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Geodynamic aspects of studies of Quaternary inland sediments in South Spitsbergen (attempt to synthesis)

ABSTRACT: Studies of Quaternary sediments of South Spitsbergen (Hornsund, Bellsund and northern Billefjorden regions) focus on their occurrence, origin and chronostratigraphy. Methods and results of geological mapping are described. Glacial, glaciofluvial, glaciolacustrine and aeolian sedimentary environments, rock glaciers, taluses and raised marine beaches are presented. Mutual relations of these sediments as well as their radiocarbon and thermoluminescence datings made chronostratigraphy of Late Quaternary glacial episodes possible. Results of preliminary neotectonic studies are also presented, the same as works on periglacial phenomena, chemical weathering and tundra vegetation. Key significance of the studies for the Quaternary evolution of the Arctic and for better recognition of geodynamic phenomena of Pleistocene glaciations in Poland (Tatra and Sudeten Mts included) is underlined.

Key words: Arctic, Spitsbergen, Quaternary geology.

Introduction

The paper summarizes results of research since 1986 within the Central Program of Basal Research 03.03. *Studies of life, lithosphere and environments of polar regions*, the project B.7.*Studies of the Quaternary inland sediments in South Spitsbergen.* This work was coordinated by Professor Leszek Lindner and realized by five teams supervised by: Professor Leszek Lindner (Institute of Geology of Warsaw University), Professor Zdzisław Czeppe (Institute of Geography of Jagiellonian University, Cracow), Professor Kazimierz Pękala (Institute of Earth Sciences of M. Curie-Skłodowska University, Lublin), Professor Andrzej Karczewski (Quaternary Research Institute of A. Mickiewicz University, Poznań) — only in 1986 and Dr. Andrzej Musiał (Institute of Physico-geographical Sciences of Warsaw University) — since 1987.

The project dealt primarily with types and extents of Quaternary sediments, their origin and chronostratigraphic location in Hornsund, Bellsund and northern Billefjorden regions (Fig. 1). They were strictly connected with previous investigations in these areas (*cf.* Birkenmajer 1960, 1964; Marcinkiewicz 1961; Lavrushin 1969; Pulina 1974; Troitsky *et al.* 1979; Salvigsen and Nydal 1981; Lauritzen and Salvigsen 1983; Karczewski *et al.* 1984; Mangerud *et al.* 1984, 1987; Mangerud and Salvigsen 1984; Musiał 1984, 1985; Kłysz 1985; Kotlyakov 1985; Landvik and Salvigsen 1985; Salvigsen and Elgersma 1985; Lindner and Marks 1986; Svendsen *et al.* 1987; and others).

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Fig. 1. Location of studied regions in Spitsbergen; A — Hornsund Region; B — southern Bellsund Region; C — northern Bellsund Region (Nordenskiöld Land); D — northern Billefjorden Region

Occurrence of Quaternary sediments

Quaternary sediments were presented on three photogeological maps (sheets 5, 6 and 7) in scale of 1:10,000 (Fig. 2), maps of Quaternary sediments of western Sörkapp Land in scale of 1:25,000, maps of Quaternary landforms and sediments of Nordenskiöld Land in scale of 1:25,000 and of Ebbadalen-Nordenskiöldbreen Region in scale of 1:20,000, and geomorphological map of Nordenskiöld Land in scale of 1:75,000.

Photogeological maps were based on fieldworks and determined rules (*cf.* Lindner *et al.* 1985). Over 30 types of sediments and morphologic features are indicated in 4 groups that comprise: (*i*) slope landforms and sediments, (*ii*) glacial and nival landforms and sediments, (*iii*) raised marine beaches, (*iv*) topographic and geodetic symbols. The map of the Hilmarfjellet Region (Fig. 2; *cf.* Szczęsny, Lindner and Marks 1987) presents also location of karst caves and sinkholes as well as pre-Quaternary strata. All the maps insert sketches of glacier extents since maximum of the Little Ice Age. Photogeological maps are the first detailed and complex presentations of Quaternary features in described areas, based on own hypsometrical backgrounds. The map of Quaternary landforms and sediments of the Ebbadalen-Nordenskiöldbreen region (Kłysz *et al.* 1987) is based on fieldworks in 1984, compiled on topographic background prepared from air photos by the District Geodetic-Cartographic Survey of Szczecin. But geomorphologic-geological symbols, the map contains also the locations of key exposures of Quaternary sediments.

Maps of Quaternary landforms and sediments of fragments of the Nordenskiöld Land (Musiał *et al. unpubl*; Drecki *et al. unpubl.*) and geomorphological map of this area (Musiał *et al.* 1988) are based on enlarged Norwegian topographic maps in original scale of 1:100,000. The maps comprise over 50 symbols, with pre-Quaternary rocks, and 5 genetic groups of Quaternary landforms and sediments including slope, glacial, glaciofluvial and glaciolacustrine, alluvial, and marine features. Ancient glacial sediments in this area are preserved on valley slopes at over 50 m a.s.l. Erratics indicate primary glacier movement along valleys but from east westwards when vast ice-fields developed (Drecki *et al. unpubl.*). Such varied glacial directions could occur during different glacial episodes.

Maps of Quaternary sediments of fragments of western Sörkapp Land (Czeppe and Ziaja *unpubl.*) are based on enlarged Norwegian topographic map in original scale of 1:100,000 and are supplied with data from previously published photogeological maps (*cf.* Fig. 2). Map explanations are arranged in 4 genetic groups: periglacial deposits, marine shingle, alluvia and glacial moraines. These maps could verify the photogeological maps (*cf.* Ziaja 1987) and formed the basis to present geomorphological evolution of northwestern Sörkapp Land (*cf.* Czeppe *unpubl.*).

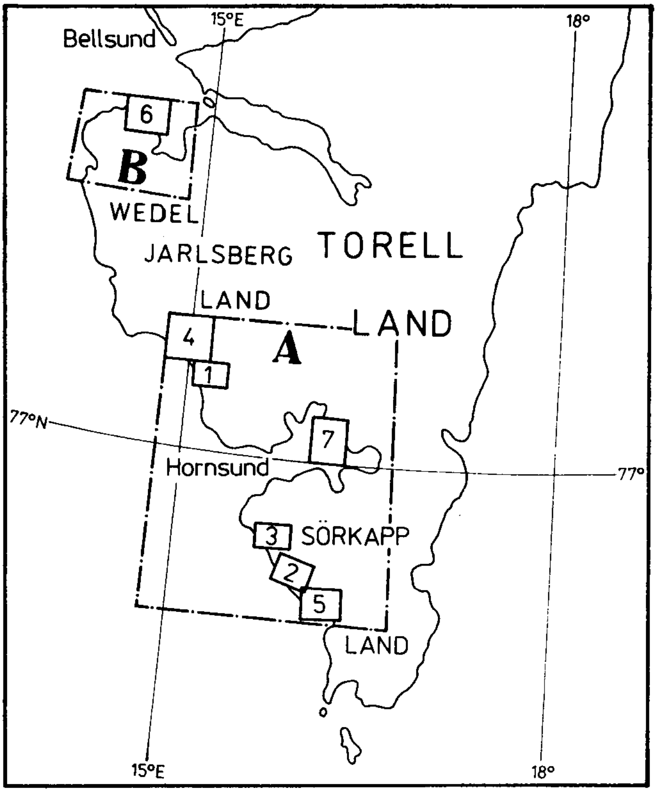

Fig. 2. Location sketch of prepared photogeological maps (1–7) in scale of 1:10,000 against boundaries of Hornsund (A) and southern Bellsund (B) regions; 1 — forefield of Nann and Torell glaciers (Ostaficzuk, Marks and Lindner 1980); 2 — forefield of Bunge Glacier (Ostaficzuk, Lindner and Marks1982); 3 — Slakli Valley area (Ostaficzuk, Lindner and Marks 1986); 4 — interlobal zone of Torell Glacier (Szczęsny et al. 1985); 5 — Hilmarfjellet area (Szczęsny, Lindner and Marks 1987); 6 — forefield of Renard, Scott and Blomli glaciers (Szczęsny, Dzierżek, Harasimiuk, Nitychoruk, Pękala and Repelewska-Pękalowa 1989); 7 — Treskelen-Hyrnefjellet-Kruseryggen area (Szczęsny, Lindner and Marks 1989)

Advantages of photogeological maps come mainly from accurate location *i.e.* extents and altitudes of distinguished Quaternary landforms and sediments. Disadvantages lie however in occassionally incorrect genetic interpretation, especially when field verification is not possible. Landforms and sediments on other aforementioned maps are generally correctly classified if their genesis is concerned as due to extensive field observations but their location and extents are generally inaccurate. In Hornsund Region this problem could be at least partly overcome with use of prepared topographic maps in scale of 1:25,000, although their contents are still far incomplete (*cf.* Dzierżek *et al.* 1987, 1991). Closer connection of photographic interpretation with field observations is therefore badly needed. The most suitable seem short-term field verifications of preliminary versions of photogeological maps.

Origin of Quaternary sediments and landforms

Development of rock glaciers, taluses, raised marine beaches and glacial sediments, present aeolian processes and Pleistocene solifluction phenomena, all create significant items in Spitsbergen studies.

Glacial, glaciofluvial and glaciolacustrine sediments are presented on all the mentioned maps and in papers on glacial evolution of Spitsbergen (among others by Lindner, Marks and Pękala 1986; Marks and Wysokiński 1986; Szczęsny 1986, 1987; Lacika and Musiał 1988; Pękala and Repelewska-Pękalowa 1988; Kłysz *et al.* 1988, 1989b).

In northern Billefjorden Region particular attention was paid to mixtites in downslope part of Gizehfjellet (Rygielski *unpubl.*). They are composed of clays, silts, sands and boulders, and glacial origin is indicated by poor sorting, erratics and limited extent. They form the third glacial bed of the Late Quaternary age.

Supraglacial sediments were studied in morainal zone of the Hörbye Glacier (Maćkowiak and Ulatowski *unpubl.*). They form 9 bands composed of block-size material of varied petrographic composition, resulting from derivation from different parts of glacier bedrock.

Mineralo-chemical analyses of glacial, glaciofluvial and glaciolacustrine sediments of this region prove (Stankowska *unpubl.*) that the older are tills, the more Mg, Na and K, and less Ca they contain in their sorption complex. Glacial sediments contain more carbonates and their clay minerals are predominated by illite, with admixture of chlorite and kaolinite.

Recent terminal and lateral moraines in southern Bellsund Region are composed of tills, blocks and boulders with gravels. Ablation moraines cover glacier snouts. Ground moraine in glacial forefields is composed mainly of tills and sands with abundant rock blocks. In forefields of Renard and Chamberlindalen glaciers a ground moraine mantles paleosols with remnants of tundra vegetation (Pękala 1987; Pękala and Repelewska-Pękalowa 1988).

Studies of glacial sediments in forefields of Renardbreen, Blomlibreen and Scottbreen but particularly measurements of direction marks in fluted moraine (Merta 1988b) proved distinct connection of flutes with linear arrangement of ablation deposits on glacial snouts. Possible supraglacial derivation of fluted moraines (Merta 1989) ascribes their ridges to reprints of glacier snout relief. Their orientation marks therefore directions of glacier retreat (Fig. 3) instead of its advance and accompanied deposition (*cf.* Kłysz 1983; Kozarski and Szupryczyński 1973).

Glaciofluvial sediments in South Spitsbergen are considerably vari-grained sized, and form intra- and extramorainal outwash plains and kames (Pękala 1987). Sandur deposits in forefield of the Renard Glacier are any finer downstream (Łanczont 1988).

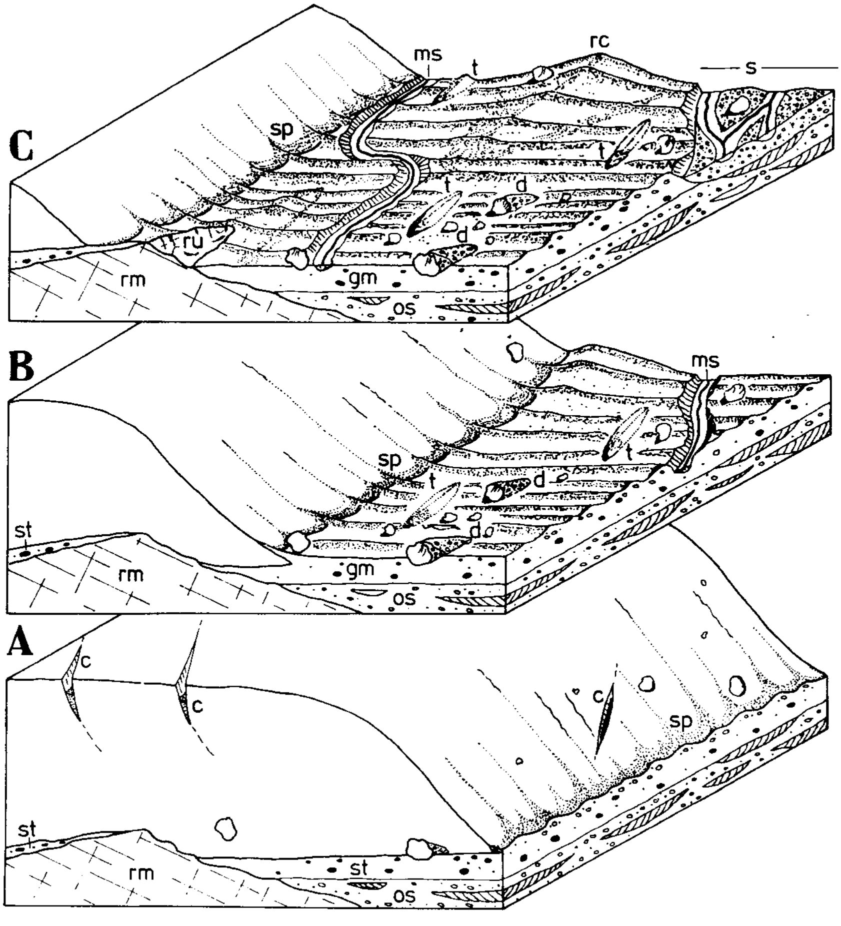

Fig. 3. Development of glacial forefield (*after* Merta 1989): A — glacier occupies entire area; B — partial retreat of glacier; C — almost entire area is ice-free; c — sediment-filled crevasse; st — subglacial till; sp — supraglacial till; rm — roche moutonnée; os — older sandur deposit; gm — till of supraglacial origin in its uppermost part; d — drumlinlike features; t — transversal crests; rc — till mantle on roche moutonnée; ru — bare roche moutonnée ("exaration" niche); ms — marginal proglacial stream; s — contemporary sandur deposits

Glaciolacustrine sediments were analyzed from point of view of their depositional dynamics and cyclicity (Merta 1988a, c). A small flood lake in Scottbreen forefield proves alternate fluvial and pseudovarve accumulation whereas recorded structures resemble the ones that directly preceded the Pleistocene varve sequences in Poland (*cf.* Merta 1986). Closed ponds at snout of Blomlibreen recorded rhythmic deposition, with pairs of layers presumably corresponding to annual sedimentary cycles, so typical in proximal varves (*cf.* Merta 1986). This cyclicity comprised 13 years of reservoir existence (Merta 1988b).

Raised marine beaches and their shingle are widespread and significant Quaternary features in Spitsbergen. They form several raised steps that indicate glacioisostatic uplifting of Spitsbergen during the Quaternary. Enclosed mollusc shells, driftwood and marine plants stimulate studies of Late Quaternary sea-level variation and glacial episodes (*cf.* Lavrushin 1969; Birkenmajer and Olsson 1970; Boulton 1979; Troitsky *et al.* 1979; Salvigsen 1981, 1984; Salvigsen and Nydal 1981; Lindner, Marks and Pękala 1983, 1984, 1986, 1987; Mangerud *et al.* 1984, 1987; Chmal 1987; Kłysz *et al.* 1988, 1989a).

There are two main points in studies of raised marine beaches of Spitsbergen *i.e.* their altitudes and genetic features. The latter enable to distinguish beaches from any other morphologic steps that result from flat-exposed pre-Quaternary rock strata. Measurement tests of raised marine beaches in Bellsund Region proved that all commonly applied methods (including precise but time-consuming geodetic works) are more or lęss inaccurate; however the values read directly on air photos seem to be the most correct (Nitychoruk, Ozimkowski and Szczęsny 1988, 1989). Common misinterpretation of structural flattenings of pre-Quaternary rock strata as systems of raised marine beaches (*cf.* Stankowski 1981; Ziaja 1989) is to be avoided if sufficient knowledge of bedrock lithology and tectonics is accessible. Occasional marine pebbles (*cf.* Stankowski 1981) high on mountain slopes and elevations (to 546 m a.s.l.) in northwestern Sörkapp Land come from conglomerates of pre-Quaternary marine transgressive sequences. Similar origin can be also ascribed to marine pebbles in northeastern Petuniabukta area where they occur to 540 m a.s.l. whereas Stankowski (*unpubl.*) ascribes them to such high sea level during the Quaternary. Some "rock shelves" of Stankowski (1981) and Ziaja (1989) are the trimlines, eroded by Pleistocene glaciers on mountain slopes of South Spitsbergen.

Rare use of air photos and lack of suitable topographic maps resulted in limited attention paid to morphology of raised marine beaches. Such morphologic features include not only edges that separate individual terraces or rock outliers of ancient skerries, but also systems of storm ridges and separating depressions, occasionally filled with water (*cf.* Ostaficzuk, Lindner and Marks 1982, 1986; Szczęsny, Lindner and Marks 1987). Some elongated depressions run parallel to storm ridges and are relics of ancient lagoons. The other occur on shallow pre-Quaternary rocks and are oval-shaped — they are remnants of stranded icebergs (Lindner and Marks 1989a). Such iceberg depressions occur mainly on raised marine beaches 8—12, 15—18 and 20—24 m a.s.l. (Fig. 4). If taking into account the Late Quaternary age of the lowermost mentioned beach in Hornsund Region (*cf.* Birkenmajer and Olsson 1970) as well as melting of the last Pleistocene ice cap in the Barents Sea (Elverhöi and Solheim 1987; Forsberg 1987; Matishov 1987) accompanied with intensive calving and icebergs coming to Spitsbergen shores, the two higher beaches must have

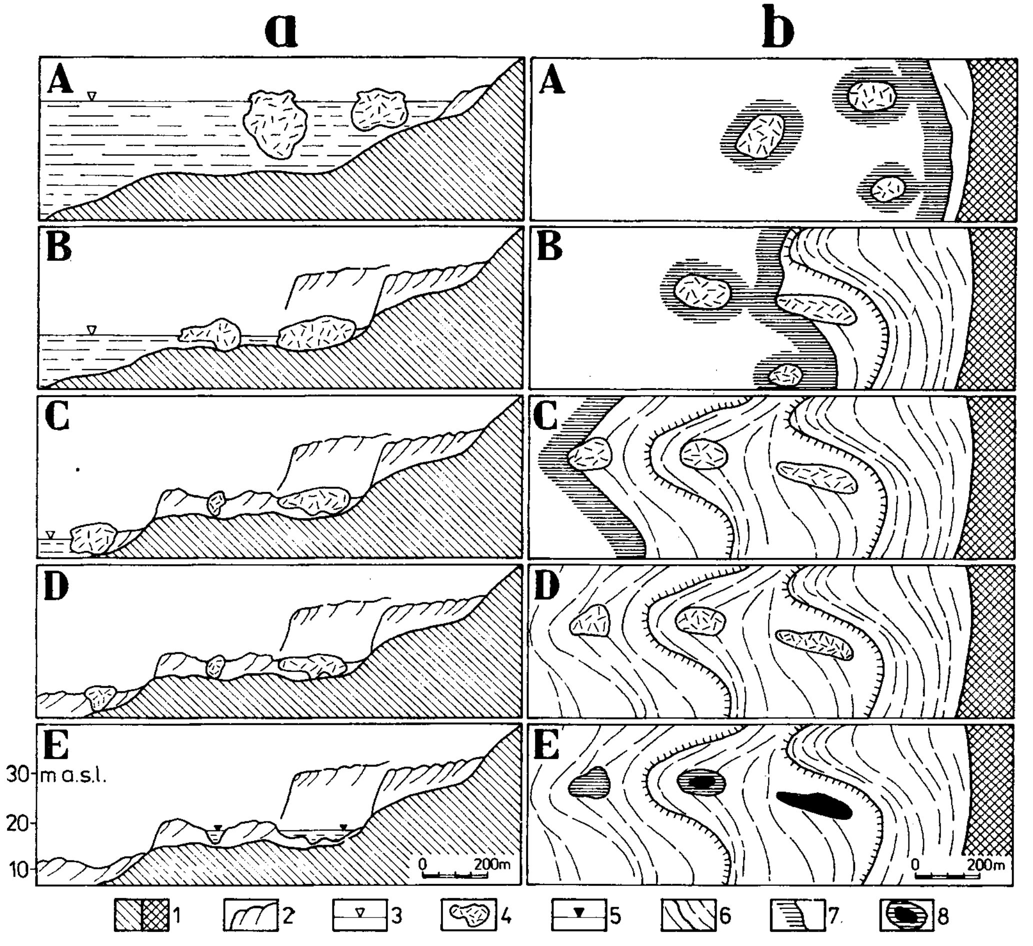

Fig. 4. Development of marine beaches in Spitsbergen (*after* Lindner and Marks 1989b): a — section, b — plan; 1 — bedrock; 2 — sediments of raised marine beaches; 3 — sea level; 4 — stranded icebergs; 5 — lake level; 6 — raised marine beaches with pattern of beach ridges and cliffs; 7 — coastline; 8 - depression with pond

developed during the Late Pleistocene deglaciation (Lindner and Marks 1989b).

Periglacial features are quite common in South Spitsbergen, either on mountain slopes (Dzierżek and Nitychoruk 1987a, 1988) or in valleys and on coastal plains (*cf.* Pękala and Repelewska-Pękalowa 1988; Repelewska-Pękalowa and Gluza 1988). They are active at present (*cf.* Klementowski 1987; Repelewska-Pękalowa, Gluza and Dąbrowski 1987; Repelewska-Pękalowa, Pękala and Wojciechowski 1987) but when fossil, indicate paleoclimatic environment of Spitsbergen (Kłysz *et al.* 1988a).

Rock glaciers develop due to downslope deposition of debris on glacial ice or movement of this debris caused by plastic deformation of interstitial ice (*cf.* Barsch 1977; Johnson 1978, 1980). In South Spitsbergen (Lindner and Marks 1985) several types of rock glaciers were distinguished on the basis of their relation to mountain slopes, glaciers or supply of debris (Fig. 5). Subslope and some cirque rock glaciers in Bellsund Region developed mainly during the Late Holocene whereas moraine rock glaciers — during the Little Ice Age (Dzierżek and Nitychoruk 1987b, c, 1988). These features were previously treated as glacial (Jahn 1959; Szupryczyński 1968), slope (Baranowski 1977) or talus (Birkenmajer 1982) moraines.

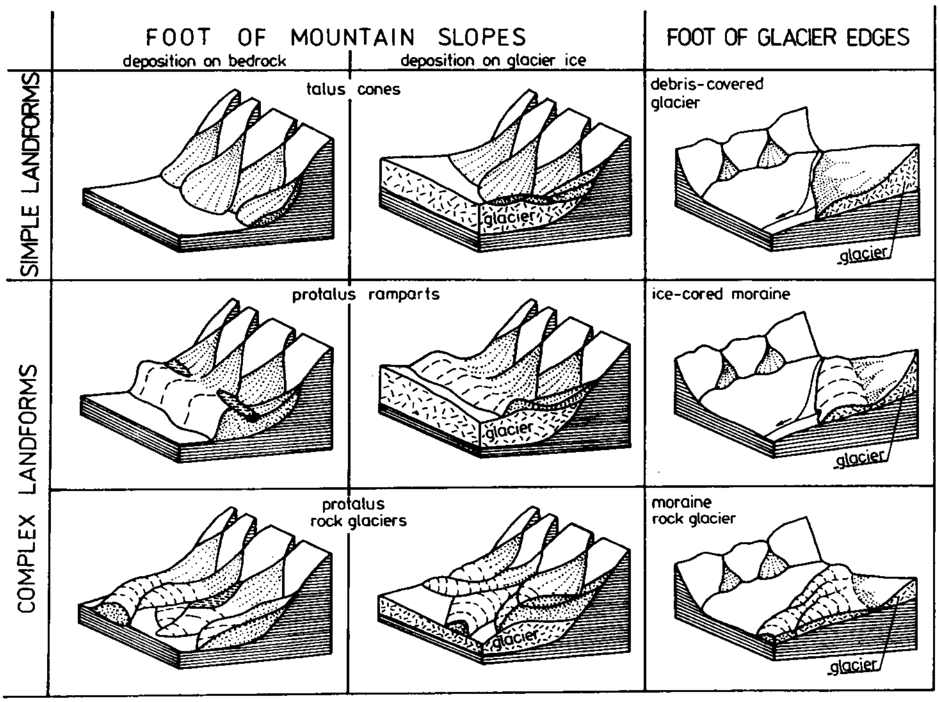

Fig. 5. Classification of landforms and sediments formed at foot of mountain slopes and glacier edges in South Spitsbergen; reprinted from "Types of debris slope accumulations and rock glaciers in South Spitsbergen" by Lindner and Marks (1985) from Boreas by permission of Norwegian University Press (Universitetsforlaget AS), Oslo

Taluses, being common on most mountain slopes in Spitsbergen (*cf.* Jahn 1976; Pękala 1980), were studied in detail in northwestern Wedel Jarlsberg Land (Nitychoruk and Dzierżek 1987a, 1988). They are composed of unsegregated coarse debris and indicate straight-convex or concave-convex longitudinal sections (Fig. 6). Three morphoclimatic zones were distinguished on the basis of talus-glacier relations (*cf.* Fig. 6).

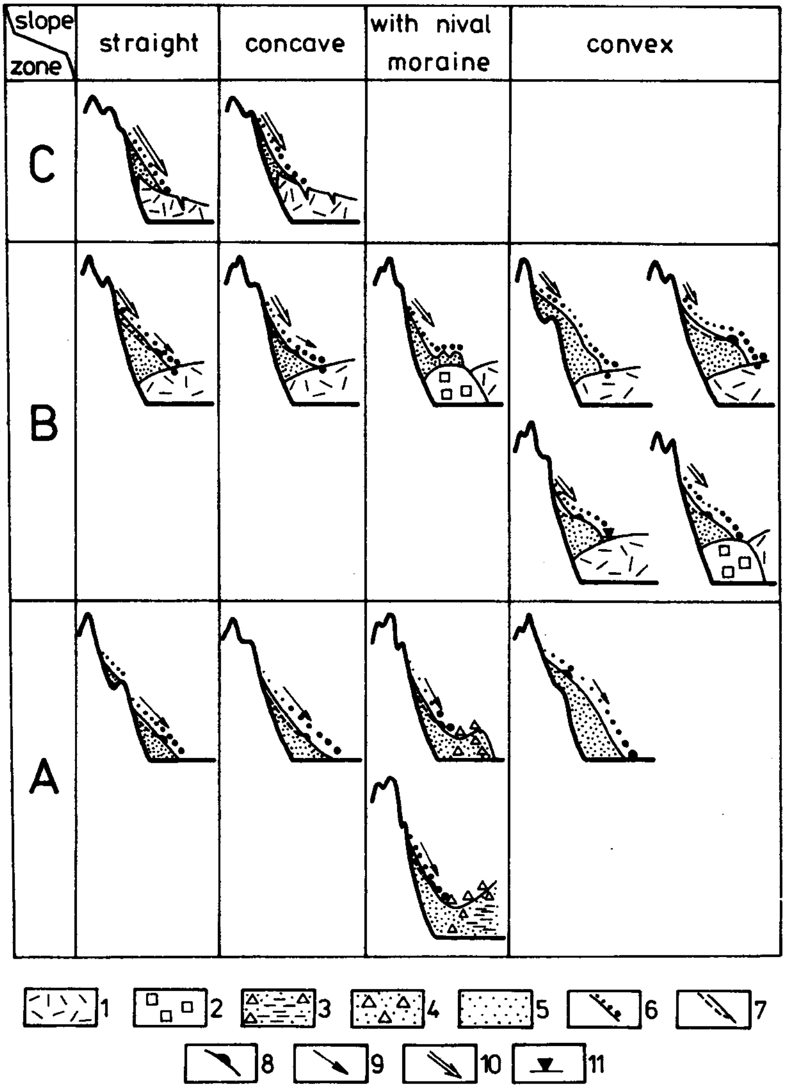

Fig. 6. Slope processes and typical profiles of taluses, dependent on morphoclimatic zones (*after* Nitychoruk and Dzierżek 1988): A — outside direct glacier influence (below 150 m a.s.l.); B — influenced by glacier snout (150—350 m a.s.l.); C — influenced by firn fields (over 350 m a.s.l.); 1 — compact glacier ice; 2 — lateral moraines; 3 — rock glaciers; 4 — nival moraines; 5 — taluses; 6 — grain size segregation of debris; 7 — debris furrows (mud flows); 8 — mud bulges (debris flows(; 9 — solifluction; 10 — avalanches; 11 — glacial streams

Aeolian sediments were studied in western Sörkapp Land (Gębica and Szczęsny 1988a, b). Sand drifts, sandy-silty hillocks and sand banks to 1 m high and 5 m long were formed by northeastern winds. Such features are quite persistent as indicated by enclosed buried soils.

Outline of Quaternary chronostratigraphy

Analysis of Quaternary sediments in key geological sections (*cf.* Kłysz and Lindner 1981; Lindner, Marks and Ostaficzuk 1982, 1984, 1986; Lindner, Marks and Pękala 1983, 1986; Marks 1983; Kłysz *et al.* 1988, 1988b, 1989b), radiocarbon and thermoluminescence dated (Lavrushin 1969; Birkenmajer and Olsson 1970; Boulton 1979; Troitsky *et al.* 1979; Salvigsen 1981; Salvigsen and Nydal 1981; Lindner, Marks and Pękala 1984, 1987; Mangerud *et al.* 1984; Mangerud and Salvigsen 1984; Marks and Pękala 1986; Marks and Wysokiński 1986; Butrym *et al.* 1987; Kłysz *et al.* 1988, 1988a), enabled to present detailed chronostratigraphic scheme of Quaternary sediments in Hornsund (Lindner, Marks and Pękala 1987) and Billefjorden (Kłysz *et al.* 1988, 1989a) regions.

In South Spitsbergen the oldest Quaternary sediments are known from Torellkjegla (Lindner, Marks and Pękala 1983, 1984, 1987). They are marine silts, TL dated at 413 ka and 383 ka and represent the **Torellkjegla Interglacial** = Holstein sensu lato (Fig. 7). These sediments are glaciodislocated together with overlying tills (the older one of which is TL dated at 313 ka and 284 ka, and the younger at 189 ka), separated with glaciofluvial sands and gravels TL dated at 222 ka, 220 ka and 190 ka (Lindner, Marks and Pękala 1986). These glacial and glaciofluvial sediments were ascribed to the bipartite **Wedel Jarlsberg Land Glaciation** = Riss (Fig. 7). A younger part of this glaciation is also indicated by glacial sediments in western Sörkapp Land on slopes of Stupryggen and Gavrilovfjellet where they are TL dated at 217 ka and 141 ka respectively (Butrym *et al.* 1987), and by glaciofluvial sediments on Fannytoppen, TL dated at 161 ka and 143 ka (Marks and Pękala 1986).

The sediments on Fannytoppen are overlapped with paleosol, TL dated at 143 ka and referred to warming of the **Bogstranda Interglacial** (Fig. 7), correlated with the Eemian Interglacial (Lindner, Marks and Pękala 1986; Marks and Pękala 1986). In Billefjorden Region thin lacustrine sands and silts, TL dated at 119 ka and presumably corresponding with this interglacial, were found on pre-Quaternary bedrock and overlain with younger glacial and marine sediments (Kłysz *et al.* 1988, 1988a, 1989a).

The last Pleistocene glaciation in South Spitsbergen is named the **Sörkapp Land Glaciation** (= Würm, Vistulian) and indicated by several glacial episodes (Fig. 7). In separating warmer intervals marine sediments (Troitsky *et al.* 1979) and highermost raised marine beaches were formed (Lindner, Marks and Pękala 1983, 1984, 1986, 1987; Kłysz *et al.* 1988, 1989a).

In northern Billefjorden Region a till high on southern slope of De Geerfjellet and TL dated at 87 ka is the oldest sediment of this glaciation (Kłysz *et al.* 1988, 1989a). In Hornsund Region the Early Würm glacial episode is indicated by a till in substrate of raised marine beaches 30—38 and 42—56 m a.s.l. in southern Breinesflya, and TL dated at 88 ka and 87 ka respectively (Butrym *et al.* 1987).

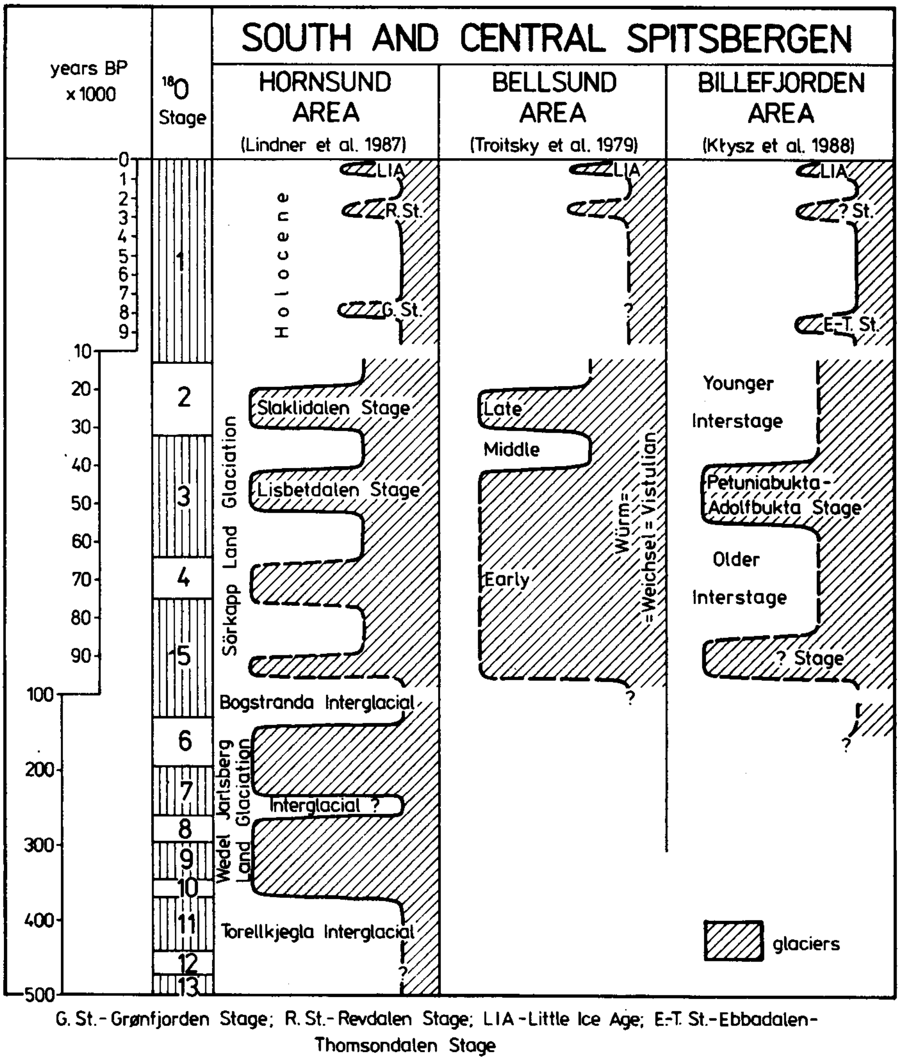

Fig. 7. Correlation of main glacial episodes and deglacial intervals in Spitsbergen

The second glacial episode of the last Pleistocene glaciation in Hornsund Region is indicated by the youngest till in Torellkejgla, TL dated at 73 ka to 209 (?) ka (Lindner, Marks and Pękala 1986, 1987). The following warming (named in northern Billefjorden Region the Older Interstage) is indicated by intratill and subtill sediments dated at 66—53 ka and by corresponding series of raised marine beaches 70—75, 60—65, 50—55 m a.s.l. (Kłysz *et al.* 1988, 1989a). In Hornsund Region this warming is indicated by marine sediments of the beach 15—18 m a.s.l. and TL dated at 63 ka (Butrym *et al.* 1987).

Glaciers of the third glacial episode (Fig. 7) are supposed to delimit maximum extent of the last Pleistocene glaciation in Spitsbergen (*cf.* Boulton 1979; Troitsky *et al.* 1979; Lindner, Marks and Pękala 1983, 1987; Kłysz *et al.* 1988, 1989a). In Hornsund Region this episode is named the Lisbetdalen Stage and its sediments are TL dated at 50—41 ka (Butrym *et al.* 1987; Lindner, Marks and Pękala 1987). In Bellsund Region it is represented by a till older than 30 ka (*cf.* Troitsky *et al.* 1979). In northern Billefjorden Region this episode is named the Petuniabukta-Adolfbukta Stage and recorded by glacial sediments, TL dated at 45—55 ka (Kłysz *et al.* 1988, 1989a). They are correlated with the Billefjorden Stage in the section Kapp Ekholm where a till is TL dated at 70—47 ka, and enclosed mollusc shells are radiocarbon dated at 41.7$\pm$12 ka to 33 ka or more than 46.3$\pm$2.1/1.7 ka (Lavrushin 1969; Troitsky *et al.* 1979; Mangerud and Salvigsen 1984).

Middle Würm warming in Bellsund Region is recorded by marine sediments with mollusc shells, radiocarbon dated at 31.91$\pm$0.5 ka and 30.75$\pm$0.8 ka (Fig. 7; Troitsky *et al.* 1979). In northern Billefjorden Region this warming is represented by sediments of the Younger Interstage that form the raised marine beach 40—45 m a.s.l. (Kłysz *et al.* 1988, 1989a). In the section Kapp Ekholm marine sediments contain mollusc shells, radiocarbon dated at more than 33 ka (Lavrushin 1969; Troitsky *et al.* 1979) and at 46.3$\pm$2.1/$-$1.7 ka (Mangerud and Salvigsen 1984).

The fourth, youngest glacial episode of the last Pleistocene glaciation in Hornsund Region (Fig. 7) is named the Slaklidalen Stage and indicated by glacial sediments, TL dated at 29—22 ka (Butrym *et al.* 1987; Lindner, Marks and Pękala 1987). In Bellsund Region this episode is recorded by till, TL dated at 26 ka and overlying the aforementioned marine sediments (*cf.* Troitsky *et al.* 1979).

During the **Holocene** three successive glacial advances occurred in South Spitsbergen (Fig. 7). In Hornsund Region the first, Early Holocene glacial advance occurred about 8 ka (Lindner, Marks and Pękala 1986, 1987) and is correlated with the Grönfjorden Stage of Punning *et al.* (1982). In northern Billefjorden a considerable glacier advance of the Ebbadalen-Thomsondalen Stage is radiocarbon dated at 9.74$\pm$0.08 ka and 8.92$\pm$0.05 ka to 7.63$\pm$0.15 ka (Kłysz *et al.* 1988).

The Middle Holocene warming is recorded by raised marine beaches 8—12 and 3—8 m a.s.l. in Hornsund Region (Lindner and Marks 1989a, b), and 12—15 and 5—8 m a.s.l. in northern Billefjorden Region (Kłysz *et al.* 1988, 1989a). The Late Holocene cooling of about 3—2.5 ka (Baranowski 1977) is named the Revdalen Stage in Hornsund Region (Karczewski, Kostrzewski and Marks 1981). In this time development of the beach 3—8 m a.s.l. in Hornsund (Lindner and Marks 1989) and 5—8 m a.s.l. in northern Billefjorden (Kłysz *et al.* 1988, 1989a) has continued.

The Late Holocene warming about 1.5—0.6 ka favored considerable retreat of glaciers, development of denser vegetation and arrival of people (Pękala 1980; Chochorowski 1987; Krawczyk 1987). In this time the marine beach 3—8 m a.s.l. was finally completed in Hornsund (Lindner and Marks 1989a, b), the same as the beach 3—4 m a.s.l. in Billefjorden (Kłysz *et al.* 1988, 1989a). Present subtill organic sediments in forefield of the Renard Glacier come also from this interval (*cf.* Dzierżek, Nitychoruk and Rzętkowska 1989).

The youngest glacial episode during the Holocene records the Little Ice Age at 0.6—0.1 ka (Fig. 7) when glaciers advanced as far as the present ice-cored moraines in their forefields (*cf.* Szupryczyński 1968; Baranowski 1977; Pękala 1980; Kłysz 1985; and others).

Other methods and research aims

Other subjects were also undertaken during studies of the Quaternary of South Spitsbergen. They comprise postulated contents of topographic maps of polar areas, measurements of altitudes of raised marine beaches, analysis of joint fractures and their significance for neotectonic phenomena in Spitsbergen. A need for description of tundra vegetation has also arisen as the reference system for evaluation of buried floras in this area. Present and ancient symptoms of physical and chemical weathering of rocks in Spitsbergen were analyzed as well as description of molluscs, shells of which were collected in Quaternary sediments of northern Billefjorden Region.

Analysis of **contents of topographic maps of polar areas** indicated (*cf.* Dzierżek *et al.* 1987) that recently published maps (Spitsbergen, Hornsund, Topographic Map in scale of 1:25,000, 1987) are hardly acceptable, especially as they do not contain such outstanding morphologic features as glaciers or moraines (demarcated however on much older Norwegian topographic maps in scale of 1:100,000) and wetlands. Such serious disadvantages make it difficult or even impossible to use these maps for field purposes. Basing on collected experience and needs, a project of postulated symbols to use on topographic maps and example of such map were presented (Dzierżek *et al.* 1991).

Applied **measuring methods of altitudes of raised marine beaches** of Spitsbergen have been already aforementioned. Evaluation of these methods could be possible by comparing measurements of beach altitudes along step-altimeter and step-clisimeter sections, directly on air photos and from photogeological maps (Nitychoruk, Ozimkowski and Szczęsny 1988). If accurate but considerably troublesome (among others due to indetermined position of 00 NN in this area) geodetic measurements are neglected, then the most accurate altitudes are to be received directly from air photos. The latter recorded also synchronous pictures of larger areas (Nitychoruk, Ozimkowski and Szczęsny 1989).

Evaluation of **neotectonic phenomena** in South Spitsbergen still demands detailed and comprehensive studies. Preliminary analysis of photolineaments, dislocations and meltwater depressions in western Sörkapp Land indicated their mutual relations (*cf.* Lindner, Marks and Szczęsny 1986). Therefore, possible rejuvenation of tectonic directions due to glacioisostatic phenomena is postulated (Fig. 8). Similar neotectonic processes are to be also expected in other parts of Spitsbergen (*cf.* Ozimkowski 1988, 1989).

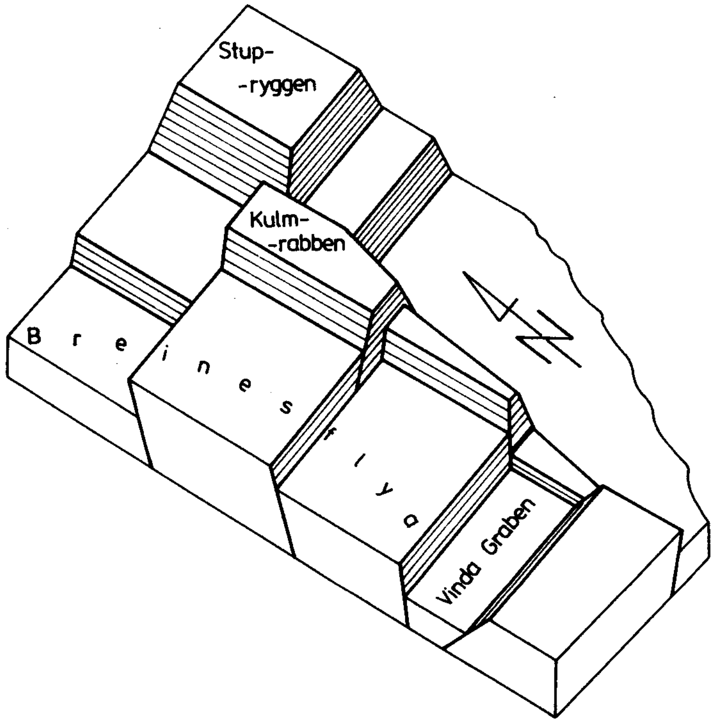

Fig. 8. Blockdiagram, to show fault pattern in Stupryggen-Kulmrabben-Breinesflya area (*after* Lindner, Marks and Szczęsny 1986)

Tundra vegetation on southern Bellsund seashore was analyzed (Rzętkowska 1987a, b, 1988a, b). 55 species of vascular plants were described from various habitats on raised marine beaches. They represent communities that are typical of deflation tundra with predominant lichens, snowbeds with abundant algae and *Saxifraga cernua,* and wet grass-mossy assemblages with *Ranunculus hyperboreas, Phippsia algida* and *Deschampsia alpina.* Shore vegetation is composed mainly of *Saxifraga oppositifolia, Silene acaulis* and *Cochlearia officinalis.* Bed-fertilized areas are occupied commonly by mosses with *Saxif-*

raga cernua. Recently exposed glacial forefields are predominantly covered with *Saxifraga oppositifolia* and viviparous grass species (*Poa alpina* var. *vivipara*, *Poa arctica* var. *vivipara*). Plant communities of intramorainal zones depend highly upon varying substrate lithology and particularly, clayey-silty material in subsoil as it considerably facilitates vegetative conditions (Rzętkowska 1987b).

Studies of **weathering processes** in polar areas dealt primarily with polymictic carbonate rocks of Hecla Hoek Formation on southern shore of Bellsund (Chlebowski 1989). Due to chemical denudation, a dissolution acts firstly on calcite and then on dolomite. Finally, only quartz-micaceous skeleton as weathering cortex is preserved. Its occurrence on buried rock fragments and surfaces indicates similar weathering processes during the Pleistocene (*cf.* Lindner and Kłysz 1989).

Species of molluscs, shells of which were collected from Quaternary sediments in northern Billefjorden (Kłysz *et al.* 1988), enabled reference to their present occurrence in Svalbard (*cf.* Różycki 1988). *Littorina littorea* and *Mytilus edulis* indicate milder conditions whereas *May truncata, Hiatella arctica* and *Macoma calcarea* lived in more severe environment. These species enabled climatic evaluation of Quaternary sedimentary environments in northern Billefjorden area (*cf.* Kłysz *et al.* 1988, 1989a).

Final remarks

Presented studies supply with new data on extents, origin and chronostratigraphy of Quaternary sediments in South Spitsbergen and they form in many cases a first information in the subject. They are the effect of several years complex and team investigations, carried through in Polish universities and supported with grants of CPBP 03.03.B7. If continued in the next few years, these studies should result in monograph on evolution of Hornsund, Bellsund and Billefjorden regions during the Quaternary and then in synthesis of the Quaternary of South Spitsbergen. Such aim still demands however many preceding works, geological mapping and sampling of sediments inclusive. First geological maps of Quaternary sediments are to be prepared for Hornsund, Bellsund and northern Billefjorden regions, in scales of either 1:75,000 or 1:50,000. They should be supplemented with lithogenetic explanations and age of terrestrial sediments, but also of sediments in fiords or at least in their littoral zones. Such work would clarify present opinions on extents of Late Quaternary glaciers, neotectonic movements and persistence of permafrost at sea bottom. But the maps and text, the monograph should present geology of key sites, key geological sections and paleogeomorphological sketches showing gradual development of Spitsbergen during the Quaternary.

Presented studies constitute already remarkable element in Polish works on the Late Quaternary history of South Spitsbergen and particularly, its glacial episodes and accompanied glacioisostatic phenomena. Reconstruction of number and age of these episodes and separating warmer intervals results in turn in knowing a paleoclimatic evolution of the Arctic but also, the mechanism and age of Pleistocene glaciations in the northern hemisphere.

Results of these works bring much to better understanding of geological structure and the Quaternary of Poland, so remarkably determined by several Pleistocene advances of Scandinavian ice sheets. They determine depositional conditions of glacial and glaciofluvial sediments which occupy over a half of the Polish territory and are therefore of great economic significance. Experience gained during studies in Spitsbergen facilitates investigations of Pleistocene sediments in the Polish Lowland and the Middle Polish Uplands, evaluation of engineering properties of these areas, search of water-bearing beds and building materials, and last but not least — it is useful for needs of farming and forestry.

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Streszczenie

W pracy przedstawiono główne aspekty i wyniki badań geodynamicznych przeprowadzonych na Spitsbergenie w rejonie Hornsundu, Bellsundu oraz północnego obramowania Billefjorden (fig. 1) w celu określenia warunków występowania, genezy i chronostratygrafii czwartorzędowych osadów lądowych. Opisano metody, zakres i wyniki prac kartograficznych oraz przedstawiono wady i zalety wykonanych opracowań mapowych. Są to z jednej strony mapy wykonane na podstawie kartowania geomorfologiczno-geologicznego i z wykorzystaniem podkładu topograficznego stanowiącego znaczne powiększenie norweskich map topograficznych w skali 1:100000, a z drugiej strony — mapy fotogeologiczne w skali 1:10 000 powstałe na własnych podkładach topograficznych w wyniku analizy norweskich zdjęć lotniczych i rekonensansów terenowych (fig. 2). W genetycznej charakterystyce osadów czwartorzędowych występujących w wyżej wymienionych rejonach Spitsbergenu przedstawiono w sposób bardziej szczegółowy warunki powstawania niektórych typów osadów lodowcowych (fig. 3), wyniesionych tarasów morskich (fig. 4), lodowców gruzowych (fig. 5), stożków usypiskowych (fig. 6), a także osadów wodnolodowcowych i eolicznych.

Wzajemna relacja różnych genetycznie i wiekowo osadów, znaczne zróżnicowanie ich sytuacji hipsometrycznej oraz coraz liczniejsze wyniki datowań metodami radiowęgla i termoluminescencji umożliwiły przedstawienie pierwszej próby korelacji chronostratygraficznej wyróżnionych głównych epizodów glacjalnych i oddzielających je okresów intensywnego zanikania lodowców (fig. 7). Po interglacjale Torellkjegla (= Holstein) wyróżniono dwa epizody glacjalne w obrębie zlodowacenia Wedel Jarlsberg Land (= Saalian) i następujący po nim interglacjał Bogstrandy (= Eemian). W obrębie ostatniego zlodowacenia plejstoceńskiego, określonego jako zlodowacenie Sörkapp Land (= Weichsel, Vistulian) wyróżniono 3—4 epizody glacjalne, zaś w czasie holocenu — 3 epizody glacjalne, z których najmłodszy jest reprezentowany przez Małą Epokę Lodową. Omówiono także problematykę zjawisk neotektonicznych (fig. 8), wietrzenia chemicznego i procesów peryglacjalnych, a ponadto dokonano charakterystyki roślinności tundrowej, jako układu odniesienia dla oceny warunków rozwoju plejstoceńskich flor kopalnych.

W zakończeniu podkreślono kluczowe znaczenie badań czwartorzędowych osadów lądowych Spitsbergenu dla rozpoznania plejstoceńskiej i holoceńskiej ewolucji obszarów arktycznych oraz konieczność większej intensyfikacji badań czwartorzędowych osadów morskich na dnie fiordów

i w otoczeniu Spitsbergenu. Wykazano, że badania geologiczne i geomorfologiczne czwartorzędu Spitsbergenu służą coraz lepszemu poznawaniu zjawisk geodynamicznych, które towarzyszyły plejstoceńskiej obecności lądolodów skandynawskich na obszarze naszego kraju oraz rozwojowi lodowców górskich w Tatrach i Karkonoszach. Dobra znajomość tych zjawisk umożliwia właściwą interpretację litogenezy i rozprzestrzenienia plejstoceńskich osadów lodowcowych, a tym samym prawidłową ocenę ich znaczenia gospodarczego.

Praca została wykonana w ramach CPBP 03.03. B7.