Meded. Werkgr. Tert. Kwart. Geol. | vol. 23(2) | pp 49-83 | 1 fig., 8 tab., 2 pls | Leiden, juni 1986

LATE MIDDLE EOCENE TO MIDDLE OLIGOCENE CALCAREOUS NANNOPLANKTON FROM THE KALLO WELL, SOME BOREHOLES AND EXPOSURES IN BELGIUM AND A DESCRIPTION OF THE RUISBROEK SAND MEMBER

by

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Steurbaut, Etienne. Late Middle Eocene to Middle Oligocene calcareous nannoplankton from the Kallo well, some boreholes and exposures in Belgium and a description of the Ruisbroek Sand Member. — Meded. Werkgr. Tert. Kwart. Geol., 23(2): 49-83, 1 fig., 8 tab., 2 pls. Leiden, June 1986.

The stratigraphy of the Late Middle Eocene to Middle Oligocene of Belgium is reviewed using calcareous nannoplankton from several outcrops and borehole sections. The Zelzate Formation is redefined to include the Bassevelde Sand (= s_3), the Watervliet Clay (symbolized here a_4) and the newly introduced Ruisbroek Sand Member (symbolized here s_4). Correlation is made between the strata of Western and Eastern Belgium, and their position within the standard chrono- and biostratigraphic scales is elucidated.

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SAMENVATTING

In het tijdsinterval van Laat-Midden-Eoceen tot Midden-Oligoceen vertonen de nannoflora's van het Belgische Bekken een toenemende verarming in soorten en gewoonlijk ook in individuen. De soorten verschijnen en verdwijnen geleidelijk, zonder dat er enige "catastrofale" gebeurtenis plaats vindt op de grens Eoceen-Oligoceen. Deze geleidelijke verandering van de nannoflora wordt veroorzaakt door een geleidelijke daling van de oppervlaktewater-temperatuur. De grootste terugval in de soortverscheidenheid, overeenkomend met de belangrijkste temperatuursdaling, situeert zich ongeveer vijf meter boven de basis van de Boomse Klei, aan de basis van de klei "facies".

De volgende afzettingen bevatten nannofossielen en kunnen worden gecorreleerd met de standaard nannozonering van Martini (1971):

— Zanden van Wemmel (53 soorten), toe te wijzen aan assemblage-unit 10 van Steurbaut (in druk), en behorende tot het onderste gedeelte van de zone NP 15;
— Klei van Asse (44 soorten), toe te wijzen aan assemblage-unit 11 van Steurbaut (in druk), en behorende tot het bovenste gedeelte van zone NP 15;
— Klei van Ursel (30 soorten), toe te wijzen aan assemblage-unit 12 van Steurbaut (in druk) en behorende tot zone NP 16.

Deze drie eenheden, die samen het onderste gedeelte van de Formatie van het Meetjesland vormen, vertonen associaties met een grote soortverscheidenheid, rijk aan discoasters en rhabdosphaeriden. Hun ouderdom is Laat-Midden-Eoceen.

— Zand van Bassevelde (35 soorten), behorende tot zone NP 20 en tot het jongste gedeelte van het Laat-Eoceen. De associatie bevat nog discoasters en lijkt nog sterk op de laatmiddeneocene associaties.
— Zanden van Grimmertingen (16 soorten), behorende tot zone NP 21, en te situeren op de overgang Eoceen-Oligoceen. De associatie heeft een gemengd karakter. Ze bevat verscheidene "koudwater"-vormen, die onbekend zijn uit de oudere afzettingen, samen met enkele eocene doorlopervormen.
— Zanden en Mergels van Oude Biesen (7 soorten), behorende tot zone NP 22 en van vroegoligocene ouderdom.
— Zand van Ruisbroek (nieuwe stratigrafische eenheid, maximale dikte 16 m) (12 soorten), behorende tot zone NP 22 en NP 23 (bovenste meter), ouderdom Vroeg-Oligoceen. De associatie wordt gedomineerd door *Isthmolithus recurvus* en *Reticulofenestra umbilica* (behalve in de bovenste meter) en bevat verscheidene soorten die in de onderliggende lagen niet voorkomen.
— Zanden van Berg, bovenste gedeelte (8 soorten), behorende tot zone NP 23 en van middenoligocene ouderdom. De associatie lijkt sterk op die van het Zand van Ruisbroek, maar sommige soorten (*Reticulofenestra umbilica, Lanternithus minutus* en *Isthmolithus recurvus*) zijn niet langer aanwezig.
— Nucula Klei of Klei van Kleine Spouwen (11 soorten), behorende tot zone NP 23 en van middenoligocene ouderdom. De associatie is vrijwel gelijk aan die van de Zanden van Berg. *I. recurvus* is ook hier afwezig.
— Klei van Boom, onderste 25 meter (14 soorten), behorende tot zone NP 23 en van middenoligocene ouderdom. De nannoflora lijkt sterk op die van de Zanden van Berg en de Nucula Klei. *I. recurvus* verdwijnt ongeveer tien meter boven de basis van de Boomse Klei.

Een vergelijking van de verschillende leden van de Formatie van Zelzate in westelijk België met de onderste afzettingen van het "Tongriaan" in Oost-België blijft speculatief. Correlatie is mogelijk tussen de Zanden en Mergels van Oude Biesen en het bovenste gedeelte van het Zand van Ruisbroek, alsmede tussen de Zanden van Berg en de Nucula Klei en het onderste gedeelte van de Klei van Boom in de typestreek.

Uit het onderzoek van de kalkschalige nannofossielen blijkt, dat de grens Eoceen-Oligoceen binnen de Formatie van Zelzate ligt, doch de exacte positie ervan kan niet worden vastgesteld vanwege ontkalking van de sedimenten. Het is echter best mogelijk dat de eo-oligocene overgang zou begrepen liggen in het sedimentatiehiaat tussen de Klei van Watervliet en het Zand van Ruisbroek.

RÉSUMÉ

Depuis la fin de l'Eocène moyen jusqu'à l'Oligocène moyen les nannoflores calcaires du Bassin belge se sont progressivement appauvries en espèces et généralement aussi en individus. Les changements se sont faits graduellement, sans aucune indication d'événements catastrophiques à la limite éo-oligocène. Les principaux facteurs en cause tiennent selon nous à un abaissement de température des eaux superficielles. La diminution la plus marquée du nombre d'espèces, correspondant selon nous au plus grand abaissement de température des eaux se situe à environ 5 m au-dessus de la base de l'Argile de Boom, à la base du "facies" argileux.

Nous pouvons situer les unités stratigraphiques suivantes dans la biozonation-standard de Martini, 1971 (zones NP):

— Sables de Wemmel (53 espèces), attribuables à l'unité 10 de Steurbaut (sous presse) et à la partie inférieure de la zone NP 15;
— Argile d'Asse (44 espèces), attribuable à l'unité 11 de Steurbaut (sous presse) et à la partie supérieure de la zone NP 15;
— Argile d'Ursel (30 espèces), attribuable à l'unité 12 de Steurbaut (sous presse) et à la zone NP 16.

Ces trois unités, constituant la partie inférieure de la Formation du Meetjesland, présentent des associations très diversifiées, riches en discoasters et rhabdosphères. Elles sont d'âge éocène moyen supérieur.

— Sables de Bassevelde (35 espèces), attribuables à la zone NP 20 et représentant le sommet de l'Eocène supérieur. L'assemblage comporte toujours de discoasters et présente encore beaucoup d'affinités avec ceux de l'Eocène moyen supérieur.
— Sables de Grimmertingen (16 espèces), attribuables à la zone NP 21 et représentant le passage de l'Eocène à l'Oligocène. L'assocation a un caractère mixte. Elle est constituée de plusieurs taxa d'eaux plus froides, absents dans les couches sous-jacentes, et de plusieurs formes éocènes persistantes.
— Sables et Marnes de Vieux-Joncs (7 espèces), rapportables à la zone NP 22 et d'âge oligocène inférieur.
— Sables de Ruisbroek (unité ici nouvellement définie, épaisseur totale: 16 m) (12 espèces), attribuables à la zone NP 22 et à la zone NP 23 (le mètre supérieur) et d'âge oligocène inférieur. L'association est dominé par *Isthmolithus recurvus* et *Reticulofenestra umbilica* (sauf dans le mètre supérieur) et contient plusieurs espèces inconnues des couches sous-jacentes.
— Sables de Berg, partie supérieure (8 espèces), attribuables à la zone NP 23 et d'âge oligocène moyen. L'association présente beaucoup d'affinités avec celle des Sables de Ruisbroek. Certaines espèces, cependant, n'y sont plus représentées (*Reticulofenestra umbilica, Lanternithus minutus* et *Isthmolithus recurvus*).
— Argile à Nucula ou de Kleyn-Spauwen (11 espèces), attribuable à la zone NP 23 et d'âge oligocène moyen. L'assemblage est presque identique à celui des Sables de Berg. *I. recurvus* y manque également.
— Argile de Boom, les 25 m inférieurs (14 espèces) étant attribuables à la zone NP 23 et d'âge oligocène moyen. L'association se rapproche de très près de celles des Sables de Berg et de l'Argile à Nucula. *I. recurvus* disparaît à environ 10 m au-dessus de la base de l'Argile de Boom.

Les équivalences stratigraphiques d'est et ouest ne sont pas entièrement élucidées, entre les couches de la région de Tongres d'une part et les différents membres de la Formation de Zelzate d'autre part. Les corrélations suivantes sont toutefois bien établies: les Sables et Marnes de Vieux-Joncs équivalent à la partie supérieure des Sables de Ruisbroek, les Sables de Berg et l'Argile à Nucula à la partie inférieure de l'Argile de Boom de la région-type.

La limite Eo-Oligocène se situe certainement au sein de la Formation de Zelzate d'après l'inventaire des nannofossiles calcaires, sans qu'on puisse la localiser exactement par cause de décalcifications locales. Il est aussi possible que la transition soit comprise dans l'hiatus de sédimentation entre l'Argile de Watervliet et les Sables de Ruisbroek.

INTRODUCTION

The general outline of the Belgian Palaeogene stratigraphy dates from the second part of the 19th century, relying basically on the pioneering work by Dumont, Rutot and Vincent. Little new data was added during the following decades, except for the contributions by Leriche (1927, 1939), Gulinck & Hacquaert (1954) and Gulinck (1954). More recently Gulinck (1965b) and Marechal & De Breuck (1979) summarized and discussed this classic sequence.

The study of the Kallo well, which started some 15 years ago, has led to a major advance in the knowledge of the Belgian Tertiary stratigraphy. The Kallo borehole was drilled by the Foraky Company in 1965 on behalf of the Belgian Geological Survey. It is located in the northern part of Belgium (fig. 1), 10 km West of Antwerp (Kallo, "Fort la Perle", municipality of Beveren, map-sheet 15/2, co-ordinates: X = 144.86, Y = 217.84). Because of its position in the North of the country the Kallo well reveals one of the most complete sequences of Belgian post-Palaeozoic strata. It was drilled to a depth of 622 m, penetrating 444 m of Cenozoic and 148 m of Mesozoic sediments. The top of the Palaeozoic lies at a depth of 592 m. The Cenozoic consists of a very thin Quaternary cover (about 3 m), resting on some 20 m of Pliocene shelly sands which in turn overlie 418 m of Palaeogene sediments.

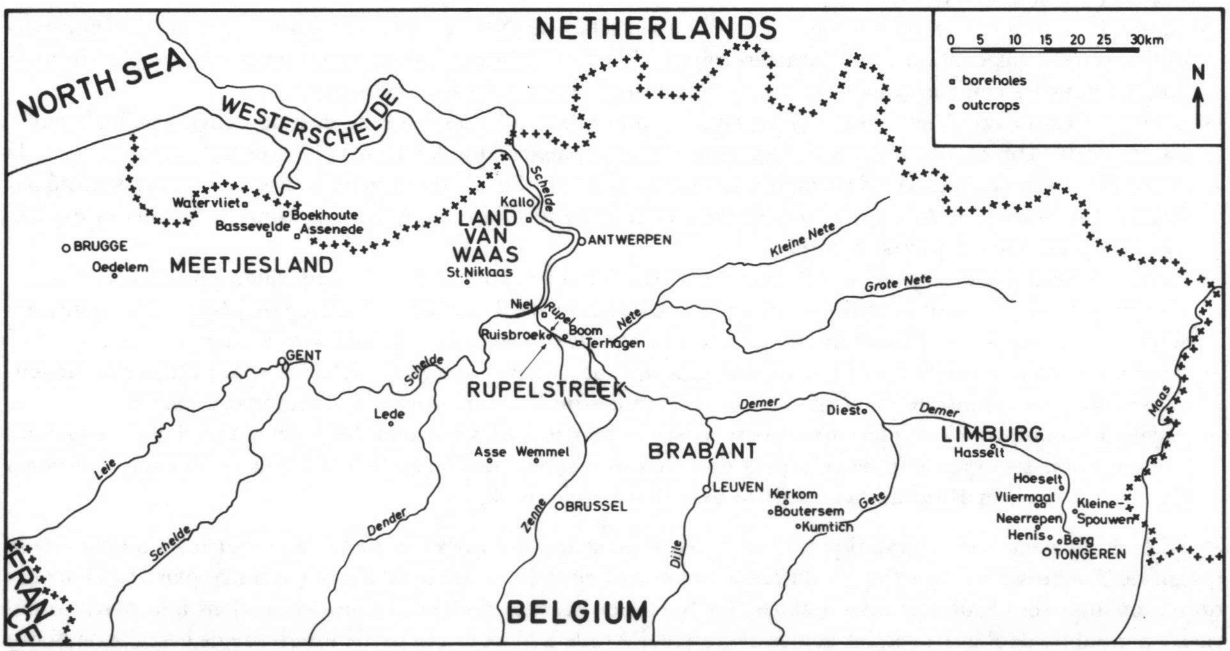


Fig.1 Location of sampled sites.

Of the Kallo well strata only the Ieper Formation has been extensively studied. Gulinck (1967) described the lithostratigraphy mentioning the levels yielding macrofossils. The major microfossil groups have also been investigated: foraminiferids (Willems, 1974, 1980, 1982, 1983; Müller & Willems, 1981), ostracods (Willems, 1973a), radiolarians (Willems, 1981), calcareous nannofossils (Müller & Willems, 1981), dinoflagellates (De Coninck, 1969, 1975, 1981; Costa & Downie, 1976; Costa, Denison & Downie, 1978), pollen and spores (Roche, 1973), and some additional enigmatic microfossils (Willems, 1975).

The overlying strata have been less well studied. Attention has been mainly focussed on the "Kallo Complex", because of its key position in establishing the Eo-Oligocene boundary in Belgium. The "Kallo Complex" was defined by Gulinck (1969a, b) to include the clays and sands intermediate between the Wemmel Sands and the Boom Clay. Six units were recognized, successively from the base a_1, s_1, a_2, s_2, a_3 and s_3 (a stands for "argile" and s for "sable", the french terms for clay and sand respectively). A distinct level of s_3 yielded a fairly rich macrofauna. As this fauna was identical to the one recognized in the Bassevelde borehole, Gulinck (1969a) proposed the new lithostratigraphic term "Bassevelde Sands" for the s_3 unit. Gulinck also attempted to correlate his "Kallo Complex" units with the classic "Tongrian" deposits of eastern Belgium. On the basis of sedimentological features, he concluded that unit a_2 might correlate with the Grimmertingen Sands, while units s_2 and s_3 might be lateral equivalents of respectively the Neerrepen Sands and the upper Tongrian deposits. These stratigraphic conclusions were adopted by Gaemers (1984) and slightly refined: unit a_3 is correlated with the Henis Clay and s_3 or the Bassevelde Sand Member with the Oude Biesen Sand and Marl Member (the stratigraphic terms used in the present paper are summarized in table 8).

In his lithostratigraphic study of the Late Eocene and Early Oligocene subsurface deposits of NW Belgium, Jacobs (1978) introduced somé new formations, redefined certain units and correlated them with Gulinck's "Kallo Complex" units. The Meetjesland Formation was proposed to include the Wemmel Sand Member, the Asse and Ursel Clay Members (= Gulinck's a_1), the Onderdale Sand Member (= s_1), the Zomergem Clay Member (= a_2), the Buisputten Sand Member (= s_2) and the Onderdijke-Adegem Clay Member (= a_3). The Zelzate Formation (= s_3 *sensu* Gulinck) was defined to include the Bassevelde Sand Member (= s_3 *sensu* Jacobs) and the Watervliet Clay member.

Very little is known about the micropalaeontology of the "Kallo Complex". Drooger (1969b) examined the foraminiferids in the interval between 87 m (base Boom Clay) and 178 m (base Asse Clay) in order to define the Eo-Oligocene boundary in the Belgian Basin. Although no definite conclusions could be drawn, Drooger suggested that this boundary might lie somewhere above the 124 m level, which is situated some 4 m above the base of Gulinck's s_3 or Bassevelde Sand. Hooyberghs (1976) discussed Drooger's results and came to the same conclusion. He also found an interesting association of planktonic foraminiferids in the interval between 92 and 110 m. The association seems to be similar to the one recorded by Marks & Van Vessem (1971) from the Silberberg Formation (neostratotype of the Latdorfian *sensu* Martini & Ritzkowski, 1968). The Silberberg Formation is considered to be an equivalent of the Grimmertingen Sands (Martini, 1969a).

The stratigraphic position of the Bassevelde Sands was discussed by Martini (1969b). The study of the calcareous nannofossils from Kallo (level 124.60 m) led him to recognize zone NP 21. The Bassevelde Sands therefore were correlated with the Grimmertingen Sands and assigned to the Oligocene. These correlations were confirmed by Roche & Schuler (1980), investigating the pollen and spores of the "Kallo Complex" units. Cavelier (1979) and Chateauneuf (1980) came to the same conclusions, suggesting, however, a late Eocene age for the Bassevelde and Grimmertingen Sands.

From the foregoing, it is clear that the position of the "Kallo Complex" units within the global standard chronostratigraphic and biostratigraphic scales is far from elucidated. The present paper aims at resolving these problems through the investigation of calcareous nannoplankton.

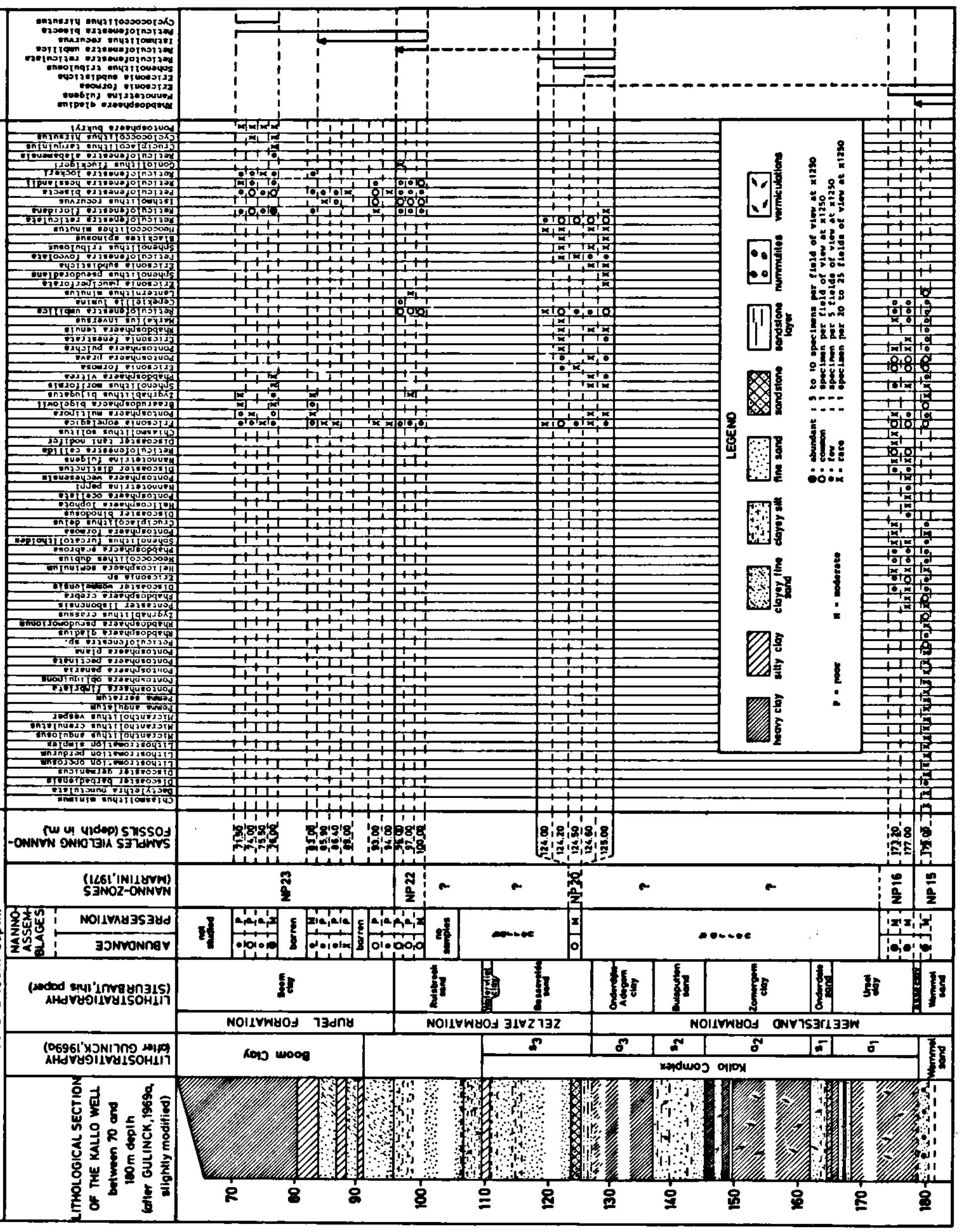
LITHOSTRATIGRAPHY OF THE KALLO WELL

The lithostratigraphic units which were defined in the Meetjesland area by Jacobs (1978) can also be recognized in the Kallo well. Table 1 illustrates Gulinck's classification, compared with the one proposed here, and based on Jacob's terminology (see also Steurbaut, 1986).

Most authors agree on the position, within the Kallo well, of the different members of the Meetjesland Formation. This is not so for the overlying units beneath the Boom Clay Member.

The position of the lower limit of the Boom Clay has also been contested. According to Roche & Schuler (1980, table) this limit lies at a depth of 86 m. Gulinck (1969b) and Drooger (1969), however, place it somewhat lower, at approximately 92 m. Between 92 and 96 m some 4 m of greybrown

TABLE I
DISTRIBUTION OF CALCAREOUS NANNOFOSSILS IN THE KALLO WELL (27E-148) between 70 and 180m depth.



micaceous very clayey fine quartz sand occurs which becomes coarser towards its base and clearly less well-sorted, containing small gravel elements. This unit is here regarded as the basal part of the Boom Clay Member, as it corresponds very well with the basal strata of the Sint-Niklaas claypit, as defined by Vandenberghe (1978, p. 36).

Between the top of the Meetjesland Formation, which corresponds to a sedimentary hiatus, and the base of the Boom Clay Member, some 33 m of sediments have not yet been clearly defined. A green glauconitic sand between 111 and 129 m depth, including a basal green calcareous sandstone and an upper intercalated silt and clay unit, is here considered to represent the Bassevelde Sand Member. The overlying, 2 m thick, hard micaceous silty clay, which was incorporated by Gulinck in his s_3, is here regarded as the Watervliet Clay Member and named a_4. It is overlain by a predominantly clayey fine sand, previously named Berg Sands (Drooger, 1969b), or labelled "Sandy Lower Rupelian" without further comment by Gulinck (1969b). This 13 m thick unit (from 96 to 109 m), bounded above and below by coarse sand to fine gravel layers (1-4 mm), is regarded as a separate lithostratigraphic unit. It represents the uppermost member of the Zelzate Formation and is named the Ruisbroek Sand Member (after the locality of a temporary, well-studied outcrop) and symbolized s_4. It should be emphasized that in the Kallo well the Meetjesland and Zelzate Formations are characterized by very low sedimentation rates and by breaks in sedimentation.

ESTABLISHMENT OF THE RUISBROEK SAND MEMBER

Name — Ruisbroek, small village 2 km West of Boom (see fig. 1).

Rank — new member, corresponding in part with the "Sands of Ruisbroek and Sint-Niklaas", an ambiguous and provisional term introduced by Van den Bosch, Cadee & Janssen (1975) and which, since then, was replaced by the same author with Gulinck's term Bassevelde Sand (Van den Bosch, 1984; Van den Bosch & Hager, 1984). It represents the uppermost member of the Zelzate Formation, which is redefined to include the Bassevelde Sand, the Watervliet Clay and the Ruisbroek Sand Members.

Type-area — "Rupelstreek", area South of Antwerp, extending along the river "Rupel".

Holostratotype — Niel well (see fig. 1 and table 2), a borehole drilled in the claypit De Neef-Landuyt (number 43W-270VII of the Belgian Geological Survey); map-sheet 15/7-8; X = 148.557, Y = 199.240, Z = 1.55 m O.P.

Drilling data: N.V. Smet, December 1962.

Depth level of unit: from 13.20 m to 29.50 m below surface.

Thickness: 16.30 m.

Lithology: upper 14 m consist of clayey sands and fine sands, sometimes calcareous, resting on some 2 m highly micaceous clayey silt with lignitic discolorations (plant remains ?).

Overlying unit: a clayey silt, with a more sandy basal part, representing the base of the Boom Clay Member; the boundary is characterized by change in lithology and small phosphatic sandstone concretions.

Underlying unit: hard, green clay considered to represent the Watervliet Clay Member; the boundary is sharp.

Macrofossils: not yet studied, mentioned only in the well description (at 17.50 m broken shells; at 20.00 m shells and macroforaminiferids; at 23.50 m shells and *Ditrupa*).

TABLE 2

LITHOLOGY AND STRATIGRAPHY OF THE NIEL WELL STRATA (43W-270/VII) (after GULINCK, files Belgian Geological Survey)

Depth (m)	Lithology	Stratigraphy (Gulinck)	LITHOSTRATIGRAPHY (STEURBAUT, this paper)		NANNO-ZONES (MARTINI, 1971)
0–2					
2–8	clay	Boom Clay	Boom Clay	RUPEL FORMATION	NP 23
8–13	silty clay to clayey silt; ± clayey silt; sandstone concretion?	Lower Rupelian	Boom Clay	RUPEL FORMATION	NP 23
13–21	slightly clayey sand; f	Lower Rupelian	Ruisbroek Sand	ZELZATE FORMATION	NP 23 / Barren / NP 22
21–30	green clayey sand f; green loose sand; very clayey sand f; fine slightly clayey sand; fine green sand; highly micaceous clayey silt; lignitic spots	Transition Formation?	Ruisbroek Sand	ZELZATE FORMATION	NP 22 / Barren
30–31	hard green clay	?	Watervliet Clay	ZELZATE FORMATION	Barren
31–37	highly glauconitic sand; fine green slightly clayey sand; highly glauconitic sand	?	Bassevelde Sand	ZELZATE FORMATION	Barren
37–42	hard silty clay; hard green clay; id. laminated silt intercalations	?	Onderdijke-Adegem Clay	MEETJESLAND FORMATION	Barren

NANNO-SPECIES

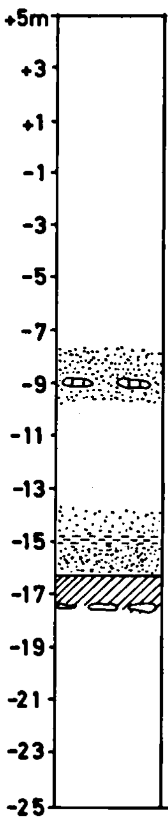
STUDIED SAMPLES (depth in m)	Ericsonia eopelagica	Reticulofenestra bisecta	Reticulofenestra umbilica	Isthmolithus recurvus	Lanternithus minutus	Zygrhablithus bijugatus	Cyclococcolithus hirsitus	Cepekiella lumina	Reticulofenestra foveolata	Reticulofenestra floridana	Reticulofenestra lockeri
13.00	X	o		o							X
13.80	X	o		X						X	X
15.30											
17.50	X	o	o	X				X	X	X	X
20.00	o	X	O	O	X	X	X	X	X		
23.50	X	X	X								
26.50											
29.00											
30.00											
31.00											
32.50											
37.00											
38.50											
39.50											

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.

Microfossils: seven samples were investigated for nannofossils; the uppermost 1 m of the Ruisbroek Sand belongs to Martini's nannoplankton zone NP 23; the remainder, except for the lowermost 5 m which are barren, is assigned to Martini's NP 22 (see table 2).

TABLE 3

LITHOLOGY AND STRATIGRAPHY OF THE RUPEL TUNNEL DEPOSITS (files Belgian Geological Survey)



Depth (m)	Lithology		Lithostratigraphy (STEURBAUT, this paper)		Nanno-zones (MARTINI, 1971)
+5 to -7.5		QUATERNARY	QUATERNARY		?
-7.5 to -10	darkbrown micaceous silty fine sand with septaria	S_3	Ruisbroek Sand	ZELZATE FORMATION	NP 22
-10 to -13.5		S_3	Ruisbroek Sand	ZELZATE FORMATION	?
-13.5 to -16	lightbrown micaceous silty fine sand; black organic clay	S_3	Ruisbroek Sand	ZELZATE FORMATION	barren
-16 to -17.5	greygeen micaceous fine sandy to silty clay with septaria	a_3	Watervliet Clay	ZELZATE FORMATION	barren
-17.5 to -19.5		a_3	Watervliet Clay	ZELZATE FORMATION	?
-19.5 to -25		S_2	Basseveldę Sand	ZELZATE FORMATION	?

NANNO-SPECIES

Studied samples (depth in m)	Blackites spinosus	Cyclococcolithus hirsutus	Ericsonia eopelagica	Isthmolithus recurvus	Lanternithus minutus	Reticulofenestra alabamensis	Reticulofenestra bisecta	Reticulofenestra hesslandii	Reticulofenestra umbilica	Rhabdosphaera tenuis	Reticulofenestra lockeri	Sphenolithus moriformis
8.00	X	X	o	O	X	X	o	O	O	X	X	X
9.00	X	X	o	O	X	X	o	O	O	X		
14.43												
15.23												
15.65												
16.40												
17.30												

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.

Parastratotypes —

Rupel tunnel construction pit at Ruisbroek (table 3).

Localisation: section exposed during the construction of the Rupel tunnel, 2 km southeast of Ruisbroek village area; map-sheet: 23/3-4; X = 148.875; Y = 196.875, Z = + 5.55 m O.P.

Description of the exposure: Belgian Geological Survey.

Position of unit: between -7.50 and -16.30 m O.P.; the top is attacked by Quaternary erosion.

Thickness: 8.80 m.

Lithology: the upper 3 m consist of dark brown bioturbated micaceous silty fine sand with large calcareous concretions; the basal part below -13.50 m O.P., is characterized by silty fine sands with an intercalated black organic clay-layer at -15.00 m; the middle part was not described (data Geological Survey of Belgium).

Overlying unit: no lithological description is given; recorded as Quaternary.

Underlying unit: grey-green micaceous fine sandy to silty clay with large calcareous concretions, regarded as part of the Watervliet Clay Member; sharp boundary with the overlying Ruisbroek Sand Member.

Macrofossils: molluscs are recorded, but no details are published yet; the fish-otoliths were studied by Gaemers (1984), who considered the Rupel tunnel deposits to correspond with the Bassevelde Sands.

Microfossils: 7 samples were examined for nannofossils (see table 3); only the upper part of the Ruisbroek Sand Member (between 7.80 and 9.00 m) yields nannofossils which are referrable to Martini's nannoplankton zone NP 22; its lower part as well as the underlying Watervliet Clay Member are devoid of nannofossils.

Terhagen well (see table 4)

Localisation: borehole drilled in the claypit De Beuckelaar (number 58W-213III of the Belgian Geological Survey); map-sheet 23/3-4; X = 152.132, Y = 197.252, Z = + 11.19 m O.P.

Drilling data: N.V. Smet, December 1962.

Depth level of unit: from 25.80 to 37.80 m below surface.

Thickness: 12.00 m.

Lithology: clayey fine sand with two distinctive thin shell-layers; the lowermost 1 m consists of a micaceous clayey silt.

Overlying unit: clayey silt, representing the lowermost part of the Boom Clay Member, with quartz gravel and shell fragments at the base.

Underlying unit: a hard green clay, representing the Watervliet Clay Member; sharp boundary with the overlying Ruisbroek Sand Member.

Macrofossils: a few shell bands are recorded, without further specification.

Microfossils: 3 samples were stufied for nannofossils, containing *Reticulofenestra umbilica, Lanternithus minutus* and *Isthmolithus recurvus*. They are assigned to Martini's NP 22 (see table 4).

Hypostratotype —

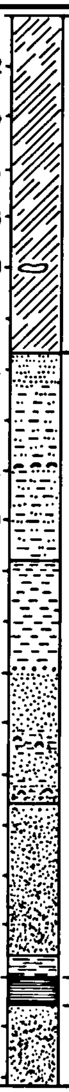
Kallo well (see table 1)

Localisation: borehole drilled near "Fort la Perle", Kallo, municipality of Beveren (number 27E-148 of the Geological Survey of Belgium); map-sheet: 15/2; X = 144.86, Y = 217.84, Z = + 2.00 m O.P.

Drilling data: N.V. Foraky, 13 July to 23 December 1965.

TABLE 4

LITHOLOGY AND STRATIGRAPHY OF THE TERHAGEN WELL STRATA (58W-213/III) (after GULINCK, files Belgian Geological Survey)



Depth (m)	Lithology		LITHOSTRATIGRAPHY (STEURBAUT, this paper)		NANNO-ZONES (MARTINI, 1971)
0–13	hard clay; septaria (at 10 m)	Boom Clay	Boom Clay	RUPEL FORMATION	NP 23
13–26	very fine micaceous sand; id. ± clayey; silty micaceous sand; id. slightly clayey; very clayey; greenish ± clayey silt	Lower Rupelian	Boom Clay	RUPEL FORMATION	NP 23
26–38	quartz gravel-shells; green clayey very fine sand f; ± clayey silt f; very fine glauconitic sand, slightly clayey; fine grey sand; micaceous clayey silt	Transition Formation?	Ruisbroek Sand	ZELZATE FORMATION	Barren (26.20); NP 22 (28.50–32.00); Barren (below)
38–39	hard green clay	?	Watervl. Clay	ZELZATE FORMATION	Barren
39–42	highly glauconitic sand; green clayey sand	?	Bassevelde Sand	ZELZATE FORMATION	Barren

NANNO-SPECIES

STUDIED SAMPLES (depth in m)	Ericsonia eopelagica	Isthmolithus recurvus	Lanternithus minutus	Reticulofenestra bisecta	Reticulofenestra umbilica	Zyghrablithus bijugatus	Blackites spinosus	Reticulofenestra floridana	Reticulofenestra foveolata	Reticulofenestra lockeri	Cepekiella lumina	Pontosphaera bukryi	Sphenolithus moriformis	Pontosphaera multipora
17.80	X			o						X				X
20.80	o	o		O				o		O	X		X	
25.00	o	o		O		X		X	X	X		X	X	
26.20														
28.50	X	o		X	o					X	X			
30.50	o	X	X	o	o		X	X	X	o				
32.00	O	O	X	o	O	X								
36.50														
38.50														
40.00														
42.00														

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.

Depth level of unit: from 96.00 to 109.00 m below surface.

Thickness: 13.00 m.

Lithology: grey-brown micaceous slightly clayey fine sand; at 107.00 m poorly sorted glauconitic sand, becoming gradually more clayey and containing gravel at 109.00 m.

Overlying unit: grey-brown micaceous clayey to silty fine quartz sand; towards its base coarser and distinctly less well-sorted, containing small gravel elements; regarded as the base of the Boom Clay Member.

Underlying unit: light brown silty clay passing into clayey fine sand; representing the Watervliet Clay Member; the boundary with the Ruisbroek Sand Member is sharp.

Macrofossils: some shell fragments of *Pinna* are recorded.

Microfossils: the nanno-assemblages from the interval 96.00 to 100.00 m are referrable to Martini's NP 22; from the interval 100.00 to 106.00 m no samples were recovered; the associations of the basal part, 106.00 to 109.00 m, do not contain nannofossils.

Distribution — In its type area the Ruisbroek Sand Member consists of an upper fine sandy part and a lower, much thinner (1 to 2 m), silty part. The maximum recorded thickness is 16.30 m. It rests on a 1 m thick green hard clay, known as the Watervliet Clay. The same succession is recognized in the hypostratotype in the Kallo well, but its thickness is less, while the underlying Watervliet Clay Member has slightly increased in thickness (c. 2 m). As the Ruisbroek Sand Member does not outcrop and exposures are scarce and only temporary, no distribution charts can be drawn.

Palaeoecology — The fish fauna indicates that the Ruisbroek Sand Member was deposited in a fairly shallow open marine shelf environment with normal salinities (Gaemers, 1984). The same conclusions can be drawn from the nanno-assemblage.

Biostratigraphy — Only the upper part yields calcareous nannofossils; the uppermost 1 m is assignable to Martini's NP 23, the remainder to NP 22.

Correlation with other units — From their respective nannofloras it is clear that the Ruisbroek Sand Member is younger than the Bassevelde Sand Member and the Grimmertingen Sand Member, and older than the Berg Sand Member. It is considered to be the lateral equivalent of the Oude Biesen Sand and Marl Member of the Tongeren area.

Geologic age — The Ruisbroek Sand Member is of Early Oligocene age ("Tongrian", *sensu* De Heinzelin & Glibert, 1957; Rupelian, *sensu* Berggren *et al.*, 1985).

References — The Rupel tunnel deposits were studied or cited by Van den Bosch, Cadee & Janssen (1975), Janssen (1981), Van den Bosch (1981), Gaemers (1984) and Van den Bosch (1984), but were usually erroneously attributed to the Bassevelde Sands.

ADDITIONAL SAMPLE LOCALITIES

The additional sample localities are listed alphabetically. See fig. 1 for their location.

Asse, Terheiden: well 235DB1 of the Geological Institute of Ghent, map-sheet 23/5; X = 135.752, Y = 179.175.

TABLE 5

Calcareous nannoplankton from the Wemmel Sand Member and the Asse Clay Member

NANNO-ZONE (MARTINI,1971)	ASSEMBLAGE-UNITS (STEURBAUT,in press)	LITHOSTRATIGRAPHY	LOCALITIES	Braarudosphaera bigelowii	Cruciplacolithus cribellus	Cruciplacolithus delus	Discoaster barbadiensis	Discoaster tani nodifer	Micrantholithus vesper	Neococcolithes nudus	Pemma rotundum	Pentaster lisbonensis	Pontosphaera formosa	Zygrhablithus crassus	Ericsonia sp.	Markalius inversus	Pontosphaera pulchra	Reticulofenestra sp.	Blackites spinosus	Chiasmolithus solitus	Discoaster distinctus	Discoaster wemmelensis
NP 15	XI	ASSE CLAY MEMBER	Oedelem																X	X	o	o
NP 15	XI	ASSE CLAY MEMBER	Asse (stratotype)												o	X	X	o	X	X	o	o
NP 15	X	WEMMEL SAND MEMBER	Wemmel (stratotype)	o	X	X	X	X	o	X	o	o	o	O	O	X	o	o	o	X	o	o
Marker species												M		M								

NANNO-ZONE (MARTINI,1971)	ASSEMBLAGE-UNITS (STEURBAUT,in press)	LITHOSTRATIGRAPHY	LOCALITIES	Ericsonia eopelagica	Ericsonia fenestrata	Ericsonia formosa	Helicosphaera seminulum	Lanternithus minutus	Neococcolithes dubius	Pontosphaera multipora	Pontosphaera obliquipons	Pontosphaera ocellata	Pontosphaera prava	Reticulofenestra umbilica	Rhabdosphaera crebra	Rhabdosphaera gladius	Rhabdosphaera scabrosa	Rhabdosphaera vitrea	Sphenolithus furcatolithoides	Zygrhablithus bijugatus	Lithostromation operosum	Pontosphaera sigmoidalis
NP 15	XI	ASSE CLAY MEMBER	Oedelem	O	X	o	o	O	o	o	X	X	X	O	O	X	X	o	o	O	X	o
NP 15	XI	ASSE CLAY MEMBER	Asse (stratotype)	O	X	o	X	o	X	o	X	X	o	O	O	o	X	X	o	O		o
NP 15	X	WEMMEL SAND MEMBER	Wemmel (stratotype)	o	X	O	X	O	o	o	o	X	o	o	●	X	●	O	O	o	o	o
Marker species								M								M						

NANNO-ZONE (MARTINI,1971)	ASSEMBLAGE-UNITS (STEURBAUT,in press)	LITHOSTRATIGRAPHY	LOCALITIES	Sphenolithus moriformis	Rhabdosphaera pseudomorionum	Rhabdosphaera trochos	Discoaster binodosus	Discoaster germanicus	Helicosphaera lophota	Lithostromation perdurum	Lithostromation simplex	Lophodolithus reniformis	Rhabdosphaera tenuis	Discoaster stradneri	Nannotetrina fulgens	Nannotetrina pappi	Reticulofenestra callida	Reticulofenestra foveolata	Cepekiella lumina	Martiniaster fragilis	Pontosphaera punctosa	Neococcolithes minutus
NP 15	XI	ASSE CLAY MEMBER	Oedelem	X	X	X								o	X	X	o	X	X	o	X	X
NP 15	XI	ASSE CLAY MEMBER	Asse (stratotype)	X	X	X	X	X	X	X	X	X	X	X	o	X	o	X	X			
NP 15	X	WEMMEL SAND MEMBER	Wemmel (stratotype)	o	X	o																
Marker species															M	M						

● = 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

Provenance of the sample: a 33.50 m deep borehole was drilled; only one sample, taken at a depth of 29.70 m (at about + 51.50 m O.P.), was examined.
Lithology: greyish glauconitic calcareous sandy clay with shell fragments.
Calcareous nannoplankton: rich and diversified assemblage (42 species) assignable to Martini's *Nannotetrina fulgens* Zone (= NP 15).
Stratigraphy: Asse Clay Member, Lutetian, Middle Eocene.
Interpretation of the well: see Jacobs (1978: 67).

Assenede, Hollekensdijk: well DB 43002 of the Belgian Geological Survey, map-sheet 14/2; X = 107.70, Y = 215.18.
Provenance of the samples: a 150 m deep borehole was drilled; six samples were examined in the interval from 17.50 to 47.50 m; only the sample of 32.70 m depth yielded a rich and diversified nannoflora.
Lithology: fine glauconitic, micaceous clayey sand with numerous nummulites and shell-debris.
Calcareous nannoplankton: a fairly well preserved and diversified assemblage (29 species) assignable to Martini's *Sphenolithus pseudoradians* Zone (= NP 20) (see table 5).
Stratigraphy: Bassevelde Sand Member; Priabonian, Late Eocene.

Bassevelde, Doodhoek: well 143(II)A of the Belgian Geological Survey, map-sheet 14/1; X = 102.82, Y = 215.56.
Provenance of the samples: a 31 m deep borehole was drilled; 17 samples have been examined, situated in the interval 16.80 to 30.80 m; only the sample from 22.00 m contained a rich nannoflora.
Lithology: greenish glauconitic fine sand with numerous nummulites and oyster-fragments.
Calcareous nannoplankton: fairly well preserved, but low diversity assemblage (15 species) assignable to Martini's *Sphenolithus pseudoradians* Zone (= NP 20) (see table 6).
Stratigraphy: Bassevelde Sand Member; Priabonian, Late Eocene.
Interpretation of the well: 0.00-16.65 m: Quaternary; 16.65-26.50 m: Bassevelde Sand Member (= s_3); 26.50-30.90 m: Onderdijke-Adegem Clay Member (= a_3).

Berg, Galgenberg: map-sheet 34/5-6; X = 230.100, Y = 164.900.
Provenance of the samples: two samples, taken by A.W. Janssen in 1972, at 1.25 and 2.20 m depth in the

TABLE 6

Calcareous nannoplankton from the stratotype of the Grimmertingen Sand Member and from the type-area of the Bassevelde Sand Member

Member	Locality	Birkelundia arenosa	Blackites spinosus	Braarudosphaera bigelowii	Cepekiella lumina	Chiasmolithus oamaruensis	Discoaster tani nodifer	Ericsonia pauciperforata	Lanternithus minutus	Naninfula sp.	Pemma stradneri	Pontosphaera ocellata	Rhabdosphaera crebra	Rhabdosphaera pseudomorionum	Rhabdosphaera tenuis	Rhabdosphaera vitrea	Ericsonia subdisticha	Reticulofenestra foveolata	Zygrhablithus bijugatus	Pontosphaera obliquipons	Reticulofenestra reticulata
GRIMMERTINGEN SAND MEMBER																					
BASSEVELDE SAND MEMBER	Watervliet																				X
	Boekhoute																			X	O
	Bassevelde																X	X	o		●
	Assenede	X	o	o	X	X	X	X	X	X	X	X	O	X	X	X	X	o	o	X	●
Marker species						M			M	M							M				M

Member	Locality	Ericsonia eopelagica	Pontosphaera prava	Pontosphaera pulchra	Reticulofenestra umbilica	Micrantholithus vesper	Markalius inversus	Pontosphaera multipora	Pontosphaera labrosa	Sphenolithus moriformis	Discoaster saipanensis	Sphenolithus tribulosus	Sphenolithus pseudoradians	Neococcolithus minutus	Reticulofenestra floridana	Ericsonia formosa	Ericsonia fenestrata	Isthmolithus recurvus	Pontosphaera zigzag	Reticulofenestra bisecta	Reticulofenestra daviesi
GRIMMERTINGEN SAND MEMBER		O	X	X	●	X	X	o	X	X					O	O	o	●	o	O	o
BASSEVELDE SAND MEMBER	Watervliet	X			X																
	Boekhoute	o	X		O					o			X			X					
	Bassevelde	●	O	X	●		X				o	X	o	X	X	o					
	Assenede	o	O	X	O	X	X	O	o	X											
Marker species					M						M	M	M			M		M	M		M

● = 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

Galgenberg exposure, were examined (= excursion point 3 of Janssen et al., 1978: 26); only the former yielded nannofossils.
Lithology: grey sandy clay with abundant shells.
Calcareous nannoplankton: poorly preserved and scarce assemblage, relatively rich in *Lanternithus minutus*, correlable with Martini's *Helicosphaera reticulata* Zone (= NP 22).
Stratigraphy: Oude Biesen Sand and Marl Member; "Tongrian" *sensu* De Heinzelin & Glibert, 1957; Early Oligocene.

Boekhoute, Barierken: well 141DB10 of the Geological Institute of Ghent, map-sheet 14/1; X = 103.560, Y = 215.225.
Provenance of the samples: a 38 m deep borehole was drilled; only one sample situated at a depth of 21.30 m was examined.
Lithology: yellowish green glauconitic fine sand with rare shell fragments.
Calcareous nannoplankton: a moderately to poorly preserved, low diversity assemblage (8 species) assignable to Martini's *Sphenolithus pseudoradians* Zone (= NP 20) (see table 6).
Stratigraphy: Bassevelde Sand Member; Priabonian, Late Eocene.
Interpretation of the well (see Jacobs, 1978: 70): 0.00-17.40 m: Quaternary; 17.40-24.70 m: Bassevelde Sand Member (= s_3); 24.70-35.60 m: Onderdijke-Adegem Clay Member (= a_3); 35.60-38.00 m: Buisputten Sand Member (= s_2).

Boutersem, excavation on the Brams' property, sampled by Gulinck, 1968, map-sheet 32/3-4; X = 182.500, Y = 170.250.
Provenance of the sample: the sample was taken in a small excavation made by Gulinck in 1968, some 70 cm below the surface, at approximately + 72 m O.P. (= excursion point 6 of Gulinck, 1968).
Lithology: greenish to yellowish glauconitic and micaceous fine sand with numerous well preserved molluscs, mainly *Polymesoda* and some cerithiids.
Calcareous nannoplankton: barren.
Stratigraphy: Boutersem Sand Member; "Tongrian" *sensu* De Heinzelin & Glibert, 1957, Early Oligocene.

Boutersem, "Maison Vleminckx", excavation by Janssen et al. (1978: 39-40), map-sheet 32/3-4; X = 183.86, Y = 170.95.
Provenance of the sample: a 2,5 m deep temporary excavation on the property of Mr & Mrs Nackaerts-Vleminckx (excursion point 7 of Janssen et al., 1978); the sample was taken in the interval 1.31-1.44 m at about + 78 m O.P.
Lithology: greenish yellow to light brown micaceous fine sand with many shells and small limonitic aggregations.
Calcareous nannoplankton: devoid of nannofossils.
Stratigraphy: Boutersem Sand Member; Early Oligocene.
References: Glibert & de Heinzelin de Braucourt, 1954.

Hoeselt, Overbosmast: sampled by T. Leroy (Ghent), map-sheet 34/1-2; in the vicinity of X = 227.075, Y = 173.225.
Provenance of the sample: only one sample was examined; its position in the exposed section was not precisely identified by Leroy (pers. comm.).
Lithology: green stiff clay without macrofossils.
Calcareous nannoplankton: not observed.
Stratigraphy: Henis Clay Member; "Tongrian" *sensu* de Heinzelin & Glibert, 1957; Early Oligocene.

Kleine Spouwen: excursion point 5 of Gulinck (1968), map-sheet 34/1-2; X = 233.425, Y = 170.700.
Provenance of the sample: one sample taken at + 106 m O.P. was examined.
Lithology: fine orange-brown quartz sand with many shells, mainly *Glycymeris*.
Calcareous nannoplankton: not observed.
Stratigraphy: Berg Sand Member; Rupelian, Middle Oligocene.

Kleine Spouwen, Keistraat: temporary excavation made by A.W. Janssen and M. van den Bosch in 1971, map-sheet 34/1-2; X = 233.025, Y = 171.325.
Provenance of the samples: two samples taken at 2.40 and 2.70 m below surface.
Lithology: sample from 2.40 m: green fossiliferous clay; sample from 2.70 m: whitish shelly quartz sand.
Calcareous nannoplankton: both samples yield nannofossils, referrable to Martini's NP 23.
Stratigraphy: uppermost sample (2.40 m): Nucula Clay Member, Rupelian, Middle Oligocene; lowermost sample (2.70 m): Berg Sand Member, Rupelian, Middle Oligocene.

Kumtich, Galgenberg: temporary sandpit, sampled by A.W. Janssen *et al.* Map-sheet 32/3-4; X = 186.800, Y = 169.000.
Provenance of the sample: one sample was examined, taken at 6.72 m below the surface (excursion point 5 of Janssen *et al.*, 1978).
Lithology: yellowish brown fine to very fine sand with small limonite aggregations and numerous shells.
Calcareous nannoplankton: not observed.
Stratigraphy: Boutersem Sand Member, "Tongrian" *sensu* de Heinzelin & Glibert, 1957; Early Oligocene.
References: Glibert & de Heinzelin de Braucourt, 1954.

Oedelem, Berg: sampled by D. Nolf (Brussels), map-sheet 13/2; X = 77.470, Y = 208.790.
Provenance of the sample: one sample was examined from + 9.30 m O.P.
Lithology: greyish green slightly glauconitic silty clay.
Calcareous nannoplankton: rich and diversified assemblage assignable to Martini's *Nannotetrina fulgens* Zone (= NP 15) (see table 5).
Stratigraphy: Asse Clay Member, Lutetian, Middle Eocene.

Sint-Niklaas, in the vicinity of the Borg Fabrics N.V.: well 42W-226(VI/a) of the Belgian Geological Survey. Map-sheet 15/5-6; X = 136.095, Y = 204.070.
Provenance of the samples: a 430 m deep borehole was drilled; five samples taken in the interval 42.00 to 61.00 m were investigated.
Calcareous nannoplankton: not observed.
Lithology and stratigraphy: uncertain.

Vliermaal, Grimmertingen, map-sheet 33/4; X = 224.81, Y = 168.53; type-locality of the Grimmertingen Sand Member.
Provenance of the samples: 21 samples collected from an exposure and a boring in the type-locality were examined (see Martini & Moorkens, 1970, fig. 4; see also Weyns, 1971: 252, fig. 2 and 3); the uppermost 3 m of the exposure belong to the Neerrepen Sand Member (samples GM19 to GM12), the remainder represents the stratotype of the Grimmertingen Sand Member; samples GMI (0.00 m), GMII (-0.10 m), GMIII (-0.15 m), GMB_1 and GMB_4 yield nannofossils, among which only GMII shows a rich and diversified nannoflora.
Lithology: yellow-brown slightly glauconitic, fossiliferous fine sand.
Calcareous nannoplankton: rich and diversified assemblage, moderately preserved, assignable to Martini's *Ericsonia subdisticha* Zone (= NP 21) (see table 6).
Stratigraphy: Grimmertingen Sand Member, "Tongrian" *sensu* de Heinzelin & Glibert, 1957; Eo-Oligocene transition.
References: Martini & Moorkens, 1970; Weyns, 1971 and Willems, 1973b.

Watervliet, Maagd van Gent: well 65D83 of the Geological Institute of Ghent, map-sheet 6/5; X = 102.307, Y = 219.157; holostratotype of the Bassevelde Sand Member (Jacobs, 1978).
Provenance of the samples: a 38 m deep borehole was drilled; only one sample taken at a depth of 37.00 m (at -33.00 m O.P.) was examined.
Lithology: green calcareous, glauconitic, silty, fine sand with oyster-fragments.
Calcareous nannoplankton: very scarce and poorly preserved assemblage (3 species) assignable to Martini's *Sphenolithus pseudoradians* Zone (= NP 20) (see table 6).
Stratigraphy: Bassevelde Sand Member, Priabonian, Late Eocene.
Interpretation of the well: 0.00-17.00 m; Quaternary; 17.00-22.70 m: Watervliet Clay Member; 22.70-38.20 m: Bassevelde Sand Member.

Wemmel, along the motorway "Grote Ring" around Brussels, at the exit called "Heizel", map-sheet 31/3-4; X = 176.510, Y = 146.805; stratotype of the Wemmel Sands.
Provenance of the sample: a 6 m deep borehole was drilled; the sample was taken in the interval from 5 to 6 m.
Lithology: yellowish green, fossiliferous and slightly glauconitic silty fine sand.
Calcareous nannoplankton: well preserved; highly diversified assemblage, assignable to Martini's *Nannotetrina fulgens* Zone (= NP 15) (see table 6).
Stratigraphy: Wemmel Sand Member, Lutetian, Middle Eocene.
References: Achuthan & Stradner, 1969.

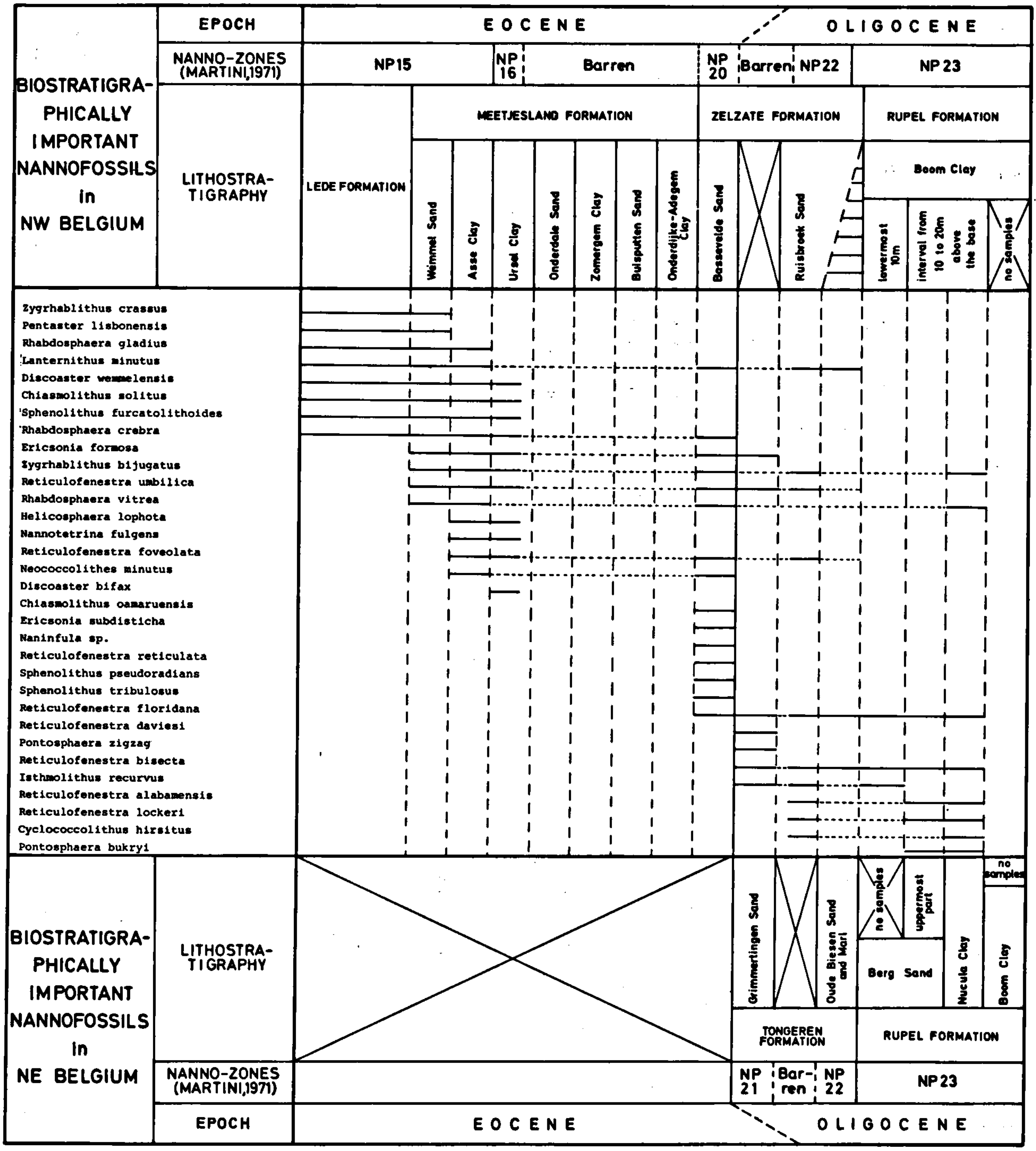
CALCAREOUS NANNOPLANKTON BIOSTRATIGRAPHY

The zonation adopted in the present paper is the standard Tertiary nannoplankton zonation of Martini (1971); for more comments on Tertiary nannoplankton biostratigraphy see Steurbaut (in press). Table 8 gives a survey of the mentioned lithostratigraphic units and their correlation with Martini's zonation.

Remarks on Late Eocene and Early Oligocene index species

The stratigraphic distribution of index species straddling the Eo-Oligocene boundary was discussed already by several authors, e.g. Müller, 1978; Perch-Nielsen in Beckmann *et al.*, 1981; Bybell, 1982; Siesser, 1983 and Aubry, 1983a and b. The extinctions of *Discoaster saipanensis, Discoaster barbadiensis*

TABLE 7



and *Reticulofenestra reticulata* are considered to be almost contemporaneous events and used, either separately or in combination, to define the Eo-Oligocene boundary. Martini (1971) considers the last occurrence of *D. saipanensis* to be the boundary-event between his standard nanno-zones NP 20 and NP 21, and consequently between the Eocene and Oligocene. Nowadays, the extinction of the planktonic foraminiferal *Globorotalia cerroazulensis* lineage is widely accepted to mark the Eocene-Oligocene boundary (see Snyder, Müller & Miller, 1984). As this event is later than the disap-

TABLE 8

SERIES	STAGES	NANNO-ZONES (MARTINI, 1971)	NW BELGIUM Formations	NW BELGIUM Members	NW BELGIUM Symbols
OLIGOCENE	RUPELIAN	NP 23	RUPEL FORMATION	Boom Clay ✱	R_{2c}
OLIGOCENE	"TONGRIAN"	NP 22 / Barren	ZELZATE FORMATION	Ruisbroek Sand ✱	S_4
	?	Barren		Watervliet Clay	a_4
EOCENE	PRIABONIAN	NP 20		Basseveld Sand ✱	S_3
	? BARTONIAN	Barren	MEETJESLAND FORMATION	Onderdijke-Adegem Clay	a_3
				Buisputten Sand	S_2
				Zomergem Clay	a_2
				Onderdale Sand	S_1
	?	NP 16		Ursel Clay ✱	a_1B
	LUTETIAN	NP 15		Asse Clay ✱	a_1A
				Wemmel Sand ✱	We
			LEDE FORMATION		Le

NE BELGIUM Formations	BRABANT Leuven region Members	BRABANT Symbols	LIMBURG Tongeren region Members	LIMBURG Symbols	NANNO-ZONES (MARTINI, 1971)	STAGES	SERIES
RUPEL FORMATION	Boom Clay	R_{2c}	Boom Clay	R_{2c}	NP23	RUPELIAN	OLIGOCENE
			Kerniel Sand	R_{2b}			
	Berg Sand	R_1	Nucula Clay ✱	R_{1c}			
			Berg Sand ✱	R_{1b}			
TONGEREN FORMATION	Kerkom Sand	Tg2k	Oude Biesen Sand and Marl ✱	Tg2o	NP22	"TONGRIAN"	
	Boutersem Sand	Tg2m					
	Hoogbutsel Horizon	Tg1n	Henis Clay	Tg2n	Barren		
	Neerrepen Sand	Tg1d	Neerrepen Sand	Tg1d			
	Grimmertingen Sand	Tg1c	Grimmertingen Sand ✱	Tg1c	NP21		
							EOCENE
LEDE FORMATION						MIDDLE EOCENE	
			Landen Form. / Heers Form. / Houthem Form.			PALAEOCENE	

✱ units yielding calcareous nannofossils /// established correlations pearance of *D. saipanensis, D. barbadiensis* and *R. reticulata*, the Eocene-Oligocene boundary is considered to lie within zone NP 21. From previous work (Proto-Decima et al., 1975: Verhallen & Romein, 1983) as well as the author's personal data from the Aquitanian Basin it is clear that during the time interval spanning the beginning of the Late Eocene (Priabonian) to the end of the Early Oligocene (base of Rupelian s.s.) only small changes in nanno-associations occurred. Only few extinctions and first appearances are recorded. These, however, are significant and need further discussion..

Bramletteius serraculoides Gartner, 1969

This species was originally described from the Late Eocene Shubuta Member of Mississippi (Gartner, 1969) and confirmed by Bybell (1982) and Siesser (1983). According to the latter *B. serraculoides* ranges from NP 15 through the lower part of NP 21. In the Aquitanian Basin (work in progress), it seems to be restricted to Martini's NP 20. It has not yet been encountered in the Belgian Basin.

Chiasmolithus oamaruensis (Deflandre, 1954) Hay, Mohler & Wade, 1966

This species, originally described from the Late Eocene Oamaru diatomite of New Zealand (distribution see Stradner & Edwards, 1968), defines the base of Martini's nannozone NP 18. Its last occurrence datum lies within NP 23 (Perch-Nielsen in Beckmann, 1981). This marker species occurs only rarely in the Aquitanian Basin deposits and does not seem to cross the Eo-Oligocene boundary there (Steurbaut, in preparation). In the Belgian Basin it is known only from the Bassevelde Sand Member.

Ericsonia formosa (Kamptner, 1963) Romein, 1979

This form has a worldwide distribution and occurs throughout the Eocene. It ranges from zone NP 10 to Zone NP 21. Its extinction defines the upper boundary of NP 21.

Isthmolithus recurvus Deflandre, 1954

This species was initially recorded from the Late Eocene Oamaru diatomite of New Zealand (Deflandre & Fert, 1954). Its first occurrence defines the base of Martini's Zone NP 19. It is generally accepted that this species disappears within Zone NP 22 (Aubry, 1983a). Benedek & Müller (1976), however, record its presence in Zone NP 23. This is confirmed here, as the last occurrence datum of *I. recurvus* lies above that of *Reticulofenestra umbilica* (see table 1). The latter marks the top of Martini's Zone NP 22. In the Aquitanian Basin *I. recurvus* is found only rarely in Zone NP 20, and has not been encountered in Zone NP 21. In the Belgian Basin it is more abundant, occurring in the Grimmertingen Sand Member, the Ruisbroek Sand Member and the base of the Boom Clay Member. It is cited from the Bassevelde Sand Member by Martini (1969b). This, however, is not confirmed by the present study.

Lanternithus minutus Stradner, 1962

This form with worldwide distribution is known to range from NP 15 to the top of NP 22. According to Aubry (1983a) it already occurs in the upper part of Zone NP 14. In the Belgian Late Eocene and Early Oligocene it is rare.

Naninfula sp.

This form resembles *Naninfula deflandrei* Perch-Nielsen, 1968 from the Middle Eocene of Belgium, Denmark and Southern France (Steurbaut, in press; Perch-Nielsen, 1971). Its central copula, however, is twice as high as in *N. deflandrei* and presents a sharp small central spine. It might therefore represent a new species. In the Belgian Basin it is known only from the Bassevelde Sand Member. In the Aquitanian Basin it was encountered in the "Marnes de Brihande" and the "Couches de Cauneille", both assignable to nannozone NP 20 (Steurbaut, in preparation). *Naninfula* sp. might be a reliable marker for nannozone NP 20.

Reticulofenestra bisecta (Hay, Mohler & Wade, 1966) Roth, 1970

This species is common in many Late Eocene and Early Oligocene deposits. It is considered to range from NP 17 to NP 25 (Perch-Nielsen in Beckmann, 1981). In the Belgian Basin it is known from the Grimmertingen Sand Member, the Ruisbroek Sand Member and the Rupel Formation. It seems to be absent in the Bassevelde Sand Member.

Reticulofenestra daviesi (Haq, 1968) Haq, 1971

According to Siesser (1983), this species ranges from NP 17 to at least NP 24 (no younger zones were studied). In the Aquitanian Basin it is fairly common in zones NP 20 and NP 21. In the Belgian Basin, however, it is only known from the Grimmertingen Sand Member.

Reticulofenestra floridana (Roth & Hay, 1967) Verhallen & Romein, 1983

R. floridana is a common component of many Late Eocene and Oligocene nannofloras. In the Belgian Basin, it occurs scarcely in the Bassevelde Sand Member and more frequently in the Grimmertingen Sand Member, the Ruisbroek Sand Member and the Rupel Formation.

Reticulofenestra reticulata (Gartner & Smith, 1967) Roth & Thierstein, 1972

This species was originally described from the basal part of the Yazoo Formation (Louisiana, U.S.A.) (Gartner & Smith, 1967). It is considered to range from the upper part of Zone NP 16 to the top of Zone NP 20. Its last occurrence datum would coincide or lie close to those of *Discoaster saipanensis* and *D. barbadiensis* and, hence, is used to define the Eo-Oligocene boundary. In the Belgian Basin it is known only from the Bassevelde Sand Member, where it is predominant in the nannoflora.

Reticulofenestra umbilica (Levin, 1967) Martini & Ritzkowski, 1968

The highest appearence of this species is used to define the top of nannozone NP 22. It is one of the most common species in the Belgian Late Eocene and Early Oligocene.

Sphenolithus pseudoradians Bramlette & Wilcoxon, 1967

In Belgium, this species is known only from the Bassevelde Sand Member, where it occurs sporadically. Its first appearance was proposed to define the base of Martini's nannozone NP 20. According to Perch-Nielsen (in Beckmann, 1981) *Sphenolithus pseudoradians* is not a reliable marker as it appears earlier in tropical regions (e.g. NP 16 in Müller, 1979). Moreover it is not easily separated from the closely related *S. radians* Deflandre, 1952.

Sphenolithus tribulosus Roth, 1970

This species was originally described from the Red Bluff Formation of Alabama (Roth, 1970; Bybell, 1982). According to Bybell (1982) its last appearance datum lies within the Red Bluff Formation (= NP 21). In the Belgian Basin it is known only from the Bassevelde Sand Member.

Calcareous nannoplankton from the Late Middle Eocene to Middle Oligocene formations in Belgium

Meetjesland Formation

Calcareous nannofossils are restricted to the lowermost part of the Meetjesland Formation. They are abundant in the Wemmel Sand Member, the Asse Clay Member and the basal part of the Ursel Clay Member. The overlying units are decalcified and therefore barren of calcareous nannofossils.

Wemmel Sand Member

The Wemmel Sand Member has already been the subject of several micropalaeontological investigations. The nannofossils were studied *in extenso* by Achuthan & Stradner (1969). These authors recognized 23 species in the Wemmel Sand stratotype, among which *Rhabdosphaera gladius, Discoaster barbadiensis, Lanternithus minutus* and *Nannotetrina fulgens*, allowing its assignment to Martini's *Nannotetrina fulgens* Zone (= NP 15). These results were adopted by subsequent authors (Martini, 1969; Martini & Ritzkowski, 1970; Martini, 1971). More recently, however, Bigg (1982) re-investigated the nannofossils of the Wemmel Sand stratotype and placed it in the upper part of Martini's *Discoaster saipanensis* Zone (= NP 17). These conclusions are most unlikely, as are most of Bigg's nannofossil-based attributions, because of his totally erroneous application of nannofossil zonation. Bigg's zonal determinations are principally based on auxiliary species, not on marker-species, which Bigg considered nearly always to be reworked. Furthermore, as the latest data concerning species-ranges are not taken into account, Bigg's results are in contradiction with those of other nannofossil specialists (see also Aubrey, 1983a).

The nannoflora of the Wemmel Sand Member was also investigated by the present author, in the type-locality (see table 5) and the Knokke (see Steurbaut, in press) and Kallo wells (see table 1). The samples are characterized by the abundance of *Zygrhablithus crassus, Lanternithus minutus* and *Rhabdosphaera crebra* and the presence of *Rhabdosphaera gladius, Pentaster lisbonensis, Cruciplacolithus delus* and *Sphenolithus furcatolithoides*. The coexistence of *Zygrhablithus crassus* (very abundant), *Zygrhablithus bijugatus* and *Rhabdosphaera gladius* and the absence of *Nannotetrina fulgens* define the Wemmel Sand Member. It is therefore assignable to Steurbaut's assemblage-unit 10 (Steurbaut, in press), which corresponds to the lower part of Martini's NP 15. These data, furthermore, suggest that Achuthan & Stradner's sample was not collected from the fossiliferous silty sands, the Wemmel Sands *s.s.*, but from the overlying sandy clay, regarded as belonging to the Asse Clay Member (*sensu* Jacobs, 1978).

Asse Clay Member

The Asse Clay was originally incorporated by Martini in his Zone NP 15 (Martini & Ritzkowski, 1968, 1969; Martini, 1969a). Later he rejected this attribution and he chose the Asse Clay at Oedelem to be the stratotype of his Zone NP16 (Martini, 1971). This inconsistent interpretation of the Asse Clay nannoflora is due to the fact that the definition of the Asse Clay is ambiguous. Formerly the Asse Clay was proposed to include the basal green fossiliferous highly glauconitic sandy clay and the much thicker overlying greyish clay. Now both units receive separate names. The green sandy clay representing the Asse Clay Member is assignable to Zone NP 15, the overlying greyish heavy clay or Ursel Clay Member to Zone NP 16.

Three samples of the Asse Clay Member, collected at the type-locality Asse, at Oedelem and from the Knokke well, were examined for nannofossils. The associations are characterized by the dominance of *Rhabdosphaera crebra, Reticulofenestra umbilica* and *Zygrhablithus bijugatus* and by the presence of *Rhabdosphaera gladius, Nannotetrina fulgens* and *Reticulofenestra callida*. They are therefore assignable to Steurbaut's assemblage-unit 11, which correlates with the upper part of Martini's NP 15. The co-existence of *Nannotetrina fulgens, Rhabdosphaera gladius* and *Zygrhablithus bijugatus*, together with the absence of *Zygrhablithus crassus*, define the Asse Clay Member and separate it from the underlying Wemmel Sand Member.

Ursel Clay Member

The Ursel Clay Member was examined in the Kallo and Knokke wells. Its nannoflora is characterized by the abundance of *Discoaster bifax, Reticulofenestra callida, Ericsonia formosa* and *Pontosphaera prava*, by the absence of *Lanternithus minutus*, and by the presence of *Nannotetrina fulgens*. The absence of *Rhabdosphaera gladius* and *Discoaster martinii* supports its attribution to Zone NP 16.

Zelzate Formation

The Zelzate Formation comprises the Bassevelde Sand Member, the much thinner Watervliet Clay Member and the Ruisbroek Sand Member. The Watervliet Clay Member is devoid of nannofossils.

Martini (1969b) studied the nannofossils from level 124.60 m in the Kallo well, which is situated in the lower part of the Bassevelde Sand Member. Some ten species were recognized, among which *Reticulofenestra re reticulata* as abundant, but regarded as reworked. Since the remainder of the flora was somewhat similar to the Grimmertingen Sand nannoflora it was assigned to Martini's NP 21. In a later paper Martini (1971) proposed nannozone NP 22 for the same level. These conclusions are rejected here. I re-investigated the Kallo well samples and material from the type-area of the Bassevelde Sand Member (Bassevelde, Assenede and Watervliet). The nanno-associations of the studied samples are closely similar. *R. reticulata* is one of the most abundant components. The specimens show no sign of corrosion and many intact coccospheres were observed. Consequently, their presence is not due to reworking. Moreover, many species, not mentioned by Martini (1969b) were identified, among which *Sphenolithus pseudoradians, S. tribulosus* and *Discoaster saipanensis*. These are lacking in the Grimmertingen Sand nannoflora. Finally, *Isthmolithus recurvus*, commonly represented in the Grimmertingen Sand Member, seems to be missing (personal investigation) or is only very rarely present (Martini, 1969b) in the Bassevelde Sand Member. The co-occurrence of *R. reticulata, D. saipanensis, S. pseudoradians* and *S. tribulosus* indicates Martini's *Sphenolithus pseudoradians* Zone (= NP 20).

The Ruisbroek Sand Member was studied in very closely spaced samples at various localities (see tables 2, 3 and 4). Its nannoflora is characterized by the abundance of *Isthmolithus recurvus* and *Reticulofenestra umbilica*, by the absence of *Ericsonia formosa* and by the presence of *Reticulofenestra lockeri, Lanternithus minutus* and *Cyclococcolithus hirsutus*, justifying its assignment to Zone NP 22. The uppermost 1 m, however, only present in the Niel well, lacks *Reticulofenestra umbilica* and should therefore be attributed to Zone NP 23.

Tongeren Formation

In its type-area, the Tongeren Formation consists of a lower sandy part, comprising the Grimmertingen Sand and the Neerrepen Sand Members, and a more clayey upper part, named Atuatuca Formation by Janssen, van Hinsbergh & Cadee (1976), comprising the Henis Clay and the Oude Biesen Sand and Marl Members. Further West, in the Leuven area, the upper part of the Tongeren Formation consists of more sandy units, known as the Hoogbutsel Horizon Member, the Boutersem Sand and the Kerkom Sand Members.

The Hoogbutsel Horizon and the Kerkom Sand Members were not examined by the author. The Neerrepen Sand, the Boutersem Sand and the Henis Clay Members were investigated at several localities. They seem, however, to be devoid of nannofossils.

The underlying Grimmertingen Sand Member is known to be highly fossiliferous. A survey of its palaeontological contents is given in Martini & Moorkens (1970), who studied the calcareous nannofossils. They recognized some 16 species, among which *Reticulofenestra umbilica, Ericsonia formosa* and *Isthmolithus recurvus*. The association was proposed to represent Roth & Hay's *Ellipsolithus subdistichus* Zone (Hay, Mohler *et al.*, 1967) redefined by Martini (1971) as the *Ericsonia ?subdisticha* Zone or Zone NP 21.

Calcareous nannofossils from the Grimmertingen Sand stratotype were revised by the present author. The abundance of *Reticulofenestra umbilica, Reticulofenestra bisecta, Ericsonia formosa* and *Isthmolithus recurvus* and the presence of *Reticulofenestra daviesi*, together with the absence of discoasters and *Reticulofenestra reticulata* allow its assignment to Martini's NP 21. This zonal attribution was contested by several authors. According to Cavelier (in: Cavelier & Pomerol, 1976: table), the Grimmertingen Sands have to be assigned to Martini's NP 19. Later, the same author suggested zone NP 20 (Cavelier, 1979: tables 19 and 34). Recently Aubry (1983a: table 34) came to the same conclusion.

If one takes into account only the presences of species (e.g. *I. recurvus* and *E. formosa*), the Grimmertingen Sand Member cannot be attributed definitely to a specific nannozone. It can be placed anywhere in the interval base NP 19-top NP 21. However, the absence of *R. reticulata, D. saipanensis* and *D. barbadiensis*, of which the last appearances define the top of NP 20, suggests that the Grimmertingen Sand Member belongs to nannozone NP 21. Besides, its nannoflora is more closely related to those of the Ruisbroek Sand and the Boom Clay Members than to the Bassevelde Sand nannoflora: *R. bisecta*, which is absent, and *I. recurvus*, which is absent (personal data) or very rare (see Martini, 1969b) in the Bassevelde Sand Member, are abundant components of the Grimmertingen Sand Member, the Ruisbroek Sand Member and the Rupel Formation; *R. reticulata, D. saipanensis, S. pseudoradians* and *S. tribulosus*, which are known from the Bassevelde Sand Member, have not been found in the other units. As the Grimmertingen flora also has some species in common with that of the Bassevelde Sand Member (*Ericsonia formosa, Pontosphaera prava* and *Markalius inversus*) a position intermediate between the Bassevelde Sand Member and the Ruisbroek Sand Member seems to be the most probable.

The Grimmertingen Sand Member may be correlated with the Latdorf and the Silberberg Schichten of Central Germany (Martini, 1969a), with the Danish Viborg Formation (Mikkelsen, 1975) and with the Aquitanian Yrieu Sands (Steurbaut, 1983).

The Oude Biesen Sand and Marl Member has been sampled in Galgenberg, some 2.5 km East of Tongeren. Seven species were identified, among which *Lanternithus minutus* and *Reticulofenestra bisec-*

ta. As no marker species occur, no zonal attribution can be given. Martini (1969a), studying nannofossils from the same locality, came to the same conclusion. The present study, however, demonstrates that the Oude Biesen Sand and Marl Member is older than the Berg Sand Member (presence of *L. minutus*), and might correlate with the Ruisbroek Sand Member (= NP 22).

Rupel Formation

The Rupel Formation consists of the Berg Sand, the Nucula Clay, the Kerniel Sand and the Boom Clay Members. Only the uppermost part of the Berg Sand Member was studied and only in its type-area. The Berg Sand Member has not been encountered in western Belgium. Its nannoflora contains *Reticulofenestra floridana, Reticulofenestra bisecta* and *Reticulofenestra lockeri. Reticulofenestra umbilica, Isthmolithus recurvus* and *Lanternithus minutus* are absent. It is therefore assigned to Martini's NP 23. The same conclusion was already put forward by Müller (1970).

The Nucula Clay was investigated in the same site. Eleven species were recognized, among which *Reticulofenestra bisecta, R. floridana, R. lockeri* and *Pontosphaera bukryi*. The nannoflora is quantitatively richer, but very similar to that of the Berg Sand Member; it belongs to Zone NP 23. The same conclusion was proposed by Müller (1970).

The Boom Clay Member was examined for nannofossils in the claypit "De Roeck & Verstrepen" (Boom) by Bramlette & Wilcoxon (1967), Müller (1970), Roth (1970) and Martini (1971). According to these authors, it belongs to nannozone NP 23. In the present study only the lowermost 25 m of the Boom Clay Member were examined (Kallo well). The nannoflora closely resembles that of the Berg Sand Member and is also assignable to Martini's NP 23. *Pontosphaera bukryi* is present at all levels and seems to characterize the lowermost part of the Rupel Formation.

Biostratigraphic and palaeoecological considerations

During the time span from Late Middle Eocene to Middle Oligocene the nanno-assemblages of the Belgian Basin show a progressive impoverishment in species and generally also in individuals. Species appear and disappear gradually. These events are evenly spread over a considerable period and do not indicate any catastrophic events at the Eo-Oligocene boundary.

The Late Middle Eocene units (Wemmel Sand, Asse Clay and Ursel Clay Members) still show relatively high diversity (c. 40 species) and fairly similar nannofloras rich in discoasters, rhabdosphaerids, *Lanternithus minutus* and *Ericsonia formosa*. During the Late Eocene a reduction in species number occurred. The Bassevelde Sand Member still contains thirty species. Its nannoflora remains strongly related to those of the Late Middle Eocene. Discoasters are still present, while *Reticulofenestra reticulata* and *Reticulofenestra umbilica* dominate. From then on, an important decrease in species occurs. The Grimmertingen Sand Member yields some 16 species and is dominated by "colder" water taxa, e.g. *Reticulofenestra bisecta, Reticulofenestra daviesi* and *Isthmolithus recurvus*. Discoasters and *R. reticulata* are no longer present. The overlying Ruisbroek Sand Member, Berg Sand Member and Nucula Clay Member contain 10 species and are dominated by almost the same species (*Reticulofenestra alabamensis, R. bisecta, R. floridana* and *R. lockeri*). Many of these are also known from the Grimmertingen Sand Member. The maximum reduction in diversity (c. 55%) occurs some 5 m above the base of the Boom Clay Member, at the base of the clay "facies". It may represent the maximum cooling event in the Belgian Palaeogene. Higher up, the Boom Clay shows a progressive enrichment to a maximum of about 25 species (see Müller, 1970).

The reduction in species diversity and the main floral changes observed during the Late Middle Eocene to Middle Oligocene in Belgium are attributed mainly to a progressive decrease in temperature of the surface waters. Another factor which may affect species diversity is the depth of deposition. This seems, however, not to have played an important role in the investigated sequence. The deposits are of shallow marine origin, except for some parts of the Tongeren Formation which are lagoonal. Bathymetric conditions in the marine sequence remained fairly uniform and cannot be supposed to have caused important floral changes.

The Eocene-Oligocene boundary in Belgium lies within the Zelzate Formation, but its exact position cannot be identified precisely on the basis of calcareous nannofossils. The most complete sequence across the boundary is encountered in the Kallo well (see table 1). Between the middle part of the Late Eocene Bassevelde Sand Member at 124 m and the middle part of the Ruisbroek Sand Member at 106 m, 18 m of decalcified clays and clayey sands occur, straddling the Eo-Oligocene boundary. This decalcification means that no precise boundary can be defined by means of nanno-associations. There is however a break in the sedimentation between the Watervliet Clay Member and the Ruisbroek Sand Member at 109 m, which might be connected indirectly with the Eo-Oligocene transition.

Correlation of the different members of the Zelzate Formation with the Early Tongrian deposits of eastern Belgium remains speculative. On the basis of its nannoflora, the Grimmertingen Sand Member has to be correlated with the interval middle part Bassevelde Sand Member-middle part Ruisbroek Sand Member. Its exact position may be established only through detailed analysis of the dinoflagellate associations (J. de Coninck, work in progress).

Correlation is established between the Oude Biesen Sand and Marl Member and the upper part of the Ruisbroek Sand Member, between the Berg Sand and Nucula Clay Members and the lower part of the Boom Clay Member in its type-area.

ALPHABETICAL LIST OF THE SPECIES RECOGNIZED

All species recognized in the present study are listed in alphabetical order according to their epitheton specificum. Each species name is followed by the original author(s), its date of first publication and possible subsequent author(s) who proposed the preferred combination. Species with special stratigraphic value are preceded by an asterisk. References to the illustrations in this paper (plates 1 and 2) are also added.

* *Reticulofenestra alabamensis* Roth, 1970 (pl. 2, figs 22-23)
Pemma angulatum Martini, 1959
Micrantholithus angulosus Stradner & Papp, 1961
Discoaster barbadiensis Tan Sin Hok, 1927
Braarudosphaera bigelowii (Gran & Braarud, 1935) Deflandre, 1947
Zygrhablithus bijugatus (Deflandre, 1954) Deflandre, 1959 (pl. 1, fig. 6)
Discoaster binodosus Martini, 1958
Reticulofenestra bisecta (Hay, Mohler & Wade, 1966) Roth, 1970 (pl. 2, figs 10, 13, 26-27)
* *Pontosphaera bukryi* Haq, 1971 (pl. 2, figs 21, 24)
* *Reticulofenestra callida* (Perch-Nielsen, 1871) Bybell, 1975
* *Zygrhablithus crassus* Locker, 1967 (pl. 1, figs 1-2)
Rhabdosphaera crebra (Deflandre, 1954) Bramlette & Sullivan, 1961
Micrantholithus crenulatus Bramlette & Sullivan, 1961

Cruciplacolithus cribellus (Bramlette & Sullivan, 1961) Romein, 1979 (pl. 1, fig. 11)
* *Reticulofenestra daviesi* (Haq, 1968) Haq, 1971
* *Cruciplacolithus delus* (Bramlette & Sullivan, 1961) Perch-Nielsen, 1971
Discoaster distinctus Martini, 1959
Neococcolithes dubius (Deflandre, 1954) Black, 1967 (pl. 1, fig. 10)
Ericsonia eopelagica (Bramlette & Riedel, 1954) Romein, 1979
Ericsonia fenestrata (Deflandre & Fert, 1954) Stradner & Edwards, 1968
Pontosphaera fimbriata (Bramlette & Sullivan, 1961) Romein, 1979
Reticulofenestra floridana (Roth & Hay, 1967) Verhallen & Romein, 1983 (pl. 2, figs 16-17)
Goniolithus fluckigeri Deflandre, 1957
* *Ericsonia formosa* (Kamptner, 1963) Romein, 1979 (pl. 1, figs 20, 22, pl. 2, fig. 8)
Pontosphaera formosa (Bukry & Bramlette, 1969) Romein, 1979
* *Reticulofenestra foveolata* (Reinhardt, 1966) Roth, 1970 (pl. 2, fig. 7)
Martiniaster fragilis (Martini, 1961) Loeblich & Tappan, 1963 (pl. 1, fig. 17)
* *Nannotetrina fulgens* (Stradner, 1960) Achuthan & Stradner, 1969 (pl. 1, figs 12-13)
* *Sphenolithus furcatolithoides* Locker, 1967 (pl. 1, fig. 7)
Discoaster germanicus Martini, 1958
* *Rhabdosphaera gladius* Locker, 1967 (pl. 1, figs 4, 13, 14, 15, 18)
Reticulofenestra hesslandii Haq, 1971
* *Cyclococcolithus hirsutus* Müller, 1970 (pl. 2, figs 14, 18, 19)
Markalius inversus (Deflandre, 1954) Edwards, 1966
Pontosphaera labrosa (Bukry & Bramlette, 1969) Perch-Nielsen, 1977
* *Pentaster lisbonensis* Bybell & Garter, 1972
Reticulofenestra lockeri Müller, 1970 (pl. 2, figs 20, 25)
Helicosphaera lophota Bramlette & Sullivan, 1961
Cepekiella lumina (Sullivan, 1964) Haq & Mohler, 1967
Chiasmolithus minimus Perch-Nielsen, 1971
* *Lanternithus minutus* Stradner 1962 (pl. 1, figs 8-9)
Neococcolithes minutus (Perch-Nielsen, 1967) Perch-Nielsen, 1971
Sphenolithus moriformis (Brönnimann & Stradner, 1960) Bramlette & Wilcoxon, 1967
Pontosphaera multipora (Kamptner, 1948) Roth, 1970
Neococcolithes nudus Perch-Nielsen, 1971
* *Chiasmolithus oamaruensis* (Deflandre, 1954) Hay, Mohler & Wade, 1966 (pl. 2, fig. 1)
Pontosphaera obliquipons (Deflandre, 1954) Romein, 1979
Pontosphaera ocellata (Bramlette & Sullivan, 1961) Perch-Nielsen, 1984
Lithostromation operosum (Deflandre, 1954) Bybell, 1975
Pontosphaera panaria (Deflandre, 1954) Aubry, 1983
* *Nannotetrina pappi* (Stradner, 1959) Perch-Nielsen, 1971
* *Ericsonia pauciperforata* Roth, 1970
Pontosphaera pectinata (Bramlette & Sullivan, 1961) Sherwood, 1974
Lithostromation perdurum Deflandre, 1942
Pontosphaera plana (Bramlette & Sullivan, 1961) Haq, 1971
Pontosphaera prava (Locker, 1967) Romein, 1979 (pl. 1, fig. 26)
* *Rhabdosphaera pseudomorionum* Locker, 1967 (pl. 1, fig. 3)
* *Sphenolithus pseudoradians* Bramlette & Wilcoxon, 1967 (pl. 2, fig. 3)
Pontosphaera pulchra (Deflandre, 1954) Romein, 1979
Pontosphaera punctosa (Bramlette & Sullivan, 1961) Perch-Nielsen, 1984
Dactylethra punctulata Gartner in Gartner & Bukry, 1969
* *Isthmolithus recurvus* Deflandre, 1954 (pl. 2, figs 9, 15)
Lophodolithus reniformis Bramlette & Sullivan, 1961
* *Reticulofenestra reticulata* (Gartner & Smith, 1967) Roth & Thierstein, 1972 (pl. 1, figs 23-25)
Pemma rotundum Klumpp, 1953
* *Discoaster saipanensis* Bramlette & Riedel, 1954 (pl. 2, fig. 2)
Rhabdosphaera scabrosa (Deflandre, 1954) Bramlette & Sullivan, 1961 (pl. 1, fig. 5)

Helicosphaera seminulum Bramlette & Sullivan, 1961
Pemma serratum (Chang, 1969) Bybell & Gartner, 1972
Pontosphaera sigmoidalis (Locker, 1967) Aubry, 1983
Lithostromation simplex (Klumpp, 1953) Bybell, 1975
* *Chiasmolithus solitus* (Bramlette & Sullivan, 1961) Locker, 1968
Blackites spinosus (Deflandre & Fert, 1954) Hay & Towe, 1962
* *Discoaster stradneri* Martini, 1961 (pl. 1, fig. 19)
Pemma stradneri (Chang, 1969) Bybell & Gartner, 1972
* *Ericsonia subdisticha* (Roth & Hay, 1967) Roth, 1969 (pl. 2, fig. 6)
Discoaster tani nodifer Bramlette & Riedel, 1954
* *Cruciplacolithus tarquinius* Roth & Hay, in Hay et al., 1967
Rhabdosphaera tenuis Bramlette & Sullivan, 1961
* *Sphenolithus tribulosus* Roth, 1970 (pl 2, figs 4-5)
* *Rhabdosphaera trochos* (Bybell, 1975) **n. comb.**
* *Reticulofenestra umbilica* (Levin, 1965) Martini & Ritzkowski, 1968 (pl. 1, figs 16, 21; pl. 2, figs 11-12)
Micrantholithus vesper Deflandre, 1954
Rhabdosphaera vitrea (Deflandre, 1954) Bramlette & Sullivan, 1961
Pontosphaera wechesensis (Bukry & Percival, 1971) Aubry, 1983
* *Discoaster wemmelensis* Achuthan & Stradner, 1967
* *Pontosphaera zigzag* Roth & Hay, in Hay et al., 1967
Ericsonia sp.
* *Naninfula* sp.
Reticulofenestra sp.

ACKNOWLEDGEMENTS

The author wishes to thank Dr P. Jacobs (Rijksuniversiteit Gent), Mr A.W. Janssen (Rijksmuseum van Geologie en Mineralogie, Leiden), Dr P. Laga (Geologische Dienst van België, Brussels), Dr D. Nolf (Koninklijk Belgisch Instituut voor Natuurwetenschappen, Brussels) and Prof. Dr N. Vandenberghe (Katholieke Universiteit, Leuven) for providing the studied samples.

He is also grateful to Mr D. Bavay for help in drafting the figures and tables, to Mr T. Temmerman for reproducing the photos and to Mrs N. Reynaert for typing the manuscript.

Financial support from the National Fund for Scientific Research (Brussels) is gratefully acknowledged.

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PLATE 1

Bar scale on each figure represents 5 μm.

Wemmel Sand Member

Fig. 1-2. *Zygrhablithus crassus* Locker, 1967
distal view, cross-polarized light
Fig. 3. *Rhabdosphaera pseudomorionum* Locker, 1967
distal view, cross-polarized light
Fig. 4. *Rhabdosphaera gladius* Locker, 1967
distal view, transmitted light
Fig. 5. *Rhabdosphaera scabrosa* (Deflandre, 1954) Bramlette & Sullivan, 1961
distal view, cross-polarized light
Fig. 6. *Zygrhablithus bijugatus* (Deflandre, 1954) Deflandre, 1959
distal view, cross-polarized light
Fig. 7. *Sphenolithus furcatolithoides* Locker, 1967
distal view, cross-polarized light, parallel to the polarization-directions
Fig. 8-9. *Lanternithus minutus* Stradner, 1962
8. cross-polarized light, parallel to the polarization-directions
9. cross-polarized light, viewed at 45° to the polarization-directions
Fig. 10. *Neococcolithes dubius* (Deflandre, 1954) Black, 1967
distal view, transmitted light
Fig. 11. *Cruciplacolithus cribellus* (Bramlette & Sullivan, 1961) Romein, 1979
distal view, a. transmitted light; b. cross-polarized light

Asse Clay Member

Fig. 12. *Nannotetrina fulgens* (Stradner, 1960) Achuthan & Stradner, 1969
transmitted light, Oedelem (Berg)
Fig. 13. *Nannotetrina fulgens* (Stradner, 1960) Achuthan & Stradner, 1969, and *Rhabdosphaera gladius* Locker, 1967
transmitted light, Asse (stratotype)
Fig. 14. *Rhabdosphaera gladius* Locker, 1967
cross-polarized light, Asse (stratotype)
Fig. 15. *Rhabdosphaera gladius* Locker, 1967
transmitted light, Oedelem (Berg)
Fig. 16. *Reticulofenestra umbilica* (Levin, 1965) Martini & Ritzkowski, 1968
proximal view, cross-polarized light, Oedelem (Berg)
Fig. 17. *Martiniaster fragilis* (Martini, 1961) Loeblich & Tappan, 1963
transmitted light, Oedelem (Berg)
Fig. 18. *Rhabdosphaera gladius* Locker, 1967
cross-polarized light, Asse (stratotype)
Fig. 19. *Discoaster stradneri* Martini, 1961
distal view, transmitted light, Oedelem (Berg)
Fig. 20. *Ericsonia formosa* (Kamptner, 1963) Romein, 1979
distal view, cross-polarized light, Oedelem (Berg)
Fig. 21. *Reticulofenestra umbilica* (Levin, 1965) Martini & Ritzkowski, 1968
proximal view, cross-polarized light, Asse (stratotype)

Bassevelde Sand Member

Fig. 22. *Ericsonia formosa* (Kamptner, 1963) Romein, 1979
proximal view, cross-polarized light, Bassevelde: -22.00 m
Fig. 23-25. *Reticulofenestra reticulata* (Gartner & Smith, 1967) Roth & Thierstein, 1972
24. distal view, cross-polarized light, Assenede: -32.70 m
25. proximal view, cross-polarized light, Assenede: -32.70 m
Fig. 26. *Pontosphaera prava* (Locker, 1967) Romein, 1979
distal view, cross-polarized light, Bassevelde: 22.00 m

Pl.1

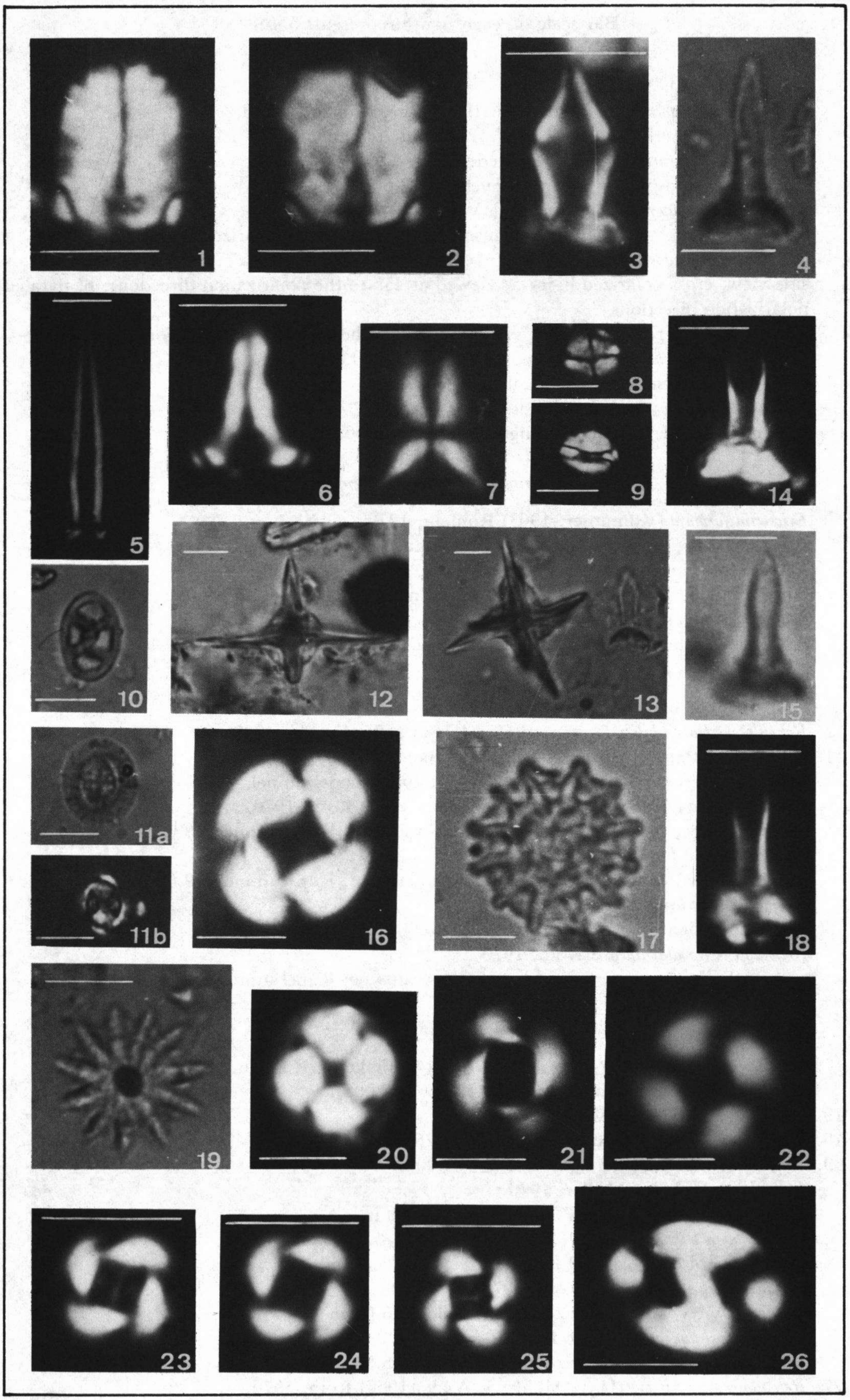


PLATE 2

Bar scale on each figure represents 5 μm.

Bassevelde Sand Member

Fig. 1. *Chiasmolithus oamaruensis* (Deflandre, 1954) Hay, Mohler & Wade, 1966
distal view, Assenede: -32.70 m; a. trandmitted light; b. cross-polarized light

Fig. 2. *Discoaster saipanensis* Bramlette & Riedel, 1954
distal view, transmitted light, Bassevelde: -22.00 m

Fig. 3. *Sphenolithus pseudoradians* Bramlette & Wilcoxon, 1967
side view, Kallo: -125.00 m, a. transmitted light; b. cross-polarized light

Fig. 4-5. *Sphenolithus tribulosus* Roth, 1970
4. side view, cross-polarized light; a. viewed at 45° to the polarization directions; b. parallel to the polarization directions
5. side view, cross-polarized light; viewed at 45° to the polarization directions

Fig. 6. *Ericsonia subdisticha* (Roth & Hay, 1967) Roth, 1969
distal view, transmitted light, Kallo: -125.00 m

Fig. 7. *Reticulofenestra foveolata* (Reinhardt, 1966) Roth, 1970
proximal view, cross-polarized light, Kallo: -124.60 m

Grimmertingen Sand Member

Fig. 8. *Ericsonia formosa* (Kamptner, 1963) Romein, 1979
proximal view, cross-polarized light, Vliermaal: Grimmertingen, GMII (-0.10 m)

Fig. 9. *Isthmolithus recurvus* Deflandre, 1954
cross-polarized light, Vliermaal: Grimmertingen, GM II (-0.10 m)

Fig. 10. *Reticulofenestra bisecta* (Hay, Mohler & Wade, 1966) Roth, 1970
distal view, cross-polarized light, Vliermaal: Grimmertingen, GMII (-0.10 m)

Ruisbroek Sand Member

Fig. 11-12. *Reticulofenestra umbilica* (Levin, 1965) Martini & Ritzkowski, 1968
11. distal view, transmitted light; holostratotype: Niel, -20.00 m
12. distal view, cross-polarized light; parastratotype: Rupel tunnel, -9.00 m

Fig. 13. *Reticulofenestra bisecta* (Hay, Mohler & Wade, 1966) Roth, 1970
proximal view, cross-polarized light; parastratotype: Rupel tunnel, -9.00 m

Fig. 14. *Cyclococcolothus hirsutus* Müller, 1970
proximal view, cross-polarized light, parastratotype; Rupel tunnel, -9.00 m

Fig. 15. *Isthmolithus recurvus* Deflandre, 1954
transmitted light, holostratotype: Niel, -20.00 m

Fig. 23. *Reticulofenestra alabamensis* Roth, 1970
proximal view, cross-polarized light, parastratotype: Rupel tunnel, -9.00 m

Boom Clay Member

Fig. 16-17. *Reticulofenestra floridana* (Roth & Hay, 1967) Verhallen & Romein, 1983
proximal view, cross-polarized light, Kallo: -76.00 m

Fig. 18-19. *Cyclococcolithus hirsutus* Müller, 1970
18. distal view, cross-polarized light, Kallo: -76.00 m
19. distal view, transmitted light, Kallo: -76.00 m

Fig. 20. *Reticulofenestra lockeri* Müller, 1970
distal view, cross-polarized light, Kallo: -76.00 m

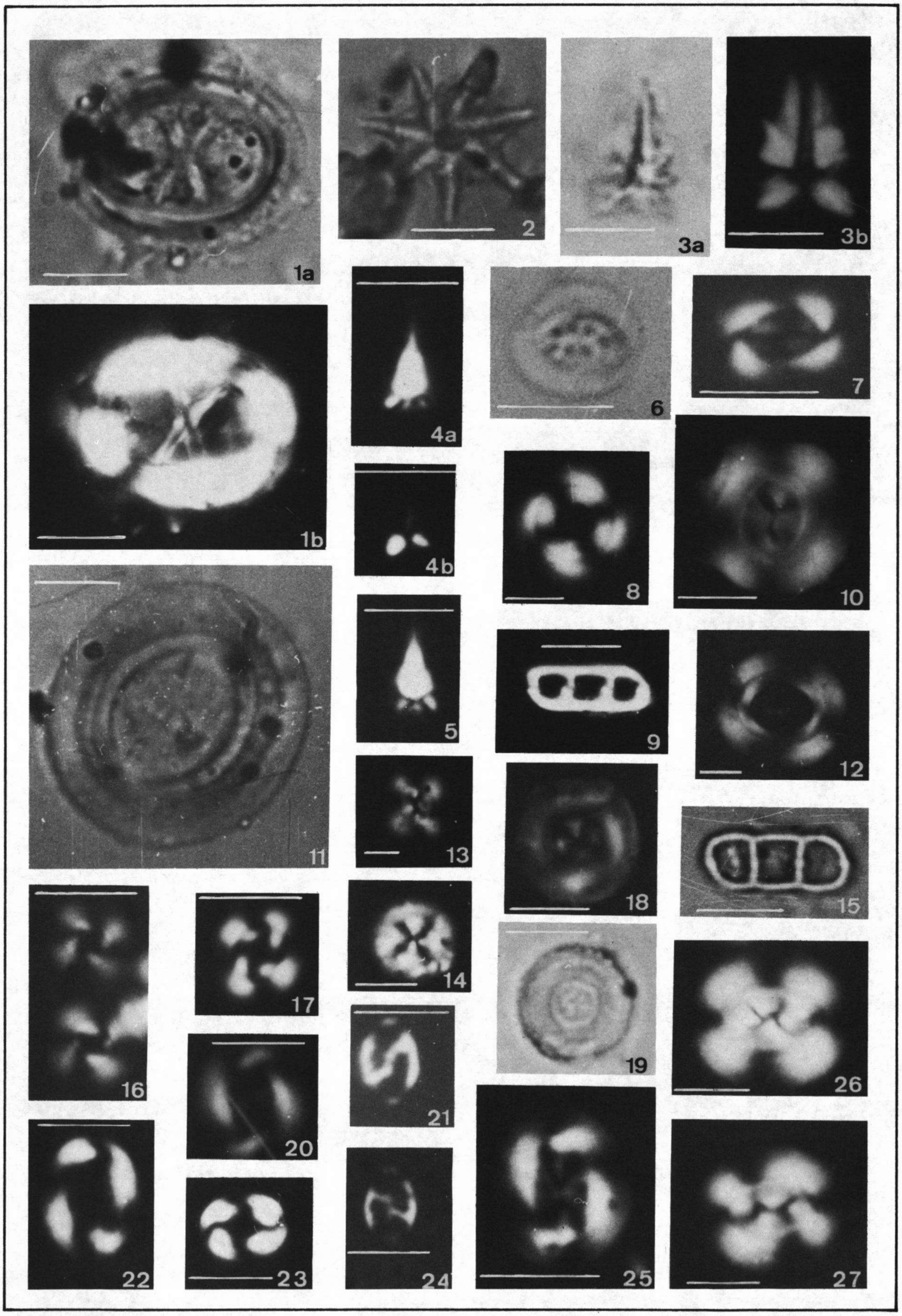
Fig. 21. *Pontosphaera bukryi* Haq, 1971
distal view, cross-polarized light, Terhagen: -25.00 m

Fig. 22. *Reticulofenestra alabamensis* Roth, 1970
proximal view, cross-polarized light, Kallo: -76.00 m

Fig. 24. *Pontosphaera bukryi* Haq, 1971
proximal view, cross-polarized light, Kallo: -76.00 m

Fig. 26-27. *Reticulofenestra bisecta* (Hay, Mohler & Wade, 1966) Roth, 1970
26. proximal view, cross-polarized light, Kallo: -76.00 m
27. distal view, cross-polarized light, Kallo: -76.00 m

Pl.2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