POLISH POLAR RESEARCH	8	1	3—23	1987

Włodzimierz KOWALEWSKI, Stanisław RUDOWSKI,
S. Maciej ZALEWSKI and Krystyna ŻAKOWICZ

Department of Polar and Marine Research
Institute of Geophysics
Polish Academy of Sciences
Pasteura 3, 00-973 Warszawa, POLAND

Seismostratigraphy of bottom sea sediments in some areas of the Spitsbergen Archipelago

ABSTRACT: The paper presents results of investigations of bottom sediments in Hornsund, Wijdefjorden and Isfjorden as well as of the shelf around the Björnöya, carried out in 1982—1985 by a continuous seismic profiling. Geophysic structures and bottom sediments on the bedrock to a depth of 170 ms have been recognized, particularly in the Hornsund region. The following seismoacoustic units have been distinguished: unit A — bedrock, unit B — till and/or compacted glaciogenic deposit, unit C — glaciomarine ice-front deposit, unit D — glaciomarine mud. These results allowed to present a model of glaciomarine sedimentation in a fiord, fed by warm tidewater glaciers.

Key words: Arctic, Spitsbergen, geophysics, seismoacoustic, bottom sediments.

Introduction

Polish expeditions in the Hornsund region of Spitsbergen were initiated in 1957—1958 during the International Geophysic Year. Since that time, the environment of this area has been systematicaly investigated.

Most attention was paid to geology and geomorphology, glacial and periglacial phenomena and processes. All these works concentrated on the land. Therefore, studies of a relief and bottom sediments of the fiord were found necessary. They called for the newest geophysic instruments, drilling machinery and suitable organizing undertakings.

Such works were found possible in summer 1982 when the Department of Polar and Marine Research (Institute of Geophysics of the Polish Academy of Sciences) could embark the ice-breaker d/e *Perkun* (which transported goods to the Polar Station of the Polish Academy of Sciences in Hornsund) with some geophysicists. They made several kilometers long boomer records of bottom sediments with a use of the seismoacoustic method (CSP — continuous seismic profiling). Such works were done in Hornsund and Isfjorden as well as at a shelf around the Björnöya (Fig. 1). A choice of the profiles resulted frequently from other tasks of the ship or from navigation possibilities.

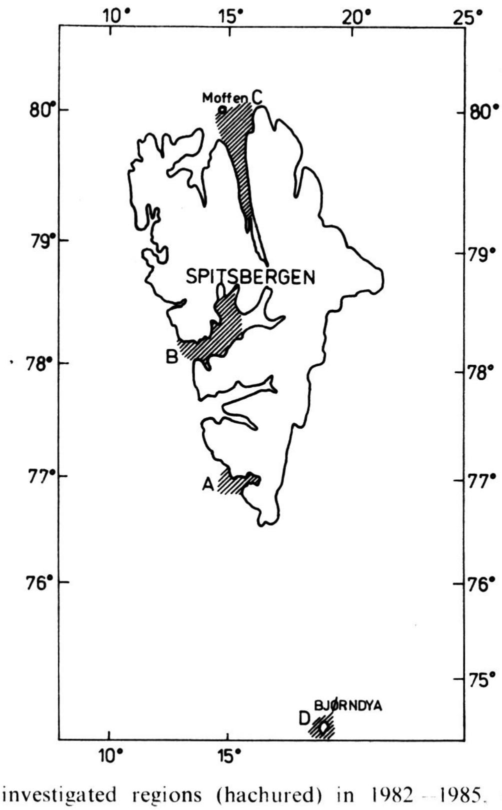

Fig. 1. Location of investigated regions (hachured) in 1982 – 1985, carried through by the Polar and Marine Department, Institute of Geophysics of the Polish Academy of Sciences, by the CSP method. A – Hornsund, B – Isfjorden, C – Wijdefjorden, D – Björnöya area

Our next expedition occurred in autumn 1983, also with a use of the d/e *Perkun*. This time a more systematic network of profiles was done in some fragments of the Hornsund. The profiling was carried through along the fiord and its main bays and also, if possible, perpendicularly to the ice cliffs of tidewater glaciers. Several dozen kilometres of profiles were collected for the Hornsund and a dozen or so for the Isfjorden.

During the Marine Geophysic Expedition of the Polish Academy of Sciences to Spitsbergen Archipelago in summer 1985, supervised by Professor A. Guterch, the seismoacoustic investigations by the CSP method were done in the Hornsund and in the north, at the Yermak Plateau near the Moffen Island and in the Wiidefjorden. Several dozens of cores (several metres long) of bottom sediments were also collected.

Studies of the sea bottom of Spitsbergen Archipelago by CSP method have been initiated at the end of the seventies by the Norwegian scientists. Results of their works in the Barents Sea and in some fiords of Spitsbergen have been lately described and recapitulated (Elverhöy *et al.* 1983, Elverhöy and Solheim 1983, Elverhöy 1984, Solheim and Kristoffersen 1984).

Results of successive phases of our research were already presented (Zalewski *et al.* 1984a, b; Jania *et al.* 1985, Kowalewski *et al.* 1985a, b). This paper encloses interpretation of all the collected data (in total several hundred kilometres of profiles), especially from the Hornsund which has been best investigated.

The fiord of Hornsund is the southernmost one of Spitsbergen. Due to the impact of a cold sea current from the Barents Sea, flowing around the southern cape of Spitsbergen and reaching the Hornsund area, the climate is more severe there than in the north (in Bellsund, Isfjorden or Kongsfjorden areas) where the influence of a branch of the Gulf Stream is noted. The Hornsund is cut into a high mountain massif (Karczewski 1986) with altitudes over 1400 m a.s.l. and alpine-like relief. The area is occupied by mountain-field glaciers (Troitsky 1985) and small mountain-valley glaciers. Most glaciers reach the fiord and form ice cliffs that consitute about one-third of the fiord coastline. All glaciers in this area belong to the so-called warm ones *i.e.* with a wet base. Many years observations of the glaciers proved that their termini retreated rapidly. During the last 50 years the Horn Glacier has retreated a distance of over 5 km, the Samarin Glacier about 3.5 km and the Hans Glacier over 1 km (Karczewski 1986). The glacier snouts show also short-term oscillations (seasonal as well as several years long), with sudden surges at distances of several hundred metres or even several kilometres (*cf.* Liestöl 1979, Jania *et al.* 1986). The fiord is in general about 100 m deep along its axis, with a maximum of 250 m. Its bottom sediments originate mainly from a glacial debris, supplied from glacier snouts.

The expeditions and works over the collected data were possible due to a grant within the Polar Research Program MR.I.29, coordinated by the Institute of Geophysics, Polish Academy of Sciences, and supervised by Professor Aleksander Guterch.

Data acquisition

Our seismoacoustic investigations by CSP method were carried out with a use of the EGG-made apparatuses: Uniboom 230 and Sparker Model 267 with the 8-element hydrophone Model 265. Different effective frequency bands were used what depended on geologic structure: Uniboom from 200 Hz to 6 kHz, Sparkar from 100 Hz to 1.2 kHz, at the energy of 100—300 J and 100—3000 J respectively. A final penetration equalled about 170 ms maximum into the bottom sediments, at resolutions below 1 m for the Uniboom and about 2 m for the Sparkar. The profiles were located by radar bearings on characteristic objects on a coast.

A drift-ice made the fieldworks more difficult as its agglomerations influenced the profile routes.

Samples were collected with a core sampler (of gravitation-piston type), with the inner diameter of 8 cm and length of 6 m. Sediments from these cores are now under detailed mineralogic, petrographic, lithologic, chemical and micropaleontologic examinations.

Acoustic stratigraphy in Hornsund

Four main units (A, B, C and D) were distinguished for the Hornsund on the basis of results from a continuous seismic profiling and a preliminary examination of the sediment cores. The seismic pattern, macroscopic description of collected samples and comparative analysis with data of CSP investigation from other areas in the Spitsbergen Archipelago (Elverhöy *et al.* 1983) and the Barents Sea (Solheim and Kristoffersen 1984) allowed for the interpretation of these units. The unit A was found to be a bedrock, the unit B — a till and/or compacted glaciogenic deposit, the unit C — the glaciomarine ice-front deposit and the unit D — a glaciomarine mud. Figures 2—5 present exemplary fragments of the CSP profiles with the distinguished units: figure 6 presents exemplary fragments of core samples of the units C and D.

Unit A. This unit is represented by a bedrock, composed of lithic metamorphic and sedimentary rocks. The bedrock is separated from the overlying units by a distinct discontinuity of a reflective type. There is here a strong, continuous reflex as well as sets of hyperbols diffraction. A top surface of the bedrock is uneven (due to glacial erosion?), with distinct irregularities of several to several dozen miliseconds. They result from the occurrence of sills, ridges and troughs of structural foundations. A morphology of the bedrock has been created by glacial erosion and is more expressive than a morphology of the present sea bottom as the young Quaternary sediments of the overlying units blur the bedrock features.

A high quality of the record enables the analysis of structural borders in the bedrock (surfaces of beds, faults, etc.) A study of the bedrock structure based upon the CSP data will constitute the subject of the further works of the authors.

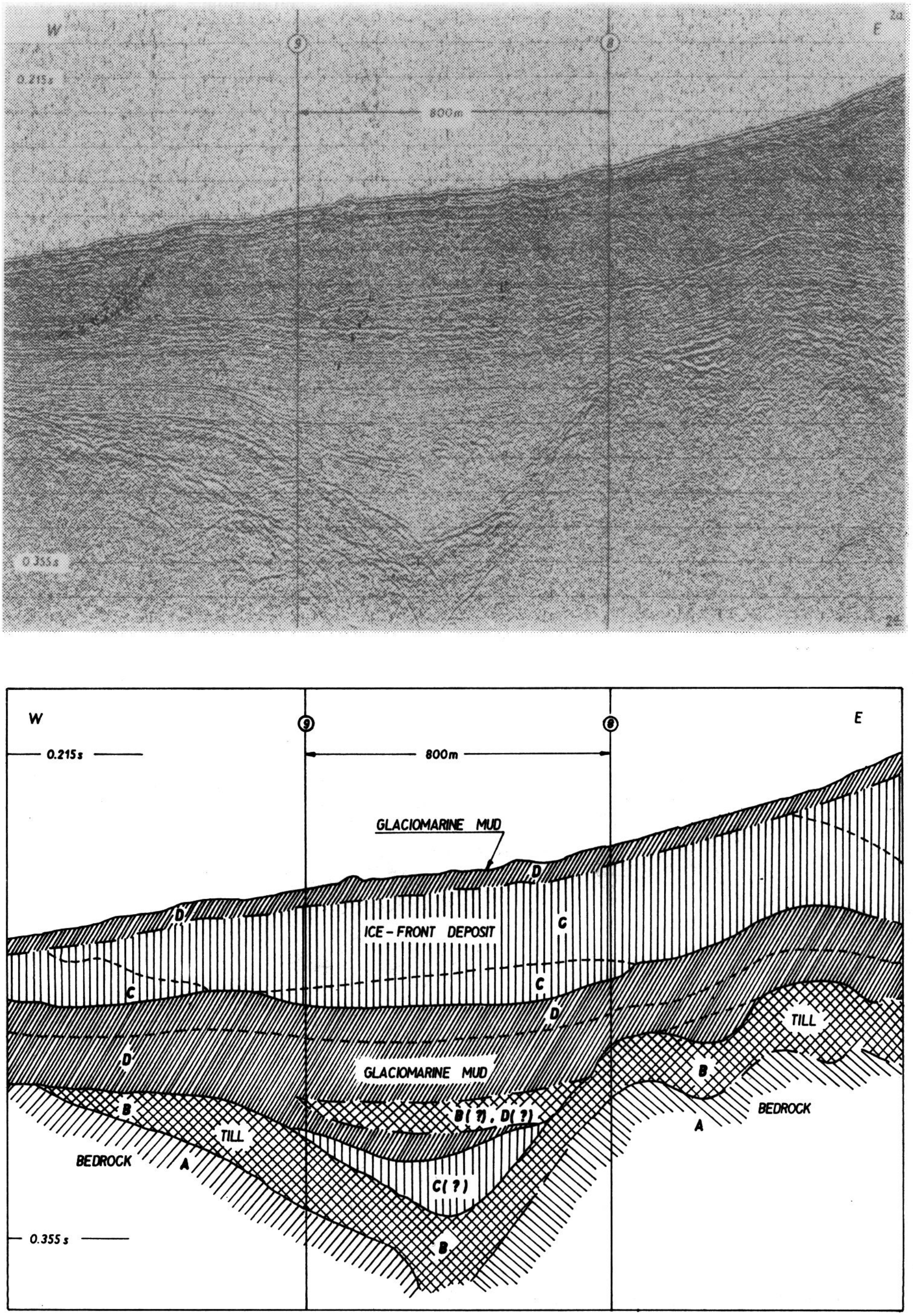

Fig. 2. Fragment of a boomer record along the Hornsund: the location mark 8 occurs abeam Sofiekammen

a — boomer record, b — interpretation of the boomer record: unit A — bedrock, unit B — till and/or compacted glaciogenic deposit, unit C — glaciomarine ice-front deposit, unit D — glaciomarine mud

a)

b)

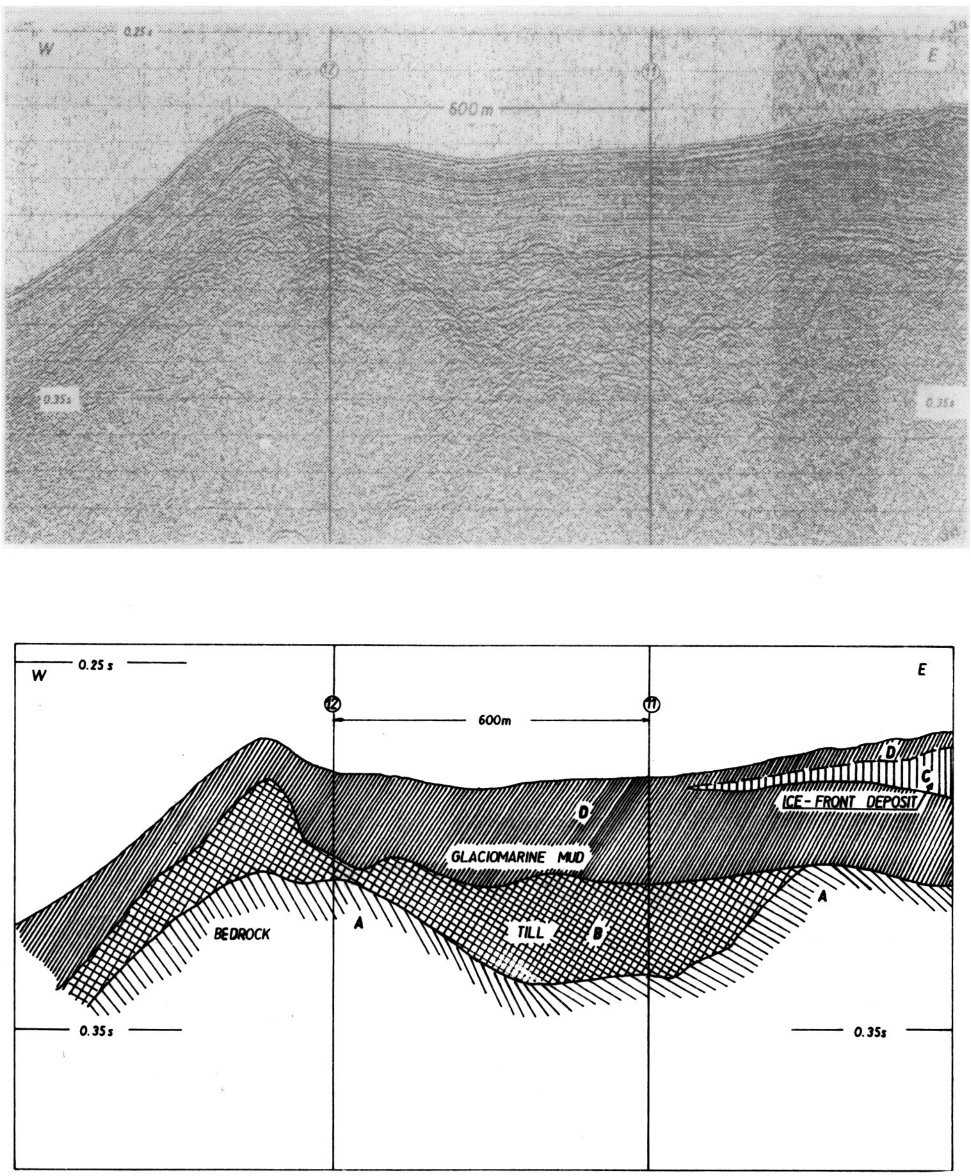

Fig. 3. Fragment of a boomer record, continuation of the profile from Fig. 2
a — boomer record, b — interpretation of the boomer record; for other explanations *see* Fig. 2

U n i t B. This unit possesses a considerably varying seismic pattern. The latter is acoustically semitransparent *sensu* Elverhöy *et al.* 1983), with numerous irregularly distributed regions of sets of hyberbols diffraction. The uneven top surface is usually formed of regions of hyperbols diffraction. The non-reflective zones are frequent. The strong reflexes occur locally only and are discontinuous.

a)

b)

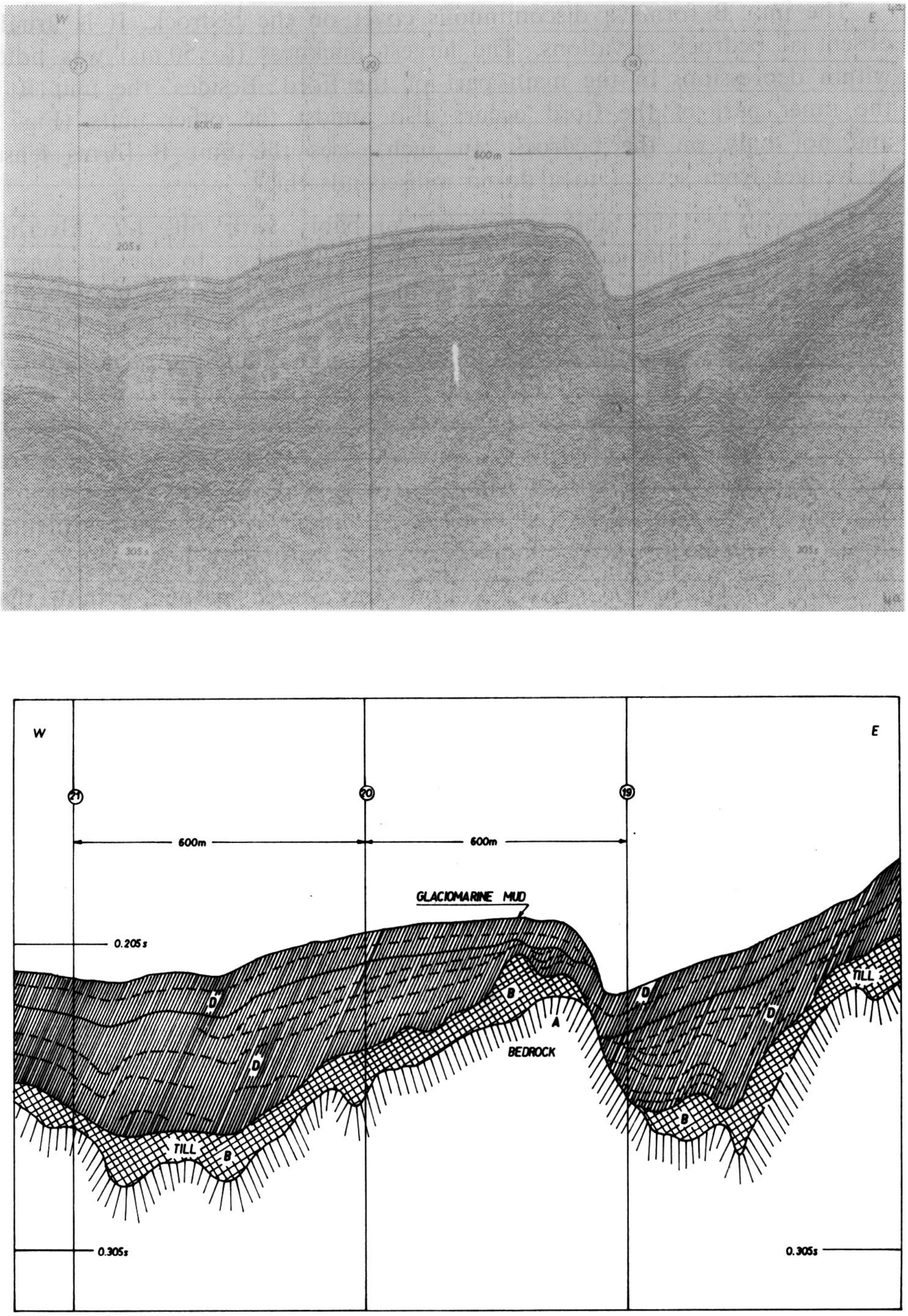

Fig. 4 Fragment of a boomer record along the Hornsund; the location mark 19 occurs abeam the Hansbreen

a — boomer record, b — interpretation of the boomer record; for other explanations *see* Fig. 2

The unit B forms a discontinuous cover on the bedrock. It is usually absent at bedrock elevations. The largest thickness (to 50 ms) was noted within depressions in the main part of the fiord. Besides, the unit B in the inner part of the fiord occurs also amidst the other units (Fig. 2) and not only on the bedrock. In such cases the unit B forms lenses or wedges from several to a dozen miliseconds thick.

Sediments of this unit correspond probably with tills (*cf.* Elverhöy *et al.* 1983) of a lodgement and/or melt-out type, or to the glaciogenic compacted deposits. A postulated possible occurrence of such glaciomarine diamictites (Elverhöy *et al.* 1983) within the unit B seems probable in our opinion if the glaciomarine diamictons (corresponding in our classification with the unit C) are subjected to a glacier push during its renewed advance. Such advance can be connected either with short-lasting oscillations of the glacier snout or with a successive ice age in the fiord area. The occurrence of the unit B within the sediments of units C or D and deformations noted above the bedrock elevations can be also explained by glacial advances. They seem to correspond with push moraines.

Unit C. The unit C has a considerably varied seismic pattern that is in general weak acousticly transparent. Some fragments show no reflexes (with quite a varying transparency), there are also regions of sets of hyperbols diffraction, with weak or strong reflexes. Such differences do not authorize to a subdivision within the described unit, mainly due to numerous transitions and a lack of borders that separate the sequences of a slightly different seismic pattern. A detailed subdivision of the unit C calls for further investigations, allowing for a description and demarcation of sedimentary bodies (as sandurs, fans, deltas, etc.).

Differentiations of the seismic pattern reflect a varying lithology of this unit and its sedimentary environment. This unit is composed (*cf.* Elverhöy *et al.* 1983) of massive, partly cross-laminated, loose and poorly compact vari-grained sediments (mainly silts and silty sands) with abundant coarser grain sizes and local concentrates of stones and boulders (massive diamictons) what is well expressed by cores from Adriabukta and Burgerbukta (Fig.6). The occurrence of the unit C was mainly noted in the inner part of the fiord where it was quite thick, reaching 170 ms. In the inner part of the fiord and particularly near ice cliffs, it outcrops at the sea bottom with the uneven hummocky top surface.

The interpretation of the seismic pattern, supported by a macroscopic description of the collected cores and their relation to the glacier snouts, proves that sediments of this unit have been deposited close to the glacier termini. A glacial debris supplied by supraglacial and inglacial streams, meltwaters, by dumping, sliding, creeping and other mass movements, has been rapidly deposited in subaquatic fans, sandurs, deltas and glaciofluvial

a)

b)

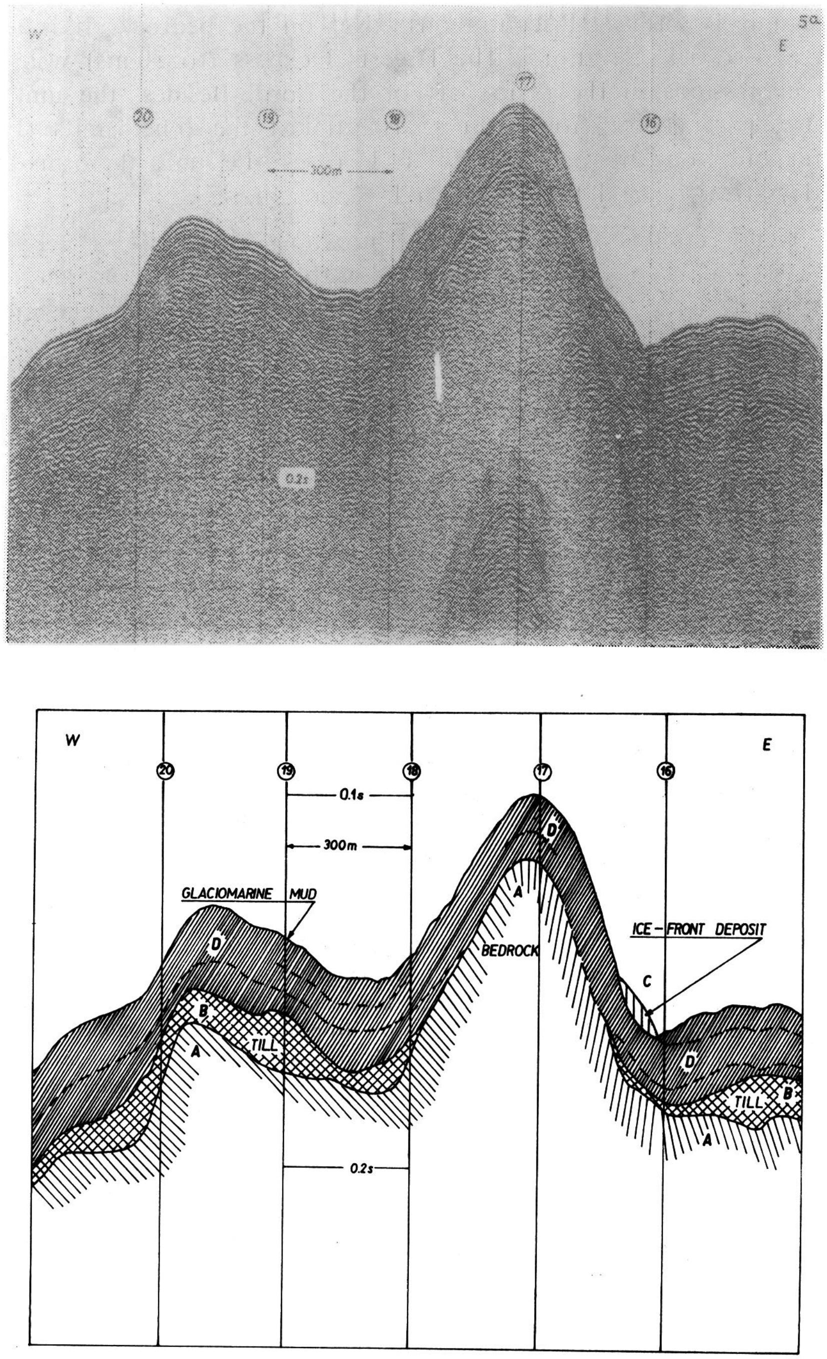

Fig. 5. Fragment of a boomer record along the Hornsund; the location mark 16 occurs abeam the Körberbreen

a — boomer record, b — interpretation of the boomer record; for other explanations *see* Fig. 2

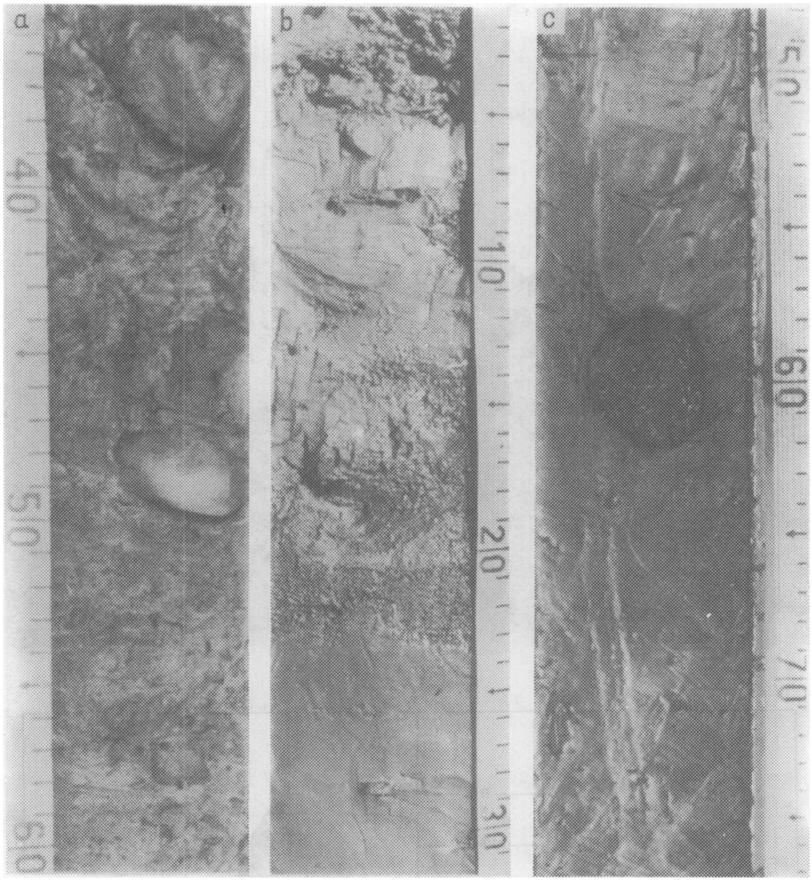

Fig. 6. Examples of cores of bottom sediments from the Hornsund, collected in 1985 a — fragment of the core 16, Burgerbukta, water depth 25 m, core length 2.8 m. Massive diamicton: stiff muddy gravel with dropstones (glaciomarine ice-front deposits). b — fragment of the core 13A, Adriabukta, water depth 85 m, core length 3.0 m. Glaciomarine ice-front deposits: 0.00 — 0.05 m dark grey muddy gravel with dropstones, massive diamicton; 0.05 — 0.12 m light-grey muddy sand, partly laminated, with dropstones; 0.12 — 0.22 m grey muddy marl with dropstones, massive diamicton; 0.22 — 0.57 m homogeneous glaciomarine mud: dark-grey mud with dropstones. c — fragment of the core 21, Isbjörnhamna, water depth 110 m, core length 1.9 m. Glaciomarine mud: 0.3 — 0.6 m sandy mud, grey with black spots; 0.6 — 0.8 m homogeneous brownish grey mud with dropstones

terminal moraines (*sensu* Ruszczyńska-Szenajch 1982). Frequent deformations are caused here by mass movements, icebergs, waves and tractional currents near the bottom. Sediments of the unit C are to be best defined as the glaciomarine ice-front deposit. Previous terms as proglacial outwash sediments (Vanney and Dangeard 1976), sea ice-proximal coarse-grained sediments (Powell 1983), surge deposits (Liestöl 1969) and surge or ice-front deposits without the attribute "glaciomarine" (Elverhöy *et al.* 1983).

deal only with some sediments and features in this zone or can be also referred to inland sediments.

The distinguished unit C comprises the unit III (surge deposits) noted in the Kongsfiorden (Elverhöy *et al.* 1983) and probably an upper part of the unit II (glaciogenic compacted deposits). In the Hornsund the unit C occurs mainly in the inner part of the fiord, suggesting a connection with a location of the glacial termini during the Little Ice Age and the short-lasting surges of the recent times. In the main part of the fiord the unit C forms a wedge within the sediments of the unit D.

Unit D. This unit is widespread within the fiord. It is composed of the complex of highly reflective, acousticly transparent sediments with distinct and continuous reflexes that can be noted at a considerable distance. The unit D frequently overlaps the lower ones and contacts with units C, D, or A and so, it smooths the bedrock morphology. A seismic pattern and cores of sediments (Fig. 6c) prove the occurrence of horizontally stratified fine-grained deposits, mainly silty and clayey ones, with a possible admixture of sand and dropstones. In the main part of the fiord where the unit D covers the unit B, filling the bedrock depressions, there are deformations of the bedding that can be interpreted as the thaw structures. The latter must have been formed due to melting of a buried dead ice (occupying vast areas but also in small isolated blocks).

The unit D contains also the deformations that are connected with sliding and creeping of sediments as well as with action of icebergs: depressions, troughs, erosive striae and sediment ramparts (*cf.* Moigne 1976).

The unit D in the main part of the fiord reaches the sea bottom and contains also the recent sediments, composed of homogeneous and laminated muds with a varying content of dropstones. These sediments correspond probably with the unit IVd *i.e.* the glaciomarine basin muds (Elverhöy *et al.* 1983). Frequently distinguished (*e.g.* by Elverhöy *et al.* 1983, Görlich 1986) proximal sediments composed of sandy-silty interbeddings and more distal homogeneous muds cannot be noted on the basis of the analysis of a seismic pattern. The unit D (to 60 ms thick) is therefore composed of these two sedimentary types (one should remember that they were distinguished on the basis of surface samples and enclose only a thin, several centimeters thick layer of superficial sediments).

Acoustic survey in Wijdefjorden, Isfjorden and around Björnöya

Bottom sediments in the Wijdefjorden are in general composed at the surface of the unit of varying thickness that corresponds with the unit D distinguished in Hornsund *i. e.* a glaciomarine mud. Its maximum

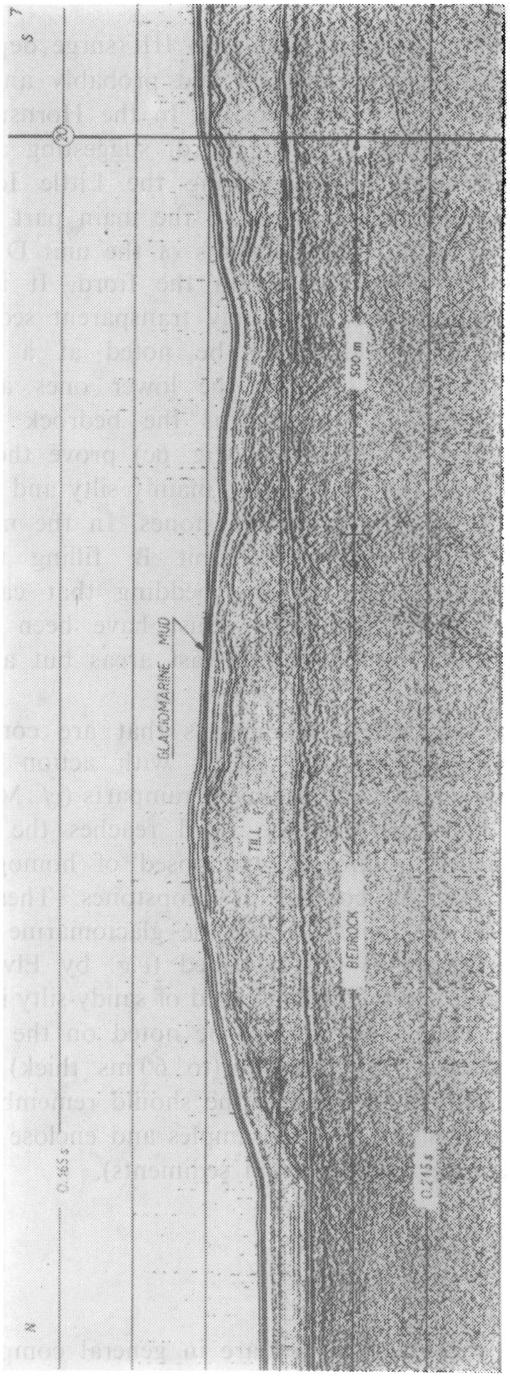

Fig. 7. Example of a boomer record from the Wijdefjorden area (central part)

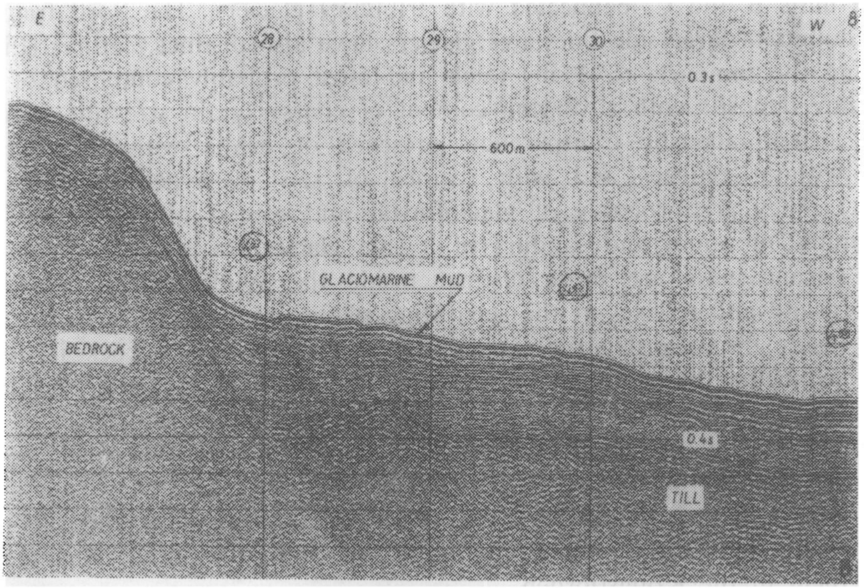

Fig. 8. Example of a boomer record from the Isfjorden area (central part)

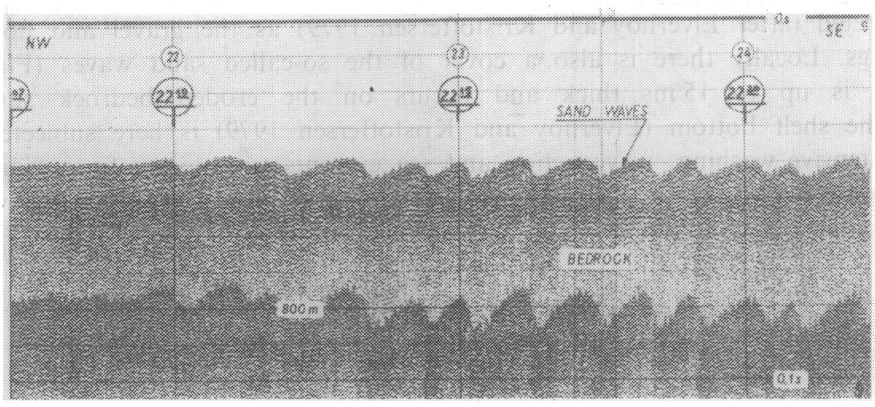

Fig. 9. Example of a boomer record from the Björnöya area

thickness is here smaller and does not exceed 10 ms. There are also common highly transparent sequences, almost without the inner reflexes. Beneath, there are the sediments that correspond to the unit C *i.e.* till and/or glaciogenic compacted deposit. They have a distinctly uneven, hummocky relief of the top surface (with height differences of several to a dozen or so miliseconds), masked by sediments of the overlying unit. The glaciogenic deposits are here to 20 ms thick. This unit covers the bedrock with the erosive sculpture of the top surface, with distinct troughs that occur in our opinion mainly at young (active?) faults and other tectonic loosenings. These troughs are filled with sediments that correspond to the ones of the units B and C, connected with tributary glaciers. The fiord fragments at outlets of large side tidewater glaciers have also distinct features (Fig. 7), being the ramparts to 40 ms thick and most probably composed of silty--sandy deposits with a varying content of coarser grain sizes (as suggested by a high acoustic transparency, presence of media with short reflexes or without reflexes and with regions of sets of hyperbols diffraction, etc.). They are probably of glaciofluvial and glacial origin, deposited in terminal moraines and sandurs of a side glacier. In general, the borders of seismic units are more distinct inside the Wijdefjorden than in the Hornsund and reflexes at the separating planes continue at large distances.

Inside the Isfjorden the erosive top surface of the bedrock is covered by sediments that correspond to the units B and D (Fig. 8), and locally probably also to the unit C. The mantle of fresh sediments is here thinner than in the Hornsund and there are also zones where the bedrock reaches the bottom surface.

Norwegian scientists (Elverhöy *et al.* 1983) noted here the silty-sandy series at the surface, corresponding to glaciomarine muds, distinguished by them in the Kongsfjorden.

In the Björnoya area the bedrock outcrops at a sea bottom, being covered by a thin (to several miliseconds thick) mantle that can be interpreted (after Elverhöy and Kristoffersen 1979) as the gravel and boulder lags. Locally there is also a cover of the so-called sand waves (Fig. 9). It is up to 15 ms thick and occurs on the eroded bedrock surface. The shelf bottom (Elverhöy and Kristoffersen 1979) is here subjected to intensive washing: wave action and sea currents transport a finer sediment away (with a local formation of sand waves) and deposit it at water depths below 150 m.

Discussion

Generally speaking the glaciomarine environment comprises the original environments of all the sediments deposited in a sea and containing a debris coming from all types of ice *i.e.* settled and floating, glacial and marine ones (Vanney and Dangeard 1976, Powell 1983, Gravenor *et al.* 1984). Boulton and Deynoux (1981) were right finding such definition too wide and postulated, that it should not include the deposition at a deep bottom of an open sea with a secondary content of glacial debris supplied from ice-rafted debris. The environment can be defined as the glacial one (glacial *sensu stricto*, glaciofluvial, glaciomarine or glaciolacustrine) if a glacier ice and/or glacial meltwater are the main transporting agents. Therefore, the glaciomarine environment should be defined according

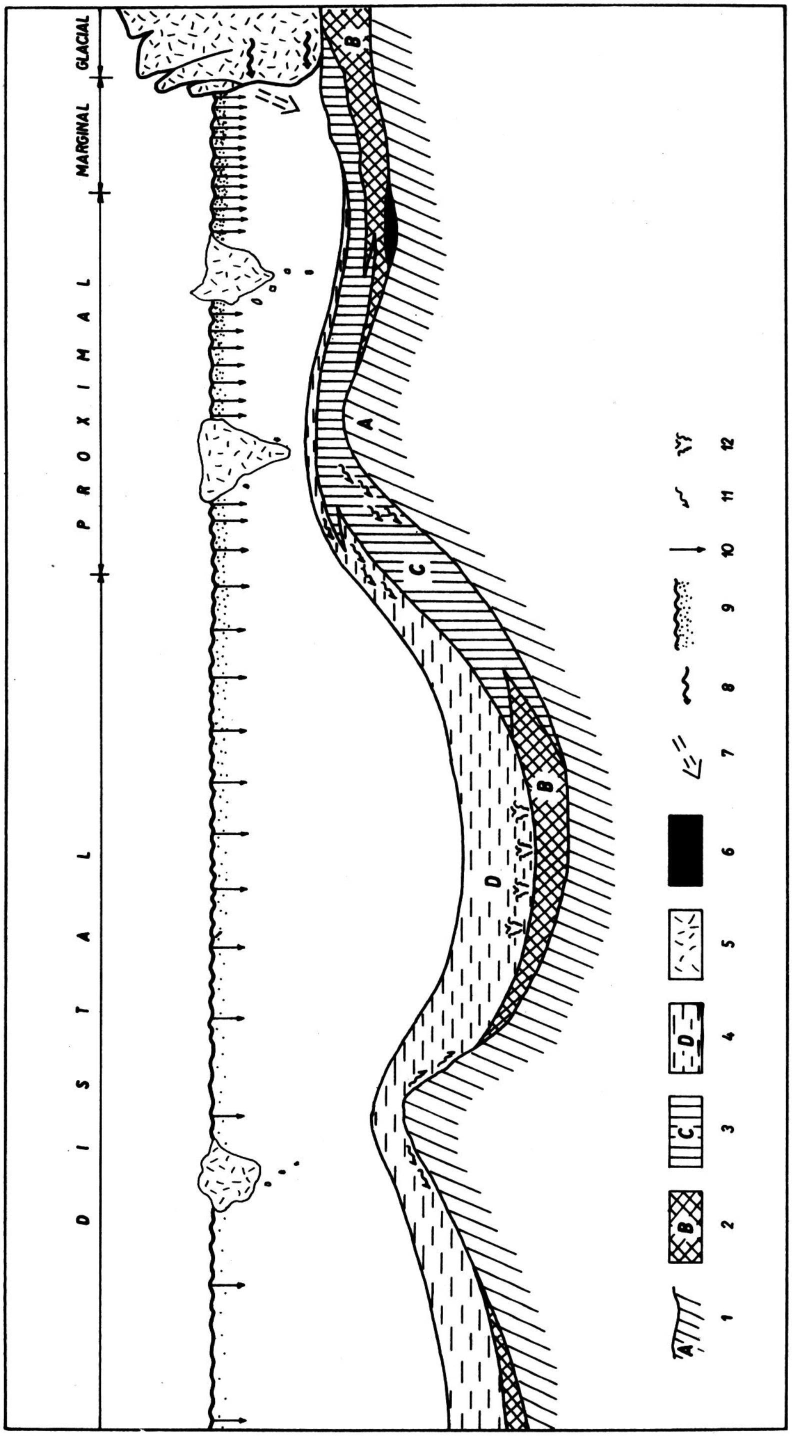

Fig. 10. Model of glaciomarine sedimentation in a fiord with warm tidewater glaciers (taking Hornsund as example)

1 — bedrock, 2 — till and/or compacted glacigenic drift, 3 — glaciomarine ice-front deposit, 4 — glaciomarine mud, 5 — glacier ice, 6 — buried dead ice, 7 — ice-marginal discharge of glacial debris, 8 — meltwater outlet, 9 — surface suspension plume, 10 — sediment settling, 11 — mass movements (creeping, sliding, etc.), 12 — thaw structures

to Boulton and Deynoux (1981, p. 398) as "sea area in which structure of the water masses is primarily determined by glacial meltwater". In such range the glaciomarine environment occurs now in polar fiords and shelfs whereas a deep-sea sedimentary environment (where no influence of glacial meltwater on the structure of water masses is noted) should be connected with the zone where spreading of glacial debris by ice rafts occurs.

Incorporation of deposits formed at a base of grounded glaciers (in a subglacial zone of the glaciomarine environment: Powell 1984, Gravenor *et al.* 1984) or due to thawing of basal ice (*cf.* Troitsky 1975) into a glaciomarine environment seems also incorrect. Such deposits are undoubtedly of glacial and subaquatic origin but they belong already to the glacial environment.

A glaciomarine environment is usually found to be composed of two zones, that is proximal and distal ones (Boulton and Deynoux 1981). In our opinion the third, marginal zone should be also distinguished, located close to the glacier front (Table 1, Fig. 10). In this zone the structure of water masses is dominated by glacial meltwaters and their distinct stratification with waters of a sea basin is noted. Outflows of supraglacial and inglacial streams as well as flows, creeps, slides and surface suspension plumes provide with glacial debris that is rapidly deposited near (several hundred metres) the ice front as dumps, terminal glacial and glacifluvial moraines (*sensu* Ruszczyńska-Szenajch 1982), sandurs, fans, deltas, etc. A marginal zone forms therefore the inner part of a proximal zone, previously distinguished in the fiords of Spitsbergen (Elverhöy *et al.* 1983, Görlich 1986).

The presented model of glaciomarine sedimentation (Table 1, Fig. 10) was first of all prepared to illustrate the mutual relations and zones, in which the distinguished seismoacoustic units are developed. In the same time it can be considered for the model of sedimentary conditions in fiords which are fed by wet tidewater glaciers and by advancing glacier fronts. The latter could advance from several dozen to several hundred kilometres every year (Liestöl 1969, Koryakin 1985, Jania *et al.* 1986) what results in a formation of push moraines as well as in a sudden supply with a glacial debris. The model neglects the effects of icebergs on the sea bottom, resulting in various deformations (especially in the proximal zone) expressed by striae, channels, troughs and depressions (Moigne 1976) but also ramparts of pushed sediments or local agglomerations of the material that is melted from grounded icebergs (*cf.* Grosswald 1982, Powell 1983).

The presented model accepts a frontal deglaciation but the areal one should be also taken into account. The latter results in a formation of buried dead ice blocks (*cf.* Fig. 10). Such deglaciation certainly occurred

Table 1

Seismostratigraphic units of bottom deposits in the fiord Hornsund and their connection with distinguished sedimentary environments

Environment	Zone	Water Structure	Main agents supplying with glacier debris	Main depositional mode	Main deposits	Units
Glacial	subglacial	—	ice	thawing in situ	lodgement till	B till and/or compacted glacigenic deposit
		meltwater	ice, meltwater	waterlain settling	undermelt till	
		glacier meltwater, marine water				
Glaciomarine	marginal	glacier meltwater dominant, distinct stratification with marine water	mass movement, debris flow, meltwater outflow	rapid deposition from dumping, outwash streams, deposition from sliding, creeping etc.	glacigenic diamicton sandy/muddy deposit, partly cross-laminated	C ice-front deposit
	proximal	glacier meltwater, marine water	glacigenic: — fluid flow — gravity flow and icebergs	waterlain sedimentation from suspension plume, deposition from tractional currents, flow over the bed dropped debris	homogeneous mud and ice rafted debris (IRD)	D glaciomarine mud
	distal	marine water, partly glacier meltwater	surface suspension plume and icebergs	waterlain settling from surface suspension, plume dropped debris	basin mud and IRD	
Marine	icebergs	open sea water	icebergs	dropped debris	marine mud and IRD	—

in the Hornsund what is marked by thaw structures within the sediments of the unit D in the main part of the fiord. Such deglaciation probably occurs also at present in the bays of the fiord although a significance of this phenomenon cannot be evaluated yet. But a find of buried dead ice in superficial sediments (Filipowicz *personal information*) confirms such opinion. The problem of a subaquatic areal deglaciation and occurrence of extensive dead and buried ice masses at a reservoir bottom, forms the subject that has been only roughly examined in glacial and marine investigations. On the other hand this phenomenon is also of a considerable significance for the studies in other, previously glaciated regions *e.g.* the Baltic Sea (*cf.* Rossa and Wypych 1981, Rudowski 1981).

The model presents an arrangement of distinguished units, with the assumption on their connection with a single glaciation and deglaciation cycle in a fiord. The collected data already allow to distinguish at least three glacial episodes in the Hornsund. The largest one, corresponding with the maximum extent of the Würm glaciers (*cf.* Lindner, Marks and Pękala 1983), occupied the whole fiord as far as its outer area. The following deglaciation resulted probably in deposition of the unit B in the outer and main fragment of the fiord. Extensive fields of dead ice blocks could be formed, later buried by sediments of the unit D and resulting in a creation of the thaw structures. The next glaciation, corresponding to the maximum glacier extent during the Holocene *i.e.* about 3.5 — 2 ka (Lindner, Marks and Pękala 1983), seems to have reached an outstanding threshold running across the fiord from the Wilczekodden to the Höferpynten. The Little Ice Age resulted in the most distinct glacial traces and a distribution of the units very close to the presented model. The glaciers advanced about a dozen kilometres further than at present, moving outside the inner bays of the fiord (Brepollen, Samarinbukta, Burgerbukta) and reaching the thresholds in this area. The deglaciation, lasting until nowadays but interrupted by occassional glacial surges, resulted in deposition of the thick unit C near the maximum glacial extent. Such a considerable thickness (to 200 m) seems to be the reason to accept a sudden supply with glacial debris what is possible in the case of a glacial advance onto the earlier glacial sediments (Troitsky 1975, 1985).

Due to repeated glaciation and deglaciation of the fiord, the distinguished units (B, C and D) are not isochronic in various parts of the fiord and therefore, they do not occur always in the model stratigraphic sequence.

Conclusions

1. Results of investigations proved a considerable usefulness of the CSP method for studies of the bottom relief and sediments in fiords and at shelfs of the polar zone.

2. A receipt of the high-quality boomer record could be possible due to numerous tests, carried through to choose the most suitable parameters for generation and record of acoustic signals dependent on geologic conditions.
3. Fieldworks were considerably disturbed by changeable ice and weather conditions in the examined areas. Thus, the performed investigations call for their good logistic preparation to make them possible to be finished in a limited time. Besides, the examined routes and sites should be chosen with a great elasticity, dependent on the real situation.
4. Collected data enabled to prepare the model of glaciomarine sedimentation in a fiord, with distinguished marginal, proximal, and distal zones of the glaciomarine environment.
5. Numerous and large thaw structures, noted for the first time in Spitsbergen within glaciomarine muds, suggest a possible occurrence of a subaquatic areal deglaciation.
6. Results of examinations of the sediments and a relief of the bottom of Spitsbergen fiords and particularly, of the Hornsund, and of sedimentary conditions in this area, create a valuable supplement for geomorphologic, geologic and glaciologic investigations on the land that have been carried through in this region for many years. The new material was found useful in a description of the Spitsbergen evolution during its recent times, its glaciation and deglaciation, conditions of sedimentation. Besides, the collected material and its interpretation play a significant role in the analysis of glaciomarine paleoenvironments.

References

Boulton G. S., Deynoux M. 1981 — Sedimentation in glacial environment and the identification of tills and tillites in ancient sedimentary sequences — Precam. Res., 15: 397—422.

Görlich K. 1986 — Glaciomarine sedimentation of muds in Hornsund fiord, Spitsbergen — Ann. Soc. Geol. Pol. 56: 433—477.

Gravenor C. P., von Braun V., Dreimanis A. 1984 — Nature and classification of waterlain glacigenic sediments, exemplified by Pleistocene, Late Paleozoic and Late Precambrian deposits — Earth Sci. Rev., 20: 105—166.

Grosswald M. G. 1983 — Pokrovnye ledniki kontinentalnych szelfov — Izd. Nauka, Moskva, 214 pp.

Elverhöy A. 1984 — Glacigenic and associated marine sediments in the Weddell Sea, fiords of Spitsbergen and the Barents Sea — Marine Geology, 57: 53—88.

Elverhöy A., Kristoffersen Y. 1979 — Holocene sedimentation on the shelf around Björnöya northewestern part of the Barents Sea — Norsk Polarinstitutt, Arbok 1978, 199—215.

Elverhöy A., Lonns O., Seland R. 1983 — Glaciomarine sedimentation in a modern fiord environment, Spitsbergen — Polar Res. 1: 127—149.

Elverhöy A., Solheim A. 1983 — The physical environment Western Barents Sea 1: 1.500.000, sheet A; Surface sediment distribution — Norsk Polarinstitutt, Oslo, 23 pp.

Jania J., Kolondra L., Rudowski S. 1986 — Annual activity of Hans Glacier (Spitsbergen) as determined by photogrammetry and micro-tremors recording — Ann. Glaciology, 8 (*in press*).

Karczewski A. (Ed.) 1986 — Geomorphological map of the Hornsund, Spitsbergen, 1:75000 — Silesian Univ., Katowice.

Koryakin V. S. 1985 — Kolebaniya i rezkie podvizhki lednikov (in: Glaciologija Shpitsbergena, Ed. Kotlyakov V. M.) — Izd. Nauka, Moskva, 80—69.

Kowalewski W., Rudowski S., Zalewski M., Żakowicz K. 1985a — Glaciomarine deposits in the Hornsund region (Spitsbergen) and a problem of the Last Glaciation in this area — Proc. Conf. European Union Earth Sciences, Strasbourg.

Kowalewski W., Rudowski S., Zalewski M., Żakowicz K. 1985b — Problemy proglacjalnej sedymentacji na dnie fiordu Hornsund, na podstawie materiałów ciągłego profilowania sejsmoakustycznego (CSP) — Proc. XII Symp. Polar. Akademia Rolnicza, Szczecin.

Liestöl O. 1969 — Glacial surges in West Spitsbergen — Can. J. Earth Sci., 6: 895—897.

Lindner L., Marks L., Pękala K. 1983 — Quaternary glaciations of South Spitsbergen and their correlation with Scandinavian glaciations of Poland — Acta Geol. Pol., 1—4: 169—182.

Moigne A. 1976 — L'action des glaces flottanes sur le littoral et les fonds sous-marine du Spitsbergen central et nord-occidental — Rev. Geograph. Montreal, 1—2: 51—64.

Powell R. D. 1983 — Glaciomarine processes and inductive lithofacies modelling of ice shelf and tidewater glacier sediments based on Quaternary examples — Marine Geology, 57: 1—52.

Rossa W., Wypych K. 1981 — Sejsmostratygrafia dna Bałtyku Południowego — Proc. Konf. Geol. Inż. Badania Pd. Bałtyku Komitet Nauk Geol. PAN, Gdańsk.

Rudowski S. 1981 — The Quaternary history of Baltic, Poland (in: The Quaternary History of the Baltic, Eds. L. K. Konigsson, V. Gudelis) — Acta Univ. Uppsalensis Univ. Ups. Annum Quingentesimum Celabrantis, 1: 175—183.

Ruszczyńska-Szenajch H. 1982 — Sedimentary environments as criteria for genetic subdivision of fluvioglacial deposits and landforms — Proc. Reunion Regional Sudamericana Comm. Genesis Lithology Quatern. deposits, Univ. Comahue, Neugen, Argentyna.

Solheim A., Kristoffersen Y. 1984 — The physical nvironment Western Barents Sea 1:1.500.000, sheet B, Sediments above the upper regional unconformity: thickness, seismic stratigraphy and outline of the glacial history — Norsk Polarinstitutt, Oslo, 26 pp.

Troitsky L. S. 1975 — Glacialnyi morfogenez (in: Oledenienie Spitsbergena (Svalbarda), Eds. L. S. Troitsky, E. M. Zinger, V. S. Koryakin, V. A. Markin, V. I. Michalev) — Izd. Nauka, Moskva, 187—225.

Troitsky L. S. 1985 — Osnovnye zakonomernosti razvitia oledenienia archipelaga (in:Glaciologia Spitsbergena, Ed. V. M. Kotlyakov) — Izd. Nauka, 176—192.

Vanney J-R., Dangeard L. 1976 — Les depots glacio-marine actuels and anciens — Rev. Geograph. Montreal, 1—2: 9—59.

Zalewski M., Kowalewski W., Rudowski S., Rossa W. 1984a — Preliminary results of seismoacoustic sounding of bottom sediments in the region of Spitsbergen — Proc. Symp. "Spitsbergen 84", Inst. Ekologii PAN, Dziekanów.

Zalewski M., Kowalewski W., Rudowski S. 1984b — Rozpoznanie procesów sedymentacji glacjalno-morskiej metodą CSP (sejsmoakustyka) na przykładzie fiordu Hornsund — Proc. XI Symp. Polar., Univ. A. Mickiewicza, Klub Polarny, Poznań.

Received September 22, 1986
Revised October 29, 1986

Резюме

Применение метода НСП (непрерывное сейсмическое профилирование) в изучении донных отложении фиордов в районе архипелага Шпицберген и вокруг острова Медвежий (фиг. 1) дало возможность выделить четыре сейсмоакустические единицы (фиг. 2—9). Единица А это коренное основание (метаморфные и осадочные породы), отделенные ярко выраженной экзарационной поверхностью несогласения от вышележащих единиц, сложенных верхнечетвертичными отложениями. Единица В соответствует валунным глинам или компактным гляцигенным отложениям. Единица С это гляциально-морские приледниковые отложения (в непосредственной близости края ледника) и единица D — гляциально-морские суглинки.

На основании полученных результатов исследований дается модел гляциально-морской седиментации в маргинальной, проксимальной и дистальной зоне фиорда (фиг. 10, табл. 1), на территорию которого поставляют материал входящие в него теплые ледники.

Streszczenie

Zastosowanie metody CSP (ciągłe profilowanie sejsmiczne) do badań osadów dennych fiordów w rejonie Archipelagu Spitsbergen i wokół Wyspy Niedźwiedziej (fig. 1), pozwoliło na wydzielenie kilku jednostek sejsmoakustycznych (fig. 2—9). Jednostka A to podłoże skalne (zbudowane ze skał metamorficznych i osadowych) oddzielone wyraźną powierzchnią niezgodności o egzaracyjnym charakterze od wyżej leżących jednostek zbudowanych z młodoczwartorzędowych osadów. Jednostka B odpowiada glinom zwałowym lub skompaktowanym osadom glacigenicznym.

Jednostka C to glacjalnomorskie osady przylodowe (w bezpośredniej bliskości frontu lodu) i jednostka D to glacjalno-morskie muły.

W oparciu o uzyskane wyniki badań przedstawiono propozycję modelu sedymentacji glacjalno-morskiej w strefie marginalnej, proksymalnej i dystalnej (fig. 10, tab. 1) fiordu zasilanego przez lodowce ciepłe wkraczające w fiord.