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SOUTHERN NORTH SEA PROJECT BOREHOLE BH 89/1 : A TECHNICAL REPORT

by

Vincent MAENHAUT VAN LEMBERGE[1]

ABSTRACT

The EEC 'Southern North Sea Project - Quaternary Geology' was carried out between 1989 and 1991. The project included geologists from the Geological Surveys of five countries : the Netherlands, Great-Britain, Germany, Denmark and Belgium. The major goal of the project was to study and to reconstruct the development of the Southern North Sea Basin during the Quaternary. To this end 9 boreholes were drilled in the Southern North Sea. These were complemented by a seismic survey, connecting most of the boreholes. A complete report is given here of the different investigations which were carried out on the Belgian core, BH 89/1, situated in the north-eastern part of the Belgian Continental Shelf. The investigations include the geographical and geological setting of the Belgian borehole, the lithological and sedimentological analysis of the core and the determination of the heavy minerals, of the isothermal remanent magnetization of the magnetic minerals and of the clay mineral composition. Furthermore different samples were analysed for their dinoflagellate and foraminiferal content. The age of organic fragments found in a sample was determined using C^{14}-dating. The sequences in the borehole were related to seismo-stratigraphic units identified on available seismic lines from this part of the Belgian Sector.

On the basis of the obtained data, the following conclusions could be drawn. The Tertiary deposits belong to the Lower Eocene (Gent Formation, Ieper Group). They were deposited in a shallow marine environment. These deposits are covered by Quaternary sediments which fill a valley-like depression scoured in Tertiary deposits. The lower Quaternary sequence consists of probably reworked marine sands, deposited by a fluvial or fluvio-periglacial system during the Weichselian. This sequence is related to or might belong to the Kreftenheye Formation. The upper Quaternary sequence has a Holocene age and consists of the active seabed sediments. This sequence corresponds with the Bligh Bank Formation.

KEYWORDS

Belgian Continental Shelf, Southern North Sea, Quaternary deposits, sedimentology, micropalaeontoloy, seismo-stratigraphy.

SAMENVATTING

Het EEG-projekt 'Southern North Sea Project - Quaternary Geology' werd uitgevoerd tussen 1989 en 1991. Het bundelde de krachten van de Geologische Diensten van vijf landen : Nederland, Groot-Brittannië, Duitsland, Denemarken en België. Doel was de ontwikkeling van het Zuidelijke Noordzeebekken gedurende het Kwartair te bestuderen en te rekonstrueren. Hiertoe werden 9 boringen uitgevoerd. Dit werd aangevuld door een seismische kampagne in de Zuidelijke Noordzee die de meeste boringen met elkaar verbindt. Een volledig verslag van de analyses

[1] Formerly employed at the Belgische Geologische Dienst, Jennerstraat 13 - B-1040 Brussel ; Vrije Universiteit Brussel, Pleinlaan 2 - B-1050 Brussel. Presently employed at Haecon N.V., Deinsesteenweg 110 - B-9031 Drongen.

die werden uitgevoerd op de Belgische boring, BH 89/1, gelegen in het noordoostelijk deel van het Belgisch Kontinentaal Plat, wordt hier weergegeven. De analyse omvat een geografische en geologische situering van de Belgische boring, de lithologische en sedimentologische analyse van de boorkern en het bepalen van de zware mineralen, van de isothermale remanente magnetisatie van de magnetische mineralen en van de kleimineralen. Verder werden verscheidene monsters onderzocht voor dinoflagellaten en foraminiferen. De ouderdom van organische resten aangetroffen in een monster werd bepaald door middel van C^{14}-datering. De sekwenties aangetroffen in de boring werden gekorreleerd met seismisch-stratigrafische eenheden die onderscheiden kunnen worden op beschikbare seismische lijnen afkomstig van dit gedeelte van de Belgische sektor.
Op basis van de bekomen gegevens kan men tot volgende konklusies komen. De tertiaire afzettingen behoren tot het Onder Eoceen (Formatie van Gent, Ieper Groep). Ze werden afgezet in een ondiep marien milieu. Deze afzettingen worden bedekt door kwartaire sedimenten die een vallei-achtige depressie opvullen. Deze is uitgeschuurd in de tertiaire afzettingen. De onderste kwartiare sekwentie bestaat uit waarschijnlijk herwerkte mariene zanden, afgezet door een fluviatiel of fluvio-periglaciair systeem gedurende het Weichsel. Deze sekwentie is geassocieerd met of behoort tot de Kreftenheye Formatie. De bovenste kwartiare sekwentie is van holocene ouderdom en omvat de huidige zeebodem afzettingen. Deze sekwentie komt overeen met de Bligh Bank Formatie.

SLEUTELWOORDEN

Belgisch Kontinentaal Plat, Zuidelijke Noordzee, kwartaire afzettingen, sedimentologie, mikropaleontologie, seismo-stratigrafie.

RESUME

Le projet de la CEE 'Southern North Sea Project - Quaternary Geology'a été exécuté entre 1989 et 1991. Ce projet réunissait les Services Géologiques de cinq pays : les Pays-Bas, la Grande-Bretagne, l'Allemagne, le Danemark et la Belgique. Le but de ce projet était d'étudier et de reconstruire le développement du Bassin de la Mer du Nord méridionale pendant le Quaternaire. A cet effet 9 forages, de même qu'une campagne sismique qui relie la plupart de ces forages, ont été éxécutés dans la Mer du Nord méridionale. Un rapport complet des analyses effectuées sur le forage belge est présenté. Ce forage est situé dans la partie nord-est du Plateau Continental belge. Les analyses comprennent une description de la géographie et la géologie du forage belge, l'analyse lithologique et sédimentologique de la carotte et la détermination des minéraux lourds, de la magnétisation isothermique rémanente des minéraux magnétiques ainsi que des minéraux argileux. Ensuite différents échantillons ont été analysés pour leur contenu en dinoflagellés et en foraminifères. L'âge de fragments organiques retrouvés dans un échantillon a été déterminé par une datation C^{14}. Les séquences retrouvées dans le forage ont eté correlées avec les unités sismo-stratigraphiques identifiées sur les données sismiques disponibles dans cette partie du secteur belge.
En se basant sur les données obtenues, on peut tirer les conclusions suivantes. Les dépôts tertiaires font partie de l'Eocène inférieur (Formation de Gent, Groupe de Ieper). Ils ont été déposés dans un milieu marin de faible profondeur. Ces sédiments sont recouverts de sédiments quaternaires qui comblent une dépression de vallée, érodée dans les dépôts tertiaires. La séquence quaternaire inférieure se compose de sables marins probablement remaniés, déposés pendant le Weichselien par un système fluviatile ou fluviopériglaciaire. Ce dépôt est associé à (ou appartient à) la Formation de Kreftenheye. La séquence quaternaire supérieure a un âge holocène et se compose de sédiments marins actuels de fond de mer.

MOTS-CLES

Plateau Continental belge, Mer du Nord méridionale, sédiments quaternaires, sédimentologie, micropaléontologie, sismo-stratigraphie.

1. INTRODUCTION

1.1. General

The EEC 'Southern North Sea Project - Quaternary Geology' was carried out between 1989 and 1991. This multidisciplinary project included geologists from the Geological Surveys of the Netherlands, Great-Britain, Germany, Denmark and Belgium for a period of two years. The major objective was to study and to reconstruct the Quaternary Geological history of the Southern North Sea Basin. To this end, nine EEC-funded boreholes were drilled in the Southern North Sea (figure 1). These were complemented by a nationally funded geophysical survey, completing the Cromer-Sylt line and linking six of the boreholes (89/3-7, 89/9).

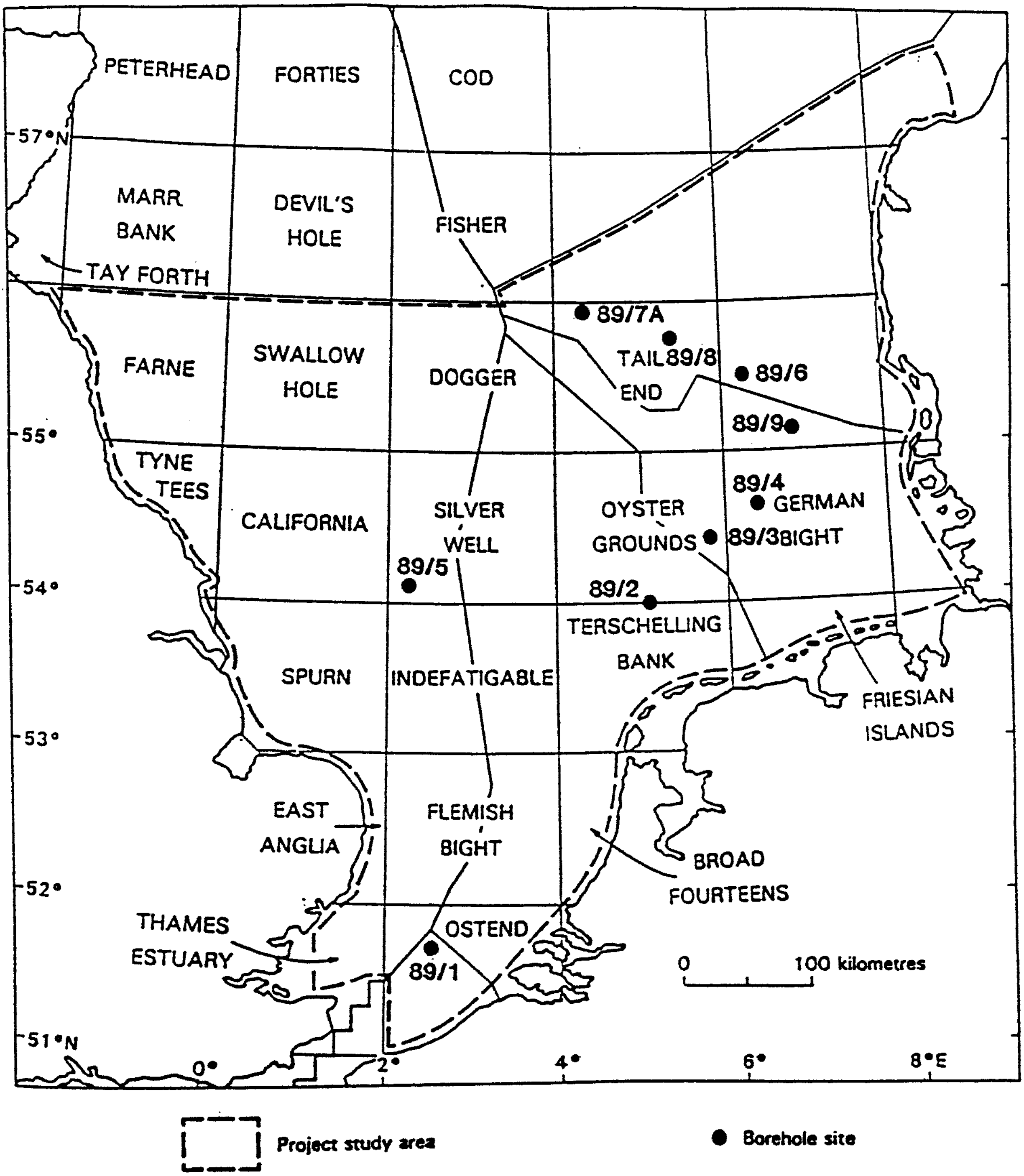


Figure 1. Project study area (dashed line) and borehole sites.

This paper presents the results of the Belgian borehole, BH 89/1. The borehole was drilled in the north-easternpart of the Belgian Continental Shelf, 12km north of the Noordhinder sand bar (geogr. coor.: 51°44.34'N, 2°32.03'E ; UTM coor.: 5.732.651N, 467.836E). The waterdepth at the drillsite is -34.56m MLLWS (-37m MSL). The core has a length of 36.14m.

The choice of the site was based on seismic information which indicated a significant thickness of likely Quaternary deposits. The underlying deposits were assumed to be of Palaeogene age.

1.2. Geographical framework

The southern part of the North Sea is a rather shallow epicontinental and macrotidal sea with water depths of mostly less than 50m. This area, known as the Southern Bight, has strong tidal currents; ebb currents flow to the south and flood currents flow to the north. The net current resulting from these tidal movements trends

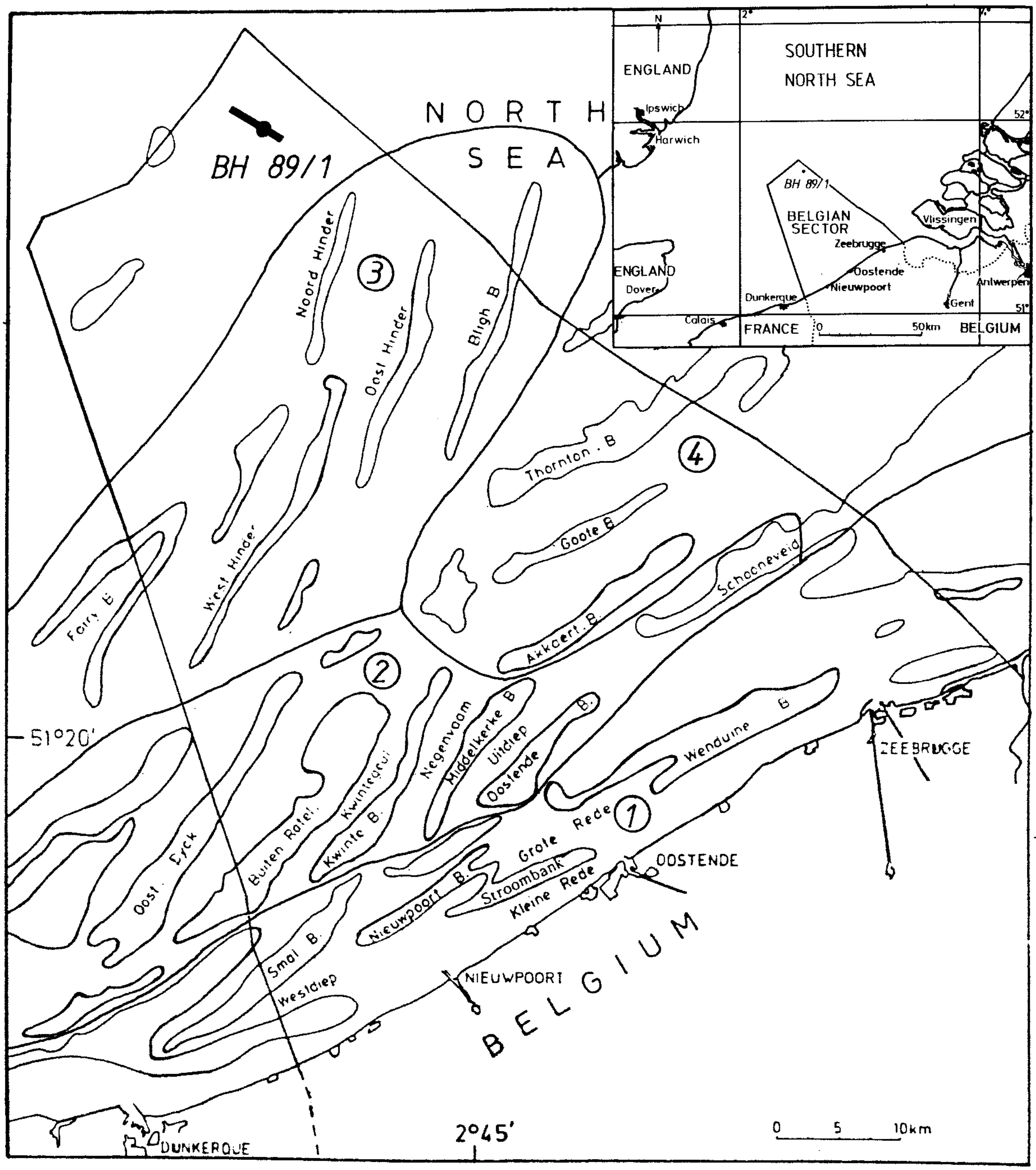


Figure 2. The Belgian Continental Shelf and the different sand bars : the Nearshore Coastal Banks (1), the Flemish Banks (2), the Hinder Banks (3) and the Zeeland Ridges (4). Solid line through borehole location corresponds with seismic profile. Compiled and modified after Bastin (1974), Willems (1989), De Moor (1989) and Houthuys (1990).

towards the north-east on the Belgian Continental Shelf, the flood currents being slightly stronger.

The Hinder Banks, to which the Noordhinder belongs, are part of a complex of large offshore sand bars (tidal current ridges) in the Southern North Sea off the Belgian and Dutch coasts (figure 2). These offshore sand bars reach lengths of tens of kilometers, widths of up to a few kilometers and relative heights of up to 30m. They are mostly transversely asymmetric and are separated by swales which are broader than the bars and which reach depths between 10-30m. Dissimilarities in orientation and position differentiate these bars into several groups.

The Nearshore Coastal Banks run parallel to the shore and to the tidal currents and have a steep landward slope (Wartel & Van Sieleghem, 1986). They are situated between the highwater line and a line more or less 10km off the coast.

The Flemish Banks are located farther from the coast and are longitudinal, NE-SW orientated parallel bars.

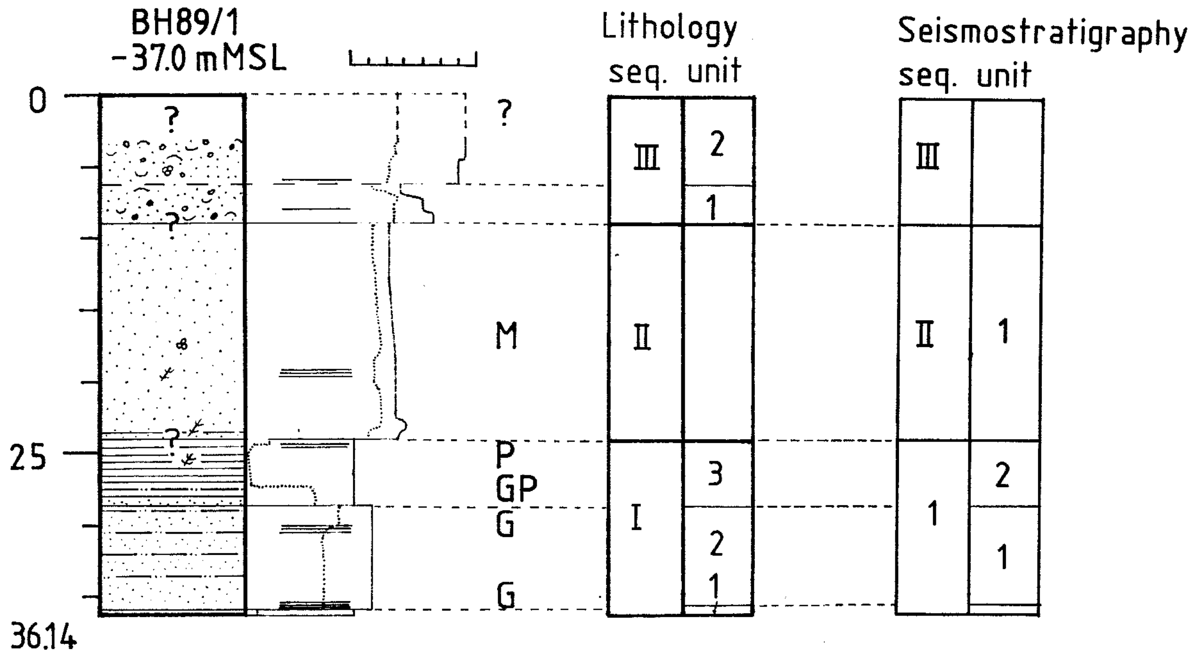


Figure 3. Sedimentological log of BH 89/1. The solid curve reflects the maximum grain size, obtained by comparative microscopic analysis ; the dotted line reflects teh mean grain size, as obtained by grain-size analysis. The correlation between lithological subdivision and seismostratigraphy is also shown.

The Hinder Banks are the farthest offshore and have a more or less N-S orientation. Each bank is about 35km long, about 30m high and have a depth of 5-10m below MLLWS. The Hinder and Flemish Banks are separated by a channel-like depression and bordered to the north and west by a flat or almost flat sea-bottom.

The sea-bottom north of the Hinder Banks is covered by 'asymmetric megaripples' with heights of up to 9m (Houbolt,1968). According to Nio (1976) megaripples with heights of up to 9 m can be called sandwaves. Dalrymple (1984) uses the term sandwave to refer to bedforms which are sufficiently large to have megaripples superimposed on them. Sandwaves are common in shallow water tidal environments.

10 km north of the Hinder Banks, steep slopes of the megaripples (foresets) predominantly dip to the south, due to net sand transport to the south (Stride, 1989, figure 1). According to McCave *et al.* (1977) this sea-bottom is part of an active sandwave field that extends northwards into the Dutch sector. The sandwaves can also be distinguished on figure 17.

The Zeeland Ridges are situated in the eastern part of the Belgian Continental Shelf. They have a W-E orientation.

The Flemish Banks, Hinder Banks and Coastal Banks were formed by active sand accumulation, but the Zeeland Ridges formed at least partly by erosion of the sea floor (Houbolt, 1968). According to Laban *et al.* (1981) several of the Zeeland Ridges seem to be formed by sand accumulation on top of or against an older core. The Hinder Banks have a stable position. Northward and southward sand transport over the bars are roughly in equilibrium. The Flemish Banks have undergone minor changes in shape and size during the last 300 years (Houbolt, 1968).

1.3. Geological setting

The south-western part of the Southern Bight of the North Sea is situated on top of the Palaeozoic London-Brabant Massif (Henriet *et al.*, 1989). This Massif was covered first by Upper Cretaceous chalk and then by a sequence of Palaeogene deposits, which dip about 0.5° towards the north-north-east. This dip is due to the combined effect of later subsidence of the North Sea Basin and the tectonic activity of the Weald-Artois anticline.

The thickness of the Palaeogene deposits increases towards the NNE (Van Den Broeke, 1984). The oldest Tertiary deposits within the Belgian Coastal Shelf are of Ypresian age in the west and the youngest are of Priabonian age in the east.

In the northern part of the Belgian Continental Shelf, the base of the Quaternary deposits cannot be recognized from the seismic data without borehole control (Mostaert *et al.*, 1989). Therefore in this area the erosional surface described is situated at the base of the Neogene.

The erosional surface at the base of the Quaternary or Neogene deposits that overlie the Palaeogene deposits has been studied by Van den Broeke (1984) and Mostaert *et al.* (1989). The top of the Tertiary dips from the SE (-30m MLLWS) to the NW and W. The morphology of the erosional surface off the Belgian coast shows a seaward dipping marginal slope, followed by a central abrasion platform. The mid-Southern Bight drainage channel borders this surface to the north-west. The marginal slope is transected by the IJzer valley system and the Ostend Valley. The north and north-western parts of the erosional surface are characterized by several scattered SW-NE orientated, asymmetrical depressions (-60 to -65m MLLWS). These are probably remnants of a fluvial palaeovalley system (Van den Broeke, 1984 ; Mostaert *et al.*, 1989).

The erosional surface is covered by thin Quaternary deposits with an average thickness of 5m. The study area does not show any direct effects of Pleistocene glaciations (Oele & Schüttenhelm, 1979 ; Streif, 1990). However, fluvio-periglacial erosive and depositional action of Weichselian rivers might have occurred (Gullentops *et al.*, 1977). In the northern part of the Belgian Continental Shelf, the Quaternary deposits are usually less than 5 m thick, but in the depressions they reach a thickness of 15-20m. North of the Belgian Continental Shelf the Quaternary deposits thicken to more than 400m in a NE direction within the Flemish Bight sheet (Cameron *et al.*, 1989a).

2. RESULTS OF THE INVESTIGATION

2.1. General

In order to obtain a clear distinction between the different types of sequences and units, the identified lithological and seismo-stratigraphic sequences and units have been labelled with a character between brackets, (L) or (S) respectively.

2.2. Lithological description

The borehole BH 89/1 recovered 24 m of Quaternary deposits and reached the Tertiary deposits at a depth of about 24m below seabed (-58.56m MLLWS). There is only limited lithological variation within the Quaternary section. No core was recovered from the top 3m of the borehole. Because of the dominantly sandy facies of the Quaternary deposits recovered, the sediments suffered extensive disturbance during drilling and recovery of the core.

It is worth mentioning that a sample taken from the core at a depth of 3.03m (-37.59m MLLWS, top of the core) could not be analyzed because of strong petroleum-derived pollution (RCMG, 1991). It could not be established whether this pollution was caused during drilling, which is most probable, or whether it occurs at the drillsite.

The lithological descriptions were tuned (words in bold characters) from the results of the grain-size analysis, using Shepard's (1954) nomenclature. The descriptions are summarized in figure 3.

Three major sequences could be recognized.

Sequence (L)I

The upper boundary occurs within a zone of no core recovery. Below about 24 m in the borehole, the sediments consist of glauconite- and mica-rich dark greenish grey clays and sands. Based on lithological characteristics, three units could be distinguished.

Unit (L)I.1

35.80m to bottom of the core : this unit has a sharp upper boundary. The sediments consist of silty and sandy, firm to stiff clay, with small lenses of silt and very fine sand. The sediments are rich in glauconite.

Unit (L)I.2

28.66m to 35.80m : The upper boundary occurs within a zone of no core recovery. The sediments consist of very fine, moderately to well sorted, slightly clayey sand and fine, horizontally laminated, silty sand. Most of the grains are subrounded to subangular quartz grains but abundant glauconite grains can be recognized. The sediments also contain large mica flakes. Near the base they are interlaminated with thin laminae of silty, firm clay. The basal 6cm is a partly cemented, Fe-stained sand concretion (hardground ?) which contains some burrows filled with looser and coarser-grained sand. The sediments are non-calcareous.

Unit (L)I.3

24m to 28.66m : The upper and lower boundaries occur within zones of no core recovery. The sediments consist of silty and slightly sandy, firm-stiff, friable and massive, occasionally slicken sided clay, with scattered sand and silt streaks, lenses and laminae. Their fresh colour is blue, but they contain black monosulfide knots, lenses and streaks, pyrite concretions and oxidized sandy pods, mostly in the vicinity of decomposed organic material. The sediments are glauconite- and mica-rich and occasionally contain plant-fragments (reed ?), disseminated or concentrated in organic rich clay laminae. At the top the sediments are slightly sandy, near the base they are interbedded with lenses, pods and thin beds of silty sand. The sediments are non-calcareous or only slightly calcareous.

Sequence (L)II

The upper and lower boundaries occur within zones of no core recovery. Between about 9m to about 24m in the borehole, the sediments consist of moderately well sorted silty fine sand. These sands contain minor lithic grains and very sparse shell fragments and mica. Most of the grains are subangular to angular, subrounded to rounded quartz grains. The sediments have an olive grey colour. Towards the base of this sequence, an increase of small black lithic grains could be noticed. The sequence includes some zones with discrete organic fragments (including wood and peat debris), occasionally concentrated in diffuse, horizontal to subhorizontal brown-black laminae. The base of the unit consists of slightly clayey, irregular laminae with strongly decomposed peat (gyttja-like). The sediments in L(II) are calcareous.

Sequence (L)III

The upper and lower boundaries of this sequence occur within zones of no core recovery. Between 3m and about 9m below seabed, the sediments consist of brown to yellowish brown and grey to brownish grey sands. Based on lithological characteristics, two units could be distinguished.

Unit (L)III.1

6.22m to 9m: The basal unit consists of fairly well sorted fine to medium sand. Its lower boundary occurs within a zone of no core recovery. The sands are slightly gravelly (small quartz and flint pebbles) and contain minor lithic grains, shells, shell fragments and reworked shell remains. Most of the grains are angular to subrounded quartz. The sediments have a grey to brownish grey colour. Occasional rounded mudballs (silt and clayey siltpebbles) with a diameter of up to 4cm occur. Some diffuse coarse, fine and thin argillaceous laminae can be distinguished. The sands are calcareous.

Unit (L)III.2

3m to 6.22m: The sediments consist of fairly well sorted medium sand. The sands are slightly gravelly (containing subangular flint) at the top and base and contain shell fragments and minor lithic grains. Most of the sand is composed of subangular to subrounded quartz. The sediments have a brown to yellowish brown colour. At the base of this unit, diffuse laminae contain a higher concentration of shell debris, and some diffuse clayey laminae could be recognized. The sands are only slightly calcareous.

2.3. Sediment colours

Van Straaten (1954) distinguished three colour zones in tidal flats and channel zones in the Wadden Sea (the Netherlands) according to the state of the authigenic iron. These are, from the surface downwards: Hydroxide-zone (L), Monosulfuric zone (M) and Bisulfuric zone (P). According to the original on-board descriptions, unit (L)III.2 (3-6.22m) had a brown or yellowish brown colour upon recovery. This is the case with most of the North Sea sands (Houbolt, 1968) and is due to the presence of ferri-hydroxide coatings on the surface of the grains in the L-zone. Van Straaten (*ibid.*) recorded thicknesses of only 60cm or less within the L-zone. The thickness of the hydroxide zone depends on the porosity of the sediments, their rate of sedimentation and the activity of the burrowing animals. The oxidation state of the sands probably indicates the recent and active character of these sediments. Oxidation to this extent is only made possible by continuous and very intense reworking of the sands in oxygen-rich water.

Precipitates of iron hydroxides can only be formed in well oxygenated environments, for instance when the sand grains were lying at or near the surface of the sediment or when they were moving over it (Van Straaten, 1965).

According to the shipboard core descriptions, unit (L)III.1 (6.22-9.00m) had a dark grey to grey colour upon recovery. This colour is due to the monosulfuric state of the iron in this zone, the M-zone. After description, these sediments were transformed from M to P within a few hours. The monosulfuric state only occurs in anaerobic conditions, within sediments that can have a thickness of several meters (Van Straaten, 1954).

Sequence (L)II also had a dark grey to olive grey colour upon recovery. After analysis, these sediments turned olive grey in colour, probably as a result of minor oxidation.

2.4. Grain-size analysis, $CaCO_3$ and organic content

Methods

At least one sample was collected from each metre of core in most of the units. Additional sampling was carried out above and below each important lithological boundary. Where only minor changes were observed within a sequence, samples were taken at two metre intervals. The samples were analyzed by the Lithostratigraphic Department of the Renard Centre for Marine Geology (RCMG) at the Rijks Universiteit Gent (RUG) for their grain-size distribution, $CaCO_3$ content and organic content. The sample numbers and corresponding depths are shown on table 1.

For the grain-size analysis, the following procedure was used. Each sample was sieved on a 500µm-sieve. The fraction < 500µm was analysed for its grain-size distribution and characteristics such as $CaCO_3$ and organic matter. The fraction > 500µm was weighed and the detrital fraction separated from shells and cementations, as these might have interfered with the granulometrical analysis. These fractions were also weighed. When more than 1% of the fraction > 500µm turned out to be detrital, it was included in the grain-size analysis.

The fraction < 500µm was divided into coarse and fine fractions by wet-sieving on a 53µm sieve. The coarse fraction was mechanically subdivided on a sieve-series with a successive difference in mesh width of 0.25ϕ The fine fraction was analyzed with a Micromeritics Sedigraph and the results were plotted on an inverse cumulative graph with 1/16ϕ intervals.

nr	m	nr	m	nr	m
1	3.31	10	9.27	19	24.18
2	4.18	11	11.32	20	24.31
3	5.32	12	13.37	21	25.03
4	6.03	13	15.26	22	27.20
5	6.28	14	17.25	23	27.50
6	6.52	15	19.37	24	30.01
7	7.22	16	21.22	25	30.48
8	8.28	17	23.22	26	35.76
9	8.66	18	23.40	27	36.01

Table 1. List of sample numbers and corresponding depth values.

Results

The mean grain sizes are illustrated in the downhole log of the borehole (figure 4a and 4b). The grain-size distributions, $CaCO_3$ and organic matter are also shown on figure 4a and 4b. These confirm the lithological description of the core. The graphs clearly illustrate the excellent sorting of sequence (L)II which moreover fines slightly upwards. Sequence (L)III is less well sorted and contain two roughly coarsening upward sequences.

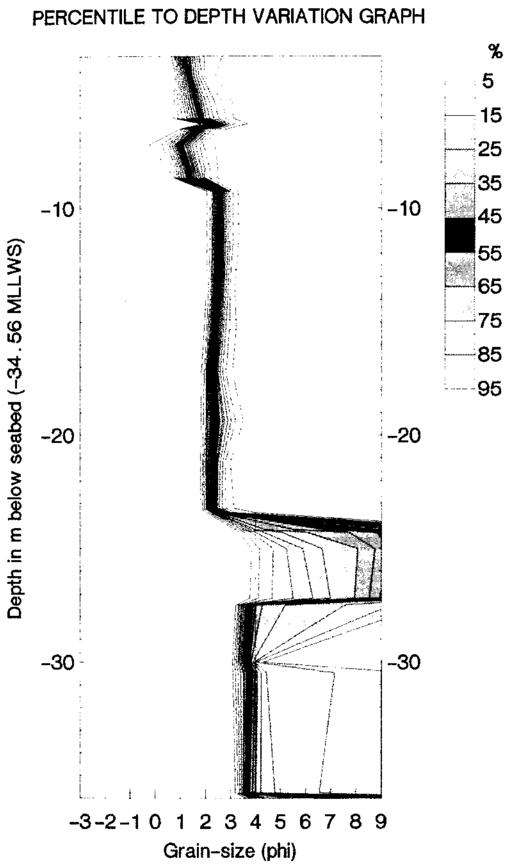
C/M diagram and F, L & A diagram. Cumulative curve analysis

The BH 89/1 samples were plotted on a C/M diagram (Passega & Byramjee, 1969). This allows several kinds of suspensions to be distinguished, enabling interpretation of the hydraulic conditions under which the sediments were deposited (figures 5 and 6). The cumulative curves on log-probability paper were compared with examples published by Visher (1969). These log-probability curves were grouped according to the C/M diagram (figures 7-10). The palaeo-environmental reconstructions are not based uniquely on the results of the grain-size analysis but are a result of the combination of this data with the lithological description.

Samples 23-26 were deposited from a uniform suspension (QR-segment of the Passega diagram, class VI), but are graded, low-turbulence (weak bottom current), suspension sediments. Figure 7 shows the log-probability curves of samples 23-26. These show a very small traction population (< 0.5%) which shifts at 2.75-3.00ϕ in a saltation population. The saltation population (65-85%) shifts at 3.50-4.00ϕ in a suspension population. The grain-size curves reflect a quiet, shallow marine environment, however shallower than samples 19-22, 27, with greater influence of tidal currents and situated closer to the coast.

Samples 19-22, 27 belong to the finest uniform suspension class of sediments (RS-segment of the Passega diagram, class VIII). C is more or less constant, M varies. Increase of the M-values corresponds with an increase of lutite (L) and clay (A) in the sediments (figure 6). These sediments were deposited at extremely low bottom turbulence conditions (bottom currents), which were not strong enough to sort the sediments. The log-probability curves of samples 19-22, 27 (figure 8) show no or a very small (19-20, 27) traction population (< 0.5%) which shift at 2.75-3.00ϕ in a saltation population (19-20, 27 : 20-30% ; 21-22 : 10%). The saltation population shifts at 3.50-3.75ϕ (19-20) or 4.00-4.25ϕ (21-22, 27) in a suspension population. The shape of the grain size curves indicates deposition in a quiet, shallow marine environment (shelf).

Samples 5, 10-18 were deposited from a moderate-turbulence, graded suspension (QR-segment of the Passega diagram, class IV and V). C is more or less proportional to the median. Such sediments can be deposited in channels in which the suspended load exceeds the transport capability, for in instance river and/or current deposits. Figure 9 indicates the



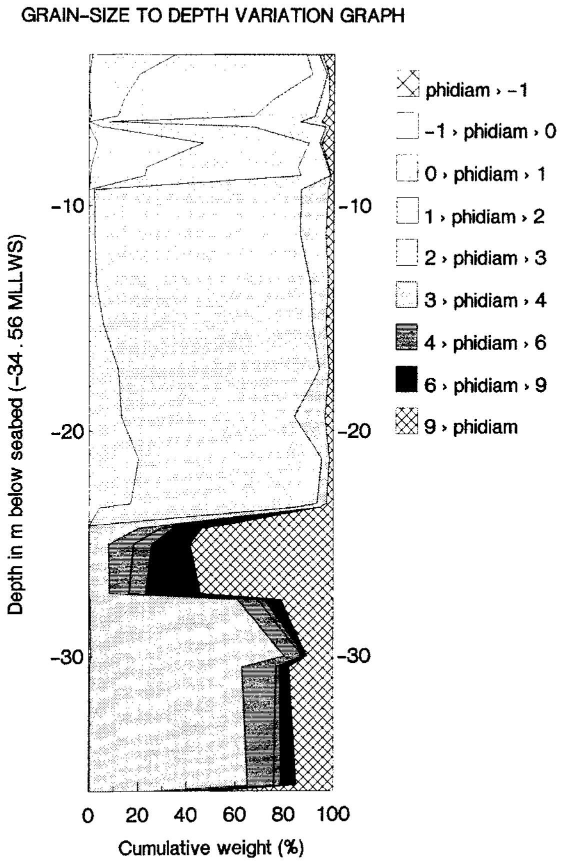


Figure 4. Results of the grain-size analysis. Data provided by P. Jacobs and E. Sevens.

Figure 4a-1. Percentile of depth variation grap.

Figure 4a-2. Grain-size to depth variation graph.

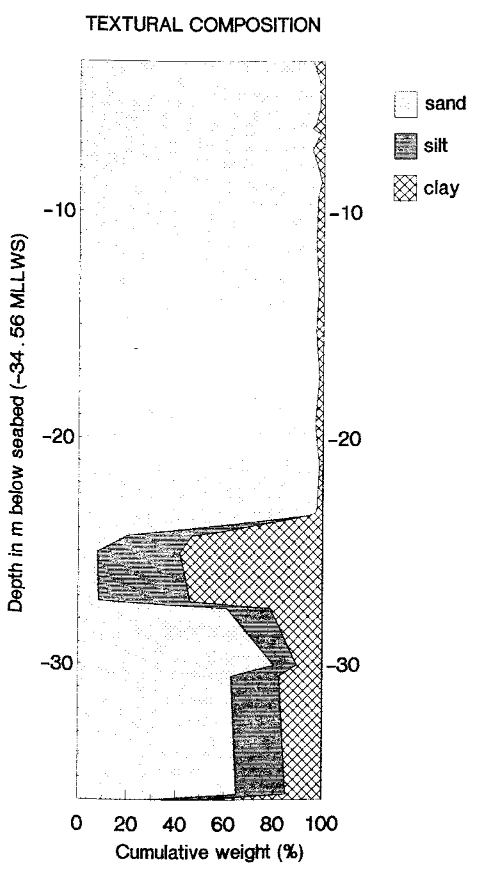


Figure 4b-1. Textural composition.

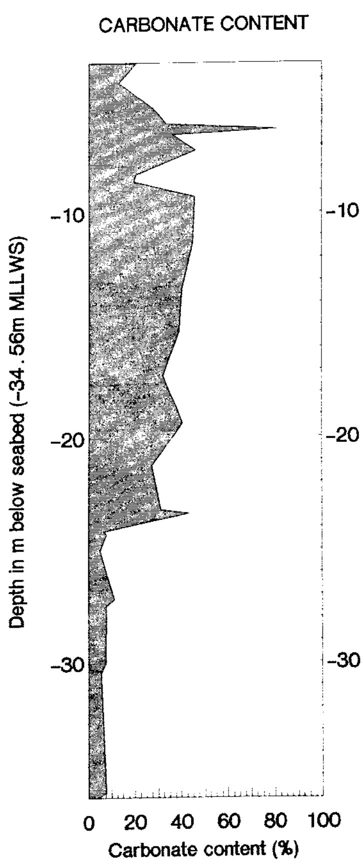


Figure 4b-2. Carbonate content.

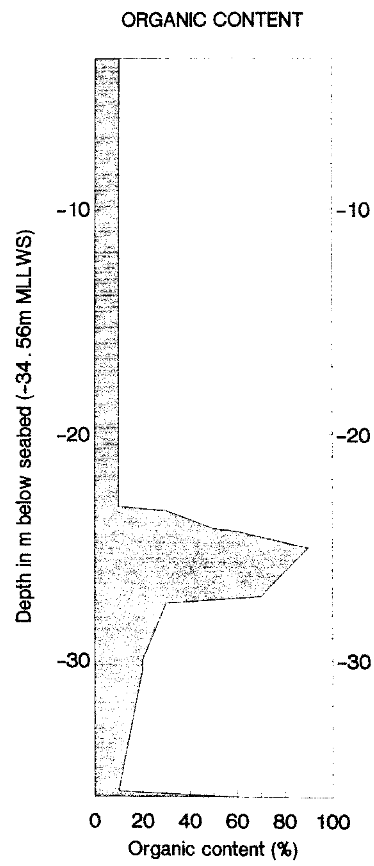


Figure 4b-3. Organic content.

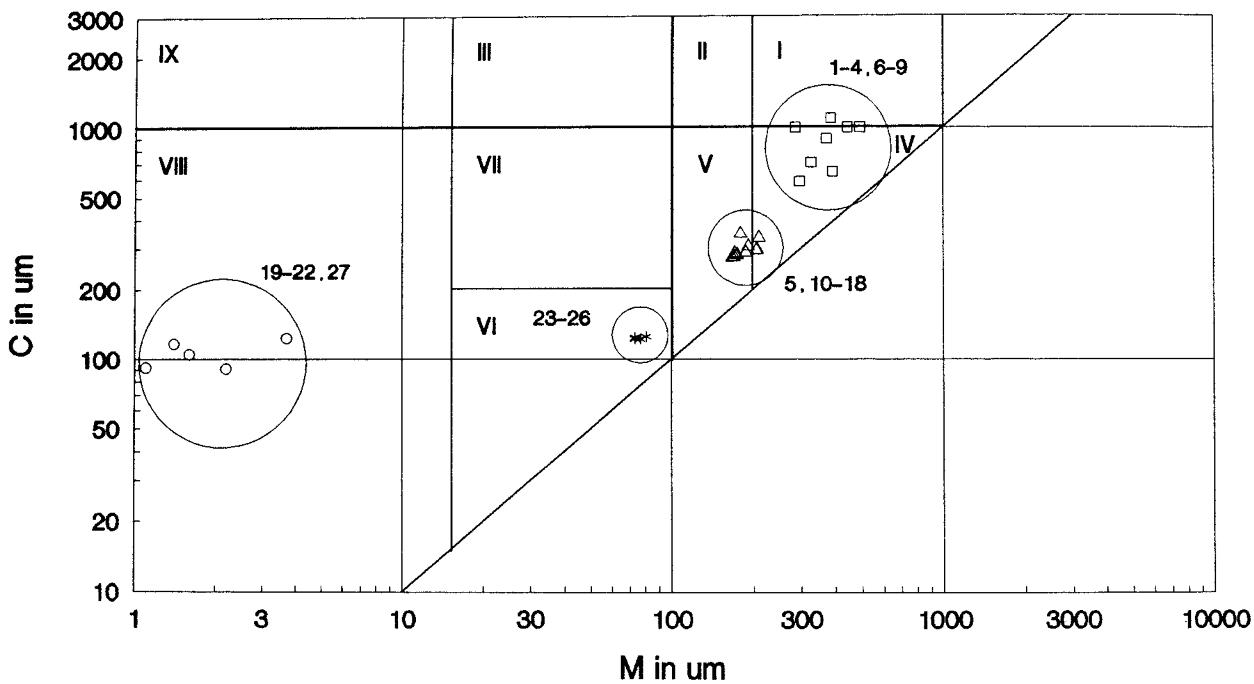


Figure 5. C/M diagram of the sediment from the BH 89/1 borehole.

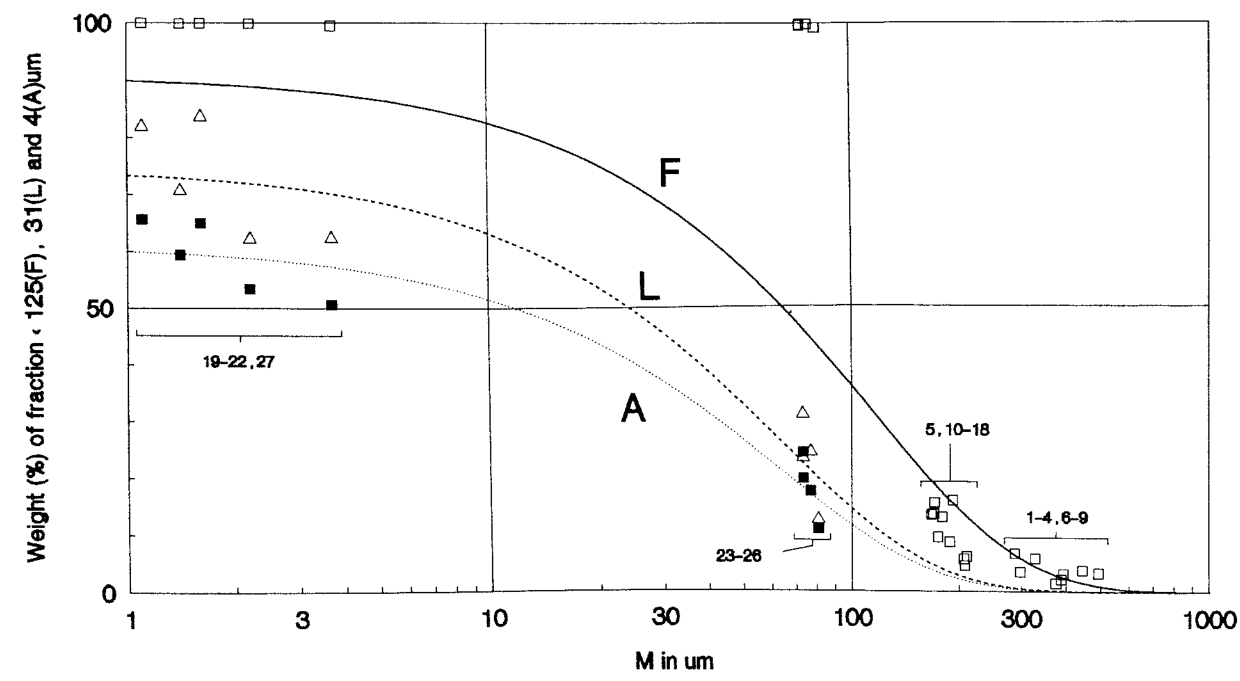


Figure 6. F, L and A diagram of the sediments from the BH 89/1 borehole. F, L and A values are indicated respectively by squares, triangles and solid squares.

log-probability curves of samples 5, 10-18. These show only a very small (samples 12-14, 18) traction population (< 1.0%) which shifts at 1.75ϕ in a saltation population (90-97%). The saltation population shifts at 2.75-3.125ϕ in a suspension population. One sample (5) shows two saltation populations, which are separated by a value of 2.25ϕ (20%). Except for sample 5, these grain-size curves clearly illustrate the fluvial origin of the deposits.

Samples 1-4, 6-9 were deposited from a high-turbulence, graded suspension, containing a small proportion of rolled grains (PQ- to OP-segment of the Passega diagram). The samples correspond with class I (sample 8) and IV. The lowest C-value measured was 586µm. The largest grains were transported by traction (rolling), the smaller ones by suspension. As rolling can be assisted by movement of fine material (Hjulstrüm, 1939), the maximum size of the particles is not sharply defined. The variation in maximum particle size could also be influenced by differences in current velocity.Figure 10 shows the log-probability curves of samples 1-4, 6-9. Except for sample 6, these show a

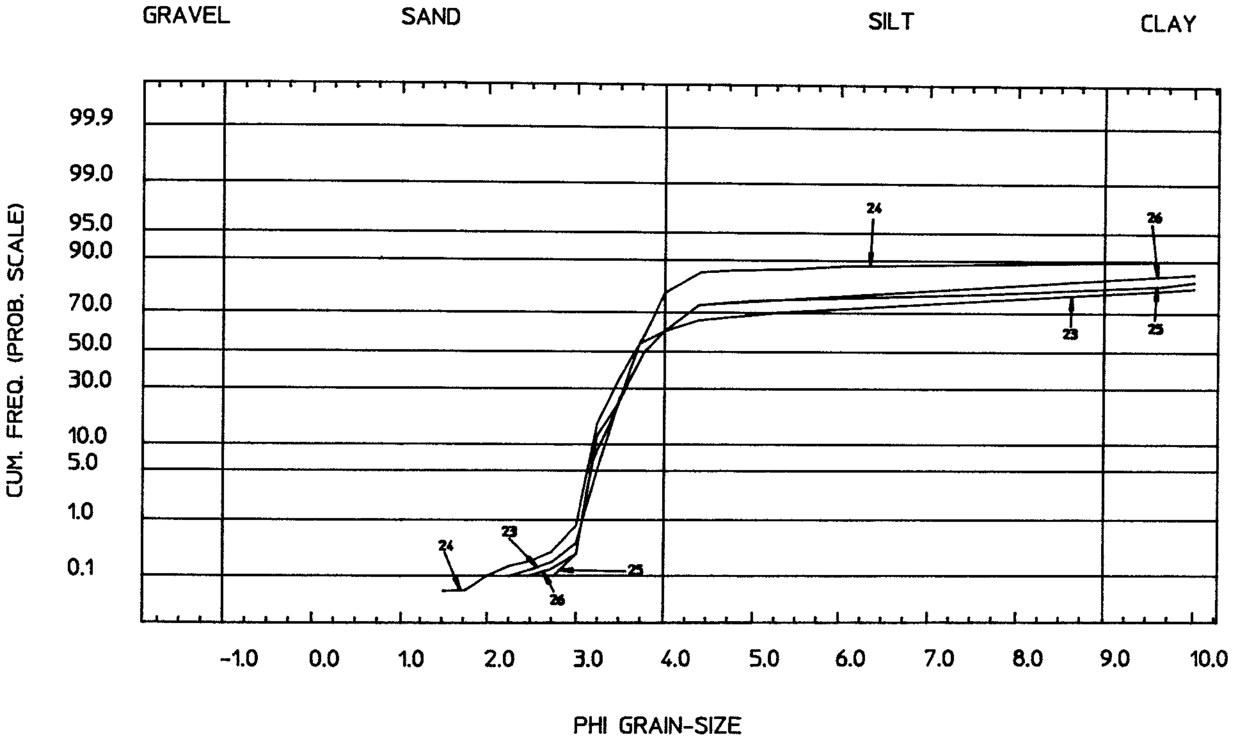


Figure 7. Cumulative curves of the sediments from samples 23-26.

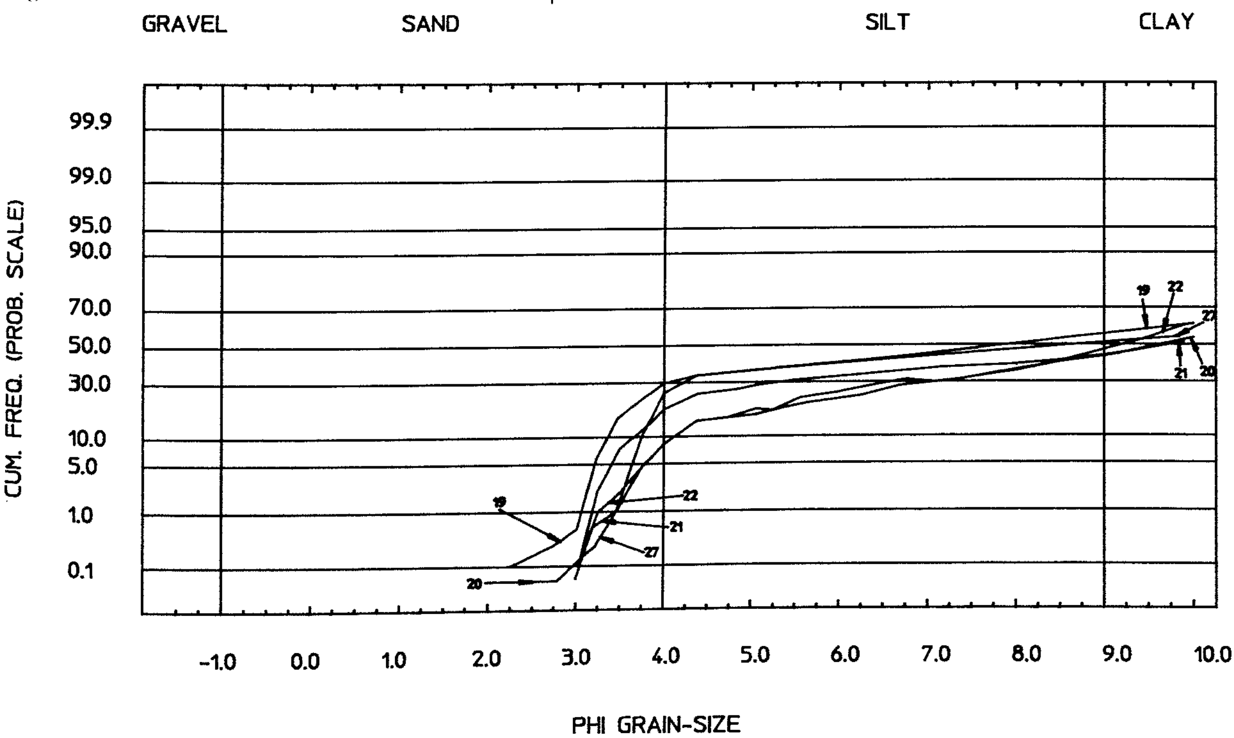


Figure 8. Cumulative curves of the sediments from samples 19-22, 27.

small to important traction population (0.3-8%) which shifts at 0.25-0.75ϕ in a saltation population (89-98%). The saltation population shifts at 2.00-3.00ϕ in a suspension population. The shape of the grain-size curves strongly indicates highly energetic, marine environmental conditions.

2.5. Heavy mineral analysis

The heavy mineral analysis was carried out by C. Schwarz from the Niedersächsisches Landesamt für Bodenforschung (NLfB), Hannover. The results are illustrated on figure 11. Eight samples were analyzed for their heavy mineral concentration and distribution in the fraction 63-355μm. Above a depth of 24m, the

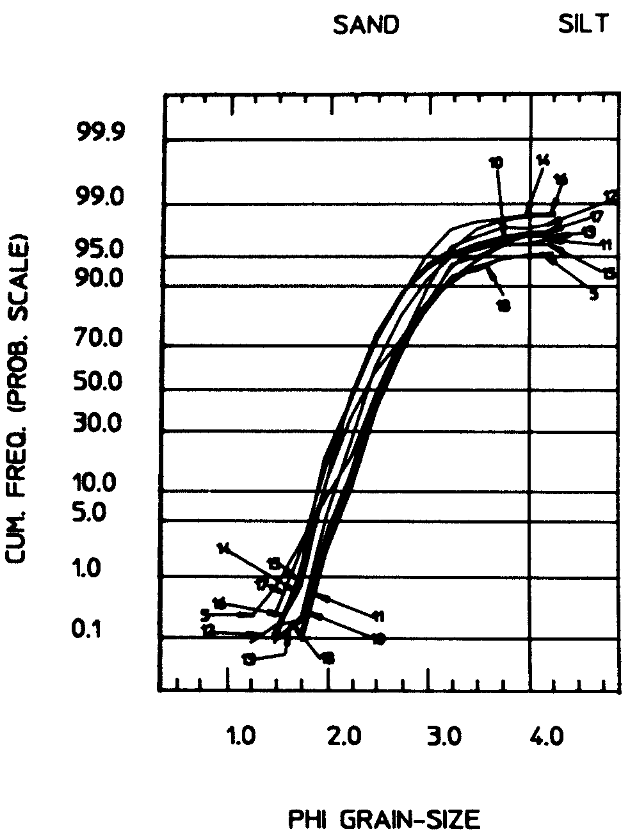


Figure 9. Cumulative curves of the sediments from samples 5, 10-18.

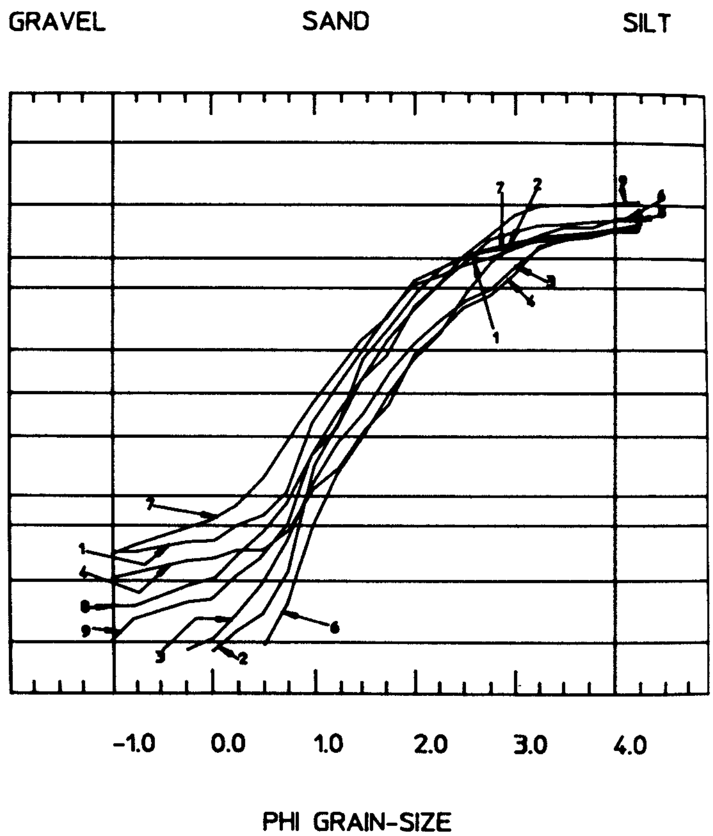


Figure 10. Cumultive curves of the sediments from samples 1-4, 6-9.

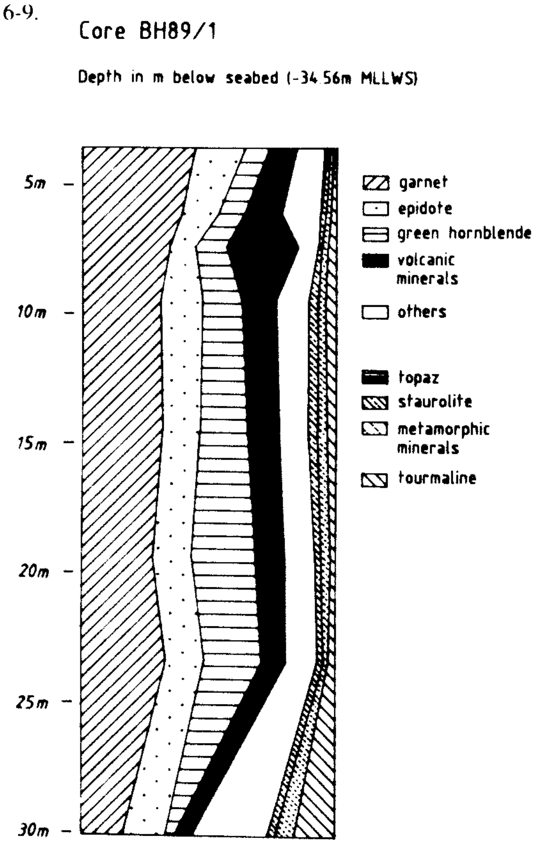


Figure 11. Heavy minearl diagram of BH 89/1. Presentation modified after Schwarz (NlfB).

heavy mineral associations aredominated by the typical Quaternary assemblage of garnet, green hornblende and epidote. In the uppermost three samples, an increased amount of augite is present (up to 20.7% at 7.27 m).This might indicate a change of the transport system or a change in source of the material. This association (0-24m, a.o. the augite content) gives evidence of provenance from the Rhine's catchment area (minerals from the Rhenish Massive) during the Late Pleistocene and Holocene.

With increasing depth, the garnet content decreases, while the content of green hornblende increases. The epidote content remains quite stable over the complete section, the decrease at 7.27m being caused by the high augite content. Between a depth of about 9m and about 24m (sequence (L)II), the association of heavy minerals suggests a Middle Pleistocene or younger age. The deepest sample (30.04m) displays a typical Tertiary assemblage. It is dominated by stable minerals, while the hornblende content decreases dramatically.

2.6. Isothermal magnetization

34 samples were collected. The measurements were carried out at Edinburgh University's Department of Geophysics by R. Thompson and D. Cameron. They

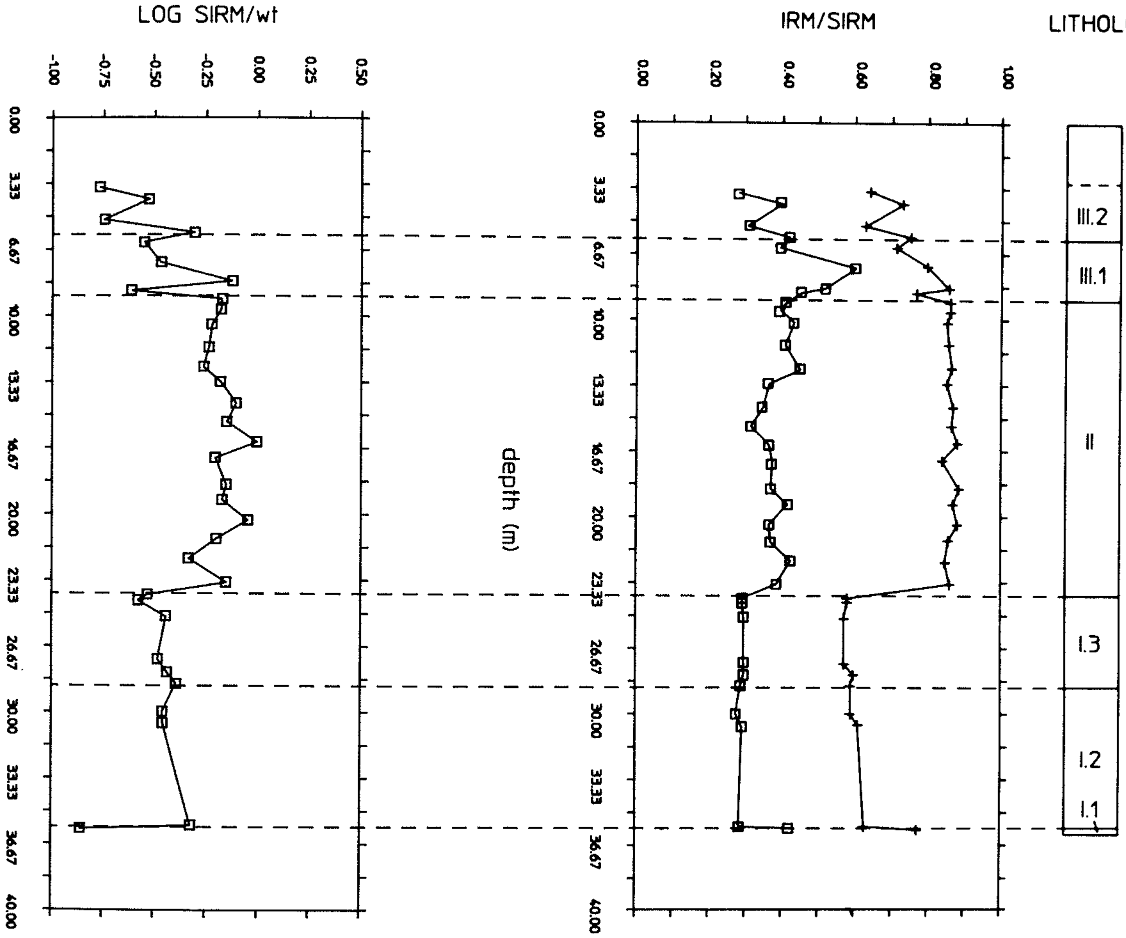


Figure 12. Log SIRM/IRM$_{40}$/SIRM (squares) and IRM$_{100}$/SIRM (crosses) graphs of BH 89/1 samples. Depths in meters below seabed. Data provided by D. Cameron (BGS).

recorded the isothermal remanent magnetization of each sample after magnetizing in a magnetic field of 40 milliTesla, then 100 milliTesla and finally 1 Tesla. These measurements are refered to as IRM40(Isothermal Remanent Magnetization in a field of 40milliTesla), IRM$_{100}$ and SIRM (Saturation Isothermal Remanent Magnetization). Figure 12 shows the results.

The LOG SIRM graph indicates the concentration of the magnetic minerals in the sediment. The IRM/SIRM graphs depict qualitative measures of the grain size of the magnetic particles in the sediment (IRM$_{40}$/SIRM: squares) and of the ratio of magnetite to haematite in the sediment (IRM$_{100}$/SIRM: crosses). The units identified on the graphs correlate very well with the sequences of the lithological log.

The LOG SIRM graph gives evidence of a very uniform and relatively high concentration of magnetic minerals in the (L)II sequence. The Tertiary sediments ((L)I.3, (L)I.2 and (L)I.1) have a slightly lower concentration of magnetic minerals ; their concentration in the sediments of sequence (L)III is markedly lower. The graph of IRM$_{40}$ against SIRM suggests a markedly lower magnetic grain size in the sediments of sequence (L)I than in sequence (L)II. The latter sequence also demonstrates a slight coarsening upwards of the magnetic grain size. This coincides with a slight upward increase of the concentration of magnetic minerals (LOG SIRM) in this sequence but apparentlynot with a corresponding trend in the grain size of the sediment (figure 4a and 4b). The fraction between 2.50 and 3.25ϕ (fraction 6) however appears to become increasingly important towards the top of sequence (L)II (figure 13), without affecting the general grain-size trend. The peak values recorded within samples 15 & 18 correspond with the occurrence of zones with finer material (section 2.2), but do not alter the general trend. Extending the former fraction to a fraction between 2.25 and 3.50ϕ (fraction 7) indicates a similar trend throughout sequence (L)II. Comparing the fractions 3.50-3.25ϕ (fraction 1), 3.25-3.00ϕ (fraction 2), 3.00-2.75ϕ (fraction 3), 2.75-2.50ϕ (fraction 4) and 2.50-2.25ϕ (fraction 5) (figure 14) suggests that the fractions 2, 3 and 4 tend to increase more towards the top of sequence (L)II than the other fractions. This is clearly illustrated in figure 15. These fractions probably contain most of the magnetic minerals.

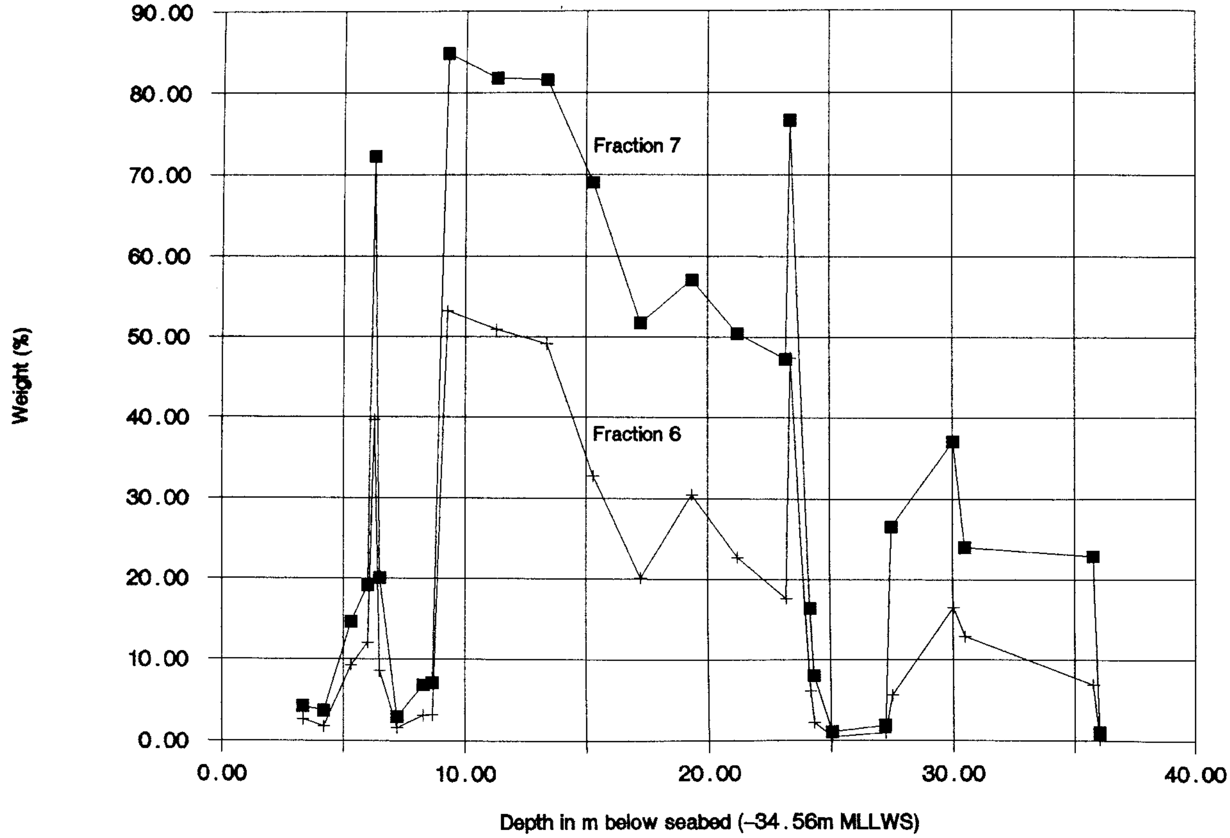


Figure 13. Percentages of weight of the fractions 6 and 7.

An attempt was made to correlate the weight of the fractions with the corresponding IRM_{40}/SIRM-value (figure 16). Although the increase of the magnetic grain size seems to be related to the relative increase of the fractions 2, 3 and 4, the correlation graph does not clearly affirm this relationship. This might be caused by the relatively low amount of grain-size samples analysed from (L)II compared to the amount of IRM analyses. Moreover, no IRM analysis was undertaken on the samples used for granulometry.

The graph of IRM_{100} against SIRM depicts a very clear distinction between the sediments of sequence (L)I and those of sequences (L)II and (L)III. The magnetic component in (L)I seems to be entirely composed of haematite, whereas in (L)II the magnetic component could be almost 100% magnetite. Sequence (L)III shows a decrease of the magnetite component as the magnetic particle size decreases. The difference between (L)I and (L)II most clearly illustrates the shift in provenance of the material from the Early Tertiary to the Quaternary. The provenance of the material remains the same throughout sequence (L)II. The mixture of haematite and magnetite in sequence (L)III probably indicates the reworking of material of the same source as (L)II with other material (for instance of (L)I).

2.7. Clay mineralogical analysis

Eight samples were analyzed by V. Zöllmer from the Forschungsinstitut Senckenberg (FIS), Wilhelmshaven, for their clay mineralogical content. Three clay mineralogical units were distinguished. The lower unit (35.91-24.04m) is characterized by a very high content of smectite, traces of kaolinite and the absence of chlorite. This assemblage is typical of Palaeocene/Eocene clays from the London Tertiary basin. Moreover, this clay mineralogical association fits perfectly with the associations characterizing the Gent Formation (formerly Mont Panisel Formation), as described by Mercier *et al.* (1990).

In the second unit (8.50-7.41m), the high content of illite and chlorite indicates the Rhenish Massif as a possible source area. In Quaternary seabed sediments from the Channel region and SE England, completely different clay mineralogical associations are found. As the clay mineralogical association differs slightly from that of the top unit, this unit might be of pre-Holocene age. The samples analysed from this unit were of soft mud pebbles.

The upper unit (above 3.02m) also has a high illite and chlorite content, which is characteristic for the seabed sediments in the region.

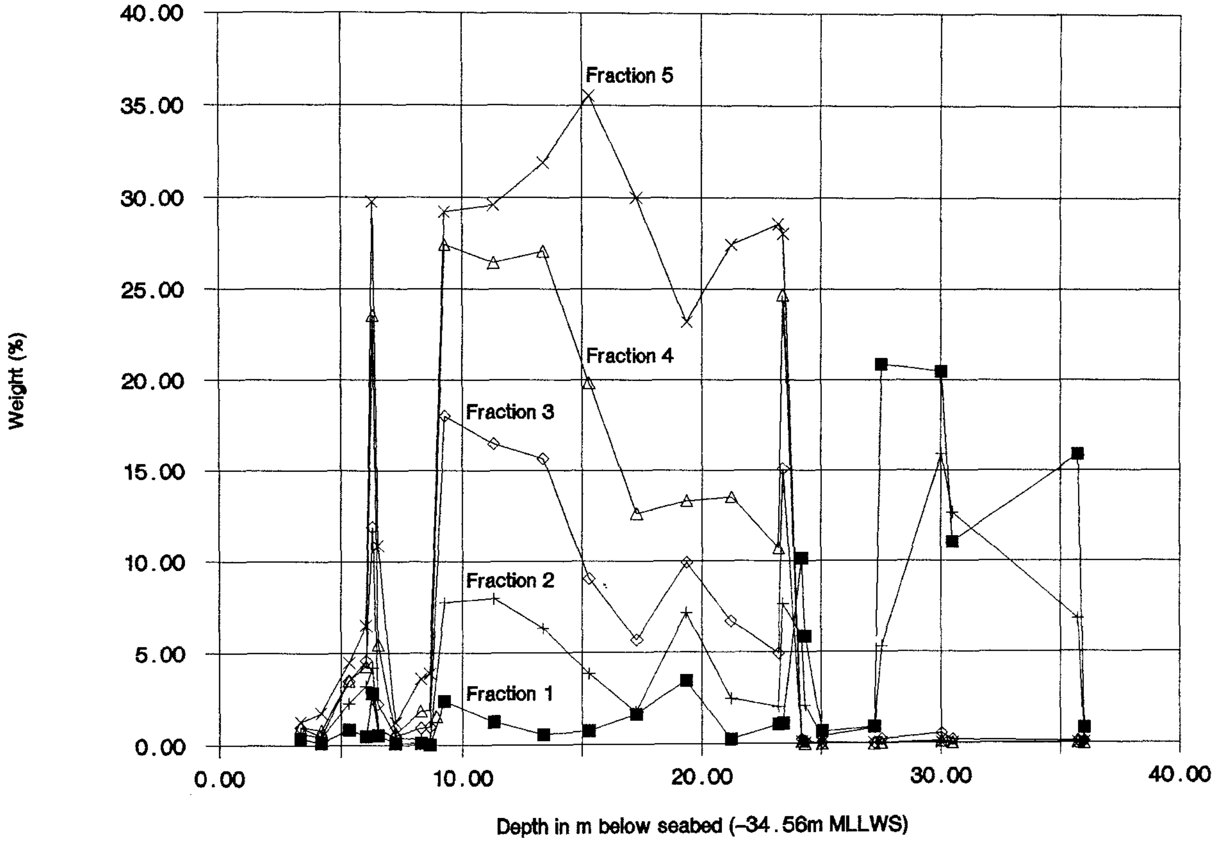


Figure 14. Percentages of weight of the fractions 1, 2, 3, 4 and 5.

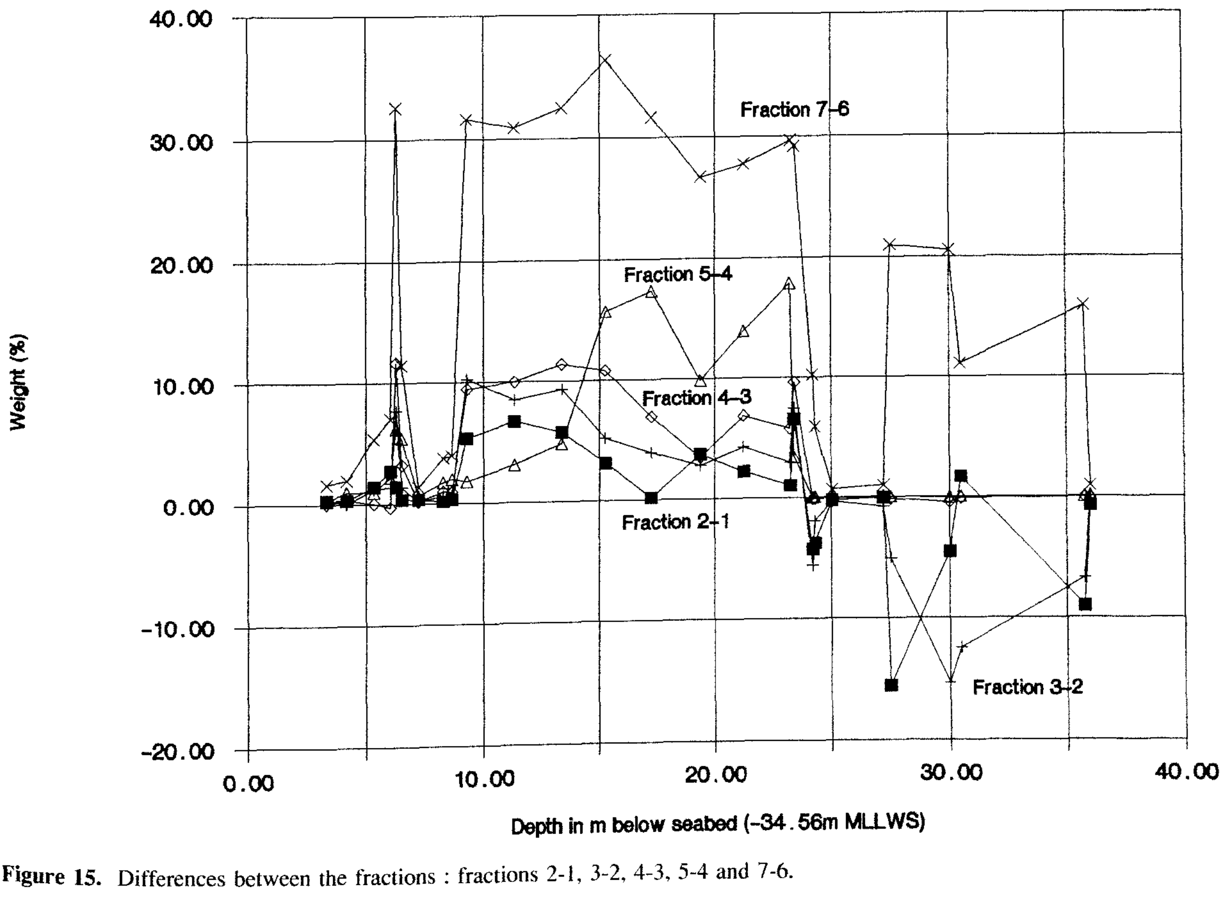


Figure 15. Differences between the fractions : fractions 2-1, 3-2, 4-3, 5-4 and 7-6.

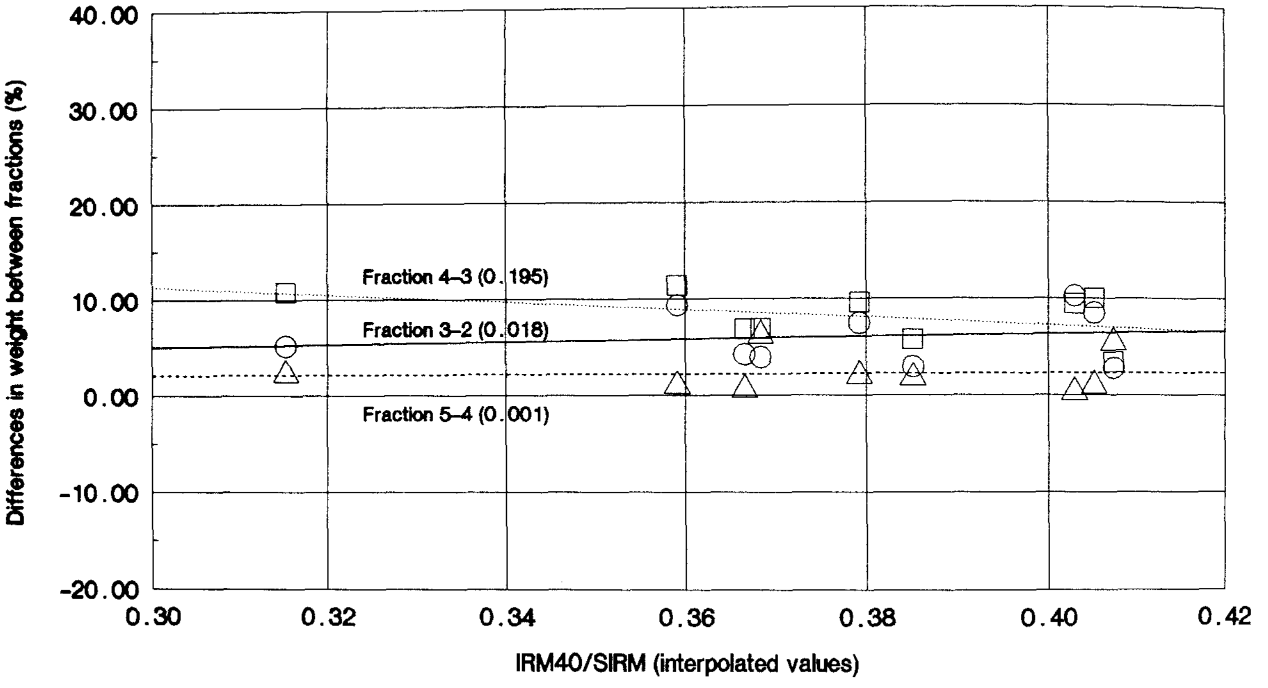


Figure 16. Correlation graphs between the weight and the differences in weight of the grain-size fractions, and $IRM_{40}/SIRM$.R^2-values between brackets.

2.8. C^{14} age determination

Three samples were taken from strongly decomposed peat at the base of sequence II for C^{14} dating. One sample was prepared at the Koninklijk Instituut voor het Kunstpatrimonium (KIK) in Brussels and measured with AMS at R.U. Delft. Sample KIK48/Utc1353, taken at the base of sequence II (-23.35m below seabed) was dated at 39000 (+7000, -4000) BP.

One has to keep in mind that the peat is not in situ. The result therefore indicates a maximum age for its redeposition or for the deposits in which it occurs.

2.9. Micropalaeontological analysis

Introduction

As a result of the generally low content of organic remains, no pollen analysis was carried out.

Foraminiferal analysis

19 samples were collected for analysis by L. Jingxing (Vrije Universiteit Brussel-IFAQ). The number of species and number of individuals are very low throughout the core.

The foraminiferal content is so poor that it does not allow a statistical analysis of the results. According toP. Konradi (pers. comm.) the sediments of sequence (L)II might be non-marine (or reworked marine). In the Danish sector similar interpretations are made for sparsely fossiliferous sediment. The size of the shell fragments, which are well rounded and have the same size as the sand grains, also points to the reworked character of these deposits.

The low foraminiferal content in (L)III has probably been caused by the active reworking which is taking place at the sea-bottom (active sand wave field).

Dinoflagellate cyst analysis

Three samples from sequence (L)I.3 (24.85m), (L)I.2 (27.81m) and (L)I.1 (36.14m) were studied by Dr. J. De Coninck (1991) at the Laboratorium voor Paleontologie (Rijks Universiteit Gent) for their dinoflagellate cyst content. The different species found in (L)I.1 suggest this sequence belongs to the upper part of the 'Clay of Merelbeke' (Merelbeke Member, Gent Formation, Ypresian) or possibly the 'Sandy Clay of Pittem' (Pittem Member, Gent Formation).
The dinoflagellate cyst content of (L)I.2 corresponds with stratigraphicly higher parts of the 'Sandy Clay of Pittem', and those of (L)I.3 with the upper part of the 'Sandy Clay of Pittem'.

Diatom analysis

Nine samples analysed by H. De Wolf (1991) at the Rijks Geologische Dienst (RGD, the Netherlands) proved to be barren of diatoms. Probably the environmental conditions, for instance high current velocities, were not appropriate for the preservation of diatoms.

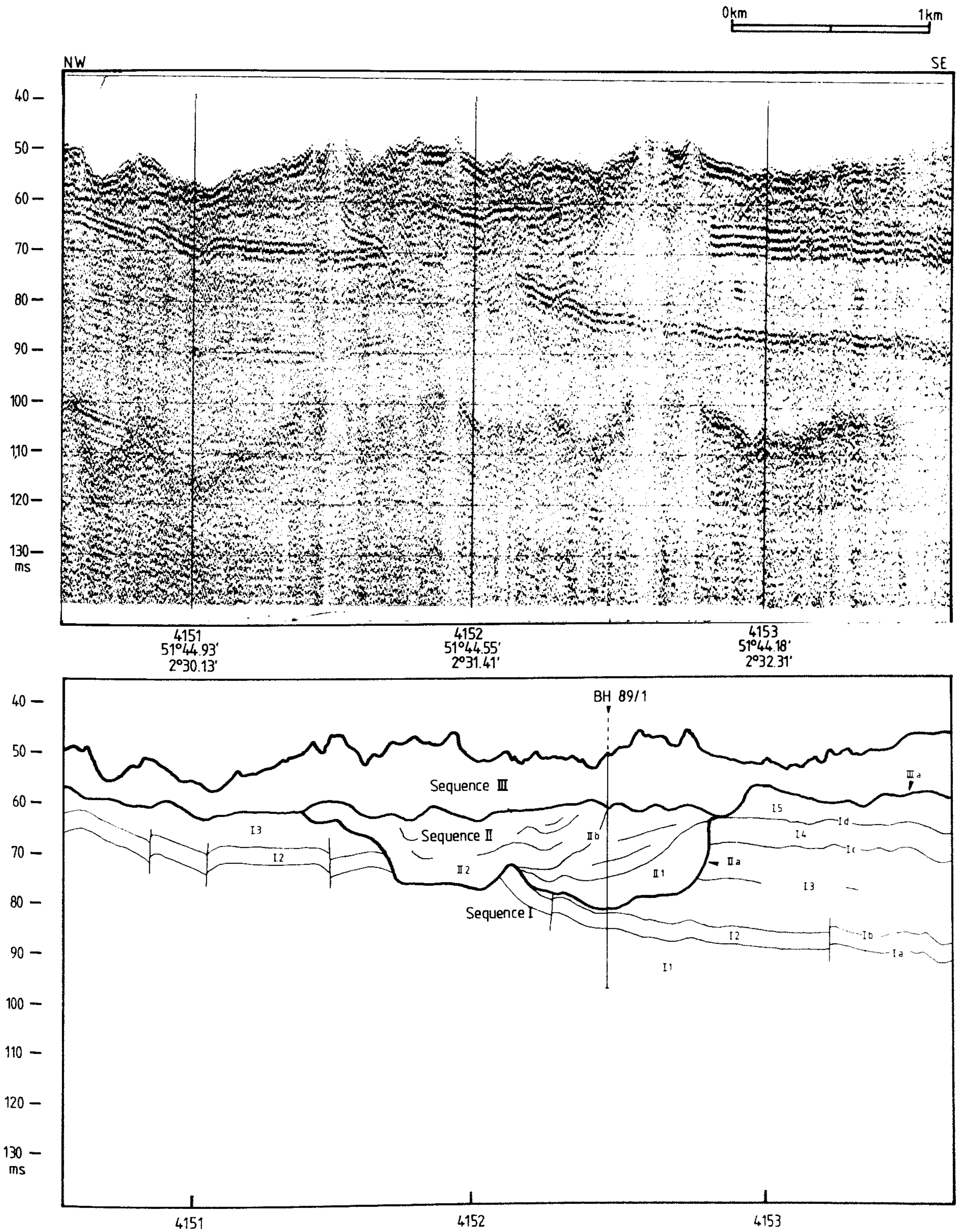
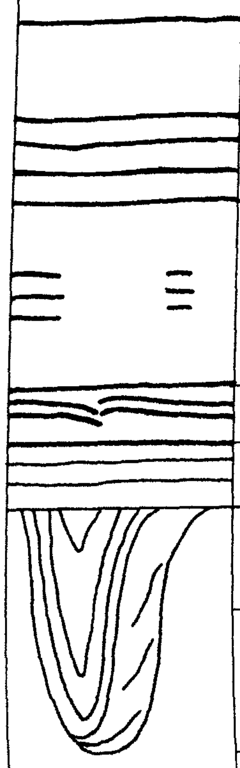


Figure 17. Analog-recorded seismic section and interpreted line drawing showing a gully scoured in Tertiary deposits. Vertical scales in ms are two-way time. Data provided by M. De Batist.

SCHEMATIC TYPE SECTION



NAME	BOUNDARY NAME	BOUNDARY TYPE	REFLECTOR DESCRIPTION AMPL	REFLECTOR DESCRIPTION CONT	REFLECTOR DESCRIPTION FREQ	THICKNESS (m/S) TWT	THICKNESS v(m/s)	THICKNESS (m)	SEISMIC FACIES DESCRIPTION	LITHOSTRATIGRAPHIC CORRELATION	BH 89/1
III						3-18	Well correlation 1512	2.25-13.50		Bligh Bank Formation (NL)	BH
	IIIa	? / trunc	varia	cont	low						
II / I.5						0-8	1700 (*)	0-6.80		Knesselare Formation (**); Oedelem/ Beernem Member	NOT IN CORE
	Id	conc / conc	high	cont	low						
I.4						±7		±5.95	Continuous, high amplitude parallel reflectors.		
	Ic	conc / conc	high	cont	low						
I.3						±15		±12.75	Reflection free or very low amplitude. A few parallel discontinuous, very low to low amplitude reflectors.	Gent Formation (**); Pittem Member	
	Ib	conc / conc	high	cont	low						
I.2						±4.5		±3.85	Continuous, high amplitude parallel reflectors, faulted blocks.	Merelbeke Member	Merelbeke Member
	Ia	conc / /	high	cont	low						
I.1						/		/	Low to very low amplitude parallel reflectors.		
II.2						0-16	1512	0-12	Continuous, parallel, low-medium amplitude reflectors. Divergent fill.	?	NOT IN CORE
	IIb	conc / trunc	low	cont	low						
II.1						0-22		0-16.50	Parallel, oblique prograding clinoforms of very low amplitude. Trough fill.	Kreftenheye Formation (NL)	KH
	IIa	downlap / trunc	low-med	cont	low						

Table 2. Type section, seismo-stratigraphic sequence chart and correlation table.
(*) Henriet *et al.*, 1989 ; (**) De Batist, 1989.

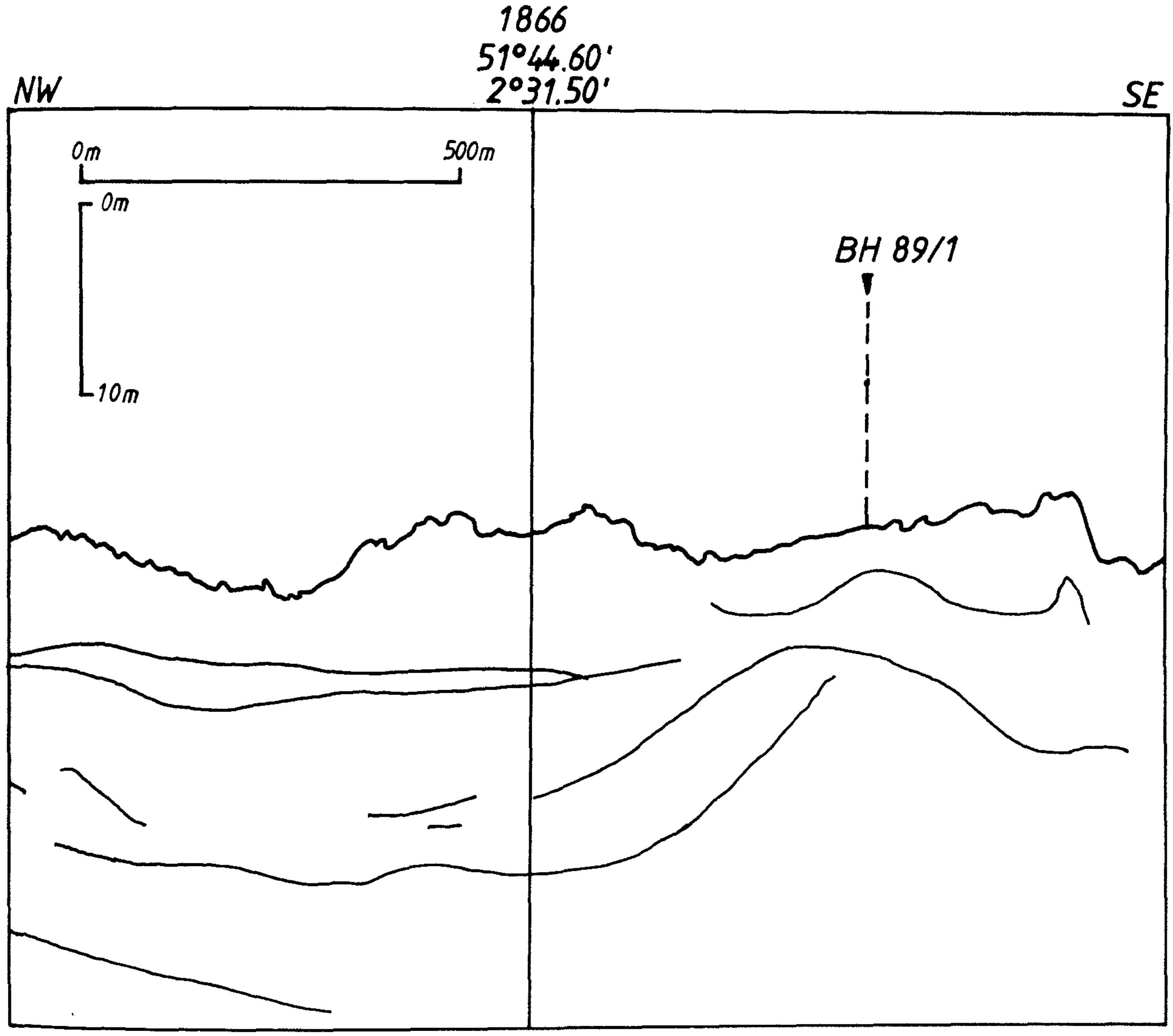


Figure 18. Sub-bottom cross-section and location. Data provided by C. Laban.

2.10. Seismic data

Introduction

The northern part of the Belgian Continental Shelf was surveyed by the RCMG within the framework of the seismic investigation of the Southern Bight of the North Sea (Van den Broeke, 1984).

Table 2 shows the results of the seismo-stratigraphic analysis of the illustrated sparker profile (figure 17). The seismo-stratiraphic principles defined by Vail *et al.* (1977) were used in the interpretation.

The different seismic sequences were labelled according to their stratigraphic position, regardless of their possible chronostratigraphic interpretation, starting with the deepest unit that could be identified. The correlation shown in table 2 is based on lithological information (BH 89/1), published seismo-stratigraphic data (Henriet *et al.*, 1989), supplemented by micropalaeontological evidence (BH 89/1) as well as data from adjacent boreholes (Vlakte van de Raan borehole : 51°29'08''N, 3°09'50''E, unpublished data Belgische Geologische Dienst ; Knokke borehole : 11E/138, Laga *et al.*, 1990).

The illustrated profile (figure 17) was shot during the 1983 RCMG seismic survey and has a NW-SE orientation (more or less perpendicular to the axis of the Hinder Banks). The profile follows the DECCA Red line I0 of the DECCA 5B network (figure 2).

Sequence (S)I

The basal seismo-stratigraphic sequence can be divided into five seismic facies units.
Unit (S)I.1 consists of a series of low to very low amplitude, parallel reflectors. Its lower boundary cannot be distinguished on the profile.
Unit (S)I.2 is characterized by continuous, parallel high amplitude reflectors. Some faulted blocks with alternately tilted and downwarped bedding terminations

at either sides of minor faults are observed in this unit. This faulting is probably connected with deeper-lying clay-tectonic deformation in the 'Ieper Clay' (Kortrijk Formation).
Unit (S)I.3 is made up of very low amplitude reflectors and is locally almost reflection free. A few parallel discontinuous very low to low amplitude reflectors occur in the centre of this unit.
Unit (S)I.4 consists of continuous, parallel high amplitude reflectors.
The internal structure of unit (S)I.5 cannot be distinguished clearly. Its upper boundary, reflector III.a, is clearly defined by an erosion surface.

Units (S)I.1, (S)I.2, (S)I.3 and (S)I.4 are truncated by reflector II.a. This reflector exhibits a well developed valley profile, described with sequence S(II) below.

Sequence (S)I corresponds with the Tertiary deposits. According to DE BATIST (1989), units (S)I.1, (S)I.2 and (S)I.3 correspond with the Gent Formation, (S)I.1 and (S)I.2 being part of the Merelbeke Member, (S)I.3 of the Pittem Member. Consequently, this part of the Gent Formation is thicker in this area than in the area adjacent to the coast. The overlying units, separated by reflector I.c, correspond with the Knesselare Formation (Oedelem/Beernem Member).

Sequence (S)II

The overlying deposits of (S)II consist of the channel fill of a gully scoured in the deposits of sequence (S)I. The base of the gully, reflector II.a, scours into all of units (S)I.5, (S)I.4, (S)I.3, (S)I.2 and (S)I.1. Reflector II.a partly represents the base-Quaternary erosion surface. Within (S)II, two units can be distinguished.
Unit (S)II.1 consists of NW prograding, oblique parallel clinoforms of very low amplitude. This facies suggests a prograded channel-fill reflection configuration. Part of the (S)II.1 unit has probably been removed by erosion, as it is truncated by the NW-dipping, downlapping very low-amplitude reflector II.b. By comparing the recorded thickness of the sediments in the borehole with their apparent thickness in the profile, an average seismic velocity for the Quaternary deposits of 1512 m/s has been derived. In general in Quaternary deposits, velocities between that of water and more than 2000 m/s have been recorded (pers. comm. M. De Batist). Using the calculated velocity, reflector II.6 corresponds with a depth of 19.7 m. This correlates with a zone in sequence (L)II consisting of diffuse horizontal and oblique laminations, characterized by a high concentration of organic matter (peat debris) and fine shell debris.

The base of unit (S)II.2 is defined by truncation of the reflectors of the underlying unit. This unit consists of continuous, nearly parallel low to medium amplitude reflectors. The seismic facies gives evidence for a divergent basin-fill reflection configuration (Mitchum *et al.*, 1977). Sequence (S)II corresponds with the pre-Holocene deposits. The internal structures of the channel fill could indicate a partial filling during the Pleistocene, (S)II.1, and a renewed scouring and filling during the Early Holocene transgression (or Late Pleistocene).

Sequence (S)III

The base of sequence (S)III, reflector III.a, truncates all underlying deposits. Where it truncates units (S)I.3, (S)I.4 and (S)I.5, it partly corresponds with the base-Quaternary erosion surface.

Sequence III consists of the actual seabed sediments and displays large differences in thickness across the profile. Internal reflections are difficult to resolve as they are masked by the sea-floor reflector.

Still assuming a seismic velocity in the Quaternary deposits of 1512m/s, reflector III.a, separating sequence (S)III and sequence (S)II, occurs at a depth of 8.7m. This reflector correlates well with the lower limit of sequence (L)III derived from the lithological description, and probably represents the Holocene/Pleistocene boundary.

Quaternary buried valley

The seismic profile shows a section through a closed gully (or valley) scoured in the Tertiary deposits. This buried valley has a SSW-NNE orientation, a length of about 8.8km and a width of about 2.1km. It has an asymmetric cross-section, the SE slope being steeper than the NW slope. Assuming a velocity of 1512m/s, the NW valley wall has a dip of 1.5° ; its SE flank has a dip of 3.1°.

The morphology of the valley wall and valley bottom (figure 17) displays a fresh erosional profile and gives evidence of lithologically controlled scouring. The massive clay of unit (S)I.2 (=(L)I.3, figure 3) exposed in the NW valley wall and valley bottom causes a step in this valley wall and a bump in the valley bottom. Unit (S)I.4, not recovered in the core but exposed in the SE valley wall, also corresponds with a steeper dip. There are indications that the position of the valley is connected with structural elements, namely the faults in (S)I.2.

As an axial seismic profile of the valley is not available, the orientation of prograded bedding in the valley fill and the corresponding flow direction are unknown.

The morphology of the fill and of the valley might indicate different generations of scouring and/or infill. The seismic facies of (S)II.1 and (S)II.2 indicate high and low energy environments, respectively. (S)II.1 might belong to a Weichselian fluvial or fluvio-periglacial system ; (S)II.2 might correspond with a Late Pleistocene or Holocene system, occupying a older valley system (for instance during a transgression) and filled later. The erosional profile suggests a rapid burial of the valley relief during the Holocene or Late Pleistocene.

2.11. Sub-bottom data

A high resolution sub-bottom profiler (Sonia) was operated by RGD along a network of NW-SE and NE-SW traverses, mostly with a line distance of about 14km. These profiles provide geological information to 40m below seabed. An interpreted profile kindly provided by C. Laban is shown in figure 18. The BH 89/1 borehole is located 0.45km north-east of the approximate location shown. The several more or less continuous reflectors interpreted from the Sonia profile are essentially the same as those observed on the sparker profiles.

2.12. Adjacent cores

Macropalaeontological analysis of an adjacent RGD core (80MK126, about 16km WSW of BH 89/1) (Spaink, 1981) revealed a 3m thick sequence of marine, possibly Eemian deposits below a 2m thick cover of Holocene deposits (*Angulus pygmaeus* fauna).

In core 81MK60, about 8.5km SSE of BH 89/1, a 2m thick Holocene sequence covers a 8m thick sequence of Eemian deposits (Van den Broeke, 1984).

Van den Broeke (1984) also mentioned a borehole (69T137) in the southern part of the Dutch sector where Holocene sediments cover deposits of the Kreftenheye Formation. Comparison of the lithology of the sediments described with the Kreftenheye Formation in the Netherlands supports this correlation. The Kreftenheye Formation has a fluviatile origin (Meuse and Rhine) with a thickness of 10 to 25m. It ranges between Saalian and Early Holocene in age but in the Netherlands most of its deposits are Eemian or Weichselian (Doppert *et al.*, 1975).

Off the mouth of the Rhine, which has been flowing westwards since Saalian times (OELE, 1969), fluvial Weichselian deposits of the Kreftenheye Formation occur, while further north their equivalent sediments are wind-blown sands of the Twente Formation (McCave *et al.*, 1977).

3. INTERPRETATION OF THE RESULTS

3.1. General

The data acquired from the analyses affirm the lithological description of the core. However it has not been possible to correlate the units identified in the BH 89/1 borehole with those in other boreholes of the Belgian Continental Shelf, containing important Quaternary deposits. All of the other boreholes are situated much closer to the coast. The BH 89/1 borehole also has an exceptional location within a scoured depression in Tertiary deposits and is not representative for the area as a whole.

In this section, all sequences referred to, except where indicated, correspond with the lithological subdivisions identified in the core. The lithological information has been complemented with results of the other analyses. For the Tertiary deposits, the lithostratigraphic division of the Palaeogene as proposed by Maréchal *et al.* (1988) has been used. For the Quaternary deposits, the lithostratigraphic division as used in the 'Ostend Sheet' (Balson *et al.*, 1991) maps has been adopted.

3.2. Tertiary deposits

Sequence (L)I consists of the Tertiary sediments. These correlate with the Lower Eocene Gent Formation (formerly Mont Panisel Formation) and were deposited in a shallow marine environment.

On the basis of this correlation, sequence (L)I could be traced to the Vlakte van de Raan borehole. Assuming a strike of N143°E for the top of the Tertiary deposits on the Belgian Continental Shelf (derived from Henriet *et al.*, 1989, figure 3), a dip of 0.26°E for the top of the Merelbeke Member has been calculated. This does not contradict the average dip of 0.5°E derived by Henriet *et al.* (*ibid.*) for the Tertiary.

The micropalaeontological results (the dinoflagellate work by J. De Coninck, 1991) however do not fit with the seismic interpretation by De Batist (1989). According to the results of De Coninck (*ibid.*), the deposits of sequence (L)I recovered in the core, except for (L)I.1, belong to the Pittem Member. De Batist (*ibid.*) correlates this sequence with the Merelbeke Member. This correlation would result in a dip value for the top of the Merelbeke Member of 0.29°.

3.3. Pleistocene deposits

It is difficult to be conclusive about sequence (L)II. This sequence has a thickness of about 15m and contains homogeneous deposits that fine slightly upwards. No different lithological units could be distinguished within this sequence. The sediments are very well sorted and seem to have been deposited in energetic environments. The deposits give evidence of lateral migration towards the north-west, but it is not clear whether there is an erosion surface truncation within this sequence.

From the C^{14} data it can be assumed that the base of the deposits has a Middle Weichselian or younger age. Considering the sedimentological results (i.e. the absence of tidal bedding), the very low foraminiferal and molluscan content and their seismic facies, the deposits most probably are non-marine. The sands thus have a fluvial or fluvio-periglacial origin (reworked fluvial and coastal Rhine and Meuse sands), or are genetically related to fluvial or reworked fluvial deposits. The heavy mineral analysis and clay mineralogical analysis suggest an influence of the Rhine in the Late Pleistocene and Early Holocene. Thus this sequence might belong to or be related to the Kreftenheye Formation (see Doppert *et al.*, 1975 ; Cameron *et al.*, 1989b). The very uniform concentration of the magnetic component in (L)II indicates a common provenance and constant input of magnetic detritus throughout this sequence.

According to Jelgersma *et al.* (1979), the distribution of the Kreftenheye Formation and of marine sands with heavy minerals having a Rhine source suggests that this river discharged into the Atlantic Ocean southwards through the British Channel. This might have continued until the Holocene.

Streif (1990) remarked that during the Weichselian, the sea level was always more than 35m below that of the present Southern North Sea. This value of course has to be reinterpreted allowing for regional subsidence. According to results published by Kiden (1989) a relative subsidence of the Netherlands with respect to Belgium of 1.6cm/year (6.24m/39.000 year) should be taken into account .

Jardine (1979) mentioned a maximum value of -145m, Eisma *et al.* (1979) a maximum value of -110m below present sea level during the Weichselian glaciation. According to Oele *et al.* (1979) the Pleistocene sea level was never at any time lower than 50m below present sea level. It is thus quite probable that Weichselian fluvial deposits might occur at the level of sequence II.

The depression scoured in the Tertiary deposits might have been formed by a fluvial system of Late Pleistocene age or by a fluvial or fluvio-periglacial system of Middle Pleistocene age . It could be analogous to the pits observed in the Ostend Valley. According to Mostaert *et al.* (1989) these might have developed during periods of interaction between fluvial or estuarine erosion (tidal scour hollows) and clay dynamical processes. Similar depressions have been observed in the modern Scheldt and Thames estuaries (RUG, 1983).

Lithologically and structurally controlled scouring of the valley systems in the northern part of the Belgian Continental Shelf might have occured during the Middle Pleistocene (Holsteinian transgression). Already during that period, the scouring of the Dover Strait might have taken place (Zagwijn, 1979). Both events might be related (Van den Broeke, 1984). The filling of the valley happened in two phases, partially during the Weichselian (fluvial phase) with a renewed scouring and rapid filling at the end of the Weichselian or Early Holocene (marine phase).

3.4. Holocene deposits

Sequence (L)III, with a thickness of about 9m, comprises the Recent (Holocene) sediments. This sequence consists of open marine deposits and contains two coarsening upward units, unit (L)III.1 being topped by finer sediments. Unit (L)III.2 was probably formed by the modern, highly oxygenated sandwave deposits. These cover older sandwave deposits of unit (L)III.1. The boundary between these units might coincide with the maximum depth of modern sandwave or storm influence, the coarser sediments at the bottom of unit (L)III.2 being lag deposits. Sequence (L)III thus probably corresponds with the Bligh Bank Formation. According to Cameron *et al.* (1989b), this formation consists of a blanket deposit (thin sheet of seabed sediments) of medium or fine to medium grained, clean yellow brown sands, gravelly at its base. The mollusc fauna is characterized by the presence of Angulus pygmaeus (Spaink, 1973). Most of the Bligh Bank Formation probably originates from reworked Pleistocene fluvial and marine sands from between the Strait of Dover and the Southern Flemish Bight (Cameron *et al.*, 1989b). The mixture of haematite and magnetite also points towards a mixture of material from different sources. Sandwaves which are widespread on the modern seabed north of the Hinder Banks (McCave *et al.*, 1977) are made up of these sediments.

The heavy mineral associations suggest a Rhine influence. This was also inferred by Eisma *et al.* (1981) from the salinity distribution reflected by Early Holocene Cardium edule shells.
The concentration of augite between 6-9.4m, with a sharp base between 7.3-9.4m (figure 11) might indicate a change of transport system or origin of these sediments.

Lithostratigraphic correlations for instance with other Southern North Sea Project boreholes is not possible. As mentioned above, BH 89/1 is not representative for the Southern Bight area, as it is located in one of the scattered depressions in the northern part of the Belgian Continental Shelf. Moreover, the other SNSP boreholes are situated in the central part of the Southern North Sea, at least a few hundreds of kilometers from BH 89/1 (BH 89/2, Dutch sector). Even correlation with a British borehole (BH 81/51) proved to be difficult : only the base-Quaternary and base-Holocene unconformities could be correlated. The results of this work will be published in a separate paper.

4. CONCLUSIONS

The data summarized above produces results that can be synthesized as follows.

Three major sequences have been distinguished. The Tertiary deposits belong to the Lower Eocene Gent Formation and were deposited in a shallow marine environment. They dip 0.26° to 0.29° towards the north-east. These deposits are separated from the Quaternary deposits by an erosional unconformity.
Within the Quaternary deposits, which fill a valley-like depression scoured in the Tertiary deposits, two sequences can be discerned. The lower sequence consists of possibly reworked marine sediments deposited by a fluvial or fluvio-periglacial system during the Weichselian, during a sea-level stand lower than at present.

The upper sequence consists of a lower unit, built up of older seabed sediments, not influenced by modern sedimentation processes, and an upper unit consisting of active seabed sediments. Both units are of Holocene age and comprise the Bligh Bank Formation. The Pleistocene/Holocene boundary cannot be located accurately.

The depression scoured in the Tertiary deposits was lithologically and structurally controlled. The scouring might have happened before the Late Pleistocene. Its filling might have taken place during a fluvial phase (Weichselian) and a marine phase (Late Weichselian or Early Holocene). The sediments of the latter phase, however, were not recovered in the core. To be conclusive about the stratigraphy, macro-palaeontological information and possibly diatom analysis are needed. Hence no formal stratigraphic subdivision for the Quaternary deposits has been proposed here.

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