GEOLOGICA BELGICA (2006) 9/1-2: 95-101

RUPELIAN

Stefan Van SIMAEYS[1] & Noël VANDENBERGHE[1]

(4 figures)

1. *Department of Historical Geology, KULeuven, Redingenstraat 16, 3000 Leuven. E-mails: stefaan.vansimaeys@geo.kuleuven.ac.be; noel.vandenberghe@geo.kuleuven.ac.be.*

ABSTRACT. The Oligocene successions of the southern North Sea Basin are internationally important as they constitute the classic Rupelian (Lower Oligocene) and Chattian (Upper Oligocene) stratotype sections. The Rupelian stratotype, i.e. the stiff clays outcropping along the Rupel River in NW Belgium, has been the topic of many (micro)paleontological, sedimentological, stratigraphical and geochemical studies. Here we present a state of the art overview on the research carried out on the Rupelian unit-stratotype and contribute on new insights concerning the Rupelian-Chattian boundary.

KEYWORDS: Rupelian, Oligocene, Rupel Group, unit-stratotype

Reference to this paper: Van Simaeys, S. & Vandenberghe, N., 2006. Rupelian. *In* Dejonghe, L., ed., Current status of chronostratigraphic units named from Belgium and adjacent areas, *Geologica Belgica*, Brussels, 9/1-2: 95-101.

1. Name

Rupelian (English), Rupeliaan (Dutch), Rupel (German), Rupélien (French)

It is important to note that the stratigraphic interval of the present international Rupelian stage has been extended compared to what was originally defined in the Belgian sections. Since the introduction of the Oligocene (Beyrich, 1854), it became common practice to have a threefold subdivision: i.e. the Lower, Middle and Upper Oligocene, corresponding respectively to the Latdorfian, Rupelian and Chattian Stages. This situation remained until the International Commission on Stratigraphy (ICS) introduced a twofold Oligocene subdivision in 1980: a Lower and Upper Oligocene, respectively equivalent to the Rupelian and Chattian Stages. The former Lower Oligocene Stage in the threefold Oligocene subdivision (i.e. the correlative regional Latdorfian, Sannoisian and Tongrian Stages) now also belongs to the Rupelian Stage in the current international stage nomenclature (see Fig. 1). As this contribution deals with the original stage definition only, the former Tongrian Stage, also defined in Belgium, is discussed in a separate section.

2. Age

In the most recent time scale, the Rupelian Stage (= Lower Oligocene, including the former Tongrian) comprises the time interval between 33.9 ±0.1 and 28.4 ±0.1 Ma (Gradstein *et al.*, 2004).

3. Author

Dumont, M.A., 1850. Rapport sur la carte géologique du Royaume, Bulletin de l'Académie Royale des Sciences, des Lettres et des Beaux-Arts de Belgique, tome XVI – IIième partie, p. 351-373. The term "*Système Rupélien*" was introduced by the author in the legend of the first geological map of Belgium.

4. Historical type area and stage description

Particular reference-sections were not formally selected; however, the early literature is clear on what is meant by the Rupelian. Ever since its introduction, the Rupelian sections in Belgium have been subdivided into a lower and upper part : '*Le système Rupélien a, dans quelques localités, pour base un lit peu épais d'argile sableuse renfermant des nucules; mais le plus souvent il commence par des sables jaunâtres plus ou moins argileux. La partie supérieure est formée de sables très argileux et d'argiles schistoïdes auxquelles je rapporte les argiles fossilifères de Rupelmonde, de Boom, de Hasselt, etc.*' (Dumont, 1850, p. 370).
Regarding the lower part of the Rupelian, comprising what is now called the Bilzen Formation, the reference area is undoubtly the Bilzen region in the Campine area (NE Belgium, Fig. 2). Vanden Broeck (1883) reports on several outcrops in that area and describes a number of lithological units which comprise the lower Rupelian, e.g. successively from base to top the Berg Sand, the Kleine Spouwen Clay (= *Nucula comta* Clay) and the Kerniel Sands (Fig. 1).

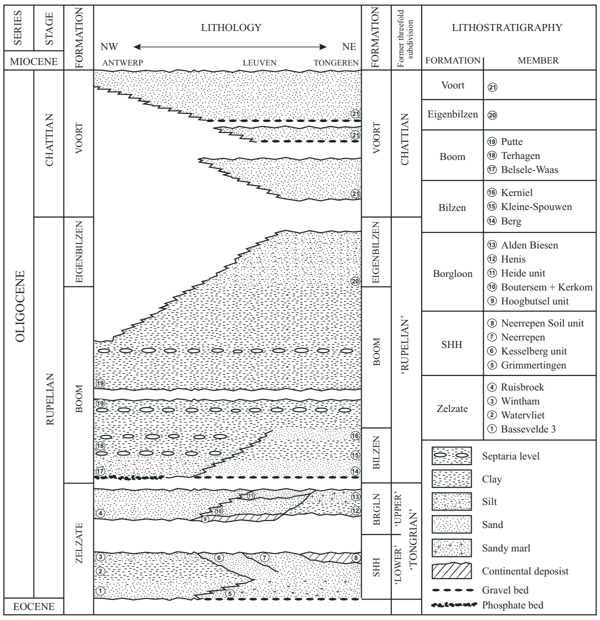

Figure 1. Stratigraphy of the Oligocene deposits in northwest and northeast Belgium. SHH = Sint-Huibrechts-Hern Formation, BRGLN = Borgloon Formation

Regarding the upper part of the Rupelian, mainly represented by the Boom Formation, it is without doubt that the clay exposures in the quarries along the Rupel and Scheldt rivers (e.g. the Boom region, Fig. 2) are meant to be the reference-sections (Dumont, 1850). Vanden Broeck (1884, 1893) furthermore identified clayey sands, now described as Eigenbilzen Formation, on top of the Boom Formation in the Campine area. Based on the similar lithology, grain size rhythmicity and stratigraphic position below the glauconitic and shell rich Chattian Voort Formation, the Eigenbilzen Formation, devoid of macro-fossils, has always been included in the Rupel Group and thus belongs to the Rupelian Stage (Fig. 1). The total thickness of the Rupelian succession in the Campine subsurface (i.e. the Weelde borehole), excluding the former Tongrian deposits, is approximately 140 m (Vandenberghe *et al.*, 2001; Van Simaeys *et al.*, 2004). It is meaningful to refer to the Rupel area as reference for the lithostratigraphic descriptions at the level of a group, the Rupel Group.

5. Lithology

5.1. Geographical extension

Rupelian deposits are found north of the Durme, Rupel and Dijle rivers and north of a line from Leuven to Tongeren. These deposits are exposed along the southern border of this area; towards the north, the Rupelian strata are only known from the Campine subsurface. They are deeply or even totally eroded by the Late Miocene Diest transgression in the Hageland. As a consequence, the Rupelian outcrop area is divided into two separate zones: in the West, stiff clays are cropping out in the 'Land van Waas', the Rupel region and the Nete-Dijle interfluvium; in the East, Rupelian deposits are exposed in the 'Hageland' and the Demer region in Limburg (Fig. 2).

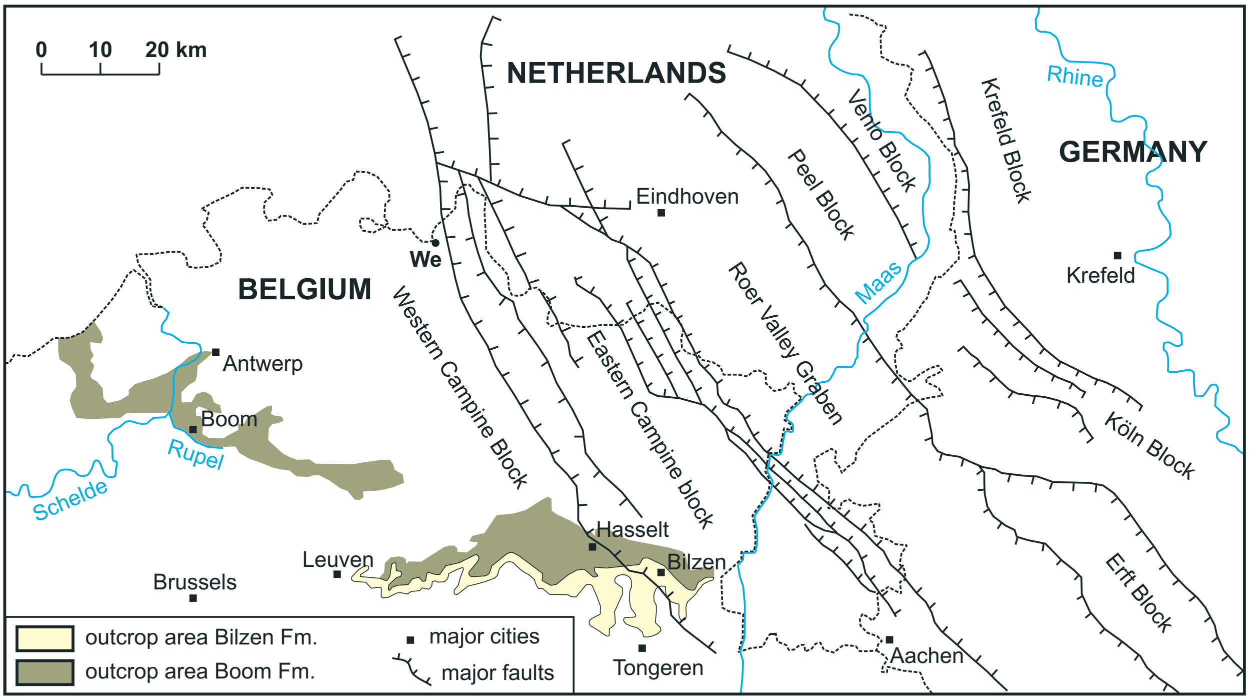

Figure 2. Location map showing the outcrop area of Oligocene deposits in northern Belgium; the major faults are taken from the regional geological maps. Location of the Weelde borehole (We) indicated by black dot.

5.2. Subdivision of the Rupelian deposits

The Rupelian stratotype can be subdivided into three formations, from bottom to top:

Bilzen Formation

The formation starts with white yellowish, locally glauconiferous, fine sands, homogenous and horizontally layered, with chert pebbles at the base. They are followed by brown, green or yellow grey sandy clay, rich in fossils. The top is formed by pale, fine sand, interbedded with some clay layers. The formation outcrops in the southeast of Brabant and Limburg and occurs in the subsoil of the Campine area. The Bilzen Formation is subdivided into the Berg Member (sand), the Kleine-Spouwen Member (clay) and the Kerniel Member (sand). This formation is the lateral equivalent of the Belsele-Waas and the lower part of the Terhagen Member (Fig. 1, see also Vandenberghe *et al.*, 2001). The total thickness of this marine unit is approximately 15 m.

Boom Formation

This marine unit consists of grey, silty clay or clayey silt, with pyrite and glauconite in the siltiest horizons. A striking feature of the Boom Formation is its rhythmic alternation of grain size, land-derived organic matter and carbonate contents. The formation is exposed in the northeastern part of East-Flanders and north of the Rupel and Nete rivers. North of this area, the formation is covered by younger deposits. The thickness of this formation varies from a few meters in East-Flanders to approximately 100 m in north Belgium. The formation is subdivided into the Belsele-Waas Member (silty clays), the Terhagen Member (grey clays) and the Putte Member (black organic-rich clays) (see Fig. 1). The Boom Formation is currently exploited in a few large excavations along the Rupel and the Scheldt rivers and in the Sint-Niklaas region (NW-Belgium).

Eigenbilzen Formation

This formation consists of dark green, glauconiferous, clayey fine to medium sands, with bioturbations. As in the underlying Boom Formation, a structure of alternating beds, caused by variations in grain-size distribution, is present. This formation is known from the Campine subsurface and in a few outcrops along the eastern and western margin of the Campine plateau (Hasselt and Maasmechelen area). The formation is not subdivided into members, however, different units can be recognised based on geophysical borehole measurements. An informal system possibly can be used as base for the definition of lithostratigraphic members in the future (Vandenberghe *et al.*, 2001). The maximum thickness of this marine unit is approximately 25 m.

5.3. Boundaries with underlying and overlying lithostratigraphic units

The Rupelian deposits (excluding the former Tongrian deposits) overlay the marine Zelzate Formation in the Mechelen – Boom – Waasland area, while in the Leuven – Tongeren area, the Rupelian strata cover different facies of the non-marine Tongrian deposits. In northwest Belgium the Rupelian strata are mainly overlain by the Berchem Formation (Lower Miocene); more to the east, the Diest Formation (Upper Miocene) covers the Boom Formation and fills a broad tidal gully incised in and even through the Rupelian strata. In northeast Belgium the Rupelian strata are covered by the Voort Formation (Upper Oligocene), remnants of which are also found in the Antwerp area (e.g. the Ekeren and Essen borehole[1]).

6. Sedimentology and palaeogeography

The most striking feature of the Boom clay, clearly exposed in several large outcrops (Fig. 3), is its banded nature (Vandenberghe, 1978). The clay deposits show an alternation of layers, coloured in different shades of grey, from pale grey to black, with a periodicity of approximately half a meter. The main cyclicity is the alternation of silty clays and stiff, heavy clays, reflecting grain-size variations (Fig. 3). Also black horizons, rich in organic matter, systematically occur in the upper part of the exposed clay

Figure 3. Picture of the lower part of the Boom Formation (Terhagen Member), showing the alternation of silty clays (light grey) and stiff, heavy clays (dark grey to black).

[1] Organic-walled dinoflagellate cyst biostratigraphy revealed only the upper part of the Chattian deposits in the Ekeren borehole (i.e. NSO-8 after Van Simaeys *et al.*, 2005), while in the Essen borehole both NSO-5b, NSO-6, NSO-7 and NSO-8 were recognised. This condensed succession of dinocyst zones spans the entire Chattian (including the Asterigerina-bloom) and is identical to the Chattian succession in the Campine subsurface.

(i.e. Putte Member). Each black horizon consistently starts in the top of a silty clay band and ends in the basal part of the overlying stiff clay (Vandenberghe *et al.*, 1997). Whitish grey marly horizons also occur throughout the clay. Generally the carbonate-rich horizons developed into septaria layers. The succession of these rhythms has a characteristic geophysical log response (Vandenberghe *et al.*, 2001) which can be used for correlation. It is found that the individual layers extend along the strike over an exposure area of more than 50 km.
The grain-size and organic matter cyclicity has been interpreted as representing orbital fluctuations of obliquity and dominant eccentricity (Van Echelpoel & Weedon, 1990). The sedimentological response to these fluctuations is explained by alternating sea-level heights, likely triggered by the waxing and waning of ice-sheets during the Lower Oligocene (Vandenberghe *et al.*, 1997).
Preliminary oxygen isotope data from the well calibrated southern North Sea Basin successions indicate that the most significant positive shift in $\delta^{18}O$ values (correlated to the Oi-1 event of Zachos *et al.*, 1996) is situated well within the Oligocene if calibrated against the Eocene-Oligocene GSSP. It suggests that the Oi-1 event correlates to the unconformity between the Bassevelde 3 sequence and the overlying Ruisbroek Member (see Fig. 1), and is thus closely associated with the base of the traditional Rupelian unit-stratotype (De Man *et al.*, 2004a).
Benthic foraminiferal analyses (De Man & Van Simaeys, 2004) show that the lower part of the Rupelian (Belsele-Waas, Terhagen and lower part of the Putte Member) is characterised by normal marine shelf conditions with temporal open connections towards the ocean realm and water depths around 100 m. The upper Rupelian successions (upper part of the Putte Member, Eigenbilzen Formation) show a gradual shallowing and the realisation of a poorly ventilated and more isolated marine environment. A major climate change coincides with the Rupelian-Chattian unconformity in the southern North Sea Basin: the tropical to subtropical benthic foraminiferal assemblages from the basal Chattian sediments in the southern North Sea Basin are in strong contrast with the cold to cold-temperate Rupelian fauna (Van Simaeys *et al.*, 2004).

7. Palaeontology

Macrofossil studies have essentially focused on bivalves (Glibert, 1955, 1957), decapods (Verheyden, 2002), and fish remains (Steurbaut & Herman, 1978). The Rupelian stratotype has furthermore been the topic of many micropaleontological investigations. A detailed benthic foraminiferal study has been executed by Batjes (1958) while Keij (1957) studied the ostracoda. Palynological analyses of the Rupelian deposits in Belgium have been undertaken by Roche & Schuler (1979, pollen and spores) and Stover & Hardenbol (1994, organic-walled dinoflagellate cysts). An overview of the macro- and micropaleontological analyses carried out on the Rupelian stratotype is given by Van Simaeys *et al.* (2004).

8. Chronostratigraphy

Overviews of the calcareous nannofossil studies have been given in Steurbaut (1986, 1992) and Van Simaeys *et al.* (2004). Nannofossil zones NP 23 and the slightly modified NP 24* have been recognised. Hooyberghs (1983) and Hooyberghs *et al.* (1992) investigated the planktonic foraminifera. He recognized planktonic foraminiferal zones P18 to P21 of Blow (1979), although no zonal boundaries could be identified since some of the zonal markers were not encountered or had a peculiar range. Both southern North Sea Basin benthic foraminiferal (De Man *et al.*, 2004b) and organic walled dinoflagellate cyst zonation (Van Simaeys *et al.*, 2005) have been established on different sections throughout the Rupelian stratotype.

9. Geochronology

A rock magnetic study of the Rupelian unit-stratotype led to the recognition of the characteristic magnetic polarity and correlation with the standard magnetobiochronologic time scale allowed accurate chronostratigraphic dating of the Boom Clay Formation. The boundary between the geomagnetic chrons C12n and C12r nearly coincides with the lithostratigraphic boundary between the Terhagen and Putte Members (Lagrou *et al.*, 2004).

10. Structural setting

During Oligocene times, the North Sea region constituted a large, north-south aligned, epicontinental basin, bordered by the elevated areas of the Fenno-Scandian Shield to the northeast, Central Europe to the south, and the British Isles to the west (Ziegler, 1990; Michelsen *et al.*, 1998, Fig. 4). Thick Oligocene successions (up to 1000 m) are recorded from the central North Sea Basin, while in the southern North Sea Basin, up to 550 m thick Oligocene sections are present in the Lower Rhine Embayment, i.e. the Roer Valley Graben (Figs 2 & 4), a NW-SE striking western branch of the European Cenozoic Rift Systems (Sissingh, 2003). During most of the Rupelian, differential tectonic movements were absent and the Lower Rhine Embayment was receiving clay-rich sediments. The absence of upper Rupelian strata in the Boom Clay outcrop area is ascribed to local tectonics, a 0.5° NE tilt of the Western Campine Block in the upper Rupelian is sufficient to explain the surplus of 80 m of younger Boom Clay deposits in the Weelde borehole as compared to the outcrop area (Van Simaeys, 2004a). This Late Oligocene uplift pulse seems to coincide with the onset of the differential subsidence of the Roer Valley graben.

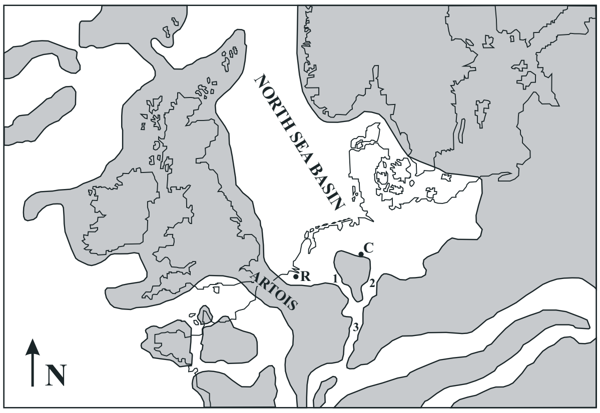

Figure 4. Paleogeographic reconstruction of the mid Oligocene North Sea Basin, showing the location of the Rupelian (R) and Chattian (C) unit-stratotypes (modified after Ziegler, 1990; Verbeek *et al*., 2002 and Sissingh, 2003). The (1) Lower Rhine Embayment (i.e. the Roer Valley Graben), (2) Leine Graben and (3) Rhine Graben are part of the European Cenozoic Rift Systems.

11. Reference sections in Belgium

St.-Niklaas, Terhagen & Kruibeke quarries, Weelde borehole.

12. Main contributions

Vanden Broeck (1887); Gulinck (1954); Keij (1957); Batjes (1958); Vandenberghe (1978); Van Echelpoel (1991); Laenen (1997); Vandenberghe *et al.* (1997); Lagrou (2001); Van Simaeys (2004a).

13. Remarks - The Rupelian-Chattian boundary

The current 'global' criterion for the recognition of the Rupelian-Chattian boundary, i.e. the demise of the planktonic foraminiferal genus *Chiloguembelina,* is not applicable in the remote North Sea Basin, home of the Rupelian and Chattian Unit Stratotypes. Moreover, records from several sections (mainly ODP boreholes) indicate that the chiloguembelinid extinction is globally time-transgressive, from the Early Oligocene at high latitudes, to the Late Oligocene at low latitudes. Because of the diachronous nature of the last occurrence of the genus *Chiloguembelina*, this criterion can no longer be uphold for the recognition of the Rupelian-Chattian boundary (Van Simaeys *et al.*, 2004).

Detailed dinoflagellate cyst analysis enabled correlation between the restricted Oligocene North Sea Basin successions and the well-calibrated pelagic sections from central Italy. Based on the established correlations, it appears that a 500 ka lasting Oligocene glaciation, and the corresponding glacio-eustatic sea level fall are genetically related to the unconformity between the Rupelian and Chattian Stages in their stratotype area. Calibrated dinoflagellate cyst events further suggests that the oldest of the time-transgressive glauconitic fine Chattian sands in the southern North Sea Basin were deposited around 26.7 Ma (Van Simaeys, 2004b).

An important consequence of these results is that any Rupelian-Chattian GSSP should be positioned to match at least the age of this Oligocene glaciation, i.e. between 27.5 and 27 Ma. (Van Simaeys, 2004b).

14. Acknowledgements

The authors would like to thank Ellen De Man for lively discussions and constructive comments on the manuscript. Dr. Kirsten Grimm is acknowledged for the careful review of this paper. SVS gratefully acknowledges the financial support from the University of Leuven (Postdoc Grant PDM/04/148/BM).

References

BATJES, D.A.J., 1958. Foraminifera of the Oligocene of Belgium. *Mémoires de l'Institut royal des Sciences naturelles de Belgique*, 143: 1-188.

BEYRICH, E., 1854. Über die Stellung der Hessischen Tertiärbildungen. *Berichte und Abhandlungen der Königlichen Preußischen Akademie der Wissenschaften Berlin,* Abteilung A 1854(11): 640-666.

BLOW, W.H., 1979. The Cainozoic Globigerinida: A study of the morphology, taxonomy, evolutionary relationships and the stratigraphical distribution of some Globigerinida. E.J. Brill, Leiden, 1-1413.

DE MAN, E. & VAN SIMAEYS, S., 2004. Late Oligocene warming event in the southern North Sea Basin: benthic foraminifera as paleotemperature proxies. *Netherlands Journal of Geosciences*, 83(3): 227-239.

DE MAN, E., IVANY, L. & VANDENBERGHE, N., 2004a. Stable oxygen isotope record of the Eocene-Oligocene transition in the southern North Sea Basin: positioning the Oi-1 event. *Netherlands Journal of Geosciences*, 83(3): 193-197.

DE MAN, E., VAN SIMAEYS, S., DE MEUTER, F., KING, C. & STEURBAUT, E., 2004b. Oligocene benthic foraminiferal zonation for the southern North Sea Basin. *Bulletin van het Koninklijk Belgisch Instituut voor Natuurwetenschappen – Aardwetenschappen*, 74: 177–195.

DUMONT, M.A., 1850. Rapport sur la carte géologique du Royaume de Belgique. *Bulletin de l'Académie royale de Sciences, des Lettres et des Beaux-Arts de Belgique*, 16(2): 251-373.

GLIBERT, M., 1955. Quelques espèces nouvelles ou mal connues de l'Oligocène moyen et supérieur de la

Belgique. *Bulletin de l'Institut royal des Sciences naturelles de Belgique*, 31: 1-76.
GLIBERT, M., 1957. Pélécypodes et gastropodes du Rupélien supérieur et du Chattien de la Belgique. *Mémoires de l'Institut royal des Sciences naturelles de Belgique*, 137: 1-98.
GRADSTEIN, F.M., OGG, J.G., SMITH, A.G., BLEEKER, W. & LOURENS, L.J., 2004. A new geologic time scale with special reference to Precambrian and Neogene. *Episodes*, 27(2): 83-100.
GULINCK, M., 1954. L'Oligocène de la Basse et de la Moyenne Belgique. *In* Fourmarier, P., (éd.), *Prodrome d'une description géologique de la Belgique*. Vaillant - Carmanne, Liège, 1954.
HOOYBERGHS, H., 1983. Contribution to the study of planktonic foraminifera in the Belgian Tertiary. *Aardkundige Mededelingen*, 2: 1-129.
HOOYBERGHS, H., VERCAUTEREN, T., DE MEUTER, F. & SYMONS, F., 1992. Foraminiferal studies in the Boom Formation. *Professional Paper, Belgische Geologische Dienst*, 8(258): 1-26.
KEIJ, A.J., 1957. Eocene and Oligocene ostracoda of Belgium. *Mémoires de l'Institut royal des Sciences naturelles de Belgique*, 136: 1-210.
LAENEN, B., 1997. The geochemical signature of relative sea-level cycles recognized in the Boom Clay. *Ph-D-thesis*, Katholieke Universiteit Leuven, Belgium, 1-496.
LAGROU, D., 2001. Magnetostratigrafie en gesteentemagnetisch onderzoek van de Boomse Klei (Rupeliaan) in België. *Ph-D-thesis*, Katholieke Universiteit Leuven, Belgium, 1-210.
LAGROU, D., VANDENBERGHE, N., VAN SIMAEYS, S. & HUS, J., 2004. Magnetostratigraphy and rock magnetism of the Boom Clay (Rupelian stratotype) in Belgium. *Netherlands Journal of Geosciences*, 83(3): 209-225.
MICHELSEN, O., THOMSEN, E., DANIELSEN, M., HEILMANN-CLAUSEN, C., JORDT, H. & LAURSEN, G., 1998. Cenozoic sequence stratigraphy in the eastern North Sea. *In* De Graciansky, P., Hardenbol, J., Jacquin, T. & Vail, P., (eds.), *Mesozoic and Cenozoic Sequence Stratigraphy of European Basins*. *SEPM Special Publication 60*: 91-118.
ROCHE, E. & SCHULER, M., 1979. Analyse palynologique de l' Argile de Boom. *Professional Paper*, *Belgische Geologische Dienst*, 176: 1-18.
SISSINGH, W., 2003. Tertiary paleogeographic and tectonostratigraphic evolution of the Rhenish Triple Junction. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 196: 229-263.
STEURBAUT, E., 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. *Mededelingen Werkgroep Tertiaire en Kwartaire Geologie*, 23(2): 49-83.
STEURBAUT, E., 1992. Integrated stratigraphic analysis of Lower Rupelian deposits (Oligocene) in the Belgian Basin. *Annales de la Société géologique de Belgique*, 115(1): 287-306.
STEURBAUT, E. & HERMAN, J., 1978. Biostratigraphie et poissons fossiles de la formation de l'argile de Boom (Oligocène Moyen du Bassin Belge). *Geobios*, 11(3): 297-325.
STOVER, L.E. & HARDENBOL, J., 1994. Dinoflagellates and depositional sequences in the Lower Oligocene (Rupelian) Boom Clay Formation, Belgium. *Bulletin de la Société belge de Géologie*, 102(1-2): 5-77.
VANDENBERGHE, N., 1978. Sedimentology of the Boom Clay Formation, Belgium. *Bulletin van de Belgische Vereniging voor Geologie*, 102(1-2): 5-77.
VANDENBERGHE, N., LAENEN, B., VAN ECHELPOEL, E. & LAGROU, D., 1997. Cyclostratigraphy and climatic eustasy. Example of the Rupelian stratotype. *Comptes Rendus de l'Académie des Sciences*, 325: 305-315.
VANDENBERGHE, N., HAGER, H., VAN DEN BOSCH, M., VERSTRAELEN, A., LEROI, S., STEURBAUT, E., PRÜFERT, J. & LAGA, P., 2001. Stratigraphic correlation by calibrated well logs in the Rupel Group between North Belgium, the Lower-Rhine area in Germany and Southern Limburg and the Achterhoek in The Netherlands. *In* Vandenberghe, N., (ed.), Contributions to the Paleogene and Neogene Stratigraphy of the North Sea Basin. *Aardkundige Mededelingen,* 11: 69-84.
VANDEN BROECK, M.E., 1883. *Carte géologique de la Belgique, Bilsen 1:20.000*. Edition 1883.
VANDEN BROECK, M.E., 1884. Sur un facies nouveau ou peu connu de l'argile supérieure rupelienne et sur les erreurs d'interprétation auxquelles il peut donner lieu. *Bulletin de la Société royale de Malacologie de la Belgique*, 19(4): 1-75.
VANDEN BROECK, M.E., 1887. L'argile de Boom. Causerie géologique, Bruxelles, 1-11.
VANDEN BROECK, M.E., 1893. Coup d'oeil synthétique sur l'Oligocène Belge et observations sur le Tongrien Supérieur du Brabant. *Bulletin de la Société belge de Géologie, de Paléontologie et d'Hydrologie*, 7: 28-302.
VAN ECHELPOEL, E. & WEEDON, G.P., 1990. Milankovitch cyclicity and the Boom Clay Formation: an Oligocene siliciclastic shelf sequence in Belgium. *Geological Magazine*, 127(6): 599-604.
VAN ECHELPOEL, E., 1991. Kwantitatieve cyclostratigrafie van de Formatie van Boom (Rupeliaan, België). Ph-D-thesis, Katholieke Universiteit Leuven, Belgium, 1-164.
VAN SIMAEYS, S., 2004a. Stratigraphic and paleoenvironmental analysis of the Rupelian and Chattian in their type regions: Implications for global Oligocene chronostratigraphy. *Ph-D-thesis*, Katholieke Universiteit Leuven, Belgium, 1-201.
VAN SIMAEYS, S., 2004b. The Rupelian-Chattian boundary in the North Sea Basin and its calibration to the international time-scale. *Netherlands Journal of Geosciences*, 83(3): 241-248.

VAN SIMAEYS, S., DE MAN, E., VANDENBERGHE, N., BRINKHUIS, H. & STEURBAUT, E., 2004. Stratigraphic and palaeoenvironmental analysis of the Rupelian-Chattian transition in the type region: evidence from dinoflagellate cysts, foraminifera and calcareous nannofossils. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 208: 31-58.

VAN SIMAEYS, S., MUNSTERMAN, D. & BRINKHUIS, H., (2005). Oligocene dinoflagellate cyst biostratigraphy of the southern North Sea Basin. *Review Palaeobotany and Palynology*, 134:105-128.

VERBEEK, J.W., DE LEEUW, C.S., PARKER, N. & WONG, T.E., 2002. Characterisation and correlation of Tertiary seismostratigraphic units in the Roer Valley Graben. *Netherlands Journal of Geosciences*, 81(2): 159-166.

VERHEYDEN, T., 2002. Decapods from the Boom Clay (Rupelian, Oligocene) in Belgium. *Bulletin de l'Institut royal des Sciences naturelles de Belgique, Sciences de la Terre*, 72:171-191.

ZACHOS, J.C., QUINN, T.M., & SALAMY, S., 1996. High resolution (10^4 yr) deep-sea foraminiferal stable isotope records of the Eocene-Oligocene climate transition. *Paleoceanography*, 11:251-266.

ZIEGLER, P.A., 1990. Geological atlas of western and central Europe. Shell Internationale Petroleum Maatschappij B.V., Den Haag, 1-239.

Manuscript received on 03.11.2004 and accepted for publication on 07.06.2005.