

Oligocene benthic foraminiferal zonation for the southern North Sea Basin

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Abstract

In the scope of the ratification of an international reference boundary for the Rupelian-Chattian transition, it is important to evaluate both stages in their original stratotype areas. In this study, quantitative analysis of benthic foraminifera of several boreholes in the historical Rupelian stratotype area enables recognition of biostratigraphic events in the upper Rupelian and the Chattian; we present a coherent biostratigraphic scheme for the Oligocene southern North Sea Basin. The Rupelian-Chattian interval is subdivided into eleven biozones, of which the lowermost four (interval I-IV) were defined by GRIMM & STEURBAUT (2001) and the overlying seven (interval V-XI) are newly defined herein. A correlation between the Oligocene benthic foraminiferal zonation scheme for the southern North Sea Basin and the adjacent areas is established. Finally, some potential problems for the future decision on an international reference boundary for the Rupelian-Chattian are discussed.

Key-words: Foraminifera – Rupelian-Chattian boundary – Belgium – biostratigraphy

Résumé

Dans le cadre de la ratification d'une limite internationale pour la transition Rupélien-Chattien, il est important d'évaluer ces deux étages dans leurs stratotypes originaux. Dans ce travail une analyse quantitative des foraminifères provenant de plusieurs sondages réalisés aux alentours du stratotype historique du Rupélien permet de distinguer une série d'événements biostratigraphiques dans le Rupélien supérieur et le Chattien. Un schéma biostratigraphique cohérent basé sur les foraminifères est présenté pour l'Oligocène de la Belgique. L'intervalle Rupélien-Chattien est divisée en onze biozones, dont quatre (intervalle I-IV) ont été définies par GRIMM & STEURBAUT (2001) et les sept autres (intervalle V-XI) sont introduites ici pour la première fois. La relation entre le schéma belge et d'autres schémas biostratigraphiques basés sur des foraminifères benthiques est mise en évidence. Finalement, quelques problèmes possibles sur la décision future d'une limite internationale pour le Rupélien-Chattien sont discutés.

Mots-clefs: Foraminifères – limite Rupélien-Chattien – Belgique – biostratigraphie

Introduction

A Global Boundary Stratotype Section and Point (GSSP) between the Rupelian and Chattian Stages (Early-Late Oligocene) has not yet been ratified. In order to contribute to ongoing discussions on the placement of this international reference boundary, and which bio-events to use for correlation, it is necessary to characterise and evaluate the biotic changes within the historical unit-stratotypes.

North Belgium is the home of the Lower Oligocene Rupelian Stage, with the outcrop area of the Boom Formation along the river Rupel as international unit-stratotype. These sections within the outcrop area have been studied in great detail (e.g. HOOYBERGHS *et al.*, 1992; STEURBAUT, 1992; VANDENBERGHE *et al.*, 1998, 2001, 2003; GRIMM & STEURBAUT, 2001), but cover only the lower 30% of the total Rupelian deposits present in the Belgian subsurface (VANDENBERGHE *et al.*, 2001). The younger part of the Rupelian sediments are only known from boreholes and have never been systematically investigated for foraminifera. Only limited information has been given in DE MAN (2002, unpub. thesis) and VAN SIMAEYS *et al.* (2004).

The Doberg section near Bünde (Germany) was selected as neo-stratotype for the Chattian Stage (ANDERSON *et al.*, 1971), and subsequently subdivided into three units based on pectinid bivalve ranges. The Chattian A and B are grouped in the Eochattian Substage, while Chattian C corresponds to the Neochattian Substage (ANDERSON, 1961). The basal unit of the Chattian unit-stratotype is characterised by a distinct bloom of the benthic foraminifer *Asterigerinoides guerichi guerichi* (INDANS, 1965). This biohorizon is known as the “*Asterigerina* Horizon” and can be recognised over the entire North Sea Basin (ELLERMANN, 1958; INDANS, 1958; KIESEL, 1962; DOPPERS & NEELE, 1983; ULLEBERG, 1987; KING, 1983, 1989).

In the international standard time-scale of BERGGREN *et al.* (1995), the Rupelian-Chattian boundary is recognised by the last (common) occurrence of chiloguembelinids, formalised as the P21a/b boundary. This micropalaeontological boundary criterion is principally based on RITZ-

KOWSKI's observations in NW Germany (1982: unpublished written communication); for discussion see VAN SIMAEYS *et al.* (2004). However, these stratotype designations are now effectively superseded by the present international effort of boundary stratotype definition, and the micropalaeontological characterisation of the base Chattian needs modification.

Quantitative analysis of foraminifera from several boreholes in northeast (NE) Belgium enables recognition of biostratigraphic events in the upper Rupelian and Chattian. This study completes earlier foraminiferal investigations carried out on the outcrop area of the Boom Formation (HOOYBERGHS, 1983; HOOYBERGHS *et al.*, 1992; GRIMM & STEURBAUT, 2001) and incorporates them into a coherent biostratigraphic benthic foraminiferal scheme for the Oligocene southern North Sea Basin.

Material and methods

Around 80 samples were analysed from 4 cored boreholes in NE Belgium, encompassing the Rupelian-Chattian transition as currently defined. The location of the boreholes and their appropriate map-sheet numbers are given

Table 1 — Location of the studied boreholes.

Borehole	Map-sheet	Studied interval	number of samples
Weelde	8E159	341,8 - 229,79 m	35
Mol-1	31W221	172,5 - 154 m	8
Hechtel	47E192	251 - 165 m	18
Helchteren	62E261	138 - 112 m	21
Molenbeersel	49W226	985 - 983 m	in progress
Egestorffhall	TK25 3624	70,45 - 66,8 m	3 (ref. sample)

in Figure 1 and Table 1 respectively; sample positions are given in Figure 2. Reference samples from the Egestorffhall 104 borehole (NW Germany) were also analysed, in order to allow comparison with contemporaneous German successions (home of the Chattian Stage).

A composite section (CS) for the Oligocene of the southern North Sea Basin is compiled using biostratigraphic and geophysical well-log data (Figure 2). The “*Asterigerina* Horizon” – defining the base of the Chattian – is designated as reference level zero and depths are given according to the appropriate reference sections. Four reference sections are chosen to cover the entire Oligocene. The outcrop area of the Boom Formation covers the lower part of the Rupelian while its upper part is recognised in the Weelde borehole. The Hechtel borehole includes the lower part of the Chattian (until +30m in the CS), while the Helchteren borehole is used as reference section for its upper part. The lowermost sample examined in this study is located at –100m in the CS, which provides a clear overlap with previous biostratigraphic studies on the outcrop area (HOOYBERGHS, 1983; HOOYBERGHS *et al.*, 1992; GRIMM & STEURBAUT, 2001). *Septaria* levels are indicated according to VANDENBERGHE (1978) in the outcrop area, and further recognised in the boreholes by Fullbore Formation Micro-imager (FMI) techniques used in the Mol-1 borehole.

Foraminifera are processed for microfaunal analysis by soaking equal sized samples (250g) in a 10% solution of a phosphate containing detergent (“Sun”), followed by wet sieving through a clean 63µm sieve. The residue is oven dried at 50–60°C and separated into three size fractions by dry sieving at 125 and 250 micron. If necessary, foraminifera are concentrated using a heavy liquid separation. The dry residue is then poured on a liquid of diluted Na-polytungstate ($\text{Na}(\text{H}_2\text{W}_{12}\text{O}_{40})$) with a density around 1.9g/cm³ and the light fraction is decanted into a labelled filter paper. The sample is thinly spread on a gridded picking tray and individuals are picked systematically from side to side along the rows. The fraction larger than 125µm is analysed quantitatively, taking into account the benthic and planktonic foraminifera, ostracods, otoliths and accessory elements such as fish remains, molluscs, sponges, organic material etc. The planktonic foraminifera are not identified to species level,

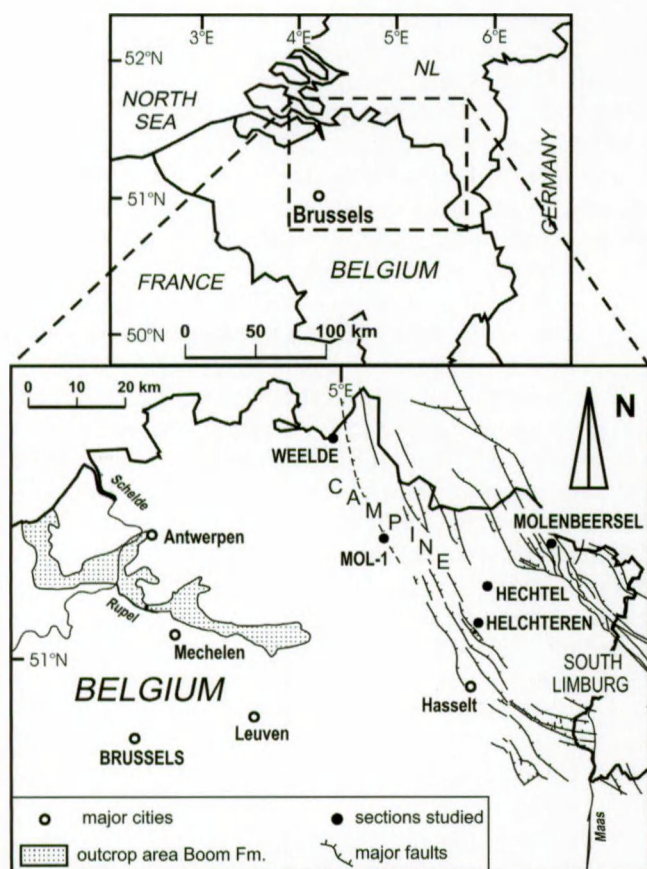


Figure 1 — Location of the studied sections. The position of each borehole or locality is given in Table 1. (NL: The Netherlands)

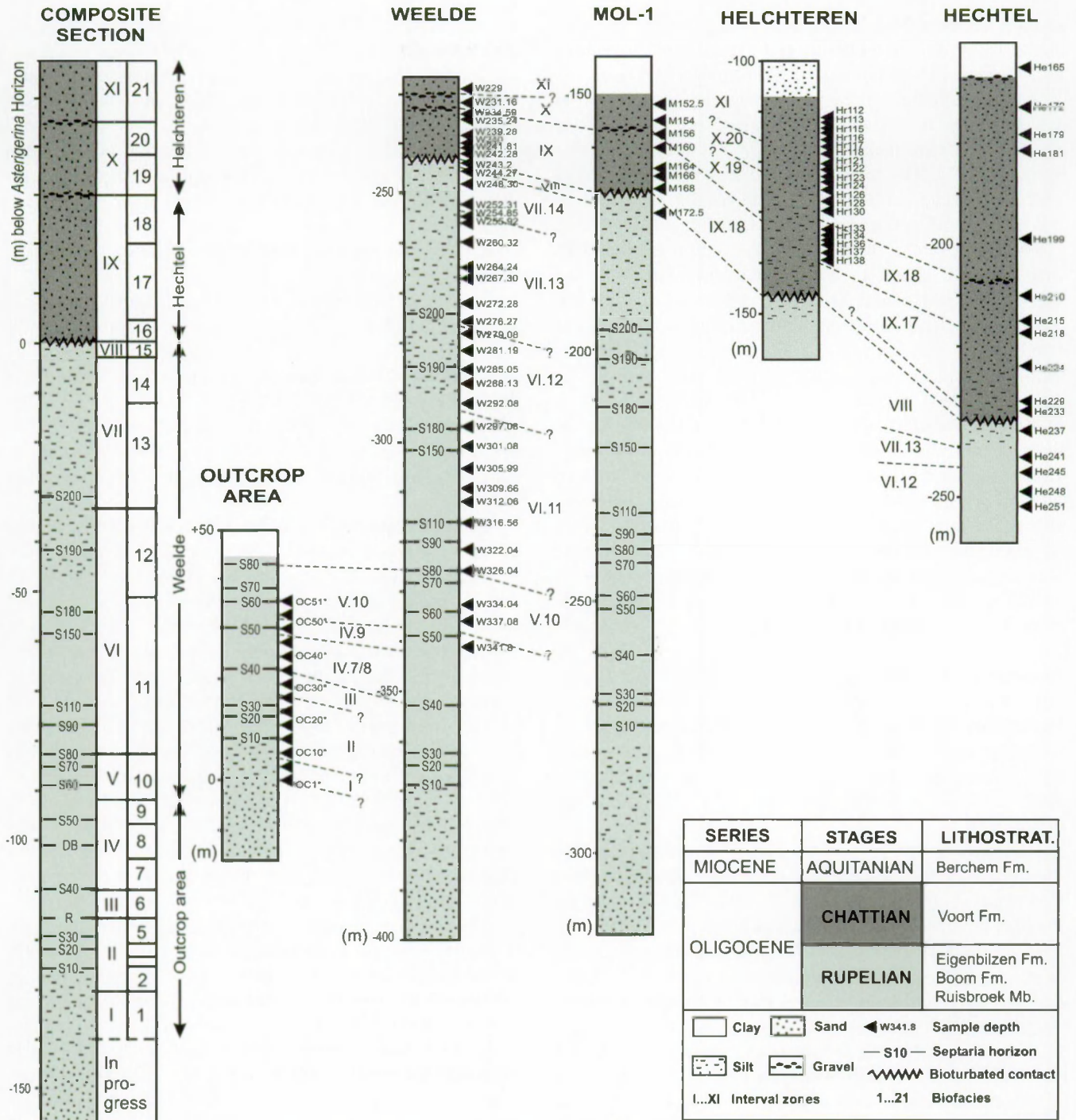


Figure 2 — Correlation between the four studied sections and the outcrop area of the Boom Clay Formation in its type locality. The outcrop area (OC1*-OC51*) is according to GRIMM & STEURBAUT (2001). The Composite Section (CS) is constructed by using the thickest (most complete) Rupelian and Chattian profile. All boreholes were linked together by using the base of the “*Asterigerina* Horizon” (= base of the Chattian in its German unit-stratotype), which has been selected as zero-level.

but only calculated as percentages ($P\% = \text{number planktonic} / (\text{total number of foraminifera}) \times 100$).

The foraminiferal material is stored in the collections of the Royal Belgian Institute of Natural Sciences (Brussels, Belgium). Photographs were taken using a Philips XL30 environmental scanning electron microscope.

Definition of foraminiferal zones

The Belgian Oligocene is represented by a 200m thick marine succession, of which the outcrop area of the Boom Formation represents only the lower 20% of the total deposits (Figures 1 and 2). This Rupelian stratotype

section has been biostratigraphically subdivided into four major foraminiferal intervals (I-IV) and nine foraminiferal biofacies (1-9) (GRIMM & STEURBAUT, 2001).

A zonal scheme for the upper Rupelian to Chattian of NE Belgium is proposed here based on foraminifera, presenting seven major intervals (V-XI) and twelve biofacies (10-21). The intervals are characterised by occurrence of species with substantial biostratigraphic potential and are defined as biozones according to SALVADOR (1994); they are informally designated in accord with their regional character. For each interval the biofacies are summarised, characterised by successive quantitative assemblage changes, reflecting modifying environmental conditions.

Interval I-IV:

GRIMM & STEURBAUT (2001) subdivided the lower part of the section (base Rupelian to S60 in CS) into four intervals based on its foraminiferal fauna. The first and third interval are almost completely devoid of calcareous microfossils. Interval II is characterised by two influx levels of planktonic foraminifera and the last occurrence of *Cassidulina carapitana*. Interval IV is defined at its base by the acme of *Turrilina alsatica* and the lowest occurrence (LO) of *Rotaliatina bulimoides*.

Interval V: *Rotaliatina bulimoides* - *Hoeglundina elegans* Assemblage Zone

Definition. The base of this zone is defined by the lowest common occurrence (LCO) of *Rotaliatina bulimoides* and *Alabamina tangentialis*. The top of this zone is defined by the lowest occurrence (LO) of *Cibicidoides ungerianus*.

Characteristics. Except for a single occurrence in bed 43 (GRIMM & STEURBAUT, 2001), *Rotaliatina bulimoides* first occurs commonly (7%) at -92 m in the CS, defining the base of this interval. This assemblage is dominated by *Hoeglundina elegans* (10-40%) and miliolids are fairly common, represented by *Quinqueloculina* spp. (<10%) and *Pyrgo bulloides* (<1%). Textulariids are not very common, with *Karreriella siphonella* reaching 3%, *K. chilostoma* 2% and *Spirorutilus carinata* 9%. At the very base of the interval (sample W337.08), planktonic foraminifera appear very frequently (17%), suggesting correlation with level S60 of the type section, which is regarded as the maximum flooding surface of a Rupelian sequence (VANDENBERGHE *et al.*, 1998).

Chronostratigraphy. Early Oligocene, latest part of early Rupelian.

Biostratigraphic correlation. This zone is equivalent to the upper part of SPIEGLER's (1965) Rupel 3; the upper

part of INDANS' (1958) Zone C₁; the lower part of Zone 2 of ELLERMANN (1958); the upper part of Zone 11 (*Rotaliatina offenbachensis* Range Zone) of GRIMM (2002) and falls within Zone NSB7b (KING, 1989) and Zone NSR 7b (GRADSTEIN *et al.*, 1994) (Figure 4).

The zone falls within calcareous nannoplankton Zone NP23 (VAN SIMAEYS *et al.*, 2004) and dinoflagellate cyst (dinocyst) Zone NSO 4a (VAN SIMAEYS *et al.*, submitted) (Figure 3).

Lithostratigraphic correlation. Boom Formation (from ~S60 to S80)

Characteristic sites. CS (-92 to -82m); Weelde borehole (W337.08 to W334.04).

Interval VI: *Cibicidoides ungerianus* - *Rotaliatina bulimoides* concurrent-range Zone

Definition. The base of this zone is defined by the LO of *Cibicidoides ungerianus*, and the top of the zone is defined by the highest occurrence (HO) of *Rotaliatina bulimoides*.

Characteristics. Two different biofacies can be recognised within this interval. The lower part of the zone – biofacies VI.11 – is dominated by *Spirorutilus* spp. (15 to 60%). *Uvigerina* spp. are common (5 to ~20%) and miliolids are virtually absent (sporadic occurrence of *Quinqueloculina* spp. <1%). Planktonic foraminifera reach a local maximum at W316 (16%), and are virtually absent in the remaining part of this zone.

The upper part of this zone – biofacies VI.12 – differs only in abundance differences from the lower part. *Spirorutilus* spp. cease to dominate the assemblage (from 60% in to 15%), while *Uvigerina* spp. become consistently more important (30-40%). *Sphaeroidina bulloides* and *Lenticulina* spp. are more common (~10% and ~20% respectively) compared to <10% in the lower part. Planktonic foraminifera are present, but very rare (~1%).

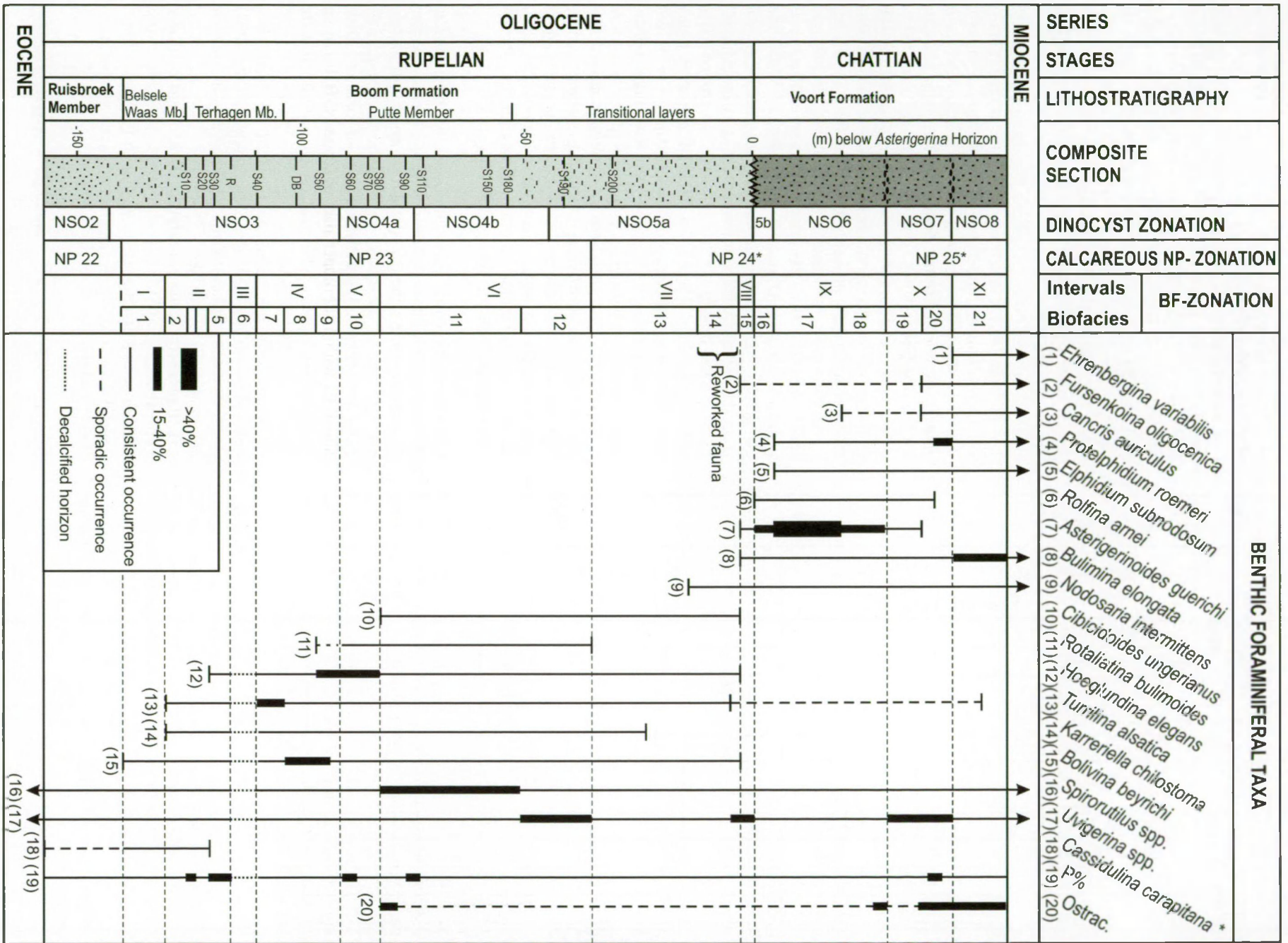
Chronostratigraphy. Early Oligocene, late Rupelian.

Biostratigraphic correlation. This zone is equivalent to the lower part of SPIEGLER's (1965) Rupel 4; Zone C₂ of INDANS (1958); the middle part of Zone 2 of ELLERMANN (1958); Zone 12 (*Spiroplectinella carinata*-*Cibicidoides ungerianus* Assemblage Zone) of GRIMM (2002) and falls within the upper part of Zone NSB7b (KING, 1989) and Zone NSR7b (GRADSTEIN *et al.*, 1994) (Figure 4).

The top of this zone coincides with the top of NP23 (VAN SIMAEYS *et al.*, 2004) and includes the top of dinocyst Zone NSO 4a, the NSO 4b Zone and the base of Zone NSO 5a (VAN SIMAEYS *et al.*, submitted) (Figure 3).

Lithostratigraphic correlation. Boom Formation (from S80 to ~S200)

Figure 3 — Simplified range chart illustrating the most important benthic foraminiferal events, completed with data from GRIMM & STEURBAUT (2001) on the lower part of the Rupelian. Calcareous nannoplankton zonation is according to VAN SIMAEYS *et al.* (2004) and the dinocyst zonation according to VAN SIMAEYS *et al.* (subm.). Full species names with reference to detailed descriptions are given in Table 2. (*): recorded by DOPPERS (1979, unpub. report). Ostrac.: ostracods.



Chronostrat.	Belgium Basin		NSB	LRE	Northwest German Basin			MB					
	Epochs	Stages											
	This study + Gr. & St. (2001)				King (1989)	Indans (1958)	Ellermann (1958)		Kiesel (1962)	Spiegler (1965)	Kummerle (1963)	Kaever and Oekentorp (1970)	Grimm (2002)
OLIGOCENE	Late	Chattian	XI	21	NSB 8b	G				Horizons: Hubach, 1957			
			X	20		F	5		3		22		
				19							9		
			IX	18		E	4				8	Oberes Oligozän	
				17							5		
				16							4		
				15							2		
			Early	Rupelian	VIII	15	NSB 8a						Oberes Mittel Oligozän
	VII	14				D	3	VI			1		
		13											
	VI	12				C ₃			R4				
		11				C ₂	2	V				Mittel Oligozän 2	
	V	10				C ₁		IV	R3				
	IV	9											
		8											
	III	6		B	1	III							
II	5					R2							
I	2				II								
	1		NSB 7a		A								

Figure 4 — Benthic foraminiferal zonation scheme for NE Belgium compared to similar studies within the North Sea Basin. NSB: North Sea Basin; LRE: Lower Rhine Embayment; MB: Mainz Basin. *: according to DOPPERT (1979, unpub. report) **: based on the LO of *Rotaliatina bulimoides*.

Characteristic sites. CS (-82 to -36.6m); Weelde borehole (W326.04 to W276.27).

Interval VII: *Sphaeroidina bulloides* – *Cibicidoides ungerianus* Assemblage Zone

Definition. This zone is the interval between the HO of

Rotaliatina bulimoides and the HO of *C. ungerianus*, *Bolivina beyrichi* and *Hoeglundina elegans*.

Characteristics. Within this zone, two biofacies can be distinguished. The lowermost part – biofacies VII.13 – is decalcified, except for two levels in the Weelde borehole (W279.08, W254.85), and one in the Hechtel borehole (He245). The calcareous fauna present is quite similar to the assemblage in the previous zone, with the same high percentages of *Sphaeroidina bulloides* (15-20%) and *Spirorutilus* spp. (5-15%). *Lenticulina* spp. reach high frequencies in Weelde (~30%), but is rarer in Hechtel (4%). *Uvigerina* spp. become distinctly less dominant (<15% compared to >30% in the previous zone), while in the upper part some *Nodosariaceae* have their LO. In W254 as well as in He245, *Nodosaria spinescens*, *N. aff. vertebralis* and *N. intermittens* occur for the first time.

The uppermost part of this zone – biofacies VII.14 – is characterised by the occurrence of many secondary silicified foraminifera, probably reworked from the Upper Cretaceous (see “discussion”). In W248, W244 and He241 this siliceous assemblage co-occurs with an indigenous calcareous Oligocene fauna, but in W252 the calcareous fauna is absent. In the latter, 96.5% of the secondary silicified foraminiferal fauna consists of planktonic species, mostly *Hedbergella* spp. and around 3.5% of Heterohelicidae (Plate I, Fig. 1-2). The accessory fauna consists of some siliceous radiolaria (Plate I, Fig. 3) and incertae sedis (Plate I, Fig. 4-6). The associated calcareous fauna is dominated by *Uvigerina* spp. (>20%) and *S. bulloides* (13%), associated with *Melonis affinis*, *Nodosaria* spp., *Lenticulina* spp. and *Lagena* spp. At the very top of this interval (W244.27), the assemblage is characterised by a sudden increase in abundance and in diversity of the benthic foraminiferal assemblage. Planktonic foraminifera are very rare (<2%).

Chronostratigraphy. Early Oligocene, late Rupelian.

Biostratigraphic correlation. This zone is equivalent to the upper part of SPIEGLER’s (1965) Rupel 4; the middle part of Zone D of INDANS (1958); the middle part of Zone 3 of ELLERMANN (1958); the middle part of Zone VI of KIESEL (1962) and falls within the basal part of Zone NSB8a (KING, 1989) and of Zone NSR8 (GRADSTEIN *et al.*, 1994) (Figure 4).

This zone is equivalent to the base of North Sea nannoplankton Zone NP24* (VAN SIMAEYS *et al.*, 2004) and falls within dinocyst Zone NSO 5a (VAN SIMAEYS *et al.*, submitted) (Figure 3).

Lithostratigraphic correlation. Sandy part of Boom Formation.

Characteristic sites. CS (-36.6 to -2m); Weelde borehole (W272.28 to W244.32), Hechtel borehole (He251 to He241), Mol-1 borehole (M172.5).

Interval VIII: *Bulimina elongata* – *Asterigerinoides guerichi guerichi* Assemblage Zone

Definition. This zone is defined at its base by the LO of *Asterigerinoides guerichi guerichi* and *Bulimina elongata*

and at its top by the bloom of *A. guerichi guerichi* (start of the "Asterigerina Horizon").

Characteristics. This zone comprises a very thin interval, represented only by 2m of sediment in the CS. At the base of this interval several species – such as *Cibicoides ungerianus*, *Bolivina beyrichi* and *Hoeglundina elegans* – have their HO's. Apart from these events, the assemblage is still quite similar to the one from biofacies VII.14. It is still very diverse and the assemblage is dominated by *Uvigerina* spp. (~40%), *Sphaeroidina bulloides* (13%) and *Bulimina elongata* (25%). Planktonic foraminifera are sparse (~1%) and a reworked siliceous fauna is absent.

Chronostratigraphy. Early Oligocene, late Rupelian.

Biostratigraphic correlation. This zone is equivalent to the uppermost part of SPIEGLER'S (1965) Rupel 4; the upper part of Zone D of INDANS (1958); the upper part of Zone 3 of ELLERMANN (1958), the upper part of Zone VI of KIESEL (1962) and falls within NSB8a (KING, 1989) and Zone NSR8 (GRADSTEIN *et al.*, 1994) (Figure 4).

This zone falls within North Sea nannoplankton Zone NP24* (VAN SIMAEYS *et al.*, 2004) and coincides with the top of dinocyst Zone NSO 5a (VAN SIMAEYS *et al.*, submitted) (Figure 3).

Lithostratigraphic correlation. Sandy part of Boom Formation.

Characteristic sites. CS (-2 to 0m); Weelde borehole (W243.2), Hechtel borehole (He237).

Interval IX : *Asterigerinoides guerichi guerichi* Abundance Zone

Definition. This zone marks the range of the "Asterigerina Horizon", a biohorizon characterised by the bloom of *Asterigerinoides guerichi guerichi* (frequencies to 86%).

Characteristics. In comparison to the underlying interval, foraminiferal species diversity drops to a minimum, related to the dominance of one taxon, *Asterigerinoides guerichi guerichi*. The rest of the association in this interval is characterised by the presence of *Uvigerina* spp. (5 to >40%), *B. elongata* (~5%), *Cibicoides* spp. (~5%) and *Sphaeroidina bulloides* (<5%). Planktonic foraminifera are absent in the sediments of the Weelde borehole and rare in the Hechtel and Helchteren borehole (<6%). Some significant biostratigraphic events and abundance shifts take place within this interval, which allows recognition of three different biofacies within this zone. The lowermost part of this zone – biofacies IX.16 – is best documented in He233 and shows a significant increase in *A. g. guerichi* (16% compared to 1% in the former zone), accompanied by the LO of *Rolfina arnei*. In the Weelde borehole the two lowermost samples (W242 and W241) are almost completely devoid of foraminifera.

The middle part of this zone (biofacies IX.17) can be recognised in the Weelde (W240 and W239) and Hechtel boreholes (He229 to 218). It shows a gradual increase in *A. g. guerichi* (reaching a maximum of 86% / 70% in W240 and He224 respectively) and the LO of *Elphidium subnodosum* and *Protelphidium roemeri* (both ~1%). Higher up in the section, the frequency of *A. g. guerichi*

drops to 40%, delineating the uppermost part of this zone (biofacies IX.18). The latter is documented in the Hechtel borehole (He215 to 210), decalcified in the Weelde borehole (W235 to 234) and in the Helchteren borehole (Hr138 to 133).

Chronostratigraphy. Late Oligocene, early Chattian ("Unter Eochat").

Biostratigraphic correlation. This zone is equivalent to the lower part of Zone E of INDANS (1958); the lower part of Zone 4 of ELLERMANN (1958), Zone 1 of KÜMMERLE (1963) and to the middle part of Zone NSB8a (KING, 1989) and Zone NSR8 (GRADSTEIN *et al.*, 1994) (Figure 4).

This zone correlates with the top of North Sea nannoplankton Zone NP24* (VAN SIMAEYS *et al.*, 2004) and incorporates the dinocyst Zones NSO 5b and NSO6 (VAN SIMAEYS *et al.*, submitted) (Figure 3).

Lithostratigraphic correlation. Voort Formation.

Characteristic sites. CS (0-30m); Hechtel borehole (He233 to He210), Weelde borehole (W242.28 to W234.59), Mol-1 borehole (M168.54 to M160.44), Helchteren borehole (Hr138 to Hr133).

Interval X: *Protelphidium roemeri* – *Fursenkoina oligocenica* Assemblage Zone

Definition. This zone is defined at its base by the top of the "Asterigerina Horizon", with *Asterigerinoides guerichi guerichi* decreasing in abundance to <20%. Its top is delineated by the LO of *Ehrenbergina variabilis*.

Characteristics. In the Weelde borehole, this zone is contained between two gravel layers. The base of this zone is characterised only by an abundance shift between *A. guerichi guerichi* and *E. subnodosum* + *P. roemeri*: the former diminishes in abundance, while the latter two vary from <3% in interval IX to ~10% in this interval X. At the same level, *Porosolenia (?) laevigata* appears for the first time. Within this zone, two smaller subdivisions can be made. The lower part of this zone (biofacies X.19) is still characterised by the presence of *A. guerichi guerichi* (20% in Weelde; <10% in Helchteren). The assemblage is dominated by *Uvigerina* spp., with frequencies >30%. Planktonic foraminifera are present, but because of the poor preservation of the calcareous fauna, no representative percentages can be given.

The upper part of this zone – biofacies X.20 – is devoid of *A. g. guerichi*, and its base is characterised by the FO of *Favulina hexagona* and by the lowest common occurrence (LCO) of *Lagena sulcata*, *F. oligocenica* (single occurrence in He237) and *Canceris auriculus* (single occurrence in Hr137). The number of planktonic foraminifera gradually increases, and reaches a local maximum in Hr119 (16%). At the same level, *Alabama perlata* and *Rolfina arnei* have their HO's. Ostracods are first encountered in this zone (apart from single occurrences in He210 and W316), although only a maximum of 3 specimens were encountered in 100g of sediment. Higher up, there is a sudden increase in *P. roemeri* (from 9% to ~25%) and decrease in planktonic foraminifera (from 16% to <2%).

Chronostratigraphy. Late Oligocene, middle Chattian ("Mittel Eochat").

Biostratigraphic correlation. Biofacies X.19 is equivalent to the upper part of Zone E of INDANS (1958), the upper part of Zone 4 of ELLERMANN (1958), Zone 2 of KÜMMERLE (1963), the uppermost part of NSB8a (KING, 1989) and falls within Zone NSR8 (GRADSTEIN *et al.*, 1994).

Biofacies X.20 is equivalent to the lower part of Zone F of INDANS (1958), the lower part of Zone 5 of ELLERMANN (1958), Zone 3 of KÜMMERLE (1963), the basal part of Zone NSB8b (KING, 1989) and falls within Zone NSR8 (GRADSTEIN *et al.*, 1994) (Figure 4).

This zone coincides with the base of North Sea nannoplankton Zone NP25* (VAN SIMAEYS *et al.*, 2004) and is equivalent to dinocyst Zone NSO 7 (VAN SIMAEYS *et al.*, submitted) (Figure 3).

Lithostratigraphic correlation. Voort Formation.

Characteristic sites. CS (+30 to 45.5m); Helchteren borehole (Hr130 to Hr117); Weelde borehole (W231).

Remarks. In the Weelde borehole, the base of this zone is accompanied by the presence of a gravel bed around -232m (+45.5m in the CS). In the Hechtel borehole, interval X could not be differentiated but is probably present in the decalcified part, above He210. In the Helchteren borehole the exact position of this zone is uncertain. Due to the low foraminiferal abundance until Hr123, it is difficult to pinpoint the top of the "Asterigerina Horizon". The lowermost part of the section (Hr138 to 133) is assigned to biofacies IX.18, due to the still rather high percentages of *A. g. guerichi* (up to 30%).

Interval XI : *Ehrenbergina variabilis* Taxon-range Zone

Definition. This zone is defined at its base by the LO of *Ehrenbergina variabilis* and at its top by its HO, or by the onset of the unconformably overlying Miocene Houthalen Sands (Bolderberg Formation), marked by the presence of *Asterigerinoides staeschei* and *Virgulinea per-tusa*.

Characteristics. The assemblage of this zone is characterised by a gradual increase in *B. elongata* (from 7% in Hr116 to 20% in Hr 112), high frequencies of *Uvigerina* spp. (>10% to 40%), and the presence of *Cancris auriculus* (<5%), *Fursenkoina oligocenica* (<5%), *Porosolenia* (?) *laevigata* (~1%), and *Protelphidium roemeri* (19% to 8%). Planktonic foraminifera never exceed values above 3%.

Chronostratigraphy. Late Oligocene, late Chattian ("Ober Eochat").

Biostratigraphic correlation. This zone is equivalent to the upper part of Zone F (INDANS, 1958); the upper part of Zone 5 (ELLERMANN, 1958) and falls within Zone NSB8b (KING, 1989) and Zone NSR8 (GRADSTEIN *et al.*, 1994) (Figure 4).

This zone falls within North Sea nannoplankton Zone NP25* (VAN SIMAEYS *et al.*, 2004) and is equivalent to dinocyst Zone NSO 8 (VAN SIMAEYS *et al.*, submitted) (Figure 3).

Lithostratigraphic correlation. Voort Formation.

Characteristic sites. CS (+45.5m to 57m); Weelde borehole (W229), Helchteren borehole (Hr116 to Hr112).

Discussion

Relationship to other benthic foraminiferal zonal schemes

The relationship between the benthic foraminiferal zonation scheme for the southern North Sea Basin proposed here and other zonation schemes for the North Sea Basin is summarised in Figure 4.

In most zonal schemes the Rupelian-Chattian boundary is recognised based on the "Asterigerina Horizon" (e.g. INDANS, 1958, 1965; ELLERMANN, 1958; KIESEL, 1962; KAEVER & OEKENTORP, 1970; DOPPERT & NEELE, 1983; ULLEBERG, 1987); with the recurrence of *Elphidium sub-nodosum* and the LO *Protelphidium roemeri* occurring slightly later. In the central North Sea Basin, the HO of *Rotaliatina bulimoides*, formalised as the NSB7b/8a boundary (KING, 1983, 1989), is believed to coincide approximately with the Rupelian-Chattian boundary. In the southern North Sea Basin, however, the HO of *R. bulimoides*, marking the limit between interval VI/VII, occurs well below the onset of the "Asterigerina Horizon".

Correlation within the southern North Sea Basin is mainly based on the LO of *Cibicidoides ungerianus*, marking the base of the upper part of the Rupelian (SPIEGLER, 1965). In the uppermost part of the upper Rupelian, the LO of *Asterigerinoides guerichi guerichi* and *Bulimina elongata* allows correlation of a single horizon within Zone D of INDANS (1958), Zone 3 of ELLERMANN (1958) and Rupel 4 of SPIEGLER (1965), a few meters below the Rupelian-Chattian boundary as currently defined in Germany (boundary between the Boom Formation and the Voort Formation in Belgium).

Chiloguembelina* vs. *heterohelicids

To define the Rupelian-Chattian boundary, BERGGREN *et al.* (1995) use the last appearance datum of (common) chiloguembelinids, formalised as the P21a/b boundary and calibrated to (mid) Chron C10n with an estimated age of 28.5 Ma. This boundary criterion is principally based on Ritzkowski's observations in NW Germany (1982: unpublished written communication), where he reports the highest occurrence of *Chiloguembelina* being positioned at the top of the Rupelian (= Rupel 4 division of SPIEGLER, 1965). This event has been calibrated by magnetobiochronologic correlations from several DSDP cores by BERGGREN *et al.* (1985; for discussion see VAN SIMAEYS *et al.*, 2004), and other reports from Rupel 4 deposits in the North Sea Basin are given in SPIEGLER (1986).

Comparison between Belgium and the North German Egestorffhall borehole (providing reference samples with typical German Rupel 4 assemblages) revealed an identical silicified fauna at the very top of the Rupelian,

including planktonic biserial foraminifera. These specimens were identified by means of SEM analyses as heterohelicids instead of chiloguembelinids, proving their reworked nature.

This phenomenon of reworked (probably Upper Cretaceous) biserial planktonic foraminifera (heterohelicids, generally previously assigned to “*Guembelina*”) in Oligocene material has been well documented in the literature.

BATJES (1958, p. 163, pl. 6, fig. 9) found *Guembelina gracillima* (ANDREAE) in many samples throughout the Belgian Oligocene and in samples from Pietzpuhl (Germany).

KÜMMERLE (1963, p. 64) reports *Guembelina* sp. as an allochthonous faunistic element in his assemblages of the Upper Oligocene of the Kasseler Meeressandes in Ahnetal (Kassel, Germany).

HAUSMANN (1964, p. 371, pl. 6, fig. 15) reports *Guembelina globulosa* (EHRENBERG) from the Septarienton in Magdeburg and Dessau (Germany) and places the species in synonymy with BATJES' (1958) record of *Guembelina gracillima* (ANDREAE).

As similar observations of such reworked specimens have been made during the present study in the Belgian upper Rupelian (W252-W240 and He241) and Chattian (He233-He210) and in the German Rupel 4 unit (Egestorffhall borehole, -70.45m), we suggest that all these records are the result of enhanced reworking of Upper Cretaceous material during the late Rupelian to the Chattian.

The occurrence of *Chiloguembelina cubensis* (PALMER) in the Belgian Basin is reported by HOOYBERGHS (1983, p. 15, pl. 1, fig. 3-4). He documents the HO of the species in level S10 of the type section (Mol borehole, St. Nikolaas, Terhagen). We therefore suggest that the true HO of *Chiloguembelina cubensis* (PALMER) in the Belgian Basin is situated in the lower part of the Rupelian (level S10 in the type area) and that records of biserial planktonic foraminifera in the Rupel 4 unit do not represent in situ *Chiloguembelina cubensis* (PALMER), but rather reworked heterohelicids from the Upper Cretaceous. Hence, VAN SIMAEYS *et al.* (2004) suggest that RITZKOWSKI's (1982, unpub.) record of *Chiloguembelina cubensis* (PALMER) in the German Rupel 4 unit should be questioned.

Systematics

A full list of all cited taxa is given in alphabetical order in Table 2, where reference is made to the most detailed description. Remarks on selected taxa, with appropriate synonymy, is given below. The majority of the taxa on the range chart (Table 3) are illustrated in Plates I-II by SEM photographs.

Suborder Textulariina

Karreriella chilostoma (REUSS, 1852)

Differs from *Siphotextularia labiata* (REUSS) by having

an initial triserial stage, a rounded cross section, more depressed and bent sutures and a non-calcareous cement.

Karreriella siphonella (REUSS, 1851)

No attempt was made to differentiate *K. siphonella exilis* HAGN, because the two morphotypes co-occur in all samples.

Spirorutilus carinata (D'ORBIGNY, 1846)

The generic assignment is ambiguous (discussion see GRIMM, 1993; CÍCHA *et al.*, 1998, p. 128): the species is sometimes referred to *Spiroplectammina* CUSHMAN, *Spiroplectinella* KISEL'MAN or *Spirorutilus* HOFKER. Since the species has pseudopores and a rhombic cross section, it is considered to belong to *Spirorutilus* HOFKER. *S. carinata* can be distinguished from *S. deperdita* and *S. pectinata* by its broad sutures, broad membranous keel and lenticular chambers.

Suborder Lagenina

Astacolus gladius (PHILIPPI, 1843)

Cited as *Lenticulina* (*Vaginulinopsis*) *gladia* (PHILIPPI) by BATJES (1958), and *Lenticulina* (*Astacolus*) *gladia* (PHILIPPI) by ELLERMANN (1958) and GROSSHEIDE & TRUNKÓ (1965). It differs from *A. arcuatus* (PHILIPPI) by the presence of sutural ribs.

Dentalina calomorpha REUSS, 1865

The specimens in this material differ from the ones reported by GROSSHEIDE & TRUNKÓ (1965, pl. 5, fig. 6) by having poorly pronounced rounded longitudinal ribs in the sutural area, a feature which allows assignment to the genus *Dentalina*.

Dentalina intermittens ROEMER, 1838

The specimens encountered in the Weelde borehole strongly resemble the ones figured by BATJES (1958, pl. 3, fig. 22) and KIESEL (1962, pl. 3, fig. 8), but differ from the ones figured by KING (1989, pl. 9.4, fig. 7) and GROSSHEIDE & TRUNKÓ (1965, pl. 5, fig. 2). The latter two have a less distinct pear-shaped last chamber.

Dentalina aff. *vertebralis* (BATSCH, 1781)

Synonymised with *Nodosaria vertebralis* (BATSCH) of GROSSHEIDE & TRUNKÓ (1965, pl. 5, fig. 3) and *Nodosaria* sp. A by KING (1989, pl. 9.4, fig. 6). As KING (1989) mentions, the specimens of GROSSHEIDE & TRUNKÓ (1965) differ from the type specimen by being less coarsely ribbed.

Favulina hexagona (WILLIAMSON, 1848)

The very short neck of this species allows differentiation from *Lagena striata*.

Lagena sulcata (WALKER & JACOB, 1798)

L. sulcata (WALKER & JACOB) differs from *L. isabella* (D'ORBIGNY) by being more globular, with a longer neck and the absence of rings at the basis of the neck. *L. striata*

Table 2 — Alphabetic list of encountered taxa, with reference to appropriate systematic description.

Taxa (* = discussed in text)	Description	Iconography
Suborder Textulariina		
<i>Haplophragmoides latidorsatus</i> (Bornemann, 1855)	Kiesel (1962), p. 12	
<i>Karrerella chilostoma</i> (Reuss, 1852) *	Kiesel (1962), p. 14	Plate I, Figure 7
<i>Karrerella siphonella</i> (Reuss, 1851) *	Kiesel (1962), p. 15	Plate I, Figure 8a, 8b, 9
<i>Martinotiella communis</i> (d'Orbigny, 1846)	Grossheide & Trunkó (1965), p.57	
<i>Siphotextularia labiata</i> (Reuss, 1861)	De Meuter (1980), p. 89	Plate I, Figure 10
<i>Spirorutilus carinata</i> (d'Orbigny, 1846) *	Ten Dam & Reinhold (1942), p. 42	Plate I, Figure 11a, 11b
<i>Spirorutilus deperdita</i> (d'Orbigny, 1846)	Grimm (1993), p. 24	Plate I, Figure 12
<i>Spirorutilus pectinata</i> (Reuss, 1851)	Batjes (1958), p. 98	Plate I, Figure 13
<i>Textularia</i> aff. <i>gramen</i>	Batjes (1958), p. 99	
Suborder Miliolina		
<i>Pyrgo bulloides</i> (d'Orbigny, 1826)	Kiesel (1962), p. 21	Plate I, Figure 14
<i>Quinqueloculina ackneriana</i> d'Orbigny, 1846	Grossheide & Trunkó (1965), p. 58	
<i>Quinqueloculina juleana</i> d'Orbigny, 1846	Kiesel (1962), p. 18	Plate I, Figure 15
<i>Quinqueloculina</i> spp.		
<i>Spiroloculina</i> sp.	Grossheide & Trunkó (1965), p. 60	
Suborder Lagenina		
<i>Astaculus gladius</i> (Philippi, 1843) *	Grossheide & Trunkó (1965), p. 69	
<i>Dentalina calomorpha</i> Reuss, 1865 *	Grossheide & Trunkó (1965), p. 62	Plate I, Figure 22
<i>Dentalina intermitens</i> Roemer, 1838 *	Grossheide & Trunkó (1965), p. 65	Plate I, Figure 25
<i>Dentalina</i> aff. <i>vertebralis</i> (Batch, 1781) *	Grossheide & Trunkó (1965), p. 63	Plate I, Figure 28
<i>Favulina hexagona</i> (Williamson, 1848) *	Grossheide & Trunkó (1965), p. 72	Plate I, Figure 18
<i>Fissurina kapellensis</i> Spiegler, 1974	Spiegler (1974), p. 60	Plate I, Figure 17
<i>Fronidularia obliqua</i> Roemer, 1838	Grossheide & Trunkó (1965), p. 71	
<i>Glandulina laevigata</i> (d'Orbigny, 1846)	Batjes (1958), p. 123	
<i>Globulina gibba</i> (d'Orbigny, 1826)	De Meuter (1980), p. 110	
<i>Guttulina irregularis</i> (d'Orbigny, 1846)	Batjes (1958), p. 121	
<i>Lagena sulcata</i> (Walker & Jacob, 1798) *	Grossheide & Trunkó (1965), p. 73	Plate I, Figure 20
<i>Lagena striata</i> (d'Orbigny, 1839)	Grossheide & Trunkó (1965), p. 74	Plate I, Figure 19
<i>Lagena tenuis</i> (Borneman, 1855)	De Meuter (1980), p. 100	
<i>Lenticulina</i> spp. *		
<i>Lenticulina (Robulus)</i> sp.	Grossheide & Trunkó (1965), p. 66-68	Plate I, Figure 21
<i>Lenticulina (Planularia)</i> sp.	Grossheide & Trunkó (1965), p. 70	
<i>Marginulina</i> sp.	Grossheide & Trunkó (1965), p. 70	
<i>Neugeborina longiscata</i> d'Orbigny, 1846	Ten Dam & Reinhold (1942), p. 64	Plate I, Figure 26
<i>Nodosaria emaciata</i> Reuss, 1851	Batjes (1958), p. 116	Plate I, Figure 24
<i>Nodosaria soluta</i> (Reuss, 1851) *	Batjes (1958), p. 115	Plate I, Figure 27
<i>Porosolenia (?) laevigata</i> (Reuss, 1849) *	Bhatia (1955), p.680	Plate I, Figure 16
<i>Pyralina fusiformis</i> (Roemer, 1838)	Grossheide & Trunkó (1965), p. 82	
<i>Siphonodosaria hirsuta</i> (d'Orbigny, 1826)	Batjes (1958), p. 120	Plate I, Figure 23
Suborder Rotaliina		
<i>Alabamina tangentialis</i> (Clodius, 1922)	Batjes (1958), p. 155	
<i>Alabamina perlata</i> (Andreae, 1884)	Grossheide & Trunkó (1965), p. 140	
<i>Alabamina wollerstorffii</i> (Franke, 1925)	Grossheide & Trunkó (1965), p. 141	
<i>Angulogerina gracilis</i> (Reuss, 1851)	Ten Dam & Reinhold (1942), p. 86	Plate II, Figure 1, 2
<i>Angulogerina gracilis</i> var. <i>tenuistriata</i> (Reuss, 1970)	Batjes (1958), p. 184	Plate II, Figure 3
<i>Angulogerina</i> sp.		Plate II, Figure 4
<i>Asterigerinoides guerichi guerichi</i> (Franke, 1912) *	Ten Dam & Reinhold (1942), p. 90	Plate II, Figure 11
<i>Asterigerinoides guerichi staeschei</i> (Ten Dam & Reinhold, 1941)	Ten Dam & Reinhold (1942), p. 91	
<i>Bolivina</i> aff. <i>antiqua</i> d'Orbigny, 1846 *	King (1989), p. 467	Plate II, Figure 5
<i>Bolivina beyrichi</i> Reuss, 1851 *	Ten Dam & Reinhold (1942), p. 83	Plate II, Figure 6
<i>Bolivina</i> aff. <i>dilatata</i> (Reuss 1850) *	Batjes (1958), p. 130	Plate II, Figure 7
<i>Bulimina alsatica</i> Cushman & Parker, 1937	Batjes (1958), p. 127	
<i>Bulimina elongata</i> d'Orbigny, 1846 *	Ten Dam & Reinhold (1942), p. 80	Plate II, Figure 9
<i>Bulimina socialis</i> Bornemann, 1855	Kiesel (1962), p. 54	
<i>Cancris auriculus</i> (Fichtel & Moll, 1798)	Ten Dam & Reinhold (1942), p. 89	Plate II, Figure 18
<i>Ceratobulimina contraria</i> (Reuss, 1851)	Ten Dam & Reinhold (1942), p. 92	
<i>Cibicides lobatulus</i> (Walker & Jacob, 1798)	Ten Dam & Reinhold (1942), p. 97	
<i>Cibicides tenellus</i> (Reuss, 1865)	Ten Dam & Reinhold (1942), p. 99	
<i>Cibicides ungerianus</i> (d'Orbigny, 1846) *	Ten Dam & Reinhold (1942), p. 85	Plate II, Figure 12
<i>Ehrenbergina variabilis</i> (Reuss, 1850) *	Spiegler (1973), p. 10	Plate II, Figure 10
<i>Elphidium subnodosum</i> (Roemer, 1838) *	Grossheide & Trunkó (1965), p. 170	
<i>Eponides pygmaeus</i> (Hantken, 1875)	Grossheide & Trunkó (1965), p. 184	
<i>Eponides umbonatus</i> (Reuss, 1851)	Batjes (1958), p. 146	
<i>Fursenkoia oligocenica</i> (Hofker, 1951) *	Reverts (1996), p. 13	Plate II, Figure 8
<i>Globocassidulina subglobosa</i> (Brady, 1881)	De Meuter (1980), p. 130	
<i>Hansenisca soldanii</i> (d'Orbigny, 1826)	Batjes (1958), p. 174	
<i>Heterolopa dutemplei</i> (d'Orbigny, 1846)	Reverts (1996), p. 67	
<i>Hoeglundina elegans</i> (d'Orbigny, 1826)	Ten Dam & Reinhold (1942), p. 89	
<i>Melonis affinis</i> (Reuss, 1851)	Ten Dam & Reinhold (1942), p. 75	
<i>Nonion nonionelloides</i> Ten Dam & Reinhold, 1942	Grossheide & Trunkó (1965), p. 130	
<i>Pararotalia canui</i> (Cushman, 1928)	Grossheide & Trunkó (1965), p. 174	Plate II, Figure 23
<i>Protelphidium roemeri</i> (Cushman, 1936) *	Grossheide & Trunkó (1965), p. 126	Plate II, Figure 19
<i>Protelphidium granosum</i> (d'Orbigny, 1846)	Grossheide & Trunkó (1965), p. 127	
<i>Pullenia bulloides</i> (d'Orbigny, 1846)	Kümmerle (1963), p. 46	Plate II, Figure 21
<i>Pullenia quinqueloba</i> (Reuss, 1851)	Batjes (1958), p. 139	Plate II, Figure 20
<i>Rolfina arnei</i> Laursen, 1994 *	Laursen (1994), p. 16	Plate II, Figure 16, 17
<i>Rotalia trochus</i> (Roemer, 1838)	Grossheide & Trunkó (1965), p. 172	
<i>Rotalatina bulimoides</i> (Reuss, 1851) *	King (1989), p. 480	Plate II, Figure 22
<i>Sphaeroidina bulloides</i> d'Orbigny 1826	Ten Dam & Reinhold (1942), p. 95	Plate II, Figure 24
<i>Turrilina alsatica</i> Andreae, 1884	Reverts (1987), p. 321	Plate II, Figure 25
<i>Quadrimorphina petrolei</i> (Andreae, 1884)	King (1989), p. 485	
Reworked fauna		
Heterohelicidae *		Plate I, Figure 1-2
Radiolaria		Plate I, Figure 3
Incertae sedis		Plate I, Figure 4-6

(D'ORBIGNY) has much finer costae and a more pronounced neck.

Lenticulina spp.

Most of the specimens can be assigned to the "subgenus" *Robulus* and vary considerably in size and shapes. Some specimens show a distinct keel.

Nodosaria soluta (REUSS, 1851)

Synonymised with *N. hirsuta* D'ORBIGNY by HOOYBERGHS *et al.* (1992, pl. 1, fig. 19) and *Dentalina globifera* REUSS by GROSSHEIDE & TRUNKÓ (1965, pl. 5, fig. 1). As in many nodosariids, generic classification is somewhat ambiguous; this species is often assigned to *Dentalina*.

Neugeborina longiscata (D'ORBIGNY, 1846)

Also referred to as *Nodosaria longiscata* (D'ORBIGNY), the species is designed to the genus *Neugeborina* POPESCU *et al.* (1998) (in CICHA *et al.*, 1998, p. 76, 113), because of the typical cylindrical chamber form and characteristic bamboo-like sutures.

Porosolenia (?) *laevigata* (REUSS, 1849)

Cited as *Entosolenia laevigata* (REUSS) by BHATIA (1955, p. 680, pl. 66, fig. 12).

Suborder Rotaliina

Asterigerinoides guerichi guerichi (FRANKE, 1912)

This species differs from the typical Miocene species *A. g. staeschei* (TEN DAM & REINHOLD, 1941) by having a less convex umbilical side and bigger supplementary chambers. Both subspecies are often regarded as chronological variants (KING, 1989), and also in the Belgian section they co-occur within the Chattian. *A. g. staeschei* is very rarely encountered in Hr126 and in He210-215.

Bolivina aff. *antiqua* D'ORBIGNY, 1846

The specimens in our samples differ from *B. antiqua* D'ORBIGNY by the lower number of chambers.

Bolivina beyrichi REUSS, 1851

Only unkeeled specimens were encountered, no keeled morphotypes – referred to *B. beyrichi carinata* HANTKEN by CICHA *et al.* (1998, p. 83, pl. 44, fig. 3) – were encountered.

Bolivina aff. *dilatata* (REUSS, 1850)

The specimens in our samples differ from *B. dilatata* (REUSS) by being more flattened and having a central rib in early stages. KING (1989) also describes a "central rib in early stages", a feature not mentioned in the description by REUSS (1850). Our specimens differ from *B. melettica* ANDREAE reported by HOOYBERGHS *et al.* (1992), by lacking the typical bent sutures.

Bulimina elongata D'ORBIGNY, 1846

Some variation within the "*Bulimina elongata* – group" is noticeable: the length-diameter ratio has a wide variation, with short specimens co-occurring with elongated

ones. The typical *B. elongata* D'ORBIGNY also occurs next to specimens that develop broader, more inflated chambers upward.

Cibicidoides ungerianus (D'ORBIGNY, 1846)

The species is assigned to the genus *Cibicidoides* because of the biconvex shape, the elliptical aperture (instead of simple slit) and the presence of spiral lappets, although these features are not always clear in all specimens. We only recognised *C. ungerianus* as defined by D'ORBIGNY, and did not see any morphotypes comparable with *C. ungerianus filicosta* HAGN (CICHA *et al.*, 1998, pl. 61, fig. 12-14).

Ehrenbergina variabilis (REUSS, 1850)

Most of the specimens encountered belong to the subspecies *E. variabilis aculeata* SPIEGLER, with typical short peripheral spines, a big proloculus and a broad test. Some specimens tend towards *Ehrenbergina variabilis* as illustrated by GROSSHEIDE & TRUNKÓ (1965, p. 125, pl. 13, fig. 1), lacking the typical peripheral spines and having a slimmer shape. No distinction within this morphological variation was made, and all specimens were classified as *E. variabilis* (REUSS).

Elphidium subnodosum (ROEMER, 1838)

Two morphotypes – by ELLERMANN (1958) referred to as *E. subnodosum minor* and *E. subnodosum subnodosum* – occur together in our assemblages. The former subspecies is much smaller and has a less pronounced keel (Plate II, Fig. 13) and occurs already in the Bartonian of Belgium (KAASSCHIETER, 1961). *E. subnodosum subnodosum* is much bigger and has a keel, and first occurs in the Upper Oligocene. In this study we formally grouped the two subspecies under the same species name.

Fursenkoina oligocenica (HOFKER, 1951)

Synonymised with *Virgulina schreibersiana* CZIZEK of TEN DAM & REINHOLD (1942, p. 82, pl. 5, fig. 14) (discussion: see REVETS, 1996, p. 13); GROSSHEIDE & TRUNKÓ (1965, p. 92, pl. 7, fig. 3); KING (1983, pl. 2 fig. 23); and of CICHA *et al.* (1998, pl. 55, fig. 1-3).

Protelphidium roemeri (CUSHMAN, 1936)

This species differs from *P. granosum* (D'ORBIGNY) by having a broader periphery.

Rolfina arnei LAURSEN, 1994

The specimens from this study differ from those recorded from Denmark and the northern and central North Sea (LAURSEN, 1994) by having bent chambers towards the umbilicus and being slightly less trochospiral. Because the last chamber is always lacking in our material, the typical aperture (umbilical arc) is not visible. This is the first record of this species in the southern North Sea Basin.

Rotaliatina bulimoides (REUSS, 1851)

Within the assemblage, *R. bulimoides* (REUSS) has a wide

variation in shape. All are trochospiral, but some are high conical to elongate and tightly coiled, others are much lower conical and tend towards *Hansenisca soldanii mammillata* (ANDREAE)

Reworked fauna

In several horizons throughout the section, a distinct, badly preserved siliceous fauna is present. The majority of this assemblage consists of secondary silicified planktonic foraminifera, with rare Heterohelicidae and of radiolaria and incertae sedis (see Plate II, Figs. 1-6). All are characterised by bad preservation and typically underwent silicification. In some levels they co-occur with the normal calcareous fauna (e.g. He241, W248-240), and one level (W252) only yields this type of siliceous assemblage.

Heterohelicidae

Within the siliceous fauna of the Belgian upper Rupelian and lower Chattian, some rare biserial planktonic foraminifera were found (W252, W244, He241, 233, 210) and compared to contemporaneous material from the German Rupel 4 unit (reference samples 70,45 - 66,8 m of the Egestorffhall borehole 104). All these specimens reveal an early planispiral stage, a simple symmetrical aperture and a striate wall (Plate I, Figs. 1-2); all features which allow identifying them as heterohelicids, typical Upper Cretaceous foraminifera. They appear to have been identified previously as the Oligocene planktonic foraminifer species *Chiloguembelina cubensis* (PALMER), which was not encountered in the upper Rupelian during this study; its range has been discussed in the former paragraph in relationship to the reworked heterohelicids.

Conclusions

The study of benthic foraminifera in the Belgian Basin reveals some major changes across the Rupelian-Chattian boundary. The very base of the Chattian is characterised by the bloom of the benthic foraminifer *Asterigerinoides guerichi guerichi* (>70%), a biohorizon referred to as "*Asterigerina* Horizon". Other significant bio-events

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within the Rupelian and Chattian of Belgium are summarised and presented as a regional zonal scheme based on benthic foraminifera. The Rupelian-Chattian interval is subdivided into eleven biozones, of which the lowermost four (interval I-IV) were introduced by GRIMM & STEURBAUT (2001). The overlying seven biozones (interval V-XI) – corresponding to the uppermost part of the lower Rupelian up to the top of the upper Rupelian and the Chattian – are newly defined in this study. These biozones are further subdivided into twelve biofacies (biofacies 10 to 21) which are characterised by successive quantitative assemblage changes, reflecting modifications in environmental conditions.

Although benthic foraminifera have only limited biostratigraphical importance for inter-basin correlation, comparison with zonal schemes from adjacent areas reveals that some species, such as *Rotaliatina bulimoides*, *Cibicoides ungerianus*, *Rolfina arnei* and *Asterigerinoides guerichi guerichi*, play an important role for regional correlation.

It is suggested that the last appearance datum (LAD) of (common) chiloguembelinids – the biostratigraphic marker event for the Rupelian-Chattian boundary in the international zonation schemes – can not be maintained for the southern North Sea Basin (see also VAN SIMAEYS *et al.*, 2004). Reference samples from contemporaneous sections in Germany are compared to the Belgian upper Rupelian assemblages and reveal a similar reworked secondary siliceous fauna of biserial planktonic foraminifera. Hence, it needs to be verified whether the material recovered by RITZKOWSKI (1982, unpub.) consists of in situ chiloguembelinids, or are of the same nature as the ones recorded in this study.

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Explanation of Plates

PLATE I

- Fig. 1 — Reworked Heterohelicidae – Egestorffhall borehole, Rupel 4 unit, –66.8m – side view
 Fig. 2 — Reworked Heterohelicidae – Weelde borehole, W252.31- VII.14 – apertural view
 Fig. 3 — Radiolarian – Weelde borehole, W252.31 – VII.14 – side view
 Fig. 4 — Siliceous incertae sedis – Weelde borehole, W252.31 – VII.14 – side view
 Fig. 5 — Siliceous incertae sedis – Weelde borehole, W252.31 – VII.14 – side view
 Fig. 6 — Siliceous incertae sedis – Weelde borehole, W252.31 – VII.14 – side view
 Fig. 7 — *Karreriella chilostoma* (REUSS, 1852) – Weelde borehole, W279.08 – VI.12 – side view
 Fig. 8 — *Karreriella siphonella* (REUSS) – Weelde borehole, W292.08 – VI.12 – a. side view, b. apertural view
 Fig. 9 — *Karreriella siphonella* (REUSS) – microspheric form – Weelde borehole, W292.08 – VI.12 – side view
 Fig. 10 — *Siphotextularia labiata* (REUSS) – Helchteren borehole, Hr116 – XI – side view
 Fig. 11 — *Spirorutilus carinata* (D'ORBIGNY) – Weelde borehole, W297.08 – VI.11 – a. side view, b. peripheral view
 Fig. 12 — *Spirorutilus deperdita* (D'ORBIGNY) – Weelde borehole, W279 – VI.12 – side view
 Fig. 13 — *Spirorutilus pectinata* (REUSS) – Weelde borehole, W279.08 – VI.12 – side view
 Fig. 14 — *Pyrgo bulloides* (D'ORBIGNY) – Weelde borehole, W334.04 – V.10 – side view
 Fig. 15 — *Quinqueloculina juleana* (D'ORBIGNY) – Weelde borehole, W297.08 – VI.11 – side view
 Fig. 16 — *Porosolenia (?) laevigata* (REUSS) – Helchteren borehole, Hr119 – X.20 – side view
 Fig. 17 — *Fissurina kapellensis* SPIEGLER – Helchteren borehole, Hr119 – X.20 – side view
 Fig. 18 — *Favulina hexagona* (WILLIAMSON) – Helchteren borehole, Hr112 – XI – side view

- Fig. 19 — *Lagena striata* (D'ORBIGNY) — Helchteren borehole, Hr122 — X.20 — side view
 Fig. 20 — *Lagena sulcata* (WALKER & JACOB) — Helchteren borehole, Hr119 — X.20 — side view
 Fig. 21 — *Lenticulina (Robulus)* sp. — Weelde borehole, W244.27 — VII.14 — side view
 Fig. 22 — *Dentalina calomorpha* REUSS — Weelde borehole, W279.08 — side view
 Fig. 23 — *Siphonodosaria hirsuta* (D'ORBIGNY) — Weelde borehole, W337.08 — V.10 — side view
 Fig. 24 — *Nodosaria emaciata* REUSS — Weelde borehole, W244.27 — VII.14 — side view
 Fig. 25 — *Dentalina intermittens* ROEMER — Weelde borehole, W244.27 — VII.14 — side view
 Fig. 26 — *Neugeborina longiscata* D'ORBIGNY — Weelde borehole, W244.27 — VIII — side view
 Fig. 27 — *Nodosaria soluta* (REUSS) — Weelde borehole, W244.27 — VII.14 — side view
 Fig. 28 — *Dentalina* aff. *vertebralis* (BATSCH) — Hechtel borehole, He237 — VIII — side view

Bar = 100 µm

PLATE II

- Fig. 1 — *Uvigerina gracilis* (REUSS) — Weelde borehole, W279.08 — VI.12 — side view
 Fig. 2 — *Uvigerina gracilis* (REUSS) — Weelde borehole, W244.27 — VII.14 — side view
 Fig. 3 — *Uvigerina gracilis* var. *tenuistriata* (REUSS) — Weelde borehole, W244.27 — VII.14 — side view
 Fig. 4 — *Uvigerina* sp. — Weelde borehole, W297.08 — VI.11 — side view
 Fig. 5 — *Bolivina* aff. *antiqua* D'ORBIGNY — Weelde borehole, W244.27 — VII.14 — side view
 Fig. 6 — *Bolivina beyrichi* REUSS — Weelde borehole, W279.08 — VI.12 — side view
 Fig. 7 — *Bolivina* aff. *dilatata* (REUSS) — Weelde borehole, W244.27 — VII.14 — side view
 Fig. 8 — *Fursenkoina oligocenica* (HOFKER) — Helchteren borehole, Hr122 — X.20 — side view
 Fig. 9 — *Bulimina elongata* D'ORBIGNY — Weelde borehole, W243.20 — VIII — side view
 Fig. 10 — *Ehrenbergina variabilis* (REUSS) — Helchteren borehole, Hr115 — XI — umbilical side
 Fig. 11 — *Asterigerinoides guerichi guerichi* (FRANKE) — Weelde borehole, W243.20 — VIII — a. umbilical —, b. periferal side, c. spiral side
 Fig. 12 — *Cibicidoides ungerianus* (D'ORBIGNY) — Weelde borehole, W244.27 — VII.14 — a. umbilical —, b. periferal side, c. spiral side
 Fig. 13 — *Elphidium subnodosum* (ROEMER), juvenile specimen — Helchteren borehole, Hr137 — IX.18 — side view
 Fig. 14 — *Elphidium subnodosum* (ROEMER) — Weelde borehole, W231.16 — X — periferal side
 Fig. 15 — *Elphidium subnodosum* (ROEMER) — Helchteren borehole, Hr121 — X.20 — side view
 Fig. 16 — *Rolfina arnei* LAURSEN — Hechtel borehole, He215 — IX.18 — a. umbilical side, b. periferal side
 Fig. 17 — *Rolfina arnei* LAURSEN — Hechtel borehole, He215 — IX.18 — spiral side
 Fig. 18 — *Cancris auriculus* (FICHEL & MOLL) — Helchteren borehole, Hr115 — XI — a. spiral side, b. umbilical side
 Fig. 19 — *Protelphidium roemeri* (CUSHMAN) — Weelde borehole, W231.16 — X — a. periferal side, b. side view
 Fig. 20 — *Pullenia quinqueloba* (REUSS) — Weelde borehole, W243.20 — VIII — a. periferal side, b. side view
 Fig. 21 — *Pullenia bulloides* (D'ORBIGNY) — Weelde borehole, W243.20 — VIII — a. periferal side, b. side view
 Fig. 22 — *Rotaliatina bulimoides* (REUSS) — Weelde borehole, W292.08 — VI.12 — side view
 Fig. 23 — *Pararotalia canui* (CUSHMAN) — Helchteren borehole, Hr122 — X.20 — umbilical side
 Fig. 24 — *Sphaeroidina bulloides* D'ORBIGNY — Weelde borehole, W243.20 — VIII — umbilical side
 Fig. 25 — *Turritina alsatica* ANDREAE — Weelde borehole, W297.08 — VI.11 — side view

Bar = 100 µm

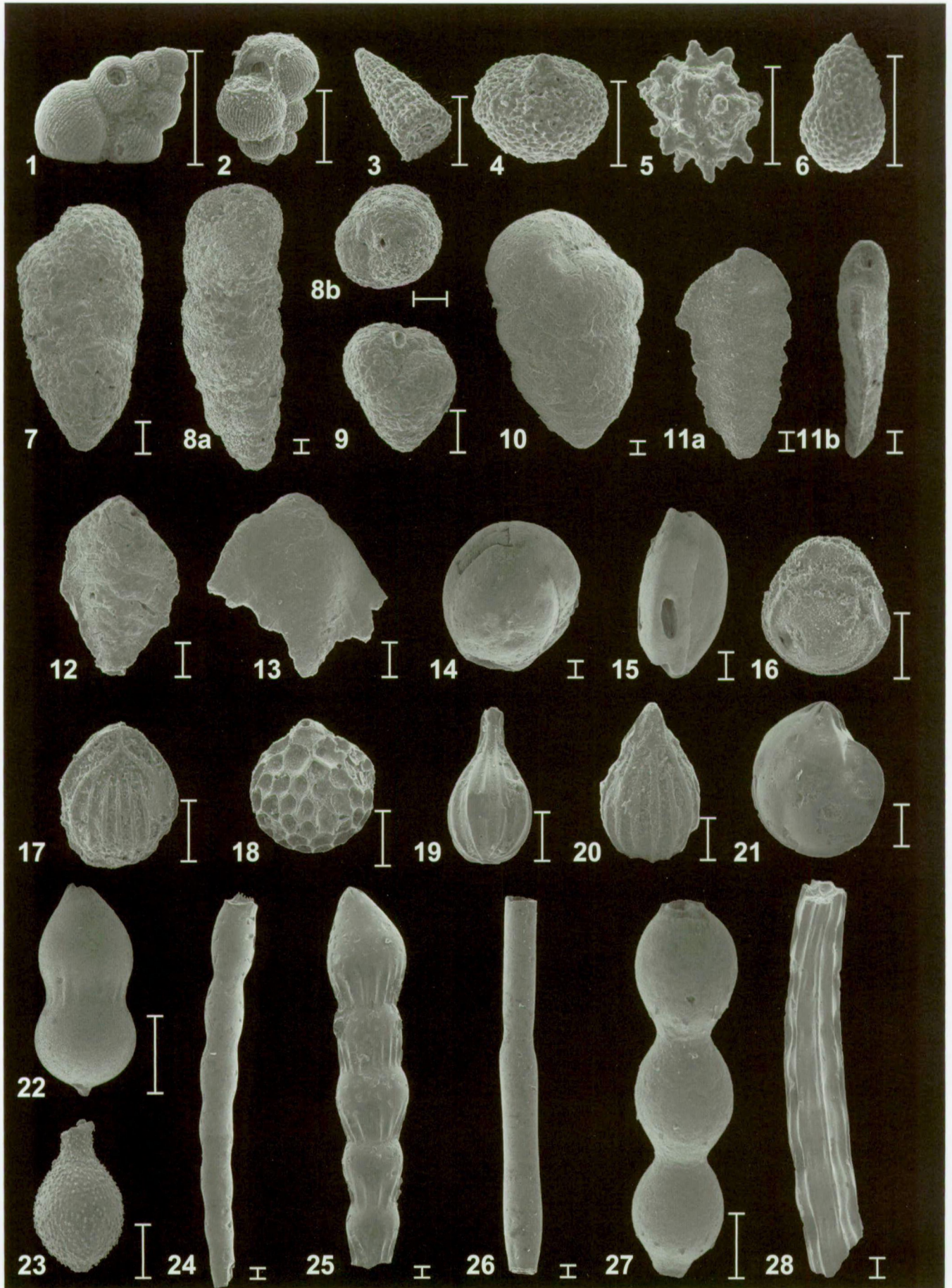


PLATE I

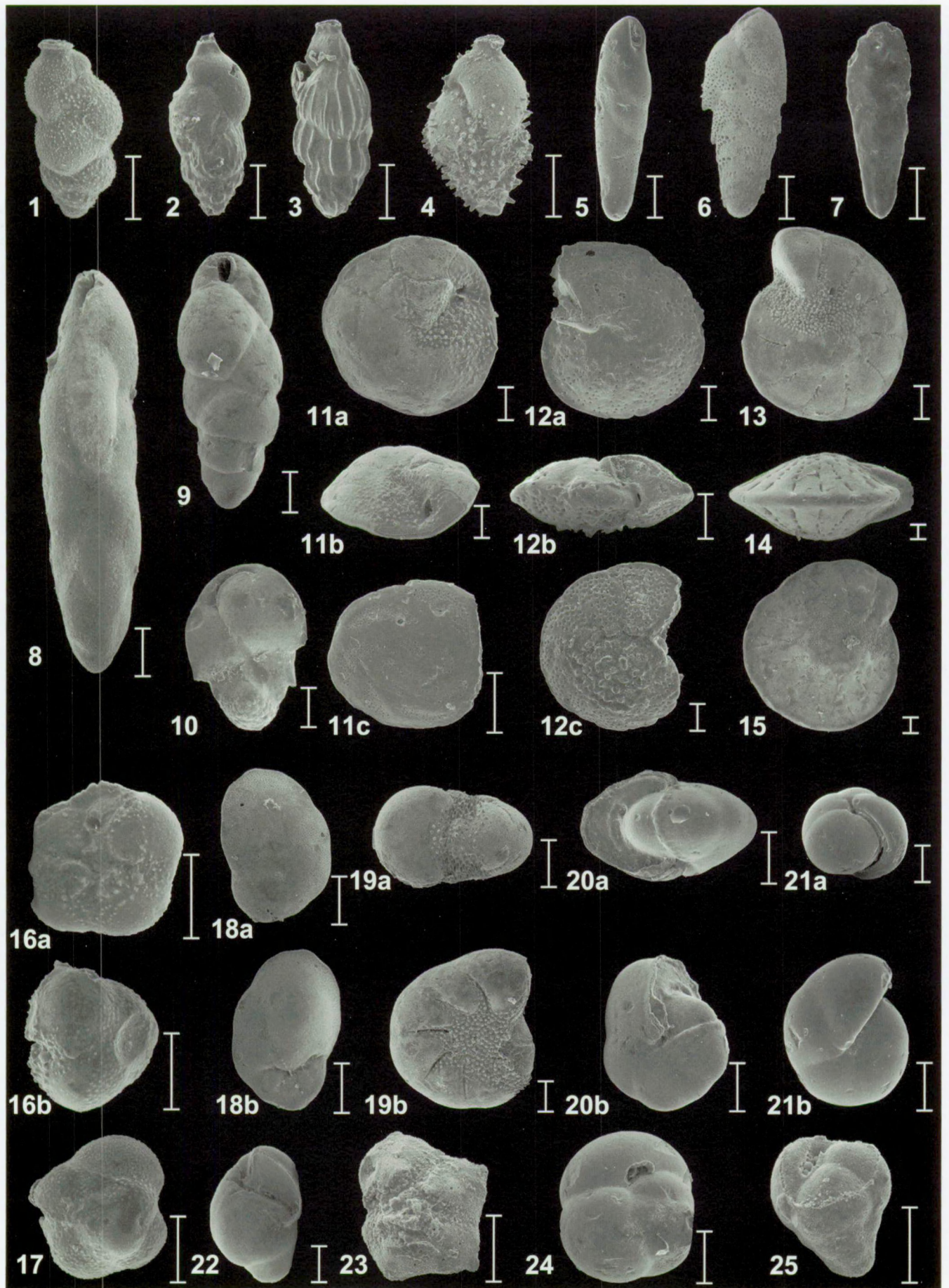


PLATE II

