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Verhandeling N° 29

THE KNOKKE WELL (11E / 138) with a description of the Den Haan (22W / 276) and Oostduinkerke (35E / 142) wells

by

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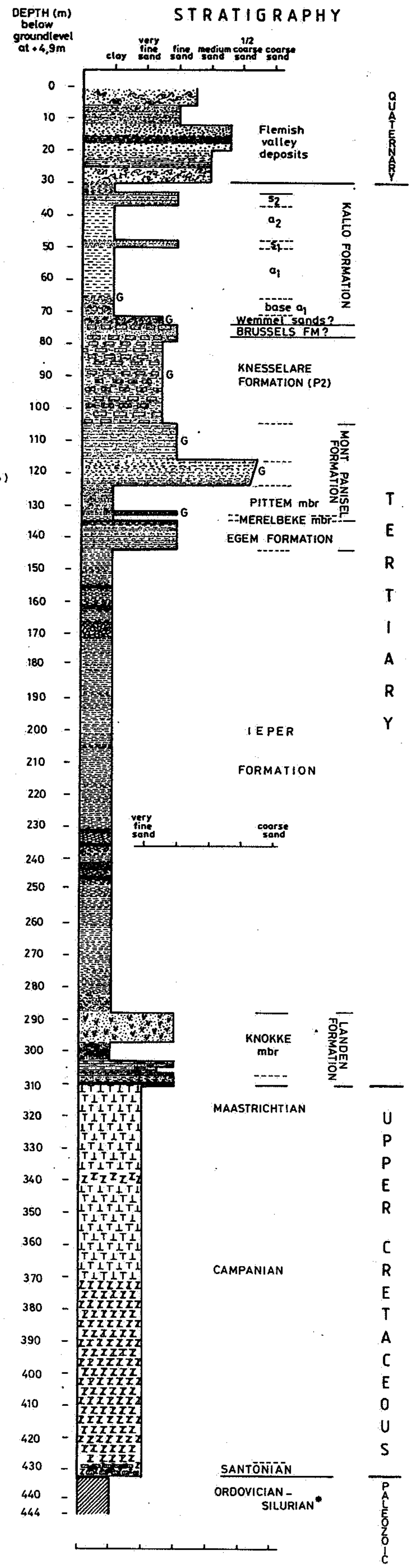
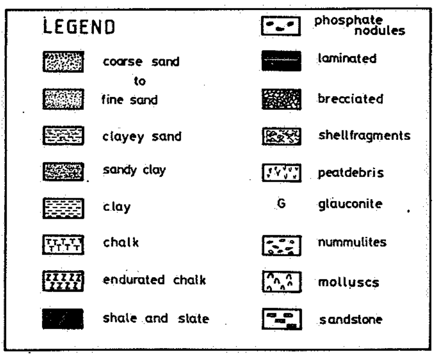
LITHOLOGICAL DESCRIPTION

- light grey yellow mm to fine sand with shellfragments (0–6)
- fine alternation of clay and fine grey sand (± every cm) (6–12)
- mm sand (at the top) to 1/2 coarse sand (at the base) with claylayers (12–20)
- grey mm sand alternated with 5–10cm thick claylayers (20–25) between 22.80 – 23.45 : silty clay
- dark grey mm sand with shellfragments (25 – 30)
- greengray sandy clay (30 – 33)
- greengray fine clayey sand (33–36)
- alternation of clay and fine sand (36–37)
- greygreen clay (37–48)
- green fine clayey sand (48 – 50)
- green grey heavy clay with glauconite at the base (50–66)
- very sandy green clay with (much) glauconite (66 – 71,5)
- greygreen fine to very fine clayey sand with glauconite, and shellfragments + nummulites + molusks (71,5 – 74)
- sandstone with sand (74 – 79)
- greygreen blue fine to very fine clayey sand with glauconite, calcareous sandstone, shells and ditrupa's (79 –105)
- darkgreen laminated fine sand with glauconite and claylaminae (105 – 110)
- greygreen fine clayey sand (with stonelayers and glauconite) and claylaminae (110 – 116)
- badly sorted greeny grey sand with glauconite and claylaminae (towards the base the sand becomes finer, at the top : sandstone) (116 – 124)
- grey silty clay with many stonelayers (124 – 132)
- greengrey fine, very clayey sand with glauconite (132 – 133)
- homogene greengrey heavey clay (133 – 135)
- altern. of fine green sand with claylaminae (135 –136)
- fine green sand with less claylaminae (136 – 138)
- alternation of claylayers with fine sand (with stonelayers) (138 –144)
- greengrey heavy clay (sometimes brecciated) with siltspots, silt lamella and pyriet (144 –283)
- silty clay (283 – 288)
- lightgrey to darkgrey – fine sand with peatdebris (288 –297)
- silty clay with several shellfragmentzones (297 – 303)
- compact fossil level (303)
- alternation of fine clayey sand with silty clay (303 – 308)
- pale clayey sand at the base laminae of fine sand and clay (308 – 311)
- pure white chalk with fossils (lower half endurated) (311–428)
- chalk with black phosphate nodules with a "greensand" sandstone at the base (428–432,05)
- soft greengrey weathered shale (432,05 – 432,70)
- soft greengrey slate





* Pers. comm. (1990) by Geert Van Grootel, based on the presence of Chitinozoa

KNOKKE 11E 138

TABLE OF CONTENT

THE KNOKKE WELL (11E/138)
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INTRODUCTION

The geometric and lithostratigraphic frame for the Belgian coastal area is well documented by the excellent profiles drawn by HALET (1921) and GULINCK (1970).

Most of the data, their work was based upon, however, were provided by samples from older water flush-wells. Hence precise and detailed lithological descriptions were rare as were the samples suitable for modern biostratigraphical analyses.

Increasing geotechnical work off-shore and the expected interest in exploration on the Belgian shelf would also benefit from the modern geological reference data along the coast.

Techniques to link the known on-shore geology to data obtained off-shore will certainly for a large part be geophysical in nature. Therefore an emphasis was put on geophysical well data.

Besides, geophysical well data are a very powerfull correlation tool and might even be more economic than classical coring techniques.

Three well sites were selected (fig. 1). At each location drilling reached the Caledonian basement of the Brabant Massif.

The Knokke well (11E/138) has been entirely cored, while both other wells at Den Haan (22/276) and at Oostduinkerke (35E/142) are flush-wells with a standard geophysical well logging program. The cored Knokke well had in addition density and sonic transit time logs as an aid to elucidate seismic investigations in the area.

The figures 2, 3, 4 gives a detailed location scheme of the three wells. The topographic levels of the three wells are in TAW: Knokke + 4,91 m, Den Haan + 5,02 m, Oostduinkerke + 6,55 m. The

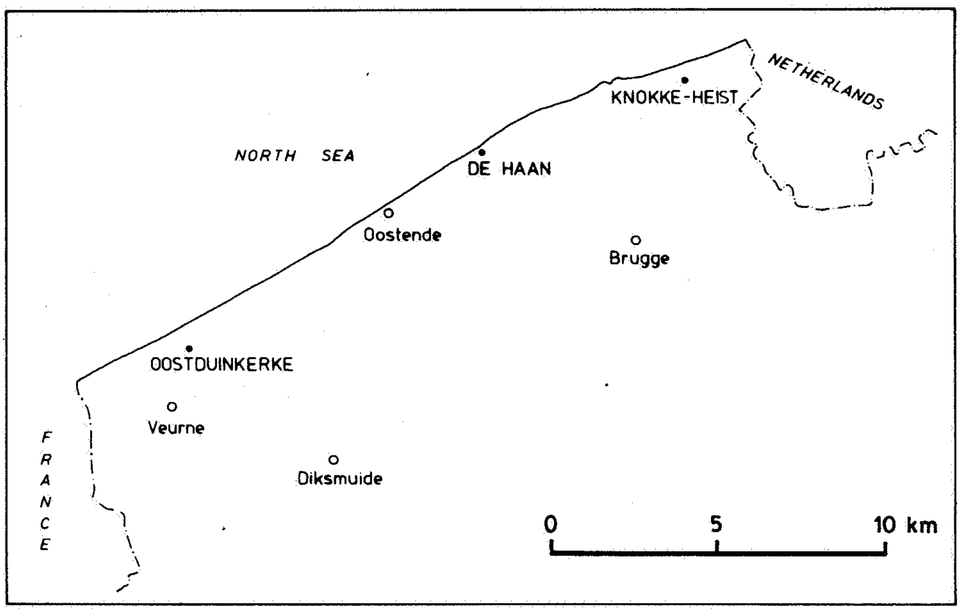


Fig. 1.- Location of the three wells, Oostduinkerke, Den Haan and Knokke

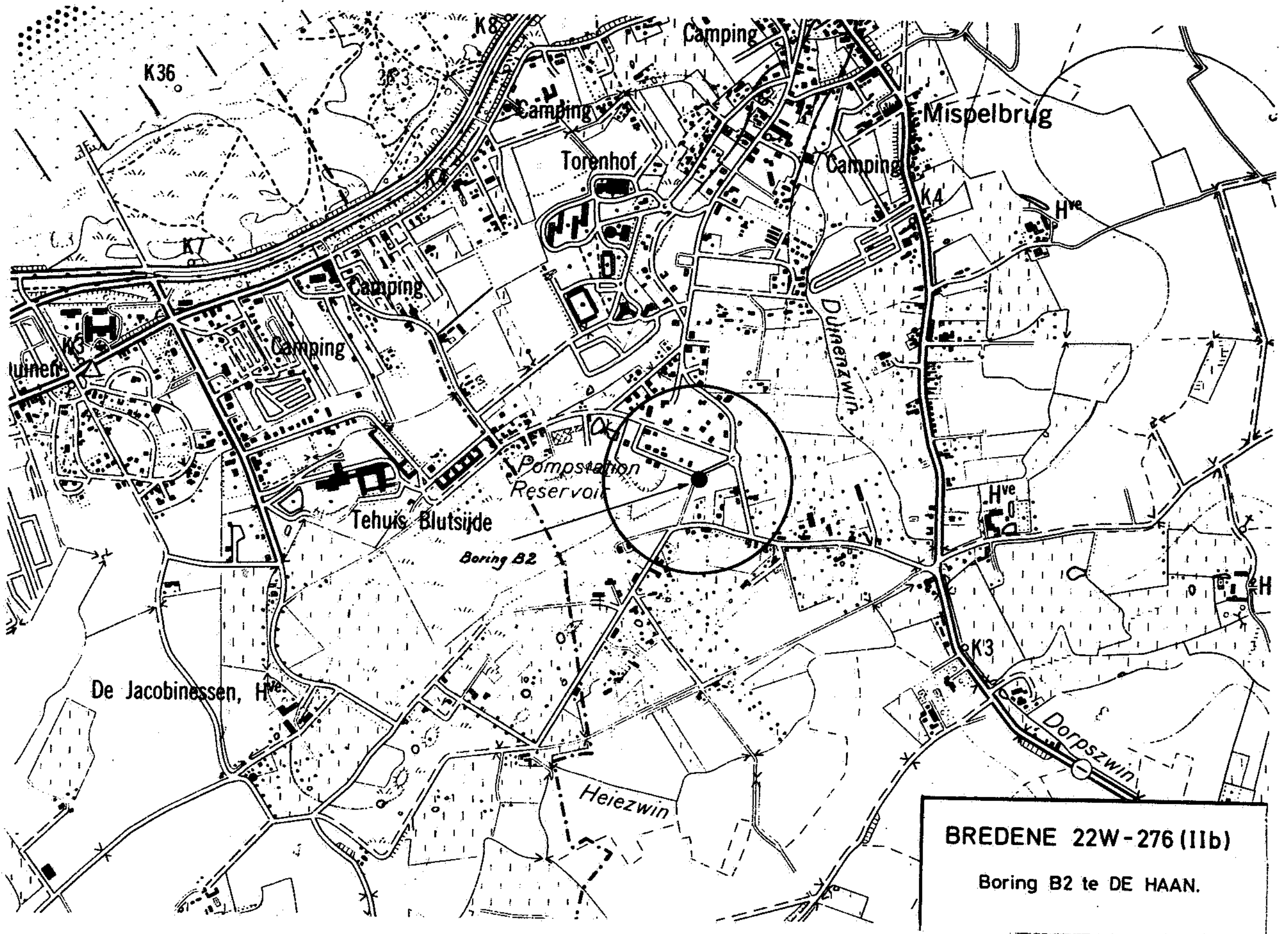


Fig. 2.- Location of the Den Haan well (22 W/276)

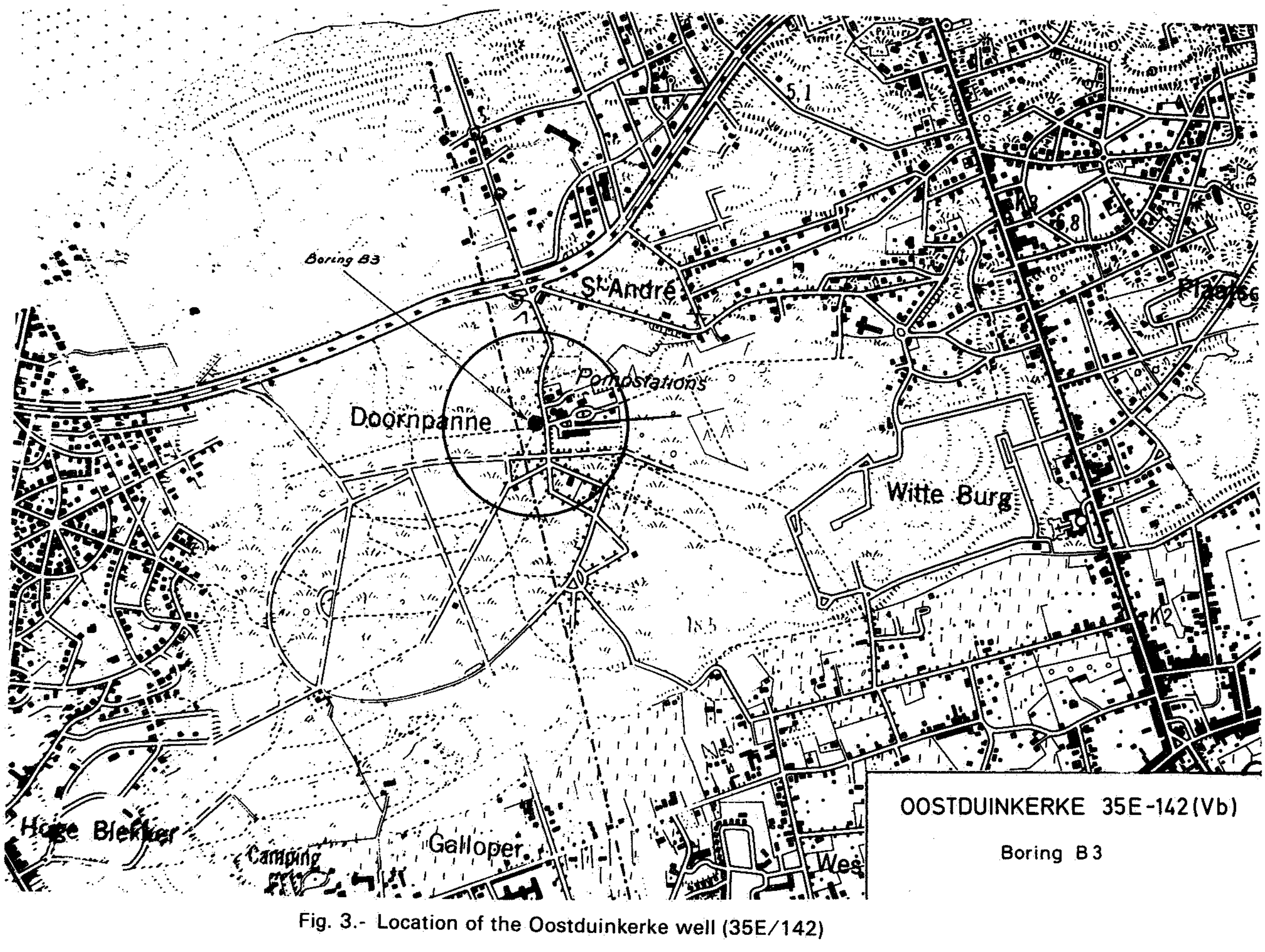


Fig. 3.- Location of the Oostduinkerke well (35E/142)

Note on the stratigraphic terminology

As the stratigraphic terminology for the Tertiary is currently under review by the appropriate National Stratigraphic Commission the editors have chosen for a consistent terminology in the different chapters.

For the members we have therefore chosen to follow the recommendations of the Commission although they were not yet published at the time of publishing this memoir.

	Different authors (see footnote)	Kallo complex terminology (GULINCK, 1969)	Geological map symbols
Kallo Formation	[1]Buisputten member	S2	
	[1]Zomergem member	A2	
	[1]Onderdale member	S1	As d
	[1]Ursel member		As c (pp)
	Asse member	A1	As b, As c (pp)
	«bande noire» bed		As a
	Wemmel member		We
Lede Formation			Le
Brussel Formation			Br
Knesselare Formation	[2]Aalter member		P2
	[2]Oedelem member		
	[3]Beernem member		
Mont-Panisel Formation	[4]Vlierzele member		P1 d (and P1 n)
	[5]Pittem member		P1 c
	[6]Merelbeke member		P1 m
Egem Formation			Yd (and P1 b)
Ieper Formation			Yc
Landen Formation			
Upper Landen Formation	[7]Knokke member		L2
Lower Landen Formation			L1

[1]terms introduced and defined by JACOBS (1978), [2]by NOLF (1972), [3]by JACOBS & GEETS (1977), [4]by KAASSCHIETER (1961), [5]by GEETS (1979), [6]by DE MOOR & GEETS (1973); [7]the Working Group of the Stratigraphic Commission has proposed to replace the term Oostende-ter-Streep member (KAASSCHIETER, 1961) by Knokke member because of the unappropriate geographic term (Oostende-ter-Streep cannot be found on a map and Oostende has already been used for a Quaternary deposit).

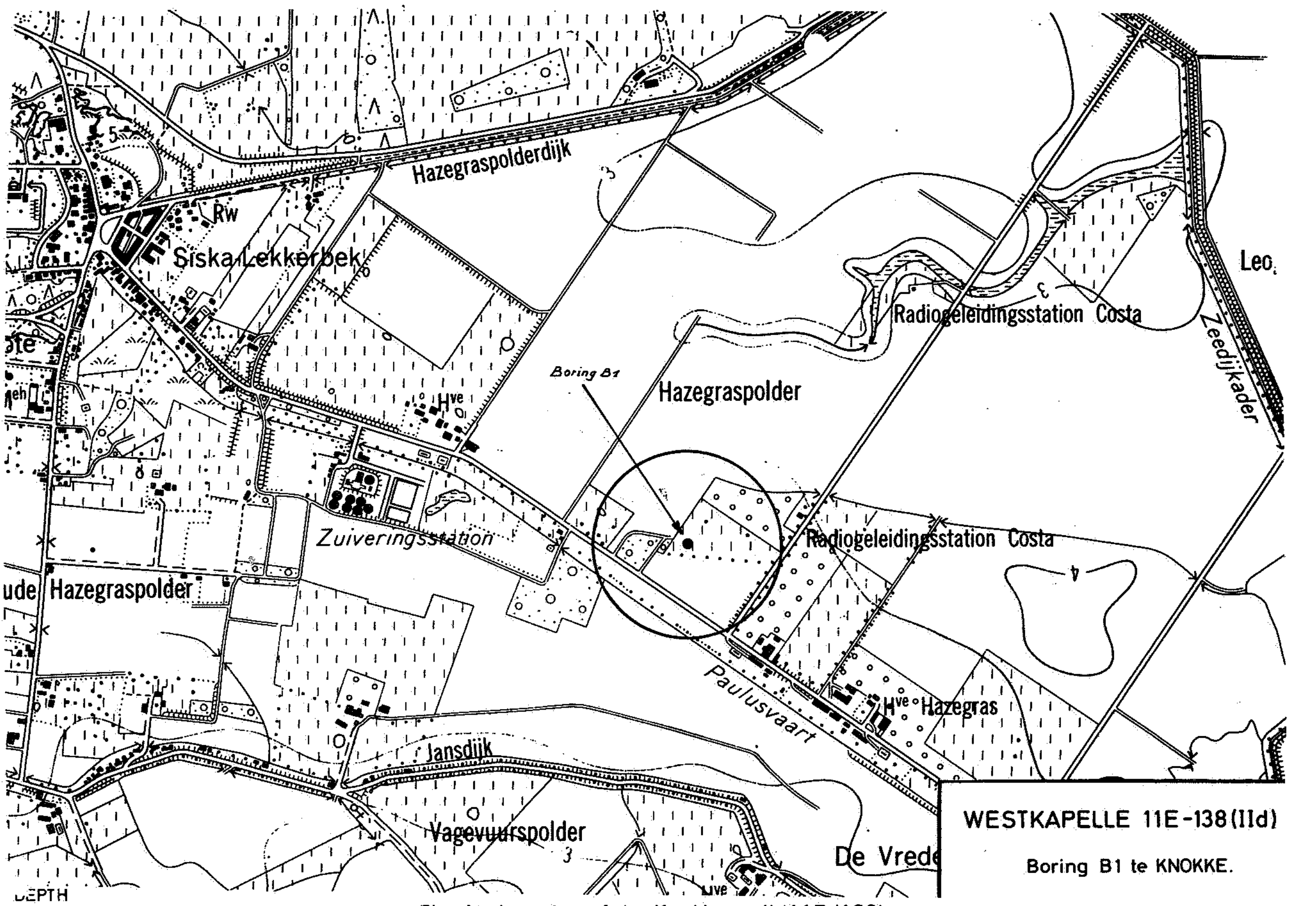
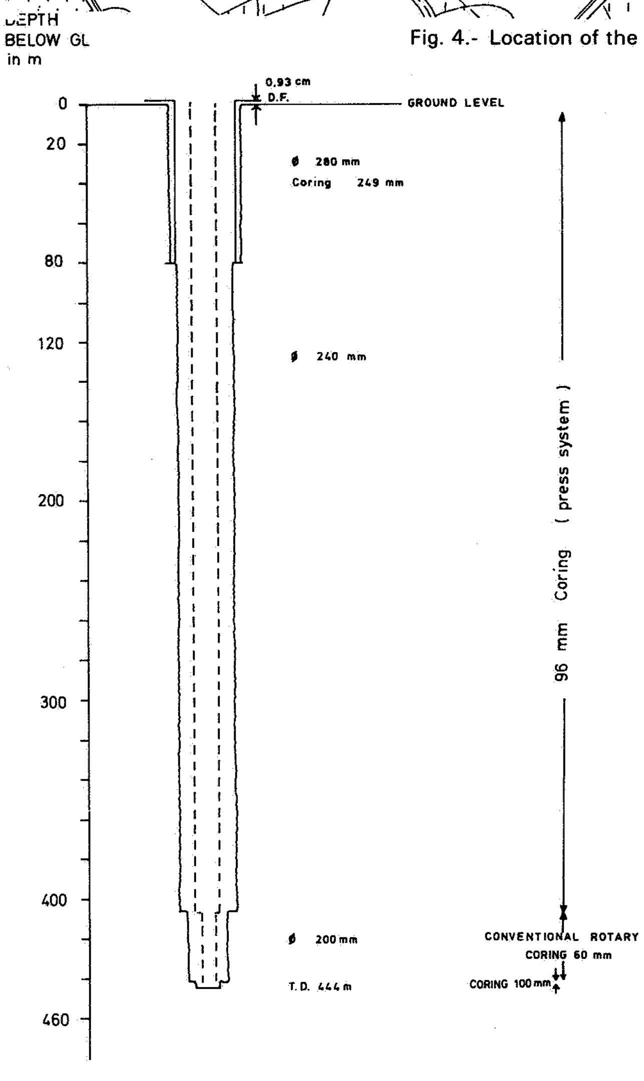


Fig. 4.- Location of the Knokke well (11E/138)



original description of cores and flush samples are kept at the Geological Survey files: 11E/138 (Knokke), 22W/276 (Den Haan) and 35E/142 (Oostduinkerke). The geophysical logs are kept in the well-log library of the Geological Survey.

Figure 5 shows a technical well sketch of the Knokke well (Smet DB, drilling company).

The Den Haan well was drilled with a 240 mm rock bit till 202,44 m depth, with 7.7/8" till 304,30 m; the 304,30 m till 321 m section was cored in 95 mm diameter.

The Oostduinkerke well was drilled with a 240 mm rock bit till 253,80 m; the 253,80 m till 270, 30 section was cored in HQ (96 mm).

Fig. 5.- Technical well sketch of the Knokke well

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Chapter I
LITHOLOGICAL DESCRIPTION OF THE KNOKKE WELL

by

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For a detailed description the reader is referred to the Geological Survey files (11E/138).

A summary description is presented together with a lithostratigraphic column on figure 1.

1.- THE QUATERNARY

The top 30 m consist of mainly sandy, often laminated deposits. They represent tidal and estuarine deposits of mainly Pleistocene age. They belong to the Flemish Valley river system deposits (TAVERNIER & DE MOOR, 1974; PAEPE & VANHOORNE, 1967).

2.- THE KALLO FORMATION

A mainly heavy clay unit forms the top of the Tertiary, from 30 m to 71,5 m. Two glauconitic fine clayey sand intervals exist at 33-36 m and 48-50 m. The general lithological appearance and the position in the stratigraphic sequence indentifies this unit as belonging to the Kallo complex (sensu GULINCK). The two sand units are s1 and s2. The glauconite rich and sandy nature of the a1 base is in accordance with the character of the Asse Clay. A formal lithostratigraphic nomenclature for this sand, clay sequence was worked out by JACOBS (1978).

3.- THE SAND UNITS BETWEEN THE ASSE AND THE IEPER CLAYS

a.- Two thin sand units below the Asse Clay have distinct lithological properties.

The 71,5-74 m interval is a fine clayey glauconitic sand with numerous nummulites and calcareous shells some not or only slightly transported, as shown by the two valves still sitting together. The 74-79 m interval is a fine sand with several layers of cemented calcareous sandstone. The presence of *Nummulites wemmelensis* in the upper sand unit identifies it as the Wemmel sands (Wemmel member of the Kallo Formation).

The lower sand unit, badly cored because of stone layers, would in the tradition of the regional geological knowledge be interpreted as the Lede sands. At 73 m however, the mollusc *Callista proxima* (1) is commonly present; it is diagnostic for the Brussel sands. The presence at the same level of numerous transported and rounded *Nummulites laevigatus* is also an indication for the former presence of the Brussel sands. In general, this type of concentration is typical for the base of the Lede sands although numerous *Nummulites laevigatus* have been found in the Brussel sands at the Mont des Récollets and in the Woensdrecht well as reported by GULINCK (op. cit.).

The idea of a widespread very thin Brussel sands shell and nummulite bed, almost completely removed before the deposition of Lede and Wemmel sands to the west of the Zenne valley, was put forward by GULINCK and HACQUAERT (1954, p. 485).

The presence of Brussels sands at 73 m means that the 74-79 m sand interval could also represents Brussel sands and hence the Lede sands could be lacking.

Similar conclusions were obtained by DEPRET and WILLEMS (1983) for the nearby area around Zeebrugge (see also chapter VII).

(1) Determined by C. King, this volume.

b.- The whole section between 79 and 135 m can be attributed to the Panisel formation. It is a typical glauconite rich sediment, in which clays and almost pure sands alternate and in which the occurrence of cemented sandstone layers is common.

Several subunits can be recognized. The 79 to 105 m interval of fine clayey glauconitic sands with numerous shells, ditrupa's and calcareous sandstones corresponds to the typical Upper-Panisel Aalter sands facies. In the terminology of DEPRET and WILLEMS (op. cit.), this Upper-Panisel facies is described as the Den Hoorn formation (2). Although several members can be recognized in this formation these authors identified in the Zeebrugge area 35 m of the Oedelem member, making up the whole Den Hoorn formation. Below 105 m, five more subunits can be recognized.

The interval between 105 and 116 m consists of fine glauconitic sands with clay laminae and stone layers in its lower part (Pl. 1, photo 1, 2, 3). The interval between 116 and 124 m is a coarsening upwards glauconitic medium to coarse grained sand.

The 124-132 m interval is a silty clay with several cemented sandstone layers. The 132-133 m interval is again a fine glauconitic clayey sand horizon. The 133-135 m is a heavy homogeneous grey clay horizon.

The latter unit is the basal Panisel clay (Merelbeke clay) and the 124-132 m silty clay with cemented sandstones fits the geometrical position and the facies of the Pittem clay (P1c map symbol).

The 105 to 124 m part is more difficult to associate with one of the known Panisel facies in the outcrop area to the south-southeast.

Generally speaking however the same lithology and depositional facies are involved as in the type area.

4.- THE IEPER FORMATION AND THE EGEM FORMATION

The Ieper Formation extends from 144 m down to 288 m. The overlying interval, 135-144 m, which is a laminated clay with fine sand horizons and even cemented sandstones is now called the Egem formation.

Except for the silty basal 5 m (283-288 m), the entire Ieper Formation consists of homogeneous greengrey heavy clay with some rare silty spots or thin silt laminae; pyrite is present as well.

A striking feature is the occurrence of several horizons of a brecciated Ieper clay. Although some of the fragments have some rounding (Plate 2, photo 5), most of the breccia fragments are still angular and have barely moved (Plate 2, photo 4, 5; Plate 3, photo 6, 3). Photo 6 shows that brecciation is associated at least in some instances with small faults, pointing to gliding phenomena in the clay. Obviously a borehole is too small to develop a detailed hypothesis for their origin. Nevertheless a few comments can be made. The angular nature of the clay fragments and especially the fact that they have not been compressed, suggests a brecciation at an already well compacted stage; we suppose that the brecciation occurred at least at some tens of meters burial depth or even deeper.

The origin at depth could then be related to the observations of HENRIET and MARECHAL (1982), who have interpreted from sparker-seismic surveys diapirs and other deformations in the Ieper clay off-shore. It is suggested that the common occurrence of Ieper clay deformation in the Belgian North Sea (HENRIET and MARECHAL, 1982) in contrast to almost undeformed Ieper Clay on land is due to unloading as the Channel was eroded. This explanation is analogous to the occurrence of clay diapirs in the Rupelian Boom clay along the tract of the eroded Scheldt valley (WARTEL, 1978; SCHITTEKAT *et al.*, 1983) in contrast to undeformed clay on land.

Thin black pyrite linings surround the fragments in many cases. The faults shown in photo 7 should not be confused with the slickensided fissures, so common in the overconsolidated Tertiary clays and also present in the Ieper clays of the Knokke well.

At the base the clay is slightly brownish.

5.- THE LANDEN FORMATION

The Landen Formation sediments occurring from 288 m to 311 m can be subdivided in three main subunits.

The upper one between 288 and 297 m consists of quartz sands with peat debris. The 297 m to 308 m interval consists of silts, fine sands, heavy clay, shell fragments and a compact shell bed at 303 m. These fossils point to a

(2) The Den Hoorn Formation is made up of the Oedelem, Beernem and Aalter members (Nolf, 1972). It is proposed now to use the term the Knesselare Formation instead of the Den Hoorn Formation.

brackish water lagoonal environment, with salinities lower than 10‰. The fossils represent a typical Sparnacian-type fauna (see also chapter IV).

The 308-311 m interval consists of pale coloured, also pink to purple sands. At the base the sediment becomes clayey and greenish.

It is thought that, except for the very lowermost greenish clayey sediments, the whole section of the Landen Formation should be associated with the continental Upper Landen Formation, sediments deposited at the sea-continent transition.

6.- THE UPPER CRETACEOUS

The Upper Cretaceous chalk sequence is very homogeneous. It is a fine grained white chalk with fossil remnants, black to blue soft pyritic linings and small patches, sometimes more grained (grenue). Several indurated horizons occur and the chalk as a whole becomes more indurated towards the base.

The base itself is more differentiated. It starts containing small black phosphatic pebbles from 428 m on whilst glauconite is present from 429,80 m depth onwards. The very base is a green cemented glauconite sandstone with small black pebbles and fish remnants.

Calcareous nannofossils (see chapter V, VI, VII) show the sequence to be mainly Campanian, in fact ranging from Santonian at the very base to Lower Maastrichtian at the very top. The macrofossil fragments, a.o. *Inoceramus* fragments, *Actinocamax, Echinocorys, Magas, Terebratula, Cidaridae* and many brachiopode and belemnite fragments had already suggested a resemblance to the white chalk sequence in northeast Belgium.

7.- THE CALEDONIAN BASEMENT

The top of the Brabant Massif consists of a jointed slate dipping 30 to 40°, attributed to the Lower Revinium (Oisquercq slates) by LEGRAND (1968) in the nearby 11E/48 well.

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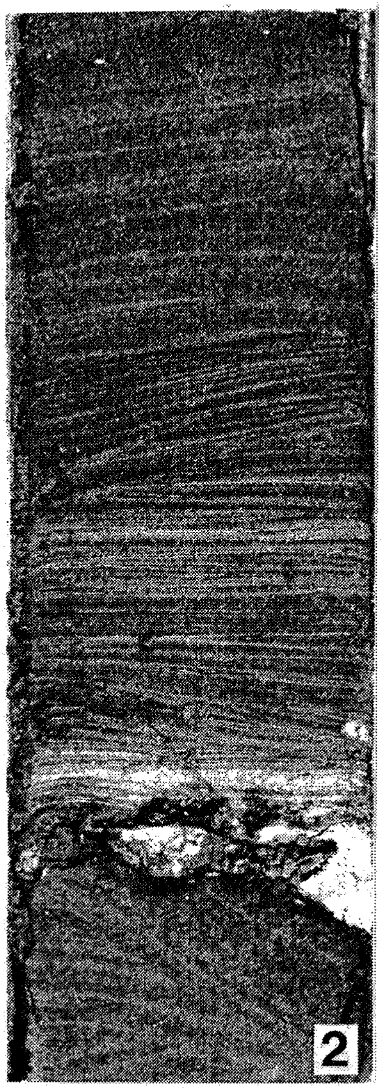
PLATE 1

1. Clay laminae with glauconitic sand layers (105.60-106 m)
2. Storm affected laminated glauconitic sands, with a thin transported clay fragment (106.35-106.60 m)
3. Bioturbation in glauconitic fine sands (112.50-112.80 m)

105,60 m - 106 m

106,35 m - 106,60 m



112,50 m - 112,80 m

PLATE 2

4. Brecciation in the Ieper clay (153.20-153-40 m)
5. Strong brecciation in the Ieper clay. Some of the breccia fragments are slightly rounded (154.20 m)

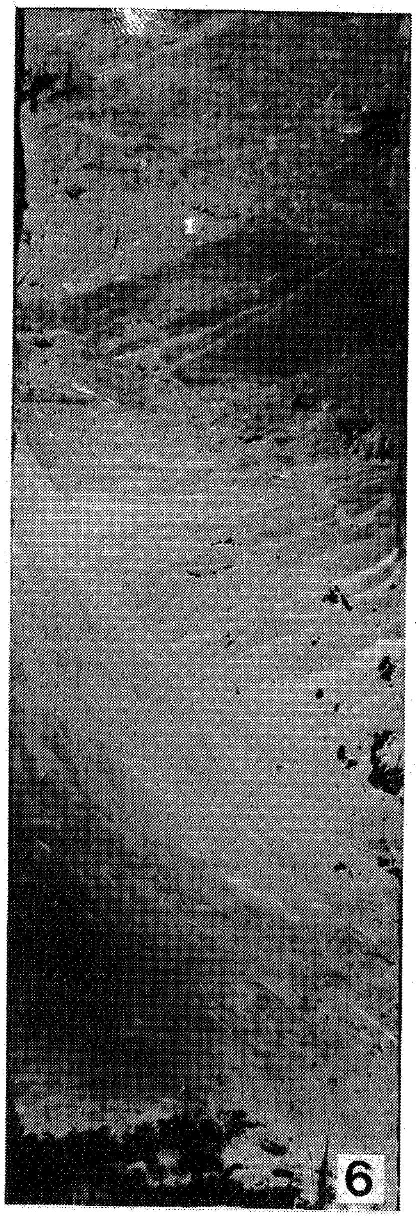
153,20 m - 153,40 m

154,20 m

PLATE 3

6. Sliding in the clay, associated with brecciation in the Ieper clay (170-171 m).
7. Slight brecciation in the Ieper clays (180-180.90 m)

170 m - 171 m



180 m - 180,90 m

Chapter II
GRAIN-SIZE AND HEAVY MINERALS OF THE TERTIARY STRATA IN THE KNOKKE WELL

by

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1.- GRAIN-SIZE ANALYSIS

A. METHOD OF INVESTIGATION

20 g of each air-dried sample was divided in a coarse and a fine fraction by wet-sieving on a 50 μm-sieve. The first part was mechanically subdivided on a sieve-series with a successive difference in mesh-width of 0.5 φ. The fine fraction was analyzed by a CAHN-R.G.-sedimentation-balance. The results are given in table I (more detailed figures are available with the authors).

Samples containing shell fragments were decalcified with 0,5 N HCl before the grain-size analysis.

B. SEDIMENT-NOMENCLATURE AND GRAPHIC REPRESENTATION

Three fractions were calculated: the sand-fraction (2000-63 μm), the silt-fraction (63-2 μm) and the clay-fraction ($<$ 2 μm). Their percentages were plotted in a modified triangular diagram after SHEPARD (1954) (GEETS, 1978).

With the classification of WENTWORTH (1922) as a base, a term has been added to the name sand (sandy) or silt (silty), which corresponds to the interval with the highest percentage in each of these fractions, in order to give a more accurate determination of each sediment.

The results of the grain-size analyses were plotted as cumulative curves on log-probability paper, which makes it more easy to read the percentiles for the calculation of the graphical parameters and to determine the percentage of the fraction $<$ 2 μm by extrapolation.

C. GRAIN-SIZE PARAMETERS AND ENVIRONMENTAL ANALYSIS

Graphic parameters, according to R.L. FOLK and R.C. WARD (1957) were calculated for the sandy and coarse-silty sediments, whereas the moment measures were determined for all samples (table II).

A few methods, based on grain-size distribution, have been used to obtain some information about the depositional environments of some members in the Knokke well.

The C/M-diagram (PASSEGA & BYRAMJEE, 1969) distinguishes several kinds of «suspensions» and is used as an indicator of the hydraulic conditions under which sediments were deposited.

The analysis of the cumulative curves on log-probability-paper in different populations and the comparison with the examples published by DOEGLAS (1946, 1947), SINDOWSKI (1957) and VISHER (1969) gives information about the energy of the depositional agent and about the environment.

D. KALLO FORMATION

Buisputten Member, S2
(33-37 m, table I and II, nrs. 3-6)

The member consists of coarse-silty, very fine sands, very poorly to extremely poorly sorted; the base is formed by an extremely poorly sorted, very-fine-sandy, clayey, coarse silt. The sediments coarsen towards the top: $\bar{x}_\varphi = 6.18\,\varphi$ to $4.95\,\varphi$: they are mostly uniform suspension sediments (fig. 1).

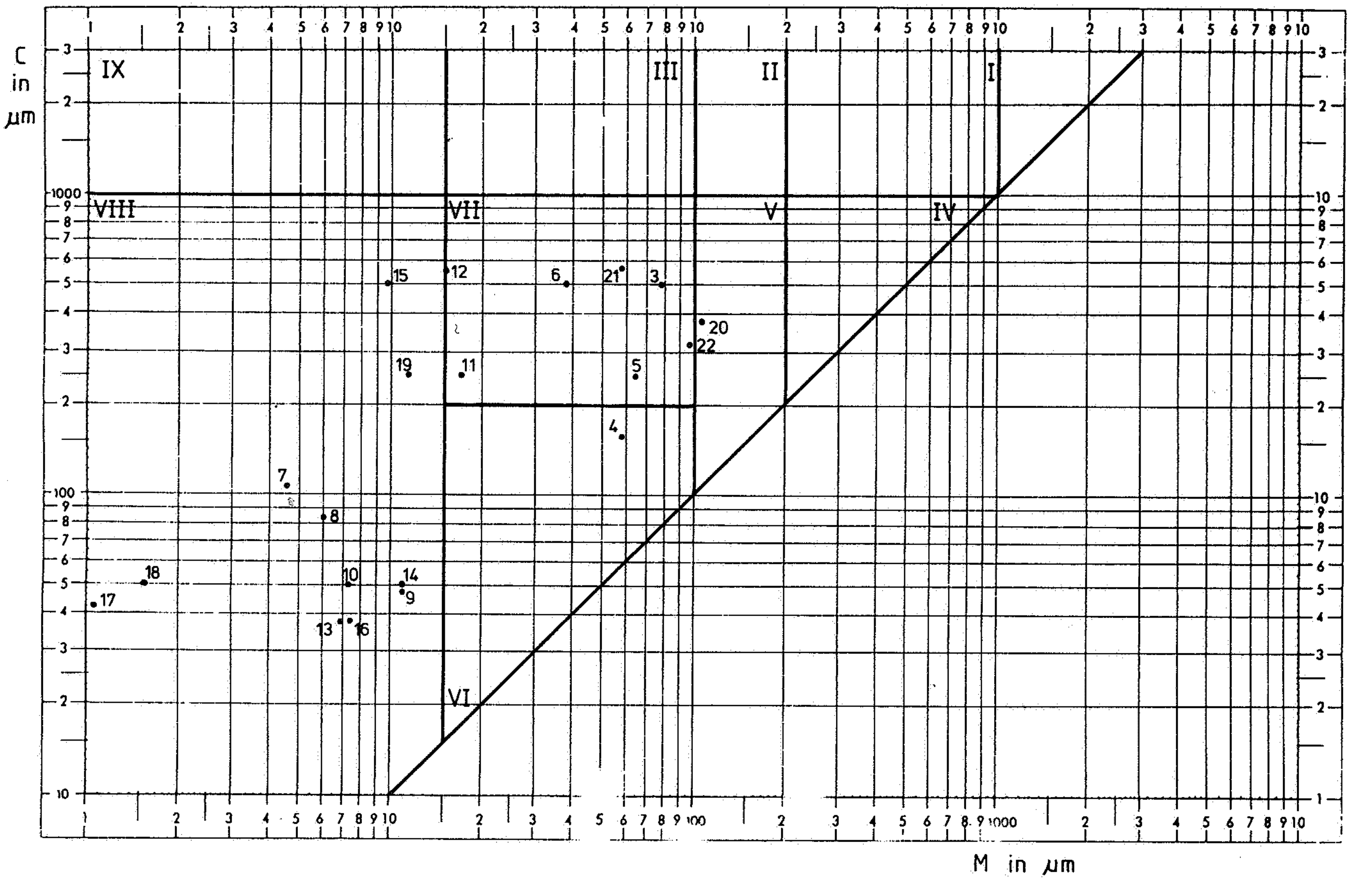

Fig. 1.- C/M diagram of the sediments from the Kallo Formation

The cumulative curves show one saltation population and a smaller suspension population. The two lowest samples (5 and 6) contain a very small traction population (±2%) (fig. 2) (the numbers along the curves correspond with these of the samples on table 1 and 2). These sediments seem to be deposited in a shallow water environment near to the coast or along distributary channels.

Zomergem Member, a2
(37-48 m, table I and II, nrs. 7-12)

At the base a very poorly sorted coarse silt (11-12, $\bar{x}_\varphi = 6{,}5\,\varphi$) occurs, which passes into a very poorly sorted clayey very fine silt (7-10, $\bar{x}_\varphi = 7.88\,\varphi$). The suspension population becomes more important towards the top of the member at the cost of the saltation population, whereas the small traction population disappears above 45.5 m (fig. 2).

These silts, which grow from uniform suspension sediments at the base into finest uniform suspension sediments (fig. 1), were probably deposited in quiet, protected areas along the coast.

Ursel Member, a1 clay unit
(50-66 m, table I and II, nrs. 13-19)

This member starts with a clayey, coarse silt at the base, passing over a very-fine- to fine-silty clay, into a (clayey) fine to very fine silt. They all belong to the finest uniform suspension sediments (fig. 1).

Their cumulative curves show a very well developed suspension population and a very high break point (at 7 φ) with the saltation population (fig. 2): their form strongly resembles the ones of the curves of crevass deposits in near-shore distributary systems (VISHER, 1969).

Asse Member, a1 sandy unit
(66-71.5 m, table I and II, nrs. 20-21)

The sediment consists of extremely-poorly sorted, medium-silty, clayey or clayey fine sands. Below it belongs to the uniform suspension sediments, passing into a graded, moderate-turbulent suspension sediment (fig. 1). Their cumulative curves show a saltation population of 60 %, which at 3.7 φ (21) or 2.4 φ (20) changes into a suspension population.

Table I.- Results of the grain-size analysis

	0-1 φ	1-2 φ	2-3 φ	3-4 φ	4-5 φ	5-6 φ	6-7 φ	7-8 φ	8-9 φ	< 9 φ
1. 30.9 m	0.50	0.50	3.00	12.00	18.35	10.95	13.00	11.10	9.60	21.00
2. 31.0 m	35.35	4.00	10.00	16.65	5.70	4.80	6.15	4.90	3.95	8.50
3. 33.8 m	1.00	-	11.00	55.00	9.15	2.05	3.15	1.80	2.05	14.80
4. 34.8 m			5.50	47.00	20.20	3.65	6.65	4.35	3.15	9.50
5. 35.35 m	0.50	0.50	0.50	52.35	11.80	5.45	6.80	3.90	3.20	15.00
6. 36.8 m	1.00	0.50	1.00	33.70	20.85	4.80	5.80	5.20	4.15	23.00
7. 38.9 m					11.00	8.70	18.60	14.00	13.20	34.50
8. 40.5 m					5.50	16.45	22.75	14.10	13.70	27.50
9. 41.5 m					9.25	27.85	23.25	12.10	9.55	18.00
10. 43.5 m					6.70	20.95	20.85	11.85	11.15	28.50
11. 45.5 m	0.50	0.50	0.50	1.50	25.95	24.60	17.50	9.80	7.15	12.00
12. 47.5 m	1.50	0.50	0.50	2.50	23.90	18.75	17.65	13.55	8.65	12.50
13. 50.5 m					0.30	10.15	33.55	26.05	17.45	12.50
14. 52.3 m					15.30	22.90	24.45	13.80	10.55	13.00
15. 54.5 m	1.00	0.50	0.50	2.00	12.35	19.35	21.45	6.40	5.95	30.50
16. 58.5 m					1.45	10.80	35.85	25.10	16.50	10.30
17. 60.5 m					3.55	4.70	13.30	5.80	4.65	68.00
18. 62.5 m					3.95	6.50	12.50	11.30	12.75	53.00
19. 65.5 m		1.00	1.00	9.50	28.80	6.20	6.70	3.80	4.00	39.00
20. 67.5 m		21.50	24.50	13.00	5.95	2.20	2.65	2.85	2.15	25.20
21. 70.5 m	1.50	11.50	26.50	8.50	7.75	9.50	6.40	2.85	2.50	23.00
22. 72.0 m	0.50	1.00	26.00	61.00	3.25	0.90	1.10	0.45	0.90	4.90
23. 79.5 m		1.00	12.50	74.00	4.30	0.60	0.00	0.45	0.25	6.10
24. 82.5 m		0.50	53.00	38.50	2.20	0.40	0.50	0.40	0.40	4.10
25. 84.5 m		1.00	26.50	41.00	3.60	1.55	2.30	1.60	1.45	21.00
26. 87.5 m		0.50	4.50	73.50	5.10	0.95	1.40	1.05	1.00	12.00
27. 90.75 m		1.00	1.00	36.50	18.60	7.55	5.35	2.45	2.05	25.50
28. 96.50 m		0.50	31.50	42.00	1.40	0.95	2.50	1.75	1.40	18.00
29. 98.85 m		0.50	48.00	30.00	3.10	0.85	1.40	0.85	0.80	14.50
30. 110.5 m	1.00	0.50	0.50	14.00	6.05	6.60	18.60	8.45	8.30	36.00
31. 113.75 m	1.50	0.50	0.50	42.00	14.30	3.65	5.40	6.15	5.50	20.50
32. 115.1 m	1.50	8.50	6.50	27.00	18.35	4.35	4.30	4.05	2.45	23.00
33. 119.8 m	1.50	35.50	49.50	6.0	7.5					
34. 120.95 m		23.00	50.00	9.50	5.25	2.95	2.25	1.10	1.45	4.50
35. 124.2 m	1.00	10.00	32.50	15.50	8.00	4.70	5.80	3.50	3.00	16.00
36. 126.5 m	1.50	2.50	27.50	12.50	4.15	5.80	6.00	3.75	3.30	33.00
37. 130.0 m	0.50	1.00	13.50	22.00	7.45	5.40	8.00	5.65	6.50	30.00
38. 132.5 m	1.00	2.00	24.50	39.50	7.30	3.25	3.25	3.10	2.60	13.50
39. 135.8 m	0.50	1.00	46.00	30.00	1.85	1.20	1.75	1.40	0.30	16.00
40. 139.5 m		1.00	1.00	50.50	11.40	3.90	4.80	2.95	2.45	22.00
41. 141,5 m	0.50	1.00	0.50	74.00	13.70	1.30	1.05	0.60	0.35	7.00
42. 144.5 m	0.50	0.50	0.50	0.50	18.95	14.85	15.75	9.25	8.20	31.00
43. 149.1 m					5.45	18.90	18.40	10.50	20.75	26.00
44. 150 m					8.95	11.50	11.60	6.35	5.60	56.00
45. 154 m						4.40	10.45	6.00	7.15	72.00
46. 154.65 m					0.75	8.10	15.50	10.30	20.35	45.00
47. 158 m					9.45	16.75	16.20	7.65	7.95	42.00
48. 162 m					8.30	12.90	11.00	6.00	4.80	57.00
49. 163.5 m					1.35	11.45	17.15	9.60	9.45	51.00
50. 164.25 m					8.95	17.50	18.65	10.55	9.35	35.00
51. 172.5 m					6.15	16.95	19.05	12.05	10.80	35.00
52. 174 m					6.25	13.50	16.70	7.90	7.15	48.50
53. 176.9 m					4.80	22.35	17.50	9.05	8.30	38.00
54. 178 m					3.55	6.60	13.20	30.25	25.40	21.00
55. 178,5 m					0.05	3.50	13.40	10.95	13.10	59.00
56. 182 m					1.80	2.00	6.85	17.20	22.15	50.00
57. 186 m					2.15	5.10	12.90	7.40	6.45	66.00
58. 190 m					3.70	11.10	15.45	6.60	6.15	57.00
59. 194 m					3.05	3.25	9.25	7.65	8.80	68.00
60. 198 m					5.15	4.90	10.30	6.55	7.10	66.00
61. 202 m					3.05	6.85	13.35	6.20	6.55	64.00
62. 210 m					3.55	5.65	11.80	6.60	6.40	66.00
63. 214 m					3.65	6.15	10.00	5.35	5.85	69.00
64. 218 m					1.45	8.00	17.10	6.80	6.65	60.00
65. 222 m					1.50	6.20	17.00	9.50	8.80	57.00
66. 224,4 m					1.55	9.45	19.05	13.45	11.50	45.00
67. 226 m					1.75	10.45	13.85	8.75	9.70	55.50
68. 228.7 m					2.25	5.45	12.90	8.35	9.05	62.00
69. 232,5 m					4.35	7.60	14.05	8.00	9.00	57.00
70. 235.8 m					4.80	7.20	14.00	8.80	8.20	57.00
71. 239.7 m					2.15	3.35	11.85	11.20	11.45	60.00
72. 243.4 m					8.10	10.65	14.60	7.05	7.10	52.50
73. 247.7 m					3.60	1.50	6.90	6.90	9.10	72.00
74. 255.6 m					3.45	3.10	11.15	9.80	12.00	60.50
75. 259.7 m					4.60	4.70	13.10	8.20	9.40	60.00
76. 263.7 m					3.60	5.60	13.30	8.60	9.40	59.50
77. 267.6 m					3.25	4.05	12.25	9.50	10.95	60.00
78. 270.7 m					4.35	2.60	9.80	9.70	10.55	63.00
79. 275.7 m					3.25	2.85	11.40	8.65	9.85	64.00
80. 280.65 m					4.85	3.90	9.55	4.50	4.20	73.00
81. 283.8 m					2.80	3.40	11.55	5.95	5.30	71.00
82. 287.7 m	0.05	0.05	0.30	31.40	26.30	5.75	4.90	3.35	4.40	23.50
83. 290.7 m		3.30	83.15	11.10	0.30	0.20	0.40	0.25	0.20	1.10
84. 294.3 m		0.05	57.30	41.00	0.55	0.15	0.20	0.15	0.10	0.50
85. 297.35 m	0.05	0.10	10.80	75.70	2.70	0.95	1.55	1.10	0.95	6.10
86. 299,7 m		0.05	0.15	1.15	5.20	4.95	6.95	6.40	7.15	68.00
87. 304.4 m		0.05	1.40	71.15	6.90	2.55	3.90	2.35	2.20	9.50
88. 306.4 m		0.05	0.10	0.60	12.70	9.00	13.45	6.60	6.50	51.00
89. 307.9 m	0.10	0.20	7.20	20.20	3.70	5.90	7.40	3.75	4.55	47.00
90. 308.5 m		0.05	23.30	55.70	2.45	0.80	0.90	0.65	0.95	15.20
91. 309.5 m	0.10	0.05	5.15	47.75	25.05	2.30	1.90	1.25	1.25	15.20

Wemmel Member
(71-74 m, table I and II, nr. 22)

The member consists of a poorly-sorted, very fine sand. It is a uniform suspension sediment (fig. 1); the cumulative curve shows a traction population, 2 saltation populations and a small suspension population (fig. 2). It seems to be deposited on a beach foreshore.

E. MONT-PANISEL FORMATION

79-99 m (table I and II, nrs. 23-29)

The sediment consists of fine (24, 29), very fine (23, 26) and clayey, very fine sand (25, 28), with an intercalation of clayey, coarse-silty sand at 90.75 m. The sorting is extremely poor at the base, but grows better towards the top of the complex.

According to PASSEGA and BYRAMJEE, most of the sands are deposited from a uniform suspension, which are graded, moderate-turbulent suspension sediments (fig. 3). The cumulative curves of the very fine sands (23, 26) comprise two saltation and one suspension population, whereas the other ones only contain one saltation and one suspension population (fig. 4).

The sediments seem to be formed along a low-energy coast.

110-116 m (table I and II, nrs. 30-32)

The extremely-poorly sorted, coarse-silty, clayey, very fine sand (30, 31) is covered by a clayey, very fine silt (32). The sediments were deposited from a finest uniform (32) or a uniform suspension (fig. 3).

One saltation and a suspension population is present, with a small traction population in sample 31 (fig. 4). Probably the sediments originated in protected areas along the coast or in parts of a distributary system.

Table II.- Grain-size parameters

	Md_ϕ	Mz	$\bar{x}_\phi$	σ_I	σ_ϕ	Sk_I	$\alpha_{3\phi}$	K_G	$\alpha_{4\phi}$
1. 30.9 m	6.35	6.78	6.84	2.84	2.89	0.25	0.42	0.90	-0.94
2. 31.0 m	3.05	3.70	3.67	3.08	3.38	0.38	0.98	0.82	0.01
3. 33.8 m	3.75	5.08	4.95	2.51	2.97	0.68	1.48	2.00	0.68
4. 34.8 m	4.10	4.95	5.01	2.05	2.51	0.67	1.63	1.47	1.56
5. 35.35 m	3.95	5.30	5.42	2.24	2.89	0.81	1.25	0.98	0.15
6. 36.8 m	4.70	6.10	6.18	2.93	3.23	0.66	0.74	0.75	-0.99
7. 38.9 m	7.80		8.32		2.55		0.11		-1.43
8. 40.5 m	7.40		8.02		2.38		0.43		-1.22
9. 41.5 m	6.55	7.28	7.25	2.27	2.26	0.49	0.92	1.13	-0.42
10. 43.5 m	7.15		7.92		2.48		0.45		-1.30
11. 45.5 m	5.90	6.33	6.46	1.80	2.28	0.38	0.98	0.97	0.52
12. 47.5 m	6.10	6.43	6.56	1.91	2.39	0.28	0.62	0.88	0.29
13. 50.5 m	7.20	7.38	7.63	1.32	1.71	0.23	1.16	1.02	0.63
14. 52.3 m	6.50	6.75	6.96	1.72	2.11	0.26	1.02	0.89	0.17
15. 54.5 m	6.70	7.90	7.60	3.24	2.85	0.50	0.24	0.91	-1.08
16. 58.5 m	7.10	7.30	7.46	1.28	1.65	0.27	1.21	1.08	1.11
17. 60.5 m			9.93		2.38		-1.01		-0.68
18. 62.5 m			9.37		2.42		-0.50		-1.30
19. 65.5 m	6.50		7.56		3.36		0.14		-1.70
20. 67.5 m	3.30	5.75	5.25	4.38	3.95	0.73	0.74	0.65	-1.16
21. 70.5 m	4.20	5.45	5.50	3.55	3.70	0.48	0.66	0.76	-1.07
22. 72.0 m	3.35	3.35	3.74	1.28	1.97	0.34	3.08	3.61	9.25
23. 79.5 m	3.50	3.50	3.95	1.35	2.03	0.38	3.12	5.05	8.74
24. 82.5 m	2.95	3.08	3.37	0.93	1.84	0.56	3.62	2.38	12.89
25. 84.5 m	3.60	5.47	5.17	3.25	3.45	0.76	1.14	1.09	-0.46
26. 87.5 m	3.70	4.12	4.61	1.60	2.67	0.69	2.02	5.22	2.41
27. 90.75 m	4.60	6.73	6.21	3.74	3.30	0.75	0.79	0.71	-1.08
28. 96.5 m	3.45	5.42	4.86	3.25	3.30	0.81	1.34	2.12	0.07
29. 98.85 m	3.05	4.33	4.33	2.31	3.10	0.83	1.72	2.83	1.24
30. 110.5 m	7.40		7.84		3.12		-0.11		-1.26
31. 113.75 m	4.40	5.97	5.98	2.97	3.20	0.72	0.78	0.82	-0.86
32. 115.1 m	4.35	5.77	5.74	3.34	3.50	0.54	0.71	0.90	-0.94
33. 119.8 m	2.20	2.23	2.33	0.92	0.86	0.30	0.90	1.80	0.83
34. 120.95 m	2.55	2.90	3.20	1.63	2.26	0.59	2.49	2.46	5.97
35. 124.2 m	3.40	4.88	4.86	2.95	3.36	0.62	1.05	0.82	-0.30
36. 126.5 m	5.25	6.62	6.42	4.15	3.92	0.45	0.29	0.69	-1.60
37. 130.0 m	6.00	7.02	6.70	3.99	3.56	0.36	0.28	0.73	-1.50
38. 132.5 m	3.60	5.43	4.75	3.31	3.02	0.73	1.40	1.87	0.60
39. 135.8 m	3.10	4.88	4.45	2.79	3.23	0.81	1.57	2.65	0.75
40. 139.5 m	3.95	5.82	5.81	2.96	3.26	0.85	0.97	0.87	-0.76
41. 141.5 m	3.70	3.85	4.26	1.33	2.11	0.61	2.80	6.28	6.87
42. 144.5 m	6.90	7.93	7.69	3.24	2.84	0.45	0.22	0.85	-1.25
43. 149.1 m	7.70		8.02		2.35		0.38		-1.20
44. 150.0 m			9.18		2.75		-0.50		-1.49
45. 154.0 m			10.26		2.06		-1.20		-0.28
46. 154.65 m			9.16		2.28		-0.21		-1.50
47. 158.0 m	8.00		8.48		2.74		-0.01		-1.69
48. 162.0 m			9.21		2.76		-0.52		-1.49
49. 163.5 m			9.19		2.48		-0.31		-1.62
50. 164.25	7.45		8.19		2.63		0.21		-1.55
51. 172.5 m	7.65		8.29		2.55		0.20		-1.53
52. 174.0 m	8.75		8.89		2.68		-0.23		-1.66
53. 176.9 m	7.55		8.34		2.64		0.17		-1.66
54. 178.0 m	7.95		8.22		1.95		0.46		-0.52
55. 178.5 m			9.79		2.15		-0.62		-1.31
56. 182.0 m	9.00		9.56		2.07		-0.42		-1.17
57. 186.0 m			9.91		2.31		-0.93		-0.83
58. 190.0 m			9.35		2.58		-0.52		-1.47
59. 194.0 m			10.06		2.22		-1.11		-0.32
60. 198.0 m			9.86		2.42		-0.99		-0.65
61. 202.0 m			9.76		2.42		-0.84		-1.00
62. 210.0 m			9.87		2.38		-0.95		-0.77
63. 214.0 m			9.99		2.36		-1.09		-0.48
64. 218.0 m			9.59		2.43		-0.63		-1.36
65. 222.0 m			9.53		2.38		-0.54		-1.41
66. 224.4 m	8.60		8.99		2.41		-0.12		-1.63
67. 226 m			9.42		2.45		-0.51		-1.44
68. 228.7 m			9.77		2.33		-0.78		-1.03
69. 232.5 m			9.45		2.50		-0.59		-1.30
70. 235.8 m			9.43		2.51		-0.59		-1.30
71. 239.7 m			9.76		2.24		-0.73		-1.04
72. 243.4 m			9.07		2.70		-0.39		-1.55
73. 247.7 m			10.26		2.10		-1.37		0.47
74. 255.6 m			9.76		2.29		-0.80		-0.89
75. 259.7 m			9.63		2.43		-0.74		-1.06
76. 263.7 m			9.62		2.41		-0.70		-1.13
77. 267.6 m			9.71		2.33		-0.75		-1.01
78. 270.7 m			9.85		2.30		-0.91		-0.67
79. 275.7 m			9.89		2.27		-0.92		-0.71
80. 280.65 m			10.14		2.33		-1.30		0.03
81. 283.8 m			10.13		2.24		-1.18		-0.25
82. 287.7 m	4.70	6.15	6.25	2.86	3.17	0.70	0.82	0.75	-1.00
83. 290.7 m	2.60	2.62	2.73	0.40	1.10	0.18	6.25	1.41	44.52
84. 294.3 m	3.00	3.07	2.99	0.31	0.85	0.30	5.79	1.23	52.17
85. 297.35 m	3.55	3.53	4.06	1.30	2.08	0.37	2.00	5.37	7.35
86. 299.7 m			9.91		2.47		-1.16		-0.17
87. 304.4 m	3.80	4.52	4.69	1.77	2.40	0.78	2.02	3.48	2.66
88. 306.4 m			8.88		2.85		-0.36		-1.55
89. 307.9 m	8.35		7.94		3.63		-0.24		-1.67
90. 308.5 m	3.50	4.82	4.62	2.35	3.03	0.80	1.70	3.65	1.13
91. 309.5 m	3.95	5.28	5.13	2.34	2.86	0.76	1.50	2.21	0.88

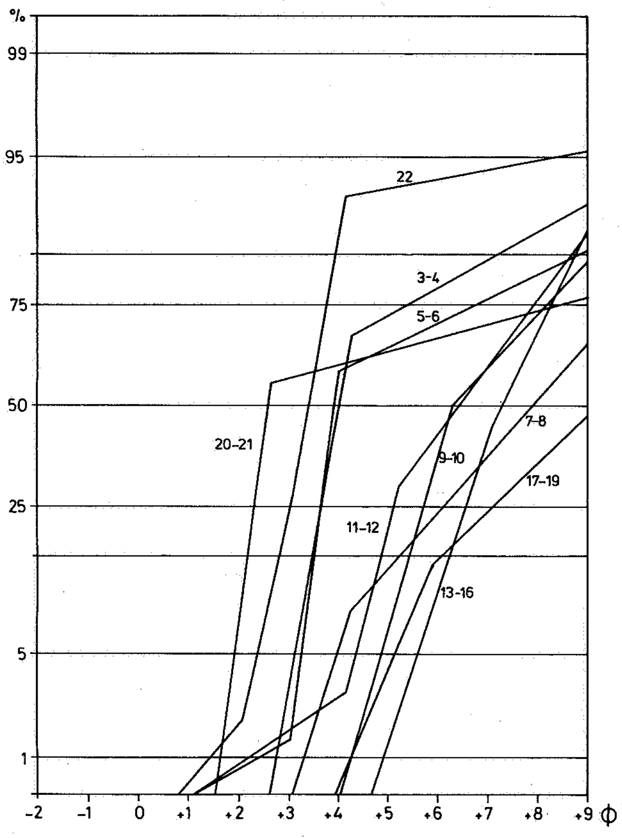

Fig. 2.- Cumulative curves of the sediments from the Kallo Formation

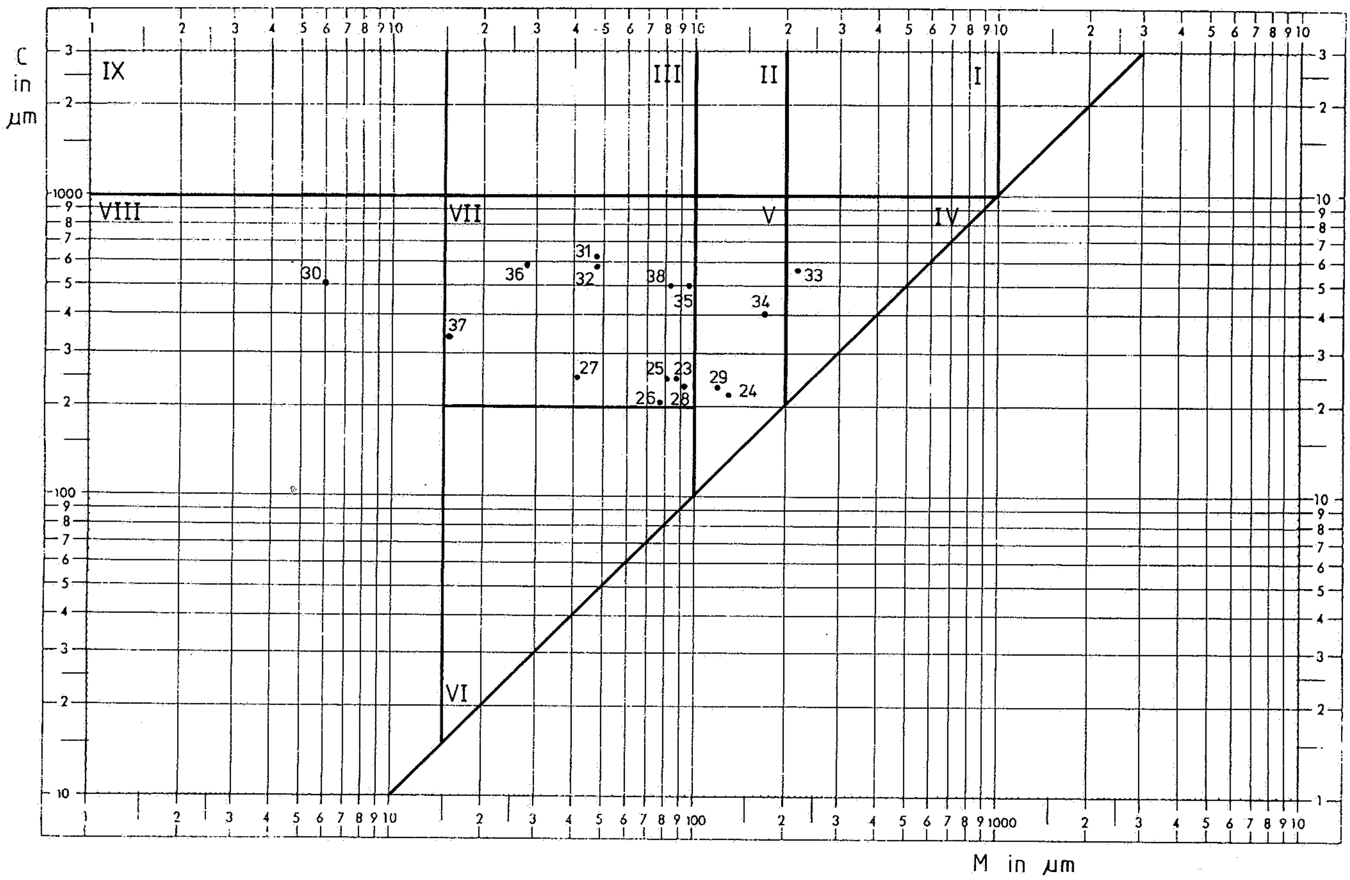

Fig. 3.- C/M diagram of the sediments from the Mont-Panisel Formation

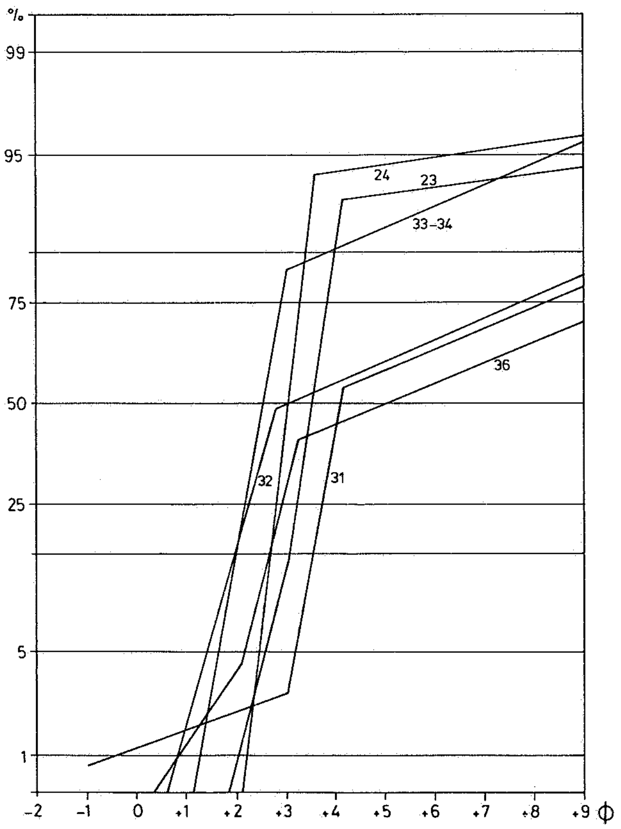

Fig. 4.- Cumulative curves of the sediments from the Mont-Panisel Formation

119-121 m (table I and II, nrs. 33, 34)

The fine sands are very poorly (34) or moderately sorted (33), and were deposited from a graded, moderate- (34) or high-turbulent suspension (33) (fig. 3). Their cumulative curves show one saltation population (85-90 %), going at 3.2 φ over into a suspension population.

-

The sediments were probably formed in shallow water along the coast under a unidirectional current.

124-133 m (table I and II, nrs. 35-38)

Between coarse-silty, fine (35) and very fine sand (38), occur very-fine-silty, clayey, fine (36) or very fine sands (37). These sediments are all extremely poorly sorted and were formed from a uniform suspension (fig. 3).

They are composed of two saltation populations and a suspension population (fig. 4). The sediments originated in a very-low-energy environment, under influence of tidal currents.

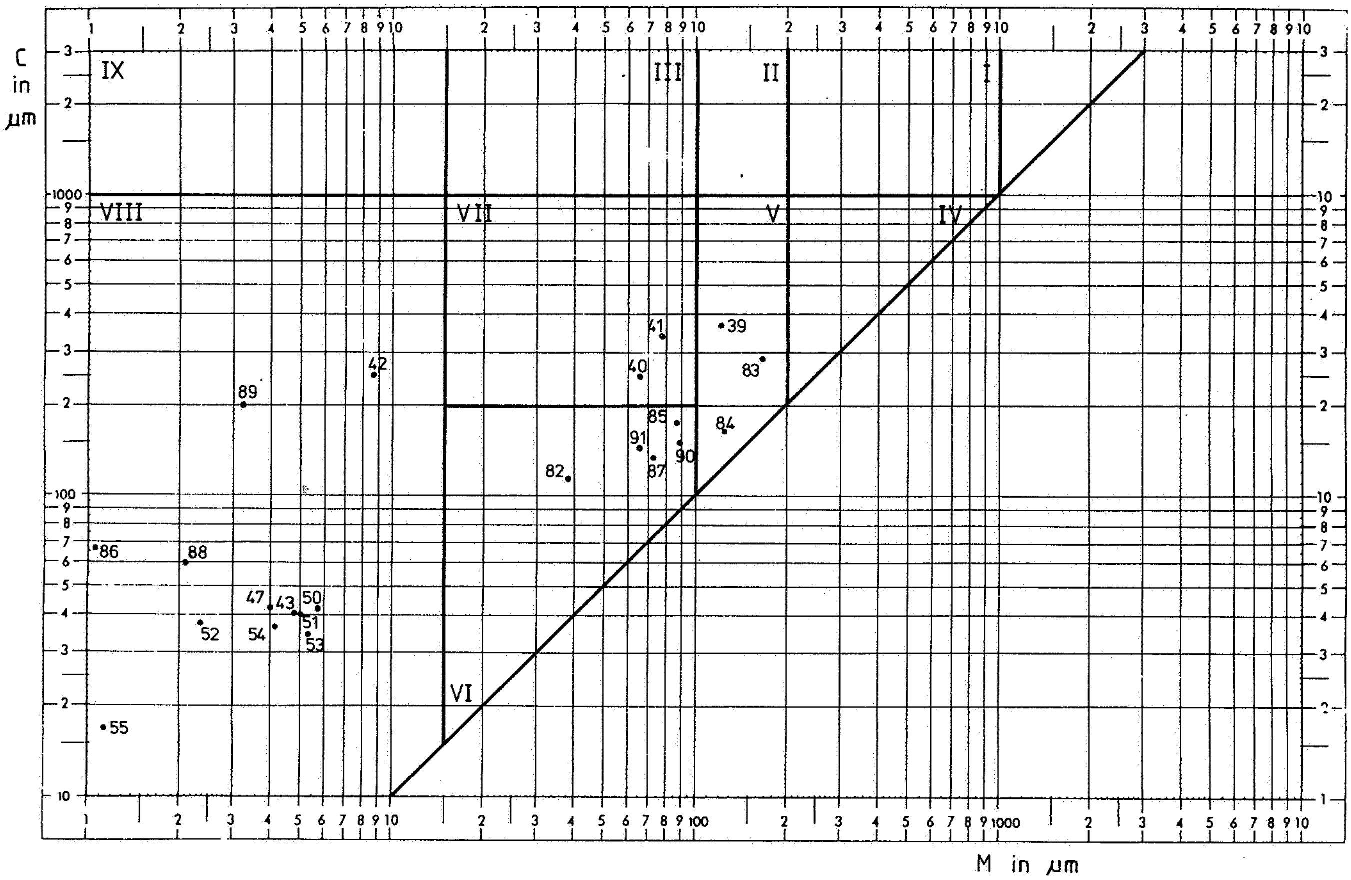

Fig. 5.- C/M diagram of the sediments from the Egem, Ieper and Landen Formations

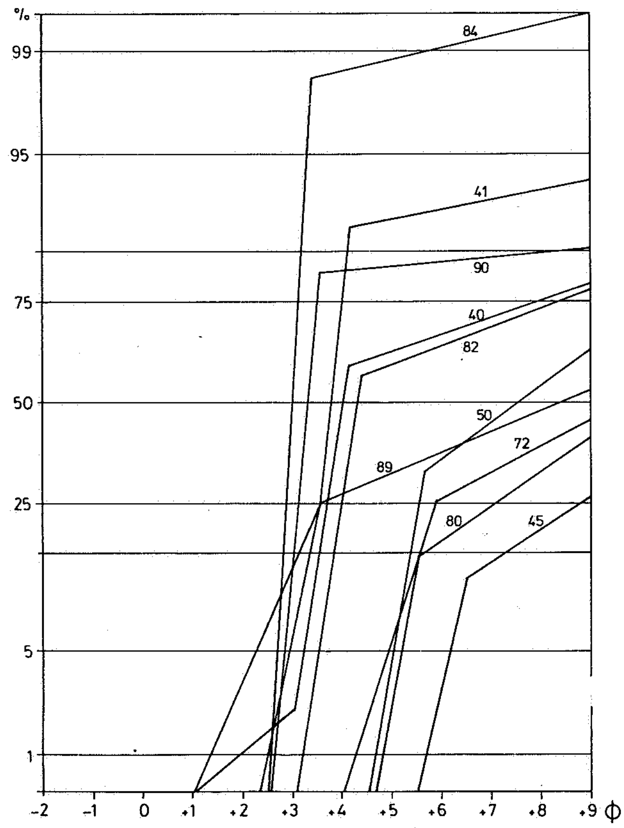

Fig. 6.- Cumulative curves of the sediments from the Egem, Ieper and Landen Formations

F. EGEM FORMATION

(133-144 m, table I and II, nrs. 39-41)

This member consists of very poorly sorted, very fine sand (41) at the base, passing into extremely-poorly sorted, coarse-silty, clayey, very fine sand (40) or fine sand (39). The sediments are deposited from a uniform suspension (fig. 5) and contain one traction, one saltation and one suspension population (fig. 6). The fine sand at the top originated from a graded, moderate-turbulent suspension, with two saltation populations and a suspension population.

They seem to have formed along a low energy coast, with tidal influence during the deposition of the top of the member.

G. IEPER FORMATION (144-284 m)

144-178 m (table I and II, nrs. 42-54)

Most of these sediments consist of clayey, medium, fine or very fine silt, with some intercalation of very fine silty clay. They were all formed from finest, uniform suspensions (fig. 5). Their cumulative curves show a saltation population (40-10 %), which passes at 5-6 φ in a suspension population (fig. 6).

178-284 m (table I and II, nrs. 55-81)

The sediments consist mostly on very-fine-to fine-silty clays, with a layer of clayey, very fine silt near 244 m. They were all formed from finest uniform suspensions (fig. 5). Their cumulative curves contain a saltation population, which occupies less than 20 % of the whole curve and which passes, between 5 and 6 φ, into a suspension population (fig. 6).

The sediments of this clayey member were probably deposited on a flat part of the shelf, under very quiet conditions.

Mont-Héribu Member
(284-288 m, table I and II, nr. 82)

The sediment is an extremely-poorly sorted, very-fine-sandy, clayey, coarse silt, originated from a graded, low-turbulent suspension (fig. 5). The cumulative curve shows a saltation population (55 %), which passes at 4.2 φ into a suspension population (fig. 6). It was probably formed in a low energy, protected environment near the coast.

H. LANDEN FORMATION
(288-311 m, table I and II, nrs. 83-91)

Knokke Member

The base is formed by extremely-poorly sorted, very fine sand or coarse-silty, very fine sand, deposited from a graded, low-turbulent suspension (fig. 5, samples 90 and 91). These sands contain one saltation population and a suspension population (fig. 6) and might have been formed in distributary channels on a broad coastal plain.

They pass into very-fine-sandy, very-fine-silty calcareous clay (sample 89 : 14.3 % $CaCO_3$) and fine-silty clay (sample 88) covered by a shell bed. At 304.4 m a very-poorly sorted, coarse-silty, very fine sand occurs, containing fragments of molluscs (10.2 % $CaCO_3$). This sandy unit (303-305 m) is again covered by very-fine-silty clay (sample 86). The clays belong to the finest uniform suspension sediments (fig. 5); the fauna of the fossiliferous beds is brackish (see part II) suggesting deposition in large shallow bays or lagoons.

The top of the Formation consists of poorly-sorted, very fine to moderately-sorted, fine sand. They are deposited from graded, low- or moderate-turbulent suspension (fig. 5, samples 83, 84 and 85). Their cumulative curves show an important saltation population, which at 3.3-4 φ passes into a suspension population (fig. 6). These sands seem to be formed in a more energetic littoral environment.

2.- HEAVY-MINERAL DISTRIBUTION

A. KALLO FORMATION (table III, nrs. 3-21)

The upper, sandy member S2 contains 56 % ubiquists on an average, with nearly 40 % zircon, as the most important mineral, followed by rutile and tourmaline. Garnet accounts for 34 %, whereas the content in parametamorphic minerals and epidote gets 5 %.

The percentage of the ubiquists reaches up to 71 % in the clayey members a 2 and a 1 of the Kallo Formation : this is especially due to the increase of zircon, at the expense of garnet, whose content drops to 17 %.

The Wemmel Member (table III, nr. 22) contains very much ubiquists (91 %), with plenty zircon; the remainder of the heavy-mineral distribution is formed by parametamorphic minerals and garnet.

B. MONT-PANISEL FORMATION
(table III, nr. 23-38)

The heavy-mineral distribution is rather constant throughout the whole formation. It is characterised by a preponderance of ubiquists,

Table III.- Heavy-mineral distribution

	OPAQUE	TOURMALINE	ZIRCON	RUTILE	ANATASE	BROOKITE	SPHENE	ANDALUSITE	STAUROLITE	SILLIMANITE	KYANITE	GARNET	EPIDOTE	AMPHIBOLE	CHLORITE	ALTERITE
3. 33.8 m	48	3	40	13							3	33	8			
4. 34.8 m	50	3	45	10					2	2	4	32	2			
5. 35.35 m	75	10	32	6					4		1	42	5			
6. 36.8 m	56		46	16					2		3	28	5			
12. 47.5 m		1	54	10					2		3	22	8			
19. 65.5 m		8	48	10	2				4		6	16	6			
20. 67.5 m	60	4	57	18					5		2	9	5			
21. 70.5 m	53	5	57	8	2				1	1	1	21	4			
22. 72.0 m	49	7	79	5					4			5				
23. 79.5 m	56	4	73	11					2		1	7	2			
24. 82.5 m	69	14	44	12					12		4	12	2			
25. 84.5 m	59	20	41	8	1			1	3		8	16	2			
26. 87.5 m	49		58	14	3				1		4	16	4			
27. 90.75 m	45	2	72	8				1	3		1	12	1			
28. 96.5 m	61	15	24	14		1			8	1	15	18	4			
29. 98.85 m	50	11	46	11				2	6		7	15	2			
30. 110.5 m	76	6	46	12					4		14	14	4			
31. 113.75 m		4	61	13	1				2		5	10	4			
32. 115.1 m		3	53	13					5		4	18	4			
33. 119.8 m	57	32	31	8	2			2	5	1	15	3	1			
34. 120.95 m	39	26	32	11				3	6	1	14	5	2			
35. 124.2 m	46	13	43	13				2	5	3	4	16	1			
36. 126.5 m	61	17	42	8				3	12	1	4	10	3			
37. 130.0 m	53	17	37	9	1	1		2	8	3	4	13	5			
38. 132.5 m	66	11	38	10		1		5	4	2	6	18	5			
39. 135.8 m	58	36	38	2	1			1	3		11	6	2			
40. 139.5 m	72	6	36	12				2	5		5	31	3			
41. 141.5 m	61	2	46	10				1	4	1	6	28	2			
82. 287.7 m	72	13	20	7	5				9		5	20	5	4	12	5
83. 290.7 m	41	33	21	5	2				10	1	20	3	4	1		2
84. 294.3 m	63	20	26	9	2	1		1	8	1	12	11	5	5		3
85. 297.35 m	60	21	26	6	2	1			10		16	10	3	3	2	3
87. 304.4 m	58	8	40	6	3	1	1	1	6	1	4	22	5	2		3
88. 306.4 m	93	6	51	5	3				8	1	6	12	3	1	4	
89. 307.9 m	69	9	47	12	4				3		9	13	2	1		2
90. 308.5 m	73	41	21	9	2		1		13	1	10		1	1		3

which attain 70 % : zircon is the most important mineral in this group, mostly followed by rutile and tourmaline.

The parametamorphic minerals fetch 14 %, with a domination of kyanite over staurolite. The garnet-content obtains 13 %, whereas epidote accounts for the remaining part.

In the sandy part of this formation, at about 120 m, the percentage of the parametamorphic minerals increases till 23 %, at the expense of garnet (4 %).

C. EGEM FORMATION (table III, nrs. 39-41)

The heavy minerals of this sand contain 63 % ubiquists, mostly zircon, with smaller quantities of rutile and tourmaline, except for the top-sample, wherein equal quantities of zircon and tourmaline occur. In that last sample, garnet obtains only 6 %, in contrast with the 30 % in the lower part of the sediments. The percentage of the parametamorphic minerals and of epidote stays constant, at respectively 13 and 2 %.

D. IEPER FORMATION

Mont-Héribu Member (table III, nr. 82)

The heavy-mineral distribution of this sediment has the lowest amount of ubiquists in the whole series of Tertiary deposits in this well : 45 %. Zircon remains the most important mineral, followed by tourmaline, rutile and anatase. In the group of parametamorphic minerals (14 %), staurolite dominates over kyanite.

Besides garnet (20 %) and epidote (5 %), there is a remarkable 4 % of amphibole and an even more remarkable 12 % of chlorite.

E. LANDEN FORMATION (table III, nrs. 83-90)

The ubiquists obtain 64 %, with a preponderance of zircon, except for the top and the base of the formation, where tourmaline dominates : rutile, anatase, brookite and sphene occur in smaller quantities. The content in metamorphic minerals is 20 %, with more kyanite than staurolite.

Garnet is absent or nearly absent in the base- and top-sample, but obtains 14 % on an average in the other samples of the Landen Formation.

There is still 3 % epidote and 2 % amphibole in this lithostratigraphic unit, whereas chlorite only sporadically occurs.

The very high percentage of opaque grains in sample 88 is due to the presence of pyrite and even larger amounts of iron sulphides are found in the samples 86 (299.7 m) and 91 (309.5 m).

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Chapitre III
ETUDE DE LA SEDIMENTATION ARGILEUSE TERTIAIRE DU SONDAGE DE KNOKKE

par

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Les mineraux primaires (chlorite, illite), des traces d' édifices interstratifiés irréguliers (illite-smectite [10-14s], chlorite-smectite [14c-14s]), la smectite et la kaolinite, constituent la fraction argileuse des sédiments tertiaires du sondage de Knokke.

1. DESCRIPTIONS DES RESULTATS (fig. 1)

A. FORMATION DE LANDEN.

La base sableuse de la formation est marquée par une arrivée brutale de kaolinite qui passe de 37% (-310m) à 94% (-308m). A -310m, les autres minéraux de la fraction argileuse sont la chlorite (3 %), l'illite (25 %) et la smectite (35 %). A -308m, seules quelques traces d'illite et de smectite accompagnent la kaolinite.

Dès que l'on aborde les niveaux argileux sus-jacents, la smectite (55 %) domine la kaolinite qui chute, sur une dizaine de centimètres, de 94 à 7 %. La chlorite (C) apparaît en quantité notable (12 %) avec l'illite (I = 26 %). Le reste de la Formation est dominé par les minéraux primaires (C = 14 %, I = 28 %) qui précèdent la smectite (44 %) et la kaolinite (11 %); des traces de minéraux interstratifiés irréguliers [10-14s] et [14c-14s] font leur apparition.

L'état cristallin des minéraux, chlorite, illite et smectite est bon en général. Quartz et feldspaths sont présents.

B. LES FORMATIONS D'EGEM ET D'YPRES

Les Formations d'Egem et d'Ypres se subdivisent en trois zones minéralogiques caractérisées par la diminution des minéraux primaires et de la kaolinite au profit de la smectite. La figure 2, reprenant par zones les teneurs moyennes des différentes espèces minérales, schématise le caractère saccadé de l'évolution. Celle-ci coïncide, semble-t-il, avec une augmentation progressive, de bas en haut, de la taille du grain moyen des sédiments.

Dans la zone I, la somme des minéraux primaires et de la kaolinite domine, et aux poussées des premiers correspondent des poussées de la seconde. Parmi ces maxima, deux sont nettement plus accusés, l'un à la base de la Formation, l'autre au sommet. Les états de la chlorite et de l'illite sont très bons.

La zone II, plus silteuse, enregistre le déclin des minéraux primaires et de la kaolinite dont les teneurs varient peu. Les interstratifiés ont disparus. La cristallinité de l'illite est inchangée par rapport à la zone I (même valeur moyenne 4,2 mm) en revanche l'état cristallin de la smectite s'améliore (9° en moyenne au lieu de 21°).

La zone III, avec la disparition quasi-totale du couple chlorite-kaolinite et la faible représentation de l'illite, est surtout smectitique.

C. LA FORMATION DU MONT-PANISEL, LES SABLES DE BRUXELLES ET DE WEMMEL ET LA FORMATION DE KALLO

Les sédiments sableux compris entre -116 et -124m ressemblent aux Sables de Bruxelles reconnus dans d'autres sondages, à Mol par exemple. Ils se singularisent par une légère poussée des minéraux primaires sans augmentation significative de la kaolinite ni présence d'interstratifiés.

Le reste de la Formation du Mont-Panisel (-80 à -105 m) est essentiellement smectitite et illitique. La chlorite ne fait sa réapparition que vers le passage à la Formation de Lede. Au même niveau, une légère progression de l'illite amorce l'importante modification qui va affecter la base de la formation de Kallo. En effet, dès l'Argile d'Asse (a), les minéraux primaires augmentent rapidement jusqu'à 40 % en même temps que la kaolinite frôle les 20%. Le sédiment est très glauconieux, cependant, le rapport I_{002}/I_{001} de l'illite oscillant autour de 4 indique l'absence d'illite glauconitique dans la fraction fine. Chlorite, illite et smectite sont bien cristallisées.

Au dessus, minéraux primaires et kaolinite retrouvent des pourcentages faibles (25 et 5 % respectivement).

2.- INTERPRETATION

La diversité et la permanence de la composition minéralogique, dans une large mesure indépendante de la lithologie ou de la profondeur, indiquent l'origine détritique du cortège argileux.

A. LA FORMATION DE LANDEN.

La Formation de Landen, probablement incomplète, est très réduite en épaisseur (23 m). Ses caractères lithologiques traduisent un milieu littoral. Sa partie supérieur, de type lagunaire est à rapprocher de certains faciès du sparnacien du Bassin de Paris (DUPUIS *et al.,* ce mémoire).

La fraction fine, riche en minéraux primaires (C=13 %,I=27 %) corrobore ce caractère littoral. La fraction smectitique proviendrait de l'érosion des sols formés dans les régions aval mal drainées et peu accidentées. La kaolinite exprimerait la contribution des amonts au relief plus accusé et bien drainé. Si elle n'est pas héritée de pédogenèses plus anciennes, sa présence témoignerait de l'établissement d'un climat chaud à humidité constante.

Remarque:

L'anomalie en kaolinite du niveau sableux de la base de la formation de Landen ne peut pas être interprétée en terme de paléoenvironnement en raison de son lien étroit avec un changement lithologique.

B. LES FORMATIONS D'EGEM ET D'YPRES

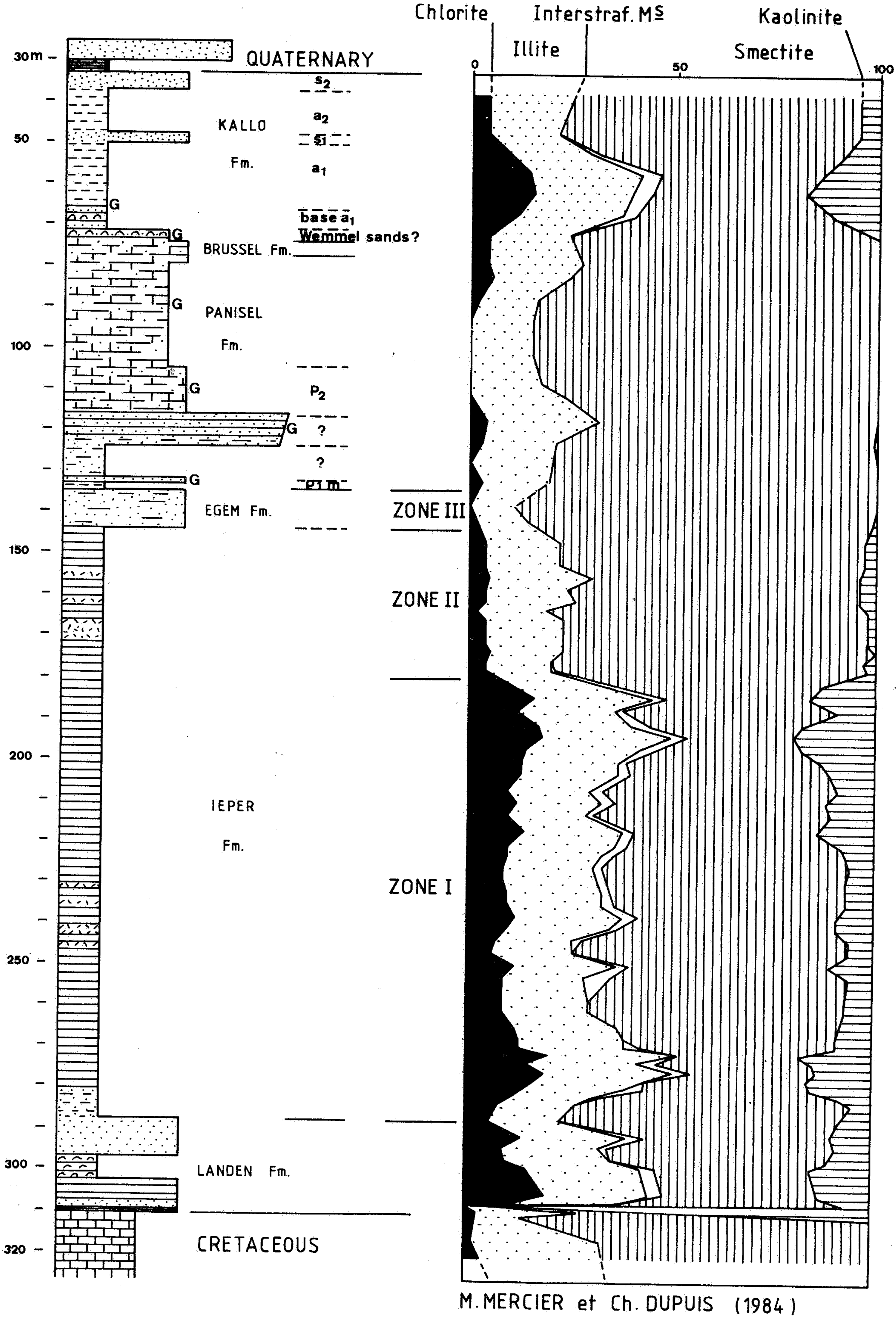
Dans la Formation d'Ypres, les changements de la minéralogie des argiles se moulent sur les évolutions de la lithologie (fig. 2).Dans la zone I, l'abondance de minéraux primaires et de kaolinite, la coïncidence de leurs maxima et le caractère saccadé des apports de chlorite et d'illite suggèrent une certaine instabilité tectonique des zones continentales amont. Par ailleurs, on remarque la qualité de la corrélation qui relie les pourcentages de chlorite et de kaolinite (fig. 3). Connaissant la plus grande vulnérabilité du premier minéral par rapport au second, on est amené à imaginer un enchaînement très rapide, de l'érosion qui les libère des roches et des sols, de leur transit et de leur enfouissement.

Les deux poussées du couple minéraux primaires-kaolinite à la base et au sommet de la Formation peuvent être considérés comme deux phases d'érosion continentale plus importantes. La première se retrouve dans les deux sondages de Mol et de Kallo. La seconde trouve probablement un écho à Kallo, mais n'est pas décelable à Mol situé plus à l'Est (MERCIER, en préparation). Cette diminution progressive d'Ouest en Est, des quantités de minéraux primaires et de kaolinite implique d'une part, un approvisionnement occidental et d'autre part, l'intervention d'une floculation sélective par rapport à la smectite (GIBBS, 1977). Il est remarquable de constater que de tels phénomènes ne se manifestent pas lors de la première poussée. En effet, les pourcentages de minéraux primaires et de kaolinite restent voisins sur l'ensemble du Bassin belge. La cause de la première reprise d'érosion semble donc avoir un caractère plus général. Elle peut être mise en relation avec l'histoire géodynamique de l'Atlantique Nord. Vers la base de l'Eocène a lieu la séparation du Groenland et du Plateau de Rockall. De nombreuses éruptions volcaniques qui montrent que ces mouvements affectent nos régions, se produisent alors en Grande-Bretagne et en Mer du Nord (JACQUE & THOUVENIN, 1975; KNOX & ELLISON, 1979).

L'arrivée de détritiques provenant probablement de l'Ouest ne se conçoit que si aucune barrière s'oppose à leur passage. Or, il est traditionnel de considérer que l'«Axe de l'Artois» est émergé à l'Yprésien inférieur. Les données de la minéralogie des argiles tendent ainsi à confirmer les résultats récents qui minimisent le rôle du horst de l'Artois (DUPUIS *et al.,* 1984). Le Sud du Bassin de la Mer du Nord aurait été en communication avec le Bassin du Hampshire, relais possible dans le transit des minéraux primaires et de la kaolinite (MERCIER, 1986).

Fig. 1.- Minéralogie des argiles du sondage de Knokke.
De gauche à droite, colonne lithostratigraphique, composition estimée de la fraction argileuse ($< 2\mu m$), rapport I_{002}-I_{001} et cristallinité de l'illite, cristallinité de la smectite.

Clay mineralogy of the Knokke borehole.
From left to right, lithostratigraphic column, estimated composition of the clay fraction ($< 2\mu m$), I_{002}-I_{001} ratio and cristallinity of the illite, smectite cristallinity.


Chlorite
Interstraf. Ms
Kaolinite
Illite
Smectite
0
50
100
30m
50
100
150
200
250
300
320
QUATERNARY
KALLO
Fm.
s2
a2
s1
a1
base a1
Wemmel sands?
G
BRUSSEL Fm.
PANISEL
Fm.
P2
?
P1m
EGEM Fm.
ZONE III
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IEPER
Fm.
ZONE I
LANDEN Fm.
CRETACEOUS
M. MERCIER et Ch. DUPUIS (1984)

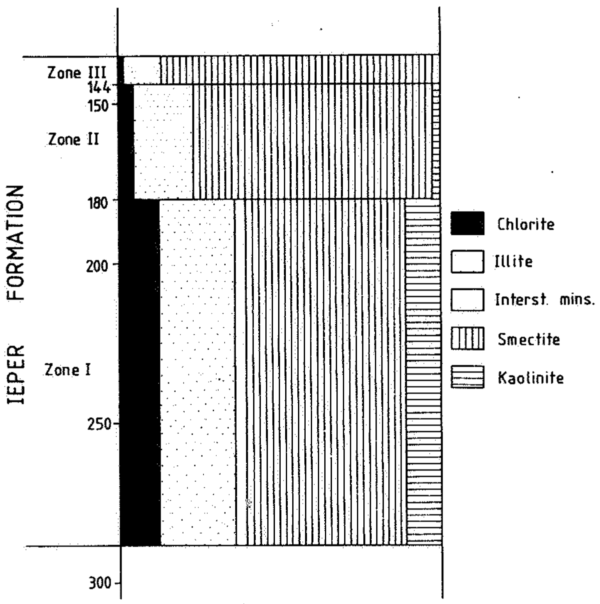

Fig. 2.- Composition minéralogique moyenne des trois zones de la Formation d'Ypres.

Mean mineralogical composition of the three zones of the Ieper Formation.

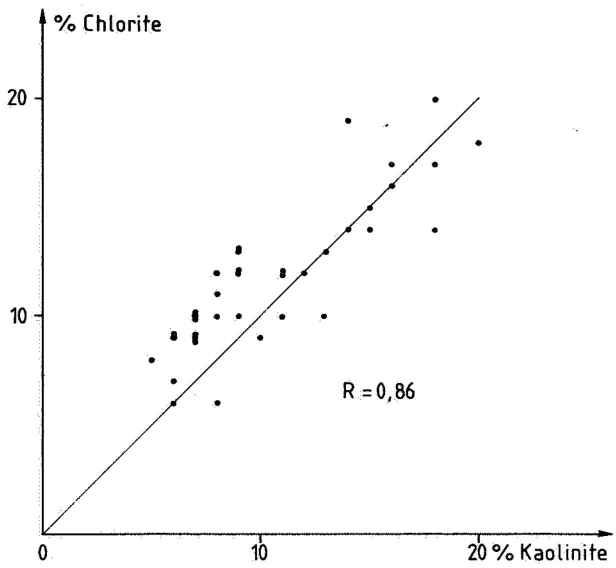

Fig. 3.- Diagramme kaolinite-chlorite pour la zone I de la Formation d'Ypres.

Kaolinite-chlorite diagram for the zone I of the Ieper Formation.

Dans les zones II et III, le cortège argileux qui s'appauvrit graduellement en minéraux primaires et en kaolinite et devient plus homogène, fait d'abord songer au rétablissement d'une certaine stabilité tectonique. Une telle intervention paraît peu conciliable avec la nature de plus en plus sableuse des sédiments. En revanche, l'augmentation de la teneur en smectite dont la cristallinité s'améliore, s'expliquerait bien par une migration de l'instabilité tectonique vers les zones littorales. Ce sont alors des sols riches en smectite bien cristallisée qui sont érodés. En outre, la présence de minéraux fibreux (± 5 %) dans la Formation d'Ypres du sondage de Mol est en accord avec cette interprétation. Les bassins semi-clos et confinés où est susceptible de se former ce type de minéraux argileux, occupent toujours une position bordière par rapport aux terres émergées. Une telle instabilité des marges ardenno-rhénanes préfigure celle, qui à l'Eocène moyen, va conduire à l'émersion du horst de l'Artois (POMEROL, 1973). On ne trouve pourtant qu'un écho très assourdi de ces mouvements dans le cortège argileux sous la forme d'une légère progression de la chlorite et de l'illite à la base de la formation du Panisel. L'abondance de la glauconie et le caractère très grossier de ces dépôts sableux soulignent aussi leur caractère littoral et peu profond.

C. LA FORMATION DE KALLO.

Dans l'Argile d'Asse (a), la composition des argiles change à nouveau. La kaolinite réapparaît avec les minéraux primaires et les interstratifiés qui prennent le pas sur la smectite. Ce changement qui se retrouve avec la même ampleur à Kallo et à Mol, résulterait d'un phénomène d'ordre tectonique. La présence de kaolinite reflète la participation des zones continentales amont, probablement l'Ardenne (MERCIER, en préparation).

Au dessus de l'Argile d'Asse, la nature des argiles, indique le retour à un certain calme tectonique. La smectite bien cristallisée y témoigne d'un climat chaud à humidité saisonnière contrastée. L'absence des terrains sus-jacents ne permet pas de saisir l'évolution du cortège argileux qui marque la dégradation climatique du début de l'Oligocène (QUINIF *et al.,* 1983).

D'une façon générale, la sédimentation argileuse du sondage de Knokke paraît plus marquée par les événements d'ordre tectonique que par les phénomènes d'origine climatique. L'abondance de la smectite bien cristallisée suggère la prépondérance d'un climat chaud à humidité contrastée. Cependant, des périodes à humidité plus constante, favorables à la formation de la kaolinite, ont dû exister à la fin de l'Eocène inférieur et à l'Eocène moyen (QUINIF *et al.,* 1983).

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Chapter IV
BIOSTRATIGRAPHIC DATA - OSTRACODS AND ORGANIC WALLED MICROFOSSILS - OF THE LANDEN FORMATION AND THE BASE OF THE IEPER FORMATION IN THE KNOKKE BOREHOLE

by

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INTRODUCTION

Some strata attributed to the «upper Landenian» show a strikking similarity with the «upper Sparnacian» of the Paris basin. The diagnostic facies is an alternation of grey clays, silts and/or sands associated with brackish coquina containing among others, *Cyrena, Tympanotonos, Unio* (LERICHE, 1899, 1929; FEUGUEUR, 1055) and with some oysters limestones.

These layers are comparable, for instance, to the Woolwich Shell Beds (DUPUIS & GRUAS-CAVAGNETTO, 1985), the Argile de Saint Aubin (DUPUIS *et al.,* 1984), the Sables et Argiles à Mollusques et Ostracodes (BIGNOT, 1973). They are transgressive on the underlying arenaceous regressive complex (BROECKMAN, 1978; DUPUIS *et al.,* 1982) usually attributed to the «middle and lower Landenian», to the «Thanetian» or to the Woolwich Marine Beds and the Thanet Beds. Higher up the transgressive sequence comprises coastal sands and/or pebbles (Sables à Galets du Mont-Hulin, DUPUIS *in* ROBASZYNSKI *et al.,* 1981, for instance) and then marine clays, silts and sands such as the Ieper Formation and the London Clay. South of the North Sea Basin, the dinoflagellate zonation allows to establish the slight diachronism of the transgression (fig. 1).

In fact, the *Cyrena* brackish layers belong to the *A. hyperacanthum* zone in the London Basin (KING, 1981), in Knokke (this work) and Kallo boreholes (DE CONINCK, 1975). They belong in part to the *W. astra* zone at Newhaven (DUPUIS and GRUAS-CAVAGNETTO, 1985) and at St. Josse-St Aubin (DUPUIS *et al.,* 1984). They are probably situated in the *W. meckelfeldensis* zone at Lihons towards the Paris Basin heart (1).

The today *Cyrena* brackish layers distribution is partly the expression of the existence of two basins separated by an Artois-Brabant high which vanished afterwards at the transgression maximum (fig. 2). From the lithologic point of view, the upper Landen Formation and the base of the Ieper Formation are readily related to the transgressive sequence elsewhere identified.

In the Knokke borehole the silty clays with several shell fragment zones (-297 m to -303 m) and a compact fossil level - an oysters limestone - (-303 m) are indentical in many aspects with the brackish deposits of the «Upper Sparnacian». The similarity is confirmed by a cursory examination of the malacologic fauna which gave for instance: *Cyrena cuneiformis* FER. and *Planorbis* cf *subovatus* DESH. between -299.28 m and -299.31 m *Ostrea bellovacensis* LAMK. and *Tympanotonos*

(1) At Lihons, the *Cyrena cuneiformis*-bearing brackish layers lie on lacustrine limestones and marls concealing a charophyta flora of the *Peckichara piveteaui* zone which is correlated with the *W. meckelfeldensis* zone in the Lower Ypresian (DUPUIS *in* ROBASZYNSKI *et al.,* 1981; RIVELINE, 1984 and DUPUIS *et al.,* 1986).

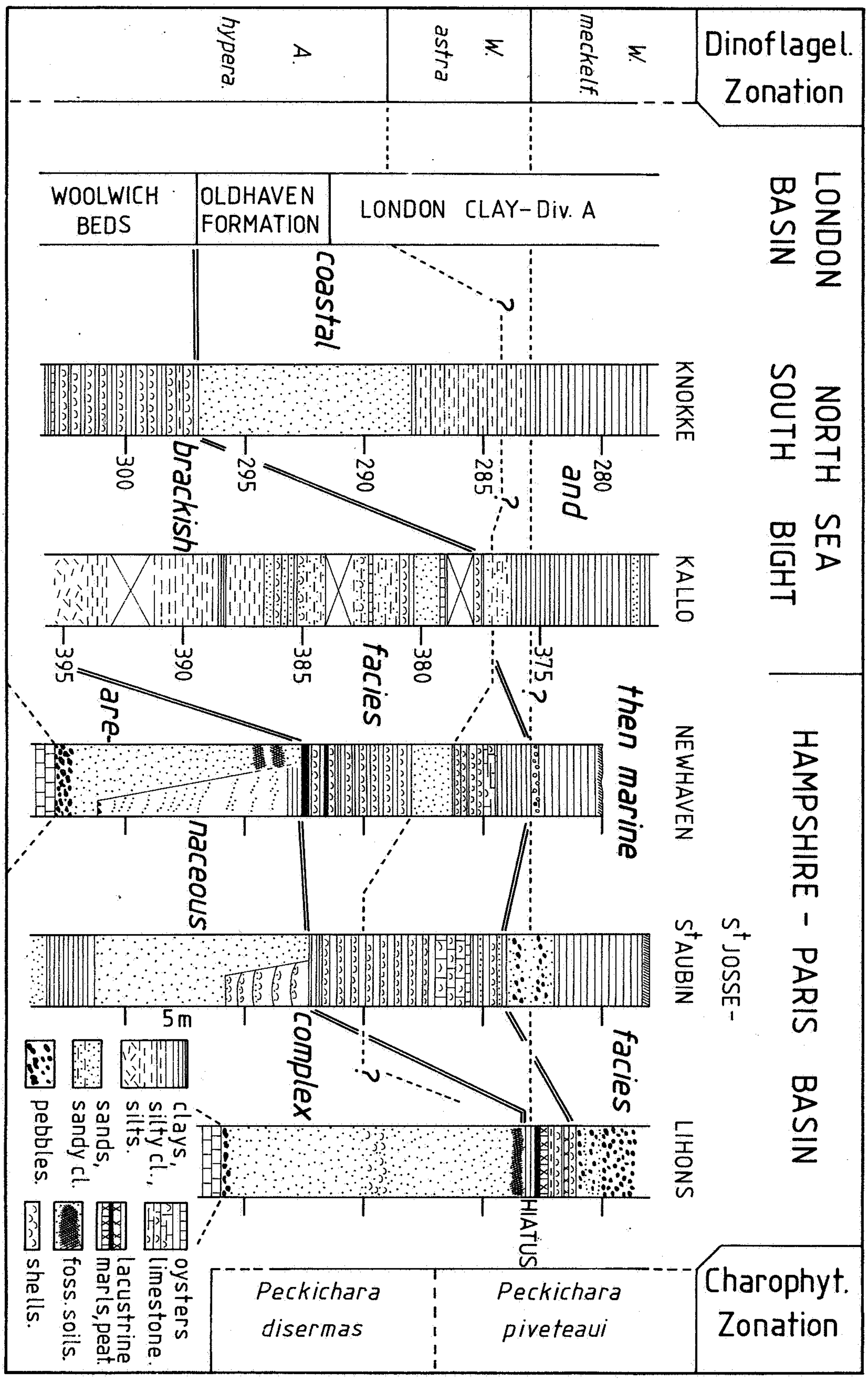

Fig. 1.- Relations between the regressive (*arenaceous complex* = «Thanétien», Woolwich Marine Beds,...) and the transgressive facies (*brackish facies* = «upper Sparnacian», «upper Landenian», Woolwich Beds; *coastal and then marine facies*: London Clay, Ieper Clay, ...) around the Paleocene-Eocene limit in the southern North Sea, the Hampshire and NW Paris Basin.

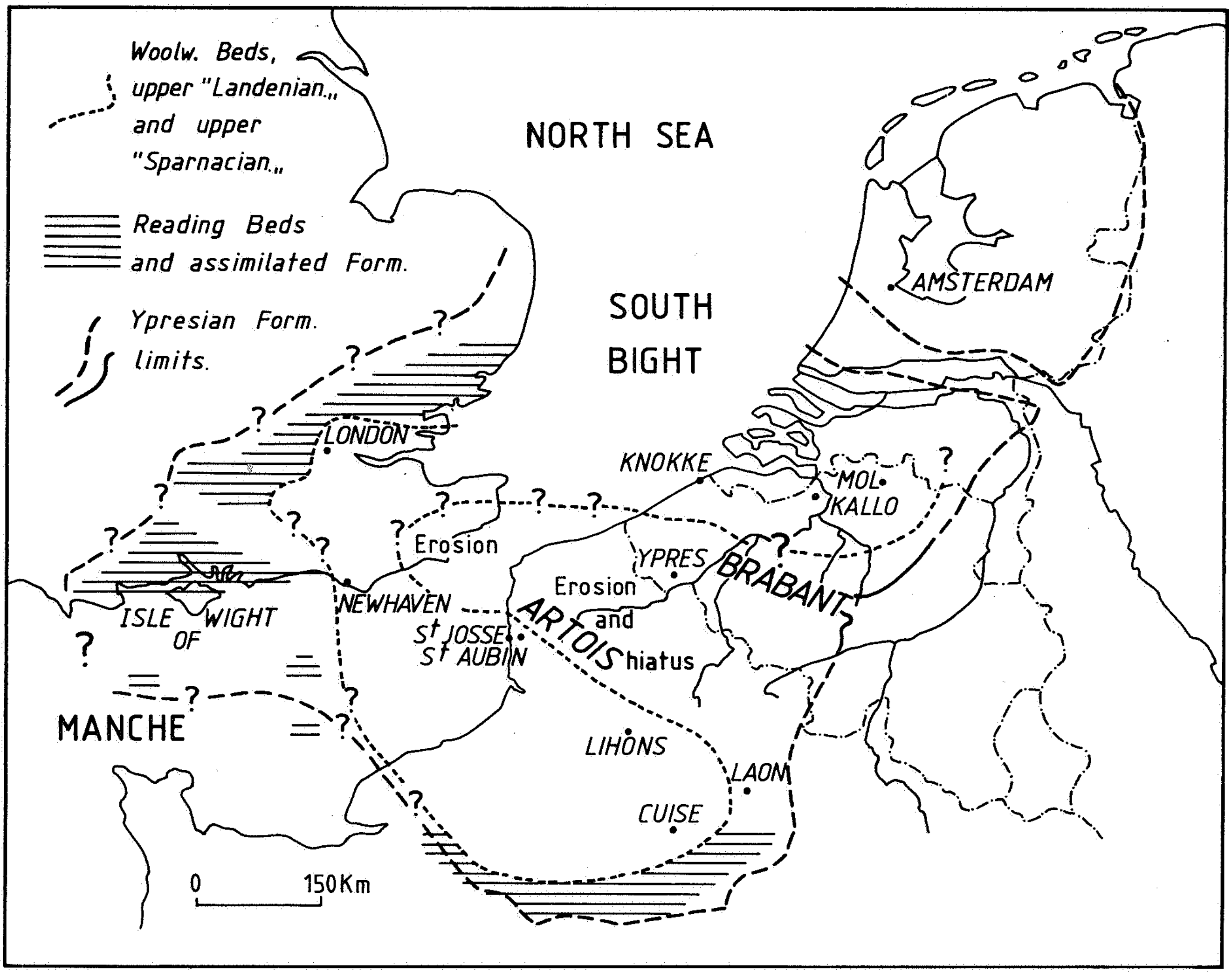

Fig. 2.- Extensions of brackish («upper Sparnacian», «upper Landenian», Woolwich Beds) and marine facies (Ypresian formations: London Clay, Ieper Clay,...) of the Landenian transgressive facies. Related and presumably related continental deposits are indicated (Reading Beds and assimilated Formations)

funatus MANTEL at -300.15 m; *T. funatus* var. *cossmani* M. CH. between -307.4 m and -307.5 m (determination of M. PERREAU, Paris). The following study of the Ostracods extracted from the «Upper Landenian» in the Knokke and Kallo boreholes, supports such an equivalence.

The fine well sorted sands (median = 114 to 145 μm ; sorting coefficient, $Qd\varphi = .13$ to $.33$) found in the Knokke borehole between -288 and -297 m represent the coastal deposit which precedes the marine facies appearance of the Ieper Formation. The chronostratigraphic situation of this appearance has been specified by the study of the dinoflagellates and sporomorphs contained in eleven palynologic samples.

1.- OSTRACODS FAUNA. COMPARISON WITH THE PARIS BASIN

The «Upper Landenian» from the wells of Knokke and Kallo has delivered Ostracods assemblages (Plate 1 and fig. 3) more or less rich in specimens but poorly diversified, as usual in brackish environments. They are nevertheless typical, in the Paris Basin of the «Upper Sparnacian» sands and ligneous clays with oysters, *Cyrena, Tympanotonos* and so on, of Epernay («Mont Bernon»,...), Reims, Soissons, Mantes,... (APOSTOLESCU, 1956; GUERNET, 1981). They are indeed composed of the following species :

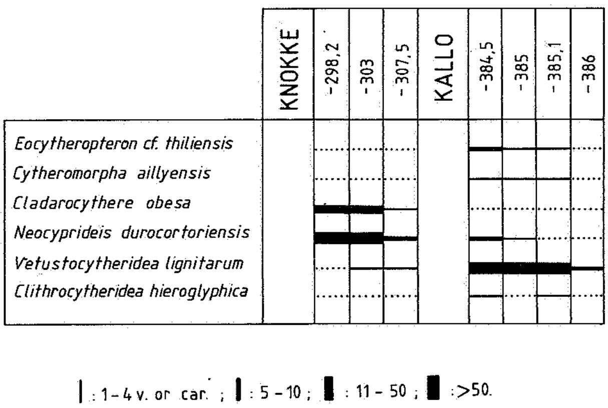

Fig. 3.- Repartition of Ostracods in some samples from the upper Landen Formation in the Knokke and Kallo boreholes

- *Vetustocytheridea lignitarum* (DOLLFUSS, 1877), at different development stages, with phenotypic nodes well developed on juvenile forms and large marginal spines in front of the right valves;
- *Clitherocytheridea ? hieroglyphica* (APOSTOLESCU, 1965) the type of which comes from the Thanetian of the Paris Basin and which is known, in the «Sparnacian», only at Mutigny, near Epernay;
- *Neocyprideis durocortoriensis* (APOSTOLESCU, 1956), particularly abundant at Knokke;
- *Cladarocythere obesa* (GUERNET, 1981), associated with the foregoing species at Knokke and corresponds perhaps to a low salinity, below 10 ‰;
- *Cytheromorpha aillyensis* (BIGNOT, 1961) which until today is only known from the «Sparnacian» of Cap d'Ailly, Criel and Epernay;
- *Eocytheropteron* cf. *thiliensis* (APOSTOLESCU, 1956), species which seems very rare in the Paris Basin «Sparnacian» (two valves encountered at Soissons, *in* GUERNET, 1981).

Among these species, *V. lignitarum, Cl. hieroglyphica, N. durocortoriensis* and *E.*cf.*thiliensis* are already present in the «Thanetian» (APOSTOLESCU, 1956). It must be stressed however that in the «Thanetian» they are accompanied by numerous other Ostracods, Foraminifers and *Algae* species characteristic of a marine environment. On the other hand, none of these «Sparnacian» species are known from the Clay of Flanders, in the Cuisian stratotype or in the London Clay. The variations in the composition of the «Upper Landenian» associations are comparable with those observed in the «Sparnacian» (BIGNOT *et al.,* 1981) and are probably linked to environmental modifications, especially salinity fluctuations (the influence of other environmental parameters such as depth, turbulency and temperature of the water, extend and nature of the vegetation cannot be appraised for the moment). *Cl. obesa, N. durocortoiensis* and *C. aillyensis* for instance may indicate a desalination tendency. No doubt these variations in the associations can only have a local stratigraphic significance. Only species which are almost not affected by these changes can be considered as more significant for biostratigraphy: for instance *V. lignitarum*, widespread in the majority of the fossiliferous «Sparnacian» deposits, is very tolerant towards salinity fluctuations; probably the same for *Cl. hieroglyphica*. Their presence in the «Upper Landenian» and «Sparnacian» associations and their absence from the Clay of Flanders can be used as an argument in favor of a biostratigraphic correlation of these «Sparnacian» deposits with «Upper Landenian» deposits.

We are therefore thinking, with other English and Belgian stratigraphers, that a part of the «Sparnacian» is probably equivalent of the upper part of the «Landenian» and not, as it is generally believed today in France since FEUGUEUR's thesis (1963) of the lower part of the «Ypresian». But this correlation may perhaps not be generalized for all «Sparnacian» deposits because they appear to be composed from some different diachronous facies as indicated by new biostratigraphic approaches in the SE Paris Basin (LAURAIN *et al.,* 1983, DUCREUX *et al.,* 1984) and considering the footnote higher in our text on the *Cyrena cuneiformis* bearing brackish deposits at Lihons (NW Paris Basin).

2. ORGANIC WALLED MICROFOSSILS.

A. PHYTOPLANKTON (table I).

1) Description of the assemblage.

Knokke -310.3 m.

One slide. Only one species of phytoplankton: *Apectodinium parvum* (three fragments).

Knokke -309.9 to -310 m.

One slide. Nine specimens recovered classified in six species with among them *Apectodinium homomorphum, A. parvum and Homotryblium sp.*

Homotryblium sp. is dominant in the levels -305.8 m, -301.4 m and -299.3 m. It seems to be somewhat different from *H. pallidum* (?) described in the Clay of Flanders from and after the «planktonic» datum. *Homotryblium* was encountered in Paleocene deposits by others too: in a

Table I.- The Phytoplankton in the Knokke borehole

<u>KNOKKE BOREHOLE</u> <u>Phytoplancton</u>	-310,30 m	-309,90 a 310,00 m	-305,80 a -305,88 m	-301,40 a -301,50 m	-399,60 a -299,69 m	-299,28 a -299,31 m	-297,40 m	-290,10 a -290,20 m	-287,90 a -288,00 m	-287,00 a -287,10 m	-284,10 a -284,20 m	-282,26 m
- Bacillariophyceae												
pyritised centric diatoms								F				
- Chlorophyceae												
Paralecaniella indentata (DEFLANDRE & COOKSON 1955)				s			ff	FF	F	f	s	
Pediastrum sp.					s		f					
- Dinophyceae												
Achomosphaera alcicornu (EISENACK 1954)									s	s		s
Achomosphaera spp. indet.			ff		f				s	ff	ff	ff
Adnatosphaeridium multispinosum (WILLIAMS & DOWNIE 1966)										s		s
Alisocysta margarita (HARLAND 1979)										s		f
Apectodinium homomorphum (DEFLANDRE & COOKSON 1955)		x	F	s	ff	F	FF		F	ff		
A. hyperacanthum (COOKSON & EISENACK 1965)				?	?						s	s
A. paniculatum (COSTA & DOWNIE 1976)					?						s	
A. parvum (ALBERTI 1961)	x	x		F	ff	f	f		f		s	
A. quinquelatum (WILLIAMS & DOWNIE 1966)			s	f	?					s	s	
A. sumisuum (HARLAND 1979)				?								
Apteodinium granulatum (EISENACK 1958)										s		
Apteodinium sp. indet.			s						s	s	s	
Areoligera coronata (O. WETZEL 1933)										s		
A. Coronata ? (O. WETZEL 1933)							s					
A. senonensis (LEJEUNE-CARPENTIER 1938)							s		s			
Areoligeraceae sp. 1 in Gruas (CAVAGNETTO 1976)		x	f									
Ceratiopsis depressa (MORGENROTH 1966)											s	s
Cordosphaeridium exilimurum (DAVEY & WILLIAMS 1966)												s
C. firbrospinosum (DAVEY & WILLIAMS 1966)						s						
C. gracile (EISENACK 1954)					s		s			s	f	
C. inodes (KLUMPP 1953)			f	f	f	f			f	ff	f	s
C. ? minimum (MORGENROTH 1966)											s	
Criboperidinium giuseppei (MORGENROTH 1966)												s
Cyclonephelium hystrix (EISENACK 1958)									s			?
Dapsilidinium ? langii (WALL 1965)												f
Deflandrea denticulata (ALBERTI 1959)										s	s	s
D. cf. denticulata (ALBERTI 1959)			f		s							
D. oebisfeldensis (?) (ALBERTI 1959)				s		s			f	f	f	s
Dinopterygium cladoides (DEFLANDRE 1935)				s						s	s	s
Diphyes colligerum (DEFLANDRE & COOKSON 1955)			f	s		s	f				s	s
Eocladopyxis hispida (DE CONINCK 1969)			s		s						s	
E. peniculata (MORGENROTH 1966)					s				ff	s	s	
E. aff. peniculata (MORGENROTH 1966)		x	f	f	ff							
Exochosphaeridium phragmites (DAVEY, DOWNIE, SARJEANT, WILLIAMS 1966)												s
Fibrocysta aff. axialis (EISENACK 1965)						f						
F. bipolaris (COOKSON & EISENACK 1965)					?				s	?		
? Gerdiocysta cassicula (DRUGG 1970)									s			
Glaphyrocysta divariacata (WILLIAMS & DOWNIE 1966)			s		s				f	f	s	
G. exuberans (DEFLANDRE & COOKSON 1955)											s	
G. ordinata (WILLIAMS & DOWNIE 1966)							s			f	s	
G. pastielsii (DEFLANDRE & COOKSON 1955)												s

	-310,30 m	-309,90 a 310,00 m	-305,80 a -305,88 m	-301,40 a -301,50 m	-399,60 a -299,69 m	-299,28 a -299,31 m	-297,40 m	-290,10 a -290,20 m	-287,90 a -288,00 m	-287,00 a -287,10 m	-284,10 a -284,20 m	-282,26 m 3.
G. aff. reticulosa (GERLACH 1961)									s	s	ff	s
G. ? sp. cf. Eatonicysta ursulae (MORGENROTH 1966)			s									
G. sp. aff. G. ordinata (WILLIAMS & DOWNIE 1966) G. Divaricata												
Glyphanodinium facetum (DRUGG 1964)			s						s	f	s	
Gonyaulacysta jurassica (DEFLANDRE 1938)												s
Gonyaulacystaceae spp. indet.						f			s	s	s	f
Homotryblium sp. indet.		x	F	F	F	FF	f		f			
Hystrichokolpoma unispinum (WILLIAMS & DOWNIE 1966)											s	
? Hystrichosphaeridium latirictum (DAVEY & WILLIAMS 1966)											s	
H. tubiferum (EHRENBERG 1838)					s				s	f	ff	s
? Hystichosphaerina schindewolfii (ALBERT 1961)												s
Impagidinium victorianum (COOKSON & EISENACK 1965)										s	s	
Impagidinium sp. indet.												S
Impletosphaeridium implicatum (MORGENROTH 1966)							s					f
Kallosphaeridium orchiesense (DE CONINCK 1976)												s
? Kenleyia lophophora (COOKSON & EISENACK 1965)		x									f	
K. pachycerata (COOKSON & EISENACK 1965)						s						
Lejeunecysta hyalina (GERLACH 1961)				s							?	
Lejeunecysta ? sp. indet.								s				
Lentinia wetzelii (MORGENROTH 1966)							s		f	s		
Leptodinium subtile (KLEMENT 1960)									s			
Lingulodinium machaerophorum (DEFLANDRE & COOKSON 1955)			f	f	ff	ff	f		f		s	s
Melitasphaeridium pseudorecurvatum (MORGENROTH 1966)										s		s
Membranilarnacia minuta (DE CONINCK 1969)												s
Microdinium ornatum ? (COOKSON & EISENACK 1960)											s	
M. aff. reticulatum (VOZZHENNIKOVA 1967)										f		f
Muratodinium fimbriatum (COOKSON & EISENACK 1967)			f		f	f						
Nematosphaeropsis reticulensis (PASTIELS 1948)			s							f	s	
Odontochitinopsis , sp. A in DE CONINCK 1976										s		
? Oligosphaeridium sp. indet.									s		s	
Operculdoninium centrocarpum (DEFLANDRE & COOKSON 1955)							f		ff	f	f	
O. microtriaina (KLUMPP 1953)												s
Palaeocystodinium , deflandreii (GRUAS - CAVAGNETTO 1968)			s	s	f	f						
Phthanoperidinium crenulatum (DE CONINCK 1976)			s									
Platycystidia ? sp. A.											s	
Polysphaeridium zoharyii (ROSSIGNOL 1962)			f	ff	FF	f	s					
? Schematophora speciosa (DEFLANDRE & COOKSON 1955)				s								
Senegalinium ? dilwynense (COOKSON & EISENACK 1965)			s		s							
? S. obscurum (DRUGG 1967)				s	s							
Spiniferites cornutus (GERLACH 1961)												s
Spiniferites spp. indet.			ff		f	f	f	ff	F	F	F	FF
Surculosphaeridium oceaniae (DE CONINCK 1969)			f				s		s	f	f	f
Tectatodinium pellitum (WALL 1967)												s
Thalassiphora delicata (WILLIAMS & DOWNIE 1966)										s	?	f
T. sp. aff. T. patula (WILLIAMS & DOWNIE 1966) T. pelagica (EISENACK1954)			s	s		ff						
Wetzeliella meckelfeldensis (GOCHT 1969)												s
- Prasinophyceae												
Cymatiosphaera aff. punctifera (DEFLANDRE & COOKSON 1955)										s		
Pterospermella hartii (SARJEANT 1960)												s
- Acritarcha												
Baltisphaeridium ligospinosum (DE CONINCK 1969)			f		s					ff	ff	ff
Comasphaeridium cometes (VALENSI 1948)				s							f	ff
C. multispinosum (PASTIELS 1948)										s		
Micrhystridium lymense (WALL 1965)									s			
M. stellatum ? (DEFLANDRE 1942)									s			
Pseudomasia trinema (DE CONINCK 1969)											s	

working paper of the I.G.C.P. project 124, COSTA (1981) points out the presence of the first *H. tenuispinosum* DAVEY & WILLIAMS, 1966 in the *A. hyperacanthum* zone. In the Newhaven outcrop, a form intermediary between *H. tenuispinosum* and *H. tasmaniense* COOKSON & EISENACK, 1967, is known in the Woolwich Beds (DUPUIS & GRUAS-CAVAGNETTO, 1985). *H. tasmaniense* itself was described in Upper Paleocene deposits in Tasmania (Australia).

Knokke -305.8 to 305.88 m.

Two slides. About twenty five species of phytoplankton.*Homotryblium* sp. and *Apectodinium homorphum* dominate. *Spiniferites* spp. and *Achomosphaera* spp. appear frequently. *Polysphaeridium zoharyii, Eocladopyxis* aff. *peniculata* and *Areoligeraceae* sp. 1 (GRUAS CAVAGNETTO, 1976) are found regularly. A few specimens of *Muratodinium fibriatum, Phthanoperidinium crenulatum (Ginginodinium crenulatum* in table 1) and *Apectodinium quinquelatum* have been encountered together with one form which resembles *Eatonicysta ursulae* (which appears higher in the Ieper Formation) and which can be compared with «*Cyclonephelium conopium*» recovered in the «lower Landenian» (SCHUMACKER-LAMBRY, 1978, p. 39, pl. 3., fig. 9 and 10) and described by DENISON in the «Upper Landenian» (unpublished thesis).

Remark: Before the present study, the first occurence of *P. zoharyii* was situated in the *Dracodinium varielongitudum* zone. Its stratigraphical range is now extended downwards. In the Upper Landenian deposits in the Knokke borehole it is encoutered up to -297.4 m.

Knokke -301.4 to -301.5 m

Two slides. About twenty species of phytoplankton. *Apectodinium parvum* and *Homotryblium* sp. dominate the assemblage. *Polysphaeridium zoharyii* is abundant. *Apectodinium homomorphum* and *A. quinquelatum* are scarce.

Remark : *A. quinquelatum* ressembles to *Wetzeliella astra* but is smaller and its endophragm remains in contact with the ectophragm except under the processes and weakly developed horns. These characteristics allow to distinguish *A. quinquelatum* from *W. astra.*

Knokke -299.28 to -299.31 m

Four slides. The assemblage counts about fifteen species. In decreasing abundance order, we find: *Homotryblium* sp. followed by *A. homomorphum, Thalassiphora patula-pelagica* and *Lingulodinium machaerophorum;* finally *A. parvum, Spiniferites* spp. and *Polysphaeridium zoharyii.*

Knokke -297.4 m

One slide. About fifteen species. *A. homomorphum* is very abundant, reaching nearly 40 %. *Paralecaniella indentata* and *Spiniferites* spp. reach between 15 and 20 %. *A. parvum* and *Lingulodinium machaerophorum* appear regularly, attaining about 5 %.

Knokke -290.1 to -290,2 m

One slide. Few fossils and a very poor assemblage in which only *Spiniferites* spp. and *Paralecaniella indentata*, have been observed. Apart from these phytoplankton species, we find some pyritized frustules and valve fragments of centric diatoms.

Knokke -287.9 to 288 m

Two slides. The number of phytoplankton species attains about thirty. *P. indentata* (20 %), *Spiniferites* spp. (20 %), *A. homomorphum* (20 %) are the most frequent ones. *Cordosphaeridium inodes, Eocladopyxis peniculatum, L. machaerophorum* and *Operculodinium centrocarpum* are less well represented (between 5 and 10 %). *A. parvum* and *Homotryblium* sp. are rare. Five forms seem reworked from the Mezosoic.

Knokke -287 to -287.1 m

Two slides. About forty species in the assemblage. *Spiniferites* spp. are the most abundant (25 %). Then follow *Achomosphaera* spp. (10 %), *A. homomorphum* (10 %), *C. inodes* (10 %), *Hystrichosphaeridium tubiferum* (5 %), *Deflandrea phosphoritica - oebisfeldensis - speciosa* (5 %) and *O. centrocarpum* (5 %). *A. parvum* is rarely encountered. Some individuals belong to *A. quinquelatum* or *A. paniculatum*, two species difficult to distinguish and probably forerunners of *W. astra.*

Remark : *Homotryblium* sp. has disappeared from the assemblage.

Knokke -284.1 to 284.2

One slide. About forty species. The assemblage is dominated by *Spiniferites* spp. (about 25 %), followed by *Impletosphaeridium ligospinosum (Baltisphaeridium ligospinosum* in table 1) (about 15 %), and *Achomosphaera* spp. (about 10 %), *A. homomorphum* has disappeared. *Deflandrea oebisfeldensis* (?) remains rather frequent as at 287 m. One specimen of *Pseudomasia trinema,* index species of the lower Ypresian, has been found. Five individuals are tentatively classified as *Achomosphaera,* three as *A. parvum* and one as *A. quinquelatum.*

Remark : *A. paniculatum* shows characteristics tending towards those of the genus *Wetzelliella* which is nevertheless not yet present.

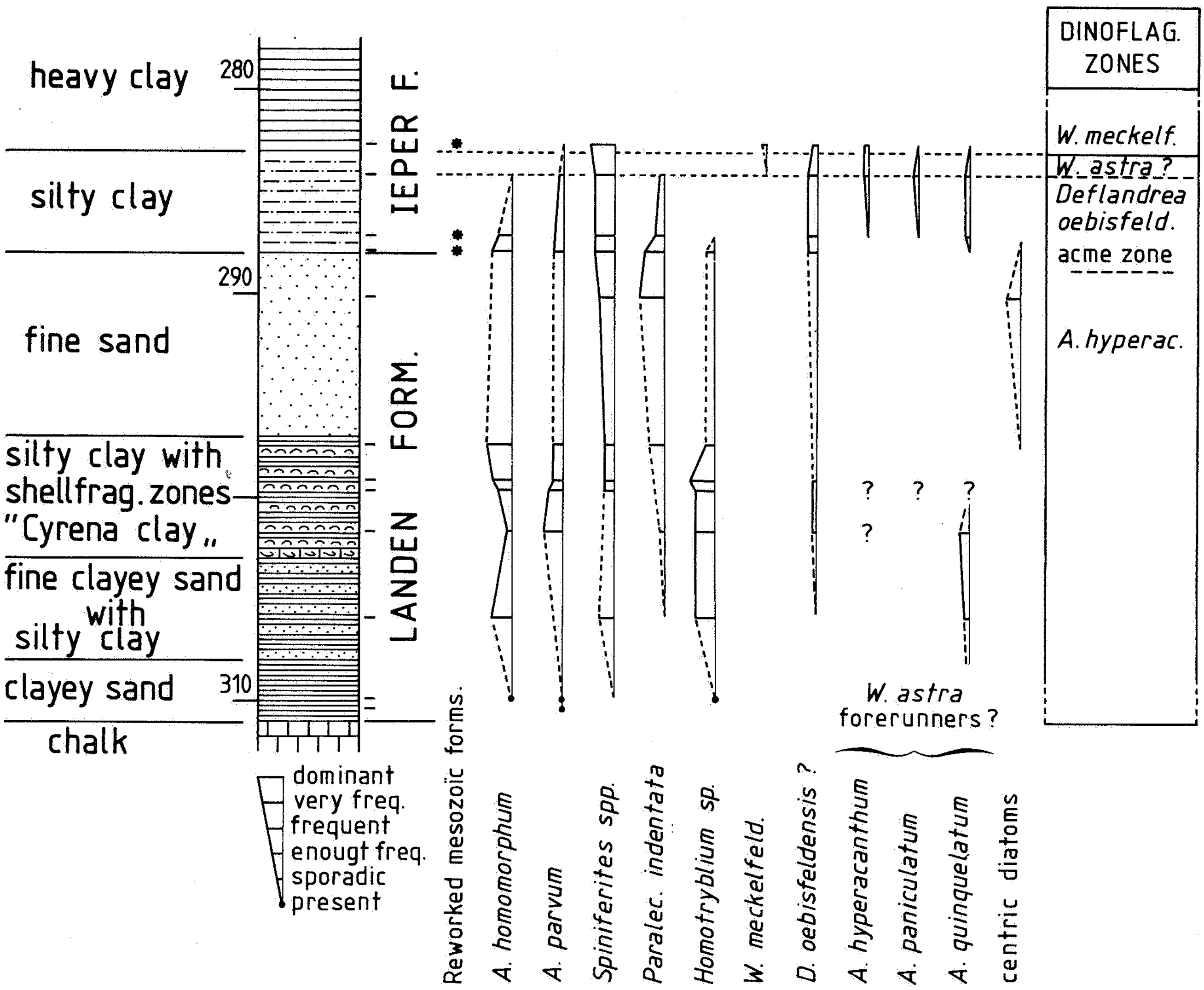

Fig. 4. Distribution and abundance of some phytoplankton species, diatoms and reworked mesozoic forms. Inferred Dinoflagellate zonation

Knokke -282.18 to -282.26 m

Two slides. About forty five species. *Spiniferites* spp. are the most abundant with approximately 40%. *Achomosphaera* spp., *Baltisphaeridium ligospinosum, Impletosphaeridium ligospinosum* and *Comasphaeridium cometes* reach 10%. One specimen of *Kallosphaeridium orchiesense* has been observed. *Apectodinium* spp. are absent, except one specimen being close to *A. hyperacanthum.* Two specimens of *Wetzeliella* have been found; the first belongs to *W. meckelfeldensis,* the second ressembles it but differs by the two antapical horns which are of more or less equal length. Five forms are probably reworked from Mesozoic.

2) Comments (J. DE CONINCK & Ch. DUPUIS)

We can outline the assemblages evolution of the «Landenian» and «Ypresian» levels in the Knokke boreole as follows: *Apectodinium parvum* and *A. homomorphum* dominate the lower argillaceous part of the Landen Formation. In the upper part of this unit (top of the «*Cyrena* Clay») *A. homomorphum* supplants *A. parvum.* In the sandy, uppermost part of the Landen Formation, microfossils are very scarce, but the presence of some valves and numerous fragments of pyritized centric diatoms suggests a correlation with the volcanic ash layers observed in the North Sea Basin, and of which the lower levels are situated in the *A. hypercanthum* zone (KING, 1981, p. 131).

In -287.9 to 288 m, at the base of the Ieper Formation, the number of species increases considerably and the *Spiniferites* spp. come to the foreground. Nevertheless, some of the main species which characterize the «Landenian» beds, namely *Paralecaniella indentata* and *A. homo-*

morphum remain well represented in this lowermost «Ypresian» assemblage in which *Homotryblium* sp. appears a last time.

Between -287 to 287.1 and -282.26 m *P. indentata* and *A. homomorphum* seem to disappear but *A. hyperacanthum* and *A. paniculatum* are present.

At -282.26 m *Wetzeliella meckelfeldensis* arrives for the first time in the assemblage which has now a pronounced «Ypresian» character.

In none of the slides we have found true *W. astra,* but forms very close to it are present such as *A. paniculatum, A. quinquelatum* and *A. hyperacanthum.* These three species are found together between -287 and -282 m. In this part of the traject they are accompanied by a slight increase of the frequency of *Deflandrea oebisfeldensis* (?) which can probably be correlated with the acme zone of this species at the top of the *A. hyperacanthum* zone and just below the W. astra zone (KNOX & HARLAND, 1979; HEILMANN-CLAUSEN, 1982).

All these data indicate that in the Knokke borehole the base of the Ieper Clay can (just as in the Kallo borehole) be situated in the summit of the *A. hyperacanthum* zone, what is also the case for the base of the London Clay in the London Basin. The delimitation of the *W. astra* zone in the Knokke borehole is conjectural just as in some areas within the London and Hampshire Basins (KNOX & HARLAND, 1979; KING, 1981). It can either be restricted to the -284 to -286 m interval approximately (hypothesis adopted in figures 1 and 4) or should be considered as missing.

B. SPORES AND POLLENS (fig. 5)

Thirteen samples, covering the Landen Formation (L_2) and the lower part of the Ieper Formation (Yc) between -310.3 m and -282.2 m, have been examinated.
Three levels are barren: -310.3 m, -310 m and 290.1 m.

The sporopollinic analysis of the others samples allows to establish the distribution of the figure 5. Examination of this distribution shows that the main floristic break coincides more or less with the lithologic L_2-Yc discontinuity (between -288 and -287 m).

Under -288 m we find the L_2 markers:

- *Basopollis basalis* (18),
- *Triporopollenites betuloides* (24),
- *Subtriporollenites magnoporatus magnoporatus* (36),
- *Subtriporopollenites magnoporatus tectopsilatus* (37),
- *Subtriporopollenites spissoexinus* (38),
- *Intratriporopollenites microinstructus* (43),
- *Striatriopollenites longostriatus* (62).

Since -287 m, characteristic forms of the Yc appear:

- *Caryapollenites circulus* (41),
- *Triatriopollenites myricoides* (28),
- *Triatriopollenites plicatus* (29),
- *Clavatricolporites iliacus* (63),
- *Retitricolporites oleides* (59).

The Normapolles which normally continue above the L_2 are also present:

- *Plicapollis pseudoexcelsus* (22),
- *Pompeckjoidaepollenites subhercynicus* (19)
- *Interpollis supplingensis* (21)
- *Nudopollis endangulatus* (20)

The L_2-Yc boundary is underlined both by the disappearance of *Intratriporopollenites microinstructus* and by the appearance of *Caryapollenites circulus.*

Briefly we can notice that the main pollinic break is located in the lower part of the *Deflandrea oebisfeldensis* acme zone, a few meters above the chronostratigraphic base of the Ypresian (sensu HARDENBOL & BERGGREN, 1978) here delimited by the conjectural *Wetzeliella astra* zone (fig. 5).

CONCLUSIONS

The study of the Landenian Ostracods of the Knokke and Kallo boreholes shows the similarity of the facies of the *Cyrena cuneiformis* - bearing beds on the southern Belgian Basin and on the north-western Paris Basin. From the palynological point of view, these deposits are probably more or less contemporary in the London-Belgian and Dieppe Hampshire Basins. But they seem to be markedly diachronous in the Paris Basin heart. The Sparnacian facies appear to be of Thanetian age in the Southern North Sea Basin and of Ypresian age in the Paris Basin. Such data point out again the ambiguity of the chronostratigraphic utilization of the «Sparnacian» term.

The analysis of the phytoplankton in the lower part of Knokke borehole confirms the synchronous sedimentation of the lowermost Ieper-London Clay facies in the southern North Sea Basin (on top of the *Apectodinium hyperacan-*

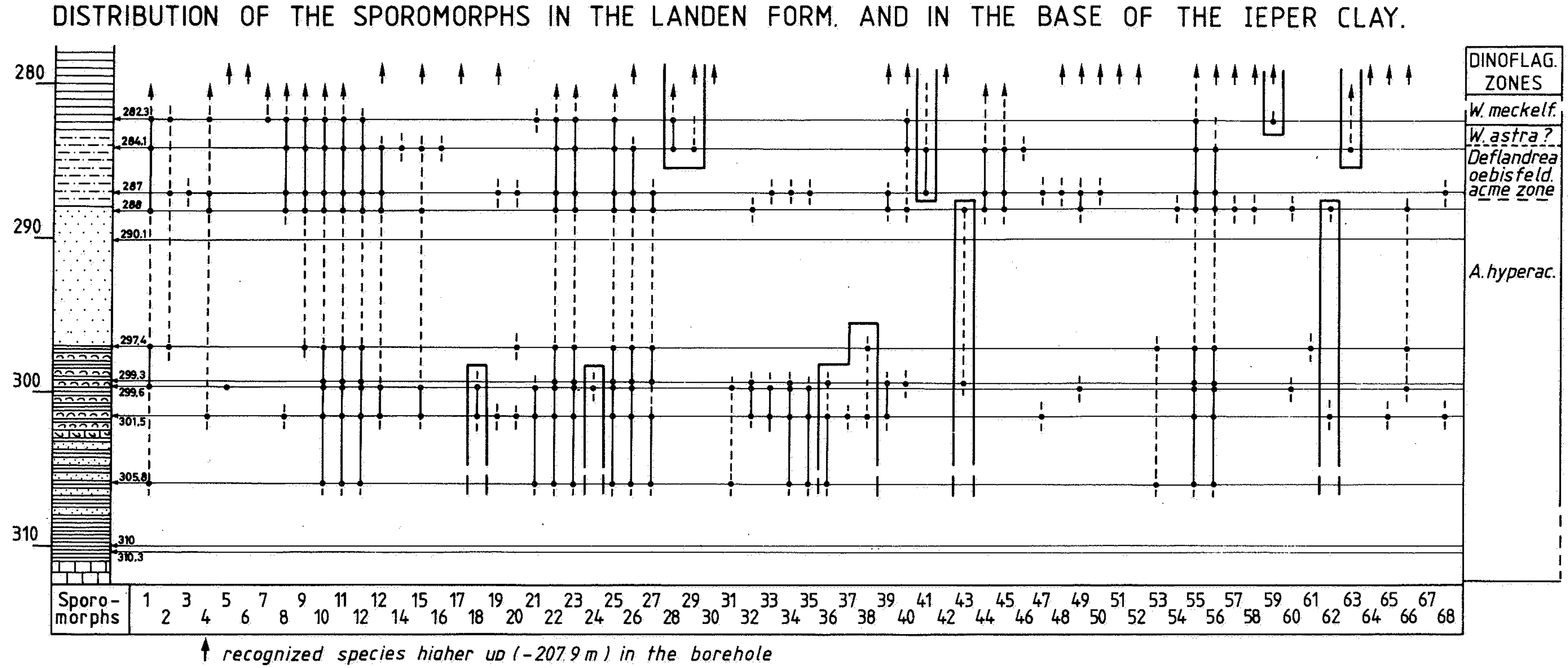

Fig. 5.- Distribution of the sporomorphs. The extensions of the main stratigraphical markers are surrounded. The adopted Dinoflagellate zonation is indicated for comparison.

List of the species : 1. *Leiotriletes adriennis;* 2. *Stereisporites stereoides;* 3. *Trilites Multivallatus;* 4. *Cicatricosisporites dorogensis;* 5. *Ischyosporites tertiarus;* 6. *Polypodiaceoisporites potoniei;* 7. *Camarozonosporites* sp.; 8. *Laevigatosporites haardti;* 9. *Laevigatosporites discordatus;* 10. *Disaccates* div.; 11. *Inaperturopollenites hiatus;* 12. *Inaperturopollenites dubius;* 13. *Sparganiaceaepollenites reticulatus;* 14. *Sparganiaceaepollenites cuvillieri;* 15. *Milfordia hungarica;* 16. *Graminidites* sp.; 17. *Diporites iszkaszentgyorgii;* 18. *Basopollis basalis;* 19. *Pompeckjoidaepollenites subhercynicus;* 20. *Nudopollis endangulatus;* 21. *Interpollis supplingensis;* 22. *Plicapollis pseudoexcelsus;* 23. *Triporopollenites robustus;* 24. *Triporopollenites betuloides;* 25. *Triatriopollenites platycaryoides;* 26. *Triatripollenites engelhardtioides;* 27. *Triatriopollenites belgicus;* 28. *Triatriopollenites myricoides;* 29. *Triatriopollenites plicatus;* 30. *Triatriopollenites sibiricus;* 31. *Triatriopollenites rurensis;* 32. *Triatriopollenites roboratus;* 33. *Triatriopollenites aroboratus;* 34. *Subtriporopollenites anulatus;* 35. *Subtriporopollenites constans;* 36. *Subtriporopollenites magnoporatus magnoporatus;* 37. *Subtriporopollenites magnoporatus tectopsilatus;* 38. *Subtriporopollenites spissoexinus;* 39. *Subtriporopollenites subporatus;* 40. *Caryapollenites triangulus;* 41. *Caryapollenites circulus;* 42. *Caryapollenites praesimplex;* 43. *Intratriporopollenites microinstructus;* 44. *Intratriporopollenites microreticulatus;* 45. *Intratriporopollenites pseudinstructus;* 46. *Pistillipollenites macgregorii;* 47. *Polyporopollenites undulosus;* 48. *Polyvestibulopollenites verus;* 49. *Monocolpopollenites tranquillus;* 50. *Monocolpopollenites parareolatus;* 51. *Dicolpopollis luteticus;* 52. *Psilatrocolpites liblarensis fallax;* 53. *Scabratricolpites deconinckii;* 54. *Scabratricolpites moorkensii;* 55. *Psilatricolporites cingulum fusus;* 56. *Psilatricolporites cingulum oviformis;* 57. *Psilatricolporites kruschi;* 58. *Retitricolporites marcodurensis;* 59. *Retitricolporites oleoides;* 60. *Verrutricolporites antwerpenensis;* 61. *Striatricolporite sittleri;* 62. *Striatricolporites longostriatus;* 63. *Clavatricolporites iliacus;* 64. *Bombacacidites europaeus;* 65. *Psilastephanocolporites dsp.;* 66. *Tetradopollenites ericius;* 67. *Tetradopollenites callidus;* 68. *Ovoidites ligneolus.*

thum zone). From a more general point of view the more or less close juxtaposition of several sporomorphs disappearances and appearances around the *Wetzeliella* emergence, forms a very interesting stratigraphical marker.

As a conclusion, it can be said that our study provides a good palynologic documentation on the classical Paleocene-Eocene limit for which the Knokke borehole can become a reference section.

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PLATE I

OSTRACODA OF THE UPPER LANDENIAN

Figs 1 & 10.- *Cytheromorpha aillyensis* Bignot.

1.- Right valve, Kallo -385 m, x 100, stereosc. view.
10.- Sieve of the same valve; the sieves are without central pores, x 2500.

Fig. 2.- *Eocytheropteron* cf *thiliensis* Apostolescu
Left valve, Kallo -384,5 m, x 70, stereo.

Fig. 3.- *Clitherocytheridea hieroglyphica* Apostolescu
R.V., Kallo -384,5 m., x 90, stereo.

Figs 4, 5, 7 & 11.- *Cladarocythere obesa* Guernet.

4. R.V., ♀, with strong phenotypic nodes and ribs
5. L.V., ♀, int. view.
7. L.V., ♂, without nodes.
All these valves from Knokke, -298,2 m., x 60, stereo.

Fig. 6.- *Vetustocytheridea lignitarum* Dollfus.
R.V., ,Kallo -385 m., x 55, stereo.

Figs 8-9.- *Neocyprideis durocortoriensis* Apostolescu
R.V., , ext. view and L.V., int. view (stereo), Knokke, -298,2 m., x 60.


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Chapter V
CALCAREOUS NANNOPLANKTON ASSEMBLAGES FROM THE TERTIARY IN THE KNOKKE BOREHOLE

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The upper part of the Knokke well sequence (from 0 to 33 m) consists of Quaternary sandy deposits with interbedded thin claylayers. These overlie 278 m of Palaeogene sediments resting on the Cretaceous at 311 m. The Palaeocene is represented by a sandy-clayey complex overlain by a 10 m thick fine sand with peat debris. The Eocene comprises a lower rather thick clayey part, known as the Flanders Clay or Ieper Clay, a sandy middle part with several sandstone bands and finally an alternation of clays and thin sandy layers, known as the Meetjesland Formation (see JACOBS, 1978) or Kallo complex (see GULINCK, 1969 a and b). The top of the Palaeozoic is at a depth of 432 m.

Core-recovery was nearly complete, except for the interval from 74 to 79 m. Tertiary calcareous nannoplankton has been studied through very close spaced samples. 190 samples were selected, of which 124 were fully examinated with the aid of the light microscope.

For the methods, preparation of the samples and investigation techniques the reader is referred to the excellent work of ROMEIN (1979).

1. GENERAL CHARACTERISTICS OF THE CALCAREOUS NANNOPLANKTON

Of the 124 studied samples only 60 yielded interpretable nanno-assemblages. Both the basal (Landen Formation and the major part of the Ieper Formation) and the uppermost part of the section are devoid of nannoplankton. The remainder contains low diversity, poorly to moderately preserved assemblages, except for the interval 62.50 to 71.95 m. Table 1 shows the species recognized and their distribution through the cored well.

The calcareous nannoflora of the Knokke well is characterized by the relative abundance of the genera *Pontosphaera, Reticulofenestra, Ericsonia, Braarudosphaera* and *Chiasmolithus*, throughout the sequence, and by *Micrantholithus* and *Rhabdosphaera* at certain levels. Many of these genera are represented in nearshore, shallow water environments, and suggest sublittoral deposition (see ROTH, 1974: 982, 989, 990; PERCH-NIELSEN, 1977: 744 and MOSHKOVITZ & EHRLICH, 1982: 44 for comments on the ecology of braarudosphaerids; see also MUELLER, 1979: 614-616 and TAPPAN, 1980: 769-771). The scarcity of discoasters and helicosphaerids as well as the absence of scyphosphaerids, groups which are well represented in the bathyal deposits of the Aquitanian Palaeogene (see STEURBAUT, 1983 and unpublished data), would also seem to indicate a sublittoral environment.

2. BIOZONATION

During the last decades several Cenozoic nanno-zonations have been proposed. For a review of these the reader is referred to the excellent work by AUBRY (1983: 273-317). The zonations of MARTINI (1971) and BUKRY (1973, 1975 and 1978), later refined by OKADA & BUKRY (1980) and BUKRY (1981), have been successfully applied on a nearly worldwide scale. Both zonations are interval zonations wherein the zonal boundaries are defined by the entry or exit of a single species. BUKRY'S zonation is based on data derived from deep-sea boreholes and covers low latitude open-ocean assemblages. MARTINI'S «Standard nannoplankton zonation» is based on middle to high latitude near-shore assemblages

Table I.- Tertiary calcareous nannoplankton from the Knokke well (NW Belgium)

TERTIARY CALCAREOUS NANNOPLANKTON FROM THE KNOKKE WELL (NW BELGIUM).

AGE	LITHOSTRATIGRAPHY	NANNO-ZONE (MARTINI, 1971)	SAMPLE depth in m.	ABUNDANCE	ASSEMBLAGE-UNITS	PRESERVATION
QUATERNARY			00.00			
			33.00			
?BARTONIAN	MEETJESLAND FORMATION S2	?	33.80	BARREN		
			34.85			
			36.30			
	a2		37.50			
			41.50			
			44.50			
	S1		48.50			
	a1		50.50			
			57.50			
-?- LUTETIAN			59.50			
			61.50			
		Discoaster tanii nodifer (NP16)	62.50	O	12	M
			65.50	●		G
	As	Nannotetrina fulgens (NP15)	67.50	O	11	M
	b-a		69.50	●		G
	We		71.65	O	10	M
	BRUSSEL FORMAT.	Discoaster sublodoensis (NP14)	71.95	O	9	M
	--?--?		73.00	O		P
	DEN HOORN FORMATION		80.00	X	8	P
			83.50	X		P
			86.50	o		M
			88.50	o		M
			89.50	o	7	M
			90.75	o		M
			97.50	o	6	P
			99.25	o		P
		?	103.50	o	5	M
YPRESIAN	PANISEL FORMATION ?		106.40	o		M
		Discoaster lodoensis (NP13)	109.40	X	4	P
			112.70	O		M
			115.70	O		M
			117.75	o		M
			121.90	O	3	P
			122.50	O		M
			124.70	●		M
			128.50	●		M
			130.00	O	2	M
			132.50	o		M
	P1m	?	134.60	BARREN		
	IEPER FORMATION Yd		136.50			
			140.80			
			143.90			
	Yc		149.70			
			155.85			
			160.50			
			172.50			
			189.50			
			209.50			
			215.80			
		Discoaster binodosus (NP11)	220.60	O	1	M
			222.50	O		M
			230.50	o		P
			235.50	O		M
			245.50	O		P
		?	247.00	BARREN		
			255.00			
			262.50			
			272.50			
THANETIAN	LANDEN FORMATION		287.50			
			291.60			
			296.75			
			298.10			
			304.25			
			306.90			
			309.70			
			310.40			
CRETACEOUS			311.00			

SAMPLE	Ellipsolithus macellus	Pontosphaera exilis	Toweius occultatus	Discoaster kuepperi	Ericsonia eopelagica	Tribrachiatus orthostylus	Toweius pertusus	Sphenolithus sp. 1	Sphenolithus radians	Toweius magnicrassus	Discoaster binodosus	Pontosphaera pulchra	Cyclolithella sp.	Chiasmolithus consuetus	Neococcolithes dubius	Neococcolithes protenus	Sphenolithus moriformis
62.50					O										o		
65.50					O						o				o		o
67.50					O										o		
69.50					O							X			o		X
71.65					o							o			o		X
71.95					O							o			o		
73.00					O				X			o			o		
80.00					X							X			X		
83.50					X							X					
86.50					o							X			X		
88.50					o							o			X		
89.50				o	o							X			X		
90.75				X	o							o					
97.50					o				X			o			X		X
99.25					o							o					
103.50					o							o			X		
106.40				X	o				X			o			X		
109.40					X							X					
112.70					o							o					
115.70					o				X			o					
117.75					X												
121.90					o							o					
122.50												o					
124.70					o							o					
128.50					o							o					
130.00			X	o	o							o					
132.50				o	o							o			X		
220.60		O	O	o	O	X	X	o	o	o	X			X	o	o	o
222.50		O	O	o	O	o	o	o	X						X	X	o
230.50		X		X	X		o										
235.50		O	O	O	O	o							X	o	X	X	o
245.50	X	o		X	X	o	o	o	X	X	X	o					

SAMPLE	Pontosphaera fimbriata	Toweius sp.	Imperiaster obscurus	Chiasmolithus californicus	Ericsonia formosa	Markalius inversus	Discoaster diastypus	Cyclococcolithus bramlettei	Rhabdosphaera solus	Pontosphaera scissura	Toweius gammation	Cepekiella lumina	Pontosphaera multipora	Chiasmolithus solitus	Zygrhablithus bijugatus	Cruciplacolithus sp. 1	Nannoturba robusta
62.50					o	X						o	X				
65.50					O							o	O	o	X		
67.50					X	X							X	o	X		
69.50					o	X						o	o	X	O		
71.65					X	X						o	X	X	X	o	
71.95		o				X								o		o	
73.00		X			X	o								O			X
80.00						X								X			X
83.50												X					
86.50												X		X	X		
88.50															X		
89.50						X						X		X	o		
90.75												X		X	o		
97.50					X							X	X	o	o	o	X
99.25					X							X				X	X
103.50	X															o	X
106.40												X		X		o	X
109.40																	X
112.70															X		o
115.70						X										X	X
117.75						X							X	X			X
121.90															X		
122.50						o									X		
124.70												X	X		o	O	
128.50															o	o	
130.00						X									o	o	o
132.50						X								o	o	o	o
220.60	o				X	X	X	X	X	X	X	X	X				
222.50	o		X	X	X	X											
230.50																	
235.50	X	X															
245.50																	

Discoaster lodoensis	X X X X X
Nannoturba spinosa	o o X X X o X X X
Imperiaster sp.	o X X X X
Reticulofenestra sp.	o o o o X X X X o o o X o X o
Micrantholithus flos	o ● ● O O X X X
Braarudosphaera bigelowi	X o o o o X X X X X X X X o X X X X X
Micrantholithus inaequalis	o ● ● O O X
Micrantholithus vesper	o ● X X X X
Lithostromation operosum	X X X X X
Reticulofenestra cf. *onusta*	o O O X
incertae sedis sp. 1	X
Discoaster mirus	X
incertae sedis sp. 2	X
Discoaster deflandrei	X X X
Cruciplacolithus mutatus	X X X X X o X O X
Pontosphaera prava	X X o X
Discoaster sublodoensis	X X X X o o
Reticulofenestra umbilica	o X o o X X o O O ● O ● O
Pontosphaera ocellata	X X X
Cyclococcolithus sp.	X X X X
Chiasmolithus expansus	X X X X X
Discoaster stradneri	o X X X X
Discoaster strictus	X X X
Rhabdosphaera crebra	X X X X X o O o X
Discoaster barbadiensis	X X o X X
Chiphragmalithus calathus	X
Discoaster distinctus	X X X X
Chiasmolithus grandis	X
Cruciplacolithus delus	X
Discoaster germanicus	X
Chiasmolithus medius	X
Ericsonia fenestrata	X X o o X X
Pontosphaera obliquipons	X X X X X
Pemma sp.	X X X
Cruciplacolithus staurion	X X X
Rhabdosphaera vitrea	X
Micrantholithus crenulatus	X
Discoaster gemmeus	X
Discoaster wemmelensis	X X X X X
Reticulofenestra callida	X X o o o o o
Birkelundia arenosa	X X X X
Pontosphaera punctosa	X X o
Zygrhablithus crassus	o O O
Chiasmolithus sp.	X
Rhabdosphaera scabrosa	o o o
Rhabdosphaera gladius	X o o
Lanternithus minutus	o o
Cruciplacolithus sp. 2	X
Lophodolithus acutus	X
Sphenolithus sp. 2	X
Sphenolithus furcatolithoides	o X X
Helicosphaera seminulum	X X
Naninfula deflandrei	X X
Rhabdosphaera pseudomorionum	X
Ericsonia subdisticha	X
Nannotetrina fulgens	o o o
Helicosphaera lophota	X
Discoaster tanii	X
Reticulofenestra foveolata	X
Pontosphaera wechesensis	X
Rhabdosphaera tenuis	X
Pontosphaera labrosa	X
Discoaster bifax	o O
Nannotetrina pappi	o
Cyclococcolithus kingi	X
Pseudotriquetrorhabdulus inversus	X
Discoaster nodifer	X
Discoaster woodringii	X

LEGEND

P = poor M = moderate G = good

● = abundant : 5 to 10 specimens per field of view at x1250
O = common : 1 specimen per field of view at x1250
o = few : 1 specimen per 5 fields of view at x1250
X = rare : 1 specimen per 20 to 25 fields of view at x1250

Table II.- Eocene calcareous nannofossil zonation

AGE		FIRST OCCURRENCES	CALCAREOUS NANNOFOSSIL ZONATION: CP		OKADA & BUKRY 1980		MARTINI 1971	NP	LAST OCCURRENCES
EOCENE	Late	S. pseudoradians I. recurvus	15	b	Isthmolithus recurvus	Discoaster barbadiensis	Sphenolithus pseudoradians Isthmolithus recurvus	20 19	D. barbadiensis, D. saipanensis
		C. oamariensis		a	Chiasmolithus oamaruensis		Chiasmolithus oamaruensis	18	C. grandis
			14	b	Discoaster saipanensis	Reticulofenestra umbilica	Discoaster saipanensis	17	D. bifax, C. solitus
	Middle	D. bifax, R. umbilica		a	Discoaster bifax		Discoaster tani nodifer	16	R. gladius
			13	c	Birkelundia staurion	Nannotetrina fulgens	Nannotetrina fulgens	15	C. gigas
		C. gigas		b	Chiasmolithus gigas				
		N. fulgens		a	Discoaster strictus				R. inflata
		R. inflata	12	b	Rhabdosphaera inflata	Discoaster sublodoensis	Discoaster sublodoensis	14	
		D. sublodoensis		a	Discoaster kuepperi				
	Early	C. crassus	11		Discoaster lodoensis		Discoaster lodoensis	13	T. orthostylus
		D. lodoensis	10		Tribrachiatus orthostylus		Tribrachiatus orthostylus	12	
			9	b	Discoaster binodosus	Discoaster diastypus	Discoaster binodosus	11	T. contortus
		D. diastypus, T. contortus		a	Tribrachiatus contortus		Tribrachiatus contortus	10	

from outcrop sections and appears to be applicable to the present study. These zonations and their respective boundary-species are shown in table 2 (slightly modified after PERCH-NIELSEN in BECKMANN *et al.,* 1981).

The zonation used in this paper is the standard Tertiary nannoplankton zonation of MARTINI, (1971). The original definition of each zone is given, together with its occurrence, its most common species and its boundaries in the Knokke well. It should be emphasized that some of MARTINI's boundary-species, such as *Discoaster lodoensis* BRAMLETTE & RIEDEL 1954, *Discoaster sublodoensis* BRAMLETTE & SULLIVAN 1961 and *Rhabdosphaera gladius* LOCKER 1967 are rather rare and often discontinuously distributed through the Knokke well which hinders stratigraphic interpretations. Additionally some *Discoaster* species, such as *D. lodoensis*, *D. strictus* and *D. sublodoensis* sometimes show a slight to moderate etching or overgrowth masking specific features, making indentification difficult.

Discoaster binodosus Zone (NP 11)

Definition

Interval from the last occurrence of *Tribrachiatus contortus* (STRADNER 1958) to the first occurrence of *Discoaster lodoensis* BRAMLETTE & RIEDEL 1954.

Occurrence

From 245.50 to 220.60 m.

Boundaries

The lower and upper boundaries could not be established as the underlying and overlying strata are devoid of nannoplankton. As *Tribrachiatus orthostylus* is common and *T. contortus* and *D. lodoensis* are absent, the interval from 245.50 to 220.60 has to be assigned to MARTINI's *Discoaster binodosus* Zone.

Common species

Pontosphaera exilis, Toweius occultatus, Toweius pertusus, Discoaster kuepperi, Ericsonia eopelagica and *Tribrachiatus orthostylus.*

Tribrachiatus orthostylus Zone (NP 12)

Definition

Interval from the first occurrence of *Discoaster lodoensis* BRAMLETTE & RIEDEL 1954 to the last occurrence of *Tribrachiatus orthostylus* SHAMRAI 1963.

Occurrence

Not encountered in the Knokke well.

Discoaster lodoensis Zone (NP 13)

Definition

Interval from the last occurrence of *Tribrachiatus orthostylus* SHAMRAI 1963 to the first occurrence of *Discoaster sublodoensis* BRAMLETTE & RIEDEL 1961.

Occurrence

From 132.50 to ? 103.50 m.

Boundaries

The lower boundary of this zone could not be detected as the underlying strata did not yield nannofossils. The upper boundary is situated between 109.40 and 99.25 m depth. The presence of *D. lodoensis* and the absence of *T. orthostylus* and *D. sublodoensis* justify the assignment of the above mentioned interval to the *Discoaster lodoensis* zone.

Common species

Ericsonia eopelagica, Pontosphaera pulchra, Nannoturba spinosa, Nannoturba robusta, Discoaster lodoensis and *Imperiaster* sp.

Discoaster sublodoensis Zone (NP 14)

Definition

Interval from the first occurrence of *Discoaster sublodoensis* BRAMLETTE & SULLIVAN 1961 to the first occurrence of *Nannotetrina fulgens* (STRADNER, 1960).

Remarks

Nannotetrina fulgens cannot be used to define the top of zone NP 14 and consequently the base of zone NP 15 in sequences of infralittoral origin. According to MUELLER (1978:48) this species seems to be restricted to offshore, circalittoral to bathyal deposits. This explains why it appears in the Knokke well only at a depth of 67.50 m, at the top of the *Nannotetrina fulgens* zone (=NP 15). The boundary between zones NP 14 and NP 15 can be determined approximately with the entry of *Rhabdosphaera gladius* LOCKER 1967. This species is known only from near-shore deposits.

Occurrence

From ? 106.40 to 71.95 m.

Boundaries

The lower boundary is situated between 109.40 and 99.25 m, the upper one between 71.95 and 71,65 m.

Common species

Ericsonia eopelagica, Pontosphaera pulchra, Chiasmolithus solitus, Cruciplacolithus mutatus, Discoaster sublodoensis, Reticulofenestra umbilica, Cyclococcolithus sp., *Rhabdosphaera crebra* and *Chiasmolithus expansus.*

Nannotetrina fulgens Zone (NP 15)

Definition

Interval from the first occurrence of *Nannotetrina fulgens* (STRADNER 1960) to the last occurrence of *Rhabdosphaera gladius* LOCKER 1967.

Occurrence

From 71,65 to 67.50 m.

Boundaries

The lower boundary was taken at the entry of *Rhabdosphaera gladius,* instead of *N. fulgens* (for comments: see above), and is situated between 71.95 and 71.65 m. The upper boundary coincides with the exit of *R. gladius* and lies between 67.50 and 65.50 m.

Common species

Ericsonia eopelagica, Reticulofenestra umbilica, Rhabdosphaera crebra, Ericsonia fenestrata, Reticulofenestra callida, Rhabdosphaera gladius, Lanternithus minutus, Nannotetrina fulgens and *Sphenolithus furcatolithoides.*

Discoaster tanii nodifer Zone (NP 16)

Definition

Interval from the last occurrence of *Rhabdosphaera gladius* LOCKER 1967 to the last occurrence of *Chiasmolithus solitus* (BRAMLETTE & SULLIVAN 1961).

Occurrence

From 65.50 to 62.50 m.

Boundaries

The lower boundary is situated between 67.50 and 66.50 m. The upper boundary could not be fixed as no nannofossils were recognized in the interval from 61.50 to 33.00 m. In the uppermost part of the well (from the surface to 33.00 m) no autochthonous nannofossils were observed.

Common species

Ericsonia eopelagica, Ericsonia formosa, Pontosphaera multipora, Reticulofenestra umbilica, Nannotetrina fulgens and *Discoaster bifax.*

The present investigation shows that most of the above mentioned standard nannoplankton zones can be further subdivided into one or more assemblage-units. Each unit is charaterized by the dominance, the presence, the paucity or absence of certain nannospecies, or by a certain combination of species. They seem predominantly determined by local paleoecological conditions and hence have local significance only. They are expected to allow short-distance correlations (in the order of some hundreds of kilometres) and are suitable for the refinement of the North Sea Basin, Tertiary biostratigraphy.

Assemblage - unit 1

This unit is characterized by the dominance of *Pontosphaera exilis, Toweius occultatus* and *Discoaster kuepperi* and by the presence of *Neococcolithes protenus* and *Tribrachiatus orthostylus.*

It covers the interval from 245.50 to 220.60 m and corresponds to MARTINI's *Discoaster binodosus* Zone.

Assemblage - unit 2

In unit 2 *Pontosphaera pulchra, Nannoturba robusta* and *Discoaster kuepperi* are common, while *Micrantholithus flos* and *Micrantholithus inaequalis* are rare.

Its lower limit is uncertain as it overlies a totally barren non-calcareous interval. Its upper boundary is situated between 130.00 and 128.50 m Unit 2 corresponds to the basal part of MARTINI's *Discoaster lodoensis* Zone.

Assemblage - unit 3

Unit 3 is characterized by the dominance of *Micrantholithus flos* and *Micrantholithus inaequalis; Braarudosphaera bigelowii* and *Zygrhablitus bijugatus* are rather common. Such assemblages are due to special environmental conditions (e.g. very shallow waters).

Unit 3 covers the interval from 128.50 to 121.90 m and can be correlated with the lower middle part of MARTINI's *Discoaster lodoensis* Zone.

Assemblage - unit 4

This unit is dominated by *Reticulofenestra* cf. *onusta*, whereas *Micrantholithus flos* and *M. inaequalis* are absent.

The lower boundary lies between 121.90 and 117.75 m, the upper one between 109.40 and 106.40 m. Unit 4 corresponds to the upper middle part of MARTINI's *D. lodoensis* Zone.

Assemblage - unit 5

Unit 5 is characterized by the final occurrence of *Nannoturba spinosa* and by the first *Chiasmolithus mutatus*. *Zygrhablitus bijugatus* seems to be missing. Moreover, in comparison with the under- and overlying units, it contains a greater number of *Discoasters*.

Unit 5 is difficult to correlate with MARTINI's nannozonation. It covers the interval from 106.40 to 103.50 m.

Assemblage - unit 6

Unit 6 shows few diagnostic characters. It contains the first *Chiasmolithus expansus*, *Reticulofenestra umbilica* and *Discoaster sublodoensis*.

Its upper limit is situated between 97.50 and 90.75 m, its lower limit between 103.50 and 99.25 m.

Unit 6 can be correlated with the lower part of MARTINI's *Discoaster sublodoensis* Zone.

Assemblage - unit 7

Unit 7 contain many *Discoaster* species, among which the final *Discoaster lodoensis* and *Discoaster kuepperi*. The first *Rhabdosphaera crebra*, *Discoaster barbadiensis* and *Discoaster stradneri* appear in this unit.

It corresponds to the lower middle part of MARTINI's *D. sublodoensis* Zone. Its upper limit lies approximately at 89.00 m, its lower limit is situated between 97.50 and 90.75 m.

Assemblage - unit 8

This unit is characterized by the presence of *Cruciplacolithus staurion* and by the last *Chiasmolithus expansus* and *Nannoturba robusta*.

It covers the interval from approximately 89.00 to 73.00 m and corresponds to the upper part of MARTINI's *D. sublodoensis* Zone.

Assemblage - unit 9

Unit 9 is essentially characterized by the abundance of *Zygrhablitus crassus*, by the first appearance of *Reticulofenestra callida*, *Discoaster wemmelensis* and *Pontosphaera punctosa* and by the last *Chiasmolithus mutatus* and *Discoaster sublodoensis*.

It comprises the interval from 73.00 to 71.90 m and is correlated with the uppermost part of MARTINI's *D. sublodoensis* Zone. The lower limit could not be established, as no cores were recovered from the interval from 79 to 74 m.

Assemblage - unit 10

This unit is characterized by the abundance of *Zygrhablitus crassus*, by the first appearance of *Rhabdosphaera gladius*, *Rhabdosphaera scrabrosa* and *Lanternithus minutus* and by the presence of some *Zygrhablitus bijugatus*.

Its lower limit is placed at 71.90 m, its upper between 71.65 and 69.50 m. Unit 10 is correlated with the lower part of MARTINI's *Nannotetrina fulgens* Zone.

Assemblage - unit 11

This unit yields *Zygrhablitus bijugatus*, *Rhabdosphaera crebra*, *Reticulofenestra umbilica* in great number and, to a lesser degree, *Rhabdosphaera gladius* and *Sphenolithus furcatolithoides*. *Zygrhablitus crassus* is no longer present.

Unit 11 corresponds to the upper part of MARTINI's *Nannotetrina fulgens* Zone. Its lower limit is situated between 71.65 and 69.50 m, the upper between 67.50 and 65.60 m.

Assemblage - unit 12

Unit 12 is characterized by the first appearance and abundance of *Discoaster bifax* and by fairly abundant *Nannotetrina fulgens*, *Reticulofenestra umbilica* and *Reticulofenestra callida*.

Its lower limit coincides with the exit of *Rhabdosphaera gladius*, and is situated between 67.50 and 65.50 m. Its upper limit has not been encountered as the overlying strata are barren of nannofossils. Unit 12 can be correlated with MARTINI's *Discoaster tanii nodifer* Zone (NP16).

3.- THE SPECIES RECOGNIZED WITH SOME REMARKS ON THEIR STRATIGRAPHIC IMPORTANCE

All species encountered in the Tertiary of the Knokke well are listed in alphabetical order according to their generic name. Each species name is followed by the original author(s) and by its date of publication and by possible subsequent author(s) who proposed the preferred combination. References to the illustrations in this paper (plates 1, 2 and 3) are added.

Most of the species are well documented elsewhere and need no further discussion. The comments concern only stratigraphically important species, species rarely found in the Tertiary assemblages of Northwestern Europe or species being taxonomically modified in the present study. No synonymy lists are given.

Birkelundia arenosa PERCH-NIELSEN 1971 (pl. 1, fig. 1a-b).
Originally described from the *Nannotetrina fulgens* Zone (NP 15) from Denmark (see PERCH-NIELSEN, 1971:10).

Braarudosphaera bigelowii (GRAN & BRAARUD 1935) DEFLANDRE 1947.

Cepekiella lumina (SULLIVAN 1965) BYBELL 1975.
Known throughout the Eo-Oligocene (see BYBELL, 1975:236).

Chiasmolithus californicus (SULLIVAN 1964) HAY & MOHLER 1967.

Chiasmolithus consuetus (BRAMLETTE & SULLIVAN 1961) HAY & MOHLER 1967.

Chiasmolithus expansus (BRAMLETTE & SULLIVAN 1961) GARTNER 1970 (pl. 1, fig. 2-3).

Chiasmolithus grandis (BRAMLETTE & RIEDEL 1954) RADOMSKI 1968.

Chiasmolithus medius PERCH-NIELSEN 1971.

Chiasmolithus solitus (BRAMLETTE & SULLIVAN 1961) LOCKER 1968 (pl. 1, fig. 4).
Originally described from the Lodo Formation (Early & Middle Eocene of California) (see BRAMLETTE & SULLIVAN, 1961:140). One of the most common species in the Belgian Eocene.

Chiasmolithus sp.
Small *Chiasmolithus* species, close to *Chiasmolithus minimus* PERCH-NIELSEN 1971 (see PERCH-NIELSEN, 1971:19, pl. 14, fig. 2, 5 and 3?).

Chiphragmalithus calathus BRAMLETTE & SULLIVAN 1961

Cruciplacolithus delus (BRAMLETTE & SULLIVAN 1961) PERCH-NIELSEN 1971.

Cruciplacolithus mutatus PERCH-NIELSEN 1971 (pl. 1, fig. 5-6).

Cruciplacolithus staurion (BRAMLETTE & SULLIVAN 1961) GARTNER 1971.

Cruciplacolithus sp. 1.
This species is characterized by small elliptical coccoliths (L=4 to 6 μm) with an elliptical central opening bridged by a thin central cross-structure, parallel to the axes of the ellipse. Unfortunately, the specimens are too poorly preserved to allow specific identification.

Cruciplacolithus sp. 2 (pl. 1, fig. 7).
This species has a small central opening, almost closed by a broad and short, cruciform structure. The bars of the cross make a small angle with the axes of the ellipse. The wall, which is very bright in cross-polarized light, is as wide as the distal shield. Up to now only a single moderately preserved specimen has been found. It might represent a new species, but, as the variability of this form is still unknown and no scanning photomicrographs are available, a specific name cannot be proposed.

Cyclolithella sp.
Small circular coccolith (6μm) with raised inner margin around the central opening, somewhat similar to *Cyclolithella aprica* ROTH 1973 (see ROTH, 1973:730, pl. 11, fig. 4-6; pl. 12, fig. 1-4).

Cyclococcolithus bramlettei HAY & TOWE 1962.

Cyclococcolithus kingi ROTH 1970.

Cyclococcolithus sp. (pl. 1, fig. 8-11).
Circular coccoliths consisting of an outer cycle composed of 30 to 35 elements with anti-clockwise oblique sutures and a central area closed by radial elements. In cross-polarized light, the outer cycle is very bright, whereas the central area is only faintly illuminated and shows a central fairly broad extinction cross. The diameter ranges from 7 to 9 μm. This form is related to *Cyclococcolithus hirsutus* MUELLER 1970 and *Cyclococcolithus hoerstgensis* MUELLER 1970 known respectively from the Middle Oligocene of Belgium and the Upper Oligocene of Germany (see MUELLER, 1970:93, pl. 9, fig. 1-4 and 94; pl. 9, fig. 5-8). However, since no SEM photos are available of any of these three forms it is difficult to decide whether the Knokke material represents a new species or not.

Discoaster barbadiensis TAN SIN HOK 1927 (pl. 1, fig. 16-17).

Discoaster bifax BUKRY 1971 (pl. 1, fig. 21).
A species easily recognizable by its rather short broad distal stem and its more elongate, slender proximal stem. Originally described from the Middle Eocene from the Atlantic Ocean (see BUKRY 1971:314-315). This species is known from MARTINI's NP15 and NP16 and disappears at the top of the *D. bifax* subzone *sensu* BUKRY (see BUKRY 1978:57; text-Fig. 13).

Discoaster binodosus MARTINI 1958.

Discoaster deflandrei BRAMLETTE & RIEDEL 1954.

Discoaster diastypus BRAMLETTE & SULLIVAN 1961.

Discoaster distinctus MARTINI 1959 (pl. 1, fig. 18).

Discoaster gemmeus STRADNER 1959.

Discoaster germanicus MARTINI 1958.

Discoaster kuepperi STRADNER 1959 (pl. 1, fig. 20).
Very common in the *Discoaster binodosus* Zone of the Knokke well. Also encountered in the *Discoaster lodoensis* Zone.

Discoaster lodoensis BRAMLETTE & RIEDEL 1954 (pl. 1, fig. 14-15).
Only a few specimens of *D. lodoensis* are present in the Knokke well.

Discoaster mirus DEFLANDRE 1952.

Discoaster nodifer BRAMLETTE & RIEDEL 1954.

Discoaster stradneri MARTINI 1961 (pl. 1, fig. 19).
It would seem that *Discoaster boulangeri* LEZAUD 1968 (see LEZAUD, 1968:23, pl. 1, fig. 9-12; pl. 2, fig. 14), known from the *Discoaster lodoensis* Zone of Aquitany, is a junior synonym of *Discoaster stradneri* from the same zone (see MARTINI, 1961:10, pl. 2, fig. 22 and pl. 5, fig. 52).

Discoaster strictus STRADNER 1961 (pl. 1, fig. 12-13).
These asteroliths are characterized by six to seven straight rather blunt rays and by a marked central knob with radial sutures on the distal side (see STRADNER & PAPP, 1961:65, pl. 3, fig. 1-6 and text-fig. 8-3).

Discoaster sublodoensis BRAMLETTE & SULLIVAN 1961 (pl. 2, fig. 14-16).
This species is regularly distributed throughout the *D. sublodoensis* Zone (NP14) from the Knokke well. It is mostly represented by its six-rayed form.

Discoaster tanii BRAMLETTE & RIEDEL 1954.

Discoaster wemmelensis ACHUTHAN & STRADNER 1967.

Discoaster woodringii BRAMLETTE & RIEDEL 1954.

Ellipsolithus macellus (BRAMLETTE & SULLIVAN 1961) SULLIVAN 1964.

Ericsonia eopelagica (BRAMLETTE & RIEDEL 1954) ROMEIN 1979.
This is the most common species in the Belgian Eocene.

Ericsonia fenestrata (DEFLANDRE & FERT 1954) STRADNER & EDWARDS 1968 (pl. 2, fig. 5).
A species of *Ericsonia* with many pores arranged parallel to the long and the short axis of the ellipse. For the definition and

description of this species and its relation with other *Ericsonia* species the reader is referred to ROTH (1970:841, pl. 1, fig. 6).

Ericsonia formosa (KAMPTNER 1963) ROMEIN 1979 (pl. 2, fig. 4).

Ericsonia subdisticha (ROTH & HAY 1967) ROTH 1969 (pl. 2, fig. 6-7).
According to MUELLER (1978:table 1) this species is restricted to the zones NP 20, 21 and 22. This study shows its presence in NP 15 of the Belgian Tertiary.

Helicosphaera lophota BRAMLETTE & SULLIVAN 1961.

Helicosphaera seminulum BRAMLETTE & SULLIVAN 1961.

Imperiaster obscurus (MARTINI 1958) MARTINI 1970.
This species is characterized by a central cone on which six arms are attached, all of the same length. These arms are arranged in two sets at different heights on the cone, so that each arm makes an angle of 60° with the adjacent one in the other set. According to MARTINI (1970:385) this species is restricted to the upper part of NP 11 and lower part of NP 12. However, MUELLER (1979:612) cites it also from the *Discoaster lodoensis* Zone (NP 13). An excellent illustration is given in PERCH-NIELSEN (1968:253, pl. 1, fig. 7-8; pl. 2, fig. 1-6).

Imperiaster sp. (pl. 2, fig. 1-3).
This form differs from *I. obscurus* by the presence of one set of three short, pointed triangular arms as well as a set of elongate arms instead of the normally developed double set of equally elongate arms. It might represent a new species or an aberrant form of *Imperiaster obscurus*.

Lanternithus minutus STRADNER 1962.

Lithostromation operosum (DEFLANDRE 1954) BYBELL 1975.

Lophodolithus acutus BUKRY & PERCIVAL 1971.

Markalius inversus (DEFLANDRE 1954) EDWARDS 1966.

Micrantholithus crenulatus BRAMLETTE & SULLIVAN 1961.

Micrantholithus flos DEFLANDRE 1950 (pl. 2, fig. 13).

Micrantholithus inaequalis MARTINI 1961 (pl. 2, fig. 10-12).
This species is very abundant in assemblage-unit 3 of the Knokke well (interval from 128.50 to 121.90 m; lower middle part of MARTINI's *Discoaster lodoensis* Zone (NP 13)). It has originally been described from the NP 13 of the Aquitanian Basin (see MARTINI 1961:7) and is here considered to be a senior synonym of *Micrantholithus attenuatus* BRAMLETTE & SULLIVAN 1961, known from the NP 12 from the Lodo section of California (see BRAMLETTE & SULLIVAN 1961:154, pl. 8, fig. 8-11). The pentaliths of this species show a considerable variability (see pl. 2, fig. 10 and 11).

Micrantholithus vesper DEFLANDRE 1954.

Naninfula deflandrei PERCH-NIELSEN 1968.

Nannotetrina fulgens (STRADNER 1960) ACHUTHAN & STRADNER 1969 (pl. 2, fig. 8-9).

Nannotetrina pappi (STRADNER 1959) PERCH-NIELSEN 1971 (pl. 3, fig. 15).
This species was well illustrated by PERCH-NIELSEN (1971:67, pl. 54, fig. 1-6; pl. 57, fig. 9).

Nannoturba robusta MUELLER 1979 (pl. 3, fig. 2).
This species has been regularly encountered in the zones NP 13 and NP 14 of the Knokke well. It is known from many Early Eocene deposits of Europe (see MUELLER 1979:617).

Nannoturba spinosa MUELLER 1979 (pl. 3, fig. 1).
This species was originally described from MARTINI's *D. lodoensis* Zone (NP 13) (see MUELLER 1979:617, pl. 8, fig. 1-3). It is common in the NP 13 of the Knokke well.

Neococcolithus dubius (DEFLANDRE 1954) BLACK 1967 (pl. 3, fig. 3).
This species has a worldwide distribution and occurs throughout the Eocene. It is particularly abundant in the *Nannotetrina fulgens* Zone (NP 15) (see ROMEIN, 1979:138 for the synonymy; see BYBELL, 1975:236 and SHERWOOD, 1974:70-71 for its distribution).

Neococcolithus protenus (BRAMLETTE & SULLIVAN 1961) HAY & MOHLER 1967.

Pemma sp.
Only poorly preserved specimens occur, not identifiable on the specific level.

Pontosphaera exilis (BRAMLETTE & SULLIVAN 1961) ROMEIN 1979.
This species is very common in the assemblage-unit 1 of the Knokke well. For an excellent illustration the reader should consult PERCH-NIELSEN (1971:38, pl. 27, fig. 3, 5 and 6; pl. 31, fig. 4).

Pontosphaera frimbriata (BRAMLETTE & SULLIVAN 1961) ROMEIN 1979.

Pontosphaera labrosa (BUKRY & BRAMLETTE 1969) PERCH-NIELSEN 1977.

Pontosphaera multipora (KAMPTNER 1948) ROTH 1970.

Pontosphaera obliquipons (DEFLANDRE 1954) ROMEIN 1979 (pl. 3, fig. 6).

Pontosphaera ocellata (BRAMLETTE & SULLIVAN 1961) PERCH-NIELSEN 1984.

Pontosphaera prava (LOCKER 1967) ROMEIN 1979.

Pontosphaera pulchra (DEFLANDRE 1954) ROMEIN 1979 (pl. 3, fig. 5).

Pontosphaera punctosa (BRAMLETTE & SULLIVAN 1961) PERCH-NIELSEN 1984.

Pontosphaera scissura (PERCH-NIELSEN 1971) ROMEIN 1979.

Pontosphaera wechesensis (BUKRY & PERCIVAL 1971) AUBRY 1983 (pl. 3, fig. 10).
Originally described from the Weches and Cook Mountain Formation of the Gulf Coastal Plain (zones NP 14 and NP 15) (see BUKRY & PERCIVAL 1971:142, pl. 7, fig. 7-10). It is suggested here that *P. wechesensis* is a senior synonym of *Pontosphaera excelsa* (PERCH-NIELSEN 1971) PERCH-NIELSEN 1977, known from NP 12 to NP 15 (see PERCH-NIELSEN, 1977:789, pl. 27, fig. 2-3). In the Knokke well it has been found only in the assemblage-unit 11, corresponding with the upper part of MARTINI's *Nannotetrina fulgens* Zone (NP 15).

Pseudotriquetrorhabdulus inversus (BUKRY & BRAMLETTE 1969) WISE & CONSTANS 1976.

Reticulofenestra callida (PERCH-NIELSEN 1971) BYBELL 1975.

Reticulofenestra foveolata (REINHARDT 1966) ROTH 1970.
This species is characterized by its relatively small rim and its central grille consisting of an outer ring of numerous elongated pores and a central area with fewer rounded smaller pores. In the Knokke well it is known from the assemblage-unit 11

corresponding with the uppermost part of MARTINI's *Nannotetrina fulgens* Zone (NP 15).

Reticulofenestra cf. *onusta* (PERCH-NIELSEN 1971) nov. comb.
These relatively small coccoliths (D = ± 5 μm) are characterized by a central grille with many small pores and a median furrow as well as a rather small rim, which is very bright in cross-polarized light. These coccoliths closely resemble PERCH-NIELSEN's *Dictyococcites onustus* (see PERCH-NIELSEN, 1971:29, pl. 20, fig. 3-4; pl. 61, fig. 28-29), which is transferred into the genus *Reticulofenestra* (*sensu* BACKMAN) because of its open central area (see BACKMAN, 1980:48 and 58). However, using only the light microscope it is difficult to prove whether both forms belong to the same species or not.

Reticulofenestra umbilica (LEVIN 1965) MARTINI & RITZ-KOWSKI 1968.

Reticulofenestra sp.
Numerous small coccoliths with a small central opening are present in the Knokke well. They can be assigned to the genus *Reticulofenestra* as they may be related to *Reticulofenestra prebisecta* AUBRY 1963.

Rhabdosphaera crebra (DEFLANDRE 1954) BRAMLETTE & SULLIVAN 1961.

Rhabdosphaera gladius LOCKER 1967 (pl. 3, fig. 7).

Rhabdosphaera pseudomorionum LOCKER 1967.

Rhabdosphaera scabrosa (DEFLANDRE 1954) BRAMLETTE & SULLIVAN 1961.

Rhabdosphaera solus (PERCH-NIELSEN 1971) AUBRY 1983.

Rhabdosphaera tenuis BRAMLETTE & SULLIVAN 1961.

Rhabdosphaera vitrea (DEFLANDRE 1954) BRAMLETTE & SULLIVAN 1961.

Sphenolithus furcatolithoides LOCKER 1967 (pl. 3, fig. 17).
This species shows a considerable variability (see LOCKER 1967a:363, fig. 7 and 8, pl. 1, fig. 14-16). It has been encountered in zones NP15 and NP16 of the Knokke well.

Sphenolithus moriformis (BROENNIMANN & STRADNER 1960) BRAMLETTE & WILCOXON 1967.

Sphenolithus radians DEFLANDRE 1952.

Sphenolithus sp. 1
This species is common in assemblage-unit 1 of the Knokke well. It is characterized by a triangular column with rather broad base and a small elongate spine. In cross-polarized light, parallel to the polarization directions, only the column and the basal cycles of the cone are illuminated and show extinction lines parallel to the polarization directions. Viewed at 45° the spine also becomes bright, while the extinction lines occupy a diagonal position.

Sphenolithus sp. 2 (pl. 3, fig. 16).
This species consists of a relatively high column, a cycle of lateral elements and four long spines. The extinction lines are parallel to the polarization directions when the specimens are aligned parallel to these directions. Viewed at 45° the extinction lines become diagonal, while the spines are no longer conspicuous (see pl. 3, fig. 16). These sphenoliths are similar to PERCH-NIELSEN's *Sphenolithus quadrispinatus* (see PERCH-NIELSEN, 1980:3, pl. 1, fig. 11-13; pl. 2, fig. 1-4) known from the Upper Miocene of the South Atlantic.

Toweius gammation (BRAMLETTE & SULLIVAN 1961) ROMEIN 1979.

Toweius magnicrassus (BUKRY 1971) ROMEIN 1979.

Toweius occultatus (LOCKER 1967) PERCH-NIELSEN 1971.

Toweius pertusus (SULLIVAN 1965) ROMEIN 1979.

Toweius sp. (pl. 3, fig. 11).
This form is composed of a composite rim and a rather large grille with many minute pores. In cross-polarized light the central area is only faintly illuminated and shows an extinction cross. The proximal shield is very bright and more conspicuous than the distal one. This species resembles *Toweius magnicrassus* (BUKRY 1971) (see BUKRY 1971:309. pl. 2, fig. 1-5) but can be distinguished by its larger central area and might therefore represent a new species.

Tribrachiatus orthostylus SHAMRAI 1963 (pl. 3, fig. 4).

Zygrhablitus bijugatus DEFLANDRE 1959.
An excellent description and illustration of this species is given by GARTNER & BUKRY (1969:1218, pl. 140, fig. 3-6 and pl. 142, fig. 1-2).

Zygrhablitus crassus LOCKER 1967 (pl. 3, fig. 13-14).
This species is no longer placed in synonymy with *Z. bijugatus*, because of its clearly different holococcoliths, having a stem which is as wide as or wider than the base of the coccolith (see LOCKER, 1967b:764, pl. 1, fig. 7; pl. 2, fig. 7-8). In the author's opinion such differences should not be regarded as mere intraspecific variations.

incertae sedis sp. 1 (pl. 3, fig. 9).
A single large specimen (33 μm) is known from the Knokke well. It is composed of a central cone to which eight arms are attached forming two crosslike structures lying in different parallel planes and covering each other when viewed from above. Each cross-bar shows short transverse protrusions at the end, pointing in the same direction, but so that the protrusions of superposed cross-bars point in opposite directions. This specimen may represent a new species but, having found no other material and lacking SEM photos, it is kept in open nomenclature.

incertae sedis sp. 2 (pl. 3, fig. 8).
Small globular enigmatic object (5 μm) showing in cross-polarized light a rather faintly illuminated central area and two small bright segments which are diametrically opposed.

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PLATE 1

Bar scale on each figure represents 5 μm

1. *Birkelundia arenosa* PERCH-NIELSEN 1971
distal view, sample Knokke 71.65m; a. cross-polarized light; b. transmitted light.

2-3. *Chiasmolithus expansus* (BRAMLETTE & SULLIVAN 1961) GARTNER 1970
2. distal view, sample Knokke 89.50 m; a. transmitted light; b. cross-polarized light;
3. distal view, sample Knokke 89.50 m; cross-polarized light.

4. *Chiasmolithus solitus* (BRAMLETTE & SULLIVAN 1961) LOCKER 1968
distal view, sample Knokke 69.50 m, transmitted light.

5-6. *Cruciplacolithus mutatus* PERCH-NIELSEN 1971
5. distal view, sample Knokke 73.00 m, cross-polarized light;
6. proximal view, sample Knokke 106.40 m, cross-polarized light.

7. *Cruciplacolithus* sp. 2
distal view, sample Knokke 71.65 m, cross-polarized light.

8-11. *Cyclococcolithus* sp.
8. distal view, sample Knokke 97.50 m; a. cross-polarized light; b. b. transmitted light;
9. distal view, sample Knokke 71.95 m; a. transmitted light; b. cross-polarized light;
10. distal view, sample Knokke 73.00 m; cross-polarized light;
11. proximal view, sample Knokke 90.75 m; cross-polarized light.

12-13. *Discoaster strictus* STRADNER 1961
12. proximal view, sample Knokke 89.50 m, transmitted light;
13. proximal view, sample Knokke 80.75 m, transmitted light;

14-15. *Discoaster lodoensis* BRAMLETTE & RIEDEL 1954
14. distal view, sample Knokke 97.50 m, transmitted light;
15. proximal view, sample Knokke 132.50 m, transmitted light.

16-17. *Discoaster barbadiensis* TAN SIN HOK 1927
16. distal view, sample Knokke 71.95 m, transmitted light;
17. proximal view, sample Knokke 71.65 m, transmitted light.

18. *Discoaster distinctus* MARTINI 1959
proximal view, sample Knokke 89.50 m, transmitted light.

19. *Discoaster stradneri* MARTINI 1961
proximal view, sample Knokke 90.75 m, transmitted light.

20. *Discoaster kuepperi* STRADNER 1959
side view, sample Knokke 89.50 m, a. transmitted light; b. cross-polarized light.

21. *Discoaster bifax* BUKRY 1971
side view, sample Knokke 62.50 m, cross-polarized light.

Pl.1

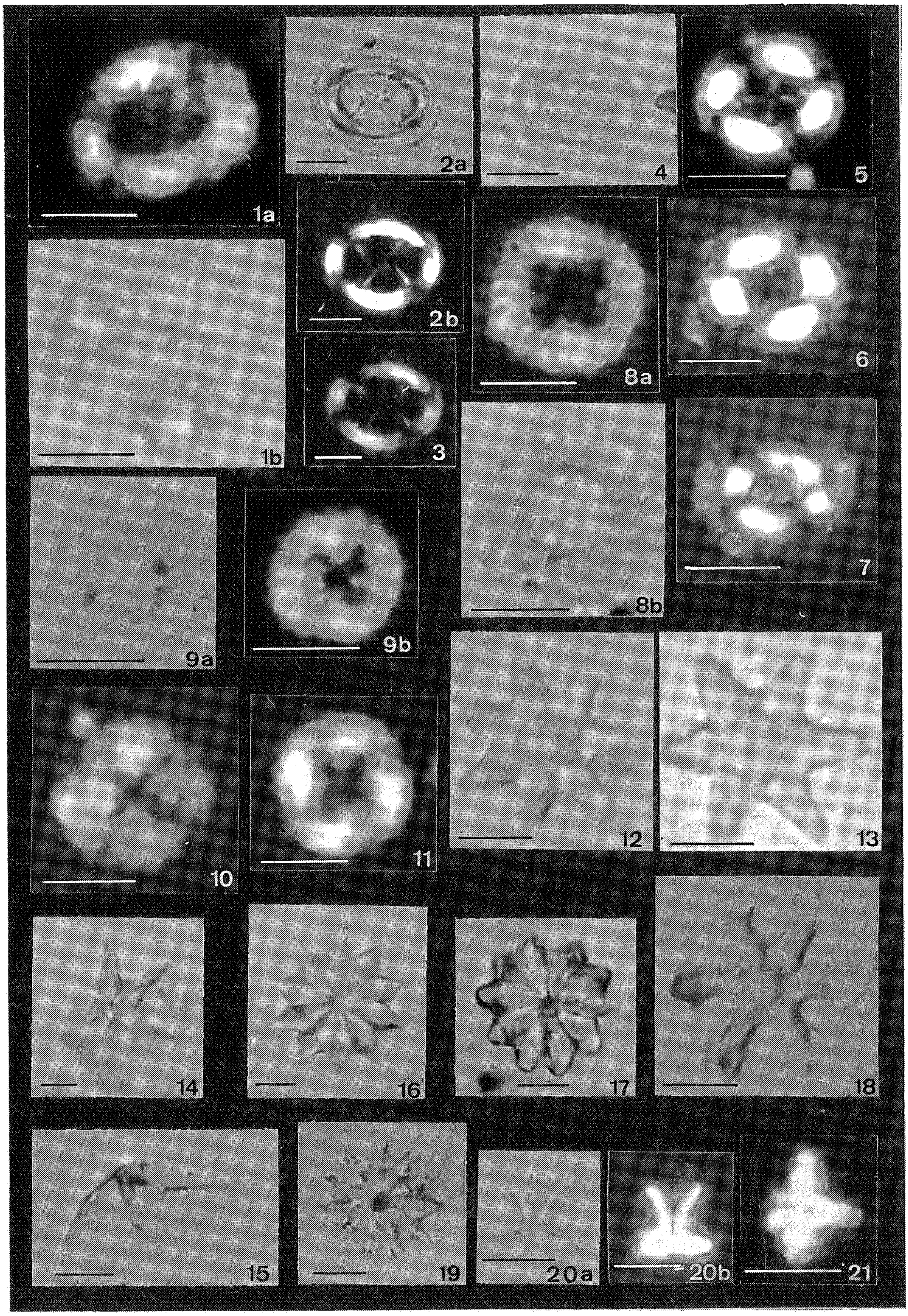

PLATE 2

Bar scale on each figure represents 5 μm

1-3. *Imperiaster* sp.

1. sample Knokke 132.50 m, transmitted light; a. high focus, b. middle focus, c. low focus;
2. sample Knokke 132.50 m, transmitted light; a. high focus, b. low focus;
3. sample Knokke 132.50 m, transmitted light.

4. *Ericsonia formosa* (KAMPTNER 1963) ROMEIN 1979
distal view, sample Knokke 69.50 m, transmitted light.

5. *Ericsonia fenestrata* (DEFLANDRE & FERT 1954) STRADNER & EDWARDS 1968
distal view, sample Knokke 69.50 m, transmitted light.

6-7. *Ericsonia subdisticha* (ROTH & HAY 1967) ROTH 1969

6. proximal view, sample Knokke 69.50 m, transmitted light;
7. distal view, sample Knokke 69.50 m, transmitted light.

8-9. *Nannotetrina fulgens* (STRADNER 1959) PERCH-NIELSEN 1971

8. distal view, sample Knokke 67.50 m, transmitted light;
9. proximal view, sample Knokke 65.50 m, transmitted light.

10-12. *Micrantholithus inaequalis* MARTINI 1961

10. proximal view, sample Knokke 124.70 m, cross-polarized light;
11. distal view, sample Knokke 122.50 m, cross-polarized light;
12. distal view, sample Knokke 128.50 m, cross-polarized light.

13. *Micrantholithus flos* DEFLANDRE 1950
distal view, sample Knokke 128.50 m, cross-polarized light.

14-16. *Discoaster sublodoensis* BRAMLETTE & SULLIVAN 1961

14. distal view, sample Knokke 73.00 m, transmitted light;
15. proximal view, sample Knokke 89.50 m, transmitted light;
16. proximal view, sample Knokke 73.00 m, transmitted light.

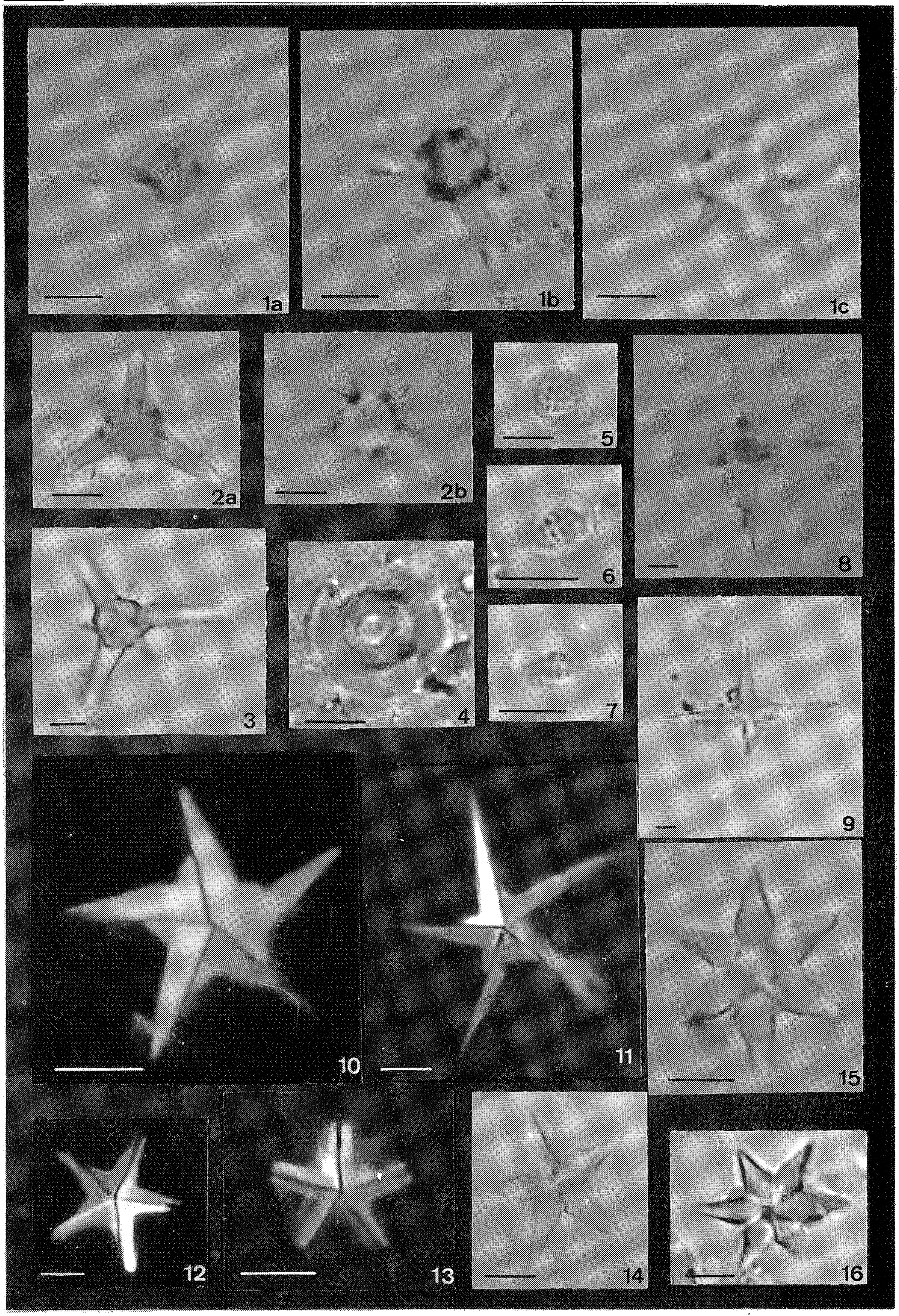
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PLATE 3

Bar scale on each figure represents 5 μm

1. *Nannoturba spinosa* MUELLER 1979
   sample Knokke 132.50 m, transmitted light, a. high focus, b. middle focus, c. low focus.

2. *Nannoturba robusta* MUELLER 1979
   sample Knokke 132,50 m, cross-polarized light.

3. *Neococcolithes dubius* (DEFLANDRE 1954) BLACK 1967
   distal view, sample Knokke 69.50 m, transmitted light.

4. *Tribrachiatus orthostylus* SHAMRAI 1963
   sample Knokke 235.50 m, transmitted light.

5. *Pontosphaera pulchra* (DEFLANDRE 1954) ROMEIN 1979
   distal view, sample Knokke 97.50 m, cross-polarized light.

6. *Pontosphaera obliquipons* (DEFLANDRE 1954) ROMEIN 1979
   distal view, sample Knokke 71.65 m, cross-polarized light.

7. *Rhabdosphaera gladius* LOCKER 1967
   side view, sample Knokke 69.50 m, transmitted light.

8. incertae sedis sp. 2
   sample Knokke 106.40 m, cross-polarized light.

9. incertae sedis sp. 1
   sample Knokke 106.40 m, a. high focus, b. low focus, transmitted light, c. middle focus, cross-polarized light.

10. *Pontosphaera wechesensis* (BUKRY & PERCIVAL 1971) AUBRY 1983
    proximal view, sample Knokke 67.50 m, cross-polarized light.

11. *Toweius* sp.
    distal view, sample Knokke 71.95 m, cross-polarized light.

12. *Reticulofenestra foveolata* (REINHARDT 1966) ROTH 1970
    proximal view, sample Knokke 67.50 m, a. and b. cross-polarized light, c. transmitted light.

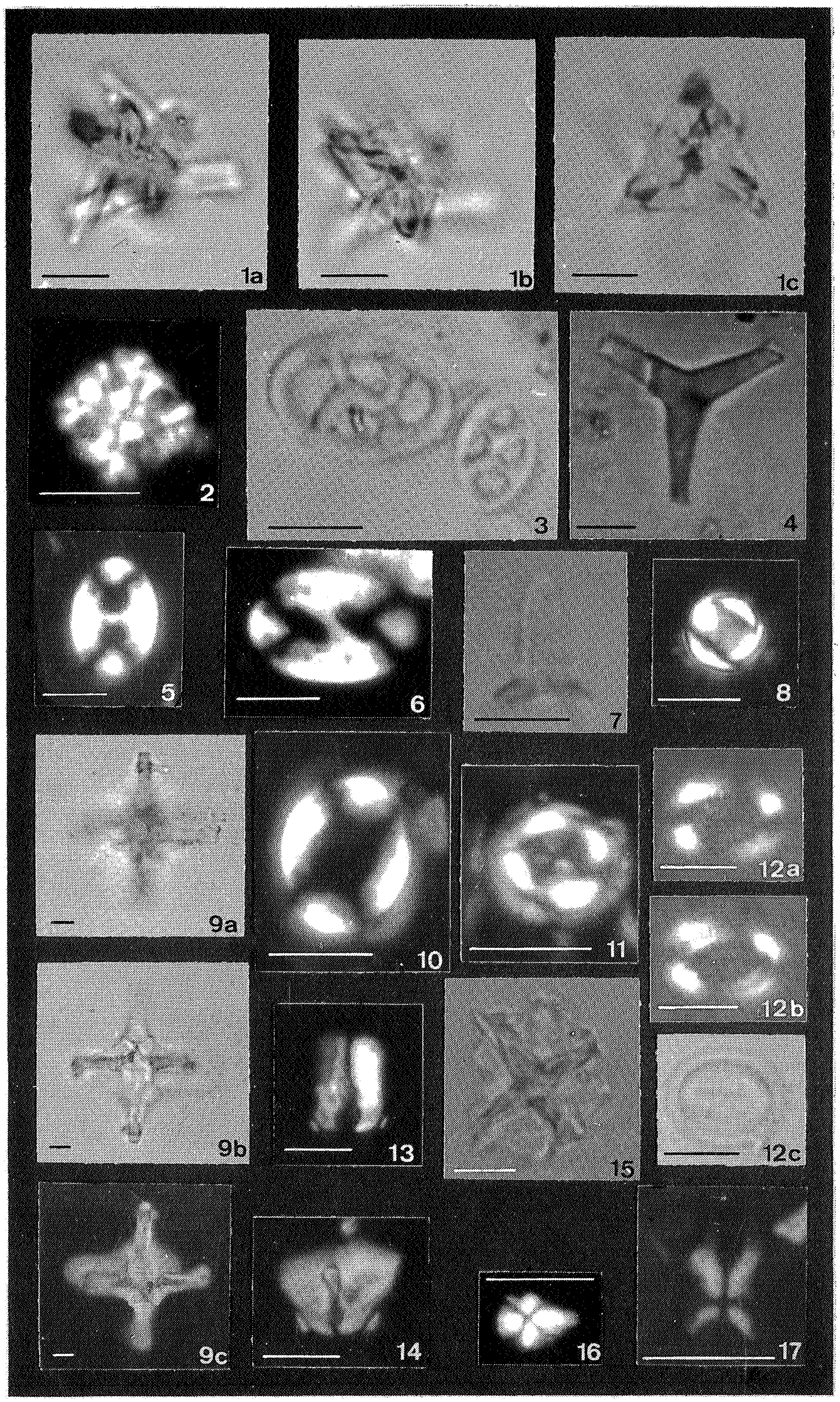
13-14. *Zygrhablithus crassus* LOCKER 1967
    13. side view, sample Knokke 71.65 m, cross-polarized light;
    14. side view, sample Knokke 73.00 m, cross-polarized light.

15. *Nannotetrina pappi* (STRADNER 1959) PERCH-NIELSEN 1971
    sample Knokke 65.60 m, transmitted light.

16. *Sphenolitus* sp. 2
    side view, sample Knokke 71.65 m, cross-polarized light, viewed at 45° to the polarization directions.

17. *Sphenolitus furcatolithoides* LOCKER 1967
    side view, sample Knokke Knokke 69.50 m, cross-polarized light, parallel to the polarization directions.

Pl.3



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POSTCRIPT

The manuscript of this paper was submitted for publication in the middle of 1984, before the publication of the author's revisions of the Tertiary stratigraphy of Belgium (several papers in 1986 and 1988). The litho- and biostratigraphic subdivisions proposed here to do not correspond to these in the author's 1986 and 1988 papers.

Chapter VI
UPPER CRETACEOUS NANNOPLANKTON IN THE KNOKKE WELL

by

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INTRODUCTION

Eight core samples taken from the Knokke well in Belgium between 430.5 m and 311 m, were analysed to determine their depositional age from their calcareous nannoplankton content. The exact location of the well and its geologic and technical data are given in the introduction to this volume. The relative position of the samples is shown in figures 1 and 2.

The authors are grateful to the Director of the Geological Survey of Belgium and The Netherlands for permission to publish this study.

1.- BIOSTRATIGRAPHY

All of the samples under study yielded a diverse but moderately well preserved nannoflora generally overgrown with secondary calcite. In all, 62 species were recorded (Fig. 1).

The zonations of SISSINGH (1977) and VERBEEK (1977) were used for chronostratigraphical correlation. The results are discussed in stratigraphical order.

Sample 8 (Late Santonian)

Sample 8 can be assigned to VERBEEK's (1977) *Z. spiralis* Zone on the basis of the presence of *Zygodiscus spiralis, Lithastrinus floralis* STRADNER, *Lucianorhabdus cayeuxii* as well as the absence of *Broinsonia parca* (STRADNER), and to SISSINGH's (1977) *Lucianorhabdus cayeuxii* Zone on the basis of the presence of *Lucianorhabdus cayeuxii* and the absence of *Phanulithus obscurus* (DEFLANDRE). Both zones can be correlated with the Late Santonian.

Sample 7 (Early Campanian)

Sample 7, taken 1.85 m above sample 8, is assigned to the *Broinsonia parca* Zone of VERBEEK (1977), indicating an Early Campanian age. This conclusion is based on the joint occurrence of *Broinsonia parca, Reinhardtites brooksii* (BUKRY), *Broinsonia lacunosa FORCHHEIMER, and Podorhabdus coronadventis (REINHARDT), and on the absence of Lithastrinus floralis* in sample 7 and higher samples.

According to SISSINGH's (1977) zonation, sample 7 belongs to the *Aspidolithus parcus* s.l. Zone (18), which is defined as the interval from the first occurrence of *Aspidolithus* ex. gr. parcus (STRADNER) (= *B. parca*) to the last occurrence of *Marthasterites furcates* (DEFLANDRE). The approximate age of this zone is Early Campanian (early part). Below the *A. parcus* s.l. Zone, SISSINGH recognizes another zone, the *Calculithus obscurus* Zone (17) placed in the earliest part of the Early Campanian, which is defined as the interval from the first (regular) occurrence of *Calculithus obscurus (= Phanulithus obscurus)* to the first occurrence of *A.* ex. gr. *parcus.* Both *P. obscurus* and *B. parca* are absent in sample 8, but they occur in sample 7. Thus, according to SISSINGH's zonation there could be a hiatus between samples 8 and 7.

According to VERBEEK (1977), the first occurrence of *B. parca* correlates with the Santonian-Campanian boundary. Due to his different species concept, SISSINGH places the first occurrence somewhat higher.

Sample 6 (Early Campanian)

Sample 6 too is assigned to the *Broinsonia parca* Zone (VERBEEK, 1977), because of the

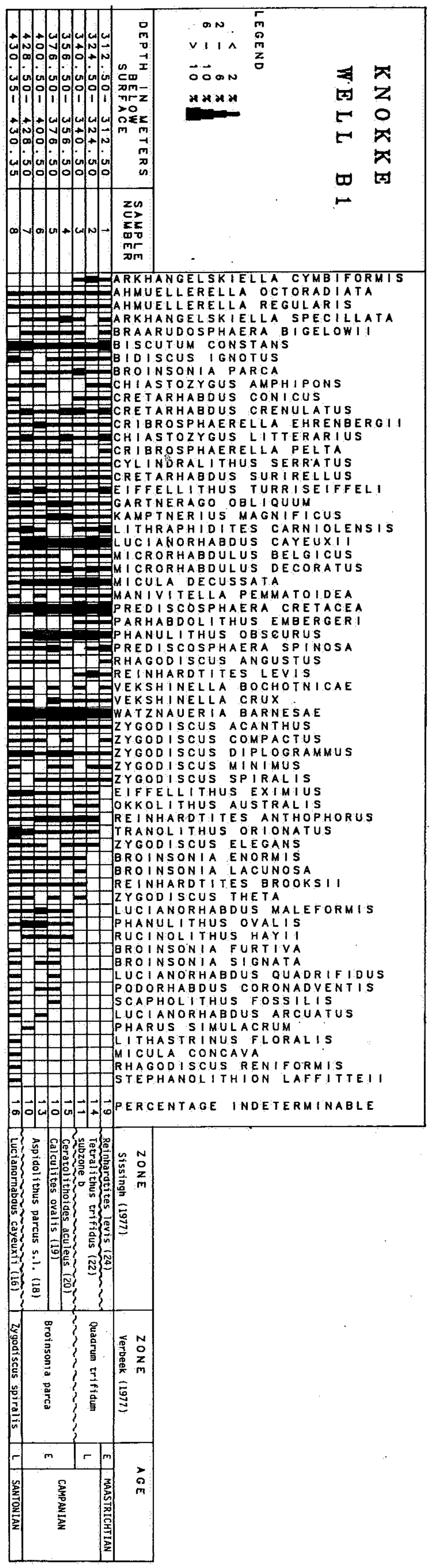

Fig. 1.- Stratigraphical distribution of Senonian calcareous nannofossils in the Knokke well in relation to the nannofossil zonation of SISSINGH (1877) and VERBEEK (1977).

occurrence of *Broinsonia parca*, *Podorhabdus coronadventis* and *Reinhardtites brooksii*. According to SISSINGH's (1977) zonation it is not certain whether sample 6 should be placed in his *Aspidolithus parcus* s.l. Zone (18) or the *Calculites ovalis* Zone (19), because the zonal marker *Marthasterites furcatus*, which marks the boundary between these two zones, was not encountered in this or the other samples. Other species that could help to distinguish between these zones are not indicated by SISSINGH's (1977) zonation.

Sample 5 (Early Campanian)

Since *Broinsonia lacunosa*, *Broinsonia parca*, *Podorhabdus coronadventis* and *Reinhardtites brooksii* are still present, sample 5 has been placed in the *Broinsonia parca* Zone of VERBEEK (1977).

For the same reason as mentioned for sample 6, it is not clear whether sample 5 should be assigned to the *Aspidolithus parcus* s.l. Zone (18) or the *Calculites ovalis* Zone (19) of SISSINGH (1977).

Sample 4 (Early Campanian)

It is not certain whether sample 4 belongs to the *Broinsonia parca* Zone, the *Ceratolithoides aculeus* Zone, or the *Quadrum gothicum* Zone of VERBEEK (1977). *Podorhabdus coronadventis* is absent from this sample. *Reinhardtites brooksii*, *Rucinolithus hayii* STOVER, and *Eiffellithus eximius* (STOVER) are still present, but the marker species *Ceratolithoides aculeus* (STRADNER) and *Quadrum gothicum* (DEFLANDRE) were not encountered, in either this or the other samples. It is quite possible that their geographical distribution was restricted (see also under Conclusions).

On the basis of the presence of *Lucianorhabdus maleformis* RHEINHARDS and *Phanulitus ovalis* (STRADNER), and the absence of these two species in higher samples, sample 4 might be placed in SISSINGH's (1977) *Ceratolithoides aculeus* Zone (20).

The approximate age of this zone is the last part of the Early Campanian.

Sample 3 (Late Campanian)

Reinhardtites brooksii and *Broinsonia enormis* (SHUMENLO) appear last between samples 2 and 3. In the zonation proposed by VERBEEK (1977) this occurs in the lower part of the *Quadrum trifidum* Zone, which can be correlated with the Late Campanian. However, the zonal marker *Quadrum trifidum* (STRADNER) is absent.

Sample 3 can be assigned to subzone b of the *Tetralithus trifidus* Zone (22) of SISSINGH (1977). SISSINGH used the first appearance of *Rein-*

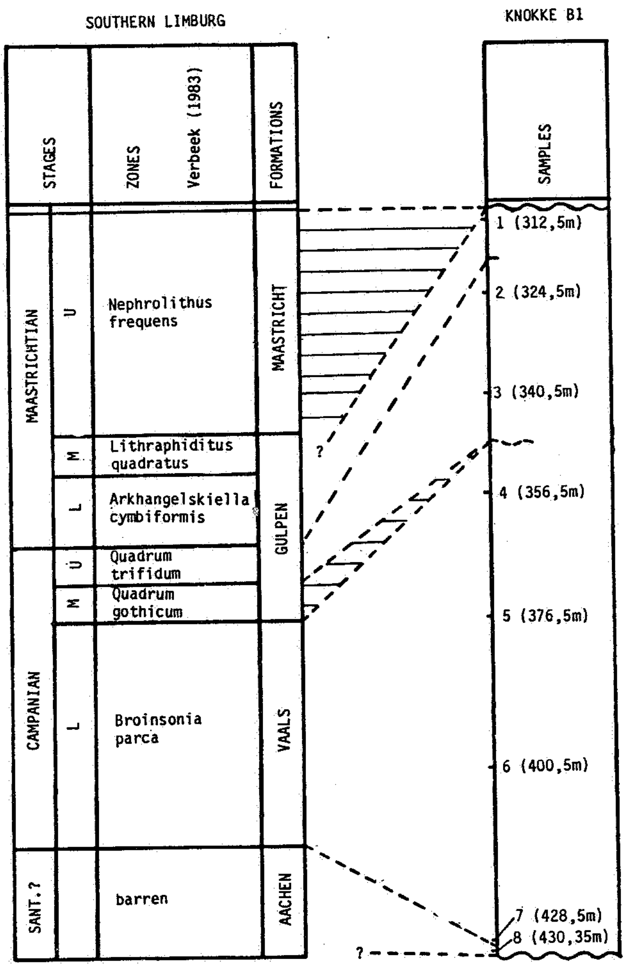

Fig. 2.- Proposed correlation of Knokke well with the results of a calcareous nannofossil study of the Senonian in southern Limburg (VERBEEK, 1983).

hardtites levis PRINS & SISSINGH to define the lower boundary of subzone b of the *Tetralithus trifidus* Zone (22) and the last occurrence of *Reinhardtites anthophorus* (DEFLANDRE) to define the upper boundary of this subzone. The first appearance of *R. levis* occurs between samples 4 and 3, and *R. anthophorus* is still present in sample 3. The approximate age of the *T. trifidus* Zone is Late Campanian (late part). Since SISSINGH's *Tetralithus nitidus* Zone (21) and subzone a of the *T. trifidus* Zone were not found, a hiatus may be present between samples 3 and 4.

Sample 2 (Late Campanian)

Sample 2 is referable to the Late Campanian part of the *Quadrum trifidum* Zone of VERBEEK (1977), because *Eiffellithus eximius* has its last occurrence between this sample and sample 1. The extinction of *E. eximius* marks the Campanian/Maastrichtian boundary.

The co-occurrence of *Reinhardtites levis* and *Reinhardtites anthophorus* indicates that sample 2 belongs to subzone b of SISSINGH's *Tetralithus trifidus* Zone (22) (see also under Sample 3).

Sample 1 (Early Maastrichtian)

Sample 1 is arbitrarily assigned to the Maastrichtian part of the *Quadrum trifidum* Zone of VERBEEK (1977). *Lithraphidites quadratus,* whose first appearance denotes the base of the next higher *Lithraphidites quadratus* Zone (Middle Maastrichtian), was not found. ROTH (1978) characterized *L. quadratus* as a species of relatively cold water. On the other hand, PERCH-NIELSEN (1979) remarked that this species occurs less consistently in higher latitudes than in the Tethyan realm, where it is a fairly reliable marker.

The nannoplankton assemblages of sample 1 fits in with SISSINGH's (1977) definition of the *Reinhardtites levis* Zone (24), as ranging from the last occurrence of *Tranolithus phacelosus* STOVER to the last occurrence of *Reinhardtites levis. T. orionatus* occurs last between samples 2 and 1 and *R. levis* is present in sample 1. The approximate age of the *R. levis* Zone is Early Maastrichtian (early part). Since SISSINGH's *Tranolitus phacelosus* Zone (23) was not recovered, a hiatus might be present between samples 2 and 1.

Conclusions

Calcareous nannofossil analyses have shown that the sediments between 430.5 m and 311 m were deposited between Late Santonian and Early Maastrichtian times.

Due to the absence of many zonal markers, zonal assignment is mainly based on other species considered to be of biostratigraphical importance. Why these marker species are absent is not clear. SISSINGH (1977) suggested that *Ceratolithoides aculeus, Quadrum trifidum* and *Tetralithus nitidus* MARTINI are geographically confined to, or are most common in, the tropical belt. PERCH-NIELSEN (1979) noted that *Marthasterites furcatus* is a reliable marker species in high latitudes and that *C. aculeus, Q. trifidum* and *Q. gothicum* might be restricted to tropical areas, because she had not found them in the North Sea area. ROTH (1978) stated that the distribution of *Q. trifidum* was latitudinally controlled. He did not find this species in Early Maastrichtian sediments at DSDP site 390A (Blake Plateau; paleolatitude 25-30°N). CRUX (1982), however, has found *C. aculeus, M. furcatus* and *W. trifidum* in northern North Sea material. FINCH (pers. comm. 1981, in CRUX 1982) has reported *Q. gothicum* from the southern part of the North Sea. VERBEEK (1983) found *Q. trifidum* in the Gulpen Formation (below the Maastrichtian stratotype) deposited in the south-eastern part of The Netherlands. According to

CRUX (1982), it seems probable that some of the species that are less common or absent have distribution patterns determined by factors other than water temperature alone.

According to SISSINGH's (1977) zonation three hiatuses may be present: one between samples 8 and 7 (Early Campanian (earliest part)), one between samples 4 and 3 (Late Campanian (early part)), and one between samples 2 and 1 (Late Campanian (latest part) to Early Maastrichtian (early part)). But according to VERBEEK's (1977) zonation, we must also take into account the possibility of a hiatus in the Late Campanian (early part). Because of the low resolution of sampling, it is impossible to delimit the stratigraphic gaps precisely and the possibility of condensed sequences between the samples cannot be ruled out.

2.- CORRELATION BETWEEN THE KNOKKE WELL AND SOUTHERN LIMBURG

VERBEEK (1983) performed a calcareous nannoplankton study in Senonian rocks in the southern part of Limburg. In the study area there are four formations (see fig. 2). Except the Aachen Formation and the top of the Maastricht Formation, the upper Cretaceous deposits of Limburg contain well-preserved nannofloras. The zonal assignment of these deposits is after VERBEEK (1983), i.e., a slightly modified version of his earlier zonation (VERBEEK, 1977). This version has only local value and therefore should not be applied to other areas without qualification. VERBEEK found a fairly complete sequence of zones in the rocks of southern Limburg. Only the *Ceratolithoides aculeus* Zone could not be defined.

Correlation between the upper Cretaceous deposits of southern Limburg and those of Knokke, give the following results (see Fig. 2). Sample 8 correlates with the Aachen Formation, and samples 7-4 correlate with the Vaals Formation. Samples 3 and 2 correlate with the Campanian part of the Gulpen Formation, and sample 1 correlates with the Early Maastrichtian part of the Gulpen Formation.

The Late Santonian Aachen Formation and the Early Campanian Vaals Formation of southern Limburg consist predominantly of sandstone sequences deposited in a marginal marine environment (ALBERS & FELDER, 1979). Based on the results of the present study, we postulate that during the same interval open marine carbonates accumulated at the Knokke locality approximately 180 km W of southern Limburg. From the Late Campanian through the Early Maastrichtian, carbonates were deposited under open marine conditions in both areas. In contrast with southern Limburg, no Middle and Late Maastrichtian deposits were found at the Knokke site.

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Chapter VII
EOCENE STRATIGRAPHY OF THE KNOKKE BOREHOLE (BELGIUM)

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INTRODUCTION

A. GENERAL FEATURES

The Knokke borehole penetrated the Eocene sediments between 30 m and 288 m, beneath the Pleistocene and overlying the Landen Formation (chapter I). The base of the Eocene is here taken for convenience to equate with the base of the Ieper Formation, although this is not strictly correct.

The Eocene sequence comprises representatives of the Ieper Formation, the Egem Formation, the Mont-Panisel Formation, the Knesselare Formation, a very thin representative of the Brussels Formation, and the lower part of the Kallo Formation (including a thin development of the Wemmel Member). The Lede Formation is absent. Core recovery was almost complete, with the exception of the section between 74 m-79 m, where little core was recovered due to drilling problems associated with the presence of hard sandstone beds.

The Knokke section is important for the study of Eocene stratigraphy, as it is situated in the area of maximum thickness of the Early Eocene in Belgium (see KAASSCHIETER 1961, Map 10). In particular, it provides a continuously cored section through the Ieper to Knesselare Formations. Its geographical location is also important for correlation with sequences in the southern North Sea and in southern England. It thus provides a key section for this part of Belgium.

This paper deals with the lithostratigraphy, microfaunas and macrofaunas of the Eocene succession, and discusses its correlation with other sections in Belgium, the southern Netherlands, the southern North Sea and southern England.

B. SAMPLES STUDIED

The borehole cores were studied and sampled at the Belgian Geological Survey office in 1982, and additional samples were supplied by the BGS in 1984. Samples were collected, as far as possible, at 1-meter intervals, and were about 10 cm in length.

The samples were processed by sieving on a 120 micron sieve, in order to concentrate the microfossils. Each sample was dried, soaked in hot water until disaggregated, and sieved. The resulting residue was soaked in a 10 % solution of Calgon (sodium hexametaphosphate) for one hour and then sieved again.

This technique produced clean residues in most cases, but some of the clays in the upper part of the Ieper Formation did not respond well to this method, and after the first sieving were treated with a 20 % solution of cold hydrogen peroxide and resieved.

The samples processed weighed between 200 and 500 grams. Initially samples were processed at 2-metre intervals, with intermediate samples being processed if necessary, in order to define faunal changes more closely. 152 samples were processed.

C. FOSSIL GROUPS STUDIED

The main fossil groups studied are the benthonic foraminiferids and the ostracods.

N.B. This paper was submitted in 1985, and only minor revisions have been made subsequently. Lithostratigraphic terminology on the figures may therefore differ from that in the text.

Planktonic foraminiferids were identified generically, but have not been studied in detail.

Molluscs were collected from the core samples before disaggregation, and also picked from the washed residues. Particular attention has been paid to the planktonic molluscs (pteropods).

Bryozoa, solitary corals and annelids (serpulids) are also recorded at some levels.

Other groups encountered include diatoms, radiolaria, sponge spicules, calcareous and phosphatic microproblematica (including *Pseudarcella* and similar taxa), fish debris, and seeds, and these have also been included in this study.

Identifications of species are based mainly on the following references:

Foraminiferids: SHERBORN & CHAPMAN (1886), KAASSCHIETER (1961), MURRAY & WRIGHT (1974), WILLEMS (1980; 1983).

'Problematica': KEIJ (1969,1970), WILLEMS (1972,1975).

Serpulids: WRIGLEY (1949, 1954).

Benthonic molluscs: COSSMANN (1886-1913), COSSMANN & PISSARRO (1904-1913), GLIBERT (1933).

Pteropods: CURRY (1965).

Ostracods: JONES (1857), JONES & SHERBORN (1889), KEIJ (1957), HASKINS (1968-1971), KEEN (1978).

Comparative material in the author's collection from various English and Belgian localities has also been utilised as far as possible.

The distribution and abundance of the fossils is plotted on a semi-qualitative basis on range charts (figs.3, 5, 8, 9, 10, 12, 13).

D. LITHOLOGICAL LOGGING

Basic lithological logging, including qualitative estimates of grainsize and sorting, has been carried out using macroscopic study and low-power stereo microscope examination.

The presence and relative abundance of pyrite, glauconite, mica, woody debris, and other components of the sediments in residues of the washed samples, has been estimated semi-quantitatively.

The lithostratigraphic interpretation and nomenclature used is taken mainly from VANDENBERGHE *et al.*,(chapter I), JACOBS, (1978) and WILLEMS *et al.*,(1981).

1.- «PRESERVATIONAL FACIES» -ITS EFFECT ON BIOSTRATIGRAPHIC AND ECOLOGICAL INTERPRETATIONS

The distribution and preservation of calcareous and siliceous Eocene fossils in the Knokke borehole has been significantly influenced by differential post-depositional diagenesis, related to the differing skeletal mineralogy of these fossils (fig. I). Similar processes have affected all fossil assemblages, but their influence in altering the original composition of the assemblage has often been ignored or under-estimated. Their recognition is critically important for interpreting fossil distributions and fossil assemblages, and for reconstructing depositional environments. As the sequence at Knokke is below the modern zone of weathering, the geochemical changes can be assumed to be due to diagenetic processes rather than to recent weathering processes.

A. SILICEOUS FOSSILS

Diatoms, radiolaria and siliceous sponges have skeletons of opaline silica. Their diagenesis in the Knokke sequence involves the dissolution of these skeletons and their replacement or infilling by pyrite.

In the Eocene of the Knokke borehole, siliceous microfossils are preserved only in two intervals: between 145 m-104 m (from the top of the Ieper Formation to the lower Mt.-Panisel Formation) and between 41.5 m-35 m (within the Kallo Formation). Throughout the rest of the section, diatoms, radiolaria and sponge spicules are represented only by pyrite casts and moulds. There is no obvious correlation between the lithology and the type of preservation, but the levels with siliceous skeletons preserved may reflect relatively high levels of original biogenic silica in the sediment.

Different groups of siliceous organisms have different relative susceptibilities to dissolution. The order of increasing susceptibility is: sponge spicules-radiolaria-diatoms (HEIN *et al.*, 1978). This may explain the often observed occurrence in the same sample of pyritised radiolaria with siliceous sponge spicules.

B. CALCITIC FOSSILS

Most foraminiferids, ostracods, several groups of bivalve molluscs (chiefly ostreids and pectidids), and serpulid annelids have entirely or partly calcitic skeletons. Calcite is a relatively stable form

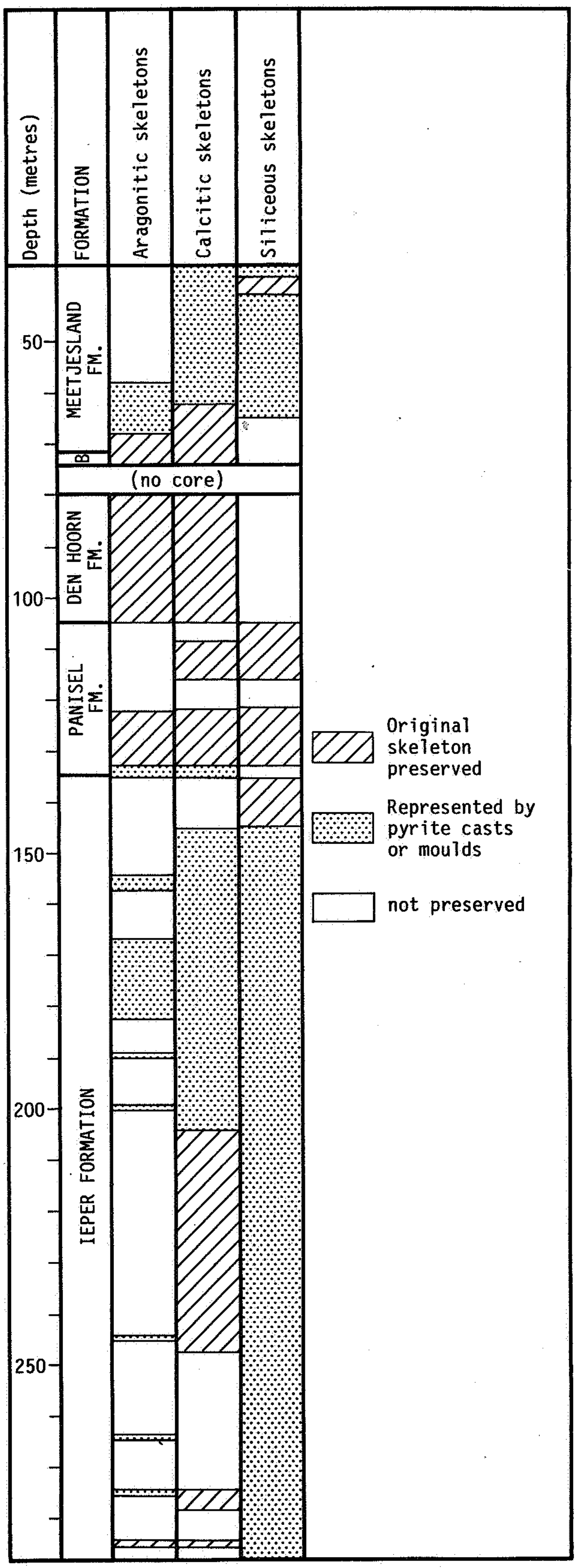

Fig. 1.- «Preservational biofacies» of the Eocene section in the Knokke borehole

of calcium carbonate, and in impermeable sediments it is often stable over very long periods of time. In more permeable sediments, it is subject to dissolution by acidic groundwater solutions.

In the Eocene of the Knokke borehole, calcitic fossils are preserved in the intervals between 248 m-217.5 m (middle Ieper Formation), and between 133 m-63 m (lower Mt.-Panisel Formation to lower Kallo Formation), but are largely or entirely absent at other levels. In the Mt.-Panisel Formation and the Knesselare Formation, the foraminiferids and ostracods are often slightly corroded and partly encrusted by reprecipitated calcite, indicating some diagenetic redistribution of calcite.

The distribution of calcitic fossils is partially related to permeability, as the coarser grained parts of the Mt.-Panisel Formation are preferentially decalcified, but some of the silty clays of the Ieper Formation and the Kallo Formation are also devoid of calcareous microfossils. This is a regional feature, seen at similar levels in other sections in Belgium, and is discussed in more detail below. It is probably due to an originally low abundance of biogenic calcite, combined with the presence of acidic porewaters. Pyrite moulds of formerly calcitic fossils occur consistently through the upper part of the Ieper Formation and in the Kallo Formation.

C. ARAGONITIC FOSSILS

Aragonite skeletons are prevalent in most groups of molluscs. Aragonite is a relatively unstable form of calcium carbonate, and so occurs in generally decreasing abundance in rocks of increasing geological age. In the Knokke borehole aragonitic molluscs are preserved only within the intervals 104 m-68 m and 133 m-122 m (in the Mt.-Panisel Formation, the Knesselare Formation and the basal Kallo Formation). They are often partly corroded and porous ('chalky'), indicating some loss of carbonate. At other levels they are represented by pyrite moulds.

D. CONCLUSIONS

The fossil distributions observed in the Knokke borehole only imperfectly reflect the original assemblages, due to significant modification at most levels by diagenetic geochemical processes. Reconstruction of the original assemblage can be partially achieved by careful observation of the presence of pyrite casts or moulds, often rare and poorly preserved, giving some indication of the nature of the original fauna. Selective dissolution of calcareous foraminiferids and calcareous-

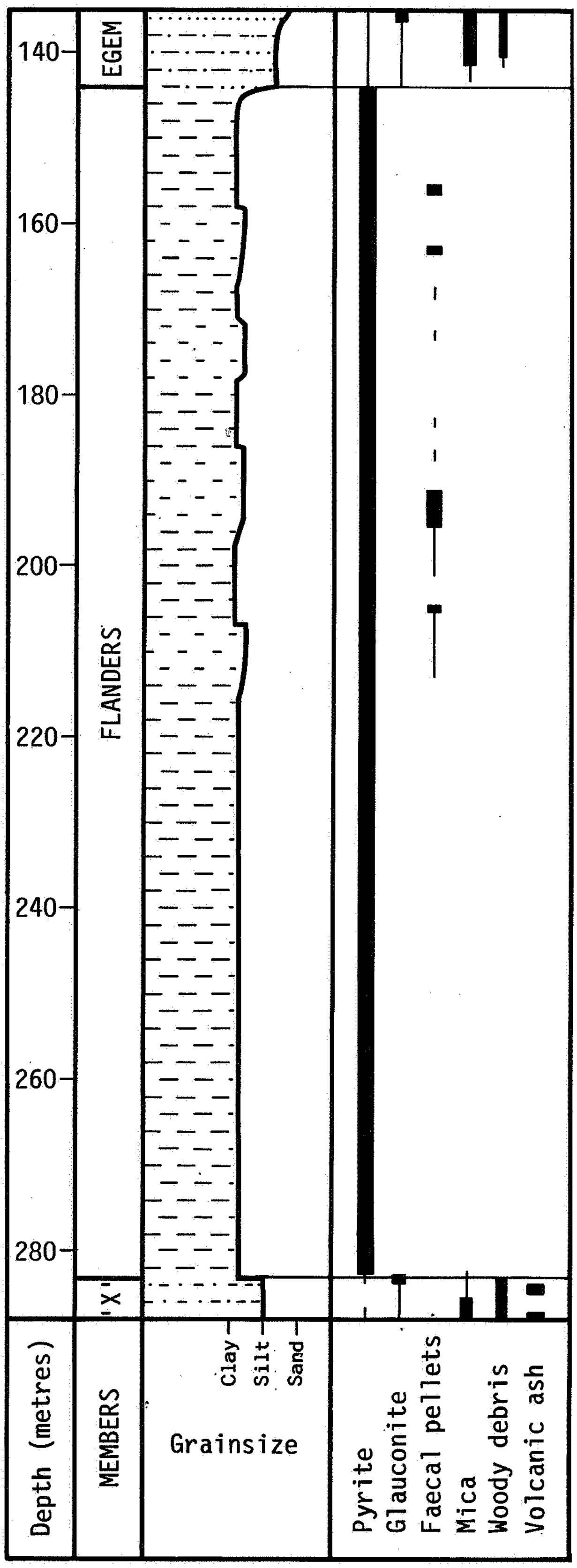

Fig. 2.- Lithostratigraphy of the Ieper Formation and Egem Formation in the Knokke borehole

cemented agglutinants in an original mixed calcareous/agglutinating assemblage (e.g. in parts of the Ieper Formation) can produce misleading environmental implications unless recognised. Sections which appear at first sight to be virtually unfossiliferous (e.g. parts of the upper Flanders Member) can reveal the presence of traces of what was originally probably a relatively diverse fauna.

2.- IEPER FORMATION AND EGEM FORMATION

A. LITHOSTRATIGRAPHY.

The Ieper formation in the Knokke borehole can be subdivided into three Members (Fig. 2). The lowest Member has not been recorded elsewhere in Belgium, but the other units (Flanders Member and Egem Formation) can be recognised regionally (see WILLEMS *et al.*, 1981, WILLEMS, 1982).

«Member X» (288.0 m-283.4 m)

Sandy clayey silt, heavily bioturbated and «streaky», with irregular pockets and lenses of very fine silty sand. Fine-grained mica, woody debris and glauconite are present throughout. The basal contact with the sands of the Landen Formation is sharp and even.

Fine to coarse-grained angular to subangular grey «inodular» particles are common in residues at 284.5 m and 287.5 m; although no obvious structure is preserved, these can be identified as degraded volcanic ash particles by comparison with similar occurrences elsewhere.They represent the first record in Belgium of the widespread Late Paleocene-basal Eocene ashes of the North Sea Basin (KNOX & MORTON, 1983).

Distinctive features of this unit are the presence of volcanic ash and frequent glauconite. Elsewhere the basal unit of the Ieper Formation is the Mont-Heribu Member (DE CONINCK *et al.*,1983), but this does not appear to be indentifiable in the Knokke borehole.

The heavy clay of the Ieper Formation (283.4 m-c.144. 0 m) (Flanders Member)

This is a relatively homogenous clay unit, but minor lithological changes can be used to subdivide it.

The basal contact is well-defined, and is marked by a thin bed (c.0. 03 m) of poorly sorted sandy clayey silt, with common medium to coarse glauconite and sand grains and rare small subangular pebbles of flint. This bed passes up gradationally into bioturbated very silty clay (283.4 m-c.282.6 m) which is overlain by homogenous silty clay.

It is possible that this basal part of the Flanders Member (283.4 m-282.6 m) corresponds to the Mt. Heribu Member, as defined elsewhere, but it is so thin that it is not separated here. The biostratigraphic data (see below) indicate that microfaunas and microfloras typical of the Mt. Heribu Member at outcrop are here found in the lower part of the Flanders Member.

Above these basal beds, the lower half of the Flanders Member (282.6m-c.213.5m) is an extremely homogenous silty clay. Rare partings of very fine sand occur near the base at 271.5 m and 275.26 m, but otherwise no bedding is visible. Thin horizontal branching pyrite «sticks» are common. These clays are probably intensely bioturbated, but due to their very homogenous texture they appear «massive».

At c.213.5 m there is a change to siltier clays with a few silt streaks and partings. The upper half of the Flanders Member (c.213.5 m-c.144.0m) consists of alternations of homogenous silty clays, and very silty clays/clayey silts with silt streaks and partings, in units c.5-10 m thick. The boundaries between these units are generally transitional, and no sharp lithological junctions were observed. Bioturbation is expressed mainly by the «streaky» texture of some of the siltier beds, but discrete burrows are rarely visible, except for *Chondrites* burrow systems at some levels (e.g. at 146 m-148 m). Pyrite «sticks» and lumpy pyrite nodules are common. Small glauconitised faecal pellets occur consistently through the interval 213.5 m-156 m; they are particularly common between 199 m and 191 m.

Egem Formation (Yd) (c. 144.0m-135.0m)

The Egem Formation is represented mainly by a bioturbated very sandy silt/very silty sand, with argillaceous streaks. The basal junction is transitional. It contains common very fine grained glauconite, and less common very fine grained woody debris and mica. The top 1-1,5 metres is coarser grained; comprising a very fine to fine silty sand, with fine and medium grained glauconite.

B. BIOSTRATIGRAPHY

Diatoms

Pyritised moulds of the large diatoms *Coscinodiscus* sp.1.and *C.* sp.2. (see KING, 1983, Pl. 1, Figs. 1-3) are common in the basal Ieper Formation (Member «X» and the basal Flanders Member) between 284.5 m and 278.5 m, associated at 281.5 m with common *Triceratium* sp. In the interval 278.5 m-217.0m, small pyritised diatoms (chiefly small biconvex and biconcave *Coscinodiscus* spp.) are recorded fairly consistently; at 253.5 m-251.5 m *Coscinodiscus* sp.1 is common. Between 212 m and 206 m no diatoms are recorded. From 206 m to the top of the Flanders Member, small pyritised diatoms again occur commonly and consistently. These are mainly small biconcave and biconvex *Coscinodiscus* spp.; *Triceratium* sp. is also recorded. A similar assemblage occurs in the Egem Formation, but specimens are less common.

Radiolaria

Occasional large pyritised spherical reticulate radiolaria, similar to the forms referred to '*Cenosphaera*' in the North Sea (KING, 1983) occur through the interval 189 m-145 m. Large lenticular radiolaria, accompanied by occasional spherical radiolaria, occur between 145 m-139 m.

'Problematica'

Problematic calcareous microfossils are recorded rarely in two samples: at 231.5 m a single specimen of *Pseudarcella trapeziformis*, and at 221.0m single specimens of *P. trapeziformis* and *Voorthuyseniella gracilis*. Both these species are recorded by WILLEMS, (1972) from the middle of the Flanders Member in the Kallo borehole.

A problematic phosphatic microfossil (recorded as 'phosphatic microproblematicum' in WILLEMS, 1982, Table 1 and as organism 'X' in KING, 1984) occurs fairly consistently but in low numbers (rarely more than one specimen per sample) through the interval 183.0-271.0m, and occasionally at other levels. This form is widespread in the London Clay Formation in England and elsewhere in the Ieper Formation, but has not yet been recorded elsewhere.

Benthonic foraminiferids

Benthonic foraminiferids occur consistently through the lower and middle parts of the Ieper Formation. Above 181 m the section is entirely barren except for occasional pyrite casts of foraminiferids (see comments above on preservation).

As noted by WILLEMS, (1983), two distinct associations of agglutinating foraminiferids are present in the Ieper Formation- and similar associations can be recognised widely in Cainozoic sediments of the North Sea Basin. The first association (AA-I of WILLEMS) includes the genera *Ammodiscus*, *Haplophragmoides*, *Miliammina*, *Recurvoides*, *Rhabdammina* and *Trochammina*; and certain species of *Textularia* and *Spiroplectammina* (*T. plummerae* and *S. spectabilis*). The second association (AA-II of WILLEMS)

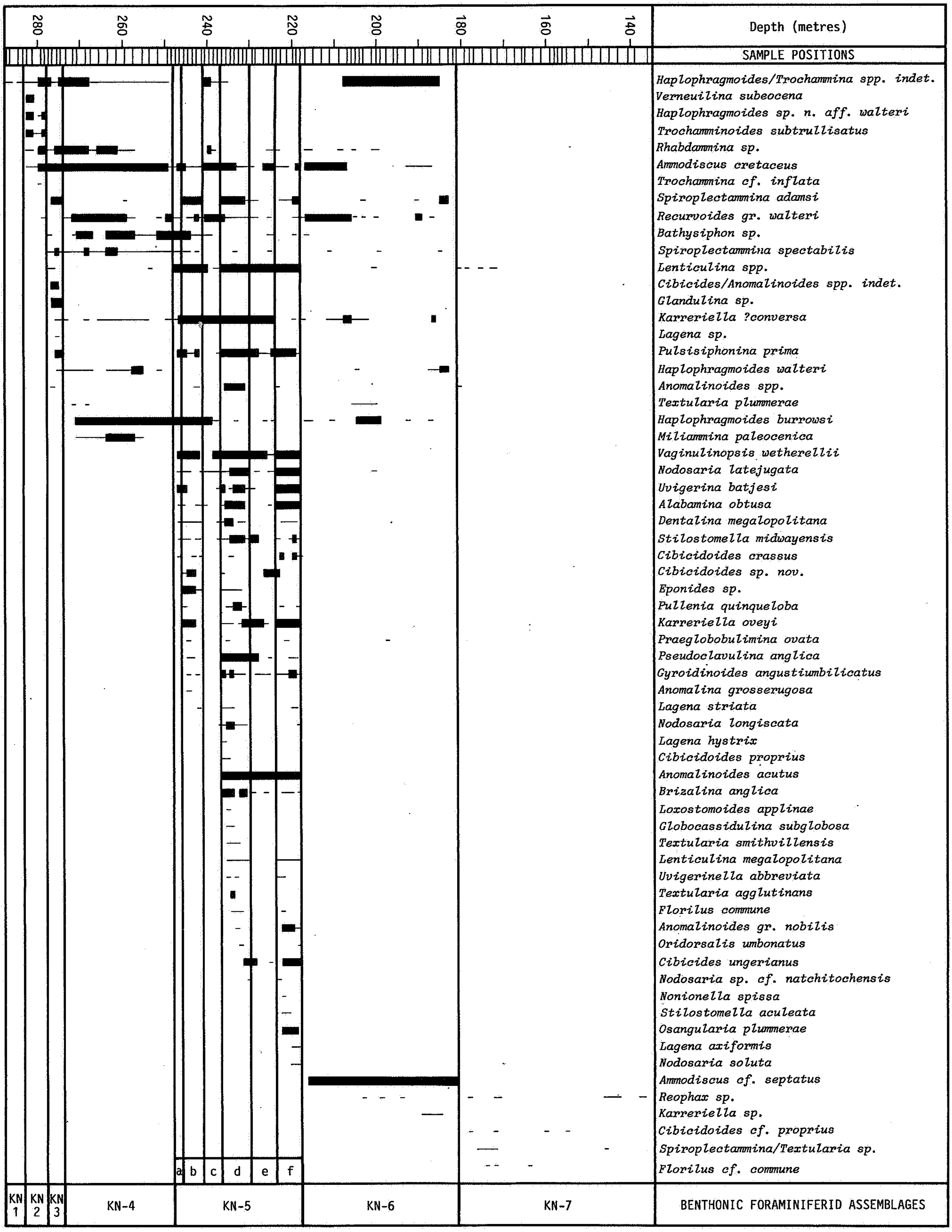

Fig. 3.- Distribution of benthonic foraminiferids in the Ieper Formation of the Knokke borehole

includes the genera *Karreriella* (except *K. conversa*) and *Pseudoclavulina* and most species of *Textularia* and *Spiroplectammina*.

The first association generally occurs either as a «pure» agglutinating assemblages, or associated with rare and often corroded calcareous foraminiferids. Individuals are often partially collapsed and deformed (see WILLEMS, 1983, Fig. 4). The second association usually occurs together with a diverse and well-preserved calcareous benthonic foraminiferid assemblage, and specimens are normally well-preserved and uncrushed.

These two associations clearly reflect differing environmental contexts. As WILLEMS notes, the first group often occurs as one of the «exclusively agglutinating» faunas discussed by MOORKENS, (1975) and GRADSTEIN & BERGGREN, (1981). These are regarded as adapted to oxygen-poor and alkaline seafloor environments, probably originating in conditions of reduced circulation, and their tests are non-calcareous or with a low carbonate content. The second group generally have a significant proportion of calcareous cement in their tests, and occur in contexts indicating a well-oxygenated marine environment.

The distinction between these two associations is often enhanced by early post-mortem dissolution of calcium carbonate in the first association, due to the acidity of the sediment pore-waters. This leads to the corrosion or dissolution of calcareous foraminiferids. In the Knokke borehole, and in similar contexts in the London Clay in England, it is noticeable that as the abundance of calcareous foraminiferids decreases, in passing vertically from dominantly calcareous to dominantly agglutinating faunas, they become corroded and partly crushed before disappearing entirely.

Here WILLEMS' terminology for these associations is modified for simplicity; the first association (AA-I of WILLEMS) is designated the **AG1 association** and the second (AA-II) the **AG2 association**.

The ratio between the numbers of individuals of calcareous and agglutinating foraminiferids in a sample is sometimes used as an environmental index, but it is considered that a much more sensitive index is provided by the ratio between the numbers of AG1 agglutinants and the remainder of the benthonic foraminiferids (AG2 agglutinants and calcareous benthonic taxa). This ratio (expressed as the percentage of speciments of AG1 agglutinants in the sample) has been calculated for the Knokke section, and is referred to here as the **'AG1 index'** (see Fig. 4).

Seven successive benthonic foraminiferid assemblages (KN-1 to KN-7) are here defined within the Ieper Formation of the Knokke section, with boundaries taken at significant changes in the total benthonic foraminiferid assemblage (Fig. 3, Fig. 4).

Assemblage KN-1 (288.0m-283.4m)

In the basal «Member X» only very rare and poorly preserved indeterminate agglutinating foraminiferids have been recorded (*Haplophragmoides/Trochammina* spp. indet). Although this hardly qualifies as a well-defined assemblage, it can be defined negatively by the absence of taxa occurring in the overlying unit, including *Ammodiscus* and *Rhabdammina*.

Assemblage KN-2 (283.5m-278.4m)

A limited and poorly assemblage of AG1 agglutinating foraminiferids (AG1 index 100%), partly crushed and distorted and often rather coarsely agglutinated, including *Ammodiscus cretaceus* (= *A. siliceus* of WILLEMS), *Trochamminoides subtrullisatus* and *Verneuilina subeocaena* The two latter species are restricted to this interval.

Assemblage KN-3 (277.5m-274.5m)

The base of this assemblage is defined by the first appearance of calcareous benthic foraminiferids. These include *Cibicides/Anomalinoides* spp. indet., *Pulisiphonina prima* and *Lenticulina* sp., and are rather poorly preserved and recrystallised. This event is associated with an increase in diversity of the AG1 agglutinating foraminiferids, including the first appearance of *Spiroplectammina spectabilis* and *Haplophragmoides walteri*. *Ammodiscus cretaceus* is the commonest agglutinant. The AG1 index varies from c.15% to c. 70%.

Assemblage KN-4 (273.5m-248.5m)

The base of this assemblage is defined by the disappearance of calcareous foraminiferids and a return to an agglutinating assemblage of AG1 type (AG1 index 100%); characterised by the association of *Ammodiscus cretaceus*, *Bathysiphon* sp., *Spiroplectammina spectabilis*, *Haplophragmoides burrowsi* and *H. walteri*. *Miliammina paleocenica* is restricted to this interval, occurring consistenly between 270.5m and 255.5m. Very rare pyrite moulds of calcareous taxa (e.g. *Lenticulina* sp.) are recorded in the upper part of this interval.

Assemblage KN-5 (247.5m-218.0m)

The base of this assemblage is defined by the incoming of a diverse assemblage of calcareous foraminiferids and AG2 agglutinating foraminiferids.At the base they form less than 10% of the foraminiferid fauna (AG1 index c.90%), but through most of this interval they constitue at least 50% of the fauna (AG1 index 0-50%). The calcareous benthonic asemblage is rather consistent throughout this interval; the most common species are *Lenticulina* spp.,*Pulisiphonina prima, Anomalinoides acutus, Vaginulinopsis wetherellii* (= *Marginulinopsis enbornensis* of WILLEMS), *Nodosaria latejugata, Alabamina obtusa, Stilostomella midwayensis* (= *'Nodosaria spinulosa'* of SHERBORN & CHAPMAN), *Uvigerina batjesi* (= *U. garzaensis* of WILLEMS). The AG2 agglutinants include common *Karreriella oveyi, Pseudoclavulina anglica* and *Spiroplectammina adamsi*. The AG1 component includes common *Ammodiscus cretaceus, Recurvoides* sp., and *Karreriella conversa*.

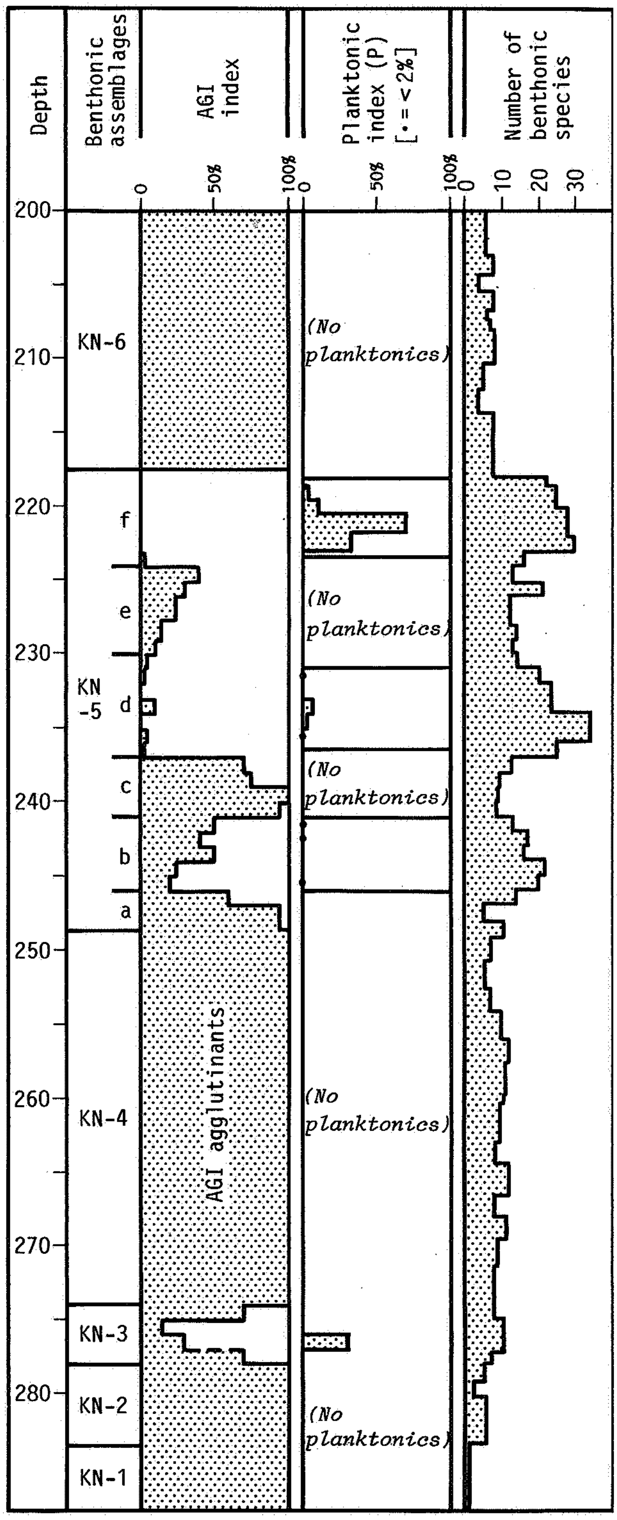

Fig. 4.- Planktonic and benthonic foraminiferid assemblages in the Ieper Formation of the Knokke borehole

There are well defined vertical changes in the AG1 index (see Fig. 4) which enable six «sub-assemblages» to be defined. They are essentially alternations of «low-AG1» and «higher-AG1» faunas.

In the highest sub-assemblage (KN-5f), the AG1 index falls to its lowest levels in the entire sequence, between 0 and 3%. In this interval the highest diversity and greatest abundance of benthonic foraminiferids is recorded.

Some species are restricted to particular levels in assemblage KN-5. *Haplophragmoides burrowsi* occurs commonly and consistenly through KN-5 a to 5 c, but is only recorded rarely in one sample at higher levels. *Brizalina anglica, Nodosaria longiscata* and *Anomalinoides acutus* are not recorded in 5a or 5b but occur consistenly through 5c to 5f. *Textularia smithvillensis* is restricted to the interval 235.5 m-233.5 m, in KN-5d. *Osangularia plummerae* occurs only in unit 5f (between 222.5 m-219.0 m).

In assemblage KN-5, several species occur which are rare or unrecorded elsewhere in the Ieper Formation in Belgium. These include *Pseudoclavulina anglica, Stilostomella midwayensis* and *Osangularia plummerae*. Species such as *Vaginulinopsis wetherellii* and *Nodosaria latejugata* are more common at Knokke than elsewhere in Belgium. The composition of the fauna is similar to the 'nodosariid-rich assemblage' (NRA) of the middle London Clay (KING 1981).

Assemblage KN- 6 (217.0 m-181.9 m)

Between 217.0 m and 218.0 m is the most abrupt microfaunal break in the Ieper Formation; from an assemblage at 218.0 m comprising 99% calcareous benthonics + AG2 agglutinants (AG1 index c1 %) to a totally agglutinating foraminiferid assemblage with an AG1 index of ± 100% (see Figs. 3, 4). This faunal change is certainly to some extent enhanced by decalcification of the interval above 218.0 m, but it nevertheless reflects a major event in the sequence of benthonic microfaunas.

The KN-6 assemblage consists almost entirely of AG1 agglutinating foraminiferids, dominated by

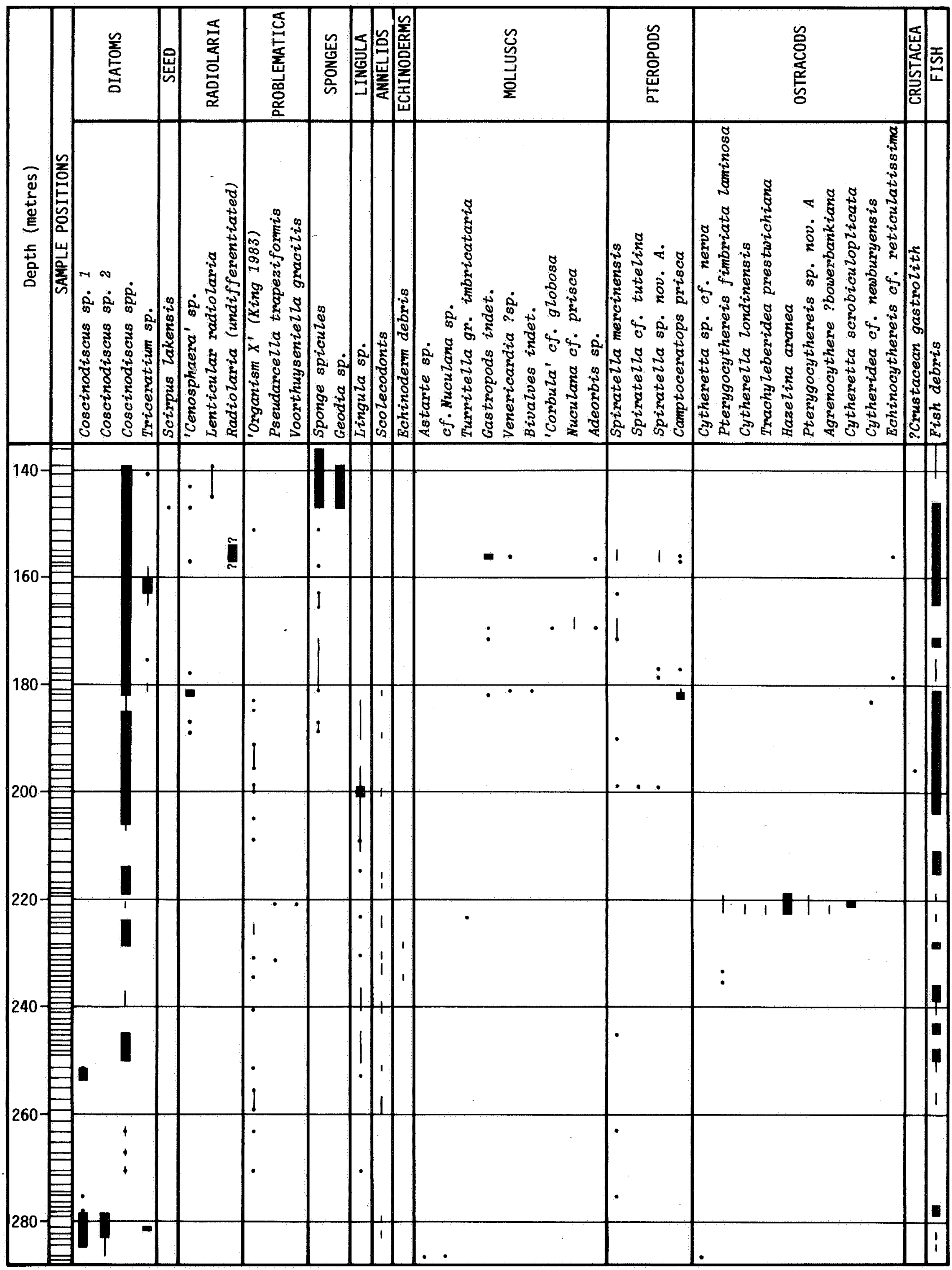

Fig. 5.- Distribution of microfossils (excluding foraminiferids) in the Ieper Formation of the Knokke borehole (for «*Agserorythere*» read *Oertliella*)

Ammodiscus cf.*septatus*; *Haplophragmoides/ Trochammina* sp. indet. and *Recurvoides* gr. *walteri*. The former existence of a significant fauna of AG2 agglutinants and calcareous benthonic foraminiferids is indicated by the occurrence of pyrite casts or pyrite-cemented specimens of *Lenticulina* sp., *Nodosaria latejugata, Praeglobobulimina ovata* and *Spiroplectammina adamsi*.

Assemblage KN-7 (180.9 m-136.0 m)

The base of this interval is defined by the disappearance of AG1 agglutinants. As the interval is entirely decalcified, foraminiferids are almost entirely absent. Much of the interval is entirely barren, but at some levels (mainly below 172 m) pyrite casts of calcareous foraminiferids occur, including *Lenticulina* sp., *Cibicidoides* cf.*proprius*, cf.*Florilus commune*, and also AG2 agglutinants (cf. *Spiroplectammina adamsi)*. Otherwise only rare agglutinants (*Reophax* sp.) occur.

Planktonic foraminiferids

The taxonomy of the planktonic foraminiferids occurring at Knokke has not been studied in detail. Here only their occurrence and relative abundance are dealt with. The ratio of planktonic to benthonic foraminiferids, expressed as the percentage of planktonics in the benthonic assemblage (P), has been calculated (Fig. 4).

The earliest planktonic foraminiferid occur at 276.5 m (P=c.30 %, uncertain due to poor preservation). This is an isolated occurrence. *Subbotina* gr. *linaperta* is dominant. Planktonic foraminiferids are absent between 275 m and 245.5 m. Isolated specimens occur from 245.5 m to 231.5 m, forming less than 1 % of the total foraminiferid assemblage, except at 234.5 m and 233.5 m, where **P** rises to 8 %.

Between 231.5 m and 222.5 m no planktonics are recorded. At 222.5 m-219.7 m there is a brief but very sharp peak of planktonic foraminiferid abundance, rising to **P**=70% at 221.9 m, falling rapidly to **P**=10% at 219.7 m and **P**=c.2 % at 219.0 m. These are predominantly *Acarinina* spp., but *Subbotina* gr. *linaperta* (*Gobigerina patagonica* of Willems) is dominant at 219.10 m-218.0 m.

In the completely decalcified section above 219.0 m, pyrite moulds of planktonics occur in samples between 157.9 m - 154.8 m, and at 171.5 m. These include rare specimens of *Pseudohastigerina wilcoxensis* (at 154.8 m).

Sponge spicules

Pyrite casts of small sponge spicules occur consistently between 189 m and 147 m. Siliceous sponge spicules are common in the top part of the Flanders Member (above 147 m), and in the Egem Member. The spicules appear to be predominantly monaxons, triaxons, and tetraxons, but sterrasters («*Geodia*» spicules) similar to those illustrated by DE GEYTER & WILLEMS (1982, plate 1, figs. 3-14) are also common, particularly between 147 m and 139 m.

Brachiopods

Fragments of small specimens of the brachiopod *Lingula* occur consistently but in low numbers in almost all samples between 215 m and 183 m, and very rarely at other levels.

Benthonic molluscs

Specimens of *Astarte* sp. and cf. *Nuculana* sp. are recorded from 'Member X' at 286.5 m.

No calcareous molluscs are preserved in the Flanders Member or the Egem Formation, and only occasional pyrite moulds are recorded. At 223.5 m a crushed mould of *Turritella* gr. *imbricataria* was found - this is an isolated record.

Molluscs occur at several levels in the upper part of the Flanders Member between 180.8 m and 154.8 m, including indeterminate gastropods, *Adeorbis* sp. and the bivalves *'Corbula'* cf. *globosa, Nuculana* cf. *prisca* and *Venericardia* ? sp.

Pteropods

Pteropods are represented by partly crushed and distorted pyrite moulds, mainly occurring within the upper part of the Flander Member. The poor preservation causes some difficulties in identification.

A pteropod zonation for the London Clay Formation was proposed in KING (1981), and this has been extended to cover the Eocene to Pliocene sequence of the North Sea Basin by JANSSEN & KING (1988). In the lower part of the Flanders Member, isolated specimens of *Spiratella mercinensis* are recorded between 265.5 m and 245.4 m. The interval between these samples can be referred to pteropod Zone GP6 (*Spiratella mercinensis* zone of KING 1981).

Between 263.5 m and 199.0 m, no pteropods are recorded. At 199.0 m rather poorly preserved specimens of *Spiratella* cf. *mercinensis, S.* cf. *tutelina* and *S.* cf. sp. nov. A are recorded. This sample can be referred to pteropod Zone GP8 (*Spiratella tutelina* Zone of KING 1981). *Spiratella* sp. nov. A is a relatively high-spired species, intermediate in proportions between *S. taylori* and *S. tutelina*. It is common in the upper part of the London Clay Formation (divisions D and E), and most of the specimens recorded at SHEPPEY as *S. tutelina* (KING, 1983) are now referred to this species.

Only rare pteropods are recorded between 199.0 m and 182.0 m. Between 182.0 m and 154.5 m pteropods occur fairly consistently, including *Camptoceratops prisca, Spiratella mercinensis* and *S.* sp. nov. A. This interval is referred to pteropod Zone GP9 (*Camptoceratops prisca* Zone of KING 1981).

Above 154.5 m no pteropods have been recorded.

Ostracods

A single fragmentary specimen identified as *Cytheretta* cf. *nerva* is recorded from Member 'X' at 286.5 m. This may indicate the presence of the *Cytheretta venablesi* ostracod Zone (KEEN, 1978). In the lower part of the Flanders Member, no ostracods are recorded. In the middle of the Flanders Member ostracods occur only in a few samples, asociated with foraminiferid assemblage KN-5. Isolated valves of *Pterygocythereis fimbriata laminosa* are recorded at 235.5 m and 233.5 m, but ostracods occur consistently only between 222.5 m and 219 m. The assemblage comprises *Hazelina aranea, P. f. laminosa, P.* sp. nov. A (an undescribed species which is widespread in the middle London Clay Formation of the central and eastern London basin), *Cytheretta scrobiculoplicata, Cytherella londinensis, Trachyleberidea prestwichiana* and *Oertliella* [*Trachyleberis*] *bowerbankiana.* This assemblage is referrable to the *Cytheretta scrobiculoplicata* ostracod zone (KEEN, 1978) which is recognised within the middle London Clay Formation (KING, 1981). A very similar assemblage (but more diverse) is recorded at a similar level at Kallo (WILLEMS, 1973; KEEN, 1978) and Tielt (WILLEMS, 1978).

In the decalcified interval of the Flanders Member above 219.0 m, occasional pyritised moulds of ostracods are recognisable, including *Cytheridea* cf. *newburyensis* (at 183.0 m) and *Echinocythereis* cf. *reticulatissima* (at 178.8 m and 156.0 m). This limited assemblage indicates correlation with the *E. reticulatissima* ostracod Zone (WILLEMS, 1973; KEEN, 1978; KING, 1981).

C. CORRELATION

Belgium (fig. 6)

The basal unit of the Ieper Formation at Knokke («Member X») has no equivalent in other sections studied in Belgium, and is represented elsewhere by a hiatus between the Ieper Formation and the Landen Formation. This is confirmed by the dinoflagellate evidence (see DUPUIS *et al.* (chapter IV) and text below).

WILLEMS (1980, 1982) subdivided the benthonic foraminiferid microfaunas of the Ieper Formation into five successive associations (BF-ass.I to BF-ass.VI), based mainly on the detailed study of the Kallo and Tielt boreholes. The vertical ranges of the foraminiferid taxa and the faunal associations in the Knokke borehole are not exactly comparable with those recorded by WILLEMS, due to lateral biofacies changes, and to the extensive decalcification of the Knokke sequence, but equivalents of WILLEMS' associations I to IV can be identified.

WILLEMS' 'BF-I association', comprising exclusively agglutinating foraminiferids of AA-I (AG1) type, recorded at the base of the Ieper Formation, corresponds to the KN-2 assemblage. The occurrence of *Coscinodiscus* sp.1 and *C.* sp.2 in the same interval as this assemblage at Knokke is consistent with their occurrence elsewhere in Belgium. WILLEMS (1982:9) notes the presence of these diatoms at the base of the Ieper Formation but gives no further details of their occurrence. In washed residues supplied to the author by WILLY WILLEMS, they occur commonly between 368 m-372 m at Kallo and 146.5 m-148.5 m at Tielt, within the interval with the BF-ass.I microfauna (see Fig. 6).

The base of WILLEMS' association BF-II, marked by the appearance of calcareous foraminiferids, is rather ill-defined at Tielt, but well-defined at Kallo. It corresponds to the base of assemblage KN-3. The first appearance of planktonic foraminiferids at this level at Knokke correlates with their first appearance at Kallo (WILLEMS 1980); they are considerably more common at Knokke than at other localities studied.

In the Knokke borehole there is a well-defined change in the agglutinating foraminiferid assemblage at the base of assemblage KN-3. At this level there is the replacement of a *'Trochamminoides subtrullisatus-Verneuilina subeocaena'* association (assemblage KN-2) by a more diverse assemblage which includes *Spiroplectammina spectabilis* and *Haplophragmoides walteri.* A similar change can be identified at Kallo at the base of BF-ass.2, but at Tielt it occurs at c.145.5 m, within BF-ass.I. (WILLEMS 1980). As this change is well-defined in all three wells, and corresponds approximately to the top of the interval with *Coscinodiscus* sp.1 and *C.* sp.2. It is believed to be synchronous event (see Fig. 6).

In the exposures of the Mt.-Heribu Member in the Tournai-Mons area described by DE CONINCK *et al.* (1983), the *'T. subtrullisatus-V. subeocaena'* association corresponding to KN-2 can be recognised at the base of the Member at Ghlin and Mt.-Heribu. At St. Maur, at c.7 m above the base of the Member, the absence of these taxa, and the

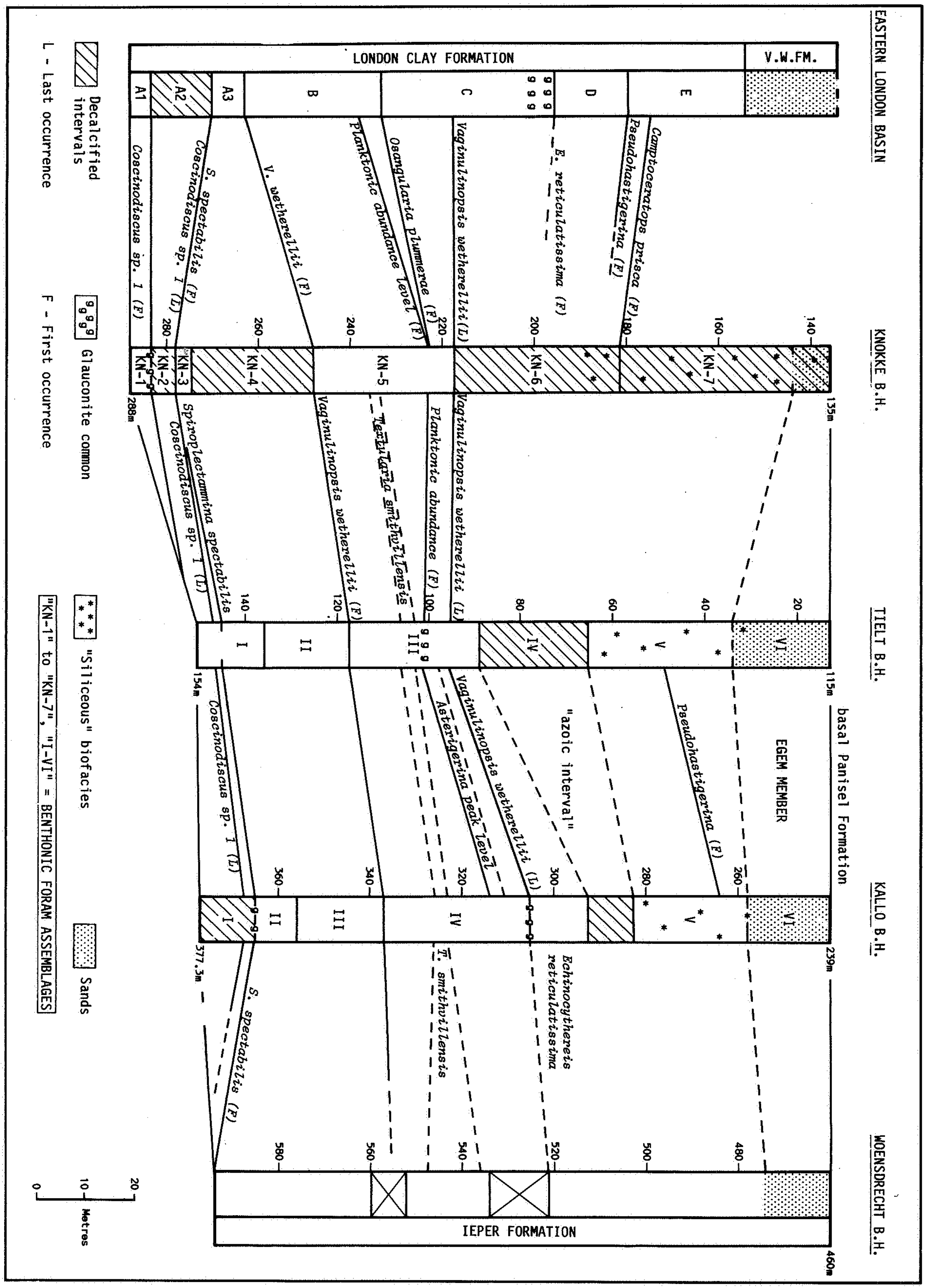

Fig. 6.- Correlation of the Ieper Formation and London Clay Formation in the southern Netherlands, northern Belgium and the eastern London basin

occurrence of *Miliammina paleocenica*, indicates correlation with association KN-4. These records demonstrate the wide extent of these successive agglutinating assemblages, and indicate that the boundary between the Mt.-Heribu Member and the Flanders Member is significantly diachronous, as at Knokke both assemblages occur within the Flanders Member.

Association BF-III has no recognisable equivalent at Knokke, probably due to decalcification, but is likely to correspond to the upper part of KN-4 (it is absent also at Tielt).

The base of assemblage KN-5, marked by the entry of nodosariids and the AG2 agglutinants *Karreriella oveyi* and *Spiroplectammina adamsi*, corresponds to the base of BF-IV. The reappearance of planktonic foraminiferids just above this level compares with a similar event at Kallo and Tielt (WILLEMS 1982:6), but this event is ill-defined, due to the rarity of planktonics in this part of the succession.

The subdivisions recognised within assemblage KN-5 at Knokke (Fig. 4) may prove identifiable elsewhere. *Textularia smithvillensis* is one species which may be useful for detailed correlation. It has a short but well-defined vertical range at Knokke, and occurs at a similar level at Kallo and Tielt (Fig. 6). Other microfaunal events recognisd in BF-IV in the Kallo and Tielt boreholes (WILLEMS 1980) cannot be identified at Knokke, probably due to lateral faunal changes. The planktonic foraminiferid abundance-level, which is sharply defined at Knokke at 222.5 m-219.7 m (Fig.6), probably correlates with the *'Globigerina patagonica* acme zone' (WILLEMS 1982). At Knokke *G. patagonica* is not so abundant as in the other boreholes, but is the dominant planktonic at 219 m-218.0m, just above the abundance-level.

The glauconite-rich horizons present at other localities in the middle of the Flanders Member ('lit glauconifère de Tielt' of DE CONINCK 1975) have not been recognised at Knokke, where the lithology is very homogenous through this part of the succession. Although it has been suggested that the main glauconite level is a lithostratigraphic marker horizon, the data of WILLEMS (1980) show that two key biostratigraphic events, the *'Asterigerina bartoniana kaaschiteri* acme' and the *'G. patagonica* acme' occur *below* the main glauconitic level at Kallo and *above* it at Tielt (Fig. 6). More detailed investigation of this interval is needed (see KING, in press).

The most significant microfaunal datum levels in this part of the Flanders Member are believed to be the highest occurrence of common nodosariids (or in the Kallo and Tielt boreholes, where nodosariids are rarer, the top occurrence of *Nodosaria latejugata* and *Vaginulinopsis wetherellii*), and the top of the planktonic foraminiferid acme.

These two events are approximately coincident in the three boreholes concerned. At Knokke they probably coincide with the top of assemblage KN-5. At Kallo they coincide with the main glauconite horizon (304.6 m); at Tielt they are probably at 95.5 m (see Fig. 6). The *'Osangularia* datum' (KING 1981), (defined by the first occurrence of *O. plummerae*), although now recognised at Knokke and important regionally in the southern North Sea Basin (see below), has not been Identified in other Belgian sections.

Assemblage KN-6 has no equivalent in the sections studied by WILLEMS. It marks the return of an agglutinating assemblage of AG1 type, restricted elsewhere to the lower parts of the Ieper Formation.

The 'azoic' (decalcified) interval present above assemblage BF-IV in the Kallo and Tielt wells is probably essentially a post-depositional feature, due to secondary decalcification of the sediments. The approximately equivalent sequences at Knokke (above 219 m) and at outcrop (e.g. in the Kortemark quarry) contain pyrite moulds and casts of formerly calcareous planktonic and benthonic organisms. Its limits are probably diachronous, as at Knokke it has expanded to include most of the upper Ieper Formation. Assemblage BF-V is probably represented within this interval at Knokke, but is now entirely decalcified. Similarly, an equivalent to assemblage BF-VI cannot be recognised at Knokke, due to the decalcification of the Egem Member.

The occurrence of pyrite casts of *Pseudohastigerina wilcoxensis* and other planktonic foraminiferids near the top of the Flanders Member at Knokke can probably be approximately correlated with similar records at Kallo and Tielt (see Fig. 6).

The 'siliceous' biofacies of the upper Flanders Member and the Egem Formation seen at Knokke, characterised by the presence of common sponge spicules, including *Geodia*, which are associated with spherical radiolaria, is widespread at this level. Samples studied by the author from the Kallo and Tielt boreholes, and from outcrops at Kortemark and Meulebeke, all have a similar siliceous spicule and radiolarian assemblage in the upper part of the Ieper Formation (see Fig. 6).

Southern England

The biostratigraphic sequence within the Ieper Formation of the Knokke borehole can be compared with the London Clay sequence in the Hampshire Basin. The data obtained from Knokke permits the correlations between England and Belgium proposed previously (KING 1981) to be refined and updated.

The basal sandy unit of the Ieper Formation (Member «X»), with ash debris, a restricted agglutinating microfauna and common *Coscinodiscus* spp., can be correlated lithologically and micropaleontologically with the (ash-bearing) division A1 of the London Clay Formation (which includes Harwich Member of Essex and Suffolk). The dinoflagellate assemblage in this unit (DUPUIS *et al.,* this volume) confirms this correlation. This is the first record of the North Sea Basin 'main tuff zone' (subphase 2b of KNOX & MORTON 1983) in Belgium. The limited calcareous microfauna recorded at 286.5 m, although too poorly preserved for definite identification, is very similar in aspect to division A1 microfaunas from the Swanscombe Member in the London Basin (KING 1981:24). Elsewhere in Belgium beds of this age are apparently absent and there is a significant hiatus between the Ieper Formation and the Landen Formation (DE CONINCK *et al.,* 1983). Their occurrence at Knokke (even though represented only by a thin remnant) reflects the geographical location of the borehole relative to the margin of the North Sea Basin.

The glauconitic level at the base of the Flanders Member at 283.7 m probably can be equated with the sedimentary discontinuity defining the base of division A2 in England. The restricted agglutinating assemblage (KN-2) in the lower part of the Flanders Member (283.7 m-278.5 m), and the continuing presence of *Coscinodiscus* sp. 1 and *C.* sp.2 in this interval, indicates correlation with division A2.

The approximately simultaneous appearance of calcareous benthic foraminiferids (at the base of assemblage KN-3), and of planktic foraminiferids (at the same level) can be correlated with the corresponding faunal change which occurs at the base of division A3 in the London Basin. Division A3 has a restricted calcareous microfauna in the central London Basin, but this becomes progressively attenuated and largely replaced by an AG1 agglutinating assemblage in the east of the London Basin. Although in England this assemblage is not as abundant or diverse as the agglutinating assemblage in assemblages KN-3 and KN-4 at Knokke, it includes some of their most characteristic taxa such as *Spiroplectammina spectabilis, Haplophragmoides burrowsi* and *Miliammina paleocenica.* The lithological junctions used to define the limits of A3 and higher divisions in England are not clearly recognisable at Knokke, but, as in the eastern London Basin, can be identified approximately by the corresponding faunal changes.

In the London Basin, the entry of the nodosariid-rich benthonic foraminiferid assemblage ('NRA'), and the associated 'planktonic datum' are both just above the base of division B (KING 1981, Text-fig. 8). The base of the NRA in England is marked by the first appearance of *Nodosaria latejugata* and *Vaginulinopsis wetherellii.* At Knokke these both appear at the base of assemblage KN-5, together with other characteristic elements of the NRA including *Pseudoclavulina anglica, Cibicidoides crassus* and *Stilostomella midwayensis ('Nodosaria spinulosa').* The 'planktonic datum' is not as well defined in Belgium as it is in the London Basin, as planktonic foraminiferids are generally rare at equivalent levels. At Knokke, they occur very rarely from 245.5 m, 2 m above the base of benthonic assemblage KN-5.

Assemblage KN-5 is significantly richer in nodosariids than its equivalent BF-IV at other localities in Belgium, and is similar to the nodosariid-rich assemblage of the eastern London Basin, which occurs through division B and the lower part of division C. The base of division C corresponds in the London Basin to the first appearance of *Osangularia plummerae (='Osangularia* sp.' of KING 1981), the *'Osangularia*-datum'. This species has not previously been recorded in Belgium, but in the Knokke well it occurs commonly in the highest part of assemblage KN-5 between 222.5 m-219.0m. The *Osangularia*-datum can thus be identified here, and enables the base of division C to be correlated with a depth of 222.5 m in the Knokke well.

The abundance-level of planktonic foraminiferids at 220 m-222 m can be correlated with the similar abundance-peak in the top of division B and the lower part of division C in the eastern London Basin (KING 1981, Text fig. 46).

The abrupt faunal break at the top of assemblage KN-5 probably correlates with the top of the NRA in the London Basin, which occurs within the middle of division C.

The higher parts of the Flanders Member and the Egem Member at Knokke cannot be accurately correlated with sequences in the eastern London Basin due to the sparse faunas and some differences in facies. The occurence of *Spiratella* sp. A from 199.0m upwards indicates probable correlation of this part of the succession with division D. The presence of *Camptoceratops prisca* at 182.0m and higher levels indicates correlation with the *C. prisca* pteropod zone, which in the London Basin begins within the lower part of division E. The limited benthonic mollusc assemblage recorded between 169 m-156 m is consistent with division E assemblages recorded at Sheppey and in Essex (KING 1983). The limits of divisions D and E cannot be identified on the basis of the fauna at Knokke, and no dinoflagellate data is available for Knokke.

There is hope that more detailed study of the relevant sections will eventually enable lithostratigraphic correlations to be made between the sequence of alternating clays and silty/sandy units which forms the upper part of the London Clay Formation in the eastern London Basin (KING 1983), and the rather similar sequence in the upper Flanders Member at Knokke. The Egem Formation is probably a shallow marine sand unit similar to the Virginia Water Formation of the London Basin, but direct correlation is still not certain.

North Sea

Correlations can be made with the zonal schemes based on benthonic and planktonic microfossils recently established (KING 1983) (see Fig. 14). The North Sea planktonic zone NSP4, defined by the occurrence of *Coscinodiscus* sp. 1 and *C.* sp. 2, can be correlated (at least in part) with the interval containing these species at the base of the Ieper Formation (284.5 m-278.5 m). The base of planktonic zone NSP5 (*'Globigerina'* gr. *linaperta* zone) is correlated with the first appearance of planktonics at Knokke at 275 m. This zone extends up to the top of the planktonic abundance level at 220 m. Planktonic zone NSP6, characterised by a siliceous microflora with abundant large spherical reticulate radiolaria (*'Cenosphaera'* sp.) can be correlated with the siliceous radolarian and sponge spicule assemblage occurring in the upper part of the Ieper Formation and the lower part of the Panisel Formation. Spherical reticulate radiolaria referable to *'Cenosphaera'* are not common at Knokke, but are recorded at several levels between 189 m and 154 m.

Benthonic zone NSB2, characterised by a very limited microfauna of agglutinants, corresponds to assemblages KN-1 and KN-2. The base of zone NSB3, defined by the incoming of calcareous benthonic microfauna, can probably be correlated with the base of assemblage KN-3. Zone NSB3 includes assemblages KN-3 to KN-5. Zone NSB4 cannot be identified due to the absence of its index-species.

3. MONT-PANISEL FORMATION

A. LITHOSTRATIGRAPHY

The sequence is here divided into seven lithostratigraphic units (Fig. 7). Detailed correlation with the units of the Mt.-Panisel Formation seen at outcrop is difficult, except for the basal unit (Unit 1) wich corresponds to the Merelbeke Clay (P1m).

Unit 1 (135.0m-133.0m). Silty clay, homogenous, probably intensely bioturbated. Small pyrite 'sticks' and burrow fills are common.

Unit 2 (133.0m-c.124.75 m). Silty sand to sandy clayey silt; divided into two sub-units with transitional boundaries :

Sub-Unit 2a (133.0m-c.129.5 m). Silty clayey sand, argillaceous; very fine grained, glauconitic, (the glauconite is very fine grained), highly bioturbated, poorly sorted, with scattered medium to coarse sand grains and chips of flint; common fine woody debris; partly cemented (? by silica) to form sandstone at some levels.

Sub-Unit 2b (c. 129.5 m-c.124.75 m). Sandy clayey silt, glauconitic, highly bioturbated (very 'streaky'), rather poorly sorted, with fine grained sand content; common fine woody debris; partly cemented (?by silica) to form sandstone.

Unit 3 (c.124.75 m-c. 124.2 m). Sandy clayey silt, highly glauconitic (fine to coarse grained glauconite), highly bioturbated, poorly sorted, with medium sand content and occasional chips of flint. Glauconite is very abundant and very coarse at the base (124.6 m-124.75 m).

Unit 4 (c. 124.2 m-122.0m). Silty sand, very fine grained, glauconitic, highly bioturbated, with argillaceous streaks and patches.

Unit 5 (122.0m-116.0m). Sand, fine to medium grained, glauconitic, moderately well-sorted, bioturbated, with argillaceous streaks and clay-filled burrows.

Unit 6 (116.0 m-c.108.5 m). Silty sand and sandy silt: divided into two sub-units with transitional boundaries:

Sub-Unit 6a (116.0 m-112.5 m). Sandy silt/sandy clayey silt, glauconitic, rather poorly sorted, with fine to coarse sand content and occasional flint chips, thoroughly bioturbated, with discrete large vertical burrows, some clay-

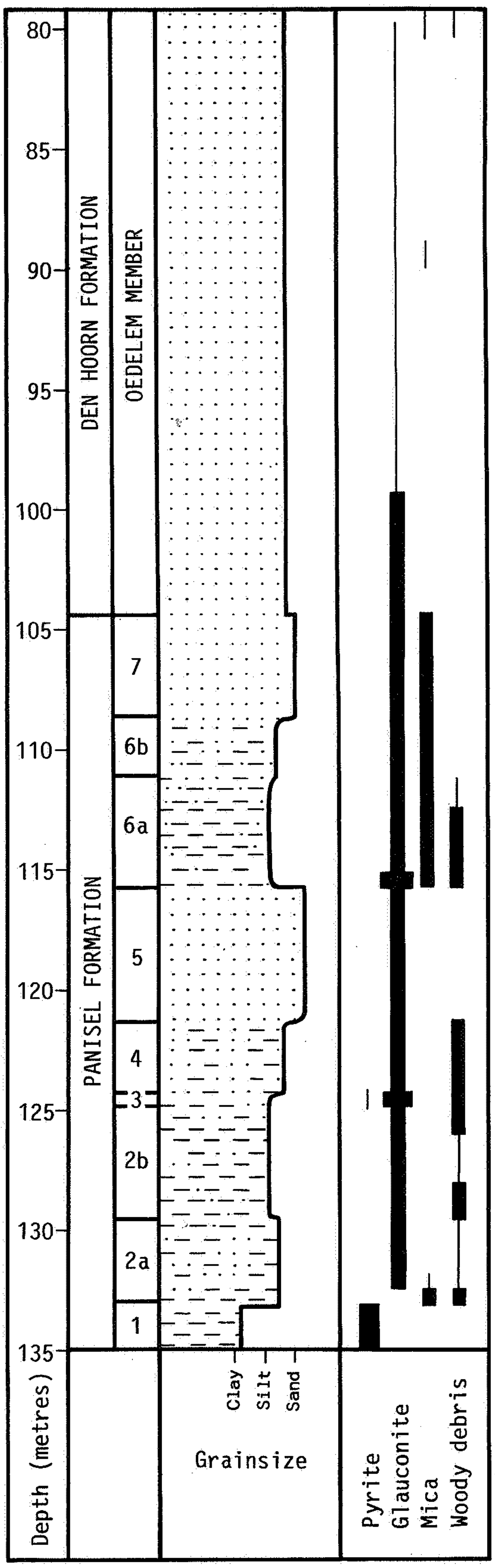

Fig. 7.- Lithostratigraphy of the Mont-Panisel and Knesselare (= Den Hoorn) Formations of the Knokke borehole

lined; large mica flakes common; fine woody debris common. Glauconite is particularly abundant at the base.

Unit 6b (c.112.0 m-c.108.5 m). Silty sand sandy silt, very fine grained, glauconitic, troughly bioturbated, with discrete large burrows and some argillaceous streaks.

Unit 7 (c.108.5 m-104.5 m). Very fine sand, glauconitic, highly bioturbated, moderately well sorted, with occasional argillaceous beds. The basal junction is transitional.

The sequence between 133 m and 108.5 m, although varying in grainsize, is characterized by the presence (and locally the abundance) of fine to medium-grained glauconite, the predominantly poor sorting, with coarse sand grains and angular flint fragments, the consistent occurrence of fine woody debris, and the partial induration at some levels, due to silica cementation. Highly glauconitic horizons at 124.7 m and 116 m appear to mark sedimentary discontinuities; each forms the base of coarsening-upwards sequences (Fig. 7).

B. BIOSTRATIGRAPHY

Due to its permeability, the Mont-Panisel Formation in the Knokke borehole has been partially decalcified. Units 1, 5 and 7 are almost entirely decalcified; at other levels the calcareous fossils are often somewhat corroded or encrusted by secondary calcite deposition.

Nevertheless, this borehole provides the most complete faunal sequence yet studied in Belgium, as most outcrops are completely decalcified.

Diatoms

Pyritised diatoms (small biconcave and biconvex *Coscinodiscus* spp.) are common in Unit 1. Occasional siliceous diatoms are recorded in Unit 2, and a distinctive «wide-rimmed» *Coscinodiscus* sp. is common at the base of Unit 6 (115.5 m-115.0 m).

Seeds

Specimens of the seed *Scirpus lakensis* occur rarely but consistently in Unit 2 between 133.5 m and 124.5 m. This species is characteristic of marginal marine and shallow marine sediments of the upper London Clay Formation (division D) and the Wittering division of the Bracklesham Group in the Hampshire Basin (COLLINSON *et al.*, 1981), and is believed to be derived from a marginal aquatic plant.

Benthonic foraminiferids

In Units 2, 4 and 6, a low-diversity assemblage (usually c.10 species) is recorded, dominated by *Anomalinoides affine, Elphidium laeve, Cibicidoides proprius, Cibicides lobatulus, Pararotalia curryi, 'Planulina' tendami* and polymorphinids. *Quinqueloculina* spp. and *Elphidium latidorsatum* occur at some levels.

No specimens of *Nummulites planulatus* have been recorded, although this species is recorded widely in the Mont-Panisel Formation at outcrop.

Planktonic foraminiferids

Planktonic foraminiferids (mainly *Acarinina* spp.) are recorded rarely (P 3%) in the upper part of Unit 2, where they occur consistently between 129.0 m and 125.5 m.

Sponge spicules

Siliceous sponge spicules, including «*Geodia*», occur commonly to abundantly through the section, except in Unit 1 and Unit 5. In Unit 1, small ovoid pyrite bodies which are believed to be casts of «*Geodia*» spicules are very common.

Annelids, bryozoa and corals

In the upper part of Unit 2 and in Unit 3, bryozoa (*Dittosaria* sp., *Lunulites* sp.), are present. Solitary corals (*Turbinolia* sp.) occur in the upper part of Unit 2. Serpulids (*Ditrupa* sp.) occur in Unit 3 and the lower part of Unit 4. These fossils have not been identified specifically.

Benthonic molluscs

In Unit 1 no identifiable specimens have been seen. In Unit 2 a diverse mollusc assemblage is present; at least 16 species of bivalves and gastropods are represented in the limited material available, although most cannot be specifically identified due to the small numbers of specimens and the rather fragmentary material. *Phacoides squamulus* and *Turritella* gr. *imbricataria* are the dominant species; *Phacoides squamulus* occurs abundantly at 131.0 m-130.0 m and 125.5 m-124.5 m. Other common species include *Trigonodesma lissa, Nuculana striata* and *Varicorbula muricina.* At higher levels no molluscs have been seen.

Pteropods

In Unit 1 pyritic moulds of pteropods are common, including *Spiratella* sp. nov. A, *S. mercinensis, Camptoceratops prisca* and apical fragments of cf. *Euchilotheca* sp.

In the upper part of Unit 2, rather crushed apical fragments of *Euchilotheca* cf. *elegans* are common. *Camptoceratops prisca* is probably also present, although represented only by very fragmentary material.

These records indicate correlation with pteropod Zone GP10 (*Euchilotheca* spp. Zone) of JANSSEN & KING (in press). *C. prisca* has not been recorded in GP10 previously, and it seems probable that GP10 can be divided into two subzones; a lower subzone with *C. prisca* and *Euchilotheca* (recorded here) - also in the top Egem Member and basal Panisel Formation at Egem, and an upper subzone without *C. prisca* (represented in the Earnley Formation in England and the lower Calcaire Grossier in the Paris Basin).

Ostracods

10 species of ostracods are recorded in the upper part of Unit 2. *Schizocythere appendiculata* is dominant, associated with *Cytheridea rigida punctata, Eopaijenborchella lomata* and isolated specimens of other species.

A single specimen of *Quadracythere* cf. *vermiculata* is recorded in Unit 3.

In Unit 6 only *Leguminocythereis bullata* is recorded; it occurs commonly at 115.05 m.

C. CORRELATION

Belgium

The basal clay unit (Unit 1) can be correlated lithologically with the Merelbeke Clay (Plm); this correlation is confirmed by the evidence of the pteropods. A washed residue from the Merelbeke Clay of the Kallo borehole (at 236.0 m), supplied by Willy WILLEMS, contained common pyrite moulds of pteropods of the same species as recorded at Knokke in Unit 1. Although no data is available from other localities, this suggests that this pteropod assemblage is probably widespread in the Merelbeke Clay.

The alternating units of poorly sorted glauconitic silts and sands which overlie the Merelbeke Clay at Knokke are similar lithologically and macrofaunally to the «**Sandy clays of Anderlecht**». Representatives of the Vlierzele Sands and the «Aalterbrugge Complex» cannot be identified. It is probable that these units are absent because of lateral facies changes, and it is also possible that the Mont-Panisel Formation is more complete at Knokke than in the outcropping areas. Detailed comparison is difficult due to the absence of adequate lithological/sedimentological logs for most outcrop and borehole sections. Several new lithostratigraphic units have recently been introduced (e.g. Pittem Member), but it is difficult to evaluate their significance.

The Knokke sequence includes at least two coarsening-upwards sequences which probably reflect transgressive-regressive events. It is probable that one of these sequences corresponds to the coarsening-upwards sequence from the Sandy Clays of Anderlecht to the Aalterbrugge Complex.

The microfaunas of the Mont-Panisel Formation elsewhere in Belgium are poorly known; most outcrops are decalcified. The Kallo borehole penetrated the Mont-Panisel Formation, but due to drilling difficulties little core was recovered (GULINCK, 1969).

A calcareous microfauna has been obtained by the author from the base of the Mont-Panisel Formation in the Ampe Quarry at Egem (the «grès tendre, très fossilifère» of De CONINCK & NOLF 1978, Unit 6 of ISLAM 1982). This comprises a foraminiferid assemblage dominated by *Cibicides,* polymorphinids, *Pararotalia curryi* and *Elphidium latidorsatum.* The ostracods include common *Schizocythere appendiculata, Eopaijenboschella lomata* and *Quadracythere* cf. *angusticostata.* The pteropods *Spiratella* sp. nov. A, *Camptoceratops prisca* and *Euchilotheca* sp. also occur at this level, and the bivalve *Phacoides squamulus* is common. This assemblage is rather similar to the fauna of Unit 2 at Knokke.

Woensdrecht borehole

The foraminiferid assemblage recorded by KAASSCHIETER (1961) from the Mont-Panisel Formation of the Woensdrecht borehole (in the beds assigned by him to the «Sandy Clays of Anderlecht- Sands of Vlierzele») is closely comparable to that recorded in the Knokke well. Of about 18 benthonic species recorded as «frequent to abundant» at Woensdrecht, all occur at Knokke, and the commonest species at Woensdrecht *(Cibicidoides proprius, C. lobatulus, Nonion affine, Globulina gibba, Guttulina irregularis, Planulina burlingtonensis* v. *tendami)* are all prominent members of the Knokke assemblage. No details are available of the other microfaunal groups at Woensdrecht.

DE CONINCK (1970) has demonstrated that there is a significant break between the Aalterbrugge Complex and the overlying Aalter Sands at outcrop, compared to the sequence in the Woensdrecht borehole, and Knokke is probably similar to Woensdrecht in this respect.

Southern England

The Mont-Panisel Formation in the Knokke borehole has yielded the ostracods *Cytheridea rigida punctata* and *Leguminocythereis bullata.* These are both recorded previously only from «Fisher's bed IV» of Whitecliff Bay and its lateral equivalents, including Unit W14 at Bracklesham Bay (CURRY *et al.,* 1977), within the Wittering division of the Bracklesham Group (HASKINS 1968-1971, KEEN 1978). The bivalve *Phacoides squamulus,* which is common in the lower part of the Panisel Formation, is one of the most common molluscs in Fisher's Bed IV, and is recorded at only one other level in the Hampshire Basin. However, these taxa have rather longer ranges in Belgium; *L. bullata* and *P. squamulus* are common at the top of the Ieper Formation (Egem Member) at Egem. Nevertheless, they probably indicate a general correlation between part of the Mont-Panisel Formation and Fisher's Bed IV. Fisher's Bed IV is overlain and underlain by marginal-marine sediments without calcareous fossils.

4.- KNESSELARE FORMATION

A. LITHOSTRATIGRAPHY

Oedelem Member

104.5 m-79.0 m: Silty sand, thoroughly bioturbated, very fine grained, moderately well sorted, glauconitic. The basal junction is sharply defined. Shell debris is present throughout, with prominent shell-rich horizons (shell beds) at c.99.0 m-98.0 m (dominated by *Venericor planicosta*) , at 88.25 m-87.5 m and at 82.5 m-81,8 m (dominated by *Venericardia carinata*).

B. BIOSTRATIGRAPHY

Calcareous fossils occur throughout the Knesselare Formation, although there is partial decalcification at some levels, indicated by corrosion or complete dissolution of shells and deposition of calcite overgrowths.

Problematica

Calcareous «problematica» are common between 97.5 m-80.0 m, although at some levels they are poorly preserved or indeterminate due to calcite overgrowths in optical continuity.

The species *Yvoniellina variabilis* and *Bignotella polygona* are dominant; at 93.0 m two apparently undescribed *Bignotella* species are also recorded.

Benthonic Foraminiferids

A relatively low-diversity assemblage is present, dominated by *Cibicidoides proprius,* polymorphinids (*Globulina* spp., *Guttulina* spp., *Pyrulina thouini*) and *Textularia agglutinans. Anoma-*

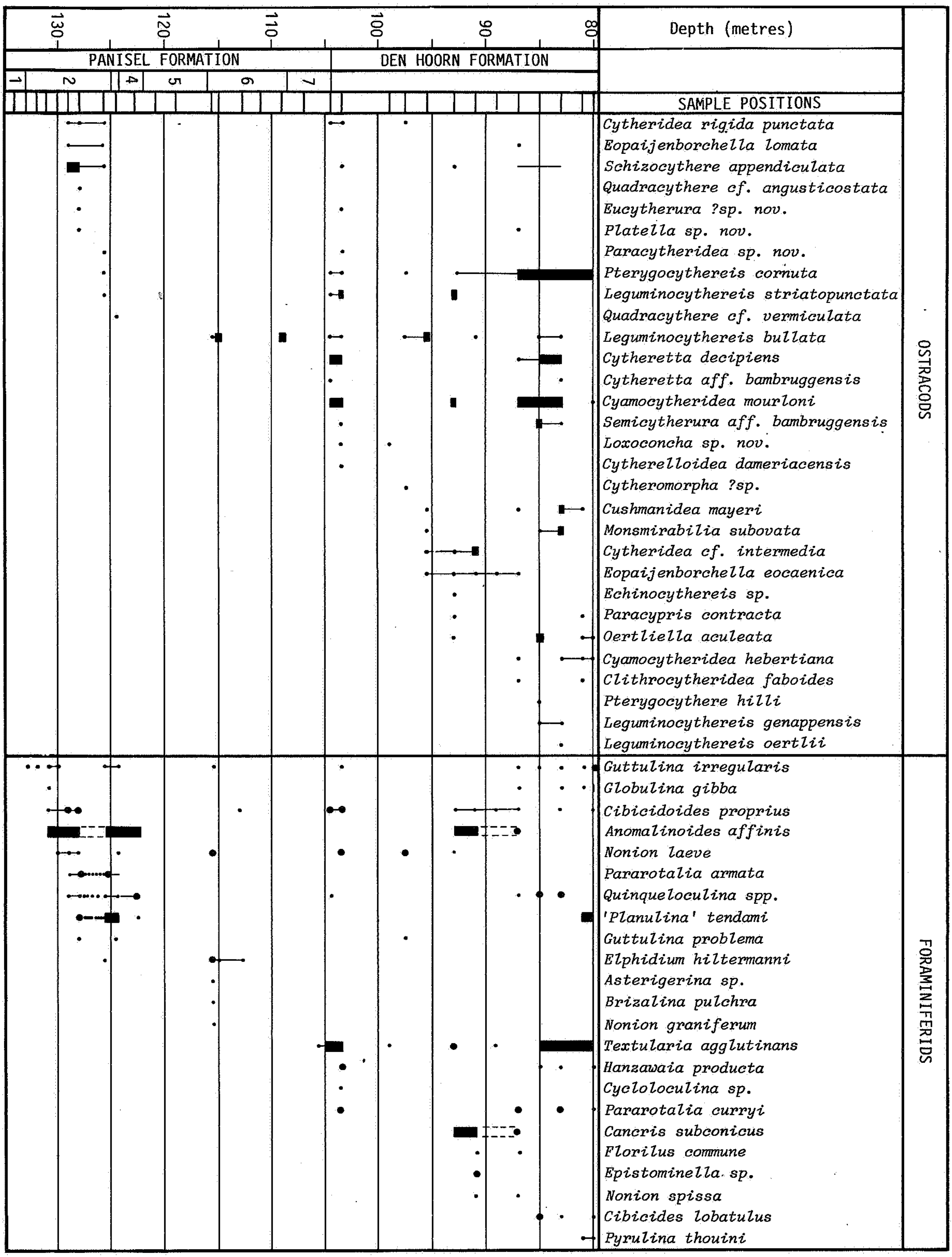

Fig. 8.- Distribution of benthonic foraminiferids and ostracods in the Mont-Panisel and Knesselare Formations of the Knokke borehole

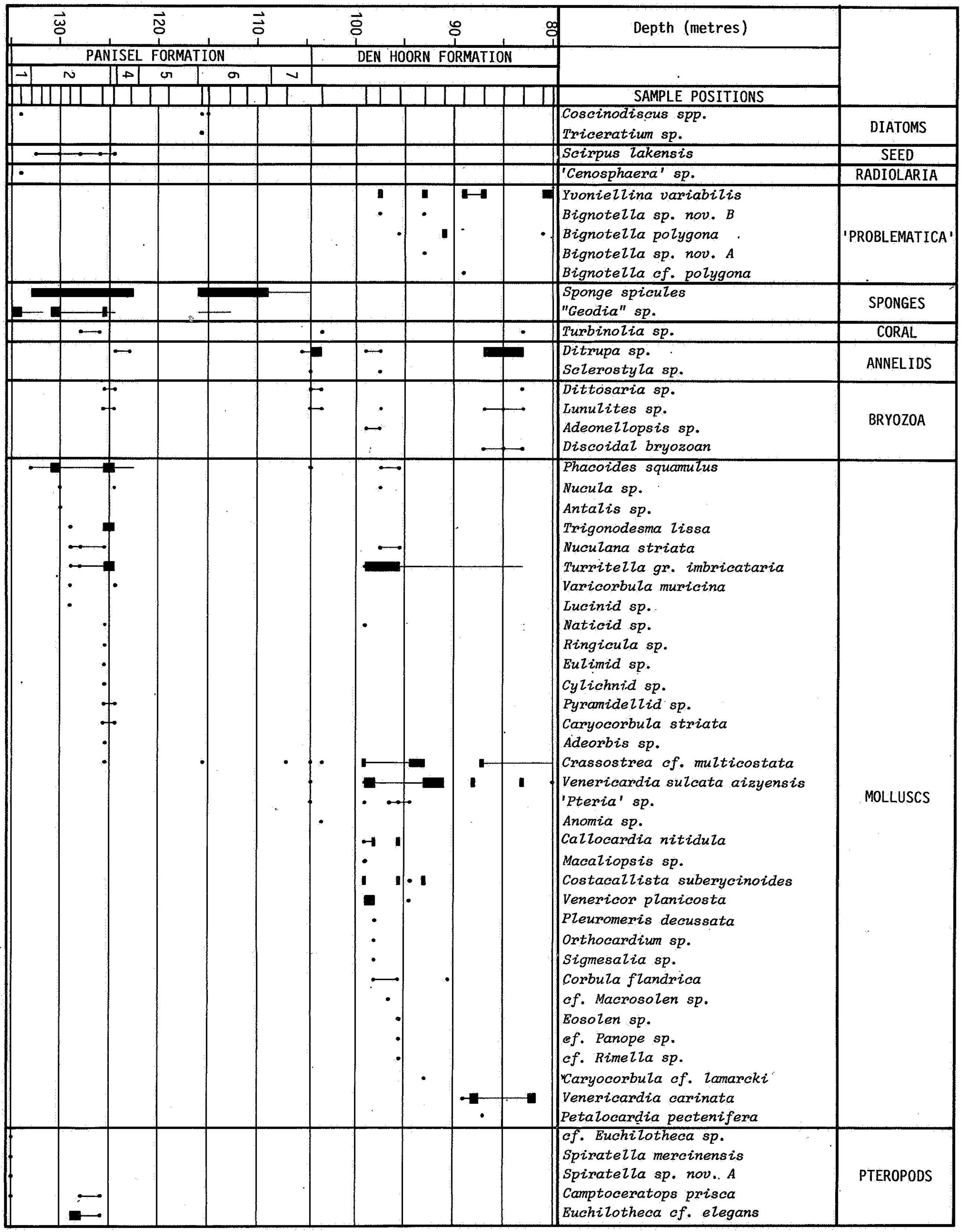

Fig. 9.- Distribution of fossils (excluding foraminiferids and ostracods) in the Mont-Panisel and Knesselare Formations of the Knokke borehole

linoides affine, Cancris subconicus, Cibicides lobatulus, Elphidium laeve, Florilus scaphum, Pararotalia curryi and *Quinqueloculina* spp. are common at some levels. «*Planulina*» *tendami* is common at the top of the sequence (81 m-80 m). The overall assemblage is similar to that in the Mont-Panisel Formation, except for the fairly consistent occurrence of *Textularia agglutinans.*

Planktonic Foraminiferids

These are recorded in several samples between 104.5 m and 89.0 m; **P** ranges from less than 1 % to c.5 %. Most specimens are referable to *Acarinina* or *Subbotina; Pseudohastigerina wilcoxensis* is recorded at 91.0 m.

Corals

The solitary coral *Turbinolia* sp. is recorded at two levels.

Bryozoa

The bryozoan *Lunulites* sp. is consistently present in most samples between 104.5 m and 83.0 m, while *Dittosaria* sp., *Adeonellopsis* sp. and an unidentified discoidal bryozoan are also recorded.

Annelids

The serpulid *Ditrupa* sp. occurs commonly at several levels between 104.5 m and 83.0 m. The serpulid *Sclerostyla* sp. is recorded at 104.5 m and 97.5 m.

Benthonic Molluscs

Mollusc shells and shell debris occur more or less commonly throughout the Knesselare Formation. The shells of the aragonitic molluscs are fragile and partially decalcified, but a number of genera and species have been identified (see Fig. 9).

Between 104.5 m and 99.0 m the rather sparse fauna includes *Phacoides squamulus, Crassostrea* cf. *multicostata* and *Venericardia sulcata gizyensis.* Between 99.0 m-98.0 m there is a shell bed dominated by *Venericor planicosta.* At this level there is an increase in diversity and abundance of the fauna; between 99.0 m and 93.0 m juvenile *Turritella* gr. *imbricataria* are abundant, associated with common *Crassostrea* cf. *multicostata, Venericardia sulcata gizyensis,* «*Pteria*» sp. and *Costacallista suberycinoides. Miodon decussata, Orthocardium* sp., *Phacoides squamulus,* corbulids and several other taxa are also recorded. Between 92.0 m and 90.0 m there is a less diverse fauna; only *Venericardia sulcata gizyensis* and *Turritella* gr. *imbricataria* are common. Between 89.0 m and 82.0 m *Venericardia carinata* is dominant, forming shell beds at two levels, associated with *V. sulcata gizyensis, Crassostrea* cf. *multicostata* and *Turritella* gr. *imbricataria.* At 81.0 m and 80.0 m a rather limited fauna includes *Crassostrea* sp. and *V. sulcata gizyensis.*

Ostracods

28 species of ostracods are recorded. The richest and most diverse assemblages occur in the upper part of the section, between 85 m-80 m, although this may reflect the rather poor preservation and partial decalcification at other levels.

The most common species are *Leguminocythereis* spp., *Pterygocythereis cornuta, Cyamocytheridea mourloni, Oertliella aculeata, Cushmanidea mayeri* and *Cytheretta decipiens.* Several species appear to be new and undescribed; this probably reflects the lack of previous study of ostracods from the Knesselare Formation.

The ranges of the *Leguminocythereis* species may be of significance in correlation. *L. striatopunctata* ranges throughout the sequence; *L. bullata* ranges from 104.5 m to 83 m, but is most common below 91 m; *L. genappensis* is recorded only from 85.0 m-83.0 m, while *L. oertlii* is found only at 83.0 m, where it is common.

C. CORRELATION

Belgium

The identification of this unit as the Oedelem Member of the Knesselare Formation is based on its lithological and palaeontological characteristics. The microfauna and macrofauna of the Oedelem Member have not yet been described in detail (except for the vertebrates and some records of benthonic foraminifera). The comparisons made here are based upon samples collected by the author from the upper part of the Oedelem Member at the «Wiedauw» locality, Oedelem, from a water-flush boring carried out by Dr. Dirk NOLF. This is the type locality of the Oedelem Member (NOLF, 1972).

The limited mollusc assemblage obtained from the Knokke borehole is closely comparable with the fauna from Wiedauw. The occurrence of abundant *Venericardia carinata* in the upper part of the formation at Knokke is significant, as this is a very common species at Wiedauw but occurs only rarely at other levels in Belgium. The foraminiferid assemblage at Wiedauw is dominated by *Cibicides* spp., polymorphinids, «*Planulina*» *tendami* and *Textularia agglutinans,* and is very similar to the assemblage from the upper part of the Oedelem Member at Knokke.

22 species of ostracods have been obtained from Wiedauw. They include *Cyamocytheridea mourloni, Cuneocythere subovata, Cushmanidea mayeri, Leguminocythereis genappensis, L. oertlii, L. striatopunctata, Pterygocythereis cornuta* and *Schizocythere appendiculata*. There is a close similarity between this assemblage and that present at Knokke between c.85 m-83 m.

The ostracod assemblage at the top of the Oedelem Member at Knokke and Wiedauw includes several species *(Leguminocythereis genappensis, L. oertlii, Cytheretta* aff. *bambruggensis)* which indicate an affinity with the Brussels Formation.

The «problematica» *Yvoniellina variabilis* and *Bignotella polygona* are common at Wiedauw; *Voorthuyseniella keiji* is also present. This assemblage is very close to that from Knokke. These species were originally described by WILLEMS (1975) from the top of the «Formation de Panisel» in the Kallo borehole (between 208.9 m and 19 m). According to DE CONINCK (1980) these beds can in fact be correlated (at least in part) with the Oedelem Member, on the basis of the microplankton. This agrees with the evidence of the «problematica». A «*Y. variabilis-B. polygona*» association can therefore probably be regarded as characteristic of the Oedelem Member.

The relationship of the Aalter Sands to the sequence at Knokke is uncertain. In the original description of the Den Hoorn (= Knesselare) Formation, Nolf (1972) interprets the Aalter Sands at Oedelem as occupying channels cut into the Oedelem Member. However, it is the fauna of the **lower** part of the Knesselare Formation at Knokke which most closely resembles the fauna of the Aalter Sands- particularly the presence of abundant *Venericor planicosta* at one level, and of *Phacoides squamulus,* a bivalve which is apparently absent from the Oedelem Member at its type locality, although common at Aalter and in the Panisel Formation. The microfauna of the Aalter Sands is poorly known and cannot yet contribute to resolution of this problem.

The Oedelem Member has been identified in the subsurface at Zeebrugge by DEPRET & WILLEMS (1983), where it is 35 m thick (as compared with between 25.5 m and 30.5 m at Knokke). GERITS *et al.* (1983) have described the benthonic foraminiferids from this locality.

Southern England

Venericardia carinata is an abundant and characteristic component of the mollusc assemblage of the lower beds of the Earnley Formation, (including the «*Cardita* bed» and the «*Turritella* bed», units E1 to E4 of CURRY *et al.,* 1977). CURRY (1967) already suggested correlation of the Aalter Sands with this part of the English succession on the basis of the general similarity of their lithology and mollusc assemblage. Some additional support is given to this correlation by the occurrence of the pteropod *Spiratella pygmaea* at Wiedauw (author's collection); in England this species is recorded only from the «*Cardita* bed» (CURRY, 1965).

The microfauna of the lower part of the Earnley Formation has not yet been sufficiently studied to provide any useful comparative data.

5.- BRUSSELS FORMATION

A. LITHOSTRATIGRAPHY

74.0 m-71.75 m. Very fine sand (maximum grainsize c.180μ), moderately well sorted, bioturbated, shelly, sparsely glauconitic (fine-grained glauconite comprises 1 %-3 % of the 125-250μ fraction).

B. BIOSTRATIGRAPHY (Fig. 10)

Problematica

Abundant calcareous «problematica» occur in the two samples studied. These are dominantly *Bignotella batiformis,* with *Yvoniellina (C) oedelemensis* at 74.0 m, and a distinctive new species of *Pseudarcella* (here referred to as *P.* sp. nov. A), which is rare at 73.0 m but occurs abundantly at 74.0 m. This species has not yet been seen elsewhere, but may prove to be a stratigraphically restricted form useful in correlation These are the first calcareous «problematica» to be recorded from the Brussels Formation.

Benthonic foraminiferids

Benthonic foraminiferids are common, but the diversity of the fauna is low. The assemblage is dominated by polymorphinids (*Guttulina, Globulina*), *Textularia agglutinans* and «*Planulina*» *tendami,* and is rather similar to the fauna from the Den Hoorn Formation. It resembles the fauna described from the Brussels Formation by KAASSCHIETER (1961).

Several well-preserved and unrolled specimens of *Nummulites laevigatus* are recorded, but it is not abundant.

Planktonic foraminiferids

No planktonic foraminiferids are recorded.

Bryozoa and corals

Specimens of the bryozoans *Dittosaria* and *Lunulites,* and the coral *Turbinolia,* are recorded. These have not been specifically identified.

Ostracods

A diverse ostracod assemblage is recorded, comprising at least 21 species. The characteristic Brussels Formation species *Aulocytheridea diegemensis* is common; other common taxa include *Leguminocythereis striatopunctata, Pterygocythereis cornuta* and *Eopaijenborchella longicosta.* One specimen of *Leguminocythereis genappensis,* another characteristic species of the Brussels Formation, is recorded at 74.0 m.

74.0	73.0	Depth (metres)	
•	•	*Epistominella oveyi*	FORAMINIFERIDS
•		*Pyrulina thouini*	
●		*Guttulina problema*	
●	•	*Guttulina irregularis*	
●		*Nonion laeve*	
●	●	*'Planulina' tendami*	
●	●	*Globulina gibba*	
●		*Textularia agglutinans*	
●	•	*Pararotalia curryi*	
•		*Nonionella wemmelensis*	
•	•	*Nummulites laevigatus*	
•	•	*Cibicides lobatulus*	
●	●	*Hanzawaia producta*	
•	●	*Anomalinoides acutus*	
•	•	*Cibicides westi*	
•	•	*Monsmirabilia subovata*	OSTRACODS
•		*Leguminocythereis oertlii*	
●	•	*Eopaijenborchella longicosta*	
•	●	*Schizocythere appendiculata*	
●	●	*Cyamocytheridea diegemensis*	
•		*Cytheridea sp.*	
•		*Loxoconcha cf. subovata*	
•		*Paracytheridea cf. oertlii*	
•		*Cytheromorpha sp.*	
•		*Cytheretta bambruggensis*	
•		*Leguminocythereis genappensis*	
●	●	*Leguminocythereis striatopunctata*	
•		*Echinocythereis scabropapulosa*	
●	•	*Pterygocythereis cornuta*	
•		*Schuleridea perforata perforata*	
●	•	*Eopaijenborchella eocaenica*	
•		*Clithrocytheridea mourloni*	
	•	*Clithrocytheridea faboides*	
	•	*Krithe rutoti*	
	●	*Brachycythere ventricosa*	
	•	*Hermanites paijenborchiana*	
•		*Yvoniellina oedelemensis*	PROBL.
●	●	*Bignotella batiformis*	
●	•	*Pseudarcella sp. nov. A*	

Fig. 10.- Distribution of microfossils in the Brussels Formation of the Knokke borehole

Molluscs

Indeterminate shell debris is common. At 73.0 m abundant specimens of the bivalve *Callista proxima* occur. Although partly crushed and very friable, they appear (by comparison with topotype specimens in the author's collection from the Brussels Formation of Neder Ockerzeel) to be referable to the subspecies *bruxellensis*: this is a characteristic mollusc of the Brussels Formation (GLIBERT, 1933).

C. CORRELATION

Belgium

The Brussels Formation is generally absent in northwestern Belgium, where the Lede Formation or the Wemmel Member rest unconformably on the Knesselare Formation or the Mont-Panisel Formation (see references in DEPRET & WILLEMS, 1983). The occurrence of reworked specimens of *Nummulites laevigatus* at the base of these units supports the suggestion that the Brussels Formation was formerly present in this area, as this species is recorded *in situ* in Belgium only in the Brussels Formation. DEPRET & WILLEMS (1983) record the occurrence of *N. laevigatus,* with an associated microfauna indicating a Lutetian date, in a thin interval between the Oedelem Member and the Wemmel Member in boreholes at Zeebrugge. They were uncertain if this interval was a representative of the Brussels Formation.

The Knokke borehole confirms the occurrence of *N. laevigatus in situ* in this area; the section btween 71.75 m-74.0 m contains characteristic microfaunal and macrofaunal elements of the Brussels Formation, and it seems reasonable to refer the interval to this Formation. The position of the base of the Brussels Formation is uncertain due to the core loss between 74 m-79 m. It is also uncertain if the very thin sequence preserved at Knokke and Zeebrugge is a condensed equivalent of the whole Brussels Formation, or represents only a part of it. It seems to be unclear from the published information whether *N. laevigatus* occurs elsewhere at a specific stratigraphic level within the Brussels Formation, or is restricted to a particular facies.

Southern England

The Brussels Formation can be correlated (at least in part) with the middle to upper part of the Earnley Formation (Earnley division, Bracklesham Group) by the presence of *Nummulites laevigatus* in both units. This correlation has been accepted for many years. No significant additional evidence has been obtained from this investigation.

6.- KALLO FORMATION

A. LITHOSTRATIGRAPHY

Wemmel Member

71.75 m-c.71.32 m: Very fine sand, bioturbated, highly glauconitic, with abundant shell debris and common *Nummulites orbignyi*. The base is coarser grained, with subrounded quartz and chert grains up to 2 mm in diameter. The position of the upper boundary is poorly defined due to mixing by bioturbation.

Asse Member (Asb)

c.71.32 m-65.9 m: Sandy clayey silt/clayey silt, rather poorly sorted, with abundant fine to coarse-grained glauconite. The sand content is mainly very fine to fine grained ($< 240\mu$). Intensely bioturbated, with glauconite concentrated into streaks and lenses. Small silt or clay-filled *Chondrites* burrows are also common. The upper boundary is transitional.

Ursel Member (Asc)

65.9 m-65.5 m: Silty clay, bioturbated, with lenses rich in glauconite, transitional to:

65.5 m-c.58.0 m: Silty clay, homogenous; with streaks of silt and silt-filled *Chondrites* burrows between c.63.9 m-c.62.0 m. Pyrite 'sticks' and 'lumpy' pyrite nodules are common.

c.58.0 m-c.50.10 m: Silty, sandy clay; fine-grained glauconite is present at some levels, *Chondrites* burrows are common. Pyrite 'sticks' and 'lumpy' nodules are common throughout.

Onderdale Member (s1)

c.50.10 m-c.48.0 m: Silty sand, very fine grained/sandy silt, bioturbated, micaceous, glauconitic (glauconite very fine to fine grained).

Zomergem Member (a2)

c.48.0 m-c.47.0 m: Sandy clayey silt, intensely bioturbated; *Chondrites* burrows are frequent. Pyrite «sticks» are common.

c.47.0 m-37.0 m: Silty clay, mainly homogeneous, but with siltier horizons between 44.0 m-43.0 m. Pyrite «sticks» are very common. The upper boundary is well-defined but intensely interburrowed.

Buisputten Member (s2)

37.0 m-33.0 m: Silty sand, very fine grained, intensely bioturbated; with thin clayey beds between 35.65 m-35.70 m. Micaceous, with fine-grained glauconite; small pyrite nodules are common.

B. BIOSTRATIGRAPHY

Diatoms

Pyritised diatoms are common throughout the section between 65 m-35 m, mainly small biconvex and biconcave specimens of *Coscinodiscus* spp. *Triceratium* sp. is common at several levels.

Radiolaria

Siliceous or pyritised radiolaria are present at several levels between 35.5 m-64 m; they are particularly common in the Zomergem Member. At 38.0 m-41.0 m, a well-preserved and diverse assemblage of siliceous radiolaria is present, including nasselariid, spongodiscid and spherical forms.

«Problematica»

Single specimens of *Voorthuyseniella gracilis* and *Bignotella batiformis* are recorded from the basal Asse Member. Both these species have been recorded from the Asse Member at Oedelem by KEIJ (1969, 1970).

Benthonic foraminiferids

The Wemmel Member contains an abundant and diverse benthonic foraminiferid assemblage, including abundant *Neoeponides karsteni* (=*Eponides schreibersi* of KAASSCHIETER), *Asterigerina bartoniana, Lamarckina cristellarioides* and *Spiroplectammina carinata.* The assemblage is very similar to the foraminiferid fauna recorded from the Wemmel Sands by KAASSCHIETER (1961, Table 6).

Nummulites orbignyi (=wemmelensis) is abundant, associated with common *N. variolarius.*

Specimens of *Nummulites laevigatus* are also common, mostly heavily abraded and often with chambers infilled by glauconite, but including some almost undamaged specimens. These are evidently reworked from the underlying Brussels Formation.

In the lower part of the Asse Member (at 71.0 m and 70.0 m), benthonic foraminiferids are abundant. *Asterigerina bartoniana* is very common, associated with *Spiroplectammina carinata, Cancris subconicus, Trifarina wilcoxensis, Loxostomum teretum, Neoeponides karsteni* and other species, forming an assemblage similar to that recorded elsewhere at this level by KAASSCHIETER (1961, Table 6). The microfauna has a somewhat «deeper-water» aspect than recorded at other localities in Belgium, indicated by the occurrence of the nodosariids *Nodosaria lateju-*

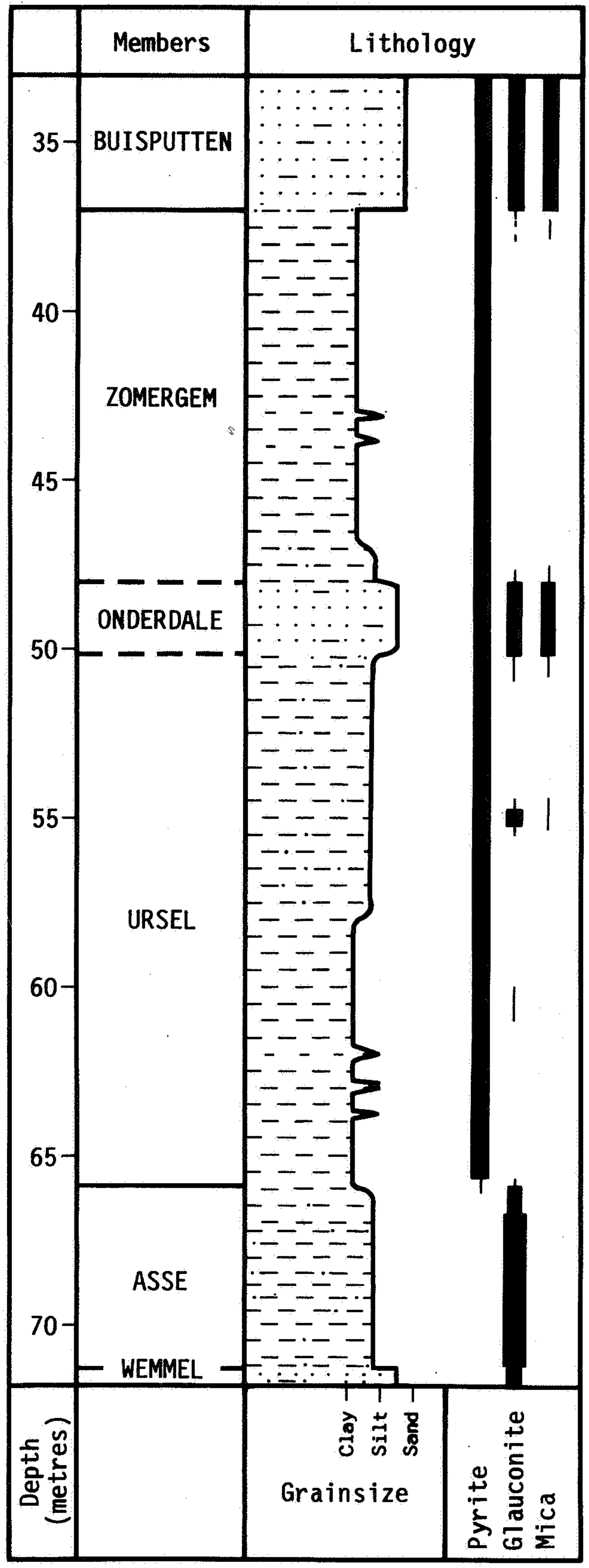

Fig. 11.- Lithostratigraphy of the Kallo Formation in the Knokke borehole

gata and *Vaginulinopsis* [*Marginulina*] *decorata*, and common *Globocassidulina globosa*.

Nummulites orbignyi occurs abundantly at 71.0 m, associated with *N. variolarius*. It is present rarely at 70.0 m.

Above 69.0 m a more restricted assemblage occurs, without *Nummulites*.

In the lower part of the Ursel Member, between 65.0 m-63.0 m, a different assemblage is present, dominated by *Cibicides pygmeus*, *C.* sp. cf. *tenellus*, *Anomalinoides acuta*, *Brizalina cookei*, *Spiroplectammina carinata*, *Uvigerina farinosa* and *Pseudoclavulina* sp. cf. *cocoaensis*. These are associated with AG1 agglutinants including *Haplophragmoides walteri* and *Glomospira charoides*. The AG1 ratio is 5-15 %. Above 63.0 m the section is decalcified. Only agglutinants persist, associated with pyritised moulds of *Cancris subconicus*; at still higher levels (58 m, 57 m) only occasional pyritised moulds of *C. subconicus* are recorded.

The Onderdale Member is barren. At the base of the Zomergem Member, at 47.3 m, several pyrite moulds of small, highly compressed *Nummulites* sp. are recorded. These are too poorly preserved for positive identification, as the septa are not visible, but comparison with specimens of Middle and Late Eocene *Nummulites* from the North Sea Basin indicates that there is a close resemblance only to *N. prestwichianus*. They are here referred to as *N.* cf. *prestwichianus*. Possible specimens of *Numulites* cf. *prestwichianus*, too poorly preserved to be definitely recognised even as *Nummulites*, also occur in the next higher sample studied (at 46.0 m). In higher levels of the Zomergem member, foraminiferids are represented only by rare and poorly preserved agglutinants, including corroded specimens of *Spiroplectammina* cf. *carinata*. A similar assemblage is recorded in the base of the Buisputten Member, at 35.5 m.

Planktonic foraminiferids

Planktonics occur very commonly in the Wemmel Member and in the basal Asse Member (P=30 % at 71.0 m, and 35 % at 70.0 m). *Pseudohastigerina* is the dominant form.

They occur much more rarely in the upper part of the Asse Member and the lower part of the Ursel Member (P=0.4 % at 63.0 m), but still including *Pseudohastigerina*. At higher levels they are absent.

Sponge spicules

Pyritised and siliceous sponge spicules are frequent in the Buisputten Member and the upper

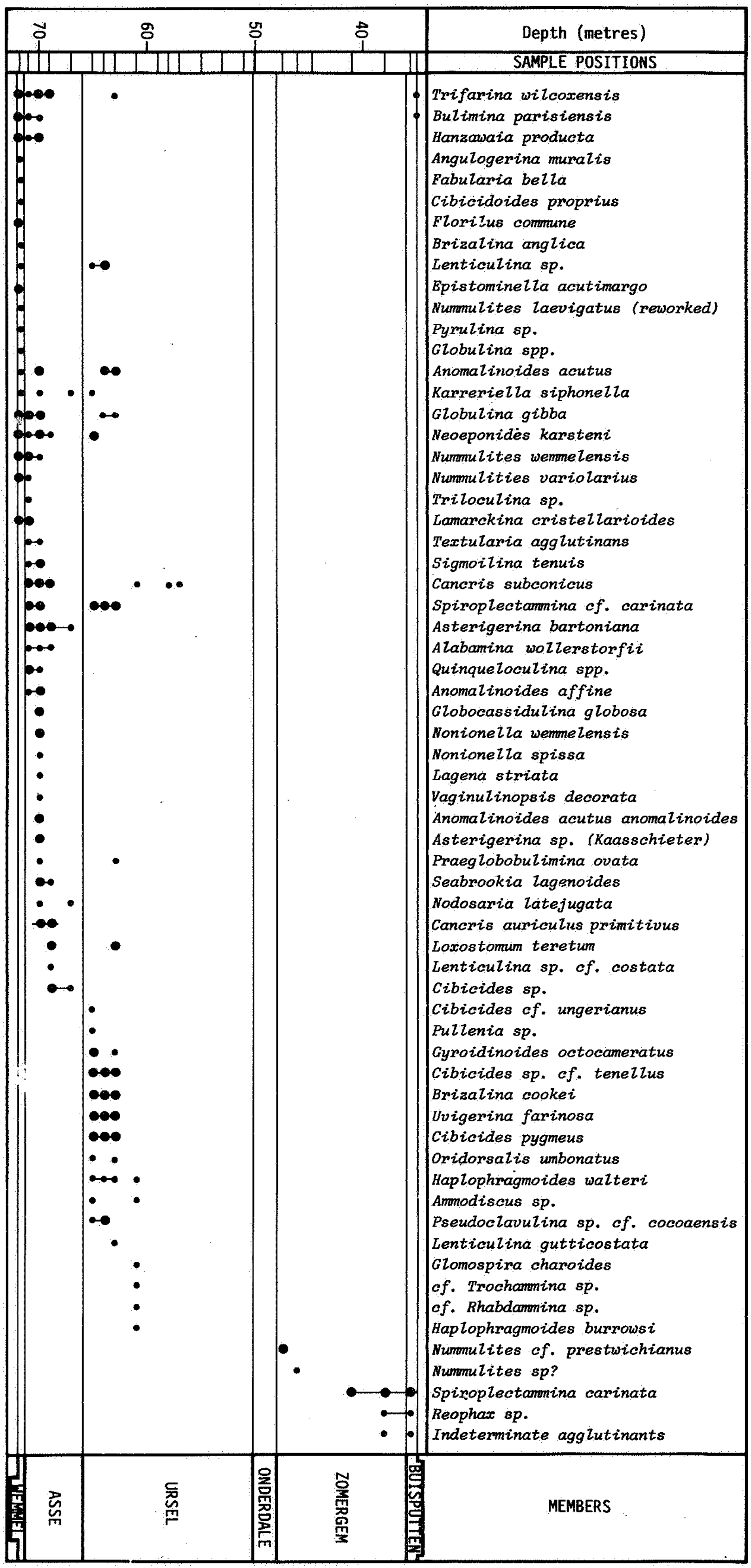

Fig. 12.- Distribution of benthonic foraminiferids in the Kallo Formation of the Knokke borehole

part of the Zomergem Member. Pyritised *?Geodia* spicules are common at several levels between 61.0 m-41.0 m.

Bryozoa

Orbitulopora petiolus is recorded in the base of the Asse Member.

Benthonic molluscs

Indeterminate bivalve shell debris is abundant in the Wemmel Member. This includes highly abraded ostreid (oyster) debris, which may be part of the reworked component. At the base of the Asse Member (71.0 m-70.0 m) poorly preserved molluscs are common. *Lentipecten* cf. *corneum* is frequent; this species is characteristic of the Asse Member. Above this level only pyrite casts and moulds are preserved; these are fairly common in the lower part of the Ursel Member, including *Turritella* sp. and *Pitar* sp.

Pteropods

Poorly preserved pteropods are recorded in the lower part of the Ursel Member. These include a specimen of cf. *Skaptotion bartonense* at 64.0 m. This suggests correlation with the *Skaptotion bartonense* pteropod Zone (Zone GP11 of JANSSEN & KING, in press).

Ostracods

A diverse ostracod assemblage is recorded from the Wemmel Member, comprising 22 species. The most common taxa are *Krithe bartonensis, Cyamocytheridea mourloni* and *Leguminocythereis striatopunctata.* The assemblage is very similar to that recorded elsewhere in the Wemmel Member (KEIJ, 1957). Several specimens of *?Idiocythere bartoniana* were found; this species has previously been recorded only in the upper part of the Bracklesham Group and in the Barton Beds, in the Hampshire Basin (HASKINS, 1968-1971, KEEN, 1978).

Ostracods are common at the base of the Asse Member, at 71.0 m and 70.0 m, including *Leguminocythereis striatopunctata, Krithe bartonensis, Cytheridea intermedia* and *Cyamocytheridea heizelensis.* They occur more rarely in the upper part of the Asse Member. The occurrence of isolated specimens of *Boldella deldenensis* and *Cytheretta eocaenica,* which are characteristic of the Lede Formation, suggets that some reworking from the Lede Formation may have taken place.

Rare fragments of *Pterygocythereis fimbriata fimbriata* are recorded in the lower part of the Ursel Member.

C. CORRELATION

Belgium

The Wemmel Member at Knokke rests unconformably on the Brussels Formation. The occurrence in the Wemmel Member and the basal Asse Member of fossils reworked from the Brussels Formation and the Lede Formation indicates that a more complete sequence formerly existed here.

The succession within the Kallo Formation can be readily correlated lithologically with the «standard» sequence present elsewhere in norther Belgium (JACOBS, 1978). The microfaunas of the Wemmel Member and the Asse Member are comparable to those recorded elsewhere in Belgium (KAASSCHIETER, 1961; KEIJ, 1957). The microfauna of the higher parts of the Kallo Formation («Kallo complex») has been studied only in the Kallo borehole (DROOGER *in* GULINCK, 1969) and is still very imperfectly known. This is partly due to the decalcification of much of the sequence, but as the present study has shown, it is still possible to obtain useful biostratigraphic data.

The record of a *Nummulites* horizon at the base of the Zomergem Member, and the presence of a diverse radiolarian assemblage in the upper part of the Zomergem Member, are new discoveries at Knokke, and further investigations may reveal their presence at other localities in Belgium. Their importance in regional correlation is discussed below.

Hampshire Basin

The Wemmel Member is currently correlated with the upper part of the Bracklesham Group (upper Selsey division/Huntingbridge division) (CURY *et al.*, 1977), based on comparisons of the mollusc and nannoplankton assemblages. The Asse Member is tentatively correlated with the Huntingbridge division. The benthonic macrofaunas and microfaunas are difficult to compare in detail, due to differences in facies between the two areas.

There is a major environmental break in Belgium at the base of the Ursel Member, from a shelly, sandy, glauconitic sequence with a diverse microfauna and marofauna (Wemmel and Asse Members) to a sequence of largely decalcified silty clays and sandy silts with limited microfauna, but common pyritised diatoms. This event is paralleled in the Hampshire Basin by a similar biofacies and lithofacies change at the base of the Huntingbridge division (see KEMP *et al.*, 1979). It

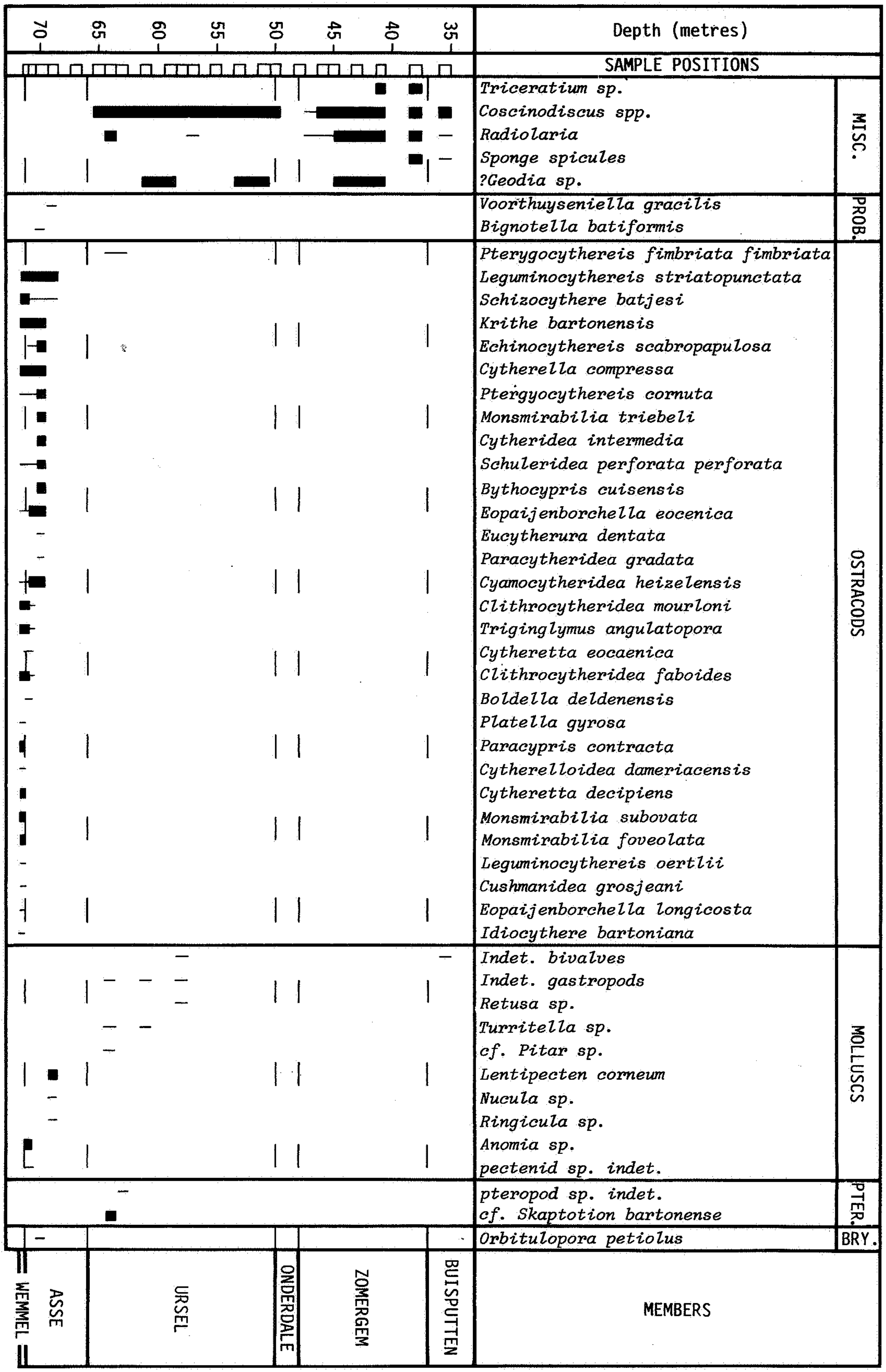

Fig. 13.- Distribution of fossils (excluding foraminiferids) in the Kallo Formation of the Knokke borehole

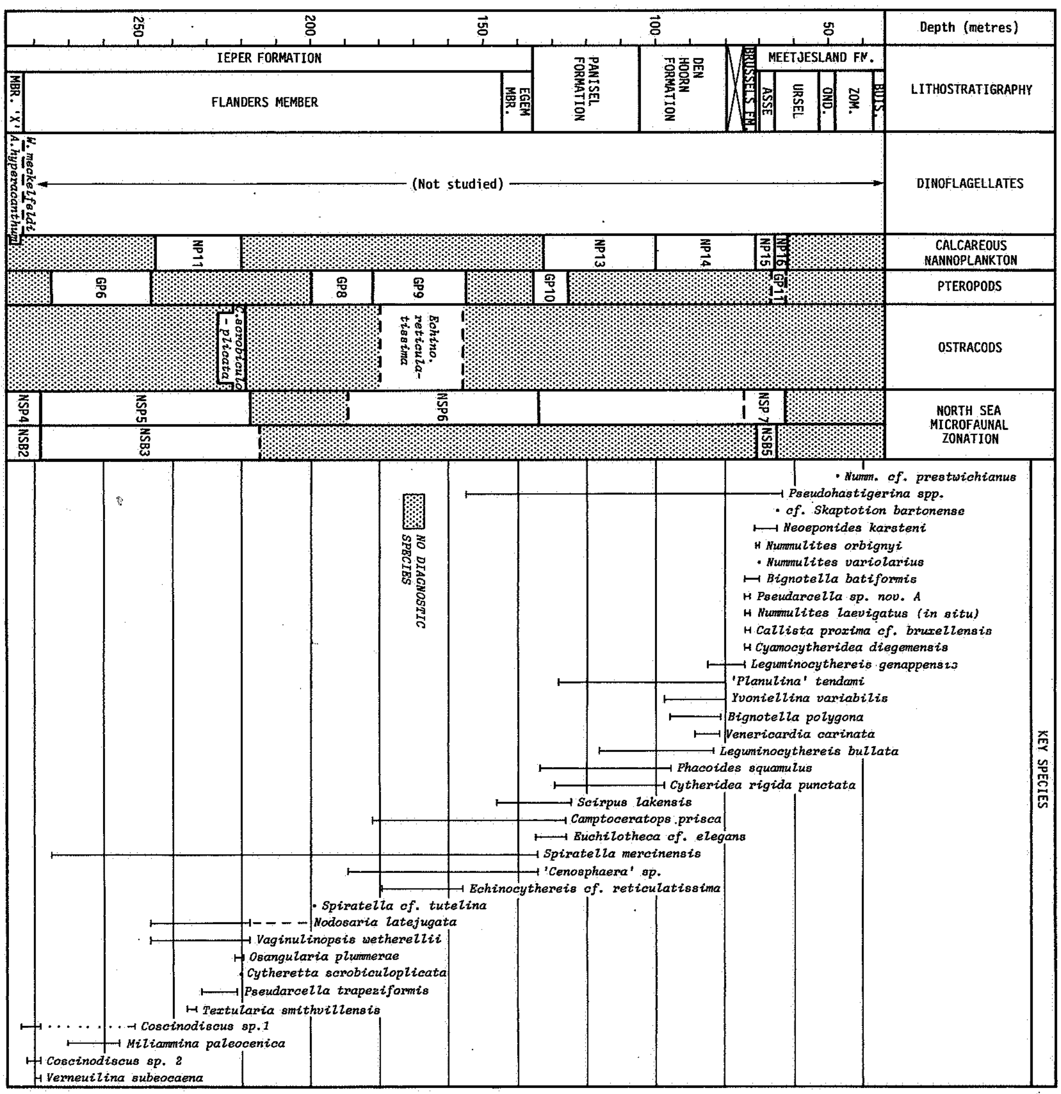

Fig. 14.- Significant fossil ranges and biostratigraphic zones identified in the Eocene sequence of the Knokke borehole

is suggested here that these events are due to eustatic sea-level changes and can be directly correlated.

Detailed correlation of the Ursel Member and higher units is difficult, but the Nummulite horizon in the Zomergem Member may be significant. *Nummulites* spp. occur at three discrete horizons in the Huntingbridge division and the Lower Barton Beds:

1) The Afton «Nummulite bed» (CURRY, 1942) in the lower part of the Huntingbridge division (KEMP *et al.*, 1979) *(N.* cf. *variolarius).*

2) The «*Nummulites prestwichianus*» bed and immediately overlying beds, at the base of the Barton Beds *(N. prestwichianus)*

3) Beds A2 and A3 in the upper part of the Lower Barton Beds *(N. rectus).*

The specimens from the base of the Zomergem Member are referred to *N.* cf. *prestwichianus.* It is therefore concluded that this Nummulite horizon at Knokke may be a correlative of the *Nummulites prestwichianus* bed. If correct, this is an important advance in the correlation of these beds. Other biostratigraphic evidence for dating and correlating these beds is discused in the following sections.

Southern North Sea

The Wemmel Member, the Asse Member and the lower part of the Ursel Member can be assigned to planktonic Zone NSP6 *(Pseudohastigerina wilcoxensis* zone) of KING 1983, by the occurrence of *Pseudohastigerina.* The same units contain *Neoeponides karsteni,* an index-fossil of the lower part of benthonic Zone NSB5 in the southern North Sea (KING, 1983).

A partially cored borehole (borehole 79/06) driled by the Institute of Geological Sciences in the southern North Sea (about 80km of the

Knokke borehole), is described by HUGHES (1981). It penetrated Oligocene (Rupelian) clays, resting on an Eocene sequence of alternating fine sands and clays (125.6 m-202.2 m). HUGHES briefly describes and illustrates a diverse and abundant siliceous radiolarian and diatom assemblage occurring through the interval 142 m to 202.2 m, which compares closely with the assemblage recorded here in the Zomergem Member. This evidence, together with the lithological similarity of the two sequences, indicates that these beds can be correlated with the Kallo Formation. More detailed comparison is difficult, as the upward extension of the radiolarian assemblage in the Kallo Formation is not yet known.

HUGHES records a glauconitic sand with *Nummulites* cf. *orbignyi* near the top of the Eocene sequence (at 130 m). This bed is probably too high to be correlated with the *Nummulites* cf. *prestwichianus* level recorded at the base of the Zomergem Member, and the illustrations suggest that the two records are of different species. It may well correlate with the sandstone containing *Nummulites* cf. *orbignyi* recorded by GULINCK (1969) at the base of the Bassevelde Sands in the Kallo Borehole (124-127 m).

7.- CORRELATION OF THE BELGIAN AND ENGLISH EARLY AND MIDDLE EOCENE

A. PREVIOUS STUDIES

The most recent general summary of the interregional correlation of the English and Belgian Eocene is by CURRY *et al.* (1978).

The additional biostratigraphic and lithostratigraphic data provided by the Knokke borehole, together with other recently published biostratigraphic information both in England and Belgium, suggests that the time is appropriate to briefly review and synthesise the correlation between the English and Belgian Early and Middle Eocene successions, and the correlation of both with the «standard» planktonic zonal schemes.

B. TECHNIQUES OF CORRELATION

Three distinct but interlocking techniques of correlation are available, each with limitations which must be taken into account:

1) Correlation of stratigraphic units with the standard planktonic zonal sequences (based on nannoplankton, planktonic foraminiferids or dinoflagellates). A more complete record of the nannoplankton and planktonic foraminiferid sequences exists in Belgium than in England, where the generally more marginal sequences are poor in planktonic foraminiferids (except for parts of the London Clay Formation) and contain a rather «patchy» sequence of nannoplankton. The dinoflagellate sequence is better known in England, but this is a reflection of more intensive study.

2) Correlation of biostratigraphic events or ranges of short-ranging species (e.g. the «*Osangularia* datum» in the London Clay Formation or the «*Nummulites prestwichianus* bed» at the base of the Barton Beds). In general, identification of events (first appearances of taxa or significant faunal «breaks») is more reliable than comparisons of the total vertical ranges of species, as the latter are more liable to be affected by environmental controls. A number of biostratigraphic events, e.g. the «planktonic datum» in the London Clay Formation (KING, 1981) are probably related to basin-wide or eustatic sea level changes, and are thus effectively synchronous, but care is always necessary in their use in correlation. The best criterion of their reliability is their consistency as tested against other techniques of correlations.

3) Correlation of distinctive lithostratigraphic units (e.g. the «ash-series») or of sedimentary «cycle-boundaries» (event-stratigraphy). «Paracyclic» sequences of sedimentation, which are most clearly exemplified in southern England (e.g. KING, 1981; PLINT, 1983), are probably largely the reflection of eustatic sea level changes. Similar types of cyclic sequence exist in Belgium, but direct correlation between these and the English cycles is still at an early stage. If calibrated by available biostratigraphic data, correlation of sedimentary cycles should eventually yield precise «tie-points» between the two areas.

All three techniques should obviously yield coherent results. If not, then the «most probable» solutions must be applied.

The data available from techniques (2) and (3) have been dealt with in preceding sections; here the available data on planktonic microfossils are summarised.

C. BELGIUM

Ieper Formation

Dinoflagellages

The *W. meckelfeldensis, D. similis, D. varielongituda* and *K. coleothrypta* dinoflagellate zones were identified in the Ieper Formation of the Kallo borehole by COSTA & DOWNIE (1976) and some of these zones are also recognised at other localities (see DE CONINCK, 1975).

The Mt. Heribu Member in the Mons-Tournai area is assigned to the *W. meckelfeldensis* zone (DE CONINCK *et al.*, 1983).

At Knokke, «Member X» is assigned to the upper part of the *A. hyperacanthum* zone, and the base of the Flanders Member corresponds approximately to the base of the *W. meckelfeldensis* zone (DUPUIS *et al.*, this volume). This confirms the correlation with the London Clay Formation discussed above, based on the diatoms and the microfaunal assemblages. The *W. astra* zone has not been recorded in Belgium, but is such a thin unit in the London Basin that it nevertheless could be present in the basal part of the Flanders Member. The *W. meckelfeldensis* zone is identified in the Mt. Heribu Member in its type-area (DE CONINCK *et al.*, 1983), confirming the diachronism of this unit. The position of the base of the *Wetzeliella similis* zone is only defined at Kallo (COSTA & DOWNIE, 1971), where it is recorded at 357 m.

The base of the *W. varielongituda* zone is again only defined at Kallo (COSTA & DOWNIE, 1976). Here it coincides with the «glauconite level».

The base of the *Kisselovia coleothrypta* zone is located in the upper part of the Flanders Member, at a depth of 266 m in the Kallo section (COSTA & DOWNIE, 1976).

The base of the *Kisselovia coleothrypta rotundata* zone (Zone W7 of CHATEAUNEUF & GRUAS - CAVAGNETTO) is identified by ISLAM (1981) in the topmost part of the Egem Member («Sables de Mons-en-Pevele») at Egem.

Calcareous nannoplankton

The lower part of the Ieper Formation has not yielded calcareous nannoplankton at any locality studied so far.

The *Discoaster binodosus* zone (Zone NP11) is identified between 245.50 m and 220.60 m at Knokke (STEURBAUT, this volume). Zone NP11 is identified at Kallo between 325.5 m and 306 m (MULLER & WILLEMS, 1981).

The upper part of the Ieper Formation is decalcified at Knokke. At Kallo the *Marthasterites tribrachiatus* zone (NP12) is identified between 306 m and the top of the Ieper Formation (MULLER & WILLEMS, 1981). The base of this zone corresponds to the «glauconite level», which may mark a discontinuity.

The upper part of the Flanders Member in the claypit at Kortemark is assigned to the *M. tribrachiatus* zone (NP12) by HAY & MOHLER (1967), MARTINI (1971:756) and BIGG (1982).

Planktonic foraminiferids

The planktonic foraminiferids from the Ieper Formation are mainly long-ranging taxa, but in the Mol borehole at 395.5 m-382.5 m, Zone P8 is identified (HOOYBERGHS, 1983a).

The first occurrence of *Pseudohastigerina wilcoxensis* in the upper Ieper Formation - and at equivalent levels in the uper London Clay - is not equivalent to the *Pseudohastigerina datum* of Berggren (base of subzone P6b) but is younger.

Mont-Panisel Formation & Knesselare Formation

The sequence from the Mont-Panisel Formation to the Asse Member all lies within the *K. coleothrypta* Zone (s.l.), but correlation with Zones W7 to W9 has not yet been established.

The Knokke borehole has yielded a good sequence of nannofossil assemblages from the Mont-Panisel Formation and Knesselare Formation (STEURBAUT, this volume) which for the first time permits an adequate evaluation of this interval. Zone NP 13 (*Discoaster sublodoensis* zone) is identified between 132.50 m and 103.50 m (within the Mont-Panisel Formation and the basal Knesselare Formation) and NP14 (*Discoaster lodoensis* zone) between 99.25 m and 80.0 m (within the Knesselare Formation). No data from other localities is available.

The planktonic foraminiferids of these formations have not yet been studied in detail.

Brussels Formation

Samples from the Brussels Formation at Knokke are assigned to nannoplankton Zone NP14 (*D. sublodoensis* zone) by STEURBAUT (this volume). This is in agreement with previous records of this zone from the Brussels Formation by MARTINI (1971:757) and MULLER (*in* DEPRET & WILLEMS, 1983).

The *Nannotetrina fulgens* zone (NP15) is recorded in the Brussels Formation by BIGG (1982). The zonal attributions of BIGG are discussed extensively by AUBRY (1983:19-20), and are not entirely consistent with other results.

The Brussels Formation at Mol and Haacht is assigned to planktonic foraminiferid Zone P10 by HOOYBERGHS (1983a, 1983b).

Lede Formation

The Lede Formation at Bambrugge was tentatively assigned to Zone NP15 by MARTINI (1971:758).

Planktonic foraminiferids from the Lede Formation at Mol and Balegem are referred by HOOYBERGHS (1983a, 1983b) to the uppermost part of Zone P10.

Kallo Formation

The Asse Member at Oedelem (CHATEAUNEUF, 1980) yields a dinoflagellate assemblage similar to that of the Upper Bracklesham Beds. This assemblage is referred by COSTA & DOWNIE (1976) to the *W. coleothrypta* zone (s.l.).

Dinoflagellates

At the depth of 129 m in the Kallo borehole (i.e. within a3) CHATEAUNEUF records an assemblage with *Rhombodinium porosum,* referable to the *R. porosum* Zone (W11).

Calcareous nannoplankton

A sample from the Wemmel Member of the Knokke borehole (at 71.65 m) is referred to the *N. fulgens* nannoplankton zone (NP15) (STEURBAUT, this volume). MARTINI (1971:758) had previously identified this zone at Wemmel itself.

BIGG (1982) refers the Wemmel Member to the *Reticulosphaera umbilica* subzone or higher (NP16). He attributes the presence of *Nannotetrina fulgens* in this unit to reworking; but this species has not been recorded in older units in Belgium.

A sample from the Asse Member at Knokke is assigned to NP15 (STEURBAUT, this volume). The Asse Member at Oedelem and in the Kallo borehole was assigned to NP16 by MARTINI (1971:758). These results are not necessarily inconsistent, as the highly glauconitic Asse Member may be a condensed deposit which spans the NP15/ NP16 boundary . Samples from the lower part of the Ursel Member at Knokke are assigned to NP16 (STEURBAUT, this volume). Above this level the Meetjesland Formation is decalcified; the *Nummulites prestwichianus* bed at Whitecliff Bay (Isle of White), which is believed to correlate with the base of the Zomergem Member, is probably in the upper part of Zone NP16 (AUBRY, 1983:268).

Planktonic foraminiferids

The upper part of the Wemmel Member in Brussels is referred to the Zone P11/P12 boundary (HOOYBERGHS, 1984a). The base of the Asse Member in the Mol borehole is referred to the upper part of Zone P12 (HOOYBERGHS, 1983a). The Berg Sands at Mol fall within Zones P14-P17 (HOOYBERGHS, 1983a).

D. SOUTHERN ENGLAND

Dinoflagellate zonations have been developed by COSTA & DOWNIE (1976), and BUJAK *et al.* (1980).

Several partial studies of the calcareous nannoplankton (see references in AUBRY, 1983) have been followed by a thorough investigation by AUBRY (1983), from which most of the following information is abstacted, with some revision and correction of the lithostratigraphic terminology.

Planktonic foraminiferids are of low diversity, and (except in parts of the London Clay Formation) are generally rare or absent. Some species are illustrated by MURRAY & WRIGHT (1974) and MURRAY *et al.* (1981), but their contribution to stratigraphical correlation with the standard planktonic foraminiferid zonation is at present negligible.

London Clay Formation

Dinoflagellates

Data up to 1980 are summarised in KING (1981). Subsequent revisions are as follows:

1) The base of the *Wetzeliella similis* zone falls within division A3 in the Hampshire Basin (KNOX *et al.*, 1983).

2) The base of the *Kisselovia coleothrypta* zone is within the upper part of division D in the Isle of Sheppey (Kent) (ISLAM, 1981; KING, 1984).

Calcareous nannoplankton

The lower part of the London Clay Formation (division A) has not yielded indigenous calcareous nannoplankton. BIGNOT & LEZAUD (1969) identified Zone NP11 at Alum Bay and Whitecliff Bay (Isle of Wight), most probably in division B2, although the precise level from which their samples were obtained is not stated. AUBRY (1983:59, fig. 13) refers samples from the Manor Farm Pit at Lower Swanwick (Hampshire) to the upper part of NP11 : this section is within division B2 (KING 1981, Text-Fig. 27). Higher levels in the London Clay Formation have so far not yielded calcareous nannofossils. Selected samples from divisions C, D and E submitted by the author to D. CURRY for study all proved to be barren (D. CURRY, pers. com.).

Bracklesham Group

The Bracklesham Group falls entirely within the *Kisselovia coleothrypta* zone of COSTA &

The Mt. Heribu Member in the Mons-Tournai area is assigned to the *W. meckelfeldensis* zone (DE CONINCK *et al.*, 1983).

At Knokke, «Member X» is assigned to the upper part of the *A. hyperacanthum* zone, and the base of the Flanders Member corresponds approximately to the base of the *W. meckelfeldensis* zone (DUPUIS *et al.*, this volume). This confirms the correlation with the London Clay Formation discussed above, based on the diatoms and the microfaunal assemblages. The *W. astra* zone has not been recorded in Belgium, but is such a thin unit in the London Basin that it nevertheless could be present in the basal part of the Flanders Member. The *W. meckelfeldensis* zone is identified in the Mt. Heribu Member in its type-area (DE CONINCK *et al.*, 1983), confirming the diachronism of this unit. The position of the base of the *Wetzeliella similis* zone is only defined at Kallo (COSTA & DOWNIE, 1971), where it is recorded at 357 m.

The base of the *W. varielongituda* zone is again only defined at Kallo (COSTA & DOWNIE, 1976). Here it coincides with the «glauconite level».

The base of the *Kisselovia coleothrypta* zone is located in the upper part of the Flanders Member, at a depth of 266 m in the Kallo section (COSTA & DOWNIE, 1976).

The base of the *Kisselovia coleothrypta rotundata* zone (Zone W7 of CHATEAUNEUF & GRUAS - CAVAGNETTO) is identified by ISLAM (1981) in the topmost part of the Egem Member («Sables de Mons-en-Pevele») at Egem.

Calcareous nannoplankton

The lower part of the Ieper Formation has not yielded calcareous nannoplankton at any locality studied so far.

The *Discoaster binodosus* zone (Zone NP11) is identified between 245.50 m and 220.60 m at Knokke (STEURBAUT, this volume). Zone NP11 is identified at Kallo between 325.5 m and 306 m (MULLER & WILLEMS, 1981).

The upper part of the Ieper Formation is decalcified at Knokke. At Kallo the *Marthasterites tribrachiatus* zone (NP12) is identified between 306 m and the top of the Ieper Formation (MULLER & WILLEMS, 1981). The base of this zone corresponds to the «glauconite level», which may mark a discontinuity.

The upper part of the Flanders Member in the claypit at Kortemark is assigned to the *M. tribrachiatus* zone (NP12) by HAY & MOHLER (1967), MARTINI (1971:756) and BIGG (1982).

Planktonic foraminiferids

The planktonic foraminiferids from the Ieper Formation are mainly long-ranging taxa, but in the Mol borehole at 395.5 m-382.5 m, Zone P8 is identified (HOOYBERGHS, 1983a).

The first occurrence of *Pseudohastigerina wilcoxensis* in the upper Ieper Formation - and at equivalent levels in the uper London Clay - is not equivalent to the *Pseudohastigerina datum* of Berggren (base of subzone P6b) but is younger.

Mont-Panisel Formation & Knesselare Formation

The sequence from the Mont-Panisel Formation to the Asse Member all lies within the *K. coleothrypta* Zone (s.l.), but correlation with Zones W7 to W9 has not yet been established.

The Knokke borehole has yielded a good sequence of nannofossil assemblages from the Mont-Panisel Formation and Knesselare Formation (STEURBAUT, this volume) which for the first time permits an adequate evaluation of this interval. Zone NP 13 (*Discoaster sublodoensis* zone) is identified between 132.50 m and 103.50 m (within the Mont-Panisel Formation and the basal Knesselare Formation) and NP14 (*Discoaster lodoensis* zone) between 99.25 m and 80.0 m (within the Knesselare Formation). No data from other localities is available.

The planktonic foraminiferids of these formations have not yet been studied in detail.

Brussels Formation

Samples from the Brussels Formation at Knokke are assigned to nannoplankton Zone NP14 (*D. sublodoensis* zone) by STEURBAUT (this volume). This is in agreement with previous records of this zone from the Brussels Formation by MARTINI (1971:757) and MULLER (*in* DEPRET & WILLEMS, 1983).

The *Nannotetrina fulgens* zone (NP15) is recorded in the Brussels Formation by BIGG (1982). The zonal attributions of BIGG are discussed extensively by AUBRY (1983:19-20), and are not entirely consistent with other results.

The Brussels Formation at Mol and Haacht is assigned to planktonic foraminiferid Zone P10 by HOOYBERGHS (1983a, 1983b).

Lede Formation

The Lede Formation at Bambrugge was tentatively assigned to Zone NP15 by MARTINI (1971:758).

Planktonic foraminiferids from the Lede Formation at Mol and Balegem are referred by HOOYBERGHS (1983a, 1983b) to the uppermost part of Zone P10.

Kallo Formation

The Asse Member at Oedelem (CHATEAUNEUF, 1980) yields a dinoflagellate assemblage similar to that of the Upper Bracklesham Beds. This assemblage is referred by COSTA & DOWNIE (1976) to the *W. coleothrypta* zone (s.l.).

Dinoflagellates

At the depth of 129 m in the Kallo borehole (i.e. within a3) CHATEAUNEUF records an assemblage with *Rhombodinium porosum,* referrable to the *R. porosum* Zone (W11).

Calcareous nannoplankton

A sample from the Wemmel Member of the Knokke borehole (at 71.65 m) is referred to the *N. fulgens* nannoplankton zone (NP15) (STEURBAUT, this volume). MARTINI (1971:758) had previously identified this zone at Wemmel itself.

BIGG (1982) refers the Wemmel Member to the *Reticulosphaera umbilica* subzone or higher (NP16). He attributes the presence of *Nannotetrina fulgens* in this unit to reworking; but this species has not been recorded in older units in Belgium.

A sample from the Asse Member at Knokke is assigned to NP15 (STEURBAUT, this volume). The Asse Member at Oedelem and in the Kallo borehole was assigned to NP16 by MARTINI (1971:758). These results are not necessarily inconsistent, as the highly glauconitic Asse Member may be a condensed deposit which spans the NP15/ NP16 boundary . Samples from the lower part of the Ursel Member at Knokke are assigned to NP16 (STEURBAUT, this volume). Above this level the Meetjesland Formation is decalcified; the *Nummulites prestwichianus* bed at Whitecliff Bay (Isle of White), which is believed to correlate with the base of the Zomergem Member, is probably in the upper part of Zone NP16 (AUBRY, 1983:268).

Planktonic foraminiferids

The upper part of the Wemmel Member in Brussels is referred to the Zone P11/P12 boundary (HOOYBERGHS, 1984a). The base of the Asse Member in the Mol borehole is referred to the upper part of Zone P12 (HOOYBERGHS, 1983a). The Berg Sands at Mol fall within Zones P14-P17 (HOOYBERGHS, 1983a).

D. SOUTHERN ENGLAND

Dinoflagellate zonations have been developed by COSTA & DOWNIE (1976), and BUJAK *et al.* (1980).

Several partial studies of the calcareous nannoplankton (see references in AUBRY, 1983) have been followed by a thorough investigation by AUBRY (1983), from which most of the following information is abstacted, with some revision and correction of the lithostratigraphic terminology.

Planktonic foraminiferids are of low diversity, and (except in parts of the London Clay Formation) are generally rare or absent. Some species are illustrated by MURRAY & WRIGHT (1974) and MURRAY *et al.* (1981), but their contribution to stratigraphical correlation with the standard planktonic foraminiferid zonation is at present negligible.

London Clay Formation

Dinoflagellates

Data up to 1980 are summarised in KING (1981). Subsequent revisions are as follows:

1) The base of the *Wetzeliella similis* zone falls within division A3 in the Hampshire Basin (KNOX *et al.*, 1983).

2) The base of the *Kisselovia coleothrypta* zone is within the upper part of division D in the Isle of Sheppey (Kent) (ISLAM, 1981; KING, 1984).

Calcareous nannoplankton

The lower part of the London Clay Formation (division A) has not yielded indigenous calcareous nannoplankton. BIGNOT & LEZAUD (1969) identified Zone NP11 at Alum Bay and Whitecliff Bay (Isle of Wight), most probably in division B2, although the precise level from which their samples were obtained is not stated. AUBRY (1983:59, fig. 13) refers samples from the Manor Farm Pit at Lower Swanwick (Hampshire) to the upper part of NP11 : this section is within division B2 (KING 1981, Text-Fig. 27). Higher levels in the London Clay Formation have so far not yielded calcareous nannofossils. Selected samples from divisions C, D and E submitted by the author to D. CURRY for study all proved to be barren (D. CURRY, pers. com.).

Bracklesham Group

The Bracklesham Group falls entirely within the *Kisselovia coleothrypta* zone of COSTA &

DOWNIE (1976). The base of the *K. c. rotundata* zone of CHATEAUNEUF & GRUAS-CAVAGNETTO (W7) lies withing the Wittering division, at the base of Unit W14 at Bracklesham Bay (Sussex) - equivalent to the middle of Fisher's bed IV at Whitecliff Bay (ISLAM, 1980). The position of Zones W8 and W9 has not yet been identified.

The lowest horizon in the Bracklesham Group to yield calcareous nannofossils is Fisher's bed IV at Bracklesham Bay, in the middle of the Wittering division (CURRY *et al.*, 1977). AUBRY (1983:60, 63, Figs. 17, 18) identifies Zone NP12 at both localities, and probably also the lower part of Zone NP13 at Whitecliff Bay.

The next level to yield an adequate assemblage is the *Nummulites laevigatus* bed (Unit E8) in the Earnley Formation (middle of the Earnley division), which probably lies within the upper part of Zone NP14 (AUBRY, 1983: 71, 74).

The Selsey division yields richer assemblages; Zone NP15 is identified in Fisher's beds 19 and 20 at Bracklesham Bay (Units S9 and S10 of CURRY *et al.*, 1977) by AUBRY (1973:71) and at equivalent levels elsewhere by MARTINI (1971:758) and HODSON & WEST (1970). The base of Zone NP16 is identified in Fisher's bed 21(= Unit S11) (AUBRY, 1983:71).

Samples from the stream-section at Studley Wood, in the New Forest (Hampshire) are referred to Zone NP16 by AUBRY (1983: 71, Fig. 21). Both the top of the Selsey division (bed A of STINTON, 1970) and the base of the Huntingbridge division (beds B-D) are exposed here. It is not clear from AUBRY's diagram which levels were sampled, but according to D. CURRY (pers. comm.) beds A (sample 7), and B were sampled. Samples from the top of the Huntingbridge division at Alum Bay are also referred to Zone NP16 (AUBRY, 1983:74).

Barton Beds

The base of the *Rhombodinium draco* zone (W10) corresponds to the base of the Barton Beds (the *Nummulites prestwichianus* bed) (BUJAK *et al.*, 1980). The base of the *R. porosum* zone (W11) lies within the Middle Barton Beds.

The Lower Barton Beds are referred to Zone NP16, and the Middle and Upper Barton Beds to Zone NP17 (AUBRY, 1983:75).

CONCLUSIONS

The data summarised above, taken together with the biostratigraphic and lithostratigraphic correlations discussed in previous sections, are synthesised in Figure 15. The following comments apply to this figure :

1) The time-scale, and the correlation between the P Zone and NP Zones are taken from BERGGREN *et al.* (1985). Correlation between the Wetzeliellaceae (dinoflagellate) zones and these zones are based on BERGGREN *et al.* (1985), modified by the relationships observed in the present study.

The zonal schemes used on Figure 15 are taken from BERGGREN *et al.* (1985). The dinoflagellate zonal scheme is based on the Wetzeliellaceae and is a combination of the schemes of COSTA & DOWNIE (1976), and CHATEAUNEUF & GRUAS-CAVAGNETTO (1978).

2) The stratigraphic breaks shown between the formations in Belgium are of arbitrary length, although as far as possible they conform to the available data. They are intended to indicate the probable incompleteness of the section, as indicated by the regional overstepping and truncation, and the frequent intraformational reworking of fossils.

3) The correlations based on benthonic foraminiferids, pteropods, dinoflagellates and calcareous nannoplankton produce concordant results.

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The late Willy WILLEMS (formerly Geological Institute, R.U. Gent) provided much assistance in the study of Belgian stratigraphy and microfaunas, and without the basis of his extensive work, particularly on the Ieper Formation, the present study would have been very difficult. His recent tragic death has deprived us of a much respected colleague and friend.

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Dennis CURRY (Itchenor, West Sussex) reviewed the manuscript and made useful suggestions for its improvement.

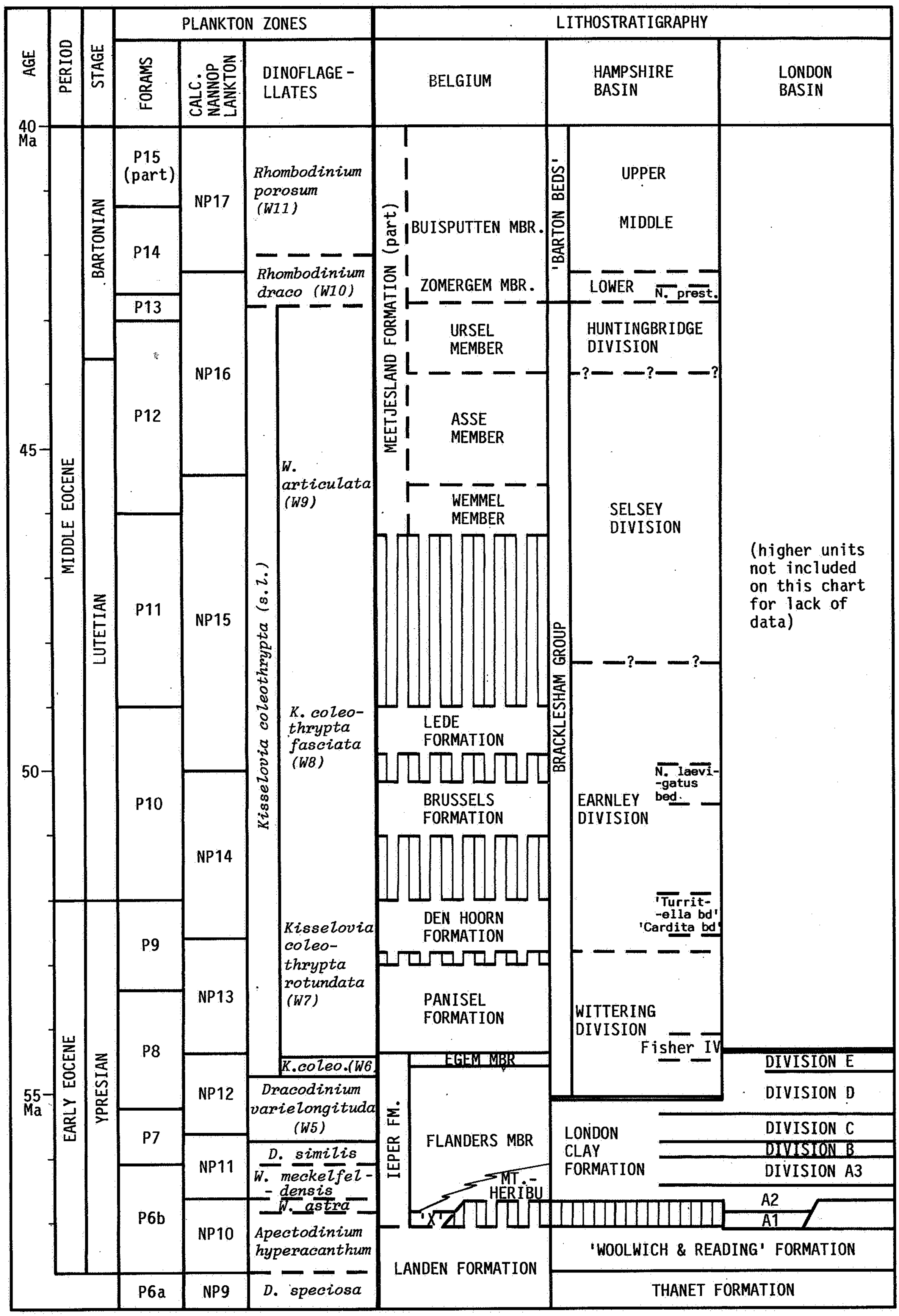

Fig. 15.- Correlation of the Early and Middle Eocene successions in Belgium and southern England with the standard planktonic zonal sequences

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Chapter VIII

TOP OCCURRENCE OF SELECTED DINOPHYCEAE FROM THE CRETACEOUS OF THE DE HAAN WELL AND CORRELATION WITH THE KNOKKE WELL

by

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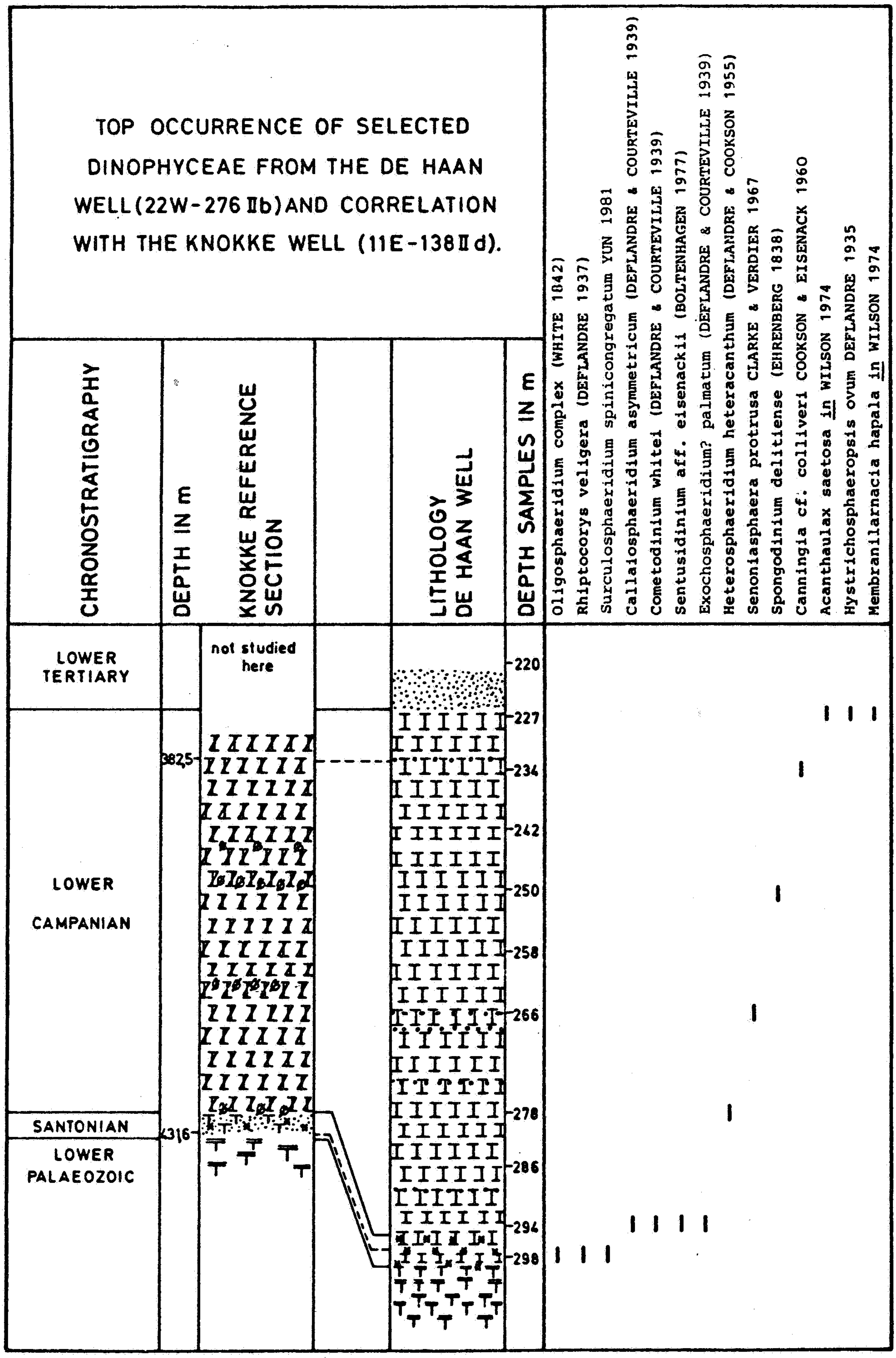
The De Haan well (Klemskerke, 22 W-276 IIb) is located in the extreme northwest of Belgium, 5 km northeast of Ostend (coordinates x= 54.582, y= 216.649, z= +5.02 m). It was drilled on behalf of the Belgian Geological Survey. The percussion drilled well penetrated 41,5 m of Quaternary sediments, 185,5 m of Tertiary sediments, 72,5 m of Mesozoic and 22,0 m of cored Palaeozoic sediments and stopped at a depth of -321,0 m. The Mesozoic sediments consist of 68,5 m of white chalk interbedded with flint horizons (from -226,5 m to -295,0 m) and 4 m of glauconiferous sandy chalk (from -295,0 m to -299,0 m). The Cretaceous interval is overlain by Lower Tertiary sand and rests unconformably on Lower Palaeozoic shales.

10 ditch-cutted samples from the Cretaceous interval have been analyzed for palynological investigation. They were prepared using standard maceration methods (WILSON, 1971). One sample was barren (-258,0 m), seven yielded well preserved, rich and diversified assemblages -227,0 m, -234,0 m, -242,0 m, -250,0 m, -266,0 m, -278,0 m, -286,0 m). The two lowermost ones presented well preserved but less diverse assemblages (-294,0 m and -298,0 m). The associations were furthermore characterized by a great amount of palynodebris. During the investigation, emphasis was laid on Dinophyceae. The top occurrence of some selected Dinophyceae is given in fig. 1. These top occurrences together with the assemblages are referred to the well known reference section of the Knokke well (11E-138 IId), situated 25 km more to the NE along the coast. Additional data concerning stratigraphical distribution of Dinophyceae is obtained from CLARKE & VERDIER (1967), FOUCHER (1979, 1980), WILLIAMS & BUJAK (1985) and WILSON (1971, 1974).

73 Dinophyceae species with Cretaceous and post-Cretaceous range have been recorded. Top sample -227,0 m yields *Hystrichosphaeropsis ovum* DEFLANDRE 1935, *Acanthaulax saetosa in* WILSON 1974 and *Membranilarnacia hapala in* WILSON 1974. In the Knokke well they are not found above -376,8 m depth. This means that the top sequence of the Cretaceous interval in the De Haan well has an Early Campanian or older age. Other evidence is given by FOUCHER (1985) who has found that *Acanthaulax saetosa* is limited to the Vaals Formation in the Maastricht area (Early Campanian). *Canningia* cf. *colliveri* COOKSON & EISENACK 1960 has its top occurrence in sample -234,0 m. This allows a fairly good correlation with level -382,5 m of the Knokke reference section (middle Early Campanian). *Spongodinium delitiense* (EHRENBERG 1838), *Senoniasphaera protrusa* CLARKE & VERDIER 1967 and *Heterosphaeridium heteracanthum* (DEFLANDRE & COOKSON 1955) (samples -250,0 m, -266,0 m and -278,0 m) are abundant and also indicate an Early Campanian age. The two lowermost samples (-294,0 m and -298,0 m) yielded only poor to moderate preserved assemblages among which *Rhiptocorys veligera* (DEFLANDRE 1937), *Oligosphaeridium complex* (WHITE 1842), *Callaiosphaeridium asymmetricum* (DEFLANDRE & COURTEVILLE 1939), *Cometodinium whitei* (DEFLANDRE & COURTEVILLE 1939), *Sentusidinium* aff. *eisenackii* (BOLTENHAGEN 1977) and *Surculosphaeridium spinacongregatum* YUN 1981. *S. spinacongregatum* allows an unequivocal corre-



TOP OCCURRENCE OF SELECTED DINOPHYCEAE FROM THE DE HAAN WELL (22W-276 IIb) AND CORRELATION WITH THE KNOKKE WELL (11E-138 II d).
CHRONOSTRATIGRAPHY
DEPTH IN m
KNOKKE REFERENCE SECTION
LITHOLOGY DE HAAN WELL
DEPTH SAMPLES IN m
Oligosphaeridium complex (WHITE 1842)
Rhiptocorys veligera (DEFLANDRE 1937)
Surculosphaeridium spinicongregatum YUN 1981
Callaiosphaeridium asymmetricum (DEFLANDRE & COURTEVILLE 1939)
Cometodinium whitei (DEFLANDRE & COURTEVILLE 1939)
Sentusidinium aff. eisenackii (BOLTENHAGEN 1977)
Exochosphaeridium? palmatum (DEFLANDRE & COURTEVILLE 1939)
Heterosphaeridium heteracanthum (DEFLANDRE & COOKSON 1955)
Senoniasphaera protrusa CLARKE & VERDIER 1967
Spongodinium delitiense (EHRENBERG 1838)
Canningia cf. colliveri COOKSON & EISENACK 1960
Acanthaulax saetosa in WILSON 1974
Hystrichosphaeropsis ovum DEFLANDRE 1935
Membranilarnacia hapala in WILSON 1974
LOWER TERTIARY
not studied here
LOWER CAMPANIAN
SANTONIAN
LOWER PALAEOZOIC
382,5
431,6
220
227
234
242
250
258
266
278
286
294
298

lation with level - 431,6 m of the Knokke reference section (Santonian).

To summarize we can conclude that the distribution of dinoflagellate cysts give biostratigraphical evidence for an Early Campanian age for the chalk interval (- 226,5 m to - 295,0 m) and a Santonian age for the glauconiferous sandy chalk interval (- 295,0 m to - 299,0 m) in the De Haan well.

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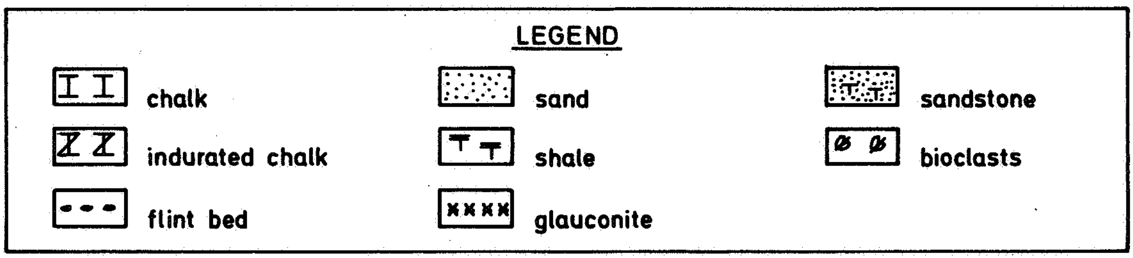

Chapter IX
THE CORRELATION OF THE KNOKKE, DEN HAAN AND OOSTDUINKERKE WELLS

by

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1. THE WELL LOG STRATIGRAPHY

A. THE KNOKKE WELL.

The Knokke well stratigraphy is discussed in chapter I and further elaborated in the chapters V, VI and VII.

On fig. 1 the geophysical log data of the Knokke well are represented.They include natural total gamma rays, resistivity, bulk density and acoustic transit time corrected with seismic check shots.

The different lithological and stratigraphical units defined in the preceding chapters can also be on the base of the geophysical well log data as shown on fig. 1.

B. THE DEN HAAN WELL.

The following stratigraphic sequence was established based on the cuttings and the cores (304,30-321 m) (for details, see Belgian Geological Survey files 22W/276) and based on geophysical logs (fig. 2):

0-41 m : Holocene and Pleistocene

41-193 m : Ieper Formation

- sandy clays and sands occur down to 43,5 m
- silty clay occurs down to 56 m
- heavy clay occur from 60 m downwards

193-223 m : Landen Formation

- 193-208,5 m : fossiliferous sands with two important clay intervals
- 208,5-223 m : silty and fine sandy clay, glauconiferous

223-297 m : Upper Cretaceous chalk

- The upper part is tentatively put equivalent with the Maisières chalk and the lower part with the Fortes Toises; both lithounits belong to the Upper Turonian.
  The presence of Campanian towards the top however is not excluded.

297-321 m : Revinian quartzic slates (Oisquercq)

- The top of which is altered to a reddish clay.

C. THE OOSTDUINKERKE WELL.

Based on the lithological description by J. BACCAERT and J. HERMAN (Belgian Geological Survey files 35E/142) and on geophysical logs (fig. 3), the following stratigraphic sequence is established:

0-27 m : Holocene and Pleistocene

27-138,5 m : Ieper clay

138,5-180 m : Landen Formation

- 138,5-154,5 m : fossiliferous sands, silts and clay
- 154,5-180 m : silty clay, glauconiferous

180-264,45 m : Upper Cretaceous chalk (cored 253,80 m)

- the main chalk mass is associated with the Upper Turonian Maisières chalk and Fortes Toises
- the Lower Turonian glauconitic Dieves are found between ± 250,5 and ± 262,40 m.

  ± 250,5-259,20 m : with *Terabratula rigida* and *Inoceramus labiatus*

  259,20 - ± 262,40 m : with *Actinomax plenus*

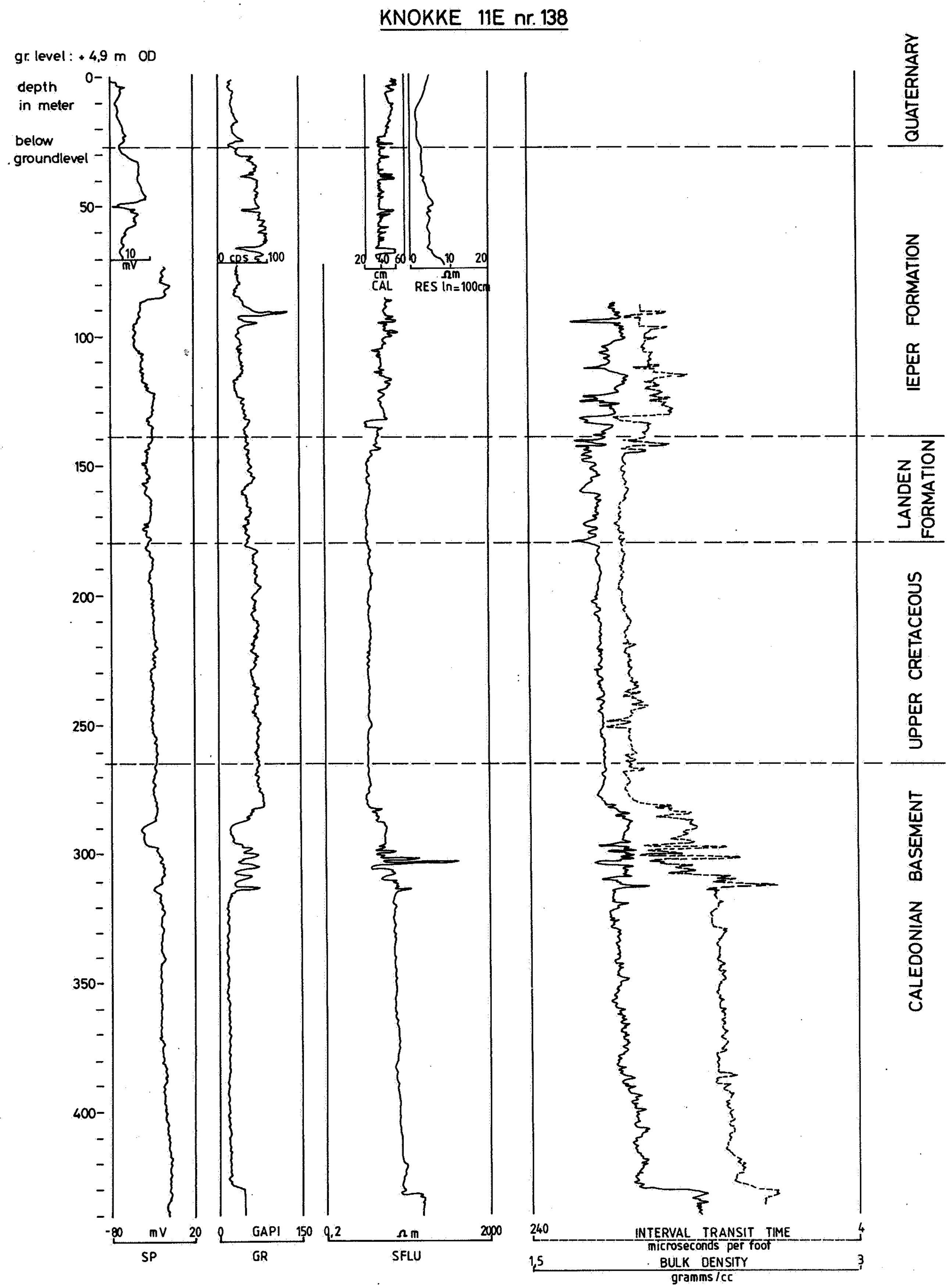


Fig. 1.- The geophysical logs of the Knokke well, with their stratigraphic interpretation.

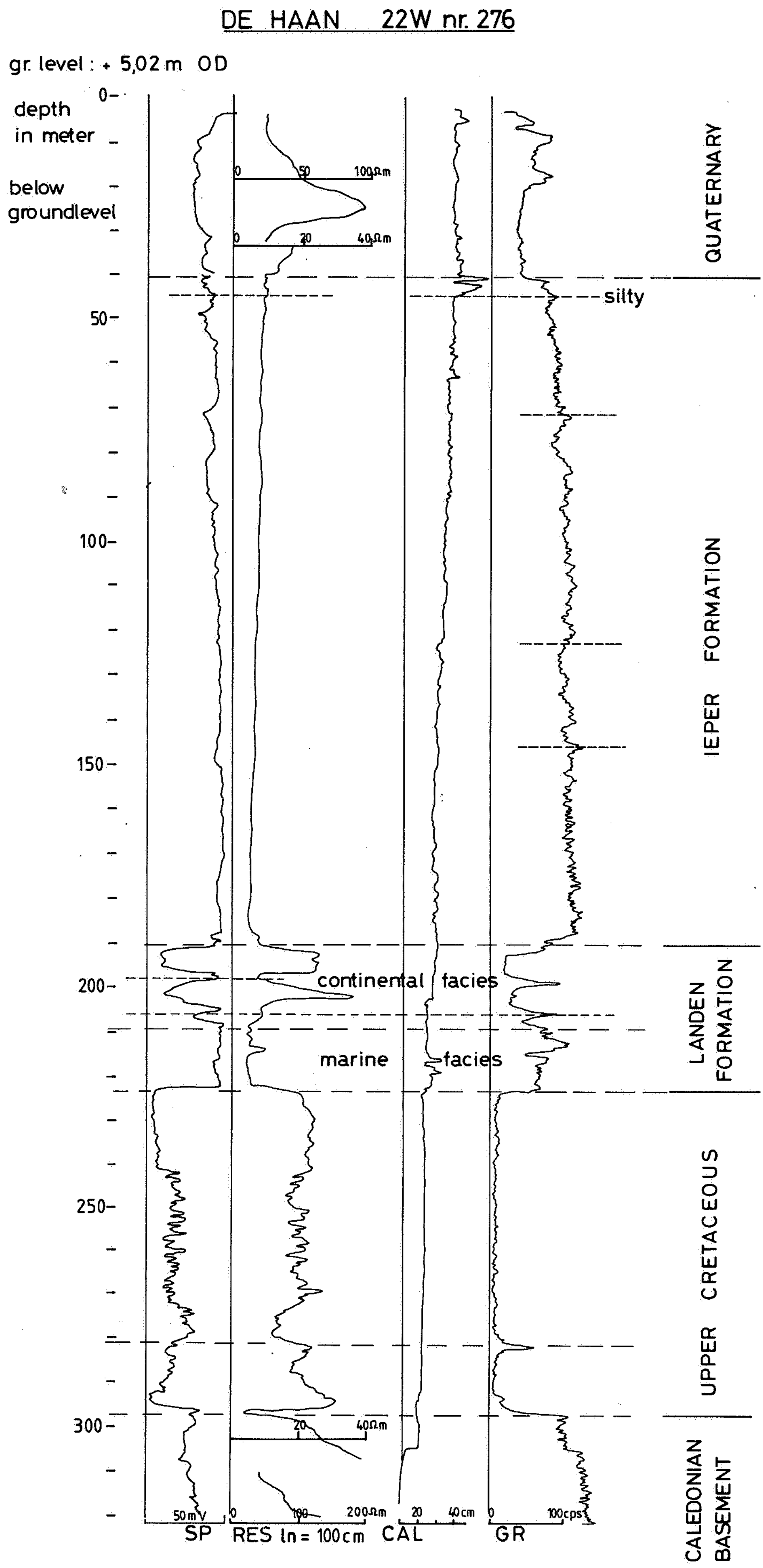


Fig. 2.- The geophysical logs of the Den Haan well, with their stratigraphic interpretation.

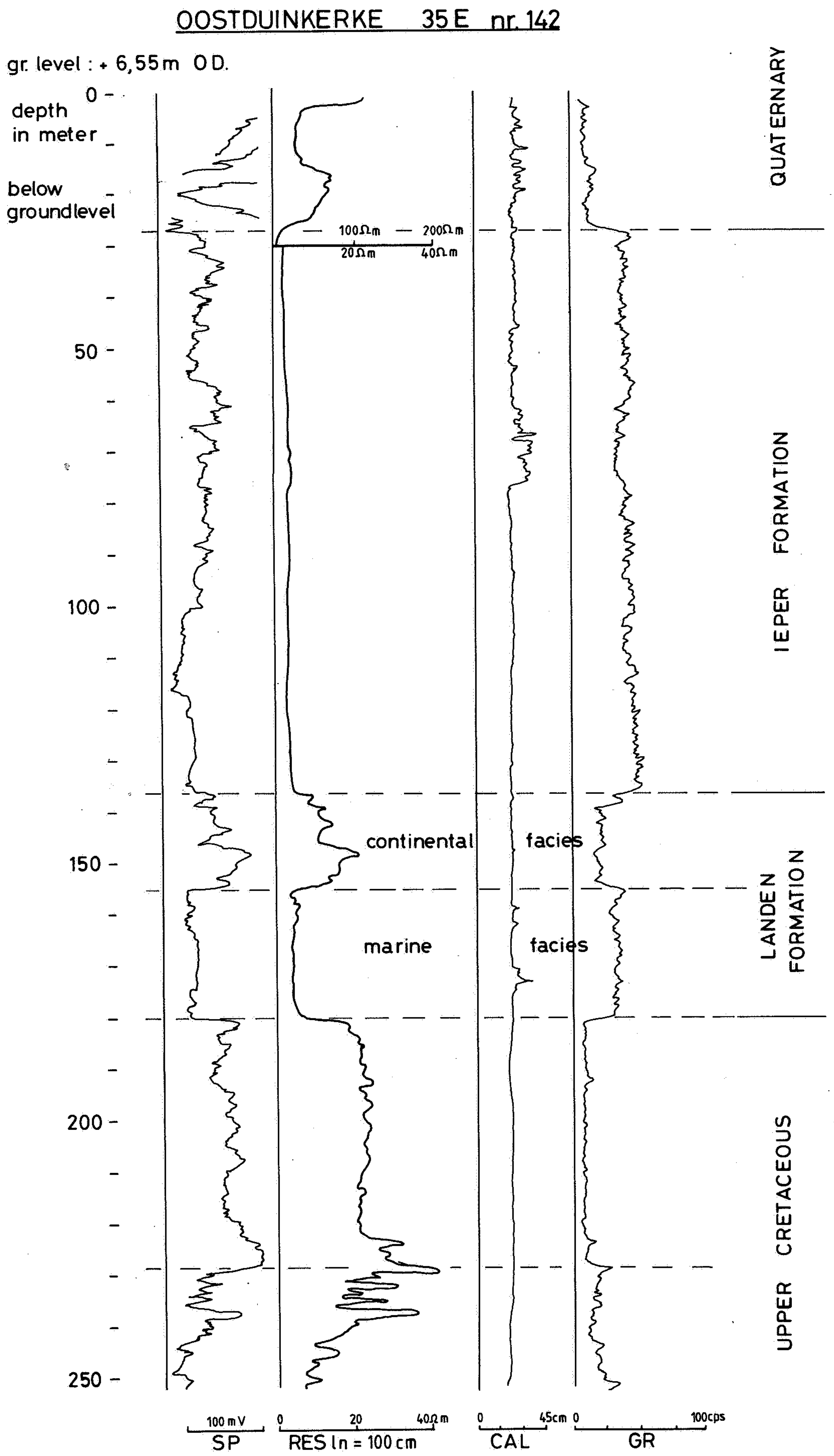


Fig. 3.- The geophysical logs of the Oostduinkerke well, with their stratigraphic interpretation.

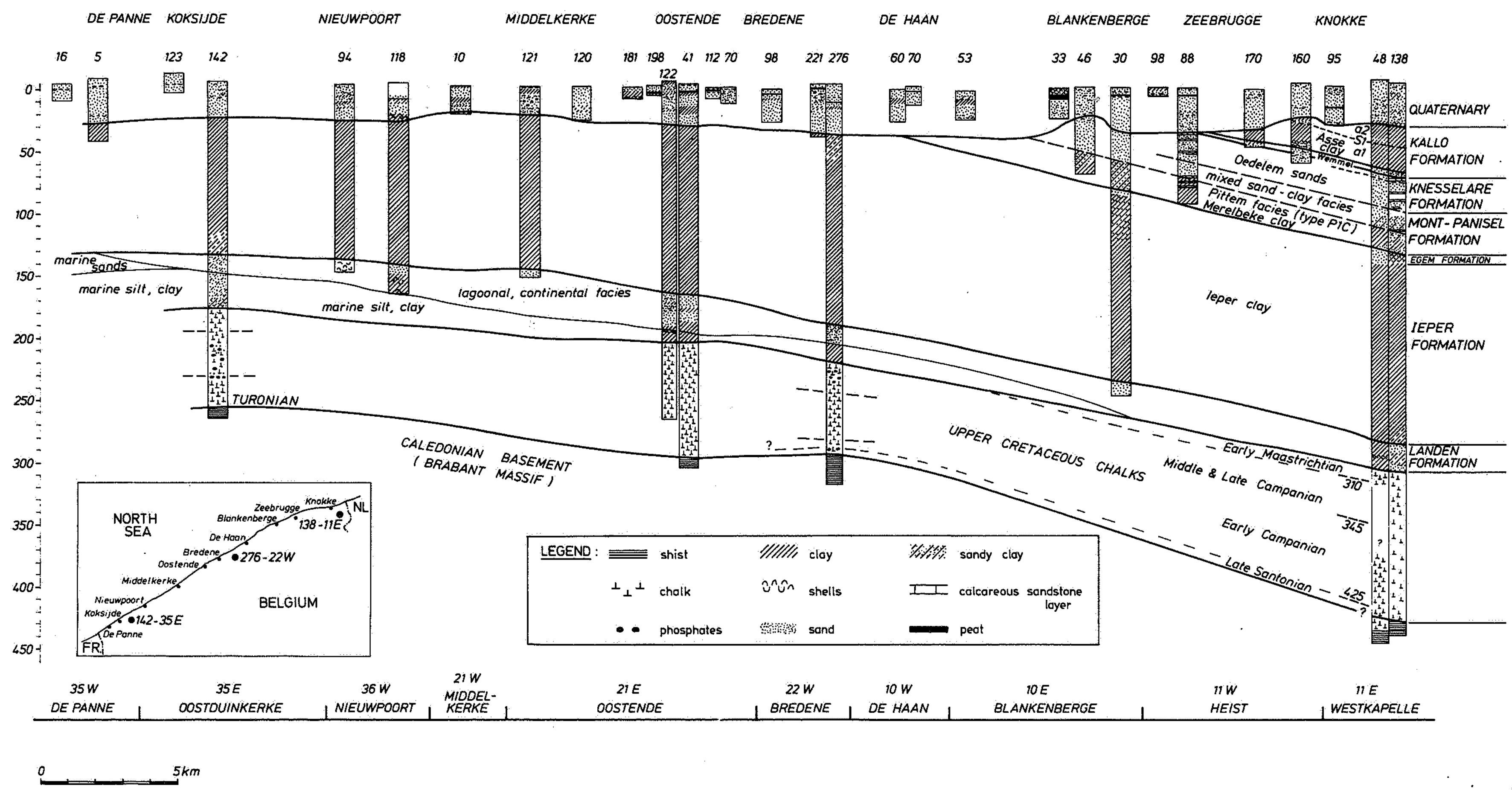


Fig. 4.- Geological cross section along the Belgian coast.

262,40-264,45 m : pale conglomerate, containing quartzite pebbles with empty pyrite cubes, slate fragments; quartz slates, dolerite; with glauconite and lime; with shell fragments, a.o. Pecten. It is equivalent of the Cenomanian base conglomerate (Pecten) (Sarrasin de Bellignies) (MARLIERE, 1954, - 424-425).

264,45 at the top - 270,30 m : slightly altered (a.o. red clay fillings), quartz-slates with a tectonic breccia at 269 m. Based on LEGRAND (1968), this rocks are associated with the Salmian.

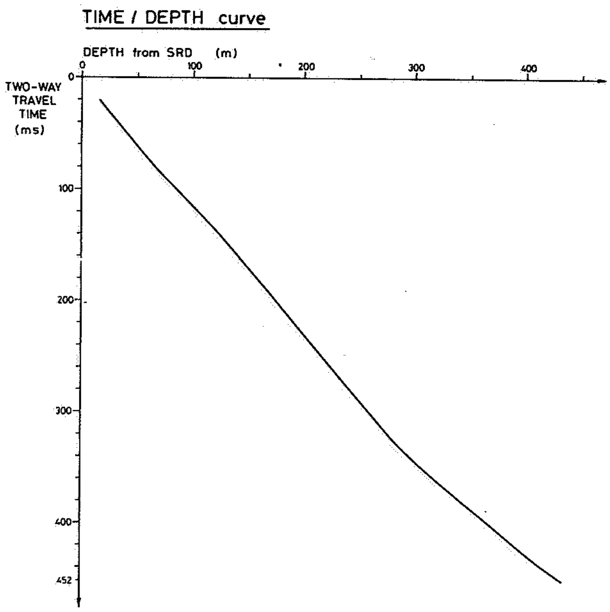


Fig. 5.- Time (TWT)-depth (Stratigraphic Reference Datum) curve as measured in the Knokke well, based on sonic log data and check shots.

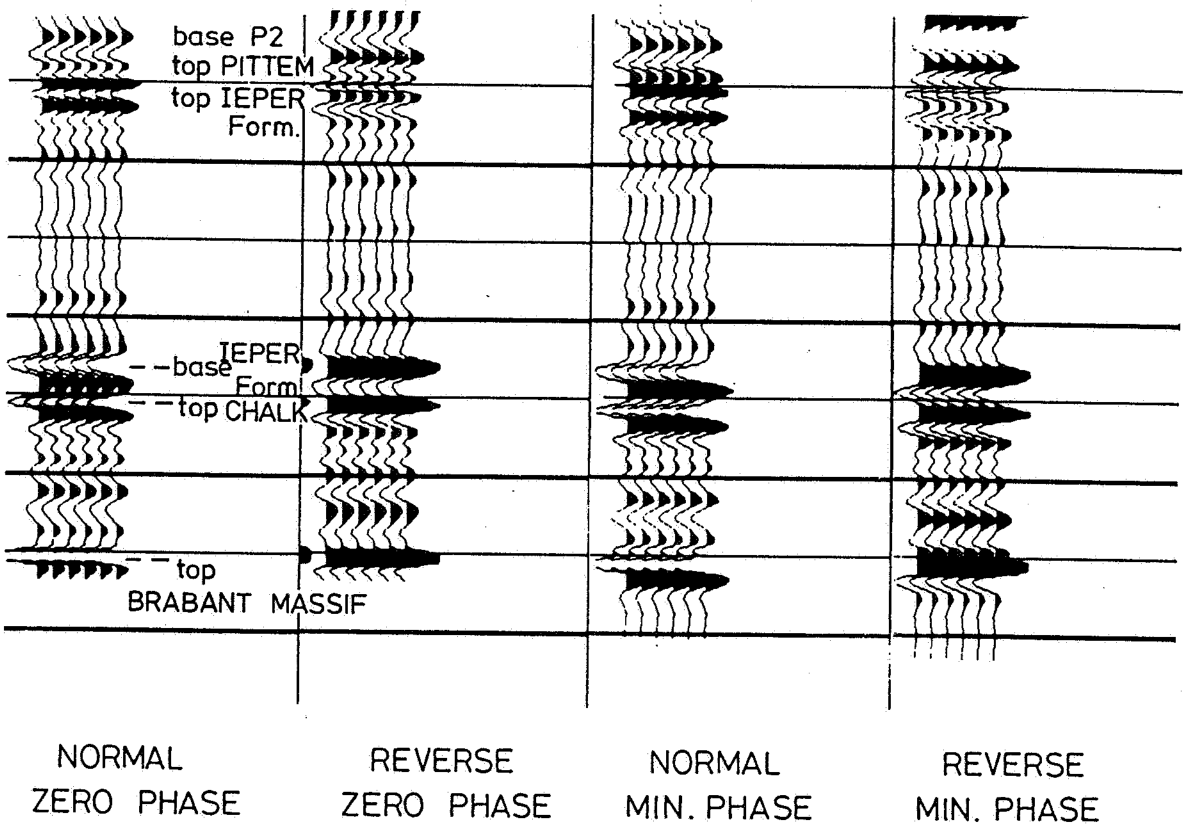
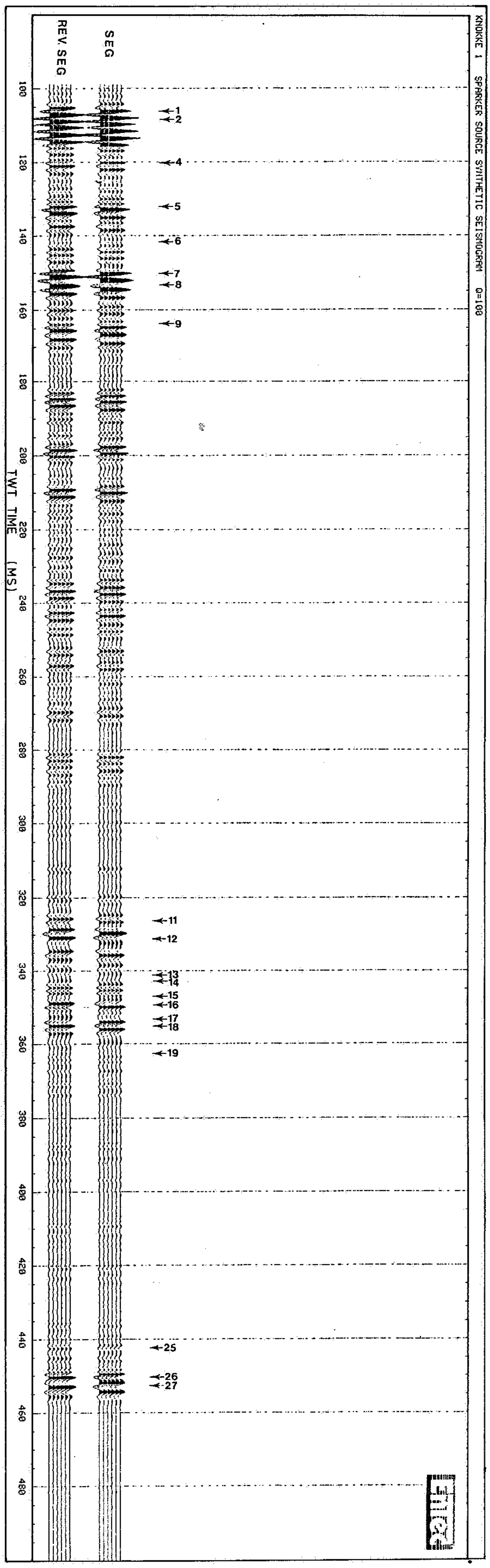


Fig. 6.- Synthetic seismograms constructed from log data in the Knokke well, 45 Hz signal, (Schlumberger).



2. THE CORRELATION

A comparison of figs. 1, 2, 3 shows that the different lithological units can easily be correlated between the three wells, based on the response of SP, gamma ray and resistivity logs.

In the Ieper Formation, the gamma ray log can be subdivided into different subunits, which are apparently consistent between the three wells.

The Landen Formation has a very different geophysical response for the marine rather homogeneous silts or silty clays, and on the other hand for the brackish fossiliferous sands and clays above. Hence the thinning and the disappearance of the marine unit to the northeast can easily be followed.

Whilst the chalk in the Knokke well does not show appreciable variations in its geophysical response, the variations in both other wells are significant and can probably be correlated as shown on figs. 2 and 3. There seems to,be little doubt that in the Oostduinkerke well an important part is of Turonian age. This is also thought for the Den Haan well, although at Oostende the main part of the chalk is attributed to the Campanian Nouvelles chalk (HALET, 1939, file 21E/122) and only a few m at the base is thought to be Turonian by HALET (1921). According to LOUWYE (this volume) no Turonian is found in the Den Haan well but the lowermost 4 m of the chalk in the Den Haan well are Santonian in age.

Although cutting samples have not been analysed for solving this stratigraphic question, it is clear from the work of BAL and VERBEEK (chapter VI) that the Turonian is lacking in Knokke and hence the northern boundary of the Turonian sea, formed by a relative high in the Brabant Massif (MARLIERE 1954, p. 420) was probably located around Den Haan.

After the Turonian the area north of Den Haan has started to subside relative to the southern area were Turonian had been deposited before.

In fig. 4 a geological cross section along coast is given incorporating older data kept in the BGS files, partly published together with the new data presented in this volume. The profile represents the Tertiary and the Mesozoic. The numbers refer to the wells in the BGS files.

Fig. 7.- Synthetic seismograms constructed from log data in the Knokke well, high frequence speaker signal (EnTec Energy Consultants). Arrows refer to table I.

Table I.- The correspondence between the major changes in sonic behaviour, the lithostratigraphic changes and their time depth relationship. The number of the prominent sonic features corresponds to the arrow numbers on fig. 7.

Arrow nr. (prominent sonic feature)	lithological meaning	depth from core	TWT below MSL msec.	comments
1	sandstone layer in Panisel formation	92m	105.96	
2	sandstone layer in Panisel formation	94m	108.19	
3				no core recovery
4	top of a sandy interval without sandstone concretions	105m	120.45	not very outspoken lithological boundary
5	sandstone at the top of a coarse sand interval	116m	132.70	
6	base of the coarse interval	124,35m	141.50	in fact the base of the coarse interval gradually becomes finer to the base, starting from 121m downwards till 124,35m ; this picture fits also the gamma ray response
7	top of the heavy clay (P1m) interval	133m	150.48	
8	base of the heavy clay (P1m) interval	135,20m	153.26	
9	sandstone layer in sandy Ieper formation top	143,75m	163.10	probably a combination of sandstone levels at 143,75m and some 30-40m above this level
10	top of the heavy clay Ieper formation	144m	163.32	the sonic kick between 145 and 146,50m is not explained neither by the cores nor by other logs
11	base of the heavy clay Ieper formation	282,30m	326.32	
12	base of the silty basal clay of the Ieper formation	288,60m	332.87	according to the drilling report a sandstone layer occurs below this level, in the top of the Landen formation
13	top of a clay interval in the Landen formation	297,15m	340.94	
14	fossil debris layer, compact (Sparnacien type) about 12cm thick	299,10m	342.92	
15	lithified fossil debris layer	303m	346.92	
16	sandy interval in Landen formation	306m 308m	349.87	
17	top of chalk	311m	354.63	
18	silex level in the chalk	312,65m	355.47	
19	hardground	321,50m 321,80m	362.76	it is difficult to precisely locate hardgrounds in a core ; sonic transit times describe well porosity changes and hence hardgrounds
20	hardground top			
21	hardground			
22	silex			possibly
23	hardground top			
24	hardground			possibly
25	coarser granular chalk top	419m	442.76	rather a gradual event
26	phosphatic, glauconitic base of the Cretaceous (top)	429,30m	450.57	rather a gradual event
27	top Paleozoic (top)	432,05m	452.54	the Paleozoic sequence is a hard rock sequence

3. THE USE OF THE KNOKKE BOREHOLE DATA TO CALIBRATE SEISMIC WORK IN THE AREA

A. THE TIME-DEPTH FUNCTION.

The sonic log combined with the seismic check shots at the Knokke well have allowed to establish at depth-time function graphically represented on fig. 5. This function allows the calculation of depths from seismic time data and vice versa.

B. THE GEOGRAM FOR SIMPLE INPUT WAVELETS AT LOW FREQUENCY (45 Hz).

The combination of density and corrected velocity values for the different lithologies in the Knokke well allows to calculate acoustic impedances for a sequence of intervals and a series of reflectivity coefficients at these interval boundaries. Using the time-depth function, the depth scale (in meters) can be converted into the time domain (in msec.). Now a chosen seismic wavelet can be convolved with the reflectivity series, to simulate a seismic section.

On figure 6,four such seismograms are shown (produced by SCHLUMBERGER) with an interpretation of the most important reflectors. They have been calculated using simple 45 Hz wavelets.

C. THE SYNTHETIC SEISMOGRAM WITH A SPARKER INPUT SIGNAL.

Using the same set of reflectivity coefficients as discussed under b, a sparker seismic source signal with a frequency range of 300-1000 Hz was used for the convolution. MSL was used as reference level for the seismic section produced.

The resulting seismogram is shown on fig. 7 (produced by EnTec Energy Consultants). The arrows point to important kicks on the sonic log which are lithostratigraphically interpreted in tabel I. It may be noticed that several of the lithological contrasts seen on the sonic log (arrows) have indeed a corresponding reflector response. Several other reflectors do occur and can be checked for their significance through the time-depth conversion and the comparison with lithocolumn given in fig. 1 of chapter I.

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