig. 9).

During the successive Lisbetdalen Stage (Butrym *et al.* 1987), the advancing glaciers occupied a vastest area during the Sörkapp Land Glaciation (Fig. 1; Boulton 1979). A till of this stade was dated in foreland of the Sofie Glacier (Sofiebreen) at 50-43.6 ka (Fig. 5) and in the northwestern Sörkapp Land - at 41.6 ka, whereas accompanying end moraines - at 47 ka (Fig. 7). In bottom of the Hornsund fiord this till is probably represented by the seismoacoustic unit B in the so-called outer basin IV (Kowalewski, Rudowski and Zalewski 1991) to the west of the section Wilczekodden-Höferpynten (Fig. 1). Retreating glaciers exposed considerable fragments of seashore from under the ice and the beach 32-25 m a.s.l. was formed (Lindner *et al.* 1991).

The next warming in the Hornsund Region is expressed in forefield of the Sofie Glacier by a palaeosol, older than 29.5 ka (Fig. 7). Melting of glaciers enlarged a seashore where the beach 22-25 m a.s.l. in the northern Hornsund area, and the beaches 28-30 and 20-26 m a.s.l. in the northwestern Sörkapp Land were formed (Szczęsny 1991). This warming is to be correlated with the ^{18}O stage 3 in deep-sea sediments (Fig. 11). Kettles preserved in surfaces of these raised beaches and surrounding storm ridges are relics of buried sea ice or icebergs (*cf.* Lindner and Marks 1989).

The youngest but less extensive glacier advance of the Sörkapp Land Glaciation occurred in the Hornsund Region during the Slaklidalen Stage (Butrym *et al.*

1987, Szczęsny 1991). In the northwestern Sörkapp Land this moment is indicated by a till, dated at 28 ka (Fig. 8) and by end moraine sediments, dated at 22 ka (Fig. 7). In the northern Hornsund Region this glacial episode is connected with a till in forefield of the Sofie Glacier and dated at 29.5 ka (Fig. 5). In extraglacial area the beach 15-18 m a.s.l. was formed. Similarly as the higher beach, this one contains numerous depressions and accompanying storm ridges, development of which was connected with buried sea ice or icebergs, coming from calving glaciers in the vicinity (*cf.* Lindner and Marks 1989). The Slaklidalen Stage should be correlated to a global cooling during the ^{18}O stage 2 in deep-sea sediments (Fig. 11) whereas the whole Sörkapp Land Glaciation - to the episode B (Miller 1982), identified in northwestern Spitsbergen.

During the **Holocene** three glacial episodes occurred in the Hornsund Region. The oldest glacier advance started before 8 ka (Fig. 6; *cf.* Marks and Pękala 1986). In bottom of the Hornsund fiord, glaciers of this episode presumably deposited a youngest till of the seismoacoustic unit B in the basins II and III (Kowalewski, Rudowski and Zalewski 1991; Fig. 1). Glacier extent in the fiord is indicated by older glaciomarine sediments of the seismoacoustic unit C (*cf.* Kowalewski, Rudowski and Zalewski 1991). This glacial episode, named the Grönfjorden Stage, occurred during development of the beach 8-12 m a.s.l. with kettles and storm ridges in the surface, the latter reflecting previous buried sea or glacier ice. Sediments of this beach were dated at 10-11 ka whereas enclosed mollusc shells and whalebones - at 7.6-9.8 ka (Birkenmajer and Olsson 1970, Lindner *et al.* 1991). In the inner Hornsund, the beach 8-12 m a.s.l. was dated at over 5.05 ka (Chmal 1987).

The Middle Holocene glacial episode (Revdalen Stage) at about 2.5-3 ka (Karczewski, Kostrzewski and Marks 1981a, Lindner, Marks and Pękala 1986) is defined by younger morainic ramparts in the Lisbetdalen and the Slaklidalen (Fig. 8), and by glacial sediments in the Revdalen (Fig. 4).

The following warming is expressed by subtill fossil flora in forefields of the Werenskiold and Hans glaciers, where it was dated at 1.5-0.7 ka (Fig. 3) and 2.1 ka (Pękala 1989) respectively. In the same time the beach 4.5-6 m a.s.l. was formed, sediments of which were dated at 3-4 ka (Lindner *et al.* 1991) and enclosed mollusc shells - at 7-8 ka (Birkenmajer and Olsson 1970).

The youngest glacier advance in the Hornsund Region occurred during the Little Ice Age and started about 600 years ago. Maximum advance of glaciers is delimited on land by ice-cored moraines (Figs 2-3, 5-6 and 8-10), and in bottom of the Hornsund fiord - by younger glaciomarine sediments of the seismoacoustic unit C, preserved in the basins I and II (*cf.* Kowalewski, Rudowski and Zalewski 1991; Fig. 1). The beach 2 m a.s.l. was formed already during the last few dozen of years and was distinctly connected with supply of terrigenic material to a sea from rapidly retreating glaciers of the Little Ice Age.

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Streszczenie

Przedstawiono wyniki badań osadów i form rzeźby rejonu Hornsundu na tle ewolucji tego obszaru w czwartorzędzie. Opisano dziewięć obszarów stratotypowych (fig. 1), w których zostały przeprowadzone szczegółowe badania terenowe, połączone z kartowaniem geologiczno-geomorfologicznym oraz opróbowaniem do datowań metodami radiowęgla i termoluminescencji (fig. 2-10). Uwzględniając wcześniejsze badania w rejonie Hornsundu określono zarys historii tego obszaru w czwartorzędzie (fig. 11), począwszy od interglacjału Torellkjegla (holsztyńskiego). Z tego okresu pochodzą iły morskie, stwierdzone w strefie interlobalnej lodowca Torella (fig. 2) i datowane na 413-383 ka. Dwudzielne zlodowacenie Wedel Jarlsberg Land (Saalian) jest reprezentowane przez dwie gliny zwałowe, datowane odpowiednio na 313-284 ka i 217-143 ka, rozdzielone osadami fluwioglacjalnymi datowanymi na 222-190 ka. Z tego okresu mogą ewentualnie pochodzić wysoko położone tarasy morskie 220-230, 200-205, 180-190 i 100-120 m n.p.m. W interglacjale Bogstranda (eemskim) nastąpiła znaczna recesja lodowców, umożliwiająca powstanie gleb tundrowych (datowanych na 143 ka) i tarasów morskich 80-95 i 56-75 m n.p.m. Zlodowacenie Sörkapp Land (Wisły) zaznaczyło się czterokrotną transgresją lodowców około 87 ka, 73 ka (?), 50-41 ka (stadiał Lisbetdalen) i 29-22 ka (stadiał Slaklidalen). Te okresy transgresji lodowców były oddzielone ociepleniami, kiedy powstawały osady morskie tworzące obecnie wyniesione tarasy 70-75, 50-60, 40-46, 43-56, 30-38, 25-32, 22-25 i 15-18 m n.p.m. W holocenie zaznaczyły się trzy transgresje lodowców: około 8 ka (stadiał Grönfjorden), 2-2.5 ka (stadiał Revdalen) oraz 0.6-0.1 ka (Mała Epoka Lodowa), a także ukształtowały się podniesione tarasy morskie 8-12, 3-8 i 2 m n.p.m.

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