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Age of raised marine beaches of northern Hornsund Region, South Spitsbergen

ABSTRACT: Basing of fieldworks geomorphologic and geologic setting of 14 raised marine beaches in northern Hornsund Region was presented. Their age is approximated by radiocarbon and thermoluminescence datings of sediments. The latter indicated that the four highest but mostly questionable marine beaches (220—230, 200—205, 180—190 and 100—120 m a.s.l.) should be referred to the Wedel Jarlsberg Land (Saalian) Glaciation. The four lower beaches (80—95, 70—75, 50—60 and 40—46 m a.s.l.) are connected with the Bogstranda (Eemian) Interglacial and the pre-maximum part of the Sörkapp Land (Vistulian) Glaciation. The post-maximum part of this glaciation, including Lisbetdalen Stage (50—40 ka) and Slaklidalen Stage (30—20 ka), was the time when the three still lower marine beaches (32—35, 22—25, 16—18 m a.s.l.) were formed. Three lowermost marine beaches (8—12, 4.5—6, 2 m a.s.l.) are of the Holocene age.

Key words: Arctic, Spitsbergen, Quaternary, raised marine beaches, thermoluminescence and radiocarbon datings.

Introduction

Raised marine beaches are a main research item in studies of landscape and Quaternary sediments of Spitsbergen. Knowing a number, origin and age of these beaches enables to find the rank and the age of glacioisostatic phenomena and sea level changes in that area but also, by reference to glacial landscape and sediments — the number and the age of Quaternary glacial episodes.

Detailed studies of raised marine beaches of the Hornsund Region have been initiated by Birkenmajer (1958, 1960) and Jahn (1959a, b). Due to highly varying altitudes of raised marine beaches in individual fragments of the area, Birkenmajer (1960) proposed a standard scheme of beaches at 40, 25—27, 13—16, 10—15, 7.5—8.8, 5.5—7.5 and 2—5.5 m a.s.l. Jahn (1959a) noted in the

Hornsund area the beaches at 230, 205, 135, 100, 75, 65, 45, 38—41, 32, 25, 16—17, 7—13 and 2—4 m a.s.l. According to Jahn (1959a, b) the Quaternary marine features could rise up to 275 m a.s.l. whereas Werenskiold (*vide* Szupryczyński 1968) hopes that raised marine beaches to the south of Hornsund occur up to 334 m a.s.l. and Stankowski (1981) thinks even about 546 m a.s.l. These two last values refer however to presence of marine shingle that could be the relic of the Lower Triassic marine transgression in the Sörkapp Land (*cf.* Birkenmajer 1964, Wendorff 1985).

Recent studies of raised marine beaches in the northern Hornsund Region (Fig. 1) enabled to identify 14 main levels at 220—230, 200—205, 180—190, 100—120, 80—95, 70—75, 50—60, 40—46, 32—35, 22—25, 16—18, 8—12, 4.5—6 and 2 m a.s.l. (Karczewski, Kostrzewski and Marks 1981).

Such hypsometric variation of marine beaches in the northern Hornsund area indicates that they have developed during a considerable part of the Quaternary. Detailed geomorphologic and geologic studies of similar beaches in the southern Hornsund area indicated (*cf.* Kłysz and Lindner 1981) a tripartite system of high (above 70 m a.s.l.), medium (from 70 to about 20 m a.s.l.) and low (below 20 m a.s.l.) beaches. But a hypsometric variation this subdivision is mainly based on distinction of analyzed beaches what is expressed by storm ridges on low terraces, only poorly preserved on medium beaches and by occasional presence of shingle on high beaches. The youngest medium beach and two older low beaches have been found lately to possess a good identificatory feature of iceberg depressions (Lindner and Marks 1989). Previous radiocarbon datings (*cf.* Blake, Olsson and Środoń 1965; Birkenmajer and Olsson 1970; Chmal 1984, 1987, 1988; Marks and Pękala 1986; Pękala 1989) of malacofauna, whale bones, driftwood and laminaria proved that three lowest beaches (8—12, 4.5—6 and 2 m a.s.l.) were formed during the Holocene whereas all the higher ones, devoid however of radiocarbon data, came from the Pleistocene. Mineral material of the oldest of these beaches (8—12 m a.s.l.) was lately thermoluminescence dated at 12 ± 1.4 ka (Pękala 1989). Thermoluminescence datings of sediments of raised marine beaches up to 120 m a.s.l. seem to indicate their deposition from about 20 ka to about 160 ka (Pękala 1989).

Geologic-geomorphologic setting and age

The authors support the opinion of Karczewski, Kostrzewski nad Marks (1981) on number and altitudes of marine beaches in the northern Hornsund Region (Fig. 1) although marine derivation of the beaches 180—190, 200—205 and 220—230 m a.s.l. seems doubtful. These raised beaches are presented in three areas (Fig. 1) where the authors' own studies have been carried through lately. Beach extents are defined with a use of the Polish topographic map in

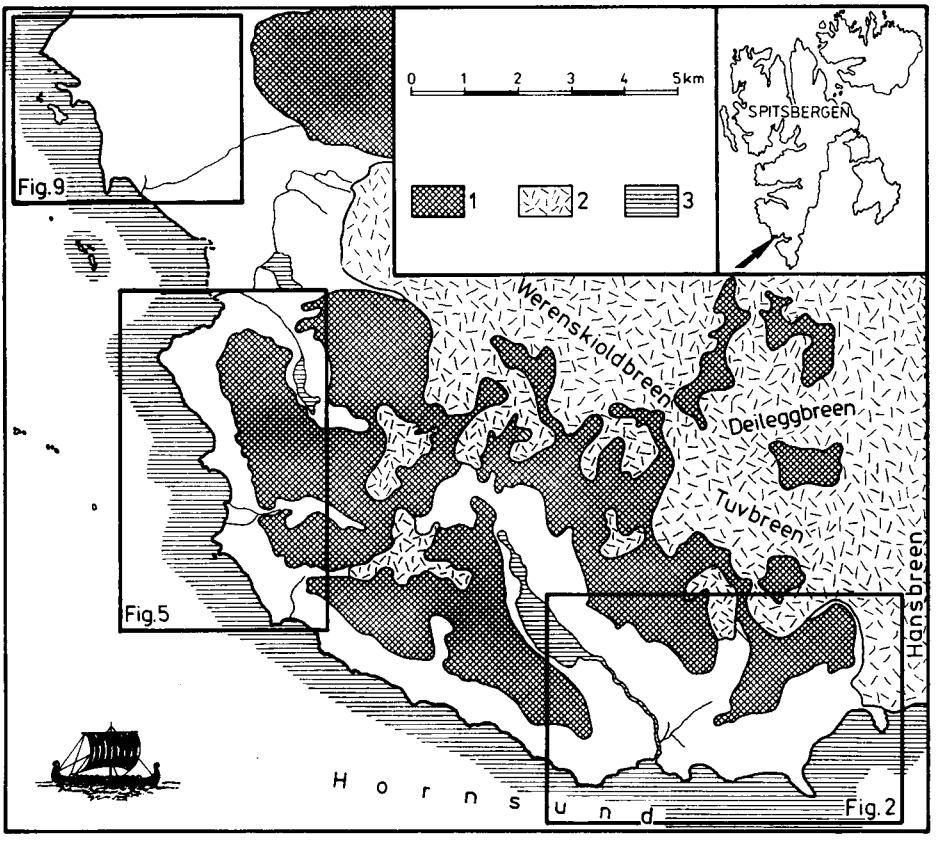

Fig. 1. Location of the studied areas (*cf.* Figs. 2, 5 and 9) in the northern Hornsund Region
1 — mountains, 2 — glaciers, 3 — seashore with larger lakes and streams

scale of 1:25,000, sheets Werenskiöldbreen (no. 1) and Isbjörnhamna (no. 2), prepared for the Hornsund Region and possessing the main contour lines at every 5 m, and supplementary ones at every 2.5 and 1.25 m.

Studies of the age of the raised marine beaches were also supplied with 14 new thermoluminescence datings of sediments, sampled in early summer 1988 (Table 1). Determinations were done by Dr. J. Butrym from the M. Curie-Skłodowska University of Lublin in agreement with the previously published stipulations and methodics (*cf.* Butrym *et. al.* 1987a).

Worcesterpynten-Wilczekodden area

This area of the northern Hornsund Region has most data on geologic and geomorphologic setting, and age of raised marine beaches (*cf.* Birkenmajer 1958, 1960; Birkenmajer and Olsson 1970; Jahn 1959a, b; 1968; Karczewski,

Table 1

Thermoluminescence datings of samples from sediments of raised marine beaches in the northern Hornsund Region

Location	Age (ka)	Lab. no	Sediments	Geomorphologic setting
Revdalen	60±9	Lub-1731	gravels, pebbles	marine beach 40—46 m
Revdalen	11±2	Lub-1732	gravels, pebbles, sands	marine beach 8—12 m
Revdalen	3.3±0.5	Lub-1733	gravels, pebbles, sands	marine beach 4.5—6 m
Wilczekodden	10.2+1.5	Lub-1721	gravels, pebbles, sands	marine beach 8—12 m
Wilczekodden	4.3±0.6	Lub-1720	gravels with shells	marine beach 4.5—6 m
Skjerstranda	24±3.6	Lub-1727	gravels, pebbles, sands	marine beach 16—18 m
Russepynten	9±1.4	Lub-1729	gravels, pebbles, sands	marine beach 8—12 m
Russepynten	4±0.6	Lub-1728	clayey mud	rivulet bed 2 m a.s.l.
Russepynten	3.9±0.6	Lub-1730	gravels, pebbles, sands	marine beach 4.5—6 m
Nottinghambukta	16±2.5	Lub-1722	sands, gravels	marine beach 8—12 m
Nottinghambukta	12±1.8	Lub-1723	gravels, pebbles, sands	marine beach 8—12 m
Elveflya	16±2.5	Lub-1726	gravels, pebbles, sands	marine beach 8—12 m
Elveflya	4.1±0.6	Lub-1724	gravels, pebbles, sands	marine beach 4.5—6 m
Elveflya	3.7±0.5	Lub-1725	gravels, pebbles, sands	marine beach 4.5—6 m

Kostrzewski and Marks 1981, 1984; Lindner, Marks and Pękala 1986; Pękała 1989). All these data, completed with the new ones of the authors indicate that there are 8 marine beaches in this area at 100—120, 70—75, 50—60, 40—46, 22—25, 16—18, 8—12 and 4.5—6 m a.s.l. (Fig. 2, Pls. 1—3), and the lowest beach at 2 m a.s.l. which is not marked due to its small size (to 5—10 m wide).

These beaches (the lowermost excluded) are from several dozen to several hundred meters wide, with surfaces insignificantly sloping southwards, towards the fiord. They are composed of zones with marine sediments (accumulative level) and outcrops of pre-Quaternary rocks, being ancient skerries (abrasive level according to Karczewski, Kostrzewski and Marks 1981). Sediments of marine beaches in the Worcesterpynten-Wilczekodden area enclose mainly gravels and pebbles of local rocks (Hecla Hoek Formation) with insignificant

admixture of sand, interbeds of clay with remains of malacofauna and whales or laminaria (particularly common in lower beaches). Thicknesses of these sediments are usually small, generally from 3—4 m to several dozen centimeters (Pl. 2). Driftwood is frequently noted in superficial sediments of two lowermost beaches.

Surfaces of raised marine beaches up to 40—46 m a.s.l. possess commonly traces of storm ridges. The latter are separated from one another by depressions which are indicated on air photos by dark tones and in the field by finer sediment with admixture of organic matter. Marine beaches 22—25, 16—18 and 8—12 m a.s.l. have also depressions partly filled with water, the origin of which could be connected with stranded sea ice or icebergs (*cf.* Lindner and Marks 1989).

In the described area most marine beaches are dissected by outwash and nival streams, and also by Revelva (Fig. 2). Many a time small outflow water reservoirs were formed along such streams as their longitudinal sections were not smooth (Birkenmajer 1960).

Thermoluminescence (TL) datings suggest that sediments (to 1.5 m thick) of the marine beach 100—120 m a.s.l. (Fig. 2) on southern slope of Fugleberget were deposited about 163±26 ka (Pękala 1989). Similar sediments on the eastern side of the Hans Glacier (outside the described area) were TL dated at 161±24 ka (Marks and Pękala 1986). The lower and therefore probably younger beach at 70—75 m a.s.l. is preserved on eastern slope of middle Revdalen and patches of sediments of marine beaches 50—60 and 40—46 m a.s.l. occur on southern slope of Fugleberget (Fig. 2). The latter are composed of gravels with interbeds of marine clays. Sediments of the higher beach were TL dated at 56±8 ka (Pękala 1989). The lower beach correlates also to patches of marine sediments at 40—46 m a.s.l. to the south and southeast from Revvatnet (Fig. 2) and TL dated (Table 1) at 61±9 ka (Lub—1731). All these data suggest that the lower beach could be formed due to erosive removal of sediments of the older beach.

Sediments of the marine beach 22—25 m a.s.l. are noted in the described area at foot of southern slopes of Rotjesfjellet, Ariekammen and Fugleberget (Fig. 2) and are many a time partly covered in the north by deluvia and nival moraines. Further to the south *i.e.* towards the seashore, sediments of this beach fill usually depressions admidst outcrops of pre-Quaternary rocks and are partly overlain by slope, glaciofluvial and glacial sediments — particularly in forefields of Arie and Hans glaciers. This raised marine beach is composed of weathered gravels and sands but also of clays with inserts of gravels and pebbles.

The successive lower marine beach 16—18 m a.s.l. occurs on southern side of Rotjesfjellet, Ariekammen and Fugleberget. It is separated from a higher beach by a distinct edge (Fig. 2) and composed of marine gravels, sands and clays, locally to 2.5 m thick. At local concentration of outcrops of rocks of the

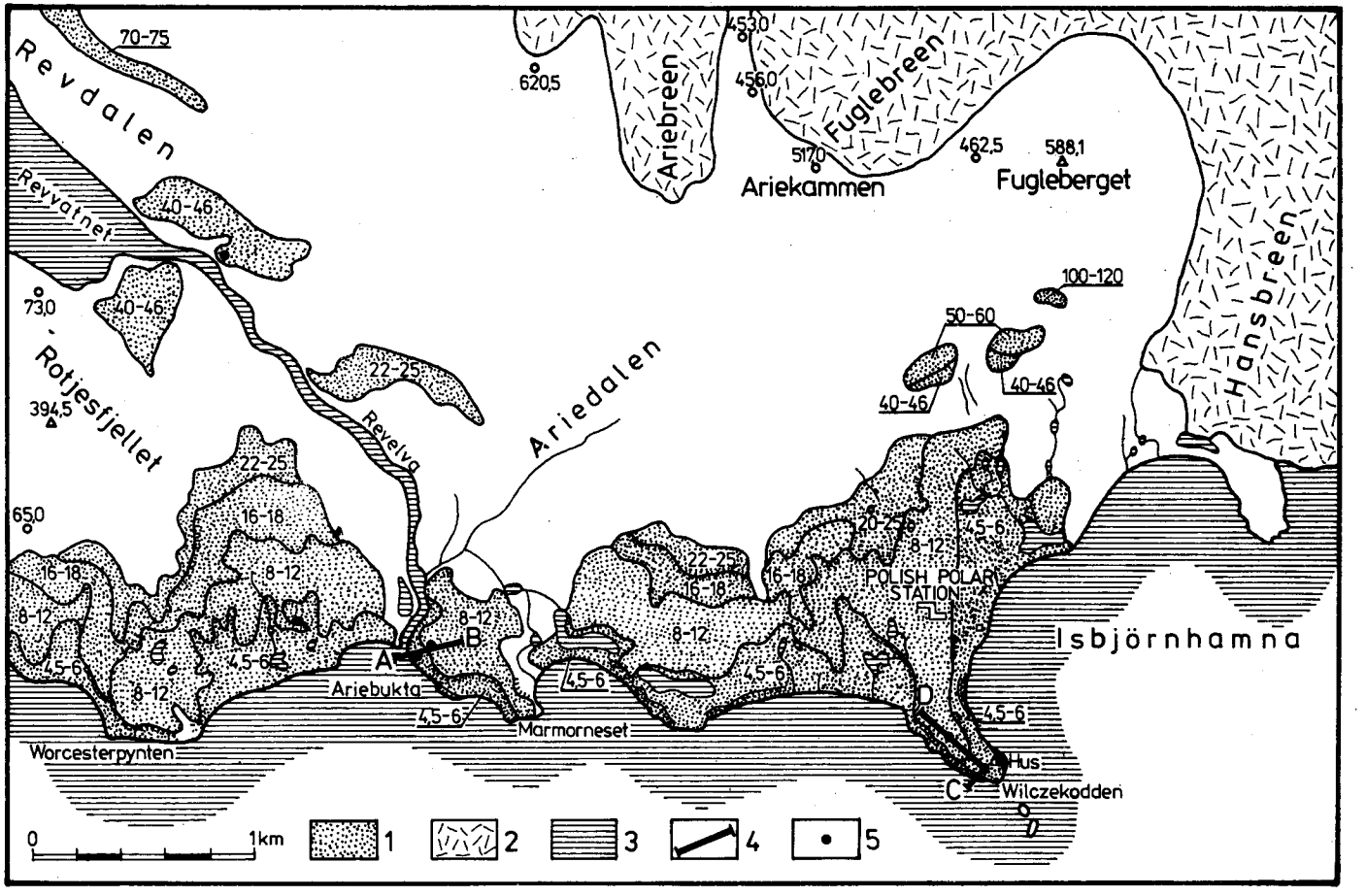

Fig. 2. Raised marine beaches 4.5—6, 8—12, 16—18, 22—25, 40—46, 50—60, 70—75, 100—120 m a.s.l. in the Worcesterpynten-Wilczekodden area
1 — marine beaches, 2 — glaciers, 3 — shoreline and greater lakes and streams, 4 — geologic sections, 5 — sampling sites of the authors for TL dating

Hecla Hoek Formation the surface of this beach is overlain by block-debris weathering mantle. Generally superficial sediments of this beach are intensively deformed and transformed by periglacial processes. In the eastern part of this area, sediments of the beach 16—18 m a.s.l. were TL dated at 25—28 ka (Pękala 1989).

Sediments of the marine beach 8—12 m a.s.l. occupy a largest area of the all raised marine beaches in the described region (Fig. 2). They are represented by marine sands and clays but also by gravels and pebbles (Pl. 2) with remains of malacofauna and whales. They are locally to 4 m thick (Fig. 3). Surfaces of storm ridges of this beach (Pl. 1, Fig. 2) are commonly dissected by triaxial systems of polygons of frost fissures (*cf.* Jahn 1975). To the west of the mouth of Revelva the marine beach 8—12 m a.s.l. has depressions, partly filled with water, that are presumably the relics of sea ice or small icebergs which have stranded here in the past (*cf.* Lindner and Marks 1989). The sediments of this beach were TL and radiocarbon dated. Radiocarbon datings of remains of malacofauna and whales indicate an age of 8 to 10 ka (Birkenmajer and Olsson 1970, Lindner, Marks and Pękala 1986). On the other hand TL datings (Figs. 3 and 4) speak for deposition from 10.2±1.5 ka (Lub—1721) to 11±2 ka (Lub—1732) or even from 8 to 14 ka (Pękala 1989).

Sediments of the marine beach 4.5—6 m a.s.l. occupy vast areas close to the fiord shore (Fig. 2). They are composed of gravels and vari-grained sands, with remains of molluscs and whales but also with abundant driftwood on the surface. Superficial sediments are also enriched with fine mineral fraction of aeolian origin (Pękala 1989). Radiocarbon datings of the mentioned organic remains indicated that some sediments of this beach, dated at 8.4±1.7 ka and 9.6±1.8 ka (Birkenmajer and Olsson 1970) should represent rest

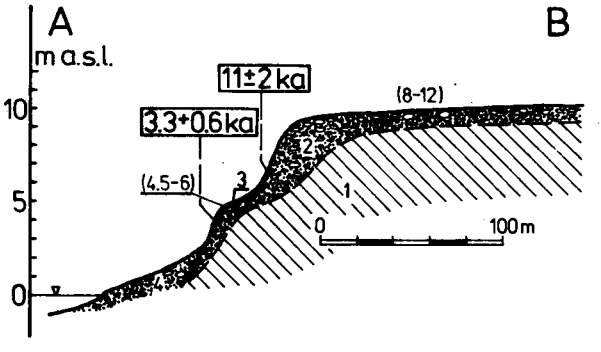

Fig. 3. Geologic section A-B of marine beaches 4.5—6 m a.s.l. and 8—12 m a.s.l. in the Worcesterpynten-Wilczekodden area (*cf.* Fig. 2) with results of TL datings
1 — pre-Quaternary rocks, 2 — gravels, pebbles and sands of the marine beach 8—12 m a.s.l., 3 — gravels, pebbles and sands of the marine beach 4.5—6 m a.s.l., 4 — sands, gravels and pebbles of the present beach

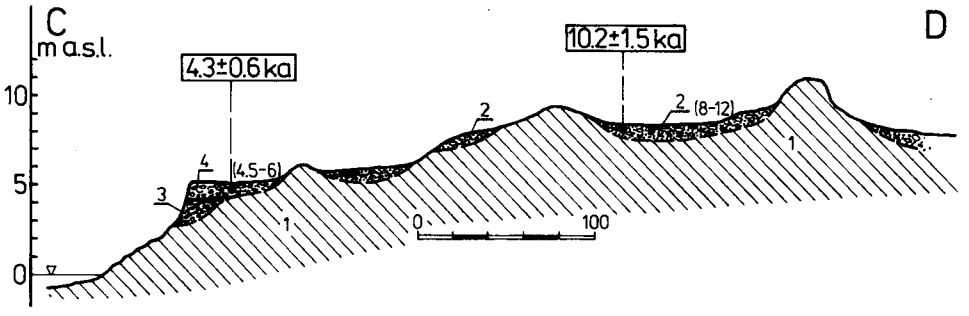

Fig. 4. Geologic section C-D of marine beaches 4.5—6 and 8—12 m a.s.l. in the Worcesterpynten-Wilczekodden area (*cf.* Fig. 2) with results of TL datings
1 — pre-Quaternary rocks, 2 — gravels, pebbles and sands of the marine beach 8—12 m a.s.l., 3 — shingle with *Balanus sp.* (*cf.* Birkenmajer 1960), 4 — shingle with shell detritus and *Balanus* plates (*cf.* Birkenmajer 1960)

series of the older beach 8—12 m a.s.l. Only the superficial part of the beach dated at 1.1 ± 0.8 ka to 0.8 ± 0.07 ka (Birkenmajer and Olsson 1970) ascribed it to a proper age (Fig. 12). Also the TL data of sediments of the beach 4.5—6 m a.s.l. (Figs. 3 and 4, Table 1) from 4.3 ± 0.6 ka (Lub—1720) to 3.3 ± 0.5 ka (Lub—1733) speak for their possible older age if referred to the beach surface itself, development due to erosive removal of earlier sedimentary series.

The youngest marine beach at about 2 m a.s.l. is usually expressed by a single and only seldom by several storm ridges. This beach is composed of gravels with pebbles as well as sands with gravel what depends on lithologic composition of sediments and rocks exposed at level of oncoming waves. There are also remains of molluscs and driftwood. Development of this beach in the part of the shore that is formed of glacial sediments of the Little Ice Age (600—100 years ago) proves its deposition to have started several dozen years ago.

Kvartsittodden-Russepynten area

In this area there are the only fragments of questionable highest raised marine beaches in the described part of Spitsbergen. They occur however outside a seashore and form relatively distinct rock shelves in valleys that dissect mountain massifs of this region. In a small valley just to the south from the main elevation of Guliksenfjellet, these beaches are noted at 220—230, 200—205 and 180—190 m a.s.l. whereas in a valley further to the south — at 80—95 m a.s.l. (Fig. 5). In the Brattegg Valley (Bratteggdalen) on northeastern side of Gulliksenfjellet, particularly around the Myrktjörn Lake, there are beaches at 180—190, 100—115 and 80—95 m a.s.l. (Fig. 5).

A seashore in the described area is composed of lower marine beaches, developed as continuous levels of gravels and pebbles of local rocks and with

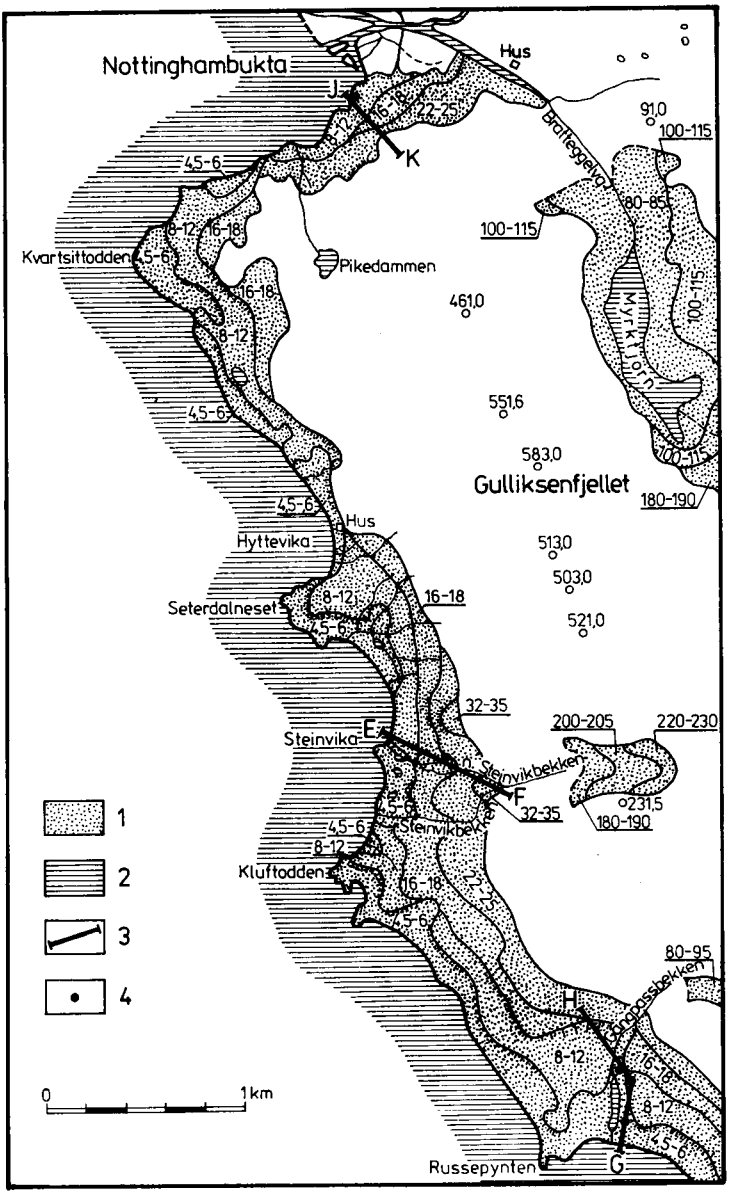

Fig. 5. Raised marine beaches 2, 4.5—6, 8—12, 16—18, 22—25, 32—35, 80—95, 100—115, 180—190, 200—205 and 220—230 m a.s.l. in the Kvartsittodden-Russepynten area
1 — marine beaches, 2 — shoreline and greater lakes and streams, 3 — geologic sections, 4 — sampling sites of the authors for TL dating

insignificant admixture of sands. These beaches have varying widths from several dozen to about 500 m and numerous outcrops of pre-Quaternary rocks. The beaches are separated from one another by erosive beaches, each 3—4 m high.

Sediments of the marine beach 32—35 m a.s.l. form two separate shelves to the east from Steinvika (Figs. 5 and 6). They are composed of gravels

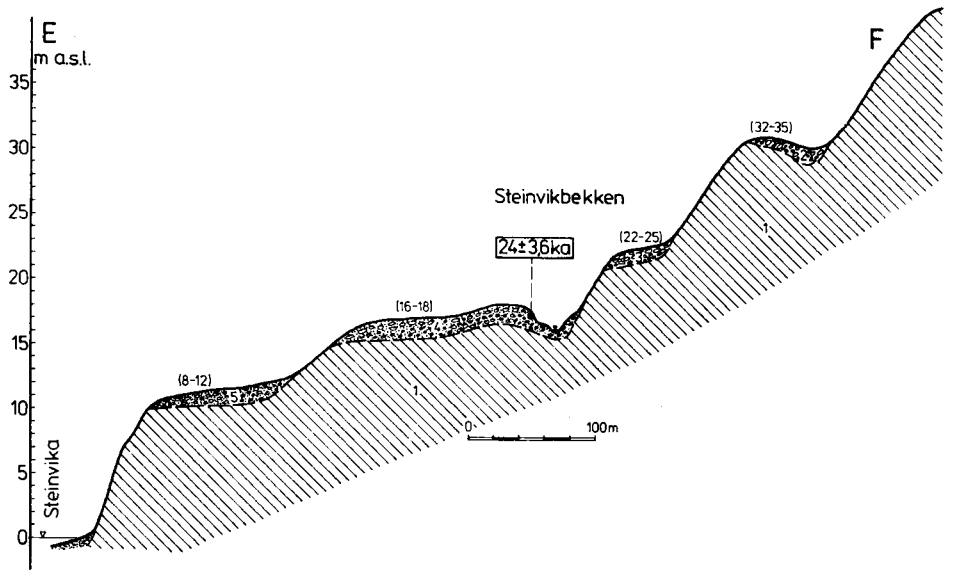

Fig. 6. Geologic section E-F of marine beaches 8—12, 16—18, 22—25, 32—35 m a.s.l. in the Kvartsittodden-Russepynten area (*cf.* Fig. 5) with results of TL datings
1 — pre-Quaternary rocks, 2 — gravels and pebbles of the marine beach 32—35 m a.s.l., 3 — gravels and pebbles of the marine beach 22—25 m a.s.l., 4 — gravels, pebbles and sands of the marine beach 16—18 m d.s.l., 5 — gravels, pebbles and sands of the marine 8—12 m a.s.l., 6 — sands, gravels and pebbles of the present beach

and pebbles, resting in a thin mantle (1—2 m thick) on pre-Quaternary rocks.

Sediments of the marine beach 22—25 m a.s.l. are considerably more widespread and to 3 m thick. They occur both in southern and northern parts of the described area (Figs. 5—8). The sediments are composed mostly of gravels with admixture of pebbles and sands, and sporadic inserts of clayey material. At outcrops of pre-Quaternary rocks the beach is mantled with debris-boulder weathering series.

Sediments of the marine beach 16—18 m a.s.l. form distinct, although occasionally discontinuous planes along the whole seashore of the described area (Pl. 4, Fig. 1). If compared with higher beaches, they contain more sands and remains of molluscs. They have considerably varied thickness from several dozen centimeters where pre-Quaternary rocks occur at small depths, to 3—4 m in deeper incisions within the latter. In the central part of the seashore close to Steinvika (Fig. 5) sediments of a small stream coming from a higher valley (Fig. 6) but located in an erosive incision within this beach, were TL dated (Table 1) at 24 ± 3.6 ka (Lub—1727). This age corresponds well with other datings of sediments of this beach in western forefield of the Hans Glacier (*cf.* Pękala 1989).

Sediments of the marine beach 8—12 m a.s.l. are in this area the best developed and most widespread. They are composed of gravels and pebbles

with admixture of sands and remains of molluscs, whales and laminaria. Frequently they are to 6—8 m thick. In numerous places and particularly at headlands (Kvartsittodden, Seterdalneset, Kluftodden, Russepynten) of a seashore in this area (Fig. 5), this beach is considerably wider to 400—500 m. This last fact results probably from preservation by numerous outcrops of pre-Quaternary rocks, rising above the beach surface as fossil skerries to 2—3 m high (Pl. 4, Fig. 1). At half-distance between Kvartsittodden and Hyttevika a surface of this beach indicates also small depressions, one of which is filled with water. They have been formed presumably partly due to stranding of sea ice or icebergs (*cf.* Lindner and Marks 1989). Such interpretation could be supported by relief of the beach surface close to these kettles, especially be specific pattern of storm ridges.

Radiocarbon datings of remains of malacofauna and laminaria within sediments of the marine beach 8—12 m a.s.l. in the Nottinghambukta area ascribe its age to about 8—7 ka (Chmal 1987, 1988) *i.e.* slightly less than in the Worcesterpynten-Wilczekodden area. TL datings of sediments of the beach 8—12 m a.s.l., collected by the authors in the Russepynten (Fig. 7, Table 1) and

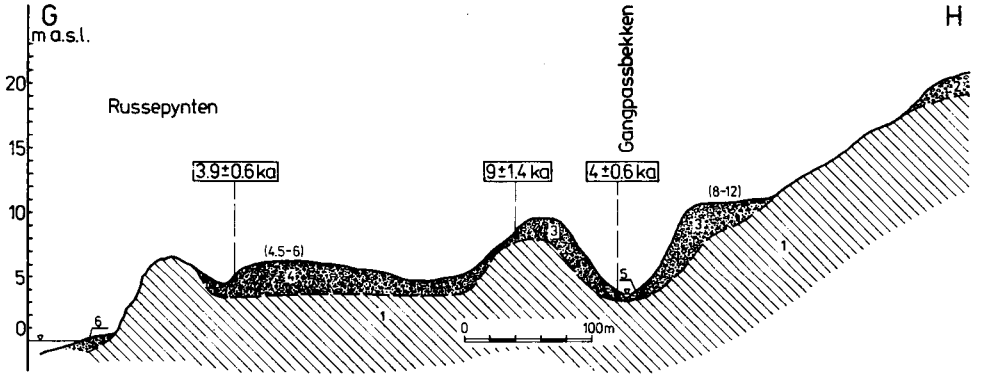

Fig. 7. Geologic section G-H of marine beaches 4.5—6, 8—12 and 22—25 m a.s.l. in the Kvartsittodden-Russepynten area (*cf.* Fig. 5) with results of TL datings
1 — pre-Quaternary rocks, 2 — gravels and pebbles of the marine beach 22—25 m a.s.l., 3 — gravels, pebbles and sands of the marine beach 8—12 m a.s.l., 4 — gravels, pebbles and sands of the marine beach 4.5—6 m a.s.l., 5 — clay mud, 6 — sands, gravels and pebbles of the present beach

in the Nottinghambukta (Fig. 8, Table 1) areas suggest the age of 9±1.4 ka (Lub—1729) in the first case but 16±2.5 ka (Lub—1722) and 12±1.8 ka (Lub—1723) in the second case. The first date is close to radiocarbon age of organic remains from this beach in Nottinghambukta and Worcesterpynten-Wilczekodden areas. Two other dates present a considerably older age of this beach, even if compared with TL data from the Worcesterpynten-Wilczekodden area.

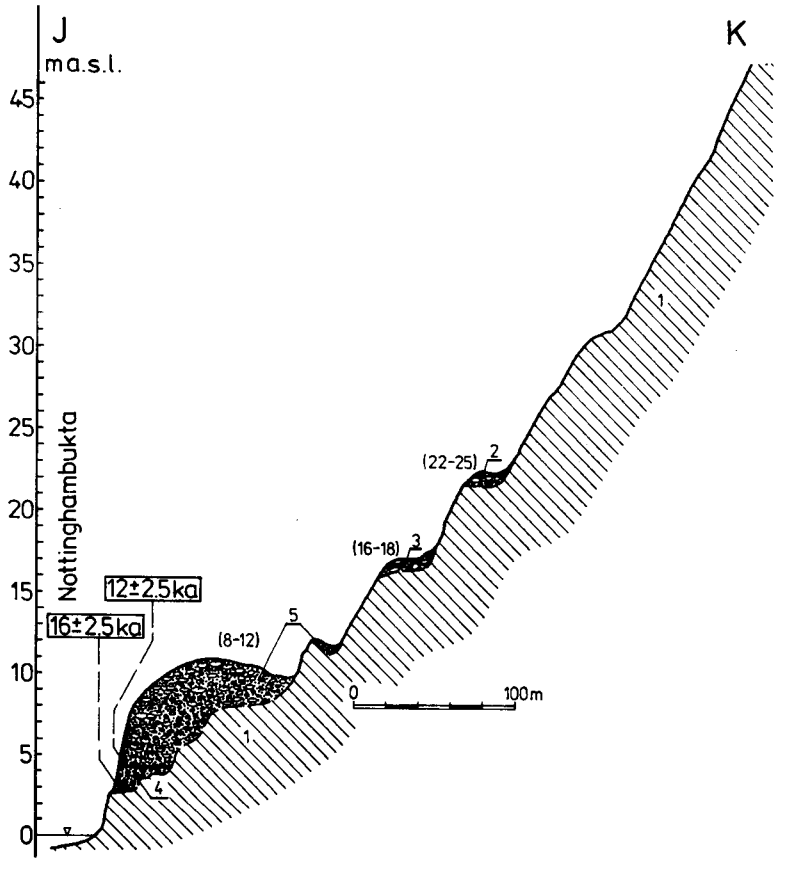

Fig. 8. Geologic section I-K of marine beaches 8—12, 16—18 and 22—25 m a.s.l. in the Kvartsittodden-Russepynten area (*cf.* Fig. 5) with results of TL datings
1 — pre-Quaternary rocks, 2 — gravels and pebbles of the marine beach 22—25 m a.s.l., 3 — gravels and pebbles of the marine beach 16—18 m a.s.l., 4 — sands and gravels of the marine beach 8—12 m a.s.l., 5 — gravels, pebbles and sands of the marine beach 8—12 m a.s.l.

A bipartite section of sediments of the beach 8—12 m a.s.l. in the Nottinghambukta area (Fig. 8; Pl. 4, Fig. 2), indicated by bottom sands with remains of molluscs and admixture of gravel (16±2.5 ka), and top gravel with sands, mollusc remains, pebbles and pieces of local rocks (12±1.8 ka), suggest that the lower part represents an older (higher) marine beach, sediments of which have been removed partly by sea during development of the beach 8—12 m a.s.l.

Sediments of the marine beach 4.5—6 m a.s.l. form a continuous step in the area Kvartsittodden-Russepynten. They are common within bays but also at headlands of the seashore. These sediments are composed mainly of gravels and pebbles with an insignificant admixture of sands and with mollusc remains. Usually the surface of the beach 4.5—6 m a.s.l. is separated from the higher beach by distinct and high (2—4 m) erosive edge (Fig. 5). This surface indicates systems of storm ridges, corresponding to a shape of the present coastline and

to outcrops of past skerries (Pl 4, Fig. 1). Superficial sediments of this beach are enriched in fine fractions of mineral material due to aeolian processes.

Radiocarbon datings of whale remains and driftwood on surface of the beach 4.5—6 m a.s.l. in the neighboring areas suggest that it has been formed at 1—0.8 ka. In the described area sediments of this beach were also TL dated (Fig. 7, Table 1) at 3.9±0.6 ka (Lub—1730) whereas interfingering sediments of a valley incision at 4±0.6 ka (Lub—1728). These dates prove that, similarly as in other areas of the northern Hornsund Region, the marine sediments are older than the beach surface due to erosive removal of older marine sediments.

The youngest marine beach of the described area at about 2 m a.s.l. is indicated by 1—3 storm ridges of the present shore. It is composed of gravels and sands with pieces of molluscs and laminaria. On its surface there are common driftwood, whale remains and also boulders coming from melting sea ice rafts and icebergs (*cf.* Giżejewski and Roszczynko 1982). In the Nottighambukta area (Fig. 5) this beach is wider as composed of deltaic sediments of Brattegelva: gravel-sandy lower member formed due to basal transport and silty-clayey mantle from deposition of suspended matter with considerable participation of flocculation. Sedimentary structures on surface of these sediments indicate their redeposition due to wave processes (Giżejewski 1986). Similarly as in other areas of the northern Hornsund Region, deposition of the beach 2 m a.s.l. has been initiated several dozen years ago.

Vimsodden-Kvislodden area

In the Vimsodden-Kvislodden area there are only three youngest marine beaches (Fig. 9). It is presumably due to the fact that seashore in this part of southern Spitsbergen is composed mainly of glaciofluvial and glacial sediments which have been deposited in front of Werenskiold, Nann and eastern Torell glaciers. These sediments indicate a relatively young but greater glacier extent (*cf.* Szupryczyński 1963, Baranowski 1977, Karczewski and Wiśniewski 1977, Lindner, Marks and Ostaficzuk 1982). Two older marine beaches (8—12 and 4.5—6 m a.s.l.) form a vast erosive outlier surrounded in the southeast by outwash sediments of Elveflya (Fig. 9) and in the north by outwash sediments of Vimsosen.

The marine beach 8—12 m a.s.l. occupies a largest area within this outlier, running from west to east at distance of about 2.5 km and from north to south at about 1.5 km (Fig. 9). A surface of this beach is very uneven and composed of gravels and pebbles with sand and mollusc remains, all together to 2—4 m thick and usually filling depressions between abundant outcrops of pre-Quaternary rocks, being ancient skerries and rising even to 18—20 m a.s.l. They are considered for fragment of older marine beach (*cf.* Ostaficzuk, Marks and Lindner 1980). TL datings of sediments collected in an exposure 2—3 m

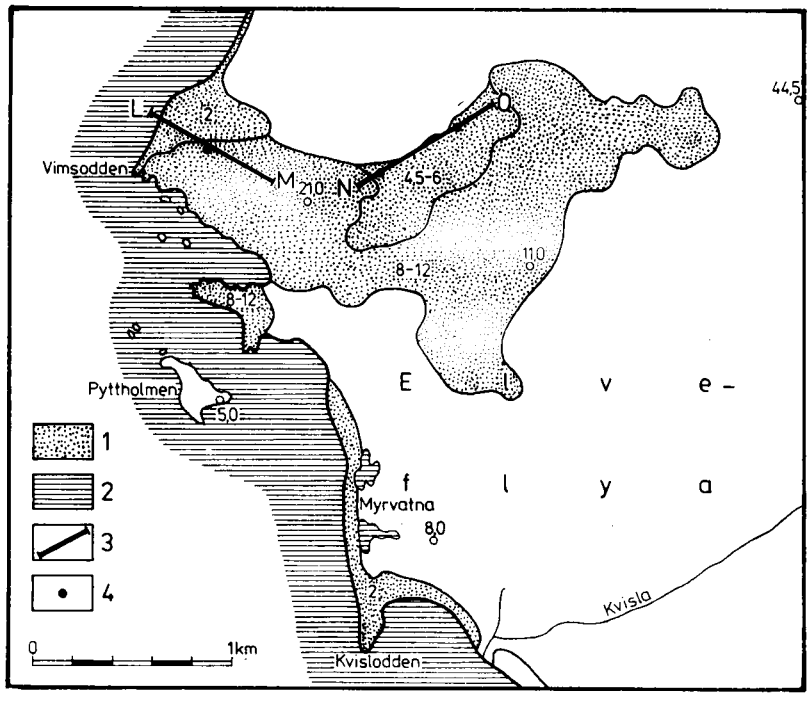

Fig. 9. Marine beaches 2, 4.5—6 and 8—12 m a.s.l. in the Vimsodden-Kvislodden area
1 — marine beaches, 2 — shoreline, 3 — geologic sections, 4 — sampling sites of the authors for TL datings

below the beach surface (Fig. 10, Table 1) indicated the age of 16±2.5 ka (Lub—1726). This value is equal to the one from the lower part of the beach 8—12 m a.s.l. in the Nottighambukta area (*cf.* Fig. 8, Table 1) and therefore, also points out a posiible preservation of older marine sediments within the dated sections.

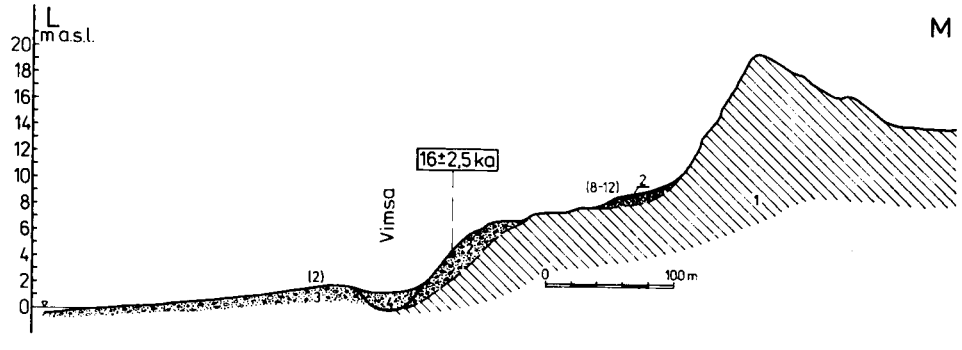

Fig. 10. Geologic section L-M marine beaches 2 and 8—12 m a.s.l. in the Vimsodden-Kvislodden area (*cf.* Fig. 9) with results of TL datings
1 — pre-Quaternary rocks, 2 — gravels, pebbles and sands of the marine beach 8—12 m a.s.l., 3 — sands, gravels and pebbles of the marine beach 2 m a.s.l. with driftwood on the surface, 4 — outwash sands and gravels

Sediments of the marine beach 4.5—6 m a.s.l. are preserved in the described area as a separate step in northern part of an erosive outlier formed by the higher beach (Fig. 9). These sediments are represented by gravels and sands with pebbles and mollusc remains and are over 2 m thick. In a close contact with bedrock outcrops that from ancient skerries of higher beach, a surface of the described beach is mantled with boulder-debris mantles. In many places of the beach 4.5—6 m a.s.l. there are small (to 20—30 cm high) swells of sand due to intensive aeolian activity. TL dating of two samples of beach sediments (Fig. 11, Table 1) indicated their age equal 4.1±0.6 ka (Lub—1724) and 3.7±0.5 ka (Lub—1725). These dates, similarly as in other areas of southern Hornsund

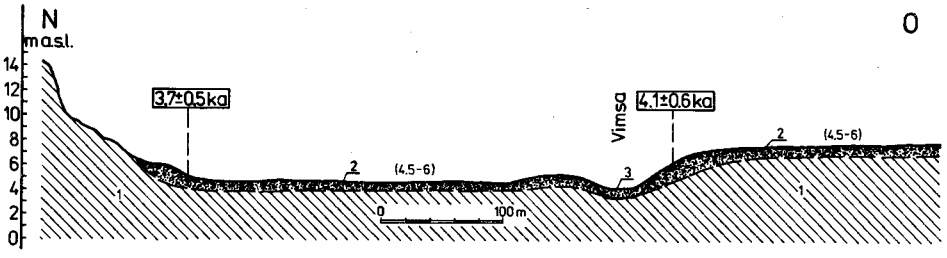

Fig. 11. Geologic section N-O of the marine beach 4.5—6 m a.s.l. of the Vimsodden-Kvislodden area(*cf.* Fig. 9) with results of TL datings
1 — pre-Quaternary rocks, 2 — sands, gravels and pebbles of the marine beach 4.5—6 m a.s.l. with remains of whale bones on the surface, 3 — outwash sands and gravels

Region, make sediments of the beach 4.5—6 m a.s.l. to be about 3.5—5 ka older in referred to radiocarbon datings of organic material (whale remains, driftwood) deposited by sea on the surface of this beach (*cf.* Birkenmajer and Olsson 1979).

The youngest marine beach at about 2 m a.s.l. is exceptionally well developed in the Vimsodden-Kvislodden area (Fig. 9). Its surface is there locally to 200—300 m wide what is distinctly connected with considerable admixture of fines, coming to the sea due to transport by outwash streams on Elveflya and Vimsosen. This material is mainly represented by sands and silts with small admixture of gravels and pebbles, and forms 2—3 storm ridges within this beach with driftwood on the surface. Similarly as in other areas, the main deposition of this beach has been started at the preliminary deglaciation after the Little Ice Age and still continues. Taking the beach 2 m a.s.l. in the Vimsodden-Kvislodden and in the Nottinghambukta as examples, widths and therefore also distinctness of raised marine beaches in the northern Hornsund Region are strictly dependent on quantity of mineral (sands and gravels) material transported to the sea by outwash streams. Development of these streams and particularly their rapid regime expressed by abundant transported mineral material, reached its highest intensity when more intensive deglaciation occurred in South Spitsbergen.

Final remarks

The presented geomorphologic and geologic data, completed with radiocarbon and thermoluminescence datings of raised marine beaches of the northern Hornsund Region indicate a complicated age nature of the beaches. On the other hand such a great number of TL datings of marine and terrestrial sediments in the Hornsund area (*cf.* Lindner, Marks and Pękala 1983, 1984, 1986, 1987; Butrym *et al.* 1987a, b; Marks and Pękala 1986; Chmal 1987, 1988; Pękala 1989) and in other parts of Spitsbergen (among others Troitsky *et al.* 1979, Karczewski and Rygielski 1989, Dzierżek and Nitychoruk 1990, Pękala and Repelewska-Pękalowa 1990, Reder 1990) makes possible, in spite of numerous limitations, use them to prepare a chronostratigraphic scheme of the Quaternary of South Spitsbergen (Lindner and Marks 1990a). Thermoluminescence datings have been lately more and more used for chronologic schemes of the Pleistocene climatic changes, also in Scandinavia (among others Hütt, Punning and Mangerud 1983; Jungner 1983, 1987; Jungner, Landvik and Mangerud 1989; Mejdahl, Kronborg and Strickertsson 1984; Mejdahl 1985, 1988), the Alps (Rögner *et al.* 1988) and the European Lowland (among other Lindner 1984, 1988; Rzechowski 1986; Zubakov 1986). Results of radiocarbon and thermoluminescence datings cited here enabled to present a chronostratigraphy of raised marine beaches of the northern Hornsund Region (Fig. 12).

Three highest although questionable marine beaches (220—230, 200—205 and 180—190 m a.s.l.) have not been dated yet. Geomorphologic and geologic settings of them suggest that they are older than the beach 100—120 m a.s.l., sediments of which were thermoluminescence dated at 163 ± 26 ka (Pękala 1989). Therefore all these four beaches should not be younger than the Wedel Jarlsberg Land Glaciation (Fig. 12), determined at 370—140 ka and correlated to the Middle Polish (Saalian) Glaciations in the European Lowland (*cf.* Lindner, Marks and Pękala 1983, 1984, 1987).

Two lower marine beaches (80—95 and 70—75 m a.s.l.) are older than the beach 50—60 m a.s.l. TL dated at 56 ± 8 ka (Pękala 1989). Presumably sediments of the same beach, TL dated in another place at 61 ± 9 ka (Table 1) are partly removed and surface of the beach 40—46 m a.s.l. is formed in them. We cannot however exclude that sediments of the same beach are of varied age due younger glacioisostatic movements. Taking into account geomorphologic and geologic sediments of the four above mentioned marine beaches and TL determinations, the beaches 80—95 and 70—75 were probably formed during the Bogstranda Interglacial and the older part of the Sörkapp Glaciation (Fig. 12) what corresponds to the Eemian Interglacial and the earlier part of the Wisła Glaciation (*cf.* Lindner, Marks and Pękala 1983, 1987). Marine beaches 50—60 and 40—46 m a.s.l. should occur in the middle part of the Sörkapp Land Glaciation (Fig. 12), when Spitsbergen glaciers were smaller than during

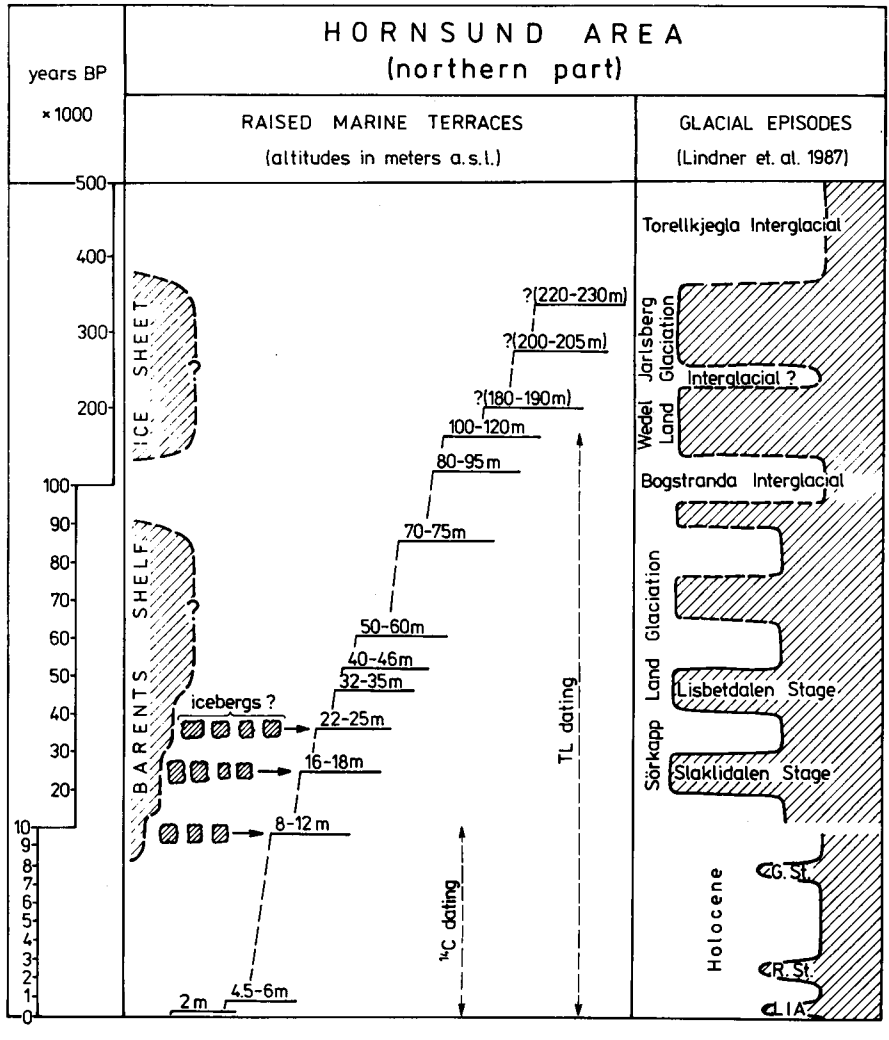

Fig. 12. Chronostratigraphic scheme of development of raised marine beaches in the northern Hornsund Region

their maximum extent about 50—40 ka (Boulton 1979) *i.e.* the Lisbetdalen Stage in South Spitsbergen (*cf.* Butrym *et al.* 1987a, b).

In Central Spitsbergen (Nordenskiöld Land) the marine beach at about 64 m a.s.l. is radiocarbon dated at 10.9—11 ka (Landvik, Mangerud and Salvigsen 1987). In the northern Billefjorden Region a similar beach (67 m a.s.l.) was TL dated at 166.6±24 ka (Stankowski *et al.* 1989). The first date seems to indicate considerably more intensive Late Glacial — Holocene glacioisostatic rebound of the outlet part of Isfjorden than of other parts of Spitsbergen. The second date may suggest slower glaciaisostatic uplift in inner Billefjorden than in the northern Hornsund Region.

Basing on TL datings the three lower marine beaches (32—35, 22—25 and 16—18 m a.s.l.) were formed at 40—25 ka (Pękala 1989; Table 1) when Spitsbergen glaciers rapidly retreated after their maximum extent during the Lisbetdalen Stage (Fig. 12). Presence of sea ice and iceberg depressions connected with ice sheet break-up in the Barents Sea or intensive calving of Spitsbergen glaciers indicate development of these beaches during the deglaciation of the Arctic. Radiocarbon datings of the lower beach with similar although smaller depressions made the authors refer this deglaciation to the Late Glacial period (*cf.* Lindner and Marks 1990b). TL datings suggest that the deglaciation could comprise the whole retreat phase of glaciers of the Lisbetdalen and Slaklidalen stages (Fig. 12). This period is also connected with deposition of marine sediments in many other parts of Svalbard (*cf.* Boulton 1979, Troitsky *et al.* 1979, Salvigsen 1981, Salvigsen and Nydal 1981, Salvigsen and Österholm 1982).

The three lowermost marine beaches (8—12, 4.5—6 and 2 m a.s.l.) of the northern Hornsund Region should be connected with the Holocene (Fig. 12). Preserved depressions after sea ice or icebergs in surface of the beach 8—12 m a.s.l. prove still intensive deglaciation of this part of Spitsbergen and surrounding seas during the Early Holocene. Age of this surface was radiocarbon determined at about 10 ka (Birkenmajer and Olsson 1970) whereas TL age of deeper sediments of this beach makes it about 2—3 ka older (Table 1), with age of mollusc and whale remains at 7.6—9.8 ka (Birkenmajer and Olsson 1970). Surface of the beach 4.5—6 m a.s.l. was formed about 1—0.8 ka if radiocarbon datings are concerned. Dating of deeper sediments of this beach by radiocarbon method at 8—7 ka (Birkenmajer and Olsson 1970) and by TL method at 3—4 ka (Table 1) suggests a possible cutting of the beach 4.5—6 m a.s.l. in sediments of the older beach or remains of malacofauna in sediments of the beach 4.5—6 m a.s.l. can be in secondary deposit. Surface of the beach 2 m a.s.l. developed during the last dozens of years and was distinctly connected with supply of terrigene material to the sea by intensively melting glaciers of the Little Ice Age.

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Streszczenie

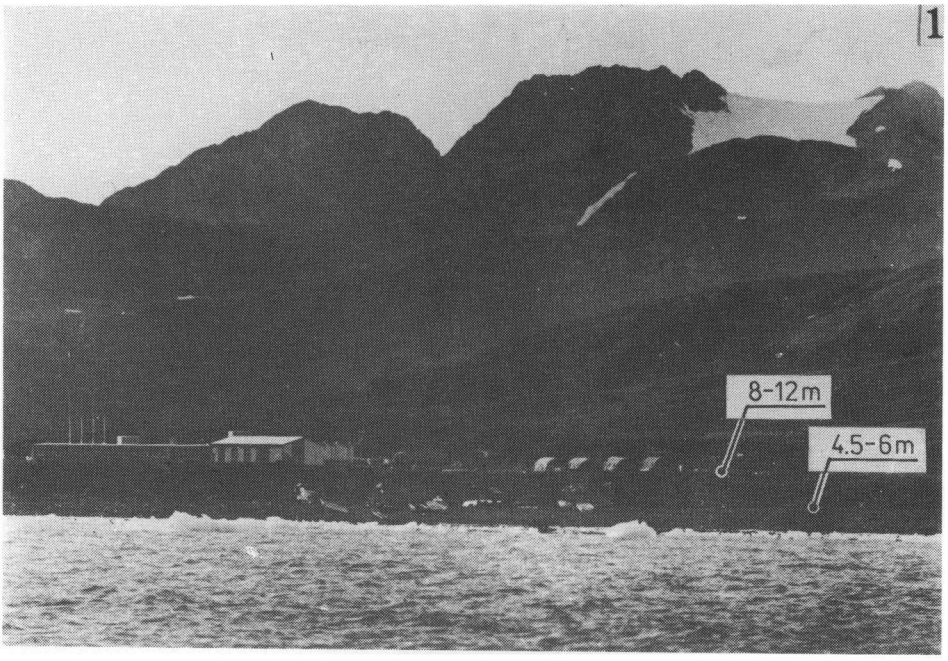
W pracy podtrzymano opinię Karczewskiego i in. (1981) co do liczby i wysokości wyniesionych tarasów morskich w strefie północnego obramowania Hornsundu oraz przedstawiono zasięgi występowania tych tarasów w trzech głównych rejonach własnych prac badawczych (fig. 1—11, pl. 1—4). Zasięgi te zostały określone przy pomocy podkładu hipsometrycznego w skali 1:25 000, jakim dla badanych rejonów są sekcje: Werenskioldbreen (nr 1) i Isbjörnhamna (nr 4) polskiej mapy topograficznej rejonu Hornsundu z 1987 roku. Z tego też powodu różnią się one nieco od zasięgów tarasów przedstawionych przez Karczewskiego i in. (1981), dla których podkładem była powiększona norweska mapa topograficzna w skali 1:100 000.

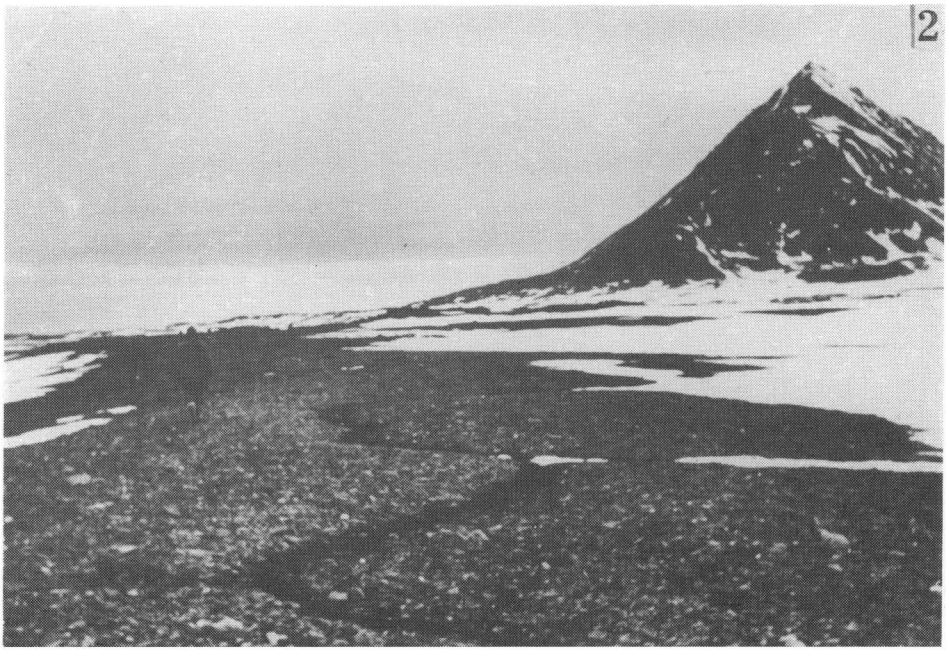
Wiek wyniesionych tarasów morskich północnego obramowania Hornsundu określono (fig. 12) wykorzystując wcześniej publikowane datowania radiowęglowe i termoluminescencyjne (*por.* Blake i in. 1965, Birkenmajer, Olsson 1970, Marks 1983, Lindner i in. 1986, Marks, Pękala 1986, Chmal 1984, 1987, 1988, Pękala 1989) oraz ostatnio uzyskane daty termoluminescencyjne 14 próbek osadów tych tarasów (tabela 1).

Na podstawie całości powyższych danych wykazano, że cztery najwyżej tu występujące tarasy morskie (220—230 m, 200—205 m, 180—190 m, 100—120 m npm), z których najniższy został wydatowany metodą termoluminescencji na 163±26 ka, należy odnieść do zlodowacenia Wedel Jarlsberg Land = Saalian (fig. 12). Utworzenie systemu czterech niższych tarasów morskich (80—95 m, 70—75 m, 50—60 m, 40—46 m npm), z których jedynie dwa najniższe zostały wydatowane metodą termoluminescencji na 56±8 ka i 61±9 ka, związano z okresem interglacjału Bogstrandy = Eemian i starszą, przedmaksymalną częścią zlodowacenia Sörkapp Land = Vistulian (fig. 12). Utworzenie trzech jeszcze niższych tarasów morskich (32—35 m, 22—25 m, 16—18 m npm), w obrębie których najniższy wydatowano metodą termoluminescencji na 24±3,6 ka, należy odnieść do pomaksymalnej części zlodowacenia Sörkapp Land, obejmującej zanik lodowców stadiału Lisbetdalen (około 50—40 ka) i stadiału Slaklidalen (około 30—20 ka). Jak wykazały datowania radiowęglowe i termoluminescencyjne utworzenie powierzchni trzech najniższych tarasów morskich opisywanego obszaru (8—12 m, 4,5—6 m, 2 m npm) nastąpiło w holocenie.

W pracy zwrócono uwagę, że zbliżone daty osadów niektórych tarasów morskich a zwłaszcza zachowanych w nich szczątków malakofauny (np. 8—12 m i 4,5—6 m npm) oraz starsze daty dla osadów niektórych tarasów niższych niż dla osadów wyższych (np. 50—60 m i 40—46 m npm) mogą być dowodem, że niektóre z analizowanych tarasów morskich Spitsbergenu stanowią jedynie młodszą powierzchnię abrazyjną, powstałą w wyniku usunięcia przez morze górnej części osadów starszych.

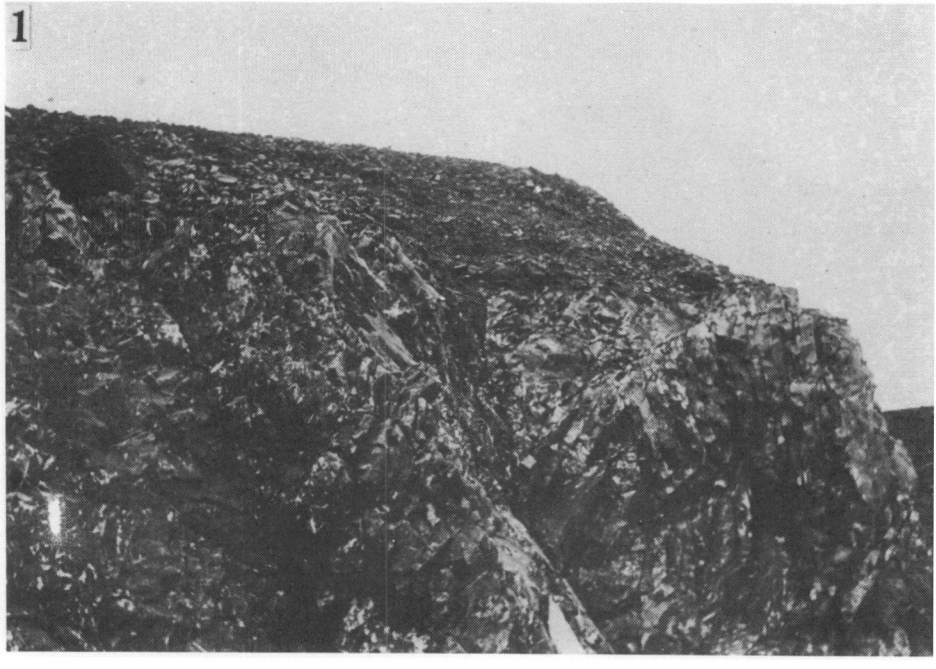
Praca została wykonana w ramach CPBP 03.03.B7.





1 — Hornsund, marine beaches 4.5—6 and 8—12 m a.s.l. with buildings of the Polish Polar Station on the higher beach

2 — Hornsund, Marmorneset; storm ridge of the marine beach 8—12 m a.s.l. with triaxial polygons of frost fissures

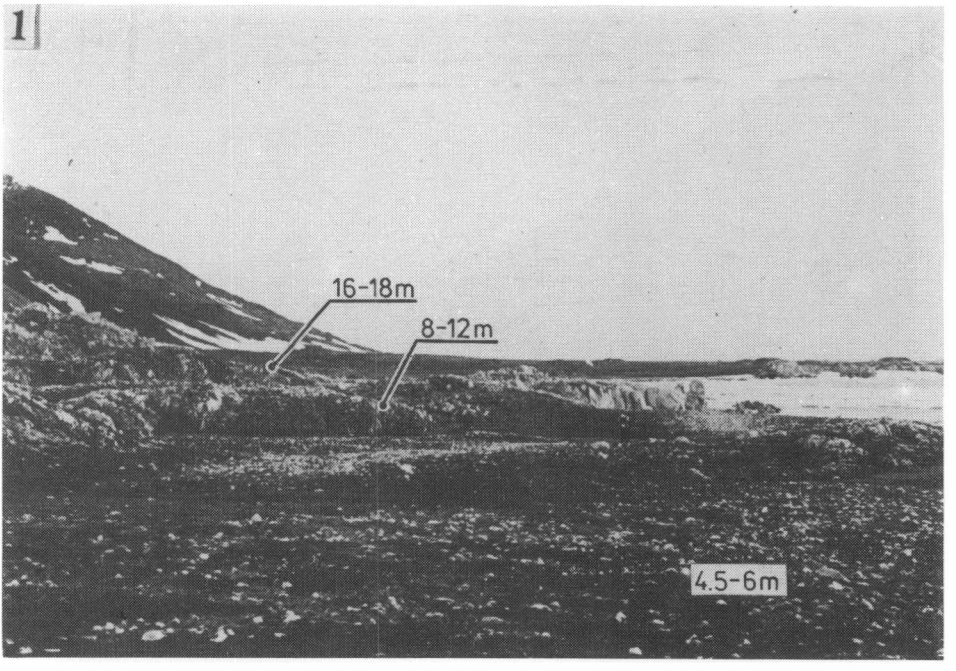


1 — Hornsund, Marmorneset — western part; gravels, pebbles and sands of the marine beach 8—12 m a.s.l. on pre-Quaternary rocks

2 — Hornsund, Marmornest — eastern part; gravels, pebbles and sands of the marine beach 8—12 m a.s.l. on pre-Quaternary rocks

1 — Revelva valley slightly downstream from the Rev Lake; in the foreground outwash of the Little Ice Age, in the background fragments of marine beaches 22—25 and 40—46 m a.s.l. and protalus rampart at foot of Rotjesfjellet

2 — Mouth of the Revelva valley; marine beaches 4.5—6, 8—12 m a.s.l.



1 — Kvartsittodden; marine beaches 4.5—6, 8—12 and 16—18 m a.s.l.
2 — Nottighambukta; gravels, pebbles and sands of the marine beach 8—12 m a.s.l. on pre-Quaternary rocks