Sea-floor morphology and Late Quaternary sediments south of the Langesundsfjord, northeastern Skagerrak

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The course of the submarine channel extending from the mouth of the Langesundsfjord into the deeper parts of the Skagerrak is believed to be structurally controlled, following the boundary zone between the Precambrian gneiss complex to the west and the Oslo graben igneous complex to the east. The formation of the channel is believed to be due to glacial erosion, and its resemblance to West-Norwegian fjords is noted.

The sediments of the channel vary in thickness, owing partly to a very irregular basement, but it is suggested that they obtain a maximum thickness of at least 180 m. The sediments can be divided into 4 units, of which all, except the upper, are thought to represent glacial marine sediments. Most of the sediments were probably deposited during the Late Weichselian under more or less ice-proximal conditions, and during the earlier parts of the Holocene.

Core sampling within the channel shows the upper sediments to be homogeneous silty clays, while the upper sediments in the areas outside the channel are heterogeneous glacial marine deposits covered with a thin, greatly re-worked Holocene accumulation, less than 50 cm thick. Winnowing by bottom currents, caused by the intrution of Atlantic water during the deglaciation, is suggested.

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The Norwegian Channel has a feature of special interest in its termination towards the northeast. Here, two submarine canyon-like valleys are seen to extend from the mouths of the Langesundsfjord and Larviksfjord respectively, to the deeper parts of the trough which have depths close to 600 m. These submarine valleys are only inadequately known, and have not been mapped in detail, but have been mentioned by O. Holtedahl (1940, 1956, 1964), who believes they are related to bedrock structure, and later eroded by ice. He also raises the possibility of their origin as pre-Quaternary river-cut valleys on a subsiding floor, subsequently eroded by ice.

To obtain more information on the submarine valleys and their origin, the author carried out bathymetric and seismic investigations in the area south of the Langesundsfjord. Based on shallow cores, the deposition of Late Weichselian-Holocene sediments inside and outside the channel were studied in some detail.

Data aquisition

The field study was carried out on the University of Bergen research vessel 'Håkon Mosby' in 1984.

The survey area (Figs. 1 and 2) extends from the mouth of the Langesundsfjord in the north east to the island Jomfruland in the south. The main purpose of the field investigations was to obtain echo-sounding profiles and sparker profiles across and along the inner part of the submarine Langesund Channel. The geophysical instrumentation consisted of a 12 KHz Simrad Scientific Sounder E. K., a hull-mounted O.R.E. penetration echosounder operated at 3.7 KHz, and a shallow seismic EG & G Sparker system with an energy output of 1 KJ. The data were bandpass filtered (60–600 Hz) and recorded on an analogue recorder.

The sediment samples were collected by gravity corer from the channel, as well as from the surrounding more shallow areas. On land the cores were X-rayed, and grain-size analyses carried out on subsamples by sieving and pipette analysis. Two cores, SK 3 and SK 5, were collected by the author in 1965 and later described by Bøe (1978) in an unpublished cand. real. thesis. The results of litho- and biostratigraphical analyses of these cores have been included. A main purpose of the sediment sampling and sediment analyses was to get information on the lithological character and origin of sediments connected with distinguishable seismic units.

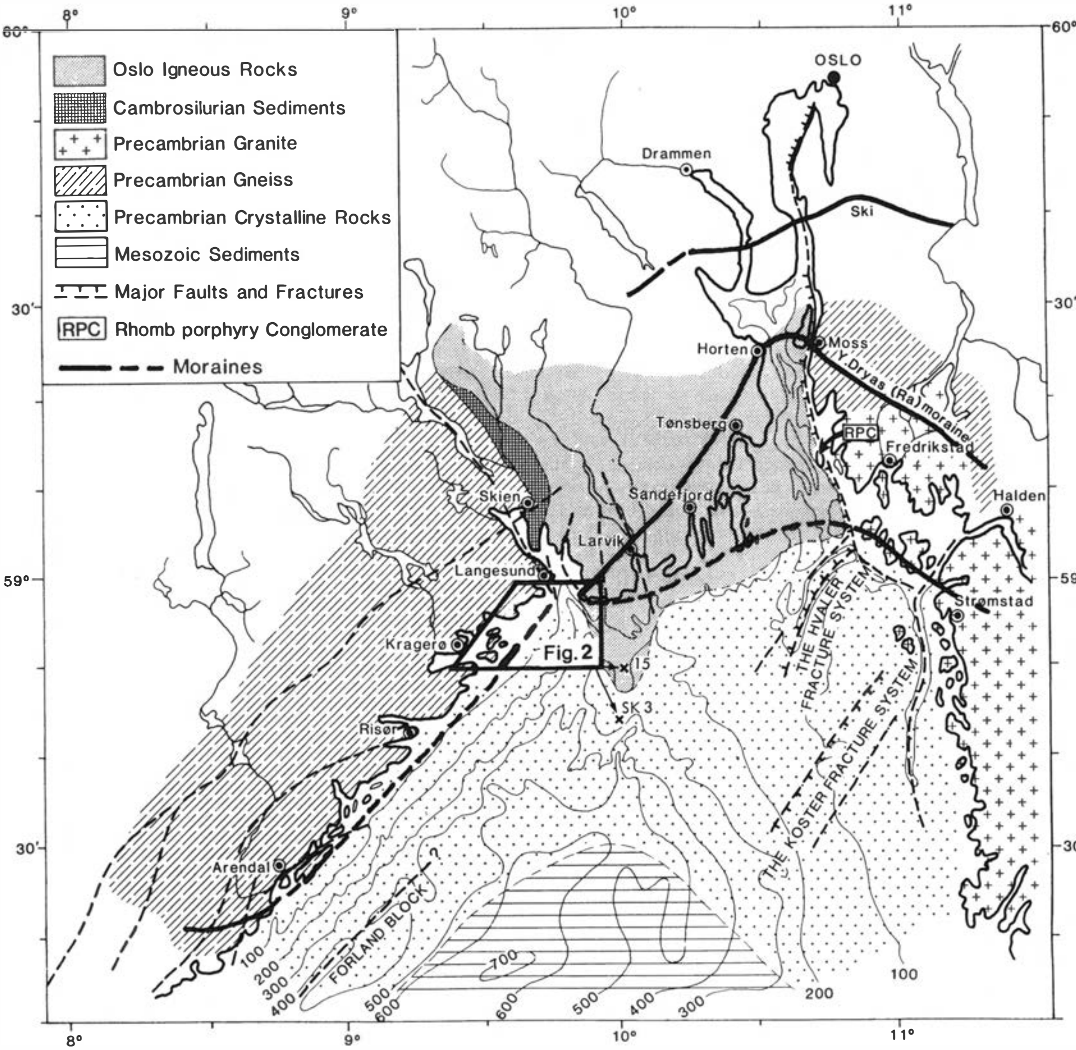


Fig. 1. Main geological features of inner Skagerrak and outer Oslofjord, with area of investigations.

Geological and geomorphological setting

Bedrock geology

Precambrian crystalline rocks of the Kongsberg-Bamble formation are present in a broad belt from the Langesundsfjord and southwestward (Fig. 1). On the east side of the Skagerrak and to the east of a major fault-line along the Oslofjord, Precambrian gneisses occur in the northern part, while granites are present further south.

Between the Precambrian areas, Permo-Carboniferous lavas and intrusive bodies of larvikite occur. A fairly narrow belt with Cambro-Silurian sediments is present from the mouth of the Langesundsfjord and northwards, bounded by the Precambrian gneiss area to the west, and the lavas and intrusives to the east. These rocks show block-faulting and increased tilting towards the larvikite.

Some of the main structural lineaments are shown on the map. In the western Precambrian area there are characteristic maxima in the NE-SW orientation. The eastern Precambrian area is cut by two major tectonic systems expressing NS and NE-SW lineaments, and the Oslo graben and vicinity are characterized by a predomi-

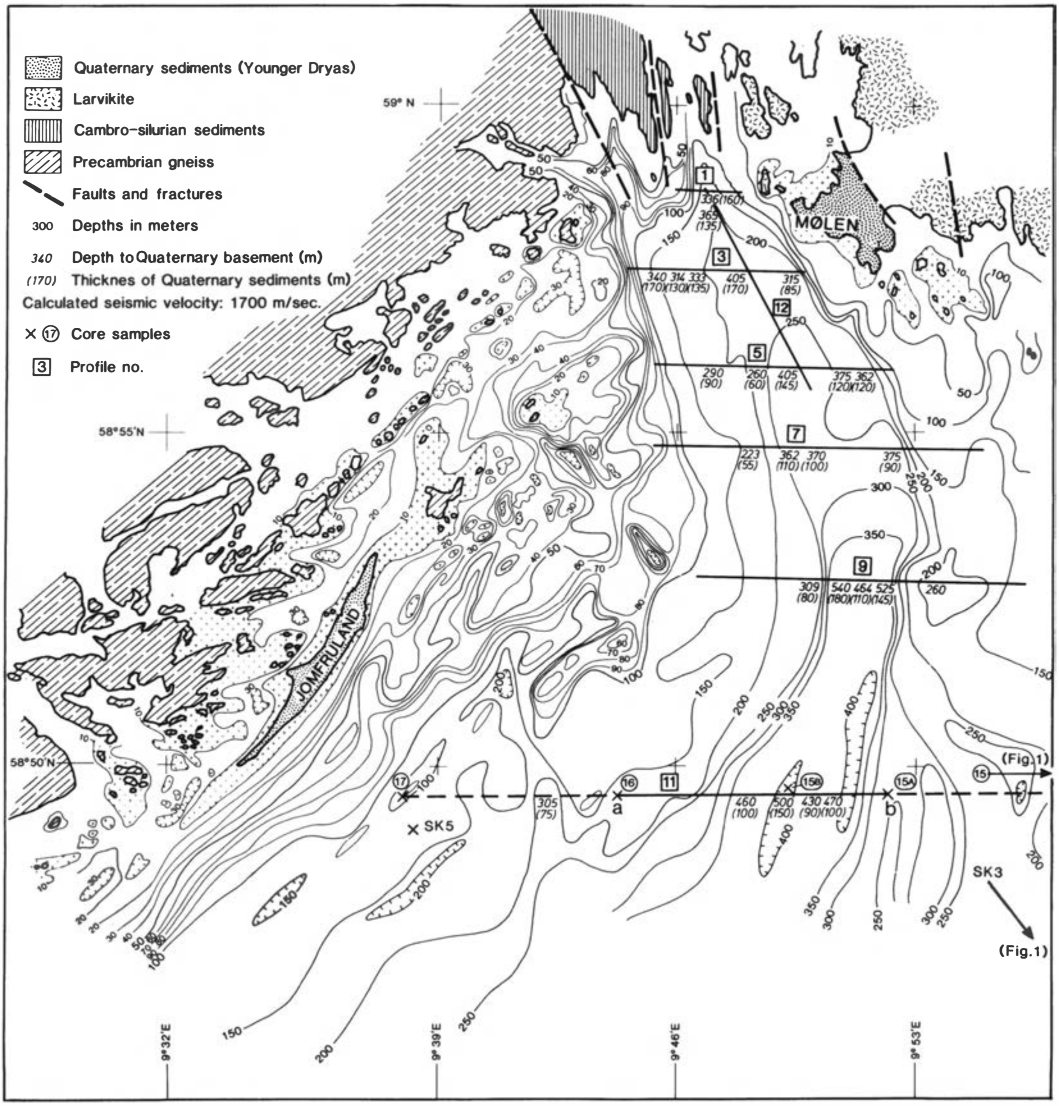


Fig. 2. Inner part of the Langesund Channel. Bathymetry, geology, location of sparker profiles, estimated depth to Quarternary basement, and thickness of Quaternary sediments.

nance of the N-S trend, while NW-SE and NE-SW trends are also seen.

With regard to the bedrock geology of the northern Skagerrak and the outer Oslofjord area, some information has been obtained, especially through geophysical investigations (Sellevoll & Aalstad 1971, Flodén 1973, Ekern 1983 and Solheim & Grønlie 1983). Of special interest is the suggested situation of the western boundary of the submarine igneous rock complex at the eastern sidewall of the submarine Langesund Channel.

The submarine valley system, especially in the outer parts of the Oslofjord and off the Swedish coast, has been explained by various writers as faults and fractures closely connected with tectonic features on land. Their present morphology is, however, supposed to be due largely to ice erosion. The Hvaler fracture system is clearly connected to the Grat Permian Oslofjord fault and shows vertical faulting. The Koster fracture system is likewise followed by vertical faulting.

Quarternary geology

The Quarternary history of the Oslofjord-Skagerrak area is characterized by oscillating ice sheets extending out from ice centres in central parts of Fennoscandia.

During the Late Weichselian the ice margin withdrew from Jutland and was situated close to the Norwegian coast between 14,000 and 13,000 years B.P. The Hvaler islands, with their end moraines, were deglaciated about 12,300 years B.P., and during the Younger Dryas chronozone end moraines (including the Ra) were deposited between 11,000 and 10,600 years B.P. (Andersen 1979, Sørensen 1979). The Ski-moraines further north were formed at about 10,200–10,000 years B.P. There was a convergence of ice masses into the inner Skagerrak-Oslofjord area, and, owing to the glacio-isostatic depression of the crust, there was a maximum inundation of 150 m in the Larvik area, increasing to about 220 m in the Oslo region. During the isostatic rebound and regression of the sea, marine sediments were exposed to wave- and current action, as well as subaerial erosion after emergence.

Bathymetry and origin of channel

Some of the major features of the Langesund Channel are shown on the map (Fig. 2) and the profiles (Figs 3, 4 and 5).

The channel is seen to vary considerably along its course, both in width, depth and general shape. The northernmost transversal profile shows a canyon-like channel, about 2 km broad, with an even sea-floor and an even basement surface. Southwards the channel widens, with a width of about 7 km (profile 7), and has an assymetrical profile, the eastern side wall being steeper than the western. The sea-floor is less even, with varying depths, explained by the irregular basement floor showing a number of ridges and depressions.

Further south (profile 9) the channel is again more narrow, only about 2 km broad. The sides are both fairly steep, ending in shoulders, the western at about 230 m, the eastern at about 200 m depth respectively. The basement of the shoulders is, however, about 100 m deeper on the western than on the eastern side. The main channel has a basement showing two depressions separated by a ridge.

South of profile 9 the channel widens again (profile 11 a–b). The width is about 7 km, and the sea bed is fairly even. The basement is, however, still irregular, with depressions and ridges.

Considering the deepest parts of the sea-floor along the bottom of the channel, there is an increase in depth from about 190 m in profile 1 to 412 m in profile 11. The maximum depth to the basement shows a similar increase from 350 m to about 550 m. The increase in depth is, however, not regular. Bot the sea-bed and the basement surface slope southwards, but depressions and elevations occur along its course.

With regard to the origin of the submarine Langesund Channel, it seems safe to assume that its features are strongly controlled by the lithology and tectonic pattern of the underlying rocks. Its northern part, with a SSE direction, corresponds well to the orientation of faults and fractures on land. The location of the eastern wall seems to coincide with a change in magnetic properties, shown by Sellevoll & Aalstad (1971) and Solheim & Grønlie (1983), suggesting a western boundary of the Oslo igneous rocks. The northern part of the channel is therefore probably situated along the extension of faulted Cambro-Silurian rocks, and bordered to the east by igneous Oslo rocks, probably larvikites.

At the locality of profile 9 there is a change in the channel profile, as well as a directional change to a more N-S trend and then to a NE-SW orientation further out, the latter being a major structural direction of the Precambrian crystalline rocks on land. The widening of the channel between profile 1 and profile 3 can probably be explained by intersection of northeasterly fractures typical of the Precambrian area to the west and more southerly fractures typical of the Oslo area.

The actual process responsible for the formation of the channel is thought to be glacial erosion. The longitudinal as well as transverse profiles show great similarities to profiles taken in fjords, for instance, the outer part of the Hardangerfjord (see Figs 6 and 7 in Holtedahl (1975)). The basement shows troughs and ridges, and there is no regular increase in maximum depths along the channel towards the deeper parts of the Skagerrak.

From the study of glacial erosional forms and deposits we know that great masses of ice converged in the inner part of the Skagerrak. This concentration of ice, and the fact that the ice border during the deglaciation formed a calving front which probably increased the velocity of ice-

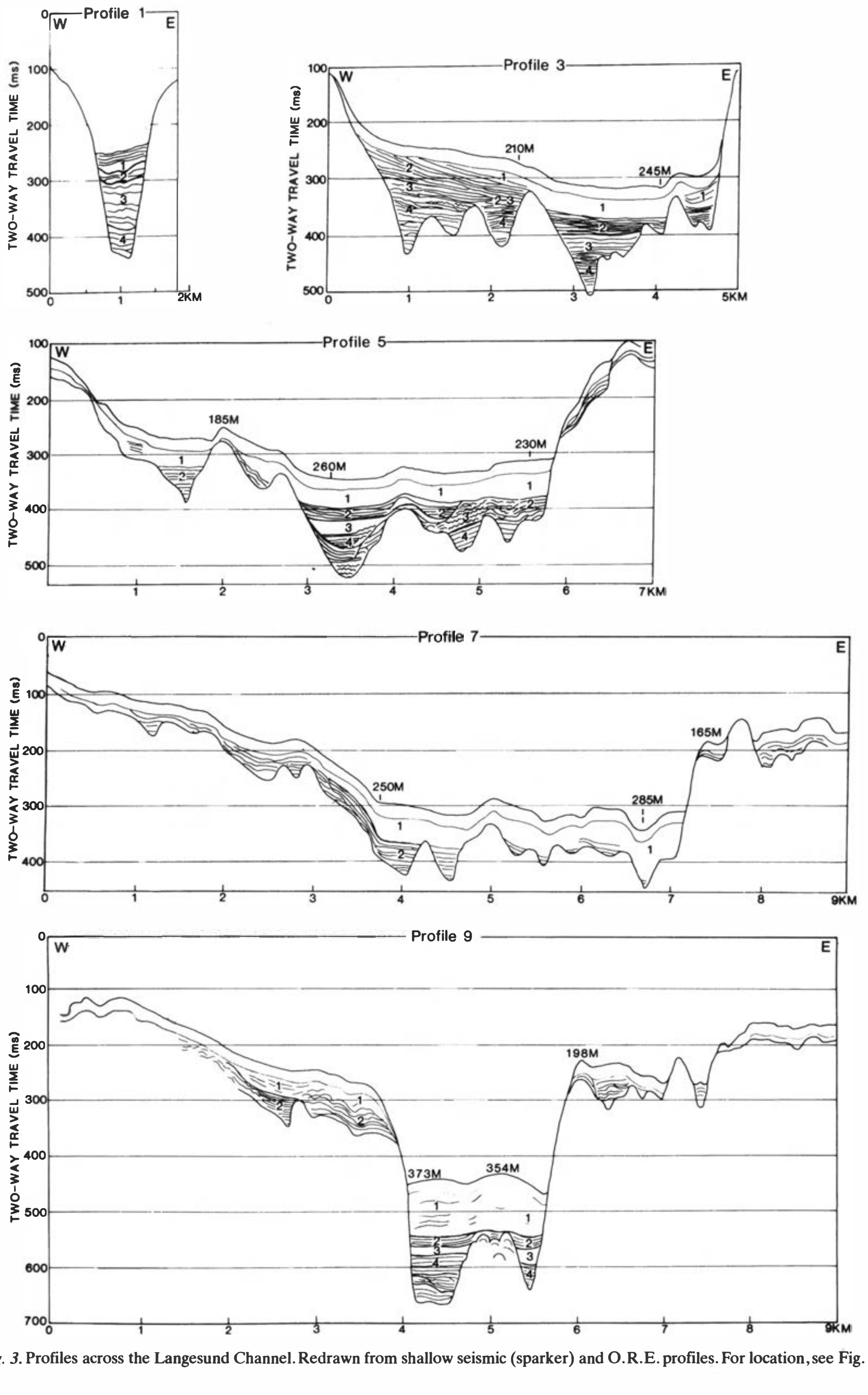


Fig. 3. Profiles across the Langesund Channel. Redrawn from shallow seismic (sparker) and O.R.E. profiles. For location, see Fig. 2.

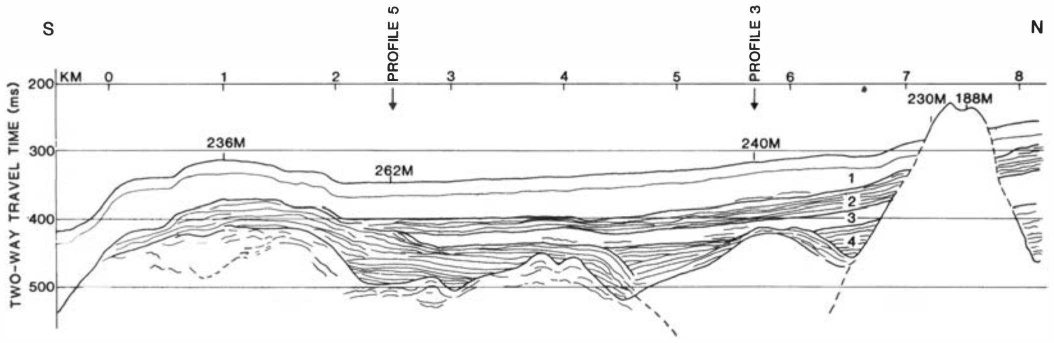


Fig. 4. Longitudinal profile of inner part of the Langesund Channel (profile 12). Redrawn from shallow seismic (sparker) and O.R.E. profiles. For location, see Fig. 2.

streams, probably enhanced the glacial erosional effect. The great ability for selective erosion, which is typical of glaciers, and the very special lithological and structural pattern of the area, were important factors in the formation of the present bathymetry.

Quaternary sediments

The Langesund Channel contains considerable thicknesses of sediments (Figs 3 and 4). The seabed surrounding the channel has a much thinner sediment cover, indicating that the channel has acted as a sediment trap. Sediment thicknesses down to acoustic basements shown in Fig. 2 and in Table 1, are based on sparker profile interpretation using an estimated mean sound velocity of 1700 m/sec. It has been possible to distinguish different acoustic units, which have been asigned numbers from 1 to 4. Because of limited sparker resolution (10–15 m) unit 2 is only apparent in a few profiles, so units 2 and 3 are usually combined in one unit class.

Unit 1 is the uppermost acoustic unit and can be recognized in all profiles. It is acoustically transparent and characterized by lack of internal reflectors. This deposit, which corresponds to unit 1 of Solheim & Grønlie (1983), van Weering et al. (1973), van Weering (1975, 1982) and Stabell et al. (1985), varies somewhat in thickness, with a maximum of about 85 m in profile 9. In profile 3 it is seen to wedge out on the western slope, and in profile 11 the thickness varies a great deal, and decreases towards the eastern channel wall.

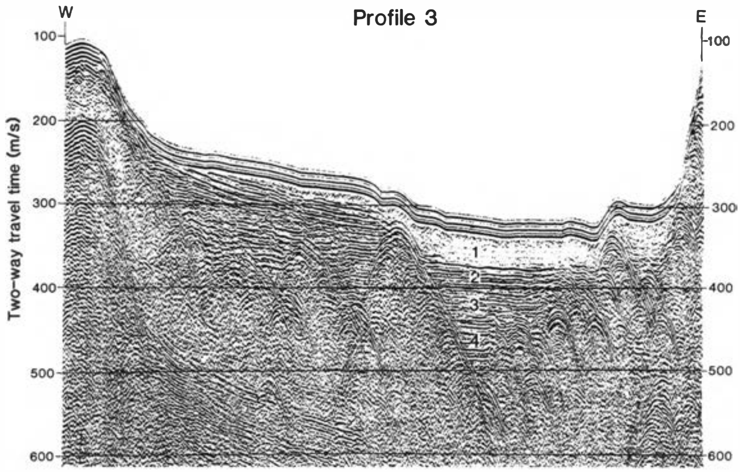
Unit 2 is a sequence with distinct reflectors, attaining a thickness of 40–50 m. In profile 3, strong reflectors within this unit occur on the western side of the channel. The strata slope eastwards towards the deeper parts of the basin and seem to be truncated near the western wall. This unit is also recognized along the full extent of the longitudinal profile, i.e. to the intersection with profile 1.

Unit 3 has less well-defined layering and shows internal diffractions. It is recognizable in profiles 1, 3 (here with more marked reflectors), 5, 9 and 11.

Unit 4, at the base, has strongly reflected layers, but is interrupted by irregular, poorly reflected zones and diffractions.

Table 1. Approximate thickness in m of sediments in the Langesund Channel. Total thickness as well as thickness of the different seismic units has been calculated.

Unit number	Approximate thickness in m (sound vel. 1700 m/sec). Profile number					
	1	3	5	7	9	11 (W–E)
1	30	<20–50	45–60	55–70	85–60	50–70
2+3	60	60	40–20	55–20	25–40	50–60
4	70	90–60	60–40	–	70–30	20
Total:	160	170	145–120	110–90	180–130	100–150



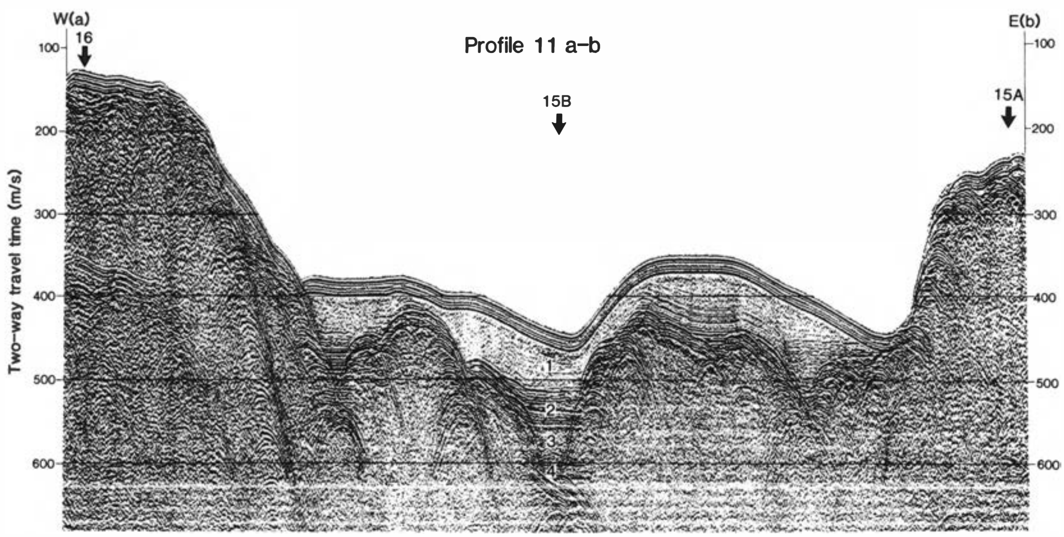


Fig. 5. Sparker profile 3 and 11 a–b. For location see Fig. 2.

Interpretation of acoustic data

The uppermost transparent sediment sequence in the Skagerrak is considered by various authors to represent Holocene, and to some extent also Late Weichselian deposits. The maximum thickness of 85 m, shown in profile 9, is somewhat less than the thickness of similar sediments in the Hvalerdjuppet depression (100 m) on the east side of the outer Oslofjord (Solheim & Grønlie 1983), but somewhat greater than the thickness described from other channels in the Oslofjord area.

In profile 9, comparatively large accumulations (c. 40 m) of unit 1 sediments can be seen on the western shoulder of the basin. This may indicate a high input of sediments from the west, with overflow into the main basin.

The major portion of the sediments of unit 1 was probably deposited during the early stages of the Holocene. From the study of cores (van Weering 1982, Stabell et al. 1985), it was evident that a major change in the depositional environment took place at the end of the Younger Dryas chronozone about 10,000 years B.P., when ice-rafting ceased drastically.

A large amount of sediments came as a result of regression of the sea associated with the glacio-isostatic rebound, following the retreat of the glaciers. This regression favoured winnowing and re-transport of older sediments. Sediment sampling on the submarine Younger Dryas moraine and on its distal slope has shown winnowing to have taken place down to a present depth of 100 m, leaving a coarse lag deposit on the moraine (Holtedahl & Bjerkli 1975).

The sediments of unit 1 in the Langesund Channel are, to a great extent, observed to drape over the subsurface topography, and must therefore have been deposited from suspension. There are, however, examples of this not being the case, e.g. in profile 11 a–b.

Unit 2, with strong and mostly continuous reflectors, very likely represents glacial marine sediments. This sequence is equivalent to van Weering's unit 2 described from the Skagerrak (van Weering et al. 1973, 1982), and unit 2 of Solheim & Grønlie (1983). The change in acoustic character from unit 1 to unit 2, as seen from the seismic profiles, reflects a lithologic change observed in the sediment cores (Stabell et al. 1985). An upper homogeneous clayey sediment is underlain by a more heterogenous sediment, containing sand- and pebble-sized grains characteristic of ice-dropped material. This lithologic boundary has been dated at about 10,000 years B.P.

The Younger Dryas moraine is shown on the maps (Figs 1 and 2) to occur on the Jomfruland island to the west of the Langesund Channel and on the Mølen peninsula at the channel's northeastern end. The submarine continuation of the Jomfruland moraine northeastwards is suggested by the shallow bathymetric trends, but is not clearly exhibited in the bathymetry further north. The ice front must, however, have continued towards the innermost part of the Langesund Channel and then swung eastwards crossing the channel west of Mølen. While the ice front, during the Younger Dryas stage at Jomfruland island, was located about 10 km from the southwestern part of the channel, it must have been situated close to the depression in the more northern parts. In this light it is interesting to observe, in profile 3, a great thickness of unit 2 sediments on the western slope of the channel, with layers sloping eastwards towards the central part of the basin.

The sediments must have been deposited proximally and close to the ice front. On the eastern side of the channel, the ice front was not so close and had a direction away from the channel. This may explain the lack of similar sedimentary features there.

Profile 12 (Fig. 4) illustrates unit 2 sediments clearly. The profile extends to the position of profile 1, which crosses the inner and most narrow part of the channel. As there are no signs of ice-marginal deposits in the channel, the ice front was probably situated further to the north.

The more transparent unit 3 which occurs below unit 2 in profiles 1, 3, 5, 9 and 11 must have been deposited in a different environment. A similarity to unit 1, but with more irregular reflectors, may suggest a less ice-proximal locality, but with intense ice-dropping from floating ice. We know from studies of the Younger Dryas moraine on land that the ice front did oscillate and that structures show an ice advance following a retreat. There is, however little evidence for a major retreat of the ice front during the Allerød chronozone in this area (Sørensen 1979, Mangerud 1980), which would be significant enough to explain the deposition of unit 3.

Another possibility is that unit 3 represents sediments which have been deposited very rapidly during the deglaciation before the halt in the retreat during the Younger Dryas. A transparent layer beneath a strongly stratified layer in the Skagerrak has been observed by van Weering et al. (1973), van Weering (1982), and Stabell et al. (1985). Van Weering is of the opinion that these sediments are of glacial marine and proglacial origin.

Unit 4, which occurs below unit 3, shows strong and continuous reflectors, and is very similar to unit 2. There is no irregular boundary between unit 3 and 4, so there is no reason to correlate unit 4 with van Weering's unit 3, which is thought to represent glacial drift. The sediments of unit 4 are most probably glacial marine, deposited proglacially during the deglaciation.

Sediment samples

Core-sampling was carried out in order to obtain information on the upper sediments of the investigated area. It was of special interest to get samples of sediments which occur stratigraphically below the homogeneous upper acoustic unit 1, where they crop out at the surface. Figs. 1 and 2 show the position of some of these cores, and the

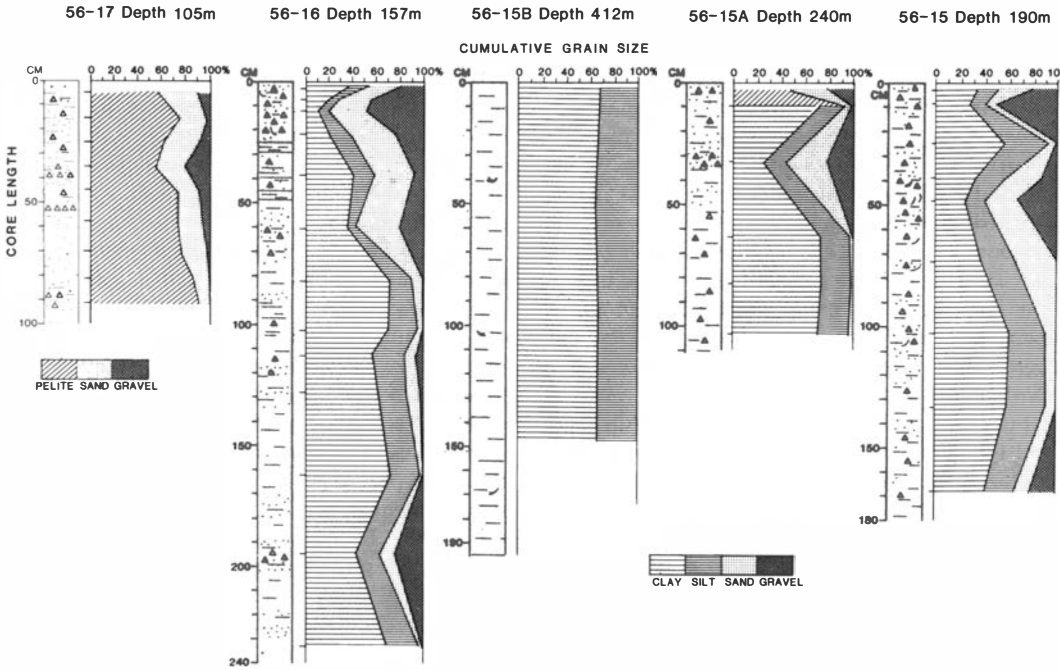


Fig. 6. Lithostratigraphy of cores.

results of a sedimentological analysis are given in Fig. 6.

Description and interpretation of cores 15–17

The sediments of cores 15, 15 A, 16 and 17 consist of olive grey clay and silt with varied amounts of sand and gravel. The sand may appear as isolated layers (15, 15A) with very little fine material, or it may be poorly sorted within clay and silt units. In core 16 sandy laminations occur. The gravel fraction is found either associated with the sand units, or as individual clasts throughout the cores. A number of clasts are dropstones, but structures in the surrounding substrate relating to their deposition were not observed. On some of the clasts, especially the larger ones, glacial striae and polish are observed.

Except for core 15 B, taken in the middle of the submarine valley, the upper 15–20 cm of the cores has a high percentage of coarse material, which probably represents the influence of winnowing, with reworking and sorting of the original material. With regard to the origin of the sampled sediments, all cores, except 15 B, must be regarded as glacial marine sediments, where the material has been derived from glacial meltwater and from floating ice and icebergs. The sediment in core 15 B is clearly younger and postglacial.

Litho- and biostratigraphy of cores Sk5 and Sk3. (Fig. 7)

Core Sk5. Lithostratigraphy. – The sediment of the core below c. 45 cm consists mainly of clayey and silty pelite with a varied mixture of sand and gravel. The upper 126 cm has an olive grey colour, while beneath it is olive black. A sandy, gravelly pelite occurs at 100–110 cm, and a band of pelitic sand at 120 cm. The upper 45 cm of the core shows a coarsening-upward sequence, with an increase in the sand content. The grains of the gravel fraction throughout the core are subangular to subrounded.

These data suggest that the bulk of the core, in any case up to a level of 45 cm below the surface, is a glacial marine sediment.

Biostratigraphy. – From 45 cm and downwards the foraminiferal fauna has low faunal diversity and low total number of species. It is dominated by *Cassidulina reniforme, Elphidium excavatum* and *Nonion labradoricum.* This faunal assemblage along with low faunal diversity indicates a deposition of sediments under arctic marine conditions (van Weering 1982, Feyling-Hanssen 1972, Nagy & Qvale 1985). This conclusion is in full agreement with the lithostratigraphic data.

Above 45 cm there is an increase in faunal diversity and in the total number of species. In the interval 45–30 cm *Cassidulina reniforme, Nonion labradoricum,* and *Elphidium excavatum* are still frequent, as are *Islandiella helenae* (and *I. norcrossi*), which are also regarded as arctic indicators. On the other hand, species like *Bulimina marginata, Hyalinea balthica* and *Cassidulina laevigata* appear, indicating milder conditions. The most significant change in the fauna is found at about 30 cm below the surface. Faunal diversity and total number of species increases, the percentage of *C. reniforme, N. labradoricum, E. excavatum* and *Islandiella helenae (I. norcrossi)* goes down, and there is an increase in the number of boreal forms like *Nonion barleeanum, Cassidulina laevigata, Bulimina marginata, Uvigerina peregrina* and *Trifarina angulosa.* This fauna indicates an environmental change to milder conditions.

As seen from Fig. 7 the main change in fauna coincides with a textural change whereby the sand and gravel content increases towards the surface of the core. As was suggested above, this might indicate increased reworking and redeposition of the glacial marine sediment. If this is true, redeposition and reworking of foraminiferal tests in this part of the core may well have occurred, and this may explain the "tail" of arctic species extending upwards.

Core Sk3. Lithostratigraphy. – The main part of this core is fine and structureless. The lower half can be classified as clay, the upper half, except for the upper 10 cm, as sandy pelite, with a very small admixture of gravel. The upper 10 cm is coarse, and is classified as sandy gravelly pelite. The sediment of this core is much finer than in core Sk5, but does contain a certain amount of sand and gravel which points to glacial marine origin. An exception is the upper 10 cm which is probably reworked.

Biostratigraphy. – From the bottom of the core and up to a level of 15 cm from the surface, the fauna is dominated by *Elphidium excavatum, Nonion labradoricum, Cassidulina reniforme* and *Islandiella helenae* and *I. norcrossi,* i.e. a fauna indicating an arctic environment. Below c. 135 cm *Cassidulina reniforme* dominates, while *Nonion labradoricum* dominates in the section 135–53 cm. In the upper 15 cm there is a decrease in the arctic fauna, and a dominance of boreal-lusitanian forms like *Nonion barleeanum, Cassidulina laevigata, Hyalinea balthica, Bulimina marginata, Uvigerina peregrina* and *Trifarina angulosa.* Faunal diversity and total number of species are higher than below.

There is therefore a very distinct change in the fauna indicating a change in the environment from arctic to boreal. In the core interval 15–53 cm, the faunal diversity is generally low and comparable to values further down in the core. The total number of species shows, however, an increase up to a level of 25 cm. The introduction of *Cassidulina laevigata* and *Bulimina marginata* in the lower part of the interval is an indication of a milder environment, even if the arctic fauna dominates. There is very little evidence in the lithostratigraphy showing the transition from arctic to boreal conditions. The coarse upper 10 cm of the core, with a mainly boreal fauna, are probably due to reworking of a glacial marine sediment, even if this is very poor in coarse material.

Age of the deposits and environmental changes

A chronostratigraphy is suggested, based on biostratigraphic data. The lower parts of the cores, below 45 cm in Sk5, and 25 cm in Sk3 (Bøe's assemblage zones 1, 2 and 3) have a benthic foraminiferal fauna suggesting arctic marine conditions, and can be correlated with zone C of van Weering (1982), the *Cassidulina reniforme* assemblage zone of Nagy and Qvale (1985), and zone D of Fält (1982). Conditions in the sea were heavily influenced by the outflow of glacial meltwater carrying silt and clay in suspension, and by coarse material dropped from drifting icebergs and other forms of floating ice.

The locality of Sk5 is less than 5 km outside the Ra-moraine, and the very coarse texture of this core indicates deposition fairly close to the ice margin. Sk3 is situated about 20 km from the Ramoraine, which may explain its finer texture. The depth of deposition at the time of the Younger Dryas chronozone was about 234 m and 341 m respectively for the locations of Sk5 and Sk3, as the sites are close to the 120 m isobase for the Younger Dryas (Andersen 1960).

In Bøe's zone 4 in Sk5 there is a definite change in the marine environment. The appearance of a temperate fauna including *Bulimina*

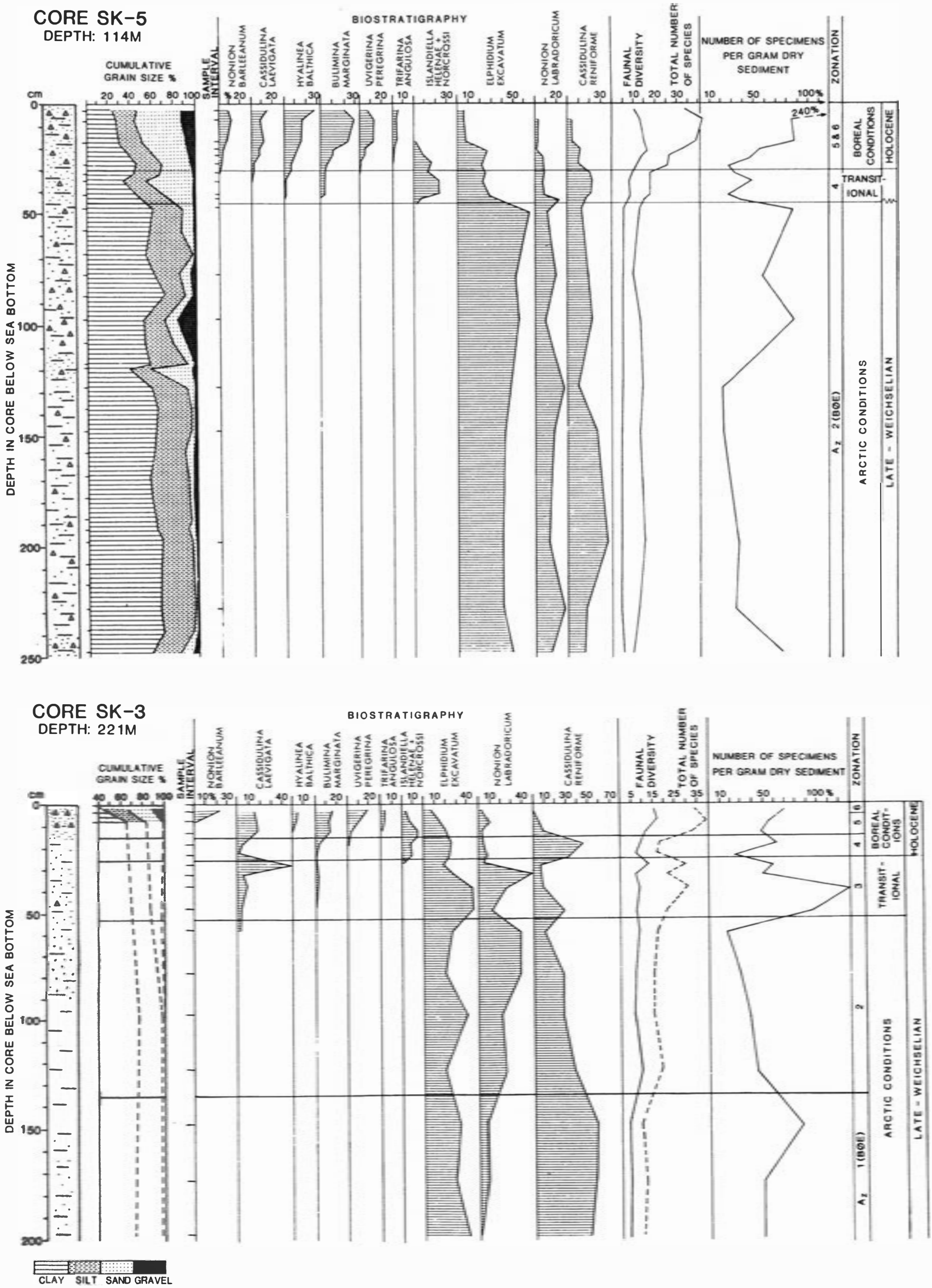


Fig. 7. Lithostratigraphy and biostratigraphy of core SK5 and Sk3, based on benthic foraminiferal assemblage of the most significant species. (Mainly after Bøe 1978).

marginata, Hyalinea balthica and *Cassidulina laevigata* indicates the intrusion of warmer bottom water which may be connected to the northward drift of the Subpolar convergence in the North Atlantic, and the entrance of this water into the Norwegian Channel and the Skagerrak (Fält 1982). According to Nagy & Qvale (1985), the Atlantic water entered the Skagerrak about 10,000 yrs. B.P. at the beginning of the Preboreal chronozone. The arctic element is, however, still strong, with *Islandiella helenae* and *I. norcrossi, Cassidulina reniforme,* and *Nonion labradoricum* as important members. The milder bottom water is also indicated by an increase in faunal diversity and in the total number of species. The drop in number of specimens per gram of sediment, seen in zone 4, might be explained as an increased rate of sedimentation due to increased melting. The Pleistocene-Holocene boundary is therefore tentatively placed at the beginning of zone 4. In zones 5 and 6 there is a decline in the arctic faunal element, and an increase in a temperate foraminiferal fauna. At the same time there is also an increase in faunal diversity, total number of species and number of specimens per gram of sediment.

The change in texture in the upper part of Sk5, with a coarsening-upward sequence, is very noticeable. If the bottom of zone 4 marks the beginning of the Preboreal chronozone, glacial marine sedimentation must still be expected for some time during the retreat of the icemargin. The increasing coarseness upwards in the core is thought to be due to reworking and sorting of the sediment. Most likely the reworking and sorting effect of the sediment is caused by bottom currents. These may have been set up in connection with outflowing surface meltwater and incoming salt Atlantic bottom water. Similar textural change is described from the Møre-Trøndelag continental shelf as a result of immigration of the Atlantic Current about 10,000 years B.P. (Holtedahl & Bjerkli 1982).

In Sk3 the Pleistocene-Holocene boundary is rather uncertain. A dominant arctic fauna is present up to about 15 cm below the surface (A.z 1, 2, 3 and 4). *Islandiella helenae* and *I. norcrossi* have their maximum at this level. Above, faunal diversity and total number of species show an increase. *Cassidulina laevigata* and *Bulimina marginata* do, however, appear further down in the core (A.z. 3), indicating the introduction of warmer water. There is also an increase in total number of species in zone 3. The great increase in number of specimens per gram of sediment in zone 3 indicates a change in the rate of deposition, and the high figure might suggest a diminished outflow of melt-water. The succeeding drop in this value, and a similar drop in faunal diversity and total number of species, could indicate increased melting and a higher rate of deposition. This oscillation may be connected with the Younger Dryas ice advance or stagnation, and the succeeding increasing outlow of melt-water during the beginning of Holocene time (Feyling-Hansen 1964, 1972). In Fig. 7 the Pleistocene-Holocene boundary is tentatively set at 25 cm below the core-surface.

There is a slight increase in coarseness in the upper part of the core, with a marked change in the upper 10–15 cm. This concentration of gravel and sand must be due to bottom currents reworking older glacial sediments, as was the case in the upper part of Sk5. The influence of currents, however, has been less than at the site of Sk5.

Correlation between cores in the area

Figs. 1 and 2 show the position of the various sediment cores taken in the area, including the cores Sk5 and Sk3. Cores 16 and 17 were collected fairly close to Sk5. Correlation of these cores on the basis of lithostratigraphy alone is difficult, but there is a textural similarity, especially between 16 and Sk5. They are both coarse glacial marine sediments, with increased coarseness towards the top. Core 17 also shows an increased coarseness towards the top.

The cores 15A and 15, taken on the eastern side of the Langesund Channel, cannot be directly correlated with Sk3. Core 15 has coarse sections below the surface and is probably deposited fairly close to an ice margin. The lower part of core 15A is fairly similar in texture to Sk3, clearly deposited in a glacial marine environment. It has a coarse band at about 25–35 cm from the surface, and the uppermost part of the core is also coarse.

Conclusion

Bathymetric and shallow seismic investigations of the submarine channel extending from the mouth of the Langesundsfjord into the deeper parts of the Skagerrak have shown the course of the channel to be structurally controlled, and the formation of the channel to be due to glacial erosion.

The channel has acted as a sediment trap for sediments deposited during the ice retreat in Late Weichselian time, and a maximum total thickness of at least 180 m has been suggested. The sediments have been divided into 4 seismostratigraphic units, of which all, except the upper, are thought to represent glacial marine sediments. The upper unit, attaining a maximum thickness of 85 m, is suggested to represent sediments of mainly Holocene age.

The sediment cores which, with the exception of core 15-B, were collected outside the channel, contain glacial marine sediments with an uppermost part which is reworked and sorted during the Holocene. In Core 15 B, which was collected from the bottom of the channel, only fine post-glacial sediments were penetrated.

The glacial marine sediments in the cores 16, 17 and Sk5 were probably deposited during the retreat of the ice margin towards its position when the Ra moraines were formed and also during the retreat of the margin in Preboreal time. The finer glacial marine sediments in Sk3 were probably deposited during the same interval of time, but owe their finer texture to a greater distance from the ice front.

The coarse character of the glacial marine sediment in core 15 indicates deposition fairly close to an ice front, in which case these sediments must be somewhat older than the coarse glacial marine sediments on the west side of the channel.

The assumed reworking and sorted upper part of the sediment cores is thought to have been formed by bottom currents in connection with the incoming Atlantic water in the Skagerrak-Kattegat area.

The sediment studies support the view that the acoustic unit 2 represents glacial marine sediments. Likewise, that acoustic unit 1, in its upper parts in any case, represents marine sediments of post-glacial (mainly Holocene) age.

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