Geological Investigation of a Lower Tertiary/Quaternary Core, Offshore Trøndelag, Norway*

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Seismic profiling carried out offshore Trøndelag, Norway, has provided a basis for selecting localities for core sampling of the bedrock.

A continuous, metre-long core revealing new information was recorded. Sedimentological, mineralogical, geotechnical and micropaleontological investigations indicate that the core consists of near-shore, silty claystone of Upper Cretaceous/Lower Tertiary age at the base, of Quaternary till in the middle, and of a Late Quaternary cover sand at the top.

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Previous work

The Continental Shelf adjacent to Trøndelag has been subject of several scientific investigations. Holtedahl (1940) has described the bathymetry of the Norwegian coastal zone. Holtedahl (1955) discussed the glacial history of the shelf area off Møre, and concluded that during the last glaciation, the ice-sheet must have extended at least 40 km from the present coast. Later investigations showed that the Quaternary sediments are thin over large areas (Eldholm & Nysæter 1969). Holtedahl & Sellevoll (1971) pointed out that in some sediment samples from the area there is a high content of local, short-transported, Mesozoic material. Bjerkli (1972) has made mineralogical analyses of the surface sediments, and Haldorsen (1974) has investigated the mineralogy of sediment cores. Bjerkli & Østmo-Sæther (1973) have found authigenic glauconite inside shells of foraminifera west of Frøya, Trøndelag. Studies of marine geology, mineralogy and palynology have been carried out by Holtedahl et al. (1974).

Several geophysical investigations including estimations of the thickness of sediments have also been carried out (Grønlie & Ramberg 1970; Åm 1970; Talwani & Eldholm 1972).

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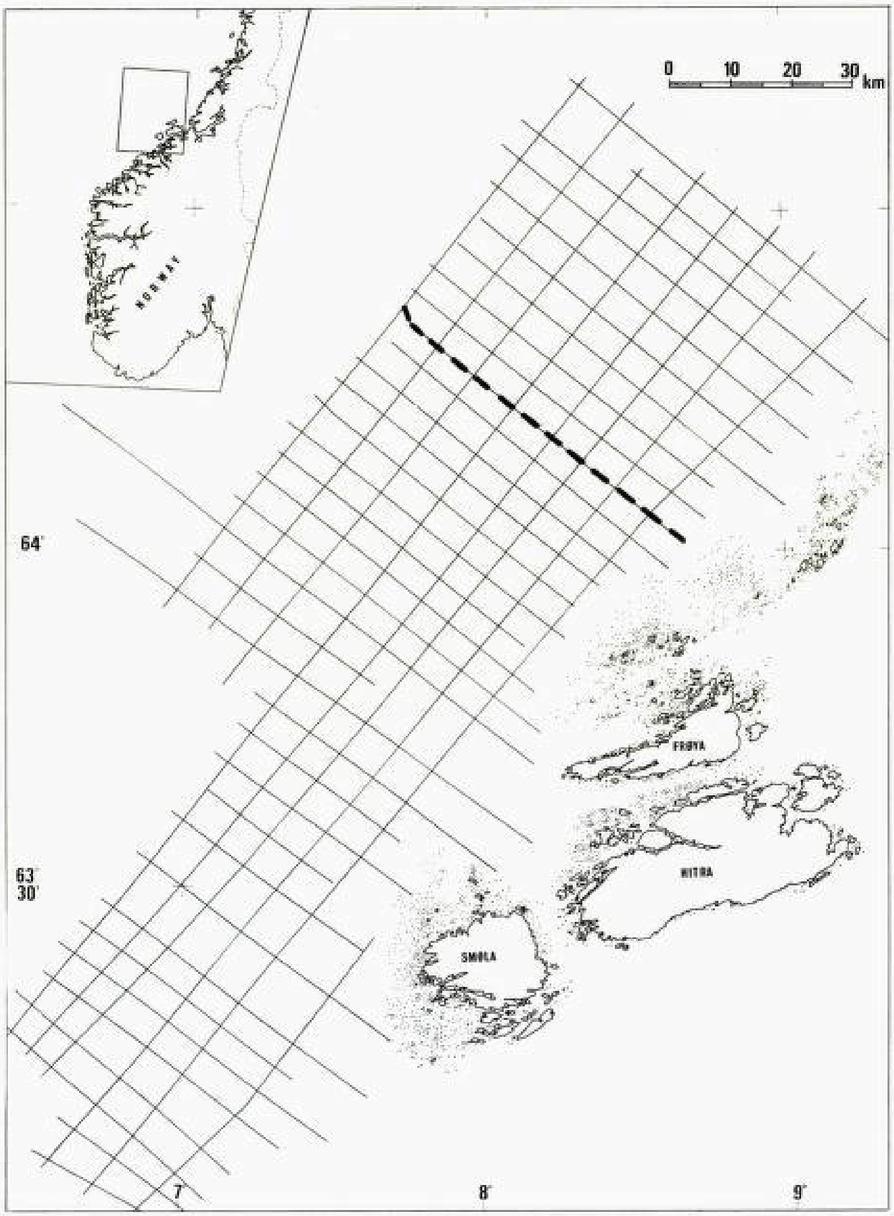


Fig. 1. Sparker and boomer profiling carried out by NTNFK 1973, offshore Trøndelag, Norway. Dashed line is the profile shown in Fig. 2.

Geological setting

NTNFK has carried out geological and geophysical studies on the continental shelf north of 62° since 1969 and has also supported and coordinated investigations carried out by other institutions.

In June 1973 a grid of about 3,500 km of sparker and boomer profiles was run offshore Trøndelag (Fig. 1). The distance between the profiles

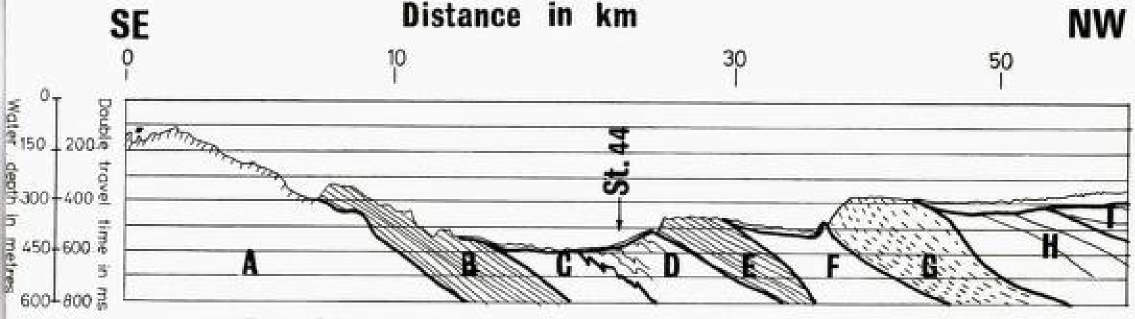


Fig. 2. Schematic interpretation of sparker profile. Letters indicate the various identifiable stratigraphical units. The thin top layer is Quaternary deposits.

is about 5 km. The profiles showed a number of identifiable rock units. A schematic interpretation of a sparker profile is shown in Fig. 2. Formation A, basement, is easy to recognize from its uneven top surface and typical parabolical reflection patterns. Formation B has thin and even layers that are only slightly disturbed. Formation C has no visible layering. Formation D has undergone block-faulting with offset in the order of about 30 m vertically. Formation E is layered and forms an elevation that can be traced topographically along strike for some distance. Formation F has no clear layering. Formation G has distinct foreset bedding and forms a topographical elevation in parts of the area. A more complete sequence to the west shows a topset, foreset and bottomset element. This formation has previously been mapped and was tentatively called a 'delta' (Eldholm & Nysæther 1969). Formation H has layers partly parallel to the delta. Formation I is discordant to H, and the layers are nearly horizontal.

These formations could be recognized in adjacent profiles and a preliminary geological map was constructed (Fig. 3). The Quaternary deposits are not yet mapped in detail, but some possible windows through the Quaternary cover have been located. It was decided to piston core these windows to obtain samples of the bedrock on a subsequent cruise in September.

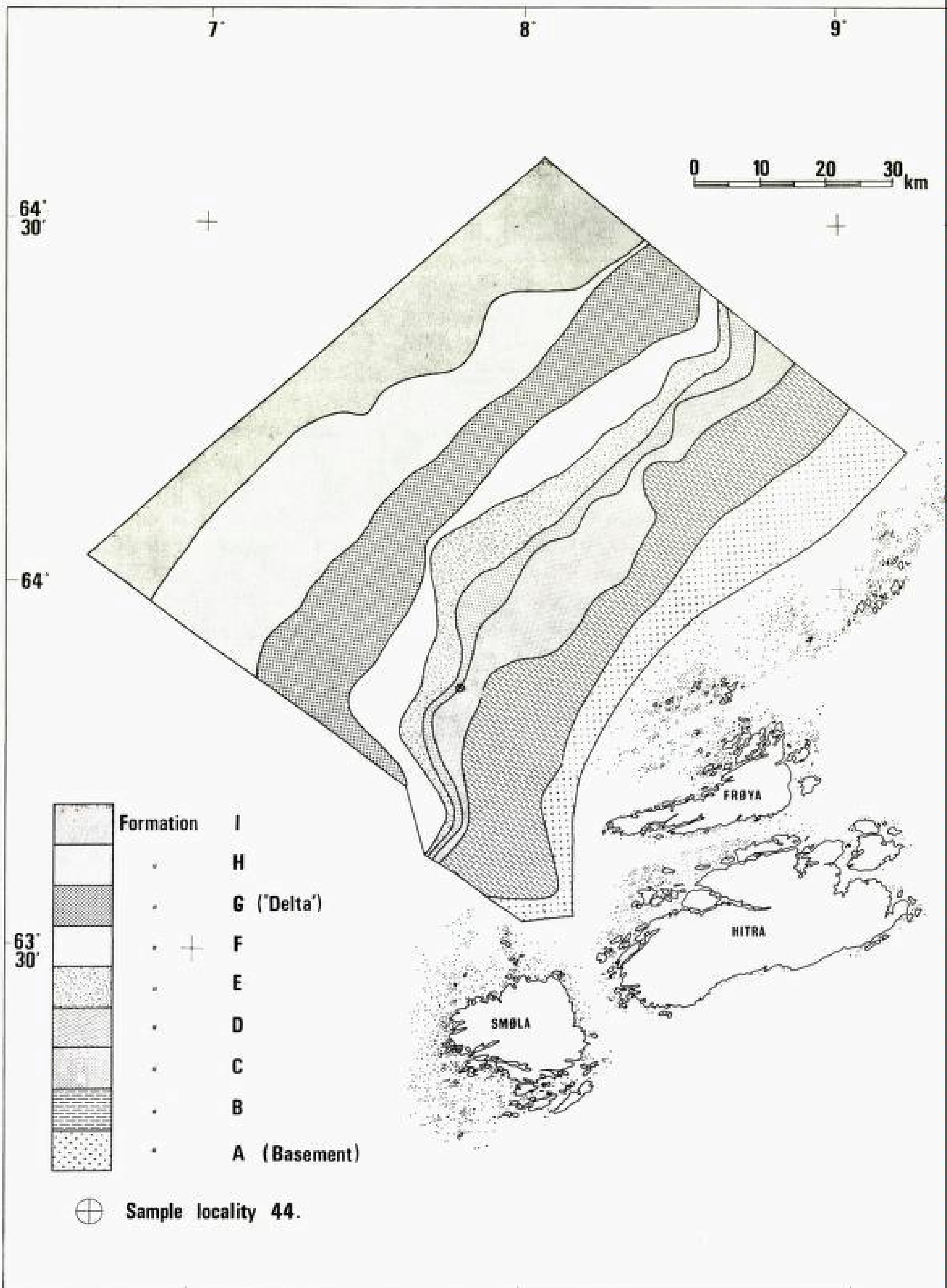
Sampling

One of the selected localities was No. 44 on cruise 5 (station 44/7305).

Bottom photographs of the selected site showed a bioturbated sandy bottom with scattered pebbles (Fig. 5). A dredge sample yielded about 15 litres of sandy mud which contained a handful of pebbles.

Table 1. Composition of pebbles in dredge sample

Rock type	Number	No. %	Weight grams	Wt. %
Magmatic	69	37	150	40
Gneiss	75	40	124	33
Sediments	34	18	89	24
Chert	9	5	14	4
Undetermined	5		21	


7°
8°
9°
64° 30'
64°
63° 30'
0 10 20 30 km
FRØYA
HITRA
SMØLA
Formation I
" H
" G ('Delta')
" F
" E
" D
" C
" B
" A (Basement)
Sample locality 44.

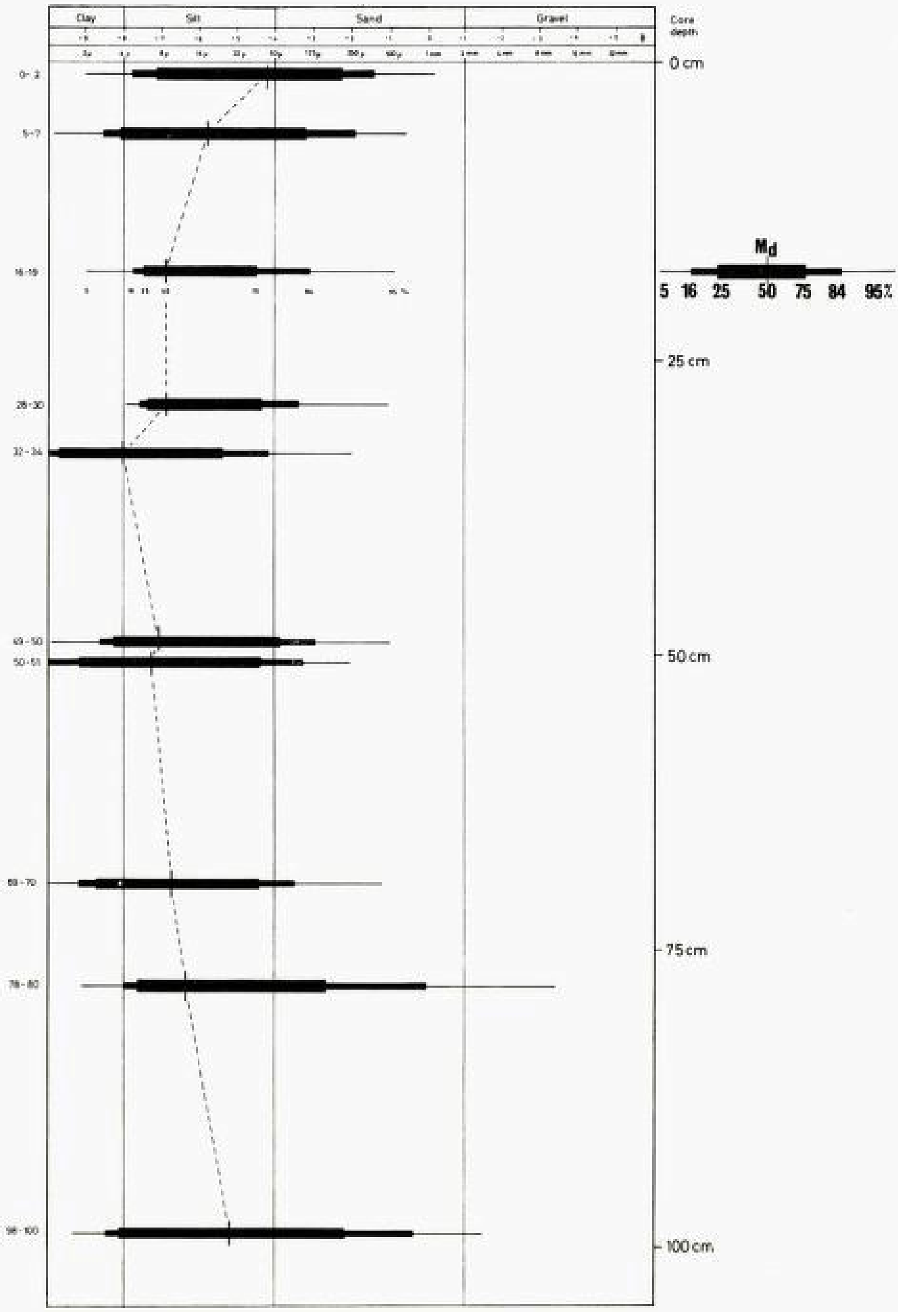


Fig. 4. Grain-size distribution, Station 44.

Fig. 3. Preliminary geological map of stratigraphic units, offshore Trøndelag, Norway.

Some pebbles consist of chert and sandstones foreign to the mainland rock types (Table 1). The degree of roundness varies from angular to well-rounded with about 80% subangular to subrounded.

At 63°52.0'N, 7°49.0'E a piston corer was tried at a depth of 230 m. The corer came up severely bent with about 5 cm of hard clay protruding from the nose. Unfortunately, bad weather prevented further sampling of the selected localities.

The core consists of a top layer of silty sand (c. 10 cm). Between c. 10 and c. 65 cm is silty clay with alternating greenish and brownish coloration. The lowermost part (c. 40 cm) is a hard clay with green glauconite grains. Scattered throughout the core are pebbles of brittle claystone up to about 1 cm in diameter with a dark, sometimes chocolate-brown colour.

Laboratory investigations

The following properties of the core have been investigated: grain-size, mineralogy, geotechnical properties, micropaleontology, chemistry of interstitial water and carbon content. A partial account of the results is given below. It is planned to present more detailed information in a subsequent NTNFK report.

Grain-size distribution

Ten levels in the core were selected for grain-size and mineralogical analyses. Claystone pebbles from three levels (0–2 cm, 50–51 cm and 98–100 cm) were analysed separately. The grain-size distribution (Fig. 4) was determined by wet sieve analysis and by pipette analysis of the fraction between 63 μm and 2 μm. The claystone pebbles were treated as grains.

The analyses show that the sediment is a poorly sorted sandy silt in the top and the bottom layers, and a poorly sorted silty clay in the middle part of the core. The median diameter for all examined samples is within the silt-size range.

Mineralogy

BULK SAMPLES

One thin-section was made from the 98 cm level by impregnating the claystone with Epofix resin. Quartz, plagioclase, amphibole, glauconite and K–feldspar are the principal minerals; in addition, fine-grained clay-minerals are present.

The quartz grains are angular and fairly uniform in size, about 50–200 μm. Some of them show secondary growth along the rims.

The claystone pebbles have distinct boundaries and consist of a uniform mixture of fine-grained clay-minerals and quartz. The quartz grains are very small and evenly distributed, and show a preferred optical orientation in each individual pebble.

Differential thermal analyses, X-ray diffractometer analyses and staining tests (Mielenz & King 1951) on bulk samples at the 25 cm and 85 cm levels show

Fig. 5. Photograph of the bottom at Station 44. Trigger weight and release wire are seen in the upper right.

small differences between the two levels. The samples consist mainly of feldspar and mica/hydromica, with about 10% quartz and less than 5% montmorillonite. The upper sample contains some calcite.

FRACTION FINER THAN 63 μm

This fraction has been examined by means of X-ray diffraction of randomly orientated specimens (Fig. 6). The samples were treated with ethyleneglycol and heated to 450°C. Montmorillonite was identified by expansion of the 14Å reflection to 17Å in glycolated samples and a collapse of the same reflection to 10Å in the heated sample.

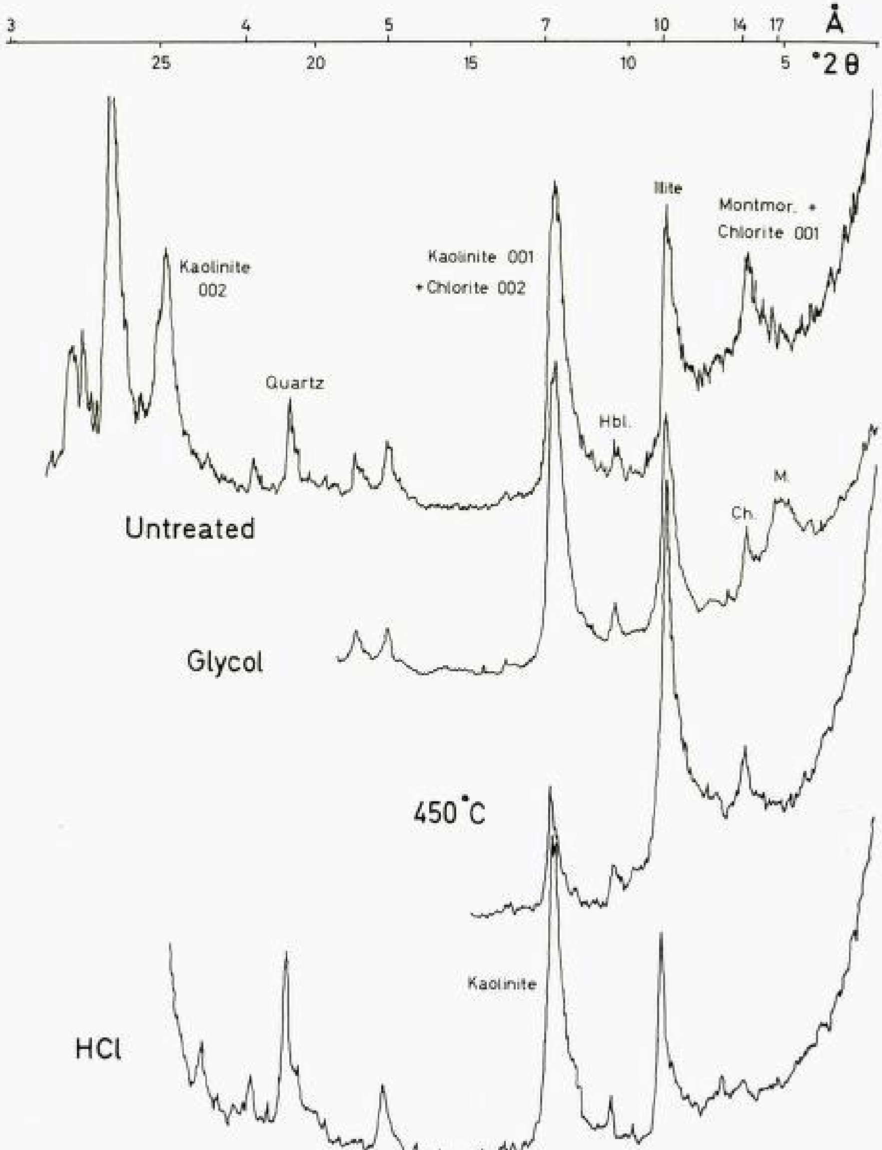


Fig. 6. X-ray diffractograms of unoriented samples of the fraction $< 63\ \mu m$, 78–80 cm core depth, $CuK\alpha_1$-radiation.

The sediment consists of illite, quartz, plagioclase, K-feldspar, montmorillonite, kaolinite, chlorite and amphiboles, in decreasing order of abundance. The content of chlorite increases upwards in the core. Towards the top the amount of calcite, in the form of animal tests, increases.

The claystone pebbles consist mostly of montmorillonite. The degree of crystallinity decreases in the uppermost pebbles where the montmorillonite is replaced by an illite–montmorillonite mixed-layer mineral. In addition to the

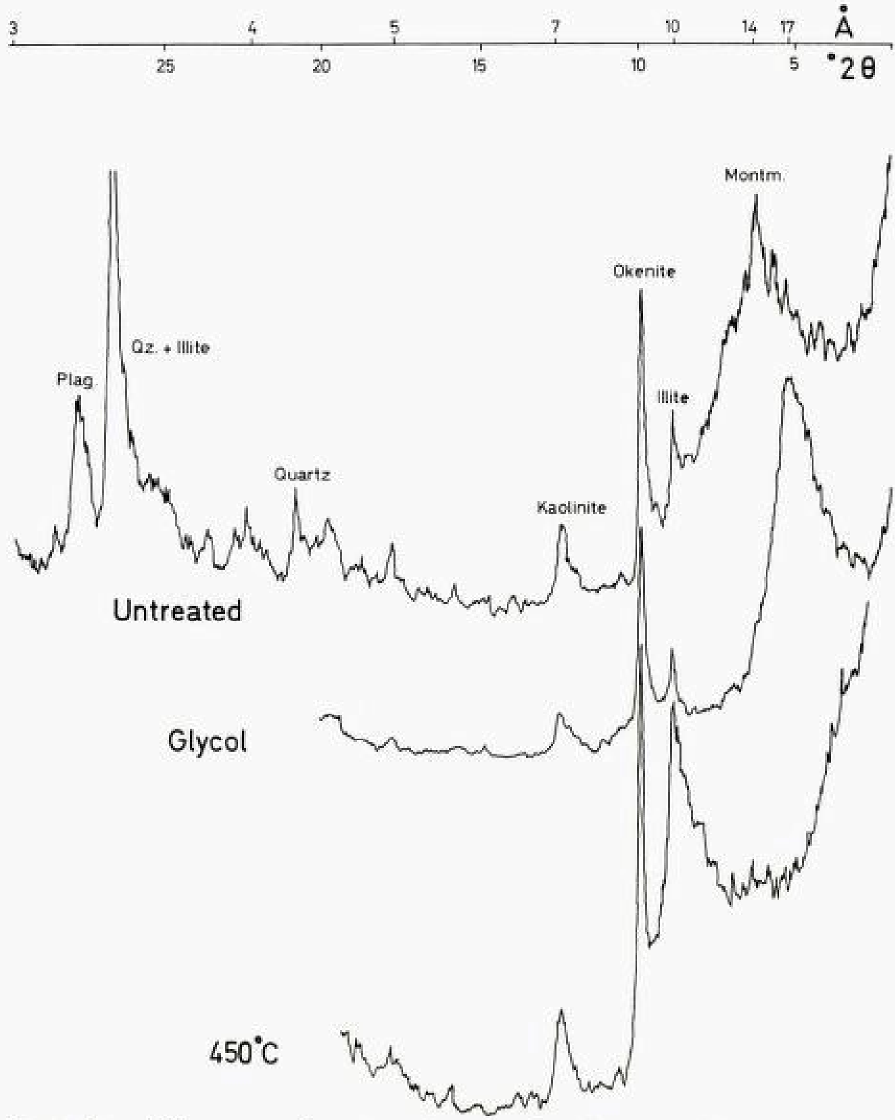


Fig. 7. X-ray diffractograms of unoriented samples of a claystone pebble at 99 cm core depth, CuKα_1-radiation.

montmorillonite there is a zeolite mineral, okenite, with a distinct 8.91Å reflection. Quartz, illite and kaolinite are also present in minor amounts (Fig. 7).

DISCUSSION

The mineral composition of the upper part of the core is somewhat different from that of typical marine clays of Quaternary age in Norway (Roaldset 1972). The fairly uniform composition of the montmorillonite pebbles throughout the core indicates the reworking of older material: the kaolinite

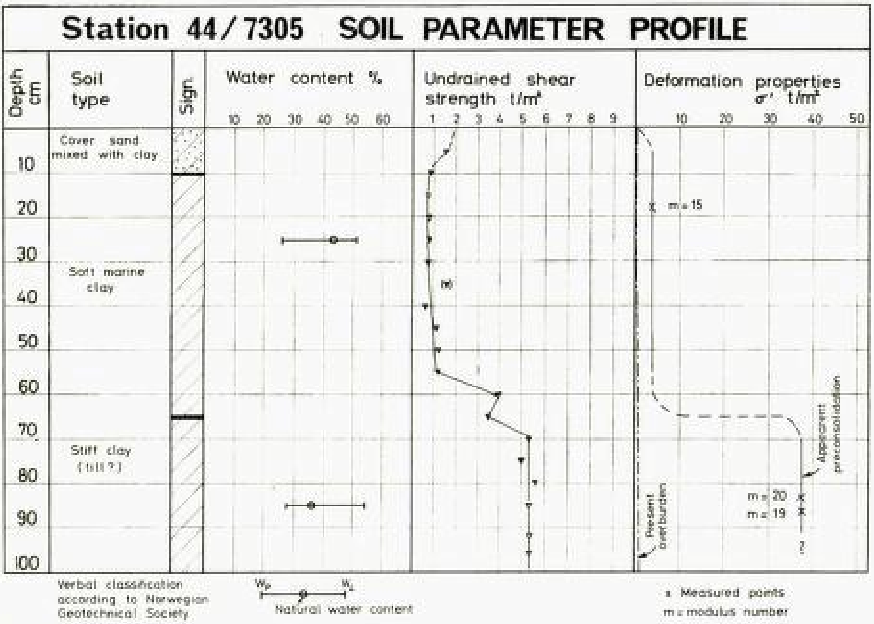


Fig. 8. Station 44, soil parameter profile.

also suggests this. The parallel greenish and brownish layers could indicate a migration and a segregation of ferrous ions, but the chemical analyses do not provide any evidence for this.

The preferred optical orientation of the quartz grains seen in the thin-section indicates diagenetic precipitation of silica. The high content of montmorillonite could indicate that the claystone pebbles originally came from a bentonite bed. During the alteration of volcanic ash to montmorillonite, silica is liberated and may precipitate within the sediment and zeolite minerals may be formed (Grim 1968).

Geotechnical investigations

The main geotechnical properties are given in the soil parameter profile (Fig. 8).

The undrained shear strength along the core was measured by the falling cone method. The profile shows several different layers. In the top layer, 0–10 cm, the higher shear strength is probably due to sand grains. From 10 to 55 cm, the shear strength, s_u, about 1 t/m^2, seems to increase slightly downwards. Between 55 and 70 cm, s_u is 3.5–4 t/m^2. From 70 to 95 cm, s_u is fairly constant between 5 and 6 t/m^2. In the lowermost part of the core, below about 95 cm, the water content may have increased after sampling, so that the natural shear strength here may have been higher than the one measured.

Two representative samples, 17–30 cm and 80–90 cm, were chosen for a more extensive geotechnical investigation of layers 10–55 cm and 70–95 cm, respectively. Natural water content and index properties, liquid limit, W_L , and plastic limit, W_P , were measured. Prior to measuring the index properties, the sample was remoulded and clay fragments crushed smaller than 0.5 mm. Compared with Quaternary clays from Norway, the liquid limit, W_L , and the plasticity index, $I_P = W_L - W_P$, are high. Both values are slightly higher in the 80–90 cm sample than in the 17–30 cm sample. A comparison of natural water content with index properties (Fig. 8) reveals that the 80–90 cm sample is more highly consolidated.

The deformation properties of three samples (17–19 cm, 82–84 cm and 85–87 cm) were measured by an oedometer and the results were interpreted by means of the resistance concepts of Janbu (1967). From the load-deformation curve one can find the tangent modulus $M = \frac{d\sigma'}{d\varepsilon}$ were σ' = effective stress (load) and ε = relative deformation.

The load-modulus curves show that the modulus is nearly proportional to the pressure $M = m \cdot \sigma'$ for a stress higher than the pre-consolidation pressure, where m = the modulus number. The pre-consolidation pressure represents a break in the load-modulus curve, showing where the behaviour of the sample changes from elastic to plastic (Janbu 1967). The modulus values and pre-consolidation pressures are shown in the soil parameter profile. The difference in modulus numbers shows that sample 17–19 cm is more easily compressed than the lower one. The pre-consolidation pressure, 35–40 t/m^2 for the samples between 80 and 90 cm, is considerably higher than the present overburden.

DISCUSSION

A pre-consolidation effect may have many explanations, such as overlying ice or soil, chemical weathering, cementation between grains, effect from the sampling, etc. The apparent pre-consolidation pressure of 3–4 t/m^2 from 10–65 cm may, with effective unit weight 0.5 t/m^2, have been caused by 6–8 m of overburden which was later removed. The load-deformation curve of sample 17–19 cm, however, indicates the breakdown of a potentially unstable structure. Cementation between the grains may therefore be a preferable explanation.

The layer below 65 cm has a pre-consolidation pressure of 35–40 t/m^2, which could have been caused by ice load.

Palynology

Ten channel samples representing the total length of the core were examined. On the basis of the palynology, the core can be divided into two parts: 0–98 cm and 98–105 cm.

UPPER PART, 0–98 CM

A pure sample of the clay could not be prepared, as all the claystone pebbles could not be separated out. The claystone pebbles contain a well-preserved and diversified assemblage of spores, pollen, dinoflagellates, cuticles and woody matter. The clay contains a similar, but much reduced assemblage to that in the claystone.

LOWER PART, 98–105 CM

This part of the core contains a rich assemblage of palynomorphs similar to that present in the upper section of the core. The taxa identified include:

Spores and pollen:

Lygodium, *Extratriporopollenites*, *Triatriopollenites*, *Taxadiaceaepollenites*, *Sequoiapollenites*, *Tricolpites*, *Caryapollenites*, *Alnus*, *Picea* and *Pinus*.

Dinoflagellates:

Deflandrea, *Hystricosphosphaera*, *Baltisphaeridium* and *Micrystridium*.

DISCUSSION

The assemblage is assigned an Upper Cretaceous/Lower Tertiary age. It has undergone little thermal alteration. Such an assemblage is characteristic of a near-shore marine environment. The pebbles in the upper part of the section appear to have been reworked from deposits of the same age as the lower part. The palynomorphs in the clay in the upper part of the core may have been derived from the breakdown of claystone pebbles. However, the reduced assemblage in the clay suggests that the sediment was formed by the mixing together of clay lacking palynomorphs with the described claystone pebbles.

Foraminifera

Three different foraminiferal faunal assemblages can be recognized (Fig. 9). The upper part of the core (0–10 cm) is very rich in foraminifera (Fig. 10), and contains 20–25% of planktonic specimens most of which are of Pre-Quaternary age. The benthonic fauna is characterized by the boreal–lusitanian deep-water species *Uvigerina peregrina* Cushman, *Trifarina angulosa* (Williamson), with the cosmopolitan species *Cibicides lobatulus* (Walker & Jacob), *Cassidulina laevigata* d'Orbigny, and *Nonion barleeanum* (Williamson) as common forms. Other common boreal–lusitanian species are *Hyalinea baltica* (Scroeter) and *Bulimina marginata* d'Orbigny. The majority of the species mentioned above are common in the deeper parts of the North Sea area today (Høglund 1947; Lange 1956; Jarke 1961; Kihle 1971; Murray 1971). In addition, these samples also have a strong arctic or arctic-boreal element (*Elphidium clavatum* Cushman, *Cassidulina crassa* d'Orbigny). Among the rarer arctic-boreal species are *Islandiella teretis* (Tappan), *Stainforthia loeblichi* (Feyling-Hanssen) and *Nonion labradoricum* (Dawson). The benthonic calcareous fauna indicates a Holocene age for the sediment in the upper portion of the core. A few arenaceous Pre-Quaternary specimens were also found, of much the same composition as the fauna in the core section between 98 and 105 cm.

The middle part of the core (10–98 cm) contains quite poor populations of foraminifera, and is characterized by the arctic or arctic-boreal species

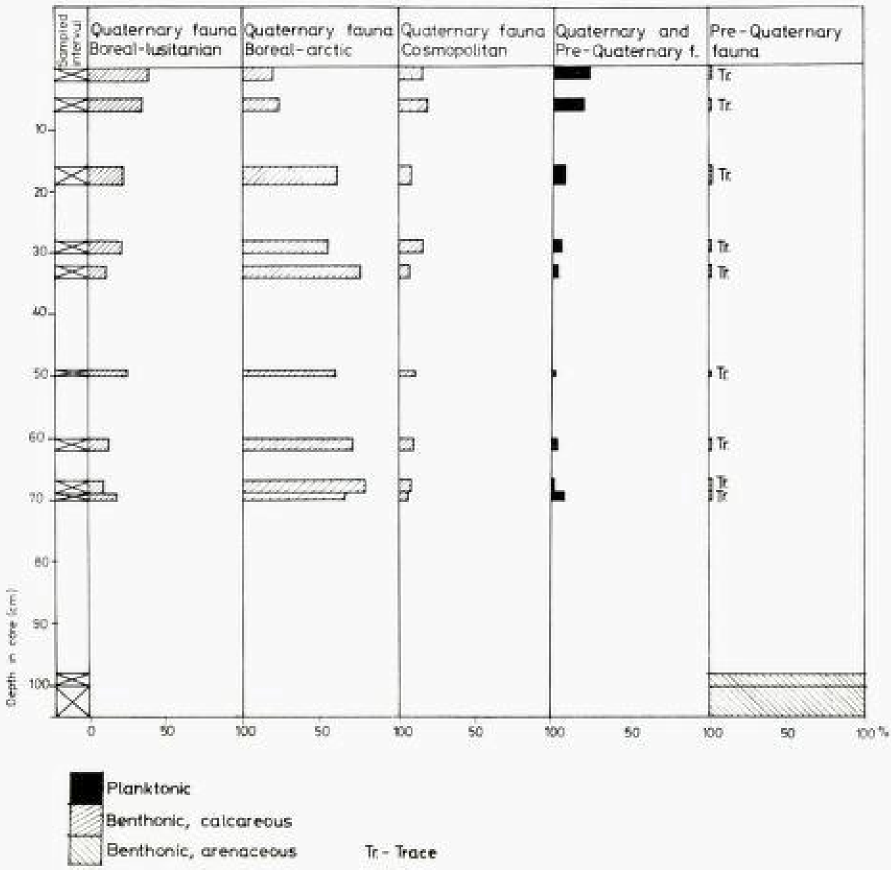


Fig. 9. Distribution of foraminiferal groups in samples selected from the core.

Elphidium clavatum Cushman and *Cassidulina crassa* d'Orbigny. In addition, a relatively strong boreal–lusitanian element occurs (*Uvigerina peregrina* Cushman, *Bulimina marginata* d'Orbigny, *Trifarina angulosa* (Williamson)). Among the rarer species are the cold-water forms *Trifarina fluens* (Todd), *Nonion labradoricum* (Dawson), *Bolivina pseudopunctata* (Høglund), *Elphidium groenlandicum* Cushman, *Quinqueloculina stalkeri* Loeblich and Tappan, *Stainforthia loeblichi* (Feyling-Hanssen) and *Islandiella teretis* (Tappan). This foraminiferal fauna shows affinities to the Late Glacial faunas from the Oslofjord area, but has a much stronger boreal–lusitanian element (Feyling-Hanssen 1964). These foraminifera indicate a Pleistocene age for the sediments in the middle part of the core. A few Pre-Quaternary arenaceous forms were found. The samples in this part of the core also contain 5–10% of Pre-Quaternary planktonic foraminifera.

The lowest portion of the core (98–105 cm) contains quite rich populations of foraminifera (Fig. 11) and is characterized by the arenaceous genera *Ammodiscus*, *Ammolagena*, *Bathysiphon*, *Cyclammina*, *Dorothia*, *Glomospira*, *Haplophragmium*, *Haplophragmoides*, *Psammosphaera*, *Saccammina*, *Spiro-*

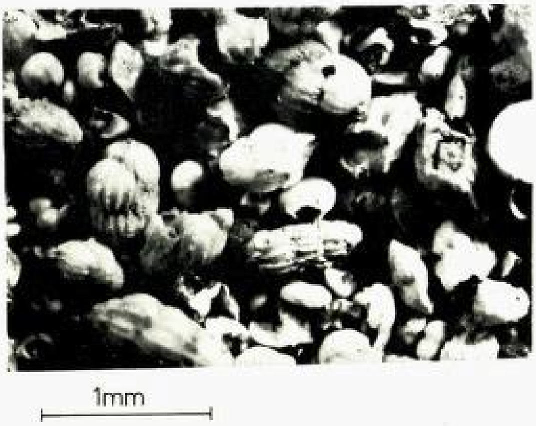


Fig. 10. Foraminifera from the interval 0–2 cm.

Fig. 11. Foraminifera from the interval 100–105 cm.

plectammina, Textularia, Thalmannammina and *Trochammina.* Some of the foraminifera found here are worn specimens and cannot be determined. The most common species are:

Ammodiscus cf. *incertus* (d'Orbigny)
Ammolagena clavata (Jones & Parker)
Cyclammina challinori Haynes
Cyclammina incisa (Stache)
Dorothia eocenica Cushman
Glomospira charoides (Jones & Parker)
Haplophragmium bulloides Beissel
Haplophragmoides eggeri Cushman
Haplophragmoides kirki Wickenden
Spiroplectammina spectabilis (Grzybowski)
Textularia smithvillensis Cushman & Ellisor
Thalmannammina recurvoidiformis Neagu & Tocorjescu

This fauna has forms in common with Upper Cretaceous and Lower Tertiary arenaceous faunas from various parts of Europe (Grzybowski 1901; Haynes 1958; Neagu 1970; Săndulescu 1972). The fauna also shows affinities to upper Cretaceous and Paleocene arenaceous faunas from America (Cushman & Waters 1927; Cushman & Ellisor 1933; Mallory 1959). The majority of the represented specimens are of Lower Tertiary age. No calcareous specimens were found in the lowest portion of the core.

DISCUSSION

The boreal–lusitanian element in the upper 10 cm of the core constitute 35–40% of the total foraminiferal fauna, whereas the arctic–boreal species make up 20–25% of the total fauna. The first group of foraminifera is more frequent than the second group; one should therefore expect a Holocene age for the sediments in this portion of the core. The relatively strong arctic–boreal element may be reworked from Pleistocene deposits, whereas the Pre Pleistocene element of the planktonic foraminifera and the few arenaceous specimens are probably reworked from Upper Cretaceous or Lower Tertiary deposits in the area.

The middle part of the core contains 55–80% of arctic or arctic-boreal foraminifera and the sediments are thought to be of Pleistocene age. The content of boreal–lusitanian species is relatively high (10–25%), and these sediments may represent a deposit from a warmer part of the Pleistocene, perhaps from an interglacial or interstadial period or perhaps from the very end of Late Glacial time. The sediments also may represent glacial deposits with reworked material from an interglacial period. The Pre-Pleistocene specimens are probably reworked from Upper Cretaceous or Lower Tertiary deposits in the area.

The lower part of the core contains only arenaceous foraminifera solely of Upper Cretaceous and Lower Tertiary age. The age of this part of the core is discussed below.

Discussion and conclusions

Evidence from the foraminiferal assemblages suggests that the core can be divided into three parts: 0–10 cm, 10–98 cm, and 98–105 cm. The geotechnical properties show that a subdivision of the middle part can be drawn at 65 cm.

The loose, sandy sediment in the upper part of the core (0–10 cm) is similar to the top portion of other cores collected from this area. This cover sand is believed to be the result of winnowing and retransportation on the shallower bank areas during the Weichselian/Late Weichselian low sea-level period. Coarse material was probably contributed by ice rafting. The sand is thus a relict sediment. The bioturbation, shown on bottom photographs from this area, appears to extend down into the underlying sediments. The nature of the cover sand therefore reflects late glacial sedimentation as well as Holocene bioturbation.

The poor sorting and mixed faunas of different ages suggest that the middle part of the core (10–98 cm) is a till. The pre-consolidation stress as well as the banded structure suggest a subglacial origin for the interval 65–98 cm, while a glacial-marine origin is likely for the interval 10–65 cm. The mixed foraminiferal assemblages indicate a Quaternary age.

In contrast to the overlying portion of the core, the palynological and foraminiferal assemblages of the lower part of the core (98–105 cm) together indicate one age, Upper Cretaceous/Lower Tertiary, which may suggest that this part of the core represents in-situ bedrock. This is supported by the very thin nature of the Quaternary sediments as seen on the sparker profile. However, the presence of claystone pebbles and banding may indicate that the sediment is a very locally derived basal till, representative of the immediately underlying bedrock. In this case, the sediment would be of Quaternary age, but nevertheless representative of the age and composition of the local bedrock.

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