Distribution of 30,000 year-old sand deposits in the northern North Sea

KÅRE ROKOENGEN, STEINAR GULLIKSEN, MAGNE LØFALDLI, LEIF RISE & HANS-PETTER SEJRUP

Rokoengen, K., Gulliksen, S., Løfaldli, M., Rise, L. & Sejrup, H.P. 1993: Distribution of 30,000 year-old sand deposits in the northern North Sea. *Nor. geol. unders. Bull. 424*, 13-21.

The northern North Sea Plateau represents mainly a coastal sedimentary accumulation towards the north and northeast of thick clay deposits separated by thin sand layers. Regional mapping on this flat plateau has revealed the presence of a NW - SE trending sand layer cut by marine erosion. The sand layer dips northeastwards and is cut by glacial erosion on the western slope of the Norwegian Trench. The sand is thus preserved in an area of more than 5,000 km² between 60°30'N and 62°N and extends further both to the northwest and the south.

A vibrocorer sample from 136 m water depth in the outcrop area on the northern North Sea Plateau (61°00'N, 1°53'E) comprised sand with abundant shell fragments in the lower part. The foraminiferal faunas showed fairly shallow, low-arctic conditions with an influx of Atlantic water. Three radiocarbon dates gave ages of 30,000 years B.P., and the sand deposition is thus correlated with the interstadial period recorded on land in Europa at that time (called the Ålesund interstadial in western Norway and Denekamp further south). The mapped sand layer (and possibly older sands) is probably representative of a period of influx of Atlantic water and a diminished sediment supply to the shelf edge. The building out of the clay deposits with sediment transport to the edge of the North Sea Plateau has apparently been faster in colder periods with a lower sea level on the shelf.

Kåre Rokoengen, Institutt for Geologi og Bergteknikk, NTH, Universitetet i Trondheim, N-7034 Trondheim, Norway. (Former address: IKU)
Steinar Gulliksen, Laboratoriet for Radiologisk Datering, Fysikkseksjonen, Universitetet i Trondheim, N-7034 Trondheim, Norway
Magne Løfaldli, Stratlab, Hvamsveien 4, N-2013 Skjetten, Norway. (Former address: IKU)
Leif Rise, IKU (IKU Petroleumsforskning a.s.), N-7034 Trondheim, Norway
Hans-Petter Sejrup, Geologisk institutt, avd. B, Universitetet i Bergen, Allégt. 41, N-5007 Bergen, Norway.

Introduction

The purpose of this paper is to present evidence for a Middle Weichselian period of deposition of sand separating thick clay deposits on the North Sea Plateau. The northern part of the plateau is today extremely flat and dips to the north-northwest with a gradient of about 0.4 m/km in the study area (Fig. 1).

The Quaternary geology between 60° and 62°N has been mapped by BGS (British Geological Survey) and IKU, based on seismic profiling and surface sampling, and presented on joint maps (Skinner et al. 1983, 1986, Rise et al. 1984, Long et al. 1988). An analog sparker (EG & G with 1kJ energy) was run on all IKU profile lines with 10 km spacing in a N - S trend, and sea-bed sampling carried out based on the interpretation of the shallow-seismic data (Rise & Rokoengen 1984).

The sample A79-156 (Fig. 1) was recovered at 136 m water depth with a 8.4 cm sample diameter Aimers MacLean vibrocorer. The litho-, chrono- and biostratigraphy in the core are presented and the regional distribution of the 30,000 year-old sediments discussed in the light of the geological development of the area.

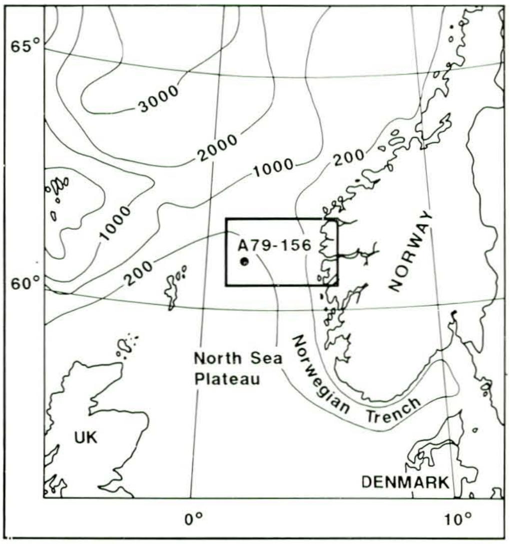

Fig. 1. Map indicating the main bathymetry, core sample location and the study area shown in Fig. 6. All water depths are in metres.

Core description

Lithostratigraphy

The core A79-156 can be divided into six lithological units, I - VI. All are sand dominated, but with varying contents of clay, silt and gravel (Fig. 2).

The lowermost unit, VI (100-55 cm), consists of sand with 10 - 15% clay. The silt and clay content in the lower part decreases upwards, and the sand fraction becomes very well sorted. This unit is very hard and clearly overconsolidated; and especially the lower part of the unit is rich in shell fragments. The top is marked by a gravel layer also containing shell fragments.

The next unit, V (55-35 cm), comprises a well-sorted fine sand (Fig. 2). Above this follows a clayey, silty sand with some gravel, unit IV (35-25 cm). This diamicton is also very hard like the base of the core and contains shell fragments.

The lithological unit III, from 25 to 20 cm, consists of rounded gravel and contains abundant worn shell fragments. The unit shows a gradual transition to unit II (20-10 cm) which comprises a gravelly sand.

The top of the core, unit I (10-0 cm), consists of a medium- to fine-grained sand with some silt.

Radiocarbon datings

Samples were dated at the Radiological Dating Laboratory in Trondheim by gas proportional counting. The outer fraction (10-20%) of the shell samples was removed to avoid contamination. Ages were corrected for both isotopic fractionation and a reservoir age of 440 years (Mangerud & Gulliksen 1975, Gulliksen 1979).

All three samples in the lower part of the core (Fig. 2) consisted mainly of shell fragments from *Macoma calcarea* and gave ages close to 30,000 years B.P., denoting that the age is real. With the standard deviations and ages encountered, however, we think that the results should not be interpreted further than to state that this part of the sand layer was deposited about 30,000 years B.P.

The dating of the gravel and gravelly sand units (25-10 cm) posed special problems. An early date on shell fragments (mainly *Modiolus modiolus* and *Mya truncata)* from 20 cm gave 14,180 ± 140 years B.P. (T-3605). This age

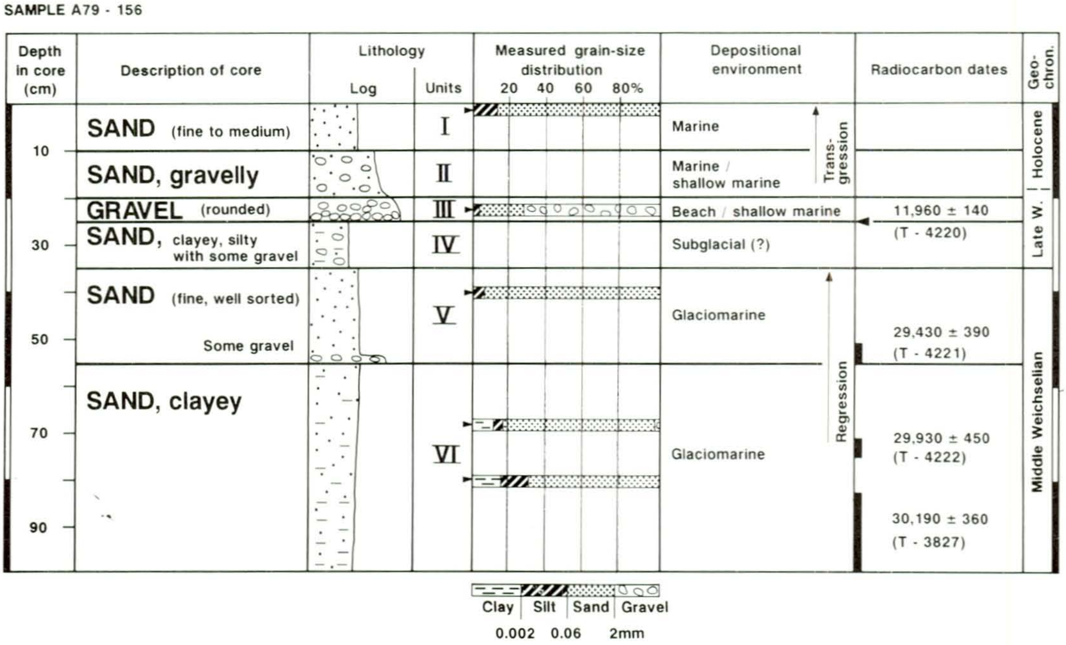

Fig. 2. Description of IKU core A79-156 with lithological log (based on median grain size and composition), unit divisions (I - VI), grain-size distribution for selected samples, interpreted depositional environment and radiocarbon dates.

was older than expected and did not fit in with other dates from the upper gravel deposits on the North Sea Plateau which had given ages in the range 12,000 - 11,000 years B.P. (Rise & Rokoengen 1984). On a new examination of the core, a single, worn half of a shell (probably *Hiatella arctica)* with a weight of about 6 grams was extracted and dated to 11,960 ± 140 years B.P. (Fig. 2).

Our conclusion is, therefore, that the 14,000 years B.P. age was obtained on two mixed populations. About 30 % of the first (30,000 year-old) and 70 % of the second (12,000 year-old) would give an age of about 14,000 years B.P.

Amino acid measurements

The amino acid measurements were performed at the Amino Acid Laboratory at the University of Bergen. The results are given in Table 1.

The results for *3 Elphidium excavatum* (average 0.056) are in general agreement with ratios obtained previously on samples of the same age along the coast of western Norway (Miller et al. 1983, Sejrup et al. 1984, 1987).

Lab. no.	Depth	Species	Alle/Ile		Note
BAL 68	80 cm	Macoma calc.	0.17	0.19	Hyd
			0.20		
			0.20		
			0.30	0,31	Free
			0.32		
			0.30		
BAL 430	51-55 cm	Elph. exc.	0.055	0.056	
BAL 429	84 cm	Elph. exc.	0.054		
BAL 428	90-95 cm	Elph. exc.	0.059		

Table 1. The alle/Ile ratios recorded in samples from core A79-156.

Foraminiferal stratigraphy

Twenty samples were prepared and analysed for foraminifera according to the methods described by Feyling-Hanssen (1958, 1983). Details of the faunas and faunal lists are given by Løfaldi et al. (1981).

The number of specimens and benthonic species per sample, faunal diversity (the number of ranked species whose cumulative percentage accounts for 95% of the total fauna, Walton 1964) and faunal dominance (the percentage of the most frequent species in a counted benthonic assemblage, Walton 1964) are shown in Fig. 3. All samples contained both planktonic and benthonic species, except in the interval from 60 to 40 cm where the content of planktonic species was very low or zero.

Water masses today can be related to groups of foraminifera of arctic and boreal affinity, and thus the past distribution of these groups can be used to reconstruct water mass changes. Foraminiferal faunas representing different water masses have been defined by several workers on the Norwegian Continental Shelf (Feyling-Hanssen 1958, 1983; Rokoengen et al. 1979, 1991; Sejrup et al. 1980, 1987, Skinner & Gregory 1983, Hald & Vorren 1984, 1987; Hald et al. 1989 and others). The faunas have varied, however, due to local conditions and different interpretations.

In the present work on core A79-156 we have mainly followed Feyling-Hanssen (1983), and defined the following five groups:

Arctic group: *Astrononion gallowayi, Buccella frigida, Cassidulina reniforme, Elphidium bartletti, Elphidium excavatum, Elphidium groenlandicum, Islandiella helenae, Islandiella norcrossi, Nonion labradoricum, Protelphidium orbiculare.*

Boreal group 1 (believed to represent the warmest conditions): *Bulimina marginata, Hyalina balthica, Paromalina coronata, Textularia bocki, Textularia sagittula, Trifarina angulosa, Uvigerina peregrina.*

Boreal group 2: *Cassidulina laevigata, Elphidium albiumbilicatum, Elphidium incertum.*

Shallow-water group: *Buccella tenerrimma, Elphidium albiumbilicatum, Elphidium bartletti, Protelphidium orbiculare.*

Deep-water group: *Bulimina marginata, Cassidulina laevigata, Hyalina balthica, Islandiella helanae, Islandiella norcrossi, Nonion labradoricum, Trifarina angulosa, Trifarina fluens, Uvigerina peregrina.*

The variations in the benthonic foraminiferal groups are shown in Fig. 3. In the lower part of the core (100-25 cm, lithological units VI, V and IV) the dominant species was *Elphidium excavatum* (and the percentage thus shown as faunal dominance in Fig. 3).

A typical faunal list for the lower interval is presented in Table 2. Especially one sample at 84 cm showed a higher content of plankto-

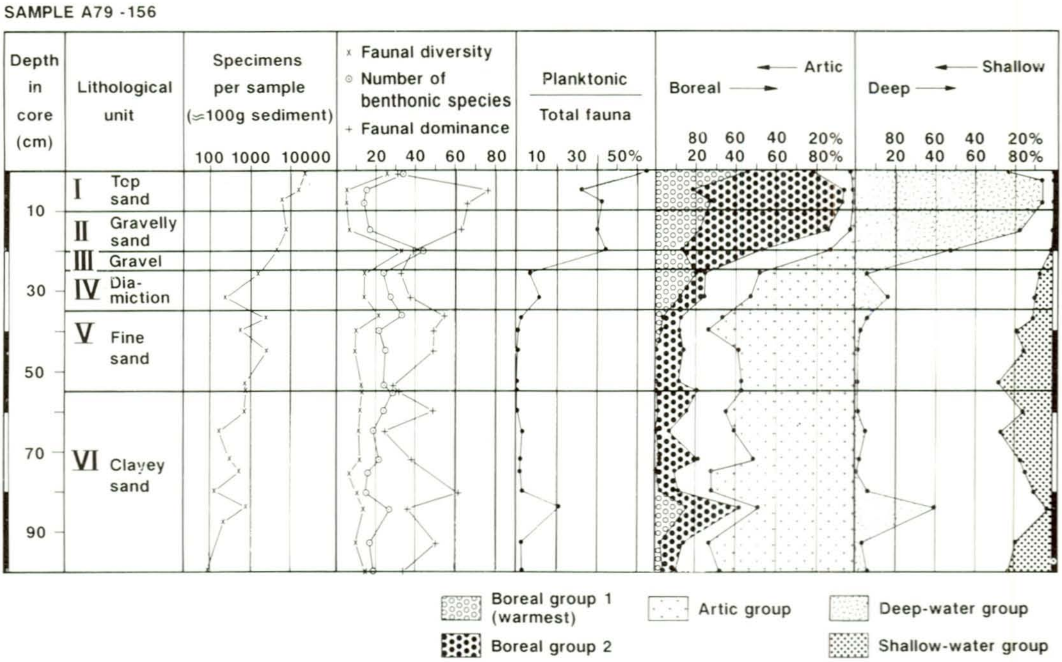

Fig. 3. Foraminiferal stratigraphy in core A79-156 with number of specimens and benthonic species per sample, faunal diversity and faunal dominance, content of planktonic foraminifera in percent of total fauna, and distribution of benthonic foraminiferal fauna groups. More details are given in the text.

	Frequency	Percentage
Benthonic species	200	98.0
Planktonic species	4	2.0
Benthonic species	**Frequency**	**Percentage**
Elphidium excavatum	100	50.0
Protelphidium orbiculare	33	16.5
Elphidium incertum	19	9.5
Elphidium spp.	14	7.0
Cassidulina reniforme	11	5.5
Cibicides lobatulus	6	3.0
Trifarina angulosa	3	1.5
Bulimina marginata	3	1.5
Elphidium albiumbilicatum	3	1.5
Cassidulina laevigata	1	0.5
Buccella tenerrimma	1	0.5
Oolina borealis	1	0.5
Oolina lineata	1	0.5
Oolina acuticosta	1	0.5
Oolina melo	1	0.5
Islandiella norcrossi	1	0.5
Islandiella spp.	1	0.5
Total	200	100

Table 2. Faunal list for sample A79-156, 90-95 cm. The complete sample was counted.

nic foraminifera in addition to deep-water and boreal benthonic species. The faunal list for this sample is shown in Table 3.

The gravel and gravelly sand from 25 to 10 cm (units III and II) show the transition from low-arctic to boreal conditions and a strong

	Frequency	Percentage
Benthonic species	298	78.4
Planktonic species	82	21.6
Benthonic species	**Frequency**	**Percentage**
Elphidium excavatum	105	35.2
Cassidulina laevigata	74	24.8
Cassidulina reniforme	30	10.1
Trifarina angulosa	26	8.7
Bulimina marginata	13	4.4
Elphidium spp.	13	4.4
Uvigerina peregrina	6	2.0
Protelphidium orbiculare	5	1.7
Textularia bocki	3	1.0
Buccella frigida	3	1.0
Trifarina spp.	3	1.0
Elphidium incertum	2	0.7
Cibicides lobatulus	2	0.7
Hyalinea balthica	1	0.3
Astronion gallowayi	1	0.3
Rosalina globularis	1	0.3
Elphidium bartletti	1	0.3
Oolina borealis	1	0.3
Bulimina gibba	1	0.3
Oolina hexagona	1	0.3
Quinqueloculina seminulum	1	0.3
Islandiella islandica	1	0.3
Fissurina marginata	1	0.3
Oolina melo	1	0.3
Fissurina danica	1	0.3
Oolina acuticosta	1	0.3
Total	298	100

Table 3. Faunal list for sample A79-156, 84 cm. Just a half of the sample was counted.

increase in both the deep-water group and the content of planktonic foraminifera.

The top 10 cm (unit I) contained a boreal shelf fauna dominated by *Cassidulina laevigata* and with a high content of planktonic foraminifera typical of fairly deep water (similar to present-day depths). It represents a top sand layer typical for the area (Skinner et al. 1983, Rise & Rokoengen 1984).

Regional distribution of the Middle Weichselian sand

The Quaternary sediments in the northern North Sea area have been investigated regionally based on sparker profiles and shallow sampling, in addition to data aquired from commercial investigations for oil field development. Regional reflectors have been mapped, dividing the sediments into seismostratigraphic units. On the northern North Sea Plateau the mappable regional reflectors commonly represent the top of thin (a few metres or less) sand layers dividing thick clay deposits (Rise et al. 1984, Skinner et al. 1986, Long et al. 1988).

An interpreted sparker section with the location of core A79 - 156 is shown in Fig. 4. The Quaternary sediments are divided in two by an irregular erosional surface (see also Fig. 5) believed to have been formed by an ice sheet following the Norwegian Trench in a north-northwesterly direction (Rokoengen & Rønningsland 1983). A closer description of this erosional feature falls outside the scope of the present paper, but it is probably of Saalian age.

Above the supposed glacial erosional surface, two regional reflectors with a northeasterly dip have been mapped on the plateau (Fig. 4 and the western part of Fig. 5). Our interpretation is that they represent the tops of sand layers separating thick firm clays. In the regional mapping the three resulting seismostratigraphic units have been named the Ferder (oldest), Cape Shore and Sperus Formations, respectively (Rise et al. 1984, Skinner et al. 1986, Long et al. 1988).

The reflector defining the top of the mapped sand layer becomes very flat on approaching the sea bed (Fig. 4), and the exact outcrop is difficult to define considering the normal sparker resolution of about 10 m. The westward extension of the top of the sand layer has, however, been mapped as shown in Fig. 6 (Rise at al. 1984, Skinner et al. 1986).

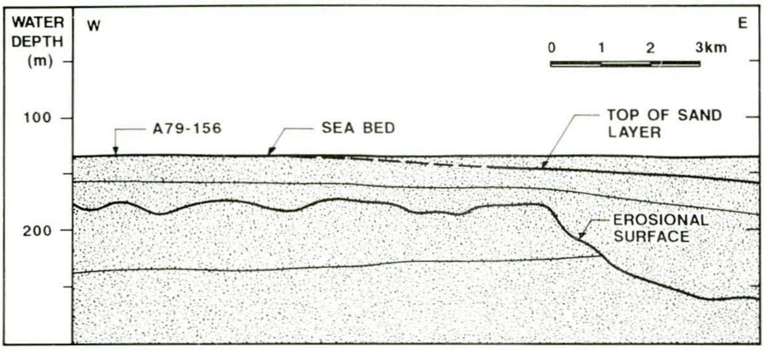

Fig. 4. Interpretation of an E - W sparker line showing the location of sample A79-156 relative to the assumed top of the sand layer. Location shown in Fig. 6.

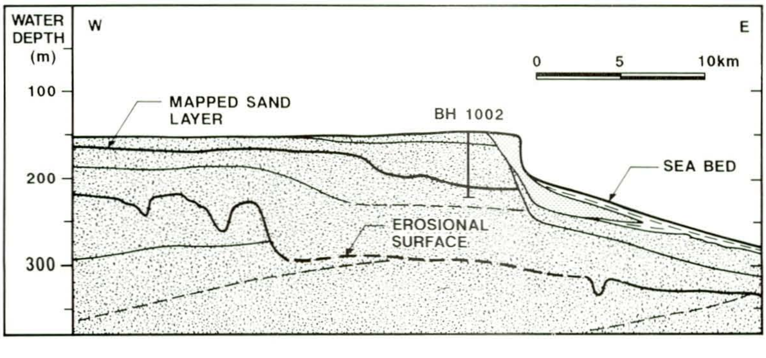

Fig. 5. Interpretation of an E - W sparker line showing the seismic stratigraphy on the northern North Sea Plateau and the western slope of the Norwegian Trench (after Rise at al. 1984). At the edge of the plateau there is a coastal unit of gravel and sand (dots), and with clay at greater water depths.

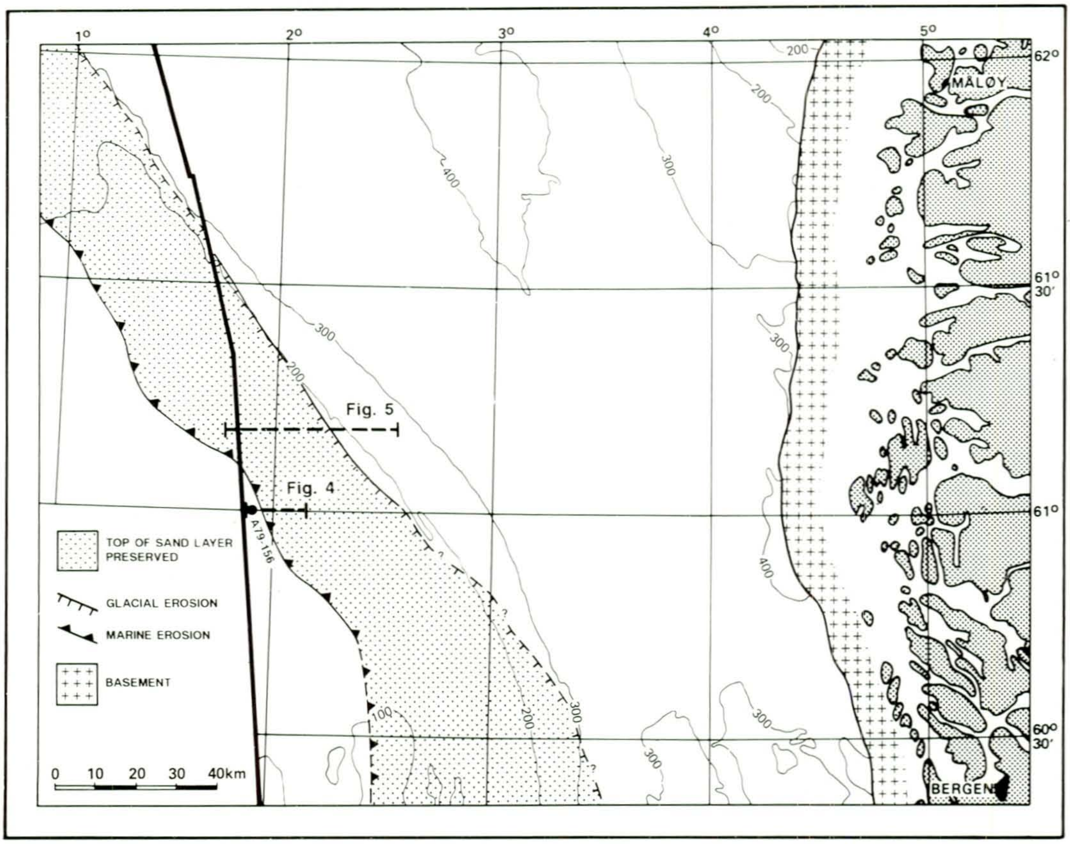

Fig. 6. Distribution of the 30,000 year-old sand layer based on the sparker interpretation. The extension of the layer to southeast is uncertain due to acoustic blanking, probably on account of the presence of shallow gas and a complex stratigraphy.

The Middle Weichselian part of core A79-156 (units VI and V) represents, in our opinion, a part of this regional sand layer. It has been sampled in several cores and boreholes in the British Sector, and also dated to 31,150 ± 1200 years B.P. in the Brent area less than 10 km west-northwest of sample A79-156 (Milling 1975, Skinner et al. 1986). A regional sand layer about 30,000 years old is thus well documented on the surface of the northern North Sea Plateau.

The reflector representing the mapped sand layer dips northeastwards and gets deeper below the sea bed towards the edge of the Norwegian Trench, as shown in the E - W section in Fig. 5. In borehole 1002 from the Gullfaks area the sand layer was penetrated at about 90 m below the sea bed (Rokoengen et al. 1982). Amino acid measurements on *Macoma calcarea* at 97 m below the sea bed gave 0.35 (Free) and 0.22 (Hyd). This is slightly higher than the values obtained for the same species in core A79-156 (Table 1). The borehole sample, however, was taken from below the sand layer. In addition, it has been buried deeper and we would expect that it has been subject to a slightly higher average temperature than the sample from core A79-156. The results from the amino acid measurements therefore support the notion that the sand layers from A79-156 and Borehole 1002 were deposited in the same period and strengthen the shallow-seismic interpretation.

Towards the northeast the sand layer is truncated in the western slope of the Norwegian Trench (Fig. 5). This truncation has been mapped regionally on sparker profile lines showing that the 30,000 year-old sediments are preserved over an area of more than 5,000 km² on the northern North Sea Plateau between 60°30'N and 62°N and continue towards both the northwest and the south (Fig. 6).

Discussion

Depositional environment of the Middle Weichselian sediments

The sediments below 35 cm in core A79-156 are all believed to represent the 30,000 year B.P. interval (Fig. 2). The grain-size distributions show decreasing clay and silt content from the base of the core and up to 35 cm. The samples show a strong resemblance to the present sea-bed sediments in the area, with the content of clay and silt decreasing up the slope and pure sand on the plateau (Skinner et al. 1983, Rise & Rokoengen 1984). The coarsening-upward trend in the lower part of the core could thus record decreasing water depth in the area of deposition.

The foraminiferal assemblages represent a glaciomarine shelf fauna deposited in a low-arctic environment and in fairly shallow water. Both the content of planktonic foraminifera and the 'deep-water group' show maximum values in the sample from 84 cm and then decrease upwards (Fig. 4). A more detailed interpretation of the depositional environment recorded in core A79-156 would thus be that the deepest and warmest conditions are recorded at around 84 cm. Later, shallower water and more arctic conditions prevailed, but there was still some influence of warmer Atlantic water up to 35 cm.

At around 30,000 years B.P. there also seems to have been deeper water and less clay deposition than in the periods both before and after. The sand may be a result of current erosion and transport, but aeolean transport should also be considered. Scanning electron microscopy (SEM) on sand in lithological unit V showed well rounded grains with possible aeolean features (Sindre 1980). The fairly rich benthonic foraminiferal faunas demonstrate, however, that the deposition took place in a marine environment.

As shown in the section in Fig. 5, the mapped sand layer is very flat-lying in the western part, followed by a slope and then again by a flatter part in the east. We believe that the reflector represents the sea-bed surface at the time of deposition, and interpret the morphology to represent a shallow shelf platform in the west with a paleoslope leading down to a deeper flat trench.

The morphology of the sand layer forming the old surface (Fig. 6) thus shows that landforms resembling the present Norwegian Trench existed 30,000 years ago. The trench, however, was not as deep as the present one and the shoulder of the North Sea Plateau was situated farther west.

The seismic interpretation shows that the growth of the North Sea Plateau towards the northeast took place both before and after the deposition of the sand layer about 30,000 years ago. The deep drillings and regional sampling in the area have demonstrated that clay is the dominant sediment type (Rise et al. 1984, Skinner et al. 1986). The coastal outbuilding of the northern North Sea Plateau thus seems to have been dominated by clay sediments transported by rivers from the south. The rivers were probably mainly confined to the subsiding Central and Viking Grabens and therefore did not enter the Norwegian Trench farther south. The transport of sediment to the edge of the plateau would have been most active in cold periods with low sea level. In periods with higher sea level (like today), most of the clay sedimentation would have taken place in the coastal areas (or in deeper water).

Late Weichselian glacial erosion

In mainland Norway, most of the 30,000 year-old interstadial sediments have been removed by the Late Weichselian ice sheet (Andersen & Mangerud 1989, Mangerud 1991 with more references). This is also the situation in the deeper parts of the Norwegian Trench where glacial erosion has removed sediments and cut the trench deeper than was the case 30,000 years ago (see Figs. 5 & 6). This glacial erosion is interpreted to have been made by a Late Weichselian ice sheet moving northwestwards along the Norwegian Trench (Rise & Rokoengen 1984) and it has limited the present eastward extent of the 30,000 year-old sediments in the area (Figs. 5 & 6).

The units interpreted as till in the eastern part of the plateau and in the trench have been mapped and described before (Rise at al. 1984, Skinner et al. 1986, Lehman et al. 1991 and others). Till is found along the edge of the plateau and in sea-bed samples and also occurs in the upper parts of boreholes. As the interpretation of the westward extension of till is based on sparker profiles with c. 10 m resolution, we consider it to represent a minimum extent of the till material (Rise & Rokoengen 1984).

The genetic interpretation of the diamicton in core A79-156 (35-25 cm) is not easy. We think, however, that the coarse lag deposit found on the top of the northern North Sea Plateau (Rise & Rokoengen 1984) represents the remnant of a till partly removed by marine erosion in the east and totally removed in the west. If this is correct the till extended across the median line at 61°N. In core A79-156 the unsorted sediment layer at 35 - 25 cm could represent a small remnant of the till material. Overconsolidation by ice would then also provide a simple explanation for the very hard sediments found in the core.

Marine erosion

Along the well-defined slope bordering the northern North Sea Plateau towards the Norwegian Trench, an up to 40 m-thick coastal unit of sand and gravel is found. The deposition of the 2 km broad and more than 50 km long unit started before 12,000 years B.P. and ended at about 10,000 years B.P. (Dekko & Rokoengen 1978, Rokoengen et al. 1982, Rise & Rokoengen 1984, Carlsen et al. 1986). The thick unit of sand and gravel deposited in the upper part of the slope gradually fines downslope (eastwards) into clay. The deposition and building out of this unit is believed to be simultaneous with the marine erosion which produced the flat top of the northern North Sea Plateau.

The westward extension of both the 30,000 year-old sediments (Figs. 5 & 6) and the overlying till material was determined by this major, marine, erosional event, leaving a very flat, assumed wave-cut platform (Rokoengen et al. 1982, Rise & Rokoengen 1984).

In core A79-156, the rounded gravel 25 - 20 cm (lithological unit III, Fig. 2) is believed to represent the lag from this marine erosion.

Regional correlation

During the last two decades a large number of sites with probable Early and Middle Weichselian sediments have been discovered and studied in Fennoscandia. In caves in western Norway, some thick sequences have been preserved (Larsen et al. 1987, Larsen & Mangerud 1989). Most of the sediments older than 15,000 years B.P. on land, however, have been removed by the Late Weichselian ice sheet and only thin stratigraphic fragments remain (Mangerud 1981, 1991, Andersen & Mangerud 1989). Due to this glacial erosion as well as serious dating problems, there are still many unanswered questions in the Fennoscandian record.

Along the west coast of Norway, however, there is good evidence for an interstadial at about 30,000 years B.P. This Ålesund interstadial is dated both by marine fossils (Mangerud et al. 1981) and by material from caves (Larsen et al. 1987). The faunas suggest cool climatic conditions, but with the presence of Atlantic water. The Ålesund interstadial may correlate with the Denekamp interstadial in western Europe (Andersen & Mangerud 1989, Larsen & Sejrup 1990). Based on the radiocarbon dates we correlate the mapped sand sediments on the northern North Sea Plateau with the same interstadial period.

The difference between mainland Scandinavia and the northern North Sea continental shelf in terms of sediment preservation is striking. While only small sections are present on land, the 30,000 year-old sediments are preserved in an area of more than 5,000 km^2 on the northern North Sea Plateau between 60°30'N and 62°N and also extend towards the northwest and the south (Fig. 7).

The period with interstadial conditions about 30,000 years ago in western Norway is recorded as an influx of Atlantic water on the shelf (Sejrup et al. 1987, Larsen & Sejrup 1990, Mangerud 1991 and others). On the North Sea Plateau, the present study has demonstrated the existence of a 30,000 year-old sand layer separating thick clay deposits.

Older periods with interstadial conditions in mainland Norway will probably also be represented by similar sand layers on the North Sea Plateau and may possibly be detected by seismic methods, like the northwest-dipping reflector mapped between the 30,000 year-old sand and the erosional reflector (Fig. 4).

Acknowledgements

The initial fieldwork for the present paper formed a part of the general mapping programme of the Norwegian Continental Shelf by IKU, and was financed by the Royal Norwegian Council for Scientific and Industrial Research. Eirik Lande identified the macrofossils, and the illustrations were prepared by Berit Fossum, IKU and Anne Irene Johannessen, NTH. We are very grateful to all who participated during field and laboratory work and in later discussions. We would especially like to thank the referees Eilif Larsen and Inge Aarseth for their critical comments and David Roberts, NGU, for improving the English language in the final manuscript.

References

Andersen, B. G. & Mangerud, J. 1989: The last interglacial- glacial cycle in Fennoscandia. *Quat. Intern. 3/4*, 21- 29.

Carlsen, R., Løken, T. & Roaldset, E. 1986: Late Weichselian transgression, erosion and sedimentation at Gullfaks, northern North Sea. *In:* Summerhayes, C.P. & Shackleton, N.J. (eds): *North Atlantic Palaeoceanography*. Geol. Soc. Spec. Publ. 21, 145-152.

Dekko, T. & Rokoengen, K. 1978: A submerged beach in the northern part of the North Sea. *Nor. Geol. Tidsskr. 58*, 233-236.

Feyling-Hanssen, R. 1958: Mikropaleontologiens teknikk. *Nor. geol. unders. 203*, 35-48.

Feyling-Hanssen, R. 1983: Quantitative methods in micropaleontology. *In* Costa, L. I. (ed.): *Palynology-micropalaeontology: laboratories, equipment and methods*. Norwegian Petroleum Directorate Bull. 2, 109-128.

Gulliksen, S. 1979: Hvor nøyaktig er 14-C metoden? *In* Nydal, R., Westin, S., Hafsten, U. & Gulliksen, S. (eds.): *Fortiden i søkelyset. 14-C datering gjennom 25 år*. Laboratoriet for Radiologisk Datering, Trondheim, 69-80.

Hald, M., Danielsen, T.K. & Lorentzen, S. 1989: Late Pleistocene and Holocene benthic foraminiferal distribution in the southwestern Barents Sea: paleoenvironmental implications. *Boreas 18*, 367-388.

Hald, M. & Vorren, T. 1984: Modern and Holocene foraminifera and sediments on the continental shelf off Troms, North Norway. *Boreas 13*, 133-154.

Hald, M. & Vorren, T. 1987: Foraminiferal stratigraphy and environments on the continental shelf off Troms, Northern Norway. *Marine Micropaleontology 12*, 129-160.

Larsen, E., Gulliksen, S., Lauritzen, S.-E., Lie, R., Løvlie, R. & Mangerud, J. 1987: Cave stratigraphy in western Norway; multiple Weichselian glaciations and interstadial vertebrate fauna. *Boreas 16*, 267-292.

Larsen, E. & Mangerud, J. 1989: Marine caves: On - off signals for glaciations. *Quat.Intern. 3/4*, 13-19.

Larsen, E. & Sejrup, H.P. 1990: Weichselian land-sea interactions: Western Norway - Norwegian Sea. *Quat.Sci. Rev. 9*, 85-97.

Lehman, S.J., Jones, G.A., Keigwin, S.D., Andersen, E.S., Butenko, G. & Østmo, S.R. 1991: Initiation of Fennoscandian ice-sheet retreat during the last deglaciation. *Nature 349*, 513-516.

Long, D., Skinner, A. C. & Rise, L. 1988: Quaternary geology. Halibut Bank. Sheet 60°N - 0°. *British Geological Survey, Edinburgh, in cooperation with Continental Shelf Institute, (IKU) Trondheim. 1 : 250 000 Series.*

Løfaldli, M., Rise, L. & Rokoengen, K. 1981: Foraminiferfaunaer i prøver fra Norskerenna og Nordsjøplatået mellom 60°30' og 62°N, tokt 7910. *Continental Shelf Institute (IKU). Project report P-155/7/81*, 26pp.

Mangerud, J. 1981: Weichselian before 15,000 years B.P. in the Nordic countries: a symposium. *Boreas 10*, 295-296.

Mangerud, J. 1991: The last interglacial/glacial cycle in Northern Europe. *In:* Shane, L.C.K. & Cushing, E.J. (eds.): *Quaternary Landscapes*. University of Minnesota Press. Mineapolis, 38-75.

Mangerud, J., & Gulliksen, S. 1975: Apparent radiocarbon ages of recent marine shells from Norway, Spitsbergen and Arctic Canada. *Quat. Res. 5*, 263-273.

Mangerud, J., Gulliksen, S., Larsen, E., Longva, O., Miller, G., Sejrup, H.P. & Sønstegaard, E. 1981: A Middle Weichselian ice-free period in Western Norway: the Ålesund Interstadial. *Boreas 10*, 447-462.

Miller, G. H., Sejrup, H. P., Mangerud, J. & Andersen, B. 1983: Amino acid ratios in Quaternary molluscs and foraminifera from western Norway: Correlation, geochronology and paleotemperature estimates. *Boreas 12*, 107-124.

Milling, M. E. 1975: Geological appraisal of foundation conditions, northern North Sea. *Conference paper Oceanology International 75, Brighton, England*, 310-319.

Rise, L. & Rokoengen, K. 1984: Surficial sediments in the Norwegian sector of the North Sea between 60°30' and 62°N. *Marine Geology 58*, 287-317.

Rise, L., Rokoengen, K., Skinner, A. C. & Long, D. 1984: Northern North Sea. Quaternary Geology map between 60°30' and 62°N, and east of 1°E. M 1 : 500 000. *Continental Shelf Institute (IKU), Trondheim, in cooperation with British Geological Survey, Edinburgh.*

Rokoengen, K., Bell, D.G., Bugge, T., Gunleiksrud, T., Lien, R.L. & Løfaldli, M. 1979: Shallow geology of the continental shelf off North Norway. *POAC 79. Port and Ocean Engineering under Arctic Conditions*, 859-875.

Rokoengen, K., Erlenkeuser, H., Løfaldli, M. & Skarbø, O. 1991: A climatic record for the last 12,000 years from a sediment core on the Mid-Norwegian Continental Shelf. *Nor. Geol. Tidsskr. 71*, 75-90.

Rokoengen, K., Løfaldli, M., Rise, L., Løken, T. & Carlsen, R. 1982: Description and dating of a submerged beach in the northern North Sea. *Marine Geology 50*, M21-M28.

Rokoengen, K. & Rønningsland, T.M. 1983: Shallow bedrock geology and Quaternary thickness in the Norwegian sector of the North Sea between 60°30' and 62°N. *Nor. Geol. Tidsskr. 63*, 83-102.

Sejrup, H.P., Holtedahl, H., Norvik, O. & Miljeteig, J. 1980: Benthonic foraminifera as indicators of the paleoposition of the Subarctic Convergence in the Norwegian - Greenland Sea. *Boreas 21*, 74-84.

Sejrup, H.P., Rokoengen, K. & Miller, G.H. 1984: Isoleucine epimerization in Quaternary benthonic foraminifera from the Norwegian Continental Shelf: A pilot study. *Marine Geology 56*, 227-239.

Sejrup, H.P., Aarseth, I., Ellingsen, K.L., Reither, E., Jansen, E., Løvlie, R., Bent, A., Bingham-Grette, J., Larsen, E. & Stoker, M. 1987: Quaternary stratigraphy of the Fladen area, central North Sea: a multidisciplinary study. *Jour. Quat. Sci. 2*, 35-58.

Sindre, E. 1980: SEM - analyser av noen utvalgte sandprøver fra Nordsjøplatået, tokt 7910. *Continental Shelf Institute (IKU). Project report P-155/3/80*, 69pp.

Skinner, A.C., Graham, C., Long, D., Rokoengen, K., Rise, L. & Sindre, E. 1983: Sea bed sediments. Cormorant. Sheet 61°N - 0°. *Institute of Geological Sciences, Edinburgh, in cooperation with Continental Shelf Institute (IKU), Trondheim. 1 : 250 000 Series.*

Skinner, A.C. & Gregory, D.M. 1983: Quaternary stratigraphy in the northern North Sea. *Boreas 12*, 145-152.

Skinner, A.C., McElvanney, E., Rucley, N., Rise, L. & Rokoengen, K. 1986: Quaternary geology. Cormorant. Sheet 61°N - 0°. *British Geological Survey, Edinburgh, in cooperation with Continental Shelf Institute (IKU), Trondheim. 1 : 250 000 Series.*

Walton, W. R. 1964: Recent foraminiferal ecology and paleoecology. *In* Imbrie, J. & Newell, N. D. (eds.): *Approaches to Paleoecology*. John Wiley, New York, 151- 237.

Manuscript received August 1992; revised typescript Desember 1992; accepted January 1993.