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LATE WEICHSELIAN GLACIAL AND GLACIOMARINE SEDIMENTATION IN THE WESTERN, CENTRAL BARENTS SEA

by

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ABSTRACT

Sedimentological and geotechnical analyses combined with earlier shallow seismic measurements give evidence for the occurrence of an overconsolidated till sequence (<30 m thick) on the slope between Spitsbergenbanken and Bjørnøyrenna. On the lower part of the slope a sequence of glaciomarine sediments onlap the till, and both units are tentatively dated to the end of the Late Weichselian (10,000 - 13,000 years BP).

The time-transgressive depositional pattern of the glaciomarine sediments combined with the presence of an adjacent till ridge in water depths of 300 m, indicate that Bjørnøyrenna was a calving bay for a grounded ice sheet which covered the shallower shelf areas. The thin (<1 m) glaciomarine cover on the slope was deposited during the retreat of the Late Weichselian ice sheet.

Holocene reworking and bioturbation preclude a detailed stratigraphic interpretation of the uppermost 0.5 m of the bottom sediments.

1. INTRODUCTION

The temporal and areal extension of the Pleistocene ice sheets in the Barents Sea is not known, but it is generally agreed upon that the area was at least once totally ice covered during the Pleistocene. For the Late Weichselian (25,000 - 10,000 BP) there are the following views:

1. The Barents Sea was totally glaciated until the end of the Late Weichselian (GROSSWALD 1980).
2. The Barents Sea, at least the western part, had a rather limited glaciation with marginal moraine deposition in front of submarine troughs extending out from Spitsbergenbanken (MATISOV 1977; ELVERHØI and KRISTOFFERSEN 1978).
3. The Barents Sea was non-glaciated throughout the Late Weichselian and consequently partly exposed subareally (BOULTON 1979a).

Strikingly different sedimentological responses would be expected from each of these proposed sequences. An elucidation of the Late Weichselian depositional history is probably best sought by interpreting the sea floor sediments. In this paper, the sedimentary environment of the surface deposits on the gentle slope from the shallow Spitsbergenbanken (40-100 m water depth) down into the inner part of Bjørnøyrenna (at 375-425 m water depth) is studied (Fig. 1). The results are combined with previous sedimentological data and shallow seismic records from adjacent areas to the west (BJØRLYKKE and ELVERHØI 1975; BJØRLYKKE et al. 1978; ELVERHØI and KRISTOFFERSEN 1978a, b; and KRISTOFFERSEN and ELVERHØI in prep.) to produce a Late Weichselian depositional model for the central western Barents Sea.

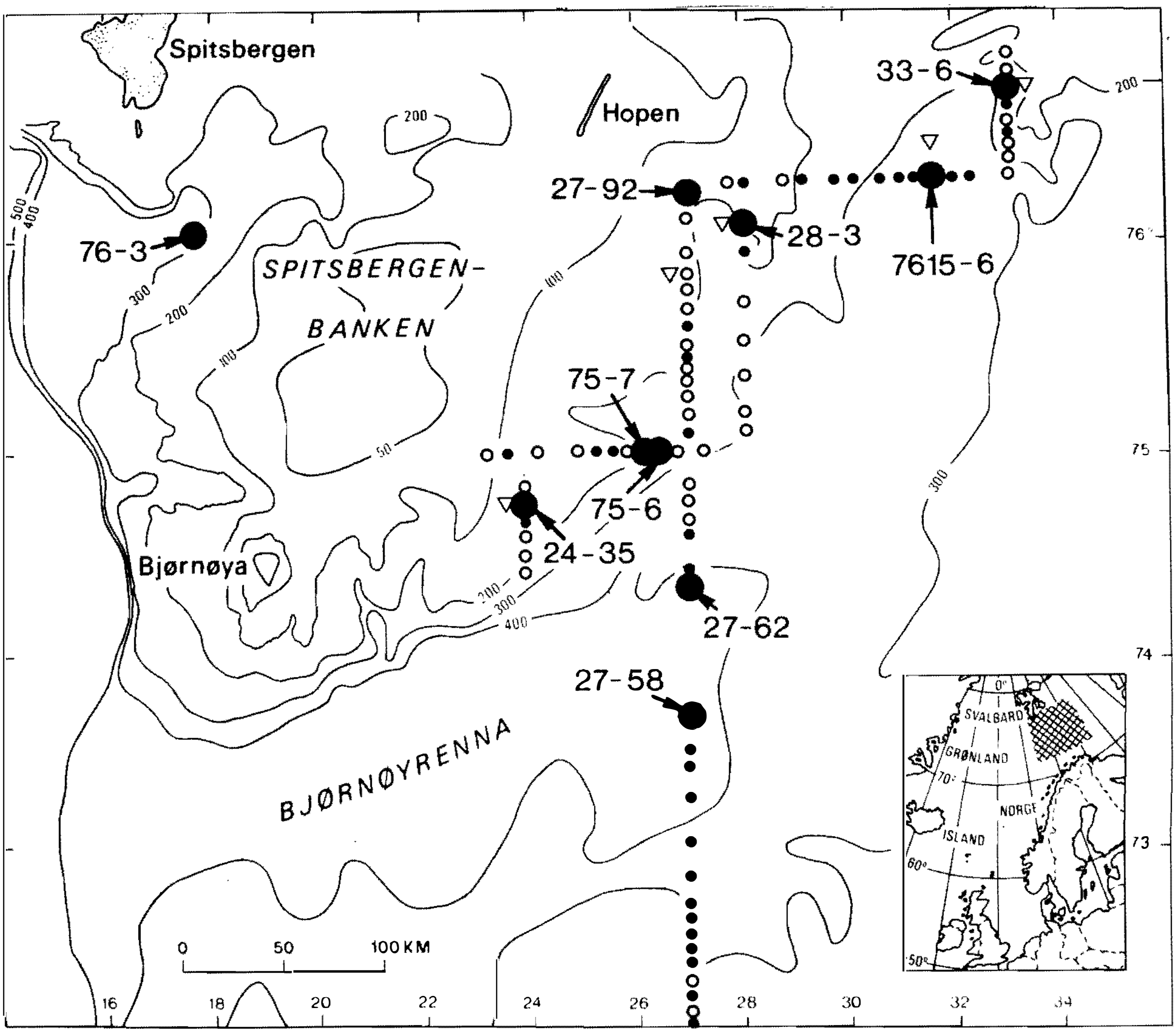

Fig. 1. Bathymetric map of the western Barents Sea showing the sample localities. Small circles: samples routinely described on board ship (black: gravity corer - open: pipe dredge); big circles: samples studied in detail; triangle: geotechnical tests (includes stratigraphical analysis).

2. SAMPLES AND LABORATORY ANALYSES

Sediment cores taken at five nautical miles intervals along N-S and E-W running lines south and east of Hopen (Fig. 1) were described (ELVERHØI 1978) on board during a geochemical (hydrocarbon) prospecting survey carried out by the Norwegian Petroleum Directorate in 1978. The lower half meter of the cores was used for the geochemical analyses and was not available for the laboratory investigations. In deeper parts (<375 m water depth) 2-3 m long gravity cores were obtained, while stiff, pebbly mud floored the sea bottom in shallower areas, allowing only short cores, 0.2-1.0 m, to be taken. Pipe dredging was commonly used in these areas. All cores were radiophotographed.

In this paper a detailed study of nine of these cores will be presented, together with one additional core from Storfjordrenna (Fig. 1).

Mineralogical analyses and X-ray diffraction were made on oriented samples prepared from stones and on the <2 um-fraction. The stones were crushed in a water mill and all samples vacuum filtrated on a Millipore slide. Clay mineral identification followed procedures described by BISCAYE (1965) and ELVERHØI and RØNNINGSLAND (1978).

Bioclastic material in a core from Storfjordrenna was dated by the C^{14} method and will be used as a reference section as its lithology is remarkably similar to cores from Bjørnøyrenna.

Samples of about 4 cm length (about 100 g dry weight) were used in the foraminiferal analyses. The sediment was dispersed in water and washed through two sieves with mesh diameters of 0.063 and 1.0 mm.

The foraminifera in the 0.063 - 1 mm fraction were concentrated by heavy liquid carbon tetrachloride (CCl_4).

In most samples about 300 benthonic specimens were found. In poor samples the entire foraminiferal content was counted. The planktonic foraminifera were also recorded.

3. THE BOTTOM SEDIMENTS

3.1. General descriptions.

Blue-grey pebbly and blocky mud is overlain by a more olive-grey unit (Figs. 2 and 3). Firmness and content of coarser material in the lower unit decrease

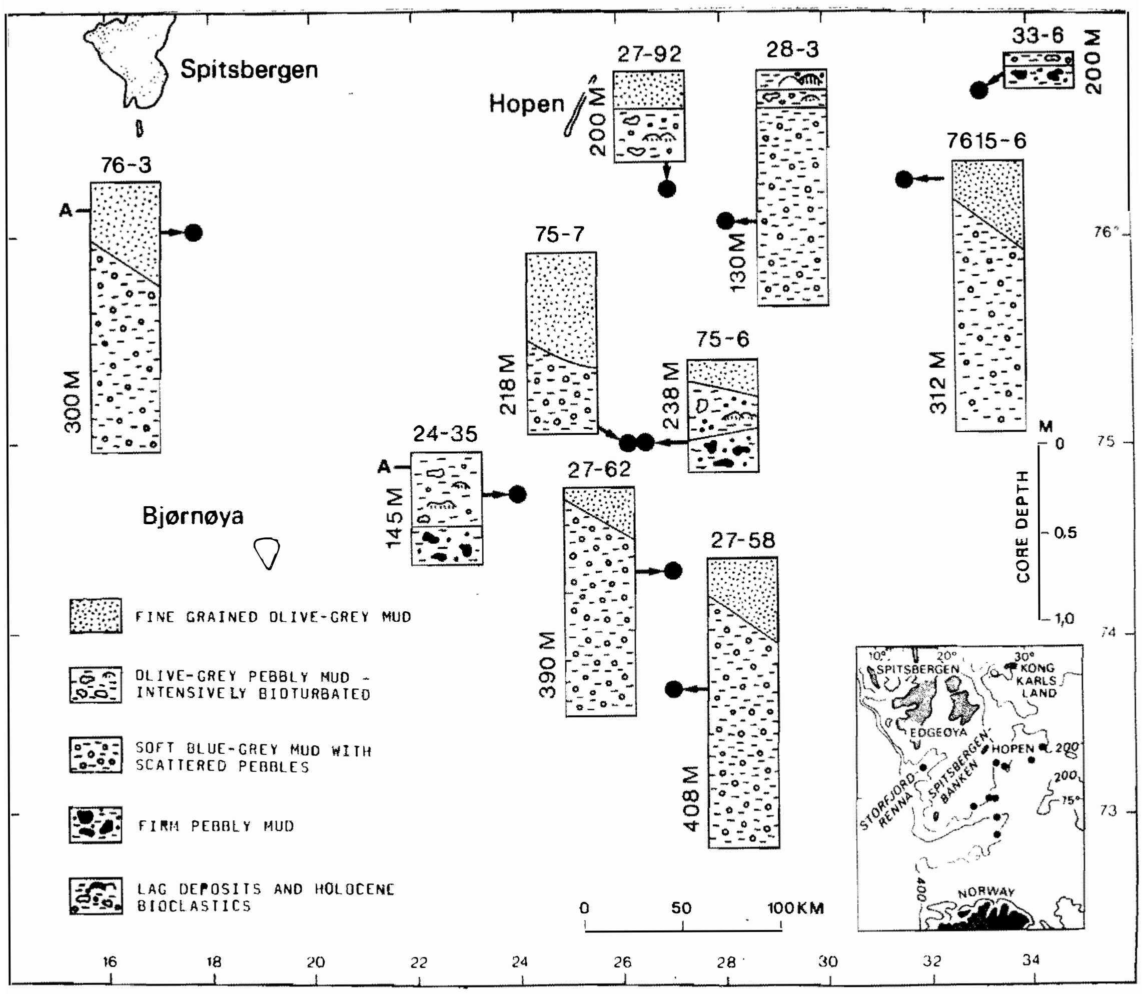

Fig. 2. Sediment stratigraphy in the studied samples. Angular boundary between two units refers to a gradual change in colour, foraminiferal fauna and texture between the two units. Horizontal line indicates a sharp boundary. Water depth of the core shown to the left.

slightly downslope. In the central part of Bjørnøyrenna soft blue-grey mud with scattered pebbles is found (Figs. 2 and 3). Bioclastics also occur in the blue-grey units.

The 10-30 cm thick olive-grey or occasionally grey-brown top unit on the slope commonly has a high content of pebbles and blocks and is intensely bioturbated, although its contact with the underlying unit is well defined. In the deeper parts of Bjørnøyrenna in water depths >350-375 m, the top unit tends to be more fine-grained, almost without sand and similarly also bioturbated. In the latter area, the colour and texture of the top unit gradually change downwards into the underlying blue-grey pebbly unit. Fine-grained sediments also occur as patches on the slope, with well defined contact to the underlying sediments.

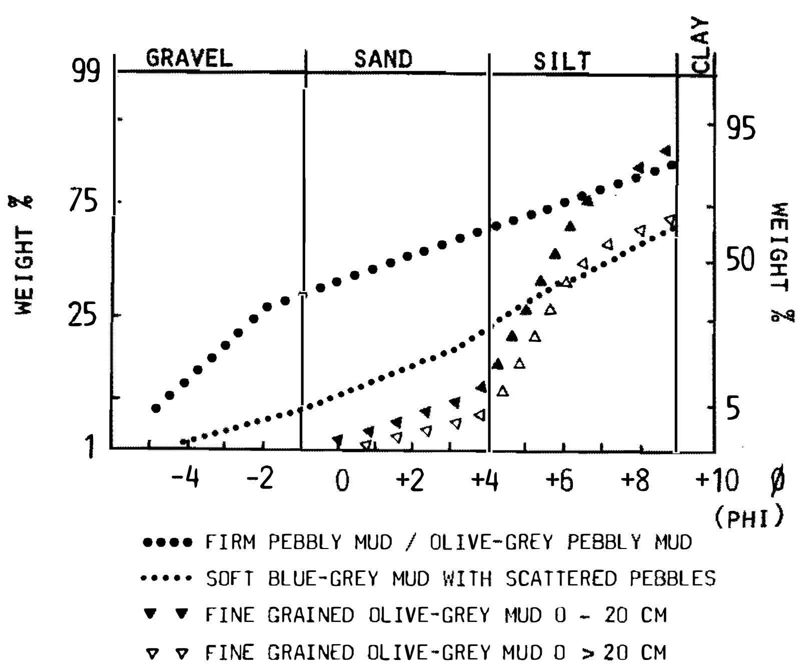

Fig. 3. Characteristic grain size distribution of the different lithologies (log probability plot).

In the shallower areas the sediments gradually change into lag deposits mixed with Holocene bioclasts, as previously described by BJØRLYKKE et al. (1978). Lag deposits with iron coated gravel and pebbles are also found on the deeper part of the slope, as far down as 400 m water depth. In some areas the sea floor is partly covered by iron crust. Similar phenomena have been observed earlier farther east in the Barents Sea (SAMOILOV and TITOV 1922), and also farther out in Bjørnøyrenna (ELVERHØI and KRISTOFFERSEN 1978b). In the latter areas it was suggested that Fe^{III} has an upwards diffusion from the Fe-rich sediments, and precipitate as Fe^{III} on the sediment surface in contact with water.

Except for core 76-3 in the outer part of Storfjordrenna, the sediments are uniform without lamination. In core 76-3 lamination was observed in the lower part of the fine-grained mud.

3.2. Bioturbation.

The olive-grey top unit on the slope from Spitsbergenbanken down to Bjørnøyrenna is generally completely bioturbated, mostly by polychaeta (Errantia), but starfish and seacucumber were also found (Fig. 4). All these organisms influence the sediment; in particular the polychaeta Errantia will rework the sediment effectively. Polychaeta were also observed in the fine-grained deposits in deeper parts of Bjørnøyrenna.

A high content of organic debris was commonly present in the olive-grey sediments and could easily be separated by washing with water. The sediment then turned blue-grey in colour. This suggests that the olive-grey colour is related to the content of organic debris, which was either deposited as primary

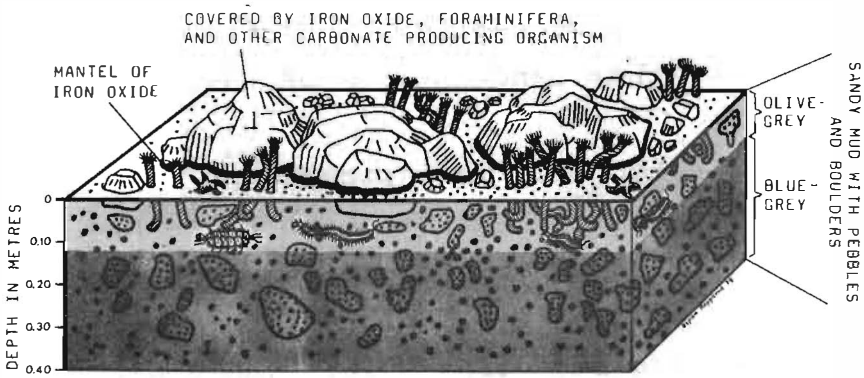

Fig. 4. Diagrammatic section of the bottom sediments east and south of Hopen (water depth 200-400 m). Big boulders are partly exposed and gravel and pebbles form a lag deposit on the sea floor. The upper 10-15 cm is burrowed by polychaeta (Sedentaria and Errantia). The Errantia rework the sediments effectively.

sediment or debris produced in situ. A combination of the two possibilities is also conceivable.

3.3. Geotechnical tests.

According to the shear strength the sediments can be classified into three groups: 1. firm pebbly mud on the upper slope of the Spitsbergen Bank and shallow areas; 2. soft mud with scattered pebbles in Bjørnøyrenna; and 3. bioturbated, fine-grained olive-grey mud from Bjørnøyrenna and the slope of the bank (Fig. 5). (The pebbly olive grey bioturbated mud from the slope is omitted from this classification as it could not be adequately geotechnically tested.)

Geotechnical investigations on glacial sediments on the Norwegian continental shelf show shear strength values of 2 - >30 t/m^2 for tills, while for glacio-marine deposits the values are 0.5 - 2 t/m^2 (ROKOENGEN et al. 1979). The values for the firm pebbly mud is within the lower limit of till, but is clearly over-consolidated. The soft blue-grey mud from Bjørnøyrenna shows on the other hand no sign of having been loaded.

The olive-grey top unit in Bjørnøyrenna shows somewhat higher values of shear strength than the underlying unit (Fig. 5). This may be explained by the higher content of coarse silt in the top unit than in the underlying blue-grey unit. The upward increasing shear strength in the top unit itself may similarly be related to a progressively higher fraction of coarser silt in the uppermost part of the olive-grey unit (Fig. 3). In addition intensive bioturbation may strongly influence the shear strength according to RICHARDS and PARK (1976). The observed values may therefore differ from what would have been found in a non-bioturbated sediment.

	FINE-GRAINED OLIVE-GREY MUD		SOFT BLUE-GREY MUD WITH SCATTERED PEBBLES	FIRM PEBBLY MUD
	0 - 20 CM	>20 CM		
SHEAR STRENGTH T/M²	0.8 - 1.2	0.5 - 0.7	0.3 - 0.5	4 - 6
WATER CONTENT %	70 - 75	70 - 75	35 - 50	15 - 20

Fig. 5. Comparison of shear strength values (measured on undisturbed samples by cone) and water content from the different lithologies in selected samples. Note the increasing shear strength in the bioturbated top unit.

3.4. Sediment distribution.

The sediment distribution is summarized in a block diagram (Fig. 6). The thickness of the different units is listed, based on sediment sampling and shallow seismic records (KRISTOFFERSEN and ELVERHØI in prep.). The sediments on the slope are usually too thin to be detected on the seismic records (1 KJ sparker). Thus, the firm blue-grey pebbly mud may be even thinner than stated in Fig. 6. The continuation of the soft blue-grey mud upslope is difficult to follow due to the intensive bioturbation, but this unit seems to pinch out in water depths of 150-200 m. On the slope the soft blue-grey unit is more coarse-grained than in Bjørnøyrenna. (Note that in Fig. 6 the bioturbated uppermost part of the sediments with the characteristic olive-grey colour is drawn separately.)

In some parts, at intermediate water depths on the slope, fine-grained olive-grey mud was recovered. The estimated thickness of the sediments in the shallowest areas are based on the sampled values.

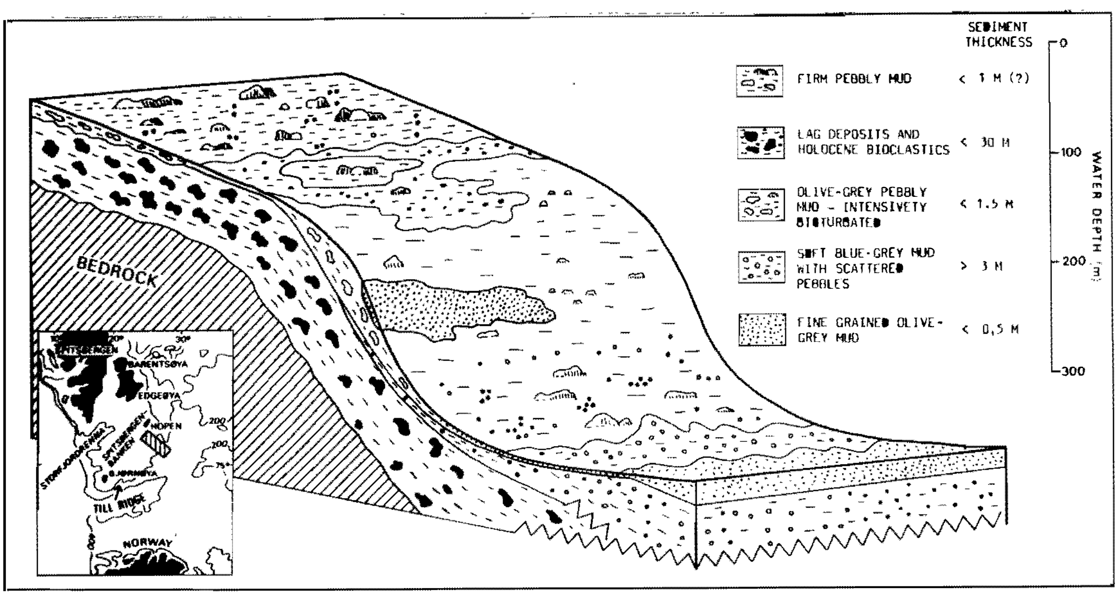

Fig. 6. Block diagram showing the sediment distribution with tentative thickness on the slope of the Spitsbergen-banken, south of Hopen.

3.5. Sediment source.

Mainly sand- and siltstones and shales are characteristic for the Mesozoic rock sequences in the Svalbard area. Hopen consists of Triassic rocks, which also occur above the Upper Palaeozoic sequence on Bjørnøya. Based on palaeogeographical investigations from Svalbard and on seismic investigations in the Barents Sea, Mesozoic rocks are believed to floor the Barents Sea (FREBOLD 1951; ELDHOLM and TALWANI 1977; HINZ and SCHLÜTER 1978). Mineralogical and geochemical data from both clasts and sediments in the northwestern part of the Barents Sea show a close relationship to the Mesozoic rocks in Svalbard (EDWARDS 1975; BJØRLYKKE and ELVERHØI 1975; BJØRLYKKE et al. 1978). Characteristic clasts on the Spitsbergenbanken are black shale of probable Jurassic/Lower Cretaceous age (NAGY 1973) whose mineralogy is quite similar to that of the bottom sediments in the Spitsbergenbanken area (BJØRLYKKE and ELVERHØI 1975). The same mineralogical assemblage is also found in both the clasts and sediments studied in this paper (Figs. 7 and 8). Based on the assumption that Mesozoic rocks floor the Barents Sea, it is reasonable to suggest that the provenance of the sediments investigated is the Barents Sea region itself, including the Svalbard area. A southern source is not likely as no granitic/gneissic fragments or minerals representing the Fennoscandian shield have been found.

4. FORAMINIFERAL ZONATION

4.1. Bjørnøyrenna.

Two different foraminiferal zones were found in cores 27/58 and 27/62 from Bjørnøyrenna at water depths of about 400 m (Fig. 9).

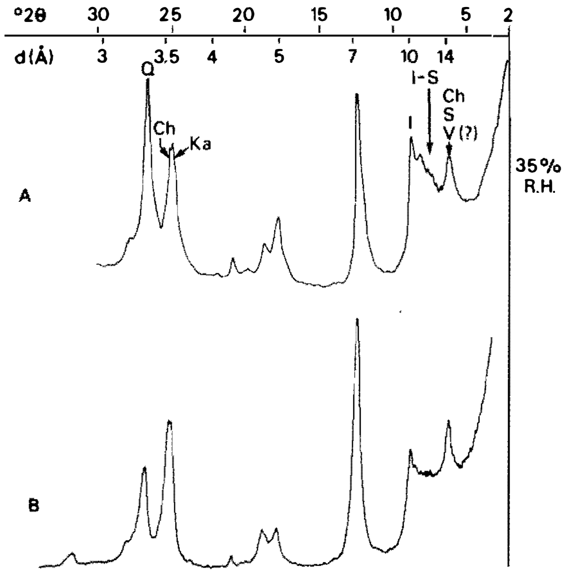

Fig. 7. X-ray diffraction analyses of black shale clasts from Spitsbergenbanken (A) and Bjørnøyrenna east of Hopen (B). (Sample No. 27-62)

A: From BJØRLYKKE and ELVERHØI 1975.

Q = quartz
Ch = chlorite
Ka = kaolinite
I = illite
I-S = mixed layer of illite and smectite
S = smectite
V = vermiculite

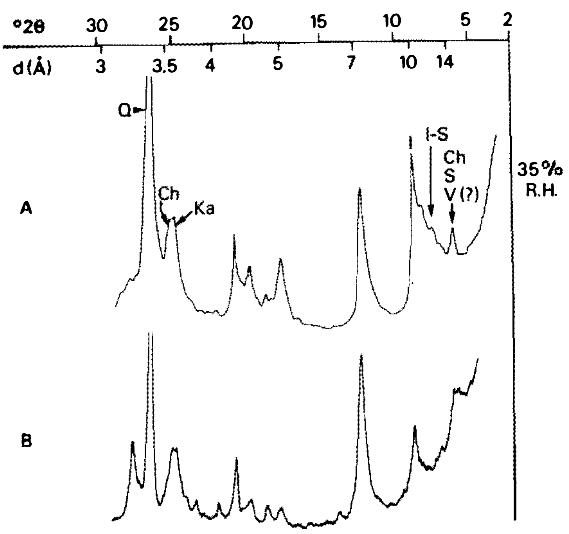

Fig. 8. Representative X-ray diffraction analyses of clay fraction from the western Barents Sea (A) and from Bjørnøyrenna southeast of Hopen (B).

A: From BJØRLYKKE and ELVERHØI 1975.

For explanation, see Fig. 7.

The *Elphidium excavatum - Cassidulina crassa* zone is the deepest in the cores. It is strongly dominated by *Elphidium excavatum forma clavata,* while *Cassidulina crassa* is abundant. *Cassidulina laevigata, Nonion barleeanum, Cibicides lobatulus, Islandiella norcrossi, Buccella frigida,* and *Elphidium frigidum* account for 2-10 per cent of the fauna in this zone. Faunal diversity (WALTON 1964) is relatively low (5-9) and there are few specimens per 100 g sediment. Planktonic specimens account for less than 10 per cent of the total planktonic and benthonic foraminiferal fauna.

Fauna zones very similar to the *Elphidium excavatum - Cassidulina crassa* zone, with its strong dominance of one species, are well known from late glacial deposits elsewhere in Scandinavia (FEYLING-HANSSEN 1954,1964; FEYLING-HANSSEN et al 1971; FÄLT 1977). The faunal diversity of 5-9 with many infrequent species and some planktonic specimens, testifies to the influx of normal marine sea water, but the strong dominance of *Elphidium excavata forma clavata* gives evidence of restricted living conditions for foraminifera.

The *Elphidium excavatum - Cassidulina crassa* zone coincides with the blue-grey pebbly mud. The same fauna is found in the western part of Bjørnøyrenna (LORANGE 1977) beneath a Holocene top fauna.

The *Nonion barleeanum - Cassidulina laevigata* zone occupies the upper 30-40 cm of the sediment (Fig. 9) in Bjørnøyrenna. *Nonion barleeanum, Cassidulina laevigata,* and *Cassidulina crassa* each accounts for 15-30 per cent of the fauna. *Cibicides lobatulus, Islandiella norcrossi, Buccella frigida, Elphidium excavatum forma clavata, Nonion labradoricum, Trifarina fluens, Pullenia osloensis, Astrononion gallowayi,* and *Elphidium frigidum* are each represented with 2-12 per cent of the fauna. Planktonic specimens account for more than 20 per cent of the total fauna. There is a high faunal diversity (13-17) and a high number of specimens per 100 g sediment. The sediment

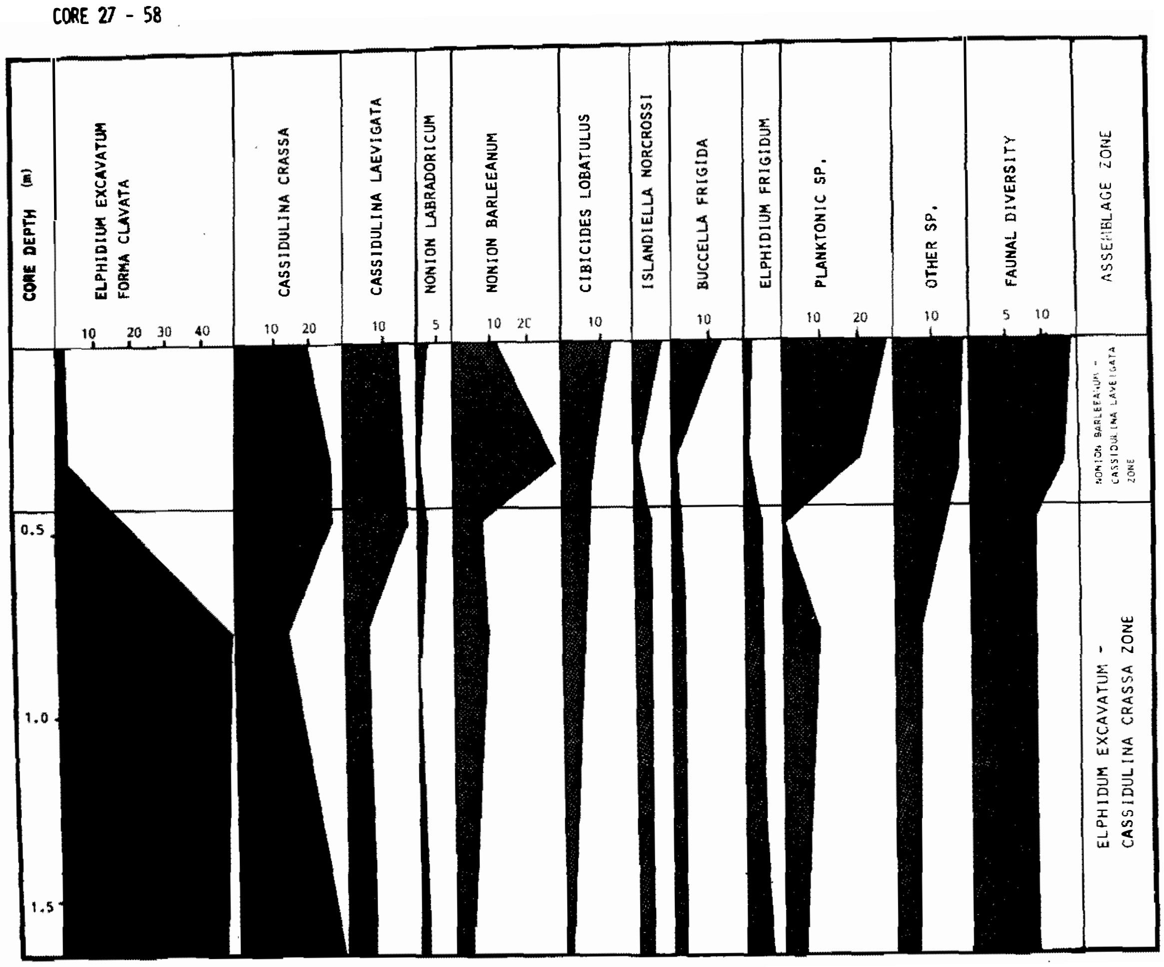

Fig. 9. Foraminiferal fauna in core 27-58. Benthonic species occurring with frequencies of more than 2 per cent of the benthonic fauna in any sample are presented separately. Other infrequent species are presented together in one column. Planktonic specimens in per cent of the total number planktonic and benthonic specimens counted, are shown in one column. The faunal diversity is given according to WALTON (1964).

is also rich in sponge spicules. The sponges need very low sedimentation rates for their existence.

We suppose that the *Nonion barleeanum - Cassidulina laevigata* zone reflects the present conditions in Bjørnøyrenna. The fauna gives evidence of similar conditions in the deeper part of Bjørnøyrenna throughout the Holocene.

In the western part of Bjørnøyrenna, LORANGE and NAGY (in prep.) found a quite similar Holocene fauna, but the relative representation of the different species is different. The Holocene top layer seems to cover the sea bottom in Bjørnøyrenna as a thin blanket.

The upper 30 cm of core 76/3 shows a remarkable faunal similarity to the fauna in the *Nonion barleeanum - Cassidulina laevigata* zone (Figs. 9 and 10) in Bjørnøyrenna.

A C^{14} dating on *Astarte* sp. found in core 76/3, 19 cm from the top, gave an age of 7230 $\pm$340 years BP (T-3333) which clearly gives the *Nonion barleeanum - Cassidulina laevigata* zone a Holocene age.

In the lower part of the core the fauna was quite identical to the fauna in the *Elphidium excavatum - Cassidulina crassa* zone in Bjørnøyrenna (Figs. 9 and 10). These two areas must have had the same depositional conditions in the Late Weichselian.

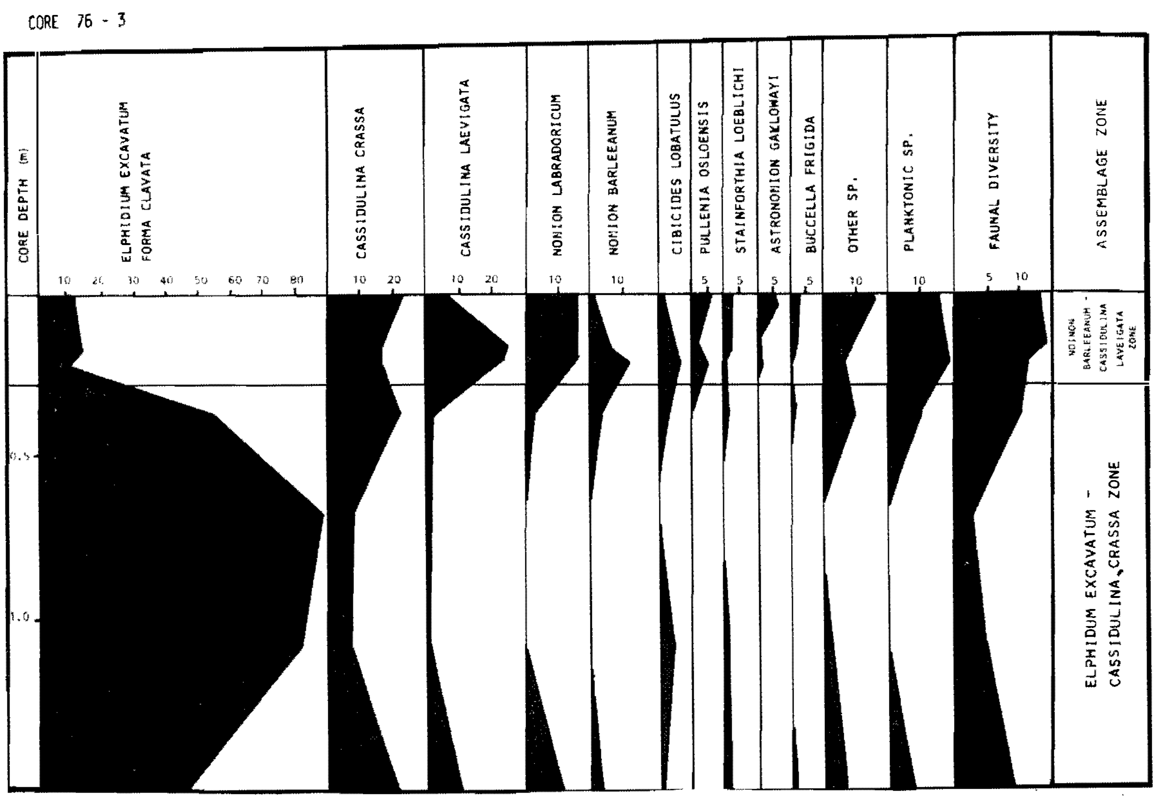

Fig. 10. Foraminiferal fauna in core 76-3. For explanation, see Fig. 9.

4.2. The south slope of Spitsbergenbanken.

On the south slope of Spitsbergenbanken, in about 200 m water depth, one foraminiferal zone - the *Nonion barleeanum - Cassidulina laevigata* zone - (Fig. 11) was found in the entire length of the cores (75/6, 75/7, and 27/92).

The deepest part of the cores where pebbly mud is reported (ELVERHØI 1978), has unfortunately not been available for this investigation.

Planktonic specimens are more unusual in the slope fauna than in the Bjørnøyrenna fauna. This is explained by the northeasterly input of polar water across the Spitsbergenbanken turning westwards along the south slope of the bank (HANSEN 1936). The *Nonion barleeanum - Cassidulina laevigata* zone on the slope is identical to what has been found in the Holocene sediments in Bjørnøyrenna. Accordingly, this zone on the slope also represents Holocene deposition.

4.3. Spitsbergenbanken.

On Spitsbergenbanken, at water depths less than about 160 m, another foraminiferal zone was found in cores 24/35 and 28/3. In the *Cibicides lobatulus - Cassidulina crassa* zone, *Cibicides lobatulus* is the dominanting species, with *Cassidulina crassa* next in frequency (Fig. 11). *Elphidium excavatum forma clavata, Buccella frigida,* and *Elphidium frigidum* are other frequent species, while *Cassidulina laevigata, Nonion barleeanum, Nonion labradoricum, Islandiella norcrossi, Trifarina fluens, Stainforthia loeblichi,* and *Astrononion gallowayi* are common. Planktonic specimens count for less than 3 per cent of the total fauna. The faunal diversity is 13-14 at the top of the cores, falling to 9-10 at the bottom. For the most common species, however, the fauna is very homogenous throughout the cores.

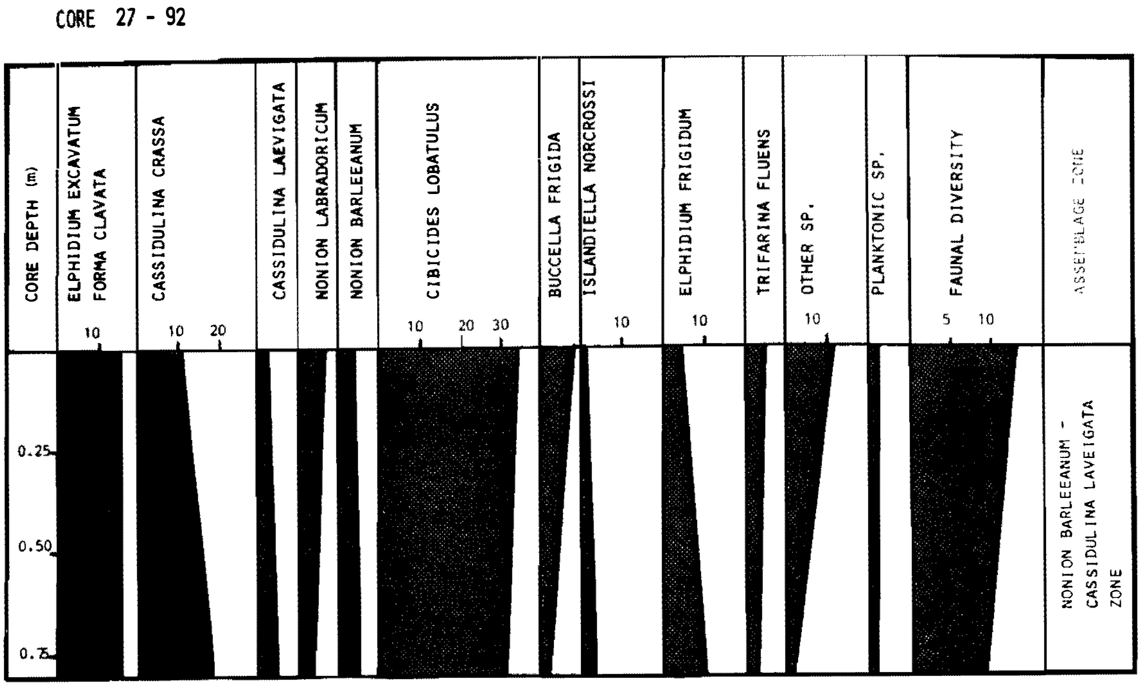

Fig. 11. Foraminiferal fauna in core 27-92. For explanation, see Fig. 9.

A C^{14} dating of *Astarte* sp. in core 24/35 at 11 cm core depth gave an age of 4210 ±330 years BP (T-3396). This gives clear evidence that also the *Cibicides lobatulus - Cassidulina crassa* zone is of Holocene age.

In this zone *Nonion barleeanum* and *Cassidulina laevigata* (FEYLING-HANSSEN et al. 1971; LORANGE 1971) are more scarce than in the Holocene zones in deeper parts of Bjørnøyrenna. Simultaneously, the hard bottom species *Cibicides lobatulus* (MURRAY 1971) becomes dominating. This reflects the coarser bottom sediments and reduced influence of warm bottom water from the Norwegian Sea. A fauna reflecting the same hard bottom conditions was also found in the western part of Spitsbergenbanken by LORANGE (1977).

In Fig. 13 the foraminiferal zones are summarized in a profile across the Spitsbergenbanken from Bjørnøyrenna to Storfjordrenna. The two upper zones are both dated (direct and in correlation) to be of Holocene age, while below this unit there is a glacially influenced foraminiferal fauna. The fine-grained sediments thus represent Holocene deposits. The foraminiferal fauna of Holocene age in the deposits on the slope is, however, not primary, but is suggested to have been mixed in by the bioturbation. The foraminifera in the soft blue-grey mud has not been dated, but the assemblage indicates a glacial depositional environment.

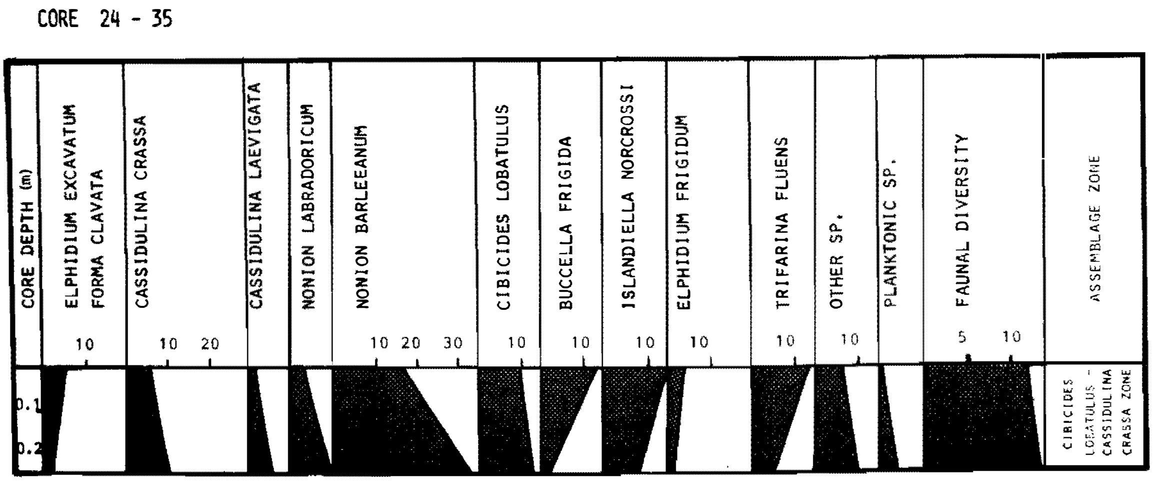

Fig. 12. Foraminiferal fauna in core 24-35. For explanation, see Fig. 9.

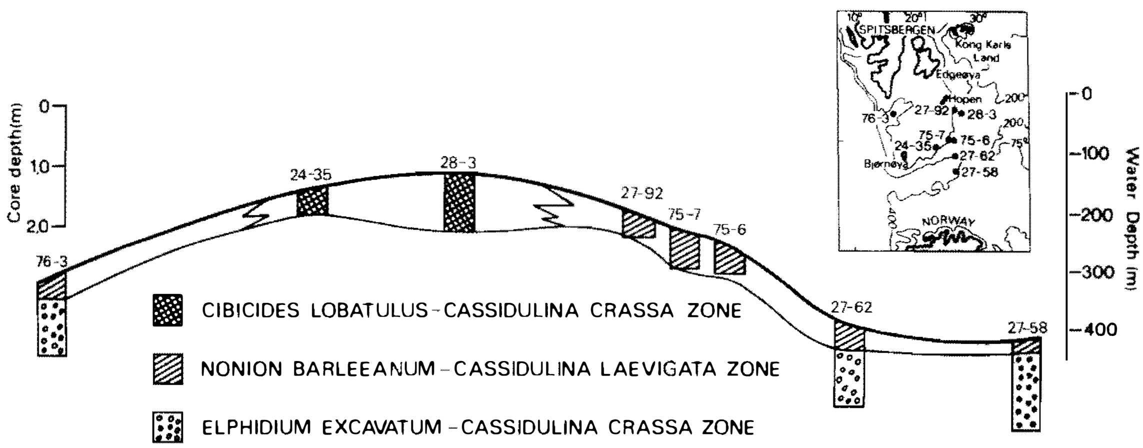

Fig. 13. A profile of the foraminiferal assemblage zones across Spitsbergenbanken from Bjørnøyrenna to Storfjordrenna.

5. DEPOSITIONAL ENVIRONMENT

When combining the environmental information of the foraminiferal fauna (Fig. 13) with the sediment lithology (Figs. 2, 3, 4, and 5), the following can be stated:

The firm pebbly mud represents deposits whose poorly sorted grain size distribution and overburden indicates a till. The few foraminiferal and bioclastic fragments found in this unit show glacial reworking of former marine or glaciomarine sediments. The soft mud with scattered pebbles is typical for ice drop facies (EDWARDS 1978) and is therefore interpreted as glaciomarine sediments. The dominance of the arctic species *Elphidium excavatum* supports this interpretation.

Bioturbation makes the stratigraphy in the upper half metre of the bottom sediments on the slope difficult to interpret. However, the olive-grey pebbly mud is well defined against the underlying units in the lower part of the bioturbated zone. No significant difference in grain size distribution was observed. It is therefore concluded that the olive-grey pebbly mud is bioturbated underlying till or glaciomarine deposits.

There is a gradual transition from the glaciomarine deposits to the fine-grained olive-grey mud in the cores from Bjørnøyrenna and Storfjordrenna. An increased content of foraminifera, number of species and influx of planktonic species (Figs. 9 and 10) is accompanied by influx of algal debris (THRONDSEN and BJÆRKE in prep.). The paucity of material >63 um and the relatively high content of foraminifera in this olive-grey unit reflect the typical open marine conditions characteristic for that part of the Barents Sea today (LORANGE and NAGY in prep.)

On the lower parts of the slope, a thin lag deposit is common, in some areas also with an iron crust. The fine-grained olive-grey unit has been found farther up the slope, while lag deposits mixed with Holocene bioclasts floor the sea bottom above 150 m depths.

To summarize the depositional environment it is concluded that deposition of the till on the shallow bank and the slope was followed by glaciomarine sedimentation. Only <1 m of glaciomarine sediments was deposited on the slope, while far thicker deposits seem to be present within Bjørnøyrenna. This upslope thinning of the glaciomarine unit suggests a time-transgressive development. The glacial and glaciomarine sedimentation was followed by winnowing and deposition of fine-grained sediments in the deepest areas and in local depressions of the slope. Pre-Holocene erosional episodes in the central part of Bjørnøyrenna are excluded due to the absence of a lag deposit below the Holocene top unit.

6. PROBABLE DISTRIBUTION OF THE ICE COVER IN CENTRAL, WESTERN PARTS OF THE BARENTS SEA IN THE LAST PART OF THE LATE WEICHSELIAN.

6.1. Discussion.

BOULTON, in two recent papers, presented ideas on a non-glaciated Barents Sea during the Late Weichselian (BOULTON 1979 a and b). Essential for his conclusions are: 1) lack of till deposits on the shelf, and 2) the presence of extensive glaciomarine sediments in the Barents Sea.

We hope to have disproved the first argument with the present data on the firm, pebbly mud, On the other hand, we fully agree with BOULTON on his conclusion on the extensive cover of glaciomarine deposits in the western Barents Sea. However, the onlapping pattern of the glaciomarine unit above the underlying overconsolidated till and pinching-out upslope (Fig. 6), strongly suggests a time-transgressive depositional system. We thus interpret the sediment record to represent a glacial phase of till deposition on the slope with contemporaneous glaciomarine sedimentation in Bjørnøyrenna. The thin cover of glaciomarine deposits on the slope is further suggested to have been deposited during the withdrawal of the ice sheet.

Sparker data seem to indicate that the glaciomarine sediments continue farther out in Bjørnøyrenna (KRISTOFFERSEN and ELVERHØI in prep.). This is not in agreement with GROSSWALD's concept of complete ice cover in the Barents Sea during the Late Weichselian.

6.2. Depositional chronology.

Absolute C^{14} dating of the glacial sediments is impossible because of insufficient material. Nevertheless, a tentative depositional chronology will be presented based on bivalve dating from Storfjordrenna and sediment stratigraphy combined with recent information on raised beaches in Svalbard.

Dating of raised beaches on Nordaustlandet shows Holocene isostatic uplift of 70-80 m, indicating a Late Weichselian glacial loading (SALVIGSEN 1978). Dating of raised shorelines on Kong Karls Land (Fig. 1) shows at least 100 m Holocene uplift, and a Late Weichselian age for this ice cover has also been suggested by SALVIGSEN (in press). Holocene isostatic uplift of at least 50 m is also observed on the Hopen island (HOPPE et al.1969).

It is reasonable to assume from the magnitude of the isostatic uplift in the area that an ice sheet extended for a great distance across the surrounding shelf. From Kong Karls Land down to the northern part of Bjørnøyrenna - a distance of 200 km, with quite level topography (Fig. 2), represents no barrier for an ice sheet.

Overconsolidated till has been found as a continuous unit on the slope both westward along Spitsbergenbanken down to Bjørnøyrenna and northwestward into the central Barents Sea (Figs. 2 and 6). This till has also been found to continue up to Hopen (Fig. 6; see also BJØRLYKKE et al. 1978).

As shown from all the islands in the eastern part of the Svalbard area, a considerable Holocene uplift has been observed. We therefore suggest that the overconsolidated till represents a Late Weichselian ice sheet which covered the central Barents Sea and extended westward onto Spitsbergenbanken.

An estimate of the extent of this ice sheet shortly before its break-up may be obtained by investigating the distribution of glaciomarine sediments. In Bjørnøyrenna itself only glaciomarine sediments were recovered. The remarkable thinning of the glaciomarine unit upslope starts at 325-300 m water depth (Fig. 6) which coincides with the level of a till ridge at the mouth of Leirdjupet, southeast of Bjørnøya (Fig. 6) (ELVERHØI and KRISTOFFERSEN 1978b). This ridge and the facies distribution along the slope in similar water depths are interpreted to indicate the outline of the latest ice sheet in the central western Barents Sea.

Core 76/3 in the outer part of Storfjordrenna (Fig. 2) lends support to the idea that a change from a glaciomarine environment to the present open marine conditions took place towards the end of the Late Weichselian. C^{14} dating of *Astarte* sp. 20 cm below the surface in the olive grey unit, gave an age of 7230 $\pm$340 BP (T-3333). This section represents the upper two-thirds of the olive-grey unit. Using this sedimentation rate (3 cm/1000Y) for the upper part of the olive-grey unit as a first approximation, the transition to the underlying glaciomarine deposits 30-35 cm downcore, corresponds to the end of the Late Weichselian (10-12,000 BP).

In our model, Bjørnøyrenna is a calving bay for a grounded Late Weichselian ice sheet in the shallower part of the Barents Sea. Similarly, the glaciomarine sediments underlying the Holocene sediments in Storfjordrenna, indicate that Storfjordrenna also was a calving bay.

6.3. Summary and final remarks.

A depositional history of the central, western part of the Barents Sea at the end of the Late Weichselian (10-13,000 years BP) may be summarized as follows:

1. A grounded ice sheet covered the shallower parts of the Barents Sea, extending down to approximately the present 300-325 m water depths in places.
2. Glaciomarine sediments were deposited in Bjørnøyrenna at this time.
3. During withdrawal of the ice sheet, glaciomarine sediments were also deposited on the lower parts of the slope of Spitsbergenbanken towards Bjørnøyrenna.
4. A Late Weichselian glacial sedimentary environment was followed by open marine conditions, characterized by winnowing and intensive bioturbation of the uppermost 0.5 m of the glacial and glaciomarine bottom sediments on the shallow bank areas.

The depositional history outlined in this paper has not solved the mystery of the Barents Sea glaciation, but we hope to have presented data and ideas which will stimulate further research on the problem.

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REFERENCES

BISCAYE, P.H., 1964: Distinction between kaolinite and chlorite in recent sediments by X-ray identification. *Am. Mineral.* 49 : 1281-1289.

BJØRLYKKE, K. and A. ELVERHØI, 1975: Reworking of Mesozoic clayey material in the north-western part of the Barents Sea. *Marine Geology* 18 :29-34.

BJØRLYKKE, K., B. BUE, and A. ELVERHØI, 1978: Quaternary sediments in the northwestern part of the Barents Sea and their relation to the underlying Mesozoic bedrock. *Sedimentology* 25 :227-246.

BOULTON, G.S., 1979a: A model of Weichselian glacier variation in the north Atlantic region. *Boreas* 8 :373-395.

1979b: Glacial history of the Spitsbergen archipelago and the problem of a Barents Shelf ice sheet. *Boreas* 8 :31-57.

EDWARDS, M.B., 1975: Gravel fraction on the Spitsbergen Bank, NW Barents Shelf. *Norges geol. unders.* 316 :205-217.

1978: Glacial environments. Pp. 416-438 in: *Sedimentary Environments and Facies*. Blackwell Scientific Publ., London.

ELDHOLM, O. and M. TALWANI, 1977: The sediment distribution and structural framework of the Barents Sea. *Bull. Geol. Soc. Am.* 88 :1015-1029.

ELVERHØI, A., 1978: *Feltrapport, Maringeologisk tokt øst-sydøst av Hopen.* Norsk Polarinstitutt. 23 pp.

ELVERHØI, A. and Y. KRISTOFFERSEN, 1978a: Glacial deposits south-east of Bjørnøya, northwestern part of Barents Sea. *Norsk Polarinstitutt Årbok* 1977 :209-215.

1978b: Holocene sedimentation on the shelf around Bjørnøya, northwestern part of the Barents Sea. *Norsk Polarinstitutt Årbok* 1977 :199-207.

ELVERHØI, A. and T.M. RØNNINGSLAND, 1978: Semiquantitative calculation of the relative amounts of kaolinite and chlorite by X-ray diffraction. *Marine Geol.* 27 :M19-M23.

FEYLING-HANSSEN, R.W., 1964: The stratigraphic position of the quick clay at Bekkelaget, Oslo. *Norges Geol.Tidsskr.* 33 :185-196.

\- 1964: Foraminifera in Late Quaternary deposits from the Oslofjord area. *Norges geol. unders.* 225 :1-383.

\- 1972: The foraminifer *Elphidium excavatum* (TERQUEM) and its variant forms. *Micropaleontology* 18 :337-354.

FEYLING-HANSSEN, R.W., J.A. JØRGENSEN, K.L. KNUDSEN, and A.-L.L. ANDERSEN, 1971: Late Quaternary foraminifera from Vendsyssel, Denmark and Sandnes, Norway. *Bull. Geol. Soc. Denmark* 21(2-3) :67-317.

FREBOLD, H., 1951: Geologie des Barentsschelfes. *Abh. der Akad. Wiss. Berlin, Kl. Math. allg. Naturiss.* 5 :1-50.

FÄLT, L.M., 1977: Gränsen Pleistocen Holocen i marina sediment utanför svenska västkusten. *Chalmers Tekn. Högsk., Göteborgs Univ., Geol. Inst., Publ. A.* 14 :1-39.

GROSSWALD, M.G., 1980: Late Weichselian ice sheet of northern Eurasia. *Quaternary Research* 13 :1-32.

HANSEN, W., 1936: Die strömungen im Barents Meer im Sommer 1927. *Aus d. Arch., Dtsch Seew.* 55(5) :1-4.

HINZ, K. and H.-U. SCHLÜTER, 1978: The geological structure of the western Barents Sea. *Marine Geol.* 26 :199-230.

HOPPE, G., A. SCHYTT, A. HÄGGBLOM, and H. ØSTERHOLM, 1969: The glacial history of Hopen. *Geogr. Annlr.* 5 (ser.A,4) :185-192.

KRISTOFFERSEN, Y. and A. ELVERHØI, (in prep.): The distribution of Quaternary sediments in the northwestern part of the Barents Shelf.

LORANGE, K., 1977: *En mikropaleontologisk undersøkelse av kvartære sedimenter i nordvestre del av Barentshavet.* Univ. Oslo, cand.real. thesis. 237 pp. Unpubl.

LORANGE, K. and J. NAGY, (in prep.): Foraminiferal distribution in Quaternary sediments in the Western Barents Sea.

MATISOV, G.C., 1977: Bottom geomorphology and the problem of Pleistocene glaciation of the Barents Sea shelf (in Russian). *Gemorfologija* 2 :91-98. Moscow.

MURRAY, J.W., 1971: An Atlas of British Recent Foraminiferids. *Heinemanns educat. books*, London. 243 pp.

NAGY, J., 1973: Fossilførende blokker av Mesozoisk alder fra Svalbard-banken. *Marin Geologiske Undersøkelser av Barentshavet. Rapport No. 1.* Internal Report N.T.N.T., Cont. Shelf Div.

RICKARDS, A.F. and J. M. PARKS, 1976: Marine Geotechnology: Average Sediment Properties, Selected Literature and Review of Consolidation, Stability, and Bioturbation - Geotechnical Interactions in the Benthic Layer. Pp. 157-181 in: I.N.McCAVE (ed.) *The Benthic Boundary Layer.* Plenum Press, New York.

ROKOENGEN, K., T. BUGGE, T. DEKKO, T. GUNLEIKSRUD, R.L. LIEN, and M. LØFALDLI, 1979: Shallow geology of the continental shelf off North Norway. *POAC 79 Proceedings* 2 :859-876. The University of Trondheim.

SALVIGSEN, O., 1978: Holocene emergence and finds of pumice, whalebones, and driftwood at Svartknausflya, Nordaustlandet. *Norsk Polarinstitutt Årbok* 1977 :217-228.

\- in press: The Weichselian glaciation in Svalbard before 15,000 BP. *Boreas.*

SAMOILOV, YA, V. and A.G. TITOV, 1922: Iron and manganese concretions on the bottom of the Black, Baltic and Barents Seas. *Trudy Geol. i Min. Muzeya Ross. Akad. Nauk.* III. (1917-1918). Petersburg.

THRONDSEN, T. and T. BJÆRKE,(in prep.): Palynodebris analyses of a shallow core from the Barents Sea.

WALTON, W.R., 1964: Recent foraminiferal ecology and paleoecology. Pp. 151-237 in: IMBRIE, J. and N.D. NEWELL (eds.) *Approaches to Paleoecology.* Wiley and Sons, New York.