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Seismoacoustic studies in Hornsund, Spitsbergen

ABSTRACT: A sea floor investigation was performed in the fiord of Hornsund by means of the seismoacoustic profiling, echosounding and core sampling. The main seismoacoustic sea floor units were recognized (the methods used according to Kowalewski *et al.* 1987a) and characterized on the basis of their relations to geomorphology and geological evolution. The bathymetrical sketch and the resulting geomorphological description of the bottom were prepared. The surface of the sea bottom and the surface of the bedrock displayed an irregular high relief with large sills dividing the fiord sea floor into several basins. Four main types of the sills were distinguished: burried sills, accumulative sills, rock sills and rock-accumulative sills. Within the internal Basins I and II there were thick (up to 170 m) covers of the glaciomarine ice-front deposit with changing thin (1–5 m) blanket of the glaciomarine muds at the bottom surface. The Basin III had a cover of the glacial and glaciomarine deposits of variable lithology, genesis and age. The most external Basin IV had a cover of glaciomarine muds up to 40–50 m thick, deposited on the tills. Four main glacial episodes were recognized, most probably referring to the stadials of Lisbetdalen, Slaklidalen, Revdalen and to the Little Ice Age.

Key words: Arctic, Hornsund, seismoacoustic, glaciomarine deposits.

Introduction

The structure and morphology of the onshore part of the Hornsund region have been studied during a long period mainly by Polish scientists and now they are well recognized (*cf.* Birkenmajer 1991, Lindner and Marks 1991). The offshore part practically had not been recognized till 1982, when the studies basing on the continuous seismoacoustic profiling (CSP) started there. During several expeditions organized by the Department of Polar and Marine Research in summer seasons 1982, 1983, 1985, 1986 and 1989 the CSP profiles of a total length exceeding one thousand kilometres were carried out. These studies were complemented by the echosounding profiling and by the collecting of a core samples set. Locally, the side-scan sonar was also used in 1985.

Before we began our survey, the investigations of the sea floor had been limited there to an analysis of surface samples collected with the bucket in selected regions (*cf.* Antkiewicz and Filipowicz 1978, Filipowicz *unpubl.*, Görlich 1986, 1988) and to a local echosounding use. Studies of the sea floor by the CSP method in the Spitsbergen region were initiated by Norwegian scientists at the end of the seventies. Their results obtained in the shelf around Spitsbergen and in some fiords were analysed and summarized some years ago (*cf.* Elverhöi *et al.* 1983, Elverhöi 1984, Elverhöi and Solheim 1987, Solheim and Pfirman 1985).

Some results of our studies were presented earlier (Kowalewski *et al.* 1987a, b). The general recognition of the geophysical structure of the Quaternary sedimentary cover was the aim of these works in order to determine their geological structure as well as sedimentogenesis and lithogenesis of glaciomarine deposits. Now we present a general pattern of the seismoacoustic unit distribution and its relation to geomorphology of the fiord bottom and to the young geological evolution of the fiord.

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Methods

The study was made at the ship of Polish Ship Salvage Company. The research points were located by the radar bearings on the characteristic points on the coast. The instruments EGG: Uniboom 230 and Sparker 267 with 8-element Hydrophone Model 265 were used. We applied the effective frequency bands from 0.4 to 6 kHz for Uniboom and from 0.1 to 1.2 kHz for Sparker with the energies 100–300 J and 300-3.000 J, respectively. The deposits were penetrated down to more than 170 m under the sea floor level.

The echosounding profiles were executed by the echo sounder of the ship d/e "Perkun" in the years 1982–1986. The measurements were made in close cooperation with the navigation engineers, in particular with Jerzy Różański. Measurements with the side-scan sonar aboard the ship d/e "Pekun" were undertaken in 1986 in the vicinity of the glacier fronts. The data were used to compile the bathymetric sketch, prepared for the Topographic Map 1:25.000 of the Hornsund region. This sketch was performed by W. Kowalewski and M. Lewandowski from the Regional Enterprise of Geodesy and Cartography in Szczecin. The informations contained on navigation carts, in the J. Różański's map of Isbjörnhamna (*unpubl.*) and on some echograms carried out by S. Swerpel were also used.

The bottom samples were collected with the gravity-piston core sampler (a modified Kullenberg-type) of the inner diameter of 80 mm. The obtained cores had the length up to 3 or 4 m. In addition some samples of the surface bottom deposits were taken by a Petterson-type bucket.

Seismoacoustic units

Basing on the results of CSP profiling and making use of the data obtained from the examinated core samples, four main seismoacoustic units were distinguished and their lithological interpretation was presented by Kowalewski *et al.* (1978).

Unit A was a bedrock composed of lithic metamorphic and sedimentary rocks (dated from Precambrian through Cretaceous) and separated from the overlaying units by a distinct discontinuity surface. The top surface of the bedrock was uneven and moutonized. This was associated with the occurrence of sills, ridges, troughs and basins of the structural foundation.

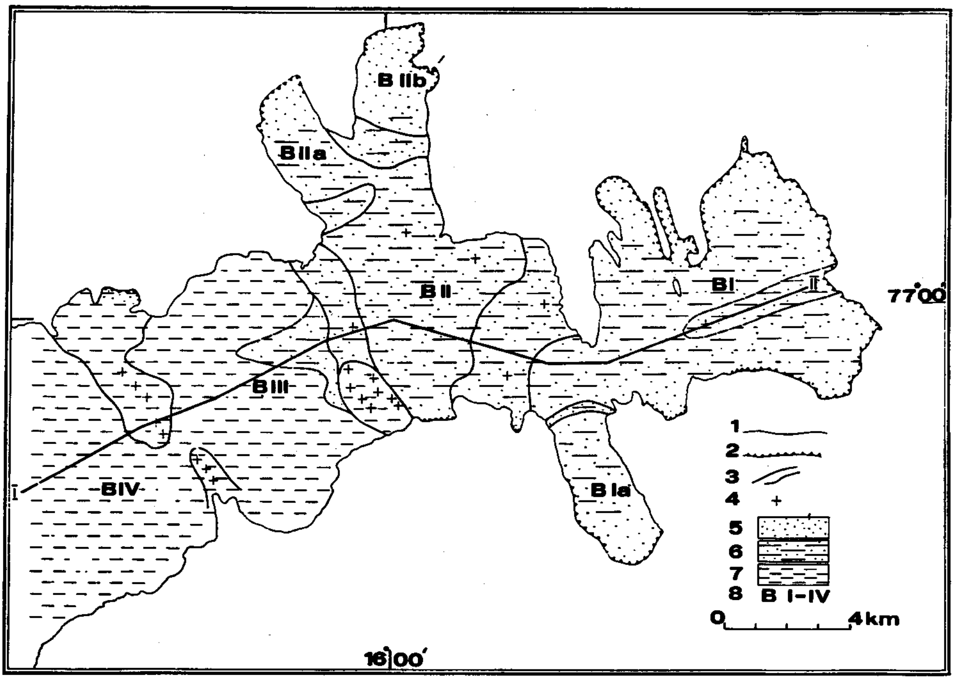

Fig. 1. Geomorphological sketch of the Hornsund bottom. 1 — shoreline, 2 — ice cliffs, 3 — main sill zones, 4 — peaks of the distinguished elevations of the bedrock, 5 — accumulative surface of the ice-front glaciomarine deposits, 6 — accumulative surface of the ice-front glaciomarine deposits with thin (1–5 m) variable blanket of the glaciomarine muds, 7 — accumulative surface of the glaciomarine muds, 8 — main basins, I–II cross-section line

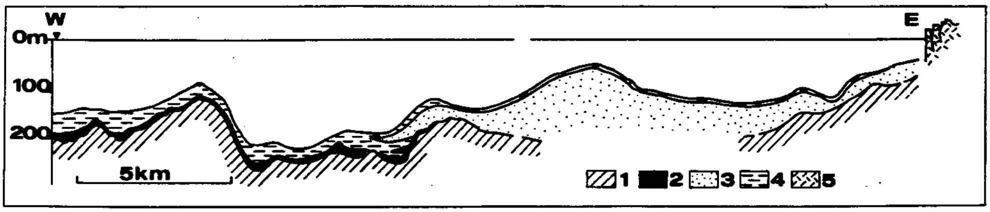

Fig. 2. Simplified cross-section along the Hornsund fiord. 1 — bedrock, 2 — tills, 3 — ice-front glaciomarine deposits, 4 — glaciomarine muds, 5 — glacier. For the section location see Fig. 1.

Unit B, a discontinuous cover on the bedrock, had the greatest thickness (up to 50 m) in depressions of the main part of the fiord. Moreover, in the inner part of the fiord, the Unit B was found among other units as lenses and pinching-out layers. The sediments of this unit comprised tills, that had deposited as a lodgement or melt-out till (*sensu* Boulton and Deynoux 1981) and/or as strongly compacted glaciomarine ice-front deposits.

Unit C consisting of the glaciomarine ice-front deposits, occurred mainly in the inner part of the fiord, and its thickness was high there. A series of the Unit C deposits more than 150 m thick was detected within the Basin II. The present-day recognition does not exclude a possible occurrence of the Unit B glacial deposits interbedded with the glaciomarine ones, especially in the lower part of the Unit C within the Basins I and II.

Unit D, glaciomarine muds, in the main part of the fiord extended as a thick cover (up to 50 m) and was dichotomous there. Within the lower part of this unit a large and well visible deformational structure were recognized and interpreted as thawing forms those have appeared due to the burried ice melting. The upper part of the Unit D covered whole surface of the bottom, with its thickness gradually changing in the inner part to 1–5 m.

Geomorphology of the bottom

The geomorphological sketch (Fig. 1) was prepared on the basis of the results obtained from the bathymetric studies, CSP profiles and sample analyses. According to our measurements, the maximum depth of the fiord amounts to about 250 m with the average depth along the fjord axis about 100 m. The surface of the bottom is irregular and uneven, with sills and basins, typical for glaciated valley. This character is mostly visible in the relief of the surface of the bedrock, glacially scoured and covered with a blanket of young Quaternary deposits from a few to more than 150 m thick.

Four main types of sills were determined: buried sills (Figs. 3c, d), rock sills (Fig. 3a) — the bedrock structural elevations covered by thin (10 m at most) sediment layer mostly of glaciomarine muds, accumulative sills — swells of

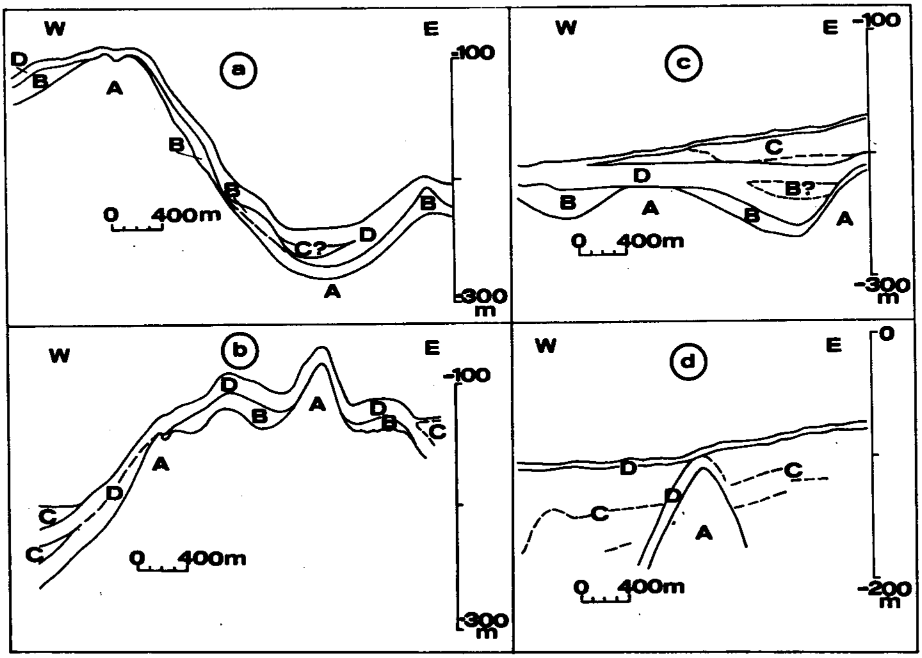

Fig. 3. Examples of the sills. Seismoacoustic units: A — bedrock, B — tills, C — ice-front glaciomarine deposit, D — glaciomarine muds

a. Rock sill within the sill zone separating the Basins II and III (in the western part), and the rock-accumulative sill (in the eastern part)

b. Rock-accumulative sill within the sill zone separating the Basins II and III

c and d. Buried sills within the Basin II

deposits formed in a direct vicinity of the glacier front are composed mainly from glaciomarine ice-front deposits (underwater marginal moraines?), rock-accumulative sills (Fig. 3b) — the bedrock elevations with an overlaying glacial and/or glaciomarine deposits cover.

The three main kinds of the accumulative covers overlaying the bottom surface were distinguished: accumulative surface of the glaciomarine muds, accumulative surface of the ice-front deposit and accumulative surface of the ice-front deposits with thin (1–5 m) variable blanket of the glaciomarine muds.

Within the distinguished main basin areas (Fig. 2) certain differences were noted. Some of the differences were connected with the occurrence of the lower order basins, the hanging tributary valleys inclusively, but mainly they were caused by the basin position in relation to the open ocean. The character of the water circulation type and thus character of sedimentation in the inner basins (called here I and II) was primarily associated with a strong influence of glaciers water, while the effect of the open sea was weakly marked. In the outer basin

(Basin IV) the water circulation was directly influenced by the open sea. The Basin III was of an intermediate type, with a distinct influence of both glacier and oceanic water.

The bottom of the inner basins (I and II) was hummocky, with denivelations up to about a dozen metres of relative height. They were mostly various accumulation forms of changing thickness, made up of the material delivered from the glacier front. The total thickness of these deposits ranged from about ten to a few dozen metres, with a maximum height of about 170 m in the Basin II. This sedimentary cover masked the bedrock relief, and frequently buried the rock sills occurring there. Besides, some isolated bedrock elevations extended over the bottom surface as ridges, spurs, pinnacles and other similar forms. The deposits occurring here belonged to the Unit C *i.e.* to the ice-front deposits with the surface cover of the glaciomarine muds from 1 to 5 metres thick. Their greatest thickness (4–5 m) was found in local depressions: the mud cover was not been detected in the vicinity of the glacier.

The outer Basin IV had its bottom covered by a thick mantle of sediments, tills and the overlaying glaciomarine muds, this mantle had deposited there since the Holocene beginning (?) till present. In the lower part of the mud layer large thawing structures were found.

Basin III had strongly diversified relief of the bedrock partly buried under a thick cover of interbedded glacial and glaciomarine deposits of various kinds, origins and ages. This is associated with at least twofold surges of the glacier at the sill separating the Basin II from the Basin III.

The numerous erosive forms of various size, such as troughs, grooves *etc.* were detected on the suface of the bottom, especially on the sills and their proximal slopes. Pronounced large troughs cutting across the sill were marked primarily in the northern and southern part of the sill separating the Basins II and III. Down to the depth of 20 m b.s.l., the surface of the fiord bottom was generally reworked by icebergs (*cf.* Moigne 1972) that resulted in numerous dishes, grooves and ramparts of sediments of variable size but generally not exceeding a dozen metres in width and a few metres in relative height. At greater depths the activity of icebergs was less pronounced.

Phenomena related to flowage, creeping and sliding of loose bottom deposits are frequently observed on the sill and basin slopes. At the foot of the distal sill slopes, in particular of the sill separating the Basins II and III, there occur elongated forms, partly buried under glaciomarine muds, which can be interpreted as underwater sandurs, cones and marginal moraines, associated with surges and/or with oscillations of a glacier.

The tributary glaciers which have reached the fiord either now or in the past from the local sedimentary cover overlaying the relief and deposits related to the activity of the main glacier.

Origin and development of the Quaternary sedimentary cover

The results of our studies (*see also* Kowalewski *et al.* 1987) have yielded the basis for distinguishing at least four glacial episodes within the Hornsund fiord. The oldest one was connected with the glacier that filled the whole fjord and extended on the open shelf at least to the point of the Hornsund Banken. During the deglaciation of this glacier, the deposits of the Unit B (tills) have formed as ground moraines on the bedrock within the Basin IV. It may be suggested that large areas of dead ice occurred there and were subsequently burried under glaciomarine deposits (the Unit D). The deformational structures were formed there as results of the long time thawing of the buried ice and they are distinctly visible in the lower part of the Unit D in the Basin IV. Thus, a durable deglaciation of the areal type occurred there. In our opinion this glacial episode was most probably contemporaneous with the maximum extent of the last (Vistulian) glaciation and it has been determined onshore as the Lisbetdalen Stadial, dated at 40–41 ka (Lindner and Marks 1991).

The position of the glacier front during the next glacial episode was marked on the sill separating the Basin IV from the Basin III, that means on the line Wilczekodden — Höferpynten. It can be related to the Slaklidalen Stadial (?).

The set of the glacial and glaciomarine ice-front deposits (the Unit B and C) occurred on the sill seperating the Basin III from the Basin II and be interpreted as an underwater terminal moraines zone, with sandurs in the foreground of the glacier front. Two surges of glacier are recognized here at least. Most probably they are related to older Holocene stadials — Grönfjord Stage and/or Revdalen Stadial, dated 3000–2500 BP (Lindner and Marks 1991). That time the axial zones of the tributary glaciers entered the fiord but they did not fill it up.

During the Little Ice Age the glaciers reached over ten kilometres beyond their present range extending out of the side bays and terminating at the large sills, perhaps thet ones separating the Basin I and the Basins IIa and IIb. The subsequent deglaciation, lasting till now but interrupted by occasional surges of glaciers has produced the thick cover of the Unit C within the Basins I and II. In our opinion, the fact that the Unit C deposit thickness is so large exceeding 150 m, makes necessary to assume that a sudden decrease in the glacier debris supply has taken place. We assume that the glacier has entered the previously formed glacial deposits and reworked them (*cf.* Troitsky 1985). It cannot be excluded that within the thick series of the deposits of the Unit C in the Basins I and II there are also deposits formed before, during the previous glacial and interglacial episodes.

The presented studies have resulted in a first step in the determination of the evolution mode of the young Quaternary sedimentary cover in the Hornsund sea floor. The seismoacoustic units distinguished there are not isochronic in different parts of the fiord and thus it is impossible to use these units as informal stratigraphic units. The chronological dating (*e.g.* by means of thermoluminescence) of the offshore deposits is necessary for an exact correlation with the detailed results of the onshore studies.

References

Antkiewicz A. and Filipowicz C. 1978. Osady denne Zatoki Isbjörnhamna, Hornsund, Spitsbergen. — Mat. III Symp. Polar., Gdańsk, 2: 7–11.
Birkenmajer K. 1991. Geological map of the Hornsund, 1: 75,000. — Uniw. Śląski, Katowice.
Boulton G.S. and Deynoux M. 1981. Sedimentation in glacial environment and the identification of tills and tillites in ancient sedimentary sequences. — Precam. Res., 15: 397–422.
Elverhöi A. 1984. Glacigenic and associated marine sediments in the Weddel Sea, fjords of Spitsbergen and the Barents sea. — Marine Geology, 57: 53–88.
Elverhöi A., Lonns O. and Seland R. 1983. Glaciomarine sedimentation in a modern fjord environment. Spitsbergen. — Polar. Res., 1: 127–149.
Elverhöi A. and Solheim A. 1987. Shallow geology and geophysics of the Barents Sea — with special reference to the existence and detection of submarine permafrost. — Norsk Polarinst. Rp., 37: 1–71.
Görlich K. 1986. Glaciomarine sedimentation of muds in Hornsund fjord, Spitsbergen. — Ann. Soc. Geol. Pol., 56: 433–477.
Görlich K. 1988. Micas and texture of the recent muds in Spitsbergen fjords: study of suspension settling. — Ann. Soc. Geol. Pol., 58: 21–52.
Kowalewski W., Rudowski S., Zalewski S.M. and Żakowicz K. 1987a. Seismostratigraphy of bottom sediments in some areas of the Spitsbergen Archipelago. — Pol. Polar. Res., 1: 3–23.
Kowalewski W., Rudowski S., Zalewski S.M. and Żakowicz K. 1987b. Geomorfologia dna fiordu Hornsund. — Mat. XIV Symp. Polar., Lublin, 68–75.
Lindner L. and Marks L. 1991. Osady czwartorzędowe południowego Spitsbergenu. — Przegl. Geol., 2: 61–68.
Moigne A. 1976. L'action des glaces flottanes sur le littoral et les fonds sous-marine du Spitsbergen Central and Nord — Occidental. — Rev. Geograph. Montreal, 1–2: 51–64.
Solheim A. and Pfirman S.L. 1985. Sea-floor morphology outside a grounded surging glacier; Bräsvellbreen, Svalbard. — Marine Geology, 65: 127–143.
Troitsky L.S. 1985. Osnovnye zakonomernosti rozvitia oledenia archipelaga. — *In*: V.M. Kotljakov (ed.), Glaciologia Špitsbergena. Izd. Nauka, Moskva: 176–182.

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Streszczenie

W sezonach letnich 1982, 1983, 1985, 1986 i 1989 wykonano w Hornsundzie profile sejsmoakustyczne o łącznej długości ponad 100 km. Ponadto wykonano profile echosondażowe oraz pobrano z dna próby rdzeniowe (do 3–4 m długości) i czerpakowe. Na podstawie analizy zebranego materiału wydzielono (za Kowalewskim *i in.* 1987a) 4 główne jednostki sejsmoakustyczne, opracowano szkic batymetryczny i szkic geomorfologiczny dna fiordu (fig. 1). Powierzchnia dna a zwłaszcza strop podłoża skalnego na urozmaiconą rzeźbę, z wyraźnymi progami oddzielającymi baseny (fig. 2). Wyróżniono 4 główne rodzaje progów: pogrzebane, akumulacyjne, skaliste

i skalisto-akumulacyjne. W obrębie basenów wewnętrznych (I i II) występuje gruba (do 170 m miąższości) seria glacjalnomorskich osadów przylodowcowych (jednostki sejsmoakustycznej C) z cienką (1–5 m), zmiennej grubości pokrywą mułów glacjalnomorskich (jednostki D). W basenie zewnętrznym (IV) na skalnym podłożu (jednostka sejsmoakustyczna A) spoczywają gliny morenowe (jednostki sejsmoakustycznej B) przykryte pokrywą kiludziesięciometrowej miąższości mułów glacjalnomorskich. W basenie III stwierdzono na skalnym podłożu występowanie zróżnicowanej serii przeławicających się osadów glacjalnych i glacjalnomorskich o różnej litologii i wieku, przykrytej mułami glacjalnomorskimi. W obrębie dna fiordu miały miejsce co najmniej 4 wkroczenia lodowca u schyłku plejstocenu i w holocenie. Najprawdopodobniej były one związane z wyróżnionymi na lądzie stadiałami: Lisbetdalen, Slaklidalen, Revdalen i z Małą Epoką Lodową (Lindner i Marks 1991).