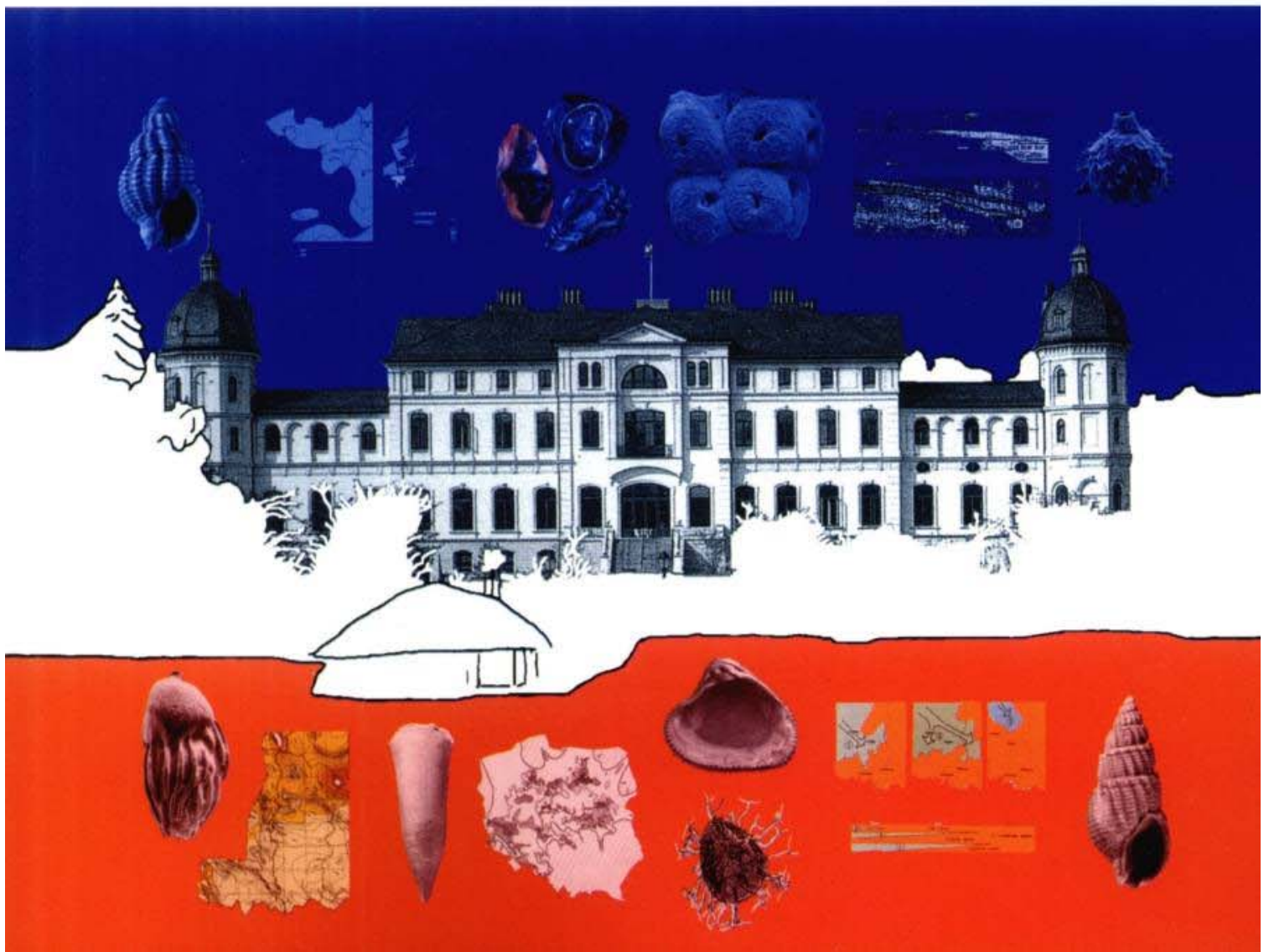


Proceedings of the 8th Biannual Meeting of the RCNNS/RCNPS

Northern European Cenozoic Stratigraphy



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Editorial

► Karl Gürs

The 8th biannual joint meeting of the Regional Committees on Northern Neogene and Palaeogene was held at Salzau Castle, the official cultural centre of the state of Schleswig-Holstein, Germany, from the 2nd to the 7th of October 2001. The Regional Committees are subgroups of the Sub-commissions on Paleogene and Neogene Stratigraphy which belong to the International Commission on Stratigraphy of the IUGS (International Union of Geological Sciences).

Every two years the meeting offers a platform for the exchange of research results and ideas in a formal as well as an informal setting. The meeting was attended by stratigraphers from Belgium, the Netherlands, Denmark, Norway, Great Britain, Poland and Germany, all involved in research on the Cenozoic North Sea. One main goal of these meetings is to promote interdisciplinary joint ventures across political borders and (palaeo)geographical boundaries. The participants come from industrial companies, geological surveys, universities, museums and research institutions or are private researchers. Field trips offer opportunities for examining the special geological background of the region in which the meeting is held.

In this book 14 selected reviewed papers of lectures or posters from the meeting which were submitted for publication in the proceedings volume are presented. Subjects are the microproblematicum *Voorthuyse-niella* and an explanation of its origin by Palaeocene material, with a description of a new species, new results on the stratigraphy of the Ypresian Egem clay pits, the reconstruction of a Palaeogene shelf margin on the basis of the combination of palaeontological and geophysical data, a new marker horizon for the Hessian Depression and the Upper Rhine Graben for the lower Oligocene containing *Bolboforma*, a detailed analysis of the spacio-temporal development of the Ru1 transgression in northern Belgium, a marker horizon with a plankton bloom of a dinoflagellate and description of a new marker species, a new biostratigraphical zonation based on the benthic gastropod genus *Nassarius*, with a description of two new species, and an evaluation of this genus for the stratigra-

phy around the Hemmoorian/Reinbekian boundary, a refined biostratigraphy using pteropoda (planktonic gastropods), the correlation of international *Bolboforma* stratigraphy with the regional *Uvigerina* (benthic foraminifera) stratigraphy of the North Sea Basin, an evaluation of the Gramian stage as a chronostratigraphical unit, coal formation in a paralic environment in the Lusatia district (eastern Germany), a detailed study on the Poznan Formation of the Polish Lowlands, and a critical comment on the impact of political borders on stratigraphical nomenclature.

The editor thanks all the authors for their willingness and readiness to contribute to this volume, special thanks goes to the state government of Schleswig-Holstein, represented by LANU (State Agency for Nature and Environment) for financial support. The editor is also very much indebted to Jayne Welling-Wolf for improvement of the English.

Karl Gürs
Editor

First Evidence of Colonial Bicorniferidae (Bryozoa incertae sedis)

► Dorothee Spiegler
► Klaus H.
Eiserhardt

Abstract

Voorthuysiella incrustans n. sp. is introduced as an incrustated taxon from the Geulhem Chaik, Houthem Formation, lower Danian-Montian, at Curfs Quarry near Maastricht (Netherlands). The four colonies of basal zooecia observed are cemented to the substrate directly or by protrusive borders. They are arranged uni- and biserially or on a plane. The classification of this new species into the *Voorthuysiella* genus depends on the subrounded zooecia with an upward-oriented frontal pore (aperture) and lateral pores.

Until recently, only isolated chambers of *Voorthuysiella* have been found. The connected bases of *Voorthuysiella* studied in this paper are the first fossil proof of a colonial growth mode with encrusting bases. *V. incrustans* is the oldest species of the genus. Therefore, the assumption that *Voorthuysiella* was separated phylogenetically from *Bicornifera* during the Eocene must be revised.

The great zooecial variability in of *Voorthuysiella incrustans* colonies may imply the possibility that the morphological differences of some of the known *Voorthuysiella* species reflect only their special position in the colony.

Kurzfassung

Aus dem unteren Geulhem Kalk der Houthem Formation (unteres Danian-Montium) der Grube Curfs bei Maastricht (Niederlande) werden die aus diversen Zooecien bestehenden kolonial arrangierten Basen als *Voorthuysiella incrustans* neu eingeführt. Deutlich erhaltene Anwachssäume dokumentieren die inkrustierende Verbindung mit dem Substrat. Die Zooecien liegen in uni- und biserialer sowie flächenhafter Ausbreitung vor. Die Zu-

ordnung der neuen Art zur Gattung *Voorthuysiella* ist aufgrund der subglobalen Einzelzooecien mit nach oben gerichteter Apertur und der Lateralporen möglich.

Alles bisher bekannte *Voorthuysiella*-Material besteht nur aus isolierten Einzelzooecien. Mit vorliegendem Fund beweist sich die bis jetzt nur vermutete koloniale Organisationsform erstmals direkt aus der fossilen Überlieferung. *V. incrustans* n. sp. ist der älteste Nachweis der Gattung. Die frühere Annahme, dass sich die *Voorthuysiella* phylogenetisch im Eozän von *Bicornifera* abspalten, lässt sich somit nicht aufrechterhalten.

Die starke zooeciale Variabilität innerhalb der ausgewerteten Kolonien von *Voorthuysiella incrustans* n. sp. lässt vermuten, dass zumindest bei einigen der bisher beschriebenen *Voorthuysiella*-Arten die zur Spezifikation herangezogenen unterschiedlichen Morphologien eher ihrer Position innerhalb der Kolonie zuzuschreiben sind.

Keywords

Bryozoa, Bicorniferidae, *Voorthuysiella*, Danian-Montian, Netherlands

Introduction and Historical Overview

VOORTHUYSEN (1949 and 1956) described calcareous microfossils from marine Pliocene and Oligocene strata from the Netherlands, namely, as imperforate milky white, with three openings and one fissure. He named this problematic form group *Lagena-X*. In addition, FERREIRA & ROCHA (in: VOORTHUYSEN 1956) recorded *Lagena-X* from the late Miocene in Portugal. BIGNOT (1962) found similar microfossils in the Eocene in France and Belgium, HUANG (1962) additionally in the Miocene of Taiwan, KEU (1964) in Recent sediments from the

South China Sea, and KÜMMERLE (1963) in Oligocene sediments in Germany.

Because the basic structures of *Lagena-X* imply an originally joint construction, SZCZUCHURA (1969) excluded *Lagena-X* from the foraminifera and created a special genus - *Voorthuyseniella* for the *Lagena-X*-like microfossils. She pointed out that *Voorthuyseniella* vesicles might be detached relics of an originally colonial or at least sedentary organism. But all observed material of *Lagena-X* sensu VOORTHUYSEN consisted only of free single tests.

In the following year KEU (1970) described typical *Voorthuyseniella* from Eocene up to Recent sediments from western Europe, North America and the South China Sea. A variety of *Voorthuyseniella* from Oligocene and Miocene sediments from northwestern Germany were discovered and placed into several form species by SPIEGLER (1976). In the same year HAMAN & KOHL (1976) published *Voorthuyseniella* from the Eocene-Oligocene Little Steve Creek section in Alabama and pointed out that the abundance of *Voorthuyseniellids* seems to correlate with an abundance of bryozoan debris. POIGNANT & USALDO (1973) reported *Voorthuyseniella* from the lower Miocene in southwestern France, HAMANN (1977, 1978, 1981) from Pleistocene and Quaternary sediments in Texas and Louisiana, and MALLUMIAN & COSTA (1991) from middle Eocene sediments at Tierra del Fuego (Argentina). Recent report of fossil *Voorthuyseniella* from Miocene sediments in northwestern Germany has been given by GÜRS & SPIEGLER (2000).

LINDENBERG (1965) created the new genus *Bicornifera* for problematica from lower to middle Oligocene marine sediments in Austria, northern Slovenia and Turkey. The problematica were described as having a calcareous hyaline test consisting of two chambers of various sizes, separated by a double layered wall. In typical cases each chamber shows an appendix-like prolongation (the interior of which is not confluent with the interior of the chamber). Chambers and prolongations have a lateral opening similar to that of *Lagena-X* (since 1969: *Voorthuyseniella*). KEU (1969) confirmed the *Bicornifera* genus in upper Eocene sediments in southwestern France.

In addition, POIGNANT & USALDO (1973) created another new genus, *Bifissurinella*,

for two-chambered tests showing no bicorniferoid prolongations. The most striking features of *Bifissurinella* are simple pores between chambers and similar pores at their distal ends.

KEU (1977) detected such pores on some *Bicornifera* and suggested that these pores are openings for flexible uncalcified connecting rootlets. This interpretation led to the hypothesis that *Bicornifera* should represent uniserial internodes of 3 to 4 bounded vesicles (zoecia), which were originally connected by an unfossilized axial filament (rootlet). Consequently, KEU (1977) created the new family Bicorniferidae within the cheilostomatous Bryozoa, covering *Voorthuyseniella*, *Bicornifera*, and *Bifissurinella*. This classification was confirmed by RUGGIERI (1978) and SZCZUCHURA (1985). FINGER ET AL. (1986) concluded that *Bicornifera lagajii* was attached to a substrate at the terminus of its proximal stem.

A comprehensive evaluation of the Bicorniferidae including the *Voorthuyseniella* genus was given by SZCZUCHURA (1992). She estimated the *Voorthuyseniellids* to be descendants of an early (i.e. Palaeocene) *Bicornifera*.

All of the rich *Voorthuyseniella* material reported since VOORTHUYSEN (1949) was completely decayed into single chambers.

Locality and Stratigraphical Data

The specimens studied in this paper belong to a sample (Sample 105) which was collected by E. VOIGT in the 1960's at Curfs Quarry, 6 km ENE of Maastricht (Geulthal, Berg en Terblijt district, Netherlands). The sample is derived from a calcarenite layer, the so-called Geulhem Chalk, part of the lower Dano-Montian Houthem Formation (JAGT ET AL. 1996, BRINKHUIS & SMIT 1996).

The Geulhem Chalk was deposited in a shallow subtropical sea on the emersion surface of the Vroenhoven hard ground, which tops the Meerssen Member of uppermost Maastrichtian. First observation of a post-Maastrichtian age of the Geulhem Chalk was made by TRIGER (1859/60) and later rediscovered by HOKER (1956, 1961). The basal part of the

Geulhem Chalk contains reworked bryozoa of late Maastrichtian age (VOIGT 1987). A faunal division is possible, but is very complicated without profound knowledge of the faunal elements involved.

Until 1996 the K/T boundary was defined to the underlying Vroenhoven hard ground. SMIT & BRINKHUIS (1996) pointed out that the K/T boundary should probably be placed 3 to 4 m deeper, i.e., within the Berg en Terblijt horizon (ZEVENBERG 1999). Therefore, Sample 105 should be correlated to the lower, but not lowermost, Dano-Montian. Nevertheless, the age of the *Voorthuyseniella* colonies studied remains somewhat uncertain because of the reworked faunal relics of Maastrichtian age described above, but an interpretation as reworked Maastrichtian is rather unlikely because of the good state of preservation.

Systematics

(sensu GORDON 2002)

Phylum Bryozoa EHRENBERG 1831
Order: Cheilostomata BUSK 1852
INCERTAE SEDIS
Family: Bicorniferidae KEU 1977

Voorthuyseniella SZCZECZURA 1969
Type species: *Voorthuyseniella lageniformis* SZCZECZURA 1969

Voorthuyseniella incrustans SPIEGLER & EISERHARDT, n. sp.
Plate 1, Figures 1-4; Plate 2, Figures 1-4

Holotype: Colony D (Plate 1, Figure 1, Plate 2, Figures 1-4)

Paratypes: Colony A, B, and C

Stratum typicum: Base of Geulhem Chalk, Houthem Formation, lower Dano-Montian

Locus typicus: Curfs Quarry, 6 km ENE of Maastricht, Berg en Terblijt district, Netherlands

Material: Four encrusted colonies (overview: Plate 1, Figure 1)
Collection Voigt No. 7390-A, Naturmuseum Senckenberg, Frankfurt/Main

Diagnosis: *Voorthuyseniella* with bulbous, subrounded-cubiform zoecia and endstanding elongate tube-like pioneer zoecia, single upward-oriented aperture and various lateral pores. Specimens form colonies which are spread uniserially, biserially, or on a plane. The zoecia are cemented to the substrate directly or by protrusive basal encrusting edges.

Description: Colony of up to 15 attached zoecia, arranged uniserially, biserially and/or on a plane spread over the substrate. The shape of the zoecia is bulbous and cubiform, when zoecia are attached to each other. The upward-oriented circular aperture (frontal tubus pore sensu KEU 1970) may be wide or nearly closed. There is no collar or rim around the simple, somewhat depressed aperture. The terminal pioneer zoecium develops an elongated, tube-like shape with a small frontal tubus pore, and ends into an open, mostly destroyed tip. One or two lateral pores at several zoecia may be communication pores. The zoecia are directly cemented to the substrate or attached by protrusive basal encrusting edges.

Dimensions and measurements:

Length [of zoecia]: 0.11 - 0.26 mm
Height/length ratio: 0.9 - 1.25
Max. number of aggregated zoecia: 15

Occurrence: Only the type locality

Remarks: The basal part of the colonies observed clearly shows the direct attachment of the zoecia to the substrate. It seems that the various zoecia of the different colonies were probably connected by nonfossilized rootlets through the tubus pore and lateral pores. The connected bases of *Voorthuyseniella incrustans* studied in this paper are the first fossil proof of this colonial growth mode with encrusting bases. The fossilized zoecia of *Voorthuyseniella* have, until now, been documented only as free single bodies in sediments (in the sand fraction of washed samples). In the future we must also analyse the coarser sediment fraction containing meso- and megafossils as well as small pieces of sediment.

SZCZECZURA (1992) discussed the species concepts in the Bicorniferidae, particularly that of *Voorthuyseniella*. She was unable to find any features of taxonomic value which would permit the delimitation of boundaries between species within the genus. We do not agree totally with these findings, but, indeed, some of the observed morphologic variations of the various form species may reflect only their specific position in the colony. The species concept of the genus must be revised.

Voorthuyseniella incrustans from the lower Dano-Montian is the oldest species of the

genus. Therefore, the assumption made by SZCZECZURA (1992) which concludes that *Voorthuyseniella* separate phylogenetically from *Bicornifera* during the Eocene is no longer correct.

Summary

The connected zooecia of *Voorthuyseniella incrustans* n. sp. studied in this paper are the first fossil proof of a colonial growth mode with encrusting bases. *V. incrustans* is the oldest species within the *Voorthuyseniella* genus.

Acknowledgements

The authors are most grateful to Professor Ehrhard Voigt (Hamburg) for making this *Voorthuyseniella* material available for publication. Dr. Paul D. Taylor (NHM London) supported this study with helpful comments. SEM photographs were kindly taken at the Institute for Geosciences, Christian Albrechts University (Kiel), by Mrs. U. Schuldt and Mrs. M. Minning.

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Plate 1: *Voorthuyseniella incrustans* SPIEGLER & EISENHARDT, n. sp.

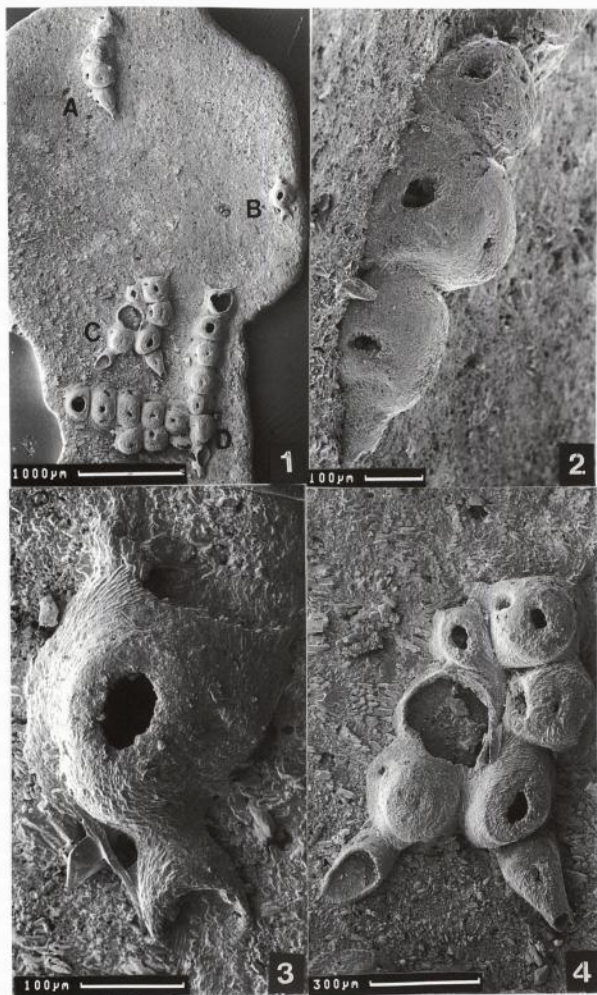
Four encrusted colonies (A - D) attached on a piece of Geulhem Chalk, Houthem Formation, lower Dano-Montium at Curfs Quarry near Maastricht, Berg en Terblijt district, Netherlands. Collection Voigt No. 7390-A, Naturmuseum Senckenberg, Frankfurt/Main.

Figure 1: Overview showing the attached colonies A - D. Holotype: Colony D

Figure 2: Colony A, three uniseriately arranged bulbous zooecia with very small upward-oriented apertures and large lateral pores. Final chamber tube-like prologated, ending in a broken tip. (Figure in a rotation position of 45°)

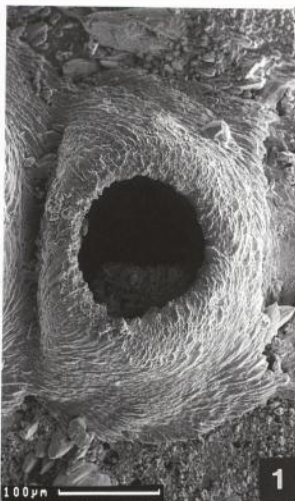
Figure 3: Colony B, single, partly destroyed zooecium with a large upward-oriented simple aperture and a broken elongate pioneer zooecium

Figure 4: Colony C, six subrounded biserially arranged zooecia with apertures of various sizes, lateral pores, and protrusive basal encrusting edges. Each row ends at one side in an elongate pioneer zooecium



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- Plate 2: *Voorthuyseniella incrustans* SPIEGLER & EISENHART, n. sp.
Colony D (holotype) consists of zoecia spread over a plane

Figure 1: Zoecium with a very wide aperture
Figure 2: Four zoecia with small apertures, lateral pores, and basal encrusting edges
Figure 3: Right part of Colony D (in a rotation position of 56°)
Figure 4: End member of Colony D, showing a broken elongate pioneer zoecium



1



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Ypresian Biostratigraphy based on Foraminifera, Ostracoda and other Biota of the Ampe Outcrop Section at Egem (NW Belgium)

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Abstract

The outcrop section of the Ypresian (Early Eocene) Ampe sand and clay pit at Egem, in NW Belgium, was studied for foraminifera, ostracoda and siliceous microfossils. The juxtaposition of the new data and previously published data on dinoflagellate cysts, nannoplankton and macrofauna with the lithocolumn permits an assessment of a high-resolution regional sequence stratigraphy, in which a number of bed sets correspond with transgressive (4th to 5th order) cycles.

The planktic foraminifera indicate NSP 5 in the North Sea biozonation of KING (1983) and P7 - 8 in the global BLOW zonation. The occurrence of *Guembeltria triseriata* and *Pseudohastigerina wilcoxensis* in the Egemkapel Clay give proof of a regional marker horizon known from other outcrop and borehole sections in Belgium. The benthic foraminiferal assemblages are typical for open marine shallow shelf settings. The ostracods are palaeoecologically indicative of a warm shallow sea. The siliceous microfossils are concentrated in two levels which can be correlated with several tephra layers in Denmark, indicating higher volcanic activity during this time.

Kurzfassung

Das Profil der Ampe Sand- und Tongrube in Egem, NW Belgien, des Ypresium (Frühes Eozän) wurde auf Foraminiferen, Ostracoden und kieselige Mikrofossilien hin untersucht. Die Gegenüberstellung der neu gewonnenen Daten und bereits publizierter Daten zu Dinoflagellaten Zysten, Nannoplankton und Makrofauna mit dem lithologischen Profil erlaubt es, eine hoch auflösende Sequenz Stratigraphie zu erstellen, in der eine Anzahl von Schichtpaketen mit

transgressiven Zyklen vierter bis fünfter Ordnung gleichzusetzen ist.

Die planktonischen Foraminiferen zeigen ein Alter von NSP 5 der Nordseebecken Biozonierung von KING (1983) an bzw. die BLOW Zonen P7 bis P8. Das Vorkommen von *Guembeltria triseriata* und *Pseudohastigerina wilcoxensis* im Egemkapel Ton lässt einen regional bedeutenden Leithorizont erkennen, der aus zahlreichen weiteren Tagesaufschlüssen und Bohrungen in Belgien bekannt ist. Die benthischen Foraminiferen-Gemeinschaften sind typisch für offene marine Bedingungen des flachen Schelfs. Die Ostracoden zeigen paläoökologisch ein warmes, flaches Meer an. Die kieseligen Mikrofossilien sind in zwei Horizonten angereichert, die mit Tephra Lagen korreliert werden können, die aus Dänemark bekannt sind, und weisen auf erhöhte vulkanische Aktivitäten während ihrer Entstehungszeiten hin.

Introduction

Locality Details and Previous Studies on the Ampe Outcrop Section

The presently studied outcrop section of the Ampe sand and clay pit at Egem is located in the province of Western Flanders, along the N 50 road from Bruges (=Brugge) to Kortrijk (Figure 1, left). Its coordinates are: x=70.150; y=190.150, and a lithocolumn of some 30 m has been accessible for study for the past 15 years (STEURBAUT 1987, 1998, p. 118, Figure 5). Localities previously sampled by that author (sections A-D) were located in the northern part of the quarry, whereas the samples taken by ourselves in 2000, and treated for the present study (sections E-F) are from the southern part [E = Egemkapel Clay and Egem Sand Members; F =

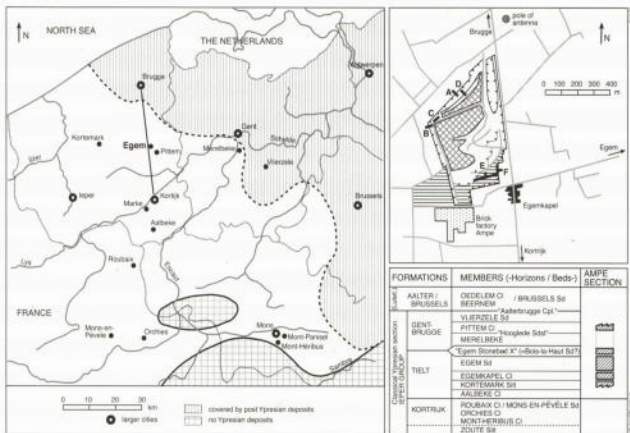


Figure 1: Location and lithostratigraphic position of the Ampe quarry at Egem (maps after STEURBAUT, 1987, Figures 3, 7; modified; position of presently studied / sampled sections E and F have been added).

uppermost Egem Sand, "stonebed X"; and Pittem Clay Members, Figure 1, right hand side).

This outcrop has been in existence for more than 30 years. In the course of time the excavation gradually reached deeper and deeper strata, and the section has been studied by numerous workers: NOLF (1973, p. 77-79, Figure 1) mapped the lithocolumn of a shallow borehole; GEETS (1979, p. 45) presented some sedimentological and granulometric data and introduced new lithostratigraphic units for the strata which were then visible in the area. The grain-size distribution of three separate intervals of the then existing quarry (down to 19 m) were later presented by GEETS (in STEURBAUT 1987, Figure 8), but these levels cannot be well juxtaposed to the presently studied lithocolumn.

Palynological analyses of the dinocysts of several selected samples have been presented by DE CONINCK & NOLF (1979), and by ISLAM (1982). Further work has been initiated on the dinoflagellates of several other levels of the quarry, but in our opinion a more closely spaced sampling of the section (at least every meter, as used for the study of the present paper) would

be necessary to be able to distinguish 4th to 5th order transgressive cycles.

Some micropalaeontological data on the benthic foraminifera have been presented by GEETS *et al.* (1981), but their sampled section cannot accurately be juxtaposed to the lithocolumn studied here. WILLEMS, (1982, briefly reviewing the results of his Ph.D. work from 1980) did not study this outcrop section, but his thorough work on the foraminifera of boreholes and outcrops of this area, allows us to use his regional biozonation based on the successive occurrence of various benthic foraminiferal associations, and to correlate the Ampe section with several borehole and outcrop sections.

Calcareous nannoplankton studies including this quarry have been initiated by STEURBAUT & NOLF (1986), STEURBAUT (1987), and have further been discussed by STEURBAUT (1988, 1998).

Lithostratigraphic Framework

The Ampe section comprises several members of two formations of the leper Group (Figure 1, regional lithostratigraphic scheme, and juxtaposed lithocolumn); from base to top:

The basal one or two meters of the section

probably correspond to the upper part of the Kortemark Silt Member (defined by STEURBAUT & NOLF 1986), which forms the lower part of the Tielst Formation (STEURBAUT 1998, p. 113).

The overlying unit is the Egemkapel Clay Member (STEURBAUT 1998, p. 114), overlain by the Egem Sand Member (LAGA et al. 1980, STEURBAUT & NOLF 1986), which is generally thought to form a lateral equivalent of the previously defined Ledeborg Sand Member (GEETS 1979).

Overlying the top of this clayey sand interval, a consolidated coquina layer / silicified opaline CT cemented sandstone (referred to as "stonebed X" by the authors) occurs, the stratigraphic position of which is still debated. STEURBAUT & KING (1994) correlated it with the thin Bois-la-Haut Sand Member as observed in the Mont Panisel section, between the Mons-en-Pèvele Sand and Mont Panisel Sand Members. But FOBE (1997) preferred to equate it with the "Hooglede Sand intercalation" which he introduced in that paper, and which according to him separates the Merelbeke Clay and Pittem Clay Members in the Flanders area (cf. lithostratigraphic table of Figure 1).

It appears that opaline-CT-cement (often connected with partly or entirely consolidated sandstone intercalations) has been observed at various intervals of the leper Group, such as (a) in several sandstone intercalations in the Pittem Clay Member (FOBE 1997, p. 95) as, e.g., observed in the Ampe section; (b) in the "Hooglede Sand Bed" stratotype section (FOBE, 1997, p. 98); (c) in "stonebed X" of the Ampe section (as already discussed in the report of the "NFWO contact group" excursion, 23/09/1983, and, e.g., further substantiated by JACOBS & DE BATIST 1996, p. 35). The predominantly biogenic origin of the opaline cement (as often co-occurs with silica microfossils, such as sponge spicules) has been emphasized by various researchers, and will be discussed below, in the sections on siliceous microfossils.

In the Ampe section it is generally assumed that a large hiatus occurs between this "stonebed X" and the overlying clays and sands, which are equated with the Pittem Clay Member (GEETS 1979), since the Merelbeke Clay Member (DE MOOR & GERMS 1971), a dark grey heavy clay of lagoonal setting as observed in the neighbour-

hood of Ghent, appears to be missing in the Ampe section and in the area around Egem in general.

The Pittem Clay Member forms part of the Gentbrugge Formation (previously called Gent Formation, but according to Dr. P. Laga, this name had already been used for a quaternary rock unit in that area).

When selecting several main reference sections (WILLEMS & MOORKENS 1991, p. 241) in order to characterise the various parts of the leper Group succession in Belgium, the Ampe section presents several great advantages compared to its lateral equivalents, as it appears that in this very large outcrop (more than half a square km) no intraformational faults have been observed, whereas this phenomenon occurs in the neighbourhood. For instance at the "Ostyn" clay pit in Meulebeke (i.e., at some 8 km to the SSE of Egem) the Egem Sand Member is strongly disturbed by numerous intraformational faults (VERSCHUREN 2001, p. 41-43, 75, Figure 69) and a detailed sampling for high-resolution stratigraphic analysis of the lithocolumn would be very difficult there.

Topic of Study

This study has been initiated for various reasons. First, a detailed analysis of the various groups of the microfauna (such as foraminifera, ostracoda, radiolaria, siliceous sponges, etc.) is possible from a single treatment of the samples (washing and picking of some 200 g of sediment).

The high-resolution biostratigraphy of the various members can be checked by juxtaposing the results of various groups of microfossils and assessing their regional biozonations.

A series of closely spaced samples permits the observance of variations in microfossil assemblages at various levels. The results obtained for the various biota are comparable, since they are all based on the same sampled levels. In addition, charts of microfossils (and their abundance, diversity, etc.) can directly be juxtaposed to the detailed lithocolumn, and thus to its granulometry and sedimentology curves. Hence, it becomes possible to check whether lithologically/sedimentologically distinguishing sequences correspond to the abundance and/or diversity cycles of several microfossil groups, e.g., planktic

and benthic foraminifera. In addition, the episodic occurrence of other biota, such as the siliceous microfossils, can be added to this framework.

Material and

Methods

A series of forty samples has been taken, as indicated along the lithocolumn of the various charts (Figures 2, 3, 4, 5). From each sample 200g sediment was washed and sieved over a 70-micron sieve. After density concentration with CCl_4 (carbon tetrachloride) the microfauna, including calcareous and silica tests of microfossils ranging in size between 70 and approx. 500 microns, were picked and counted, so that these results could be plotted along the Ampe lithocolumn.

The shell beds of the section (FT to FX horizons of Figures 2-6) were not sampled for this study since they generally consist of much larger granules, such as mollusc shells and fish teeth, which have already been treated in the literature (cf. Figure 4); the large foraminifera (Nummulites) have not been studied for the present paper, since they will be treated in a separate study on this group.

The same series of samples has been used for granulometry and calcimetry analyses, part of the results having been outlined in Figure 6, as juxtaposed to the Ampe lithocolumn.

Deposition of Microfossil Specimens

The specimens shown in Plates I to VI, as well as several others selected from the Ampe quarry samples (labelled as Egemkapel Clay, Egem Sand, and Pittem Clay Members; all of Ypresian age), have been stored in the collections of the Laboratory of Palaeontology at the Catholic University of Leuven. They have been registered under the following numbers: Planktic foraminifera: F 12632 - F 12759 and F 12783 - F 12800
Benthic foraminifera, radiolaria, and sponge spicules: F 12801 - F 12947
Ostracoda: A 1879 - A 1893

Micropalaeontological Analyses

Planktic Foraminifera

Planktic foraminifera occur at many levels of the Ampe section, several in the Egemkapel Clay, and in most levels of the Egem Sands. Some specimens have been found in a single level of the Pittem Clay, but it has not yet been determined if these are in situ or reworked.

Eighteen taxa have been observed and their occurrences are given in the range chart (Figure 2, right-hand side). Most of them have been figured in Plates I-II.; the species and the authors of the recognised taxa have been listed in the legends of the plates.

In the Ampe section, *Guembelitra triseriata* is present from the base of the Egemkapel Clay Member upwards; in Belgium it is known to range throughout the Egemkapel Clay and Egem Sand members; according to WILLEMS (1980, p. 87) it first occurs in a calcareous silt of the upper part of the Kortemark Level at Kortemark, and in the Kallo borehole it ranges from 283 m upwards.

In addition, *Pseudohastigerina wilcoxensis* occurs from the base of the Egemkapel Clay Member upwards in the Ampe section. According to BLOW (1979), and also in the updated biozonation of BERGGREN et al. (1995), its FAD (first appearance datum, worldwide) forms the base of the P7 biochron.

The LOD (last occurrence datum, local) of *Muricoglobigerina aquiensis*, which is known to range down into the Late Palaeocene, (worldwide) is observed here at sample level 28. According to BERGGREN et al. (1995), it has its LAD at the top of the P7 biochron. In the Ampe section a further specimen of this taxon has been observed in the Pittem Clay Member, level 37, but it is possibly not in situ.

In addition, *M. chascanona* and *Globorotalia pseudoimitata*, both ranging up to level 22 in the Ampe section, are known to have ranges restricted upwards to the top of the P7 biochron (BERGGREN et al. op. cit.)

From the above it appears that the

Sand are very shallow nearshore marine to deltaic deposits, with flat bottomed erosion gullies. Indeed, several levels are barren in foraminifera and other marine biota, and may be brackish to fresh-water intercalations. However, at several other levels, plankton is quite abundant and indicate a deeper open marine setting. For that reason countings of the planktic specimens of the various levels have been initiated, and the results have been plotted against the Ampe lithocolumn (Figure 6). The resulting curve permits us to distinguish a number of thin transgressive/regressive cycles, which are discussed below (sequence stratigraphic interpretation).

Benthic Foraminifera

Only a few sampled levels proved entirely barren in benthic taxa, but as is the case with the plankton the frequency (number of specimens found in 200 g of sediment) strongly varied from level to level. Nevertheless, some 44 taxa have been identified (range chart, Figure 3), all previously described (WILLEMS 1980) and figured (WILLEMS 1991) in other outcrops and boreholes of Belgium. Most of the taxa found in the Ampe section have been figured (Plates III-IV); the species and their authors have been listed in the legends of the plates.

Unfortunately, nearly all of the approx. 200 foraminiferal taxa observed by WILLEMS (op. cit.) in the Ypresian succession of Belgium, appear to range throughout that interval. A biozonation for the Early Eocene of that area, as based on first and last appearances of taxa (FAD's, LAD's), was thus not able to be established there. However, as had been observed by WILLEMS (1980, 1982) and WILLEMS & MOORCKENS (1991), the specific content of the foraminiferal assemblages clearly changed in the course of Ypresian times, and a number of "benthic association zones" (BAZ), characterised by their dominant species, permits the presentation of a regionally usable assemblage biozonation.

From the 44 taxa of the Ampe section, some ten were able to be selected for the biostratigraphic assessment (Figure 2, left-hand side; characteristic zones of each taxon indicated below the species names), which permitted a rough delimitation of WILLEMS' (op. cit.) BAZ zones V and VI, previously also known to correspond to the

Kortemark Silt / Egem Sand succession of Belgium.

The larger foraminifera specimens observed in our washed samples from the Ampe section (*Nummulites planulatus*) occur only at four levels, ranging from the shell beds Fl to FlI. The two occurrences between the shell beds prove that *Nummulites* may also occur at other levels than coquinas do. These two samples, at levels 29 and 31, thus probably represent in situ preservation of the *Nummulites*, whereas those of the shell beds are largely transported and concentrated by winnowing (cf. below).

The levels of the Ampe section which are barren or poor in planktic foraminifera (Figure 2) generally correspond to levels which are also poor in benthic specimens (Figure 3), and these levels probably represent very shallow marine to non-marine/brackish intercalations. In the more richly fossiliferous intervals strong variations in the diversity (simply counting the number of observed taxa per level) are observed. From the data presented in the two charts, diversity curves have been compiled for the planktic and benthic foraminifera, and it appears that these two curves roughly mirror that of the planktic abundance curve (Figure 6, left-hand side), the "higher diversity intervals" thus also reflecting the "more open marine phases" of the section.

Ostracoda (K. Wouters)

The material studied consists of six micropalaeontological slides containing ostracod carapaces and valves, obtained as a result of treating the sediment with carbon tetrachloride. This flotation material yielded 31 adult and 2 juvenile carapaces, 9 adult and 2 juvenile valves, belonging to 9 species. The specimens are well preserved.

The following species were found (with indication of sample number, and number of specimens; car. = carapace, v. = valve):

- E 19 *Schizocythere appendiculata* (1 car.)
- E 22 *Eopaijenborchella lomata* (1 car.)
- Cytheretta* sp. cf. *C. decipiens* (1 car.)
- E 25 *Cuneocythere (Monsmirabilia)* sp. (1 car.)
- E 28 *Loxococoncha* sp. (juv.) (1 car.)
- Cytheretta* sp. cf. *C. decipiens* (2 car.)
- Schizocythere appendiculata* (1 v)

- E 35 *Leguminocythereis pustulosa* (6 car. and 5 v.)
Cytheretta sp. cf. *C. decipiens* (1 car.)
Horriфициella aculeata (1 car.)
Cyamocythereidea hebertiana 3 car., 2 v.)
- E 37 *Schizocythere appendiculata* (7 car., 1 v.)
Cytheretta sp. cf. *C. decipiens* (1 v.)
Paracythereidea gradata (1 car.)

Comments on the recorded taxa:

The Ypresian ostracod fauna of Belgium is relatively well known, particularly through publications by BOSQUET (1852) and KEU (1957), but also by VERHOEVE (1967), WILLEMS (1973 and 1978), GUERNET (1990) and DUPUIS et al. (1990). KING (1990, p. 84 and 85) identified several ostracods of the "Egem stonebed X" (4 m below surface) of the Ampe quarry at Egem, and KING (1991, p. 351-354) gives an overview of the biostratigraphy of the Ypresian in Belgium, including ostracods. Some of the species found in the Egem quarry were already recorded from the Belgian Ypresian and are taxonomically well known. Other species, however, for which open nomenclature is used here, have a less clear taxonomic status.

Schizocythere appendiculata TRIEBEL (1950, Plate V, Figure 2) is mentioned from the Ypresian at Hyon (KEU 1957), Merelbeke (VERHOEVE 1967), and from the Kallo well (WILLEMS 1973).

Cyamocythereidea hebertiana (BOSQUET 1852) (Plate V, Figure 9) was already recorded from Eocene deposits in Belgium by KEU (1957) and VERHOEVE (1967). Our specimens show minor morphological differences in comparison with Ledian (i.e., Middle Lutetian) representatives of the species in the convexity of the dorsal margin and in the ornamentation.

Cunecocythere (Monsmirabilis) sp. (Plate V, Figure 5) probably represents an unknown species. It resembles to some extent *C. (M.) gibbosa* (LIENENKLAUS 1900) (cf. MOOS 1973, SZCZEHURA 1977) from the Upper Eocene of Germany and Poland, and the Lower Oligocene of Germany. The present species, however, differs by the much smaller punctuations and by the absence of a distinct anterior marginal rim.

Horriфициella aculeata (BOSQUET 1852) (Plate V, Figure 8) is a rather common species in Ypresian and Lutetian deposits of Western Europe. It was recorded from the Ypresian of Belgium by KEU (1957), WILLEMS (1973 and

1978) and by GUERNET (1990), who describes the species as "common" in the Nummulites planulatus sands of Mont Panisel section.

Leguminocythereis pustulosa (ROEMER 1838) (Plate V, Figures 6, 7) (cf. APOSTOLESICU 1955, HASKINS 1970, MALZ 1989) is a relatively rare species in the Eocene of Western Europe. Until now it has never been recorded from the Eocene of Belgium. The only known *Leguminocythereis* species occurring in Eocene deposits of Belgium is *L. striatopunctata* (ROEMER 1838) (KEU 1957, WILLEMS 1973, 1978, GUERNET 1990).

Cytheretta sp. cf. *C. decipiens* KEU 1957 (Plate V, Figure 1) resembles *C. decipiens* KEU 1975 forma B MONOSTORI 1985 (cf. also MONOSTORI 1998) from the Eocene of Hungary, but our species is more elongate and has a weaker reticulation. The species presented here is identical to *C. decipiens* KEU 1957 sensu WILLEMS 1978 (non KEU), from the Ypresian of the Kallo well.

Paracythereidea gradata (BOSQUET 1852) (Plate V, Figures 3, 4) has already been mentioned from the Belgian Ypresian by KEU (1957) and VERHOEVE (1967). There remains some doubt as to whether the Ypresian representatives of this species are conspecific with *P. gradata* from the Lutetian of the Paris Basin (Grignon: type locality and type level of the species).

Eopajienborchella lomata (TRIEBEL 1949) is a rather common species in Ypresian and Lutetian deposits of Western Europe. It was recorded from Ypresian deposits in Belgium by KEU (1957), VERHOEVE (1967) and WILLEMS (1973 and 1978).

Although the material which was present for this study was rather limited, this preliminary report gives an interesting first idea of the importance of the Egem quarry for the evaluation of the Ypresian ostracod fauna. From the eight species present, at least two require further study. When dealing with larger samples and with elaborate picking of specimens, the Egem quarry will prove to be an important site for ostracod research, which will permit comparison with other Belgian and foreign localities. The material studied here is indicative of a warm and shallow sea. More material, however, is needed to give more detailed information on the palaeoecology of these deposits. The above-mentioned ostracod taxa, together with ostracods already men-

tioned by KING (1990, 1991) from the Ampe quarry, are presented in the distribution chart (Figure 4, left-hand side).

Siliceous Microfossils

As presented in the chart (Figure 4, right-hand side), two groups of silica tests have been observed in the washed residues, (a) various "form taxa" of spicules of siliceous sponges, and (b) two species of radiolaria.

From their stratigraphic distribution in the Ampe section, it appears that all silica tests of these two entirely different groups of biota (protists and sponges) are largely concentrated in a couple of intervals of the section only, and that these peak levels are different from those of the planktic foraminifera. Various palaeoecological parameters must thus be inferred to explain these frequency variations at the various stratigraphic levels.

At least for some of the groups of silica test secreting organisms, such as diatoms, and siliceous sponges (MALDONADO et al. 1999), it is well known that the silica concentration of sea water forms one of the major limiting factors. Since "normal" sea water is generally strongly under-saturated in silica, some supply of dissolved Si anions may cause blooming events of these groups of microfossils.

Enhanced silica concentrations of surface waters of the sea can be obtained from various sources:

- (a) influx of river waters carrying somewhat enhanced silica concentrations,
- (b) sea waters taking up dissolved silica from an opaline-rich substrate, e.g., an older diatomite layer outcropping at the sea bottom (e.g., HELMANN-CLAUSEN 1997),
- (c) supply of silica to the deep ocean waters by volcanic/hydrothermal vents, e.g., along ocean ridges, and upwelling of these waters, mainly along eastern slopes, shelves, and coast lines,
- (d) strong volcanic events and the very wide eolian distribution of ashes.

Theoretically, all four mechanisms may cause enhanced production of siliceous test secreting organisms, but from the numerous cases discussed in the literature, it appears that major blooming events, covering large areas, are often linked to major volcanic events.

Several examples have been noticed in the North Sea Basin which appear to roughly correlate with several major tephra layers of the Early Palaeogene, as linked to the volcanic activity then occurring in the northern Atlantic.

In Belgium, siliceous sponges occur abundantly in part of the Gelinden Marl Member (Heers Formation; latest Middle Palaeocene), and also in the overlying Lincent Calcarene/Halen Clay Members (Hannut Formation, early Late Palaeocene) and lateral equivalents in the Mons basin, as noticed by GULINCK & HACQUAERT (1954, p. 463, Figure of GULINCK 1954), SCHUMACKER-LAMBRY (1978, Pls. 17, 18), DE GEYTER & WILLEMS (1982), DREESSEN et al. (2000, p. 17, Figure 6). This stratigraphic interval largely corresponds with the "volcanic Phase 1" of KNOX (1994) as recognized in the UK and in the North Sea, with several tephra layers a. o. observed in the Glamis Formation.

A further major volcanic event in the northern Atlantic, which occurred during the earliest Early Eocene, and has been referred to as "Phase 2" by KNOX (op. cit.), is characterized by rich "large diatom assemblages" and several "conical" radiolaria, in that interval of numerous North Sea wells. In addition, the basal Ypresian in Belgium contains these microfossils, now generally preserved as pyritised "Steinkerne", but originally consisting entirely of silica tests (WILLEMS 1982, MOORKENS et al. 2000).

In the Middle to Late Ypresian succession of Belgium, several stratigraphic intervals are known to include abundant siliceous sponge remains, and parts of them are also characterized by frequent "spherical" radiolaria. This entire episode has been termed "siliceous biofacies" by KING (1990), who recognized this interval in the Knokke borehole and several other sections in Belgium and the UK. WILLEMS (1981) also observed these "spherical" radiolaria in the lateral equivalent intervals of the Kallo and Tielt boreholes.

These groups of microfossils have also been found to be concentrated in restricted intervals of the Ampe section (Figure 4): (a) at the base of the Egemkapel Clay Member, where both groups are frequent, but become considerably less numerous higher up in that member, and (b) in the uppermost bed of the Egem Sand Member, in the overlying "stonebed X", and in the basal part of the Pittem Clay, where only

sponge spicules occur. When juxtaposing these two intervals of "siliceous biofacies" of the Ampe section to the correlation scheme presented by STEURBAUT (1998, p. 142, Figure 11), it is clear that they correlate quite accurately with intervals of tephra layers in the Albaekhoeved section. The Egemkapel Clay interval siliceous biofacies correlates with the V 15-17 tephra layers (Viborg borehole zonation), and those of the uppermost bed of the Egem Sand Member and overlying "stonebed X" appear to be lateral equivalents of the V18-19 tephra layers.

A third (but less conspicuous) occurrence of radiolaria has been observed in the top layers of the Pittem Clay Member (level 40), but it is not yet certain whether the microfossils of that member are in situ (cf. above for a discussion of possibly allochthonous calcitic microfauna).

However, the occurrence of radiolaria in the Pittem Clay interval in the Ampe section appears to coincide with FOLE'S (1997, p. 95-97) recording of opaline CT-cement (supposedly of biogenic origin) in the partly consolidated sand layers of the upper part of that member, as observed in several wells and outcrop sections of the area. Hence, the upper part of the Pittem Clay may include a further brief "silica episode" of the Belgian succession, but it must be ascertained by further research whether the microfossils are in situ. At the moment this "siliceous biofacies" cannot be correlated with a lateral equivalent tephra layer of the known Danish and North Sea successions.

Integrated Planktic

Biostratigraphy

The planktic foraminifera distribution in the Ampe section discussed above indicates that the P7 to P8 biochrons of the BERGGREN et al. (1995) biozonation are present (Figure 2), and that the section studied can therefore be accurately situated in BERGGREN'S (op. cit.) time scale (cf. Figure 7).

This result is in agreement with age-dating based on calcareous nannoplankton, indicating the uppermost part of the NP12 biochron (subzone VIII) according to STEURBAUT 1987, 1998) for the upper part of the Egem Sand Member. The overlying "stonebed X" and Pittem Clay Member has, so far, not

been able to be age-dated on the basis of calcareous nannoplankton.

In terms of dinocyst zonation, a large part of the Egem Sand Member corresponds to the *Kisselovia clathrata* biozone, and the FOD of *Areosphaeridium diktyoplokus* in the Ampe section occurs at some two meters below the top of the Egem Sand, according to DE CONINCK & NOLF (1979), thus indicating that the basal part of the *A. diktyoplokus* biozone of DE CONINCK (1991) occurs above that level. The overlying "stonebed X" layer also contains this dinocyst taxon (STEURBAUT & KING 1994, p. 195), and, in addition, the overlying Pittem Clay Member includes rare *A. diktyoplokus*, and thus still belongs to that same biozone; it can also be equated with the D9 biozone of COSTA & MANUM (in VINKEN, ed., 1988, p. 325).

Distribution of Megafossils and Large Foraminifera

The megafossils and larger foraminifera of the Ampe section have not been studied in detail for the present paper, and the shell beds have not been sampled in detail for the Nummulites. But an overview of published results is given, since it appears that the distribution of these biota may be of importance in gaining a better understanding of the trans-regressive history of the section.

Megafauna

For the past twenty years or so, the Ampe clay and sand pit, which has a very rich megafossil content, has regularly been visited by groups of malacologists, most of which are amateurs. Since the molluscs of this outcrop (and of most other outcrops of the Palaeogene of Belgium) have never been the object of publications of university, survey, or museum of natural history malacologists, the rich collections of these amateurs fortunately give us a preliminary overview of the most important taxa found at various levels of the Ampe section (VAN NIEULANDE & MERMUYTS 2001).

Due to the fact that in the course of the last three decennia the excavation has gradually become deeper, the shell beds of the upper part of the section have been sampled much more extensively than

those at the base. Therefore VAN NIEULANDE (2002) was able to compile exhaustive preliminary lists of the molluscs observed in the "stonebed X" coquina, and several significantly different assemblages found in the strata lying directly underneath it, i.e., Beds 21a and b, a further subdivision of Bed 21 of the STEURBAUT (1987, p. 348, Figure 7) stratigraphic interpretation of this lithocolumn.

A compilation of the megafaunal content is given in Figure 5. In addition, some data from STEURBAUT (1987, Plate 1) and KING (1990, p. 84) have been incorporated.

The lowest megafossil accumulation of the Ampe section is that at base of the Egemkapel Clay, here referred to as the FT horizon. It contains only fish remains (teeth and several otoliths), which are currently studied at the Catholic University of Leuven, and abundant *Ditrupea* worm tubes.

The next higher megafaunal accumulation is that of the FO shell bed of the STEURBAUT (1987) stratigraphic scheme, occurring in the lower part of the Egem Sand Member. The fact that its mollusc content is presently poorly known is primarily the result of the fact that the excavation of the deeper part of the quarry is much younger than that of the FI, and FII shell beds located at a higher level and of the overlying "stonebed X" (called FX in Figure 5), which have been analysed more extensively since the beginning of the original excavation of this quarry.

As may be seen from the range chart of the megafauna (Figure 4), a clear change occurs in the mollusc assemblages of Beds 21a and b (lower and upper part of the bed) and the overlying Bed 22, which represents the "stonebed X" level (major taxa compiled from VAN NIEULANDE & MERMUYTS 2001): Originally the mollusc assemblages were dominated by bivalves (Bed 21), but later the bivalves partly disappear and the gastropod taxa take over in number (Bed 22); VAN NIEULANDE & MERMUYTS (op. cit.) suggest that this turnover of the fauna largely represents a change in trophic communities, but in our opinion it should also be checked whether selective preservation of the shells may be an explanation. In the upper part of "stonebed X", which is more consolidated and strongly silicified, the molluscs (mainly gastropods) are only represented as ghosts (voids), suggesting that decalcification occurred after the silicification of sandstone.

Large Foraminifera

The associations of large foraminifera in the Ampe section consist exclusively of several relatively small "northern" Nummulites, which have not been analysed in detail for the present paper, since the assemblages of two shell beds of this outcrop (FI and FII) had previously been the topic of a biometric/statistic study of the corresponding samples Egem A and Egem B by LIMBOURG (1986). Further Nummulites also occur at the FO level and at FX, at or slightly below the basal part of "stonebed X".

It has long been thought that all Nummulites from the Early Eocene in Belgium belonged to a single species, *Nummulites planulatus* LAMARCK 1804, with its two (micro- and macrospheric) generations, but the measurements of the inner structure of the macrospheres carried out by LIMBOURG (1986) suggest that a third statistic population may be present in the assemblages. Moreover, another Nummulite taxon has been mentioned together with *N. planulatus* (STEURBAUT, in SCHULER et al. 1992, p. 57, STEURBAUT & KING 1994, p. 195), determined as *Nummulites cf. aquitanicus* BENOIST (1889) from the shell bed in the upper part of the Egem Sand Member in the Ampe section. In the Hampshire Basin in the southern UK, *N. cf. aquitanicus* was previously mentioned by CURRY et al. (1977, Figure 6), in the Wittering Formation at Bracklesham Bay, and in the Fisher IV bed of the Whitecliff Bay section. These strata are lateral equivalents of the Egem Sand Member in Belgium.

The incoming and (temporary or final) disappearance of several Nummulite taxa in the Belgian succession may have some regional biostratigraphic value:

The first incoming (regional FAD) of *N. planulatus* in Belgium occurs in the Mons-en-Pévèle Sand Member of the Mont-Panisel/Bois-la-Haut borehole section, in the course of the lower NP 11 (subzone I) according to STEURBAUT & KING (1994), and the P6b planktic foraminifera biozone, since *Guembelitra triseriata* and *Pseudohastigerina wilcoxensis* are missing in the assemblages studied from that well (HOOGBERGHS 1992). The incoming of *N. planulatus* has also been observed in the Roubais Clay Member (its lateral equivalent), e.g. at Marke, near to the NP11/NP12 boundary (STEURBAUT 1998, p. 121, Figure 7), and ranging upwards to the basal Aalbeke

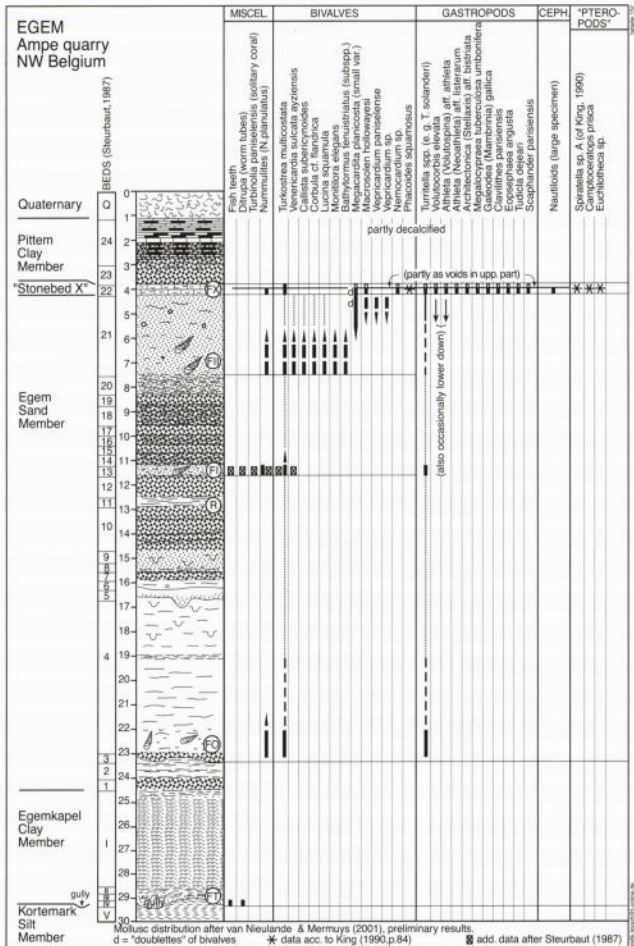


Figure 5: Preliminary range chart of megafossils as observed in the Ampe quarry, mainly after VAN NIEULANDE & MERMUYNS (2001), and data added for the horizons FI after STEURBAUT, (1987, Plate 1) and FX ("stonebed X") after KING (1990, p. 84)

Clay Member. But Nummulites apparently disappear from the area in the overlying Aalbeke Clay Member (WILLEMS 1980, 1982). The first incoming and subsequent disappearance of *N. planulatus* in Belgium is termed BNZ1a zone (Belgian Nummulite Zonation; MOORKENS in VINKEN 1988, p. 188).

Nummulites of the same taxon reappear at the base of the Egem Sand Member, (e.g., at the FO shell bed of the Ampe section, this level corresponds to the NP12, subzone VII (Figure 2). This second influx of *N. planulatus* is termed BNZ1b (MOORKENS op. cit.); in the Ampe section it appears to range only up to the base of "stonebed X" (cf. also Figure 7, benthic foraminifera column), but further *N. planulatus* assemblages are known to reappear in the considerably younger Vlierzele Sand Member (Top of BNZ1 zone) at the top of the leper Group.

Some molluscs of this section have apparently been preserved in their life position (as indicated by the presence of "doublets", i.e., still mutually attached bivalve shells, found in the upper part of Bed 21), but most shell beds appear to be the result of post-depositional concentration (winnowing of coarser sedimentary granules in high-energy environments) in the very shallow marine realm. This also appears to be valid for the concentrations of the Nummulites in these shell beds. These thanatocoenoses of molluscs and larger foraminifera may thus have a somewhat different content than that of the original biocoenoses, and caution should be exercised in using these assemblages for biometric studies.

Only with a detailed biometric and systematic study of Nummulite assemblages of the Eocene of Belgium will it be possible to elucidate several problems of taxonomic nomenclature, of the exact regional ranges of the taxa in Belgium, and of the connection with the Tethyan large foraminiferal taxa, from which the northern species are thought to be derived. Such a study, including the help of a specialist in larger Tethyan foraminifera, has recently been initiated by ourselves.

Palaeoecological and Environmental Input to Sequence Stratigraphy

"Rhythmic Pulses" of Foraminiferal Assemblages

As it appeared that the frequency of planktic foraminifera strongly varies in the Ampe section (from abundant in some levels to absent in others), the number of specimens was counted for each of the samples (200 g), and these data were plotted as a frequency curve along the Ampe lithocolumn (Figure 6). Our counting is not expressed as P/B (planktic/benthic) foraminiferal ratio, as it is thought that the technique used for concentrating microfauna (flotation in carbon tetrachloride) may have selected more of the light, planktic specimens, than of the generally somewhat heavier, benthic ones. The thus obtained P/B ratio figures would therefore have been higher than they were in reality during deposition. Hence, the "absolute" figures as given in the chart probably more accurately reflect the changes of the environment than P/B ratios would.

It is generally accepted that the higher the number of planktic specimens observed the stronger the influence of the open marine realm was, thus generally indicating a somewhat greater bathymetry. The "rhythmic pulses" observed in the planktic foraminiferal frequency curve therefore represent a number of small trans-/regressive sequences (probably primarily 5th order cycles, with durations of several tens of thousands of years).

In addition, the curves for the diversity variations (number of taxa per sample) for the planktic and for the benthic assemblages at various levels have been constructed, and juxtaposed to the Ampe lithocolumn. By and large they appear to be roughly parallel to the planktic frequency curve shown in Figure 6, and thus are thought to also reflect the local/regional sea-level changes.

The planktic frequency curve permits the identification of some eight "transgressive pulses" in the interval of the Egemkapel Clay and Egem Sand Members, and possibly a further "transgressive pulse" in the overlying Pittem Clay Member, in case the specimens are in situ.

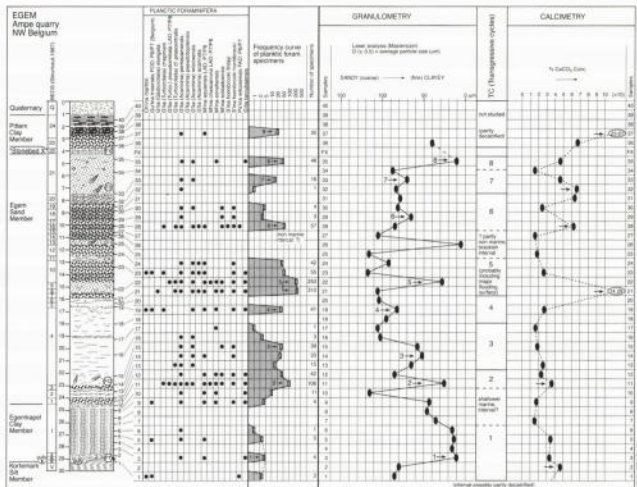


Figure 6: Planktic foraminiferal frequency curve of the Ampe quarry of present study, as juxtaposed to granulometry and calcimetry curves, and the distinction of "TC units" as local transgressive cycles (for explanations cf. text)

The strongest open marine influence is observed in the interval of the sampled levels 21 to 24, where hundreds of planktic foraminifera specimens were counted. It is thought that this interval corresponds to a mfs (main flooding surface) of sequence stratigraphy. In this interval a thin red brown (iron oxide/-hydroxide) horizon has also been observed (indicated as level "R" in the lithocolumn), which may roughly coincide with the mfs of the third order cycle including the Egem Sand Member.

Juxtaposition to Granulometry and Calcimetry Curves

The same series of samples has been used for a laser analysis (Mastersizer), and from the D (v, 0.5) data obtained (average particle size in microns) a granulometry curve has been constructed (Figure 6). When juxtaposing this curve to the planktic foraminiferal frequency curve, it is evident that the more clayey intercalations mirror to a large extent the same eight "transgressive pulses" as deduced from the planktic abundance.

One major exception is observed at the level of samples 26 and 27, where a very

clayey intercalation, which is nearly totally devoid of microfossils, occurs. The total absence of planktic microfauna and of ostracods as well as the very poor benthic microfauna of levels 26 and 27 is suggestive of a non-marine setting; a palynological analysis (dinocysts, pollen and spores) would probably be a better tool to recognize salinity variations in the Ampe section, but it would be necessary to treat a full series of samples in order to identify the non-marine intercalations in the section.

The calcimetry curve (Figure 6, right-hand side) based on several selected samples (shell beds have been omitted for this study) shows only a few "pulses" of higher percentages of calcium carbonate, which may reflect the somewhat higher content of carbonatic microfossils, but, in general, this curve appears to be less appropriate for the detection of "transgressive cycles" than planktic frequency curves, foraminiferal diversity curves, and granulometry curves.

Glauconite concentrations have not been analysed for the present study, since this analysis had already been carried out for

another (sedimentological / sequence stratigraphic) study on the Ampe quarry (M.Sc. / Bachelor studies completed by Arn Willems, 1994-1995, at the Catholic University of Leuven); these data cannot accurately be juxtaposed to our sampled section of the Ampe quarry, but a rough comparison of the glauconite curve with the previously discussed curves apparently does not give additional indications for the sequence stratigraphic interpretation of the Ampe section.

Shell Beds as "Lag Deposits"

As discussed by VAN WAGONER et al. (1990, p. 12), concentrations of mollusc shells and debris are generally the result of winnowing in high-energy settings, and they thus form "lag deposits"; the most common type of lag is known to be the "channel lag", i.e., an accumulation of shells and coarser granules occurring at the base of incised valleys which mainly accumulated during sea level falls.

This very probably applies to most or all of the shell beds observed in the Ampe section, as JACOBS & DE BATIST (1996, p. 35, Figure 10) remarked that several intervals of this section are characterized by incised valleys, which are indications of (pro)-deltaic settings.

From base to top the Ampe lithocolumn comprises the following megafauna accumulations: (cf. Figure 5 for bed numbers, for several other symbols cf. STEURBAUT 1987, Figure 7):

- FT level, corresponding to Bed IV; occurring at the base of the Egemkapel Clay Member; containing numerous *Ditrupa* worm tubes, fish teeth and several otoliths; overlying a strongly gullied surface of the underlying Kortemark Silt Member.
- F0 level, corresponding to the base of Bed 4; containing primarily *Turritellids*, oysters, and several *Nummulites*.
- several clearly gullied surface levels, occurring at Bed 5; also at Beds 8 and 9, but which are not characterized by shell beds.
- FI level, corresponding to Bed 13, including several fish teeth, *Ditrupa*, solitary corals, *Nummulites*, oysters, and *Turritellids*.

- Fil level, a broader interval rich in bivalves and containing also *Nummulites*.
- FX level, or "stonebed X" of authors; in lower part, carbonatic coquina with several *Nummulites*, bivalves and gastropods; in the upper part, a silicified sandstone, molluscs are only recognized as "phantoms" (voids).

Sequence Stratigraphic Interpretation

VAN WAGONER et al. (1990) have presented a practical system for distinguishing various types/sizes of stratal units. In decreasing hierarchic order they have been defined exhaustively: (a) sequence, (b) parasequence set, (c) parasequence, (d) bed set, (e) bed, and - occasionally - (f) laminaset, and (g) lamina. This terminology can partly be applied to the stratal units recognized in the Ampe section.

According to definitions by VAN WAGONER et al. (op. cit.) sequence boundaries (defining the base of third order cycles) correspond to levels of clear emergence and subaerial exposure, whereas parasequence sets, etc., i.e., the somewhat smaller upward shoaling cycles, are generally bound by less important hiatuses.

In the Ampe section a clear sequence boundary (SB) occurs at the (strongly silicified) top of stonebed X, but a number of further important hiatuses can be observed lower down, such as one hiatus directly below the stonebed, one hiatus at the gullied base of Bed 5, several at the transition of the Egem Sand Member and the underlying Egemkapel Clay Member, and one further clear hiatus (SB) at the base of the Egemkapel Clay, overlying the gullied top of the Kortemark Silt.

According to the terminology by VAN WAGONER et al. (op. cit.) the Egem Sand Member discussed above and Egemkapel Clay Member may together form a single sequence (or third order cycle), but this can be subdivided in parasequences corresponding to the two members.

In the Egem Sand Member some 25 beds have been distinguished by STEURBAUT (1987), which may be grouped to eight bed sets, roughly corresponding to the TC units (transgressive cycles of Figure 6). These transgressive cycles (of the order of bed sets) are characterized by the "planktic frequency pulses" discussed above (Figure

6, left) and the similarly evolving clay/sand curve of the "granulometric" cycles (Figure 6, right).

The most important "major flooding surface" of the section occurs at levels 21-22 (Beds 6-8), as characterised by very abundant planktic assemblages, but several further important flooding surfaces occur, e.g., at levels 11 (Bed 1) and 28 (Bed 16), and each of the eight TC units forms a separate smaller flooding surface.

Of course, this subdivision of the "Egemkapel Clay/Egem Sand complex" into eight bed sets (TC units) is still to be considered as a first approximation; a closer sampling of the Ampe section would probably show that also the different beds (i.e., most of the units of STEURBAUT 1987) can be recognized as separate thinner microfaunal / granulometric cycles.

Discussion of Some of the Suggested Correlations in Belgium

The Egem Sands Member of the Ampe quarry can be well correlated with its lateral equivalent studied in the temporary outcrop of the sluice of Merelbeke at the south of Ghent (MOORKENS et al. 1967). This clayey glauconitic sand was also rich in micro- and megafossils, with assemblages strongly resembling those of the Ampe quarry. In addition, a consolidated (but more carbonate cemented) layer occurred in the middle of the section at Merelbeke, which was rich in (generally less well preserved) megafossils. DHONDT (in MOORKENS et al. 1967, p. 218) listed and discussed several mollusc taxa (14 gastropods, 9 bivalves, and a single *Nautilus*) mainly collected from the shell bed.

The planktic foraminifera of that section were later reviewed and updated by MOORKENS (1968) and WILLEMS (1980), and indicate that the P 7 biochron is present (including *Muricoglobigerina aquiensis* up to level 105 (MOORKENS et al. 1967, Figure 1 and Table 1), possibly overlain by some 2m belonging to the P8 biochron.

From dinocyst data (DE CONINCK 1965, and - in MOORKENS et al. 1967), the age of the Merelbeke sluice section can be assessed as *Kisselovia chlathrata* Zone, thus older

than the *Areosphaeridium diktyoplokos* Zone, the marker of which was missing in that section.

Following the lithostratigraphic scheme at that time, as given by KAASSOETER (1961), the Merelbeke sluice section was originally erroneously equated with the Mons-en-Pévèle Sands Member also by MOORKENS et al. (1967). Presently, we know that it can be equated with the Egem Sand Member, and it is thus the lateral equivalent of the Ampe section at Egem.

The correlation of the Ampe section with that of the Mont Panisel section is much more difficult. The lower part of the latter section, as observed in the 151E340 borehole at Bois-la-Haut, belongs to the Mons-en-Pévèle Sand Member, and its age is NP 11 (subzones I-IIIb), according to the calcareous nannoplankton (STEURBAUT & KING 1993). This is in agreement with the rich planktic foraminifera assemblages indicating the P6b biochron, since *Guembelitra triseriata* and *Pseudohastigerina wilcoxensis* are missing in these assemblages (HOOGBERGHS 1992). This section is thus definitely much older than that of the Egem Sands Member, but, unfortunately, the thin overlying Bois-la-Haut Sand Member is entirely decalcified, and has not well been age dated by dinocysts thus far. Its suggested correlation with stonebed X of the Ampe section by STEURBAUT & KING (1994, p. 195) therefore remains tentative.

However, FORÉ (1997, p. 96, Figure 2), after introducing the Hooglede Sand bed as a new stratal unit, (and known to occur as a sandy intercalation between the Merelbeke Clay Member, and the overlying Pittem Clay Member) has suggested the correlation of the stonebed X layer of the Ampe section with the newly erected Hooglede Sand bed. In our opinion this correlation is erroneous, as we consider stonebed X (latest NP 12, STEURBAUT 1987, *A. diktyoplokos* Zone acc. to DE CONINCK & NOLF 1979) to be considerably older than the Hooglede Sand bed.

Palaeoclimatic History

The micro- and megafossil content of the Egem Sand Member is very rich in the Ampe section of Egem, but even more biota have been found in its lateral equivalent, (previously called Ledeborg Sand Member, by GEETS 1979) as sampled in the Merelbeke

sluice section (MOORIKENS et al. 1967), where they contain two specimens of palm fructifications, *Nipadites burtini* (determination of J. DE HEINZELIN, in MOORIKENS et al. 1967, p. 205), i.e., fruits of a mangrove Nipa palm, a plant family presently restricted to the tropical realm (ROCHE 1991, p. 377, Figures 3-5). Some fruits of the same group have also been found in the Ampe section at Egem (Mr. F. van Nieulande, pers. comm. 2001). From the Merelbeke sluice section WILLEMS & GENOT (1984) have also described some dasycladacean algae (not found so far in the Ampe section at Egem), including *Terquemella* sp.; the present-day areal distribution of this group of calcareous algae and primarily that of the Dasycladaceans is known to be restricted to the tropical / sub-tropical realm.

Hence, at the transition from Middle to Late Ypresian times, i.e., approx. 51 Ma years ago (according to the timescale of BERGGREN et al. 1995), the Ypresian type area must probably have experienced a (sub-) tropical climate.

The above-mentioned palaeobotanic data on palms and dasycladacean algae, together with the general aspect of the microfossils discussed above (warm-water ostracod assemblage and renewed (BNZ1b) influx of Nummulites in the southern North Sea Basin), suggest that at the transition from Middle to Late Ypresian times, a warm event must have occurred in Belgium. During that phase it must have been even somewhat warmer than during other periods of the Ypresian, as observed in several under- and overlying strata, although these latter sediments have virtually been deposited at the same latitude as those of the Egem Sands. Most likely, this phase corresponds to a global thermal event, or it may have been linked to warm sea currents derived from the south.

However, when comparing the Eocene palaeoclimate with that of the present day in Belgium, one has to bear in mind that this area was located considerably more to the south during the Eocene (according to the maps of DECOURT et al. 1993 the palaeo-latitude of that area lay some 8° nearer to the equator) and this may in addition explain the considerably warmer climate occurring in NW Europe at that time.

Summary

The outcrop section of the Ampe sand and clay pit at Egem, in NW Belgium, presently shows a lithocolumn of some 30m, consisting of rapidly alternating clayey and sandy facies.

Lithostratigraphically this siliciclastic succession largely belongs to the middle to upper part of the leper Group (i.e. classical Ypresian section as existing in the type area of the stage). From the base of the section upwards, the Tiel Formation is represented by part of the following members: Kortemark Silt, Egemkapel Clay, and Egem Sand; the overlying coquina "stonebed" is presently not well assessed lithostratigraphically. An important hiatus occurs at the base of the overlying Gentbrugge Formation (previously called Ghent Formation), and which is here represented by the Pittem Clay Member.

The microfauna (foraminifera, ostracoda, siliceous microfossils) has been analysed in 40 samples, and results are presented in various range charts juxtaposed to the Ampe lithocolumn. Hence these data become directly comparable with previously published biostratigraphic age datings, such as that based on dinocysts and calcareous nannoplankton. Moreover, previously published data of the rich megafossil (primarily molluscs and fish teeth) content are also juxtaposed to the section, and together with the observed frequency and diversity variations of the microfossil assemblages and the sedimentological characteristics of the deposits, they permit an assessment of a high-resolution regional sequence stratigraphy, in which a number of bed sets correspond with transgressive (4th to 5th order) cycles.

The planktic foraminifera are well represented in most intervals. They indicate the NSP 5 of the North Sea biozonation by KIVA (1983) and the P7 - P8 of the global zonation by BLOW (1979). The local appearance of *Guembelitra triseriata* and *Pseudohastigerina wilcoxensis* in the Egemkapel Clay correlates well with the regional datum in other outcrop and borehole sections of Belgium. The abundance curve of planktic foraminifera appears to form the most appropriate tool for recognizing transgressive cycles.

Benthic foraminiferal assemblages are typical for open marine shallow shelf set-

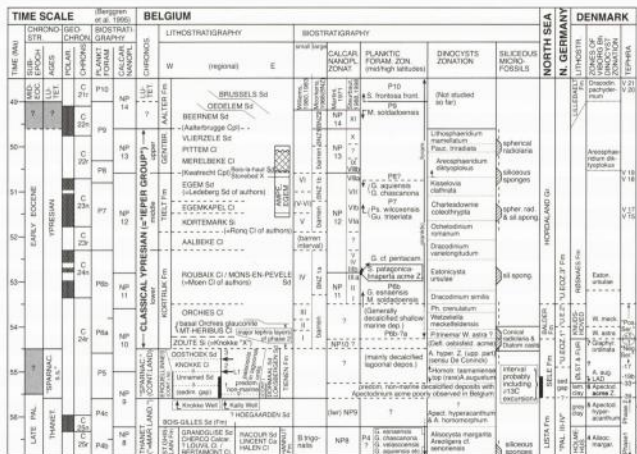


Figure 7: Present "state of the art" of the integrated litho-, bio-, and event stratigraphy of the classical Ypresian section (as corresponding to the Ieper Group) of the Belgian Basin, as juxtaposed to the time scale of BERGGREN et al. 1995 (partly from MOORKENS et al. 2000, modified and completed).

tings. Although all species observed are long-ranging, the dominance of several taxa permits the recognition of the "B.F. association Zones" V and VI of WILLEM'S (1980, 1982) regional benthic foraminiferal zonation. The diversity variations of the successive benthic assemblages also appear to reflect that of the above-mentioned planktic abundance curve, and thus form an additional tool for assessing regional / local sequence stratigraphy.

The ostracods have been observed at ten different levels of the section, all from the Egem Sand and Pitterm Clay members. The eight taxa recognized suggest an Early (to Middle) Eocene association, which is palaeoecologically indicative of a warm shallow sea.

The siliceous microfossils (sponge spicules and radiolaria) occur at 17 different levels, but they are primarily concentrated in two intervals: at the base of the Egemkapel Clay and at the top of the Egem Sands and overlying the "stonebed X". These rich siliceous microfossil assemblages are indicative of waters which were relatively rich in silica (i.e., less under-saturated than in average sea water) during sedimentation. Although the silica content of sea water may vary for various reasons, it appears that in many cases volcanic events (and

the eolian or sea-current distribution of the ashes) may have played an important role in supplying silica to the surface waters. One observes some timely coincidence of "siliceous biofacies" with major volcanic events of the northern Atlantic. In addition, the "silica episodes" observed in the Ampe section appear to correlate well with several tephra layers of Denmark.

A bio-, litho- and sequence stratigraphic interpretation is presented for the Ampe section, and the newly acquired data are integrated in the updated scheme for the Ypresian stage as known in the Belgian Basin.

Acknowledgements

We would like to extend our sincere thanks to Mrs. R. Brepoels, (earth science department of the Catholic University of Leuven), who has carried out the granulometry and calcimetry analyses of the here discussed Ampe / Egem samples. The scanning micrographs of the microfossils figured in Plates I - VI have been prepared at the Royal Belgian Institute of Natural Sciences, Brussels. We are also gratefully indebted to Mrs. A. Lingott, "Grafik.Lingott", Essen, for preparing the illustrations.

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Plate 1: Planktic foraminifera of the Ampe clay pit at Egem

- Figure 1: *Chiloguembelina martini* (PUPERS 1933), Egem 1; x175
- Figure 2: *Chiloguembelina martini* (PUPERS 1933), Egem 1; x265
- Figure 3: *Guembelitra triseriata* (TERQUEM 1882), Egem 19; x190
- Figure 4: *Guembelitra triseriata* (TERQUEM 1882), Egem 19; x255
- Figure 5: *Globorotalia (Globorotalia) elongata* GLAESSNER 1937, Egem 21; x145
- Figure 6: *Globorotalia (Turborotalia) chapmanni* PARR 1938, Egem 11; x150
- Figure 7: *Globorotalia (Turborotalia) chapmanni* PARR 1938, Egem 19; x180
- Figure 8: *Globorotalia (Turborotalia) pseudodoimitata* BLOW 1979, Egem 11; x165
- Figure 9: *Globorotalia (Turborotalia) praecentralis* BLOW 1979, Egem 11; x145
- Figure 10: *Globorotalia (Turborotalia) praecentralis* BLOW 1979, Egem 13; x245
- Figure 11: *Globorotalia (Acarinina) pentacamerata* SUBBOTINA 1947, Egem 13; x200
- Figure 12: *Globorotalia (Acarinina) pentacamerata* SUBBOTINA 1947, Egem 11; x160
- Figure 13: *Globorotalia (Acarinina) pseudotopilensis* SUBBOTINA 1947, Egem 11; x150
- Figure 14: *Globorotalia (Acarinina) wilcoxensis* CUSHMAN & PONTON 1932, Egem 14; x220
- Figure 15: *Globorotalia (Acarinina) wilcoxensis* CUSHMAN & PONTON 1932, Egem 15; x170
- Figure 16: *Globorotalia (Acarinina) acarinata* SUBBOTINA 1953, Egem 21; x150

PL. I



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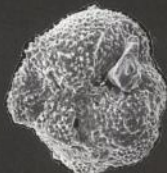
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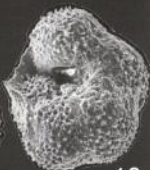
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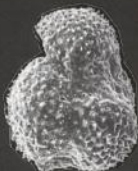
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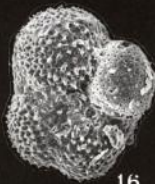
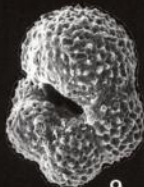
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Plate II: Planktic foraminifera of the Ampe clay pit at Egem

- Figure 1: *Globorotalia (Acarinina) acarinata* (SUBBOTINA 1953, Egem 21; x155)
 Figure 2: *Muricoglobigerina aquiensis* (LOEBLICH & TAPPAN 1957), Egem 10; x120
 Figure 3: *Muricoglobigerina aquiensis* (LOEBLICH & TAPPAN 1957), Egem 10; x160
 Figure 4: *Muricoglobigerina chascanona* (LOEBLICH & TAPPAN 1957), Egem 28; x170
 Figure 5: *Muricoglobigerina chascanona* (LOEBLICH & TAPPAN 1957), Egem 28; x190
 Figure 6: *Muricoglobigerina esnehensis* (NAKKADY 1950), Egem 9; x120
 Figure 7: *Muricoglobigerina esnehensis* (NAKKADY 1950), Egem 10; x110
 Figure 8: *Muricoglobigerina soldadoensis* (BRÖNNMANN 1952), Egem 11; x175
 Figure 9: *Muricoglobigerina soldadoensis* (BRÖNNMANN 1952), Egem 12; x190
 Figure 10: *Subbotina hornibrooki finlayi* (BRÖNNMANN 1952), Egem 28; x195
 Figure 11: *Subbotina hornibrooki hornibrooki* (BRÖNNMANN 1952), Egem 10; x170
 Figure 12: *Subbotina hornibrooki hornibrooki* (BRÖNNMANN 1952), Egem 12; x190
 Figure 13: *Pseudohastigerina wilcoxensis* (CUSHMAN & PONTON 1932), Egem 28; x175
 Figure 14: *Pseudohastigerina wilcoxensis* (CUSHMAN & PONTON 1932), Egem 1; x270
 Figure 15: *Globigerinita taroubaensis* (BRÖNNMANN 1952), Egem 3; x240
 Figure 16: *Globigerinita taroubaensis* (BRÖNNMANN 1952), Egem 12; x200

PL. II



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Plate III: Benthic foraminifera of the Ampe clay pit at Egem

- Figure 1: *Spiroplectammina adamsi* LAUCKER 1935, Egem 3; x190
- Figure 2: *Spiroplectammina deperdita* (ORBIGNY 1846), Egem 3; x170
- Figure 3: *Spiroplectammina plummerae* CUSHMAN 1948, Egem 3; x160
- Figure 4: *Spiroplectammina* sp., Egem 3; x165
- Figure 5: *Bolivina anglica* CUSHMAN 1936, Egem 3; x170
- Figure 6: *Bolivina brabantica* KAASSCHETER 1961, Egem 23; x210
- Figure 7: *Bolivina crenulata* CUSHMAN 1936, Egem 3; x190
- Figure 8: *Bullimina parisiensis* KAASSCHETER 1961, Egem 3; x190
- Figure 9: *Uvigerina garzaensis* CUSHMAN & SEIGUS 1936, Egem 5; x185
- Figure 10: *Trifarina muralis* (TÉROUJEM 1882), Egem 19; x210
- Figure 11: *Trifarina wilcoxensis* (CUSHMAN & PONTON 1932), Egem 19; x280
- Figure 12: *Cancris subconica* (TÉROUJEM 1882), Egem 11; x123

PL. III



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- Plate IV: Benthic foraminifera of the Ampe clay pit at Egem
- Figure 1: *Asterigerina guerrai* (BERMÚDEZ 1952), Egem 19; x255
- Figure 2: *Elphidium hiltermanni* HAGEN 1952, Egem 19; x195
- Figure 3: *Protelphidium sublaevum* (TEN DAM 1944), Egem 22; x175
- Figure 4: *Eponides gracillima* TEN DAM 1944, Egem 3; x235
- Figure 5: *Eponides lunata* BROTZEN 1948, Egem 3; x185
- Figure 6: *Nonionella spissa* CUSHMAN 1931, Egem 3; x210
- Figure 7: *Florilus communis* (d'ORBIGNY 1846), Egem 3; x190
- Figure 8: *Bibicoides acutimargo* (TEN DAM 1944), frontal view, Egem 3; x123
- Figure 9: *Bibicoides acutimargo* (TEN DAM 1944), spiral side, Egem 3; x100

PL. IV



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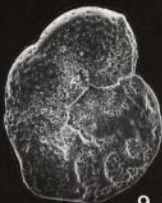
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Plate V: Ostracoda from the Ampe clay pit at Egem

- Figure 1: *Cytheretta* sp. cf. *C. decipiens* KEU 1957, right valve, Egem 37; x120
- Figure 2: *Schizocythere appendiculata* THIESEL 1950, left valve, Egem 37; x190
- Figure 3-4: *Paracytheridea gradata* (BOSQUET 1852)
- Figure 3: left valve; Figure 4: right valve, Egem 37; x140
- Figure 5: *Cuneocythere (Monsmirabilia)* sp., carapace, left valve view, Egem 25; x145
- Figures 6-7: *Leguminocythereis pustulosa* (ROEMER 1838)
- Figure 6, left valve;
- Figure 7, right valve, Egem 35; x 85
- Figure 8: *Horrficiella aculeate* (BOSQUET 1852), left valve, Egem 35; x 95
- Figure 9: *Cyamocytheridea hebertiana* (BOSQUET 1852), right valve, Egem 35; x160

PL.V



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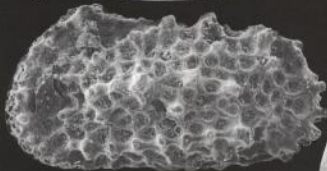
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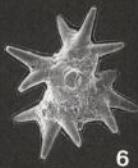
*Plate VI: Siliceous microfossils of the Ampe
clay pit at Egem*

Figures 1-6: *Porifera* (various "form taxa" of
silica sponge spicules), Egem 40; x50

Figures 7-8: *Radiolaria*

Figure 7: *Eusyringium fistuligerum*
(EISENBERG), Egem 40; x285

Figure 8: *Eusyringium lagena* (EISENBERG),
Egem 40; x360



Palaeoenvironments: A Multidisciplinary Approach

► Gitte V. Laursen

Abstract

► Iain Prince

The integration of seismic, sedimentological, palynological, and micropalaeontological data has permitted a palaeoenvironmental model for the Palaeogene in the North Sea area to be completed. For the palaeontological part this was achieved by plotting various environmental indices along dip profiles. As this study was undertaken on the basis of a previously existing dataset comprising samples analysed by various contractors and from drillings sunk by different contractors, the varying quality of the data was a general problem. Nevertheless, being aware of this fact, common features of the various dip lines were able to be worked out, thus permitting dip lines to be correlated and areas of different palaeoenvironment to be mapped. The result was then compared to the sedimentology and seismic dataset, and integrated maps were constructed; ultimately a consistent interdisciplinary palaeoenvironmental model was built.

Kurzfassung

Durch die Integration seismischer, sedimentologischer, palynologischer und mikropaläontologischer Daten konnte ein Paläoenviroment-Modell für das Paläogen des Nordsee Beckens vervollständigt werden. Aus paläontologischer Sicht wurde dies durch das Plotten von verschiedenen Environment Indices entlang einfallender Profillinien erreicht. Die Studie beruht dabei auf einer Auswertung bereits existierender Datensätze. Dabei war zu beachten, dass die Proben z.T. von unterschiedlichen Bearbeitern ausgewertet wurden und aus Bohrungen stammen, die z.T. von unterschiedlichen Gesellschaften abgeteuft wurden, wodurch die Qualität der Rohdaten sehr unterschiedlich war. Eingedenk dieser Tatsache konnten dennoch Gemeinsamkeiten der Entwicklung der Indices entlang der verschiedenen Einfalllinien festgestellt werden. Dadurch konnten diese korreliert und kartiert werden. Die Ergebnisse wurden mit den sedimentologischen und seismischen Daten verglichen und integrierte

Karten konstruiert. Auf diese Weise wurde ein konsistentes, interdisziplinäres Paläoenviroment-Modell entwickelt.

Keywords

Biostratigraphy, micropalaeontology, palaeoenvironmental model, Palaeogene, North Sea

Introduction

This palaeoenvironmental study was initiated following a discussion on the location of the shelf within the Palaeogene of the Norwegian North Sea. The aim was to obtain a solid palaeoenvironmental framework by integrating the results from sedimentological, seismic and biostratigraphical analyses. Attempts were made to explain any contradictions between the various disciplines.

Material

Eight profiles consisting of a total of 48 wells were utilised in this study; six profiles in the dip direction to illustrate the palaeontological changes progressing from shelf to basin floor; one profile across the basin from shelf to shelf for comparison, and one profile in the presumed strike direction.

The study was based on available digital data. Sampling effects, caving, counting methods, contractors, or even other ecological factors often camouflaged the information required. Therefore, to obtain as consistent a dataset as possible, most of the wells selected were analysed by a single contractor; however, in order to achieve a complete dataset, 6 wells analysed by different contractors were also included. Care was taken before suggesting that these latter wells were significantly different. A few wells lacked palynological data but had micropalaeontological data, and vice versa. Care was taken to include substitute wells for those on the profiles.

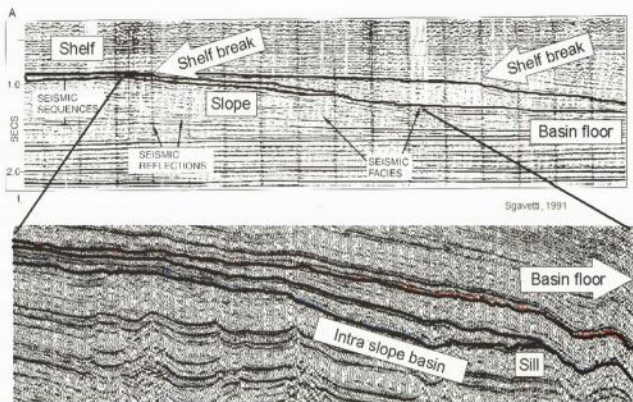


Figure 1: Example of seismic lines illustrating a slope setting with a silled intraslope basin (partly after SGAVETTI 1991)

Methods

Seismic Dataset

Flooding surfaces are considered to be timelines. Five flooding surfaces were traced from the Palaeocene to Early Eocene on the basis of seismic data. They were initially correlated and calibrated with biostratigraphical data to ensure consistent interpretation of the same surface. In general, external forms were examined from the seismic point of view. External forms are based on the 3-dimensional shape of the facies package observed on intersecting seismic profiles. Figure 1 shows an example of a seismic line illustrating a slope setting with a silled intraslope basin.

Palynology

Palynology is the study of organic microfossils, including both marine and non-marine components. The marine component consists of dinoflagellate cysts; the non-marine component consists of pollen, spores and algae. Thus, palaeoenvironmental reconstructions utilising palynology can, in theory, record both oceanographic changes (i.e. circulation, upwelling) and relative changes in palaeobathymetry (proximity to coastline, onshore/offshore trends).

Dinoflagellate Cysts (Dinocysts)

Paratabulation studies have identified three main groups of dinocysts. These are peridinoïd, gonyaulacoid and ceratioid types; the latter type is not observed within Tertiary sediments. In simple terms, these types represent a number of different environments:

- peridinoïds represent nutrient-rich and more nearshore environments
- gonyaulacoids represent more oceanic environments, although some species show marked adaptation to nearshore environments.

Gonyaulacacean Ratio (HARLAND 1973) (Gony in Fig. 2)

This is the ratio of the number of gonyaulacoid species divided by the number of peridinoïd species (i.e. gonyaulacoid diversity/peridinoïd diversity). Data from modern studies suggest that this ratio varies from 0.5-1.8 in nearshore to pelagic facies. HARLAND (1973) suggested that this ratio reflects salinity changes, with increasing salinity the environment becomes more open marine.

P/G Ratio (BLIAK 1984, POWELL et al. 1990, MAO & MOHR 1992) (P/G in Fig. 2)

This is based upon the number of peridinoïd specimens divided by the number of gonyaulacoid specimens (i.e. peridinoïd abundance/gonyaulacoid abundance). POWELL et al. (1990) show that this ratio varies

from 10-0.16 in Peruvian slope sediments and is positively correlated with upwelling intensity and deposition of laminated amorphous organic matter-rich sediments.

Dinocyst Diversity (Dino div. in Fig. 2)

WALL et al. (1977) suggested that dinocyst diversity increases offshore, but that variability in diversity increases onshore and is greatest in estuarine assemblages, which may show high dominance.

BUJAK & WILLIAMS (1979) compared dinocyst diversity with the sea-level curve of HAO et al. (1987) and showed strong linear regression between generic dinocyst diversity and either long-term sea levels or maxima on the short-term curve. Therefore, more marine, more offshore and more transgressive facies often show increasing diversity and lower dominance. Hence, dinocyst diversity can be used to indicate transgressive/regressive trends (TYSON 1995, GOODMAN 1979, MUTTERLOSE & HARDING 1987, LISTER & BATTEN 1988, PRAUSS 1989, SMELOR & LEEVELD 1989, HABIB et al. 1992).

% Peridinoids: % *D. oebisfeldensis*, % *Apectodinium* & % *P. pyrophorum* (e.g. % Aspects in Fig. 2)

BUJAK & BRINKHUIS (1998) suggested that the motile stage of the genus *Apectodinium* fed on diatoms. This led to blooms of *Apectodinium* and hence to an increase in the number of cysts deposited. It is reasonable to suggest that if large numbers of diatoms were present, large numbers of *Apectodinium* spp. should also have been present. Diatoms are most common in association with upwelling. Large numbers of peridinoids, suggested to be the result of upwelling (POWELL et al. 1990), may in this case also be caused by the increasing availability of diatoms as a food-stuff. The area of most intense upwelling is believed to be located at or just below the shelf break. Therefore, it should be possible to map the location of the shelf break over time at different flooding surfaces. Further evidence for high percentages of *Apectodinium* spp., representing more marine, nutrient-rich environments, is provided by STEURBAUT et al. (2000), who stated that low abundances (2-5 %) of this form represent shallow lagoonal parts of the North Sea. Unfortunately, blooms of *Apectodinium* spp. are only found close to the Palaeocene-Eocene boundary. However, increases or blooms of other peridinoid species and diatoms are also observed at other flooding surfaces.

These peridinoids include *D. oebisfeldensis* and *P. pyrophorum*. BUJAK & BRINKHUIS (1998) suggest that the former species, which dominates assemblages in the early Eocene-Ypresian, occupied a similar niche, having replaced *Apectodinium* spp. at the onset of a less restricted basin with cooler surface water.

% *Spiniferites* (% *Spinifs* in Fig. 2)

This genus first appears in the Mesozoic and extends to the present day. Therefore, studies on modern dinoflagellates can be used as a model for this genus' distribution. DAVEY & ROGERS (1975), studying sediments off the South African coast, noted that this form has a bimodal distribution, one peak occurring on the shelf and another at the break in slope. WALL et al. (1977) noted a similar phenomenon with high percentages of *Spiniferites* spp. occurring on the shelf, abundances dropping over the shelf break but increasing offshore (transect 1 & 2 Middle Atlantic). These authors also noted that some species of *Spiniferites* tended toward cosmopolitanism whilst others were strongly related to estuarine sediments.

Spores, Pollen and Algae

Pollen and spores are useful within the marine environment as increasing numbers can indicate closer proximity to land. Hydro-dynamically, spores and pollen show settling rates which are comparable to fine quartz silt (MULLER 1959). As a result, pollen influx is often strongly associated with the influx of silt (CLARK 1986), the total suspended sediment load and river discharge (MATSUSHITA 1985).

Bisaccate pollen are produced in vast numbers and are highly resistant to corrosion. They may also travel long distances both in the air, and on water. Thus, these forms do not show a clear onshore/offshore trend. It is also possible that they may represent modern contamination of slides. As a result of the above, bisaccates were removed from all of the calculations.

Sporomorph Ratio: Dinocyst/Pollen-Spore Ratios (Dino/Spore in Fig. 2)

This ratio is a measure of dinocyst abundance divided by spore and pollen abundance. Generally, this ratio decreases onshore and is especially depressed in areas near deltas. However, one must use this ratio with care, as it depends upon both dinocysts and spore/pollen (i.e. they are dependent upon each other). Hence it must

be used in conjunction with other values such as abundance and diversity.

Algae (ALPR in Fig. 2)

Many authors have noted the strong correlation between the abundance of prasynophyte algae and the occurrence of marine (shelf and oceanic) organic-rich, finely laminated sediments deposited under dysoxic to anoxic conditions (TYSON 1995). It has also been suggested that prasynophytes have an association or affinity with cold water (PRAUSS & RIEDEL 1989, PENIGUEL et al. 1989). It would be expected, therefore, that prasynophytes would be most abundant in a basinal to slope setting, decreasing over the slope break and onto the shelf.

TAPPAN (1980) referred to algae as "disaster species", as they are commonly found after major planktonic extinction events and are most abundant in the absence of other phytoplankton such as dinocysts. Within the interval studied, prasynophycean algae are most commonly noted around the Palaeocene-Eocene boundary, where dinocyst diversity is generally lower than in the sections below, with the genus *Apectodinium* usually dominating. This time is associated by many authors to be a time of increased restriction within the North Sea, leading to anoxic/dysoxic bottom conditions and an increased burial of AOM. Hence algae, where present, should be useful indicators of the zone of maximum dysoxia/anoxia.

Micropalaeontology

Several different microfossil groups, chiefly foraminifera, but also diatoms and radiolaria, provided data for palaeoenvironmental reconstructions based on micropalaeontological evidence. With the exception of diatoms, these groups are exclusively marine. Influxes of macrofossils (bivalves and gastropods) as well as sponge spicules have been used to identify marginal marine environments.

Foraminifera

Benthic Foraminifera

A number of environmental settings can be deduced from the composition of benthic assemblages. The benthic component provides information about bottom conditions such as temperature, salinity, acidity, oxygen availability, the degree of calcium carbonate saturation and dissolution. Although water depth is not considered to be a primary factor for the distribution of benthic foraminifera, the above-mentioned

factors help to infer a broad depth estimation or at least a basin configuration (cf. also INGLE 1980).

Calcareous Benthic Foraminifera

The following general ideas have been used to infer basin morphology (INGLE 1980):

- A low-diversity association, dominated by macrofossils and sponge spicules with porcelaneous species, is present on the inner shelf.
- Diverse hyaline fauna is found on the outer shelf.
- Oxygenated bottom environment results in calcareous benthic foraminifera dominate the benthic fauna (BRASIER 1980, MURRAY 1991).

The "% of calcareous benthic fauna" is calculated to estimate the amount of calcareous foraminifera. Most calculations are sensitive to altering sample size. Unfortunately, it has only been in recent years that volumetric analysis has been used as a standard by Statoil for the Tertiary. Therefore, it may be difficult, and even unwise, to attempt to infer any palaeoecological information from the dataset available.

Agglutinated Foraminifera

Common agglutinated forms are present in the otherwise calcareous-dominated fauna on the inner shelf (INGLE 1980), and on the base of the slope the numbers of agglutinated foraminifera again increase.

The influx of coarse-grained tubular foraminifera in low-diversity fauna (called "Flysch-type") is interpreted as upper bathyal (slope, depth exceeding 200m). To identify the point at which the agglutinating foraminifera begin to dominate the benthic assemblage, the "% of agglutinated benthic fauna" has been calculated.

The quantity of available calcium carbonate is reduced in cool waters, the presence of agglutinated foraminifera, radiolaria and sponge spicules can, therefore, point to low water temperatures (UJETZ 1996).

Faunal composition can suggest whether or not the area in question is a turbidite area: fauna consisting of simple forms with low diversity and a high dominance of primarily pioneer species points to proximal inter-turbiditic settings. Fauna of complex forms with high diversity and low dominance, on the other hand, points to a hemipelagic environment (PAYNE et al. 1999).

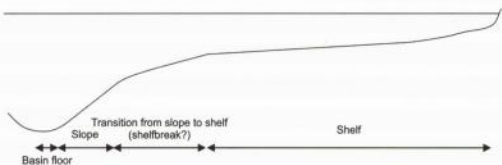
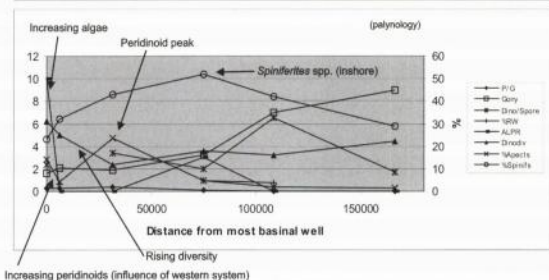
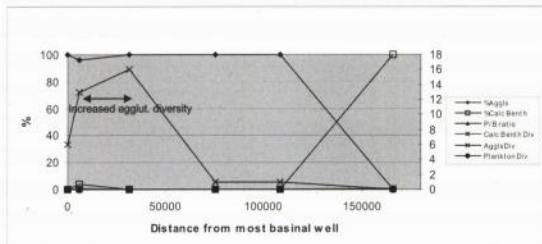
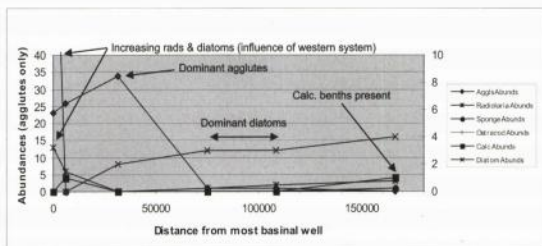


Figure 2: Example of fossil variability and suggested locations for fossils on the shelf profile

Planktonic Foraminifera

Open marine environments with good water circulation result in assemblages rich in planktonic foraminifera. On the outer shelf to upper slope planktonic foraminifera constitute 10-80 % of total fauna (called the P/B ratio) (INGLE 1980). Simple globular forms are indicative of cold waters, whereas keels and large spines point to warmer waters.

Diatoms

Diatoms require light and are therefore restricted to the photic zone (<200m) during life and are abundant in regions of oceanic upwelling caused by current divergence (BRASIER 1980). Diatoms may be related to radiolarian floods. The presence of diatoms may also indicate a tranquil environment (KAMINSKI & SCHRODER 1987).

Radiolaria

Radiolarians prefer oceanic conditions, particularly just seaward of the shelf break, in regions in which divergent surface currents bring up nutrients from the depths and planktonic food is plentiful (BRASIER 1980, INGLE 1980).

Abundance and Diversity

The abundance and diversity of various microfossil groups may indicate different depositional settings. Generally, the higher the diversity, the better the living conditions. INGLE (1980, Fig. 7) summarises this; marked in his figure are environments/ events which were mapped for micropalaeontology.

On the outer shelf, calcareous benthic foraminifera dominate faunas; further basinward, upwelling occurs at the shelf break and abundances of diatoms and radiolarians increase, peaking at this point. On the slope, planktonic foraminifera constitute a high proportion of foraminiferal faunas. At the base of the slope, agglutinated foraminifera become common to abundant. The abundance and diversity of these various microfossil groups were extracted from the data set.

Spreadsheet Construction

For each well, a spreadsheet was constructed to calculate the above-mentioned indices for the palynology and micropalaeontology of each sample. The values calculated at a given flooding surface were then extracted from all the wells into a new spreadsheet. Whilst extracting sample

data, it was often found that the flooding surface lay between two samples. In this case the value was interpolated between the samples.

Downdip Profiles

In order to ascertain onshore/offshore changes within biostratigraphic assemblages, a number of downdip profiles were constructed (Fig. 2) from the spreadsheets discussed above. Six of these profiles were constructed extending from the wells closest to the palaeocoastline to the basin floor. One profile was completed extending from one side of the North Sea Basin to the other side. The curves obtained from the spreadsheets were then correlated to each other and subsequently mapped.

Maps

Interpreted basin morphology maps were constructed for various disciplines: seismology, palynology and micropalaeontology. These maps were then combined into a single map of the basin morphology for each flooding surface.¹

Results

Profiles

Distribution patterns were found to be meaningful when examined using a number of downdip profiles, as opposed to distribution maps. It was found that, by extending the downdip profiles across the basin and up the slope on the other side, the interpretation of environmental variables was able to be better understood. By examining all the profiles for the different maximum flooding surfaces, it was observed that the most reliable palynological information was obtained by correlating peridinooid peaks (% *P. pyrophorum*, % *Apectodinium* spp. and % *D. oebisfeldensis*), in *Spiniferites* spp. and in diversity. An example of the location of these events, with respect to a theoretical basin profile, is shown in Figure 2 together with the micropalaeontological events.

The P/G and G/P ratios proved to be very variable and showed no trends. It is thought that this results from the selection of species included in the ratios. In this study, all peridinooids were included. This included widely ranging forms which probably exhibit more cosmopolitan distri-

butions and thus influence the ratios. In addition, caved peridinooid specimens will also affect the ratio (this does not affect % *D. oebisfeldensis*, % *Apectodinium* spp. and % *P. pyrophorum* as these forms have their last occurrences/last abundant occurrences at or near the relevant flooding surface).

The sporomorph ratio also showed unusual data. This ratio would be expected to decrease onshore (fewer dinoflagellates and increasing numbers of pollen and spores), but no such trend was able to be identified. This is probably because samples are usually counted primarily for dinoflagellates, as pollen and spores are generally of limited use within Tertiary biostratigraphy. Hence, pollen and spores are usually only counted up to maximum abundances of between 25 and 50, thus obscuring any large-scale fluctuations.

By examining all the profiles for the different maximum flooding surfaces it was observed that the most reliable micropalaeontological information, even though microfossil content is extremely low, was seen in the distribution pattern of the higher groups: agglutinated and planktonic foraminifera, radiolaria and diatoms. Ostracods were too rare for a meaningful interpretation.

Sponge spicules were not plotted on the maps, since they showed no trends. As sponge spicules are made of silica, they are resistant to corrosion and can be transported far out in the basin without being destroyed. This may explain their erratic distribution.

Planktonic foraminifera in the North Sea Basin do not react in the same way as planktonic foraminifera from the California example (INGLE 1980). In the North Sea planktonic foraminifera seem to be concentrated in the middle of the basin, which may be caused by the fact that most planktonic foraminifera need a water column of at least 200m for their daily cycles.

The distribution of radiolaria at the base Balder Formation flooding surface is rather curious, as the radiolaria seem to indicate slightly more nearshore conditions than the diatoms do. At all other times it seems to be the other way around.

A standardised processing and counting method (e.g. volumetric) could give more

consistent abundance information, which could then be mapped.

Maps

The shelf breaks interpreted from the two biostratigraphic disciplines were in general agreement with each other. When biostratigraphy and seismic data were compared there was a tendency for biostratigraphic data to interpret the shelf break further out in the basin than seismic data does. This may be understood as an indication that the location of the "upwelling situation" actually occurs on the basinward side of the shelf break, or perhaps that shelf indicators have been transported toward the basin.

Another interesting feature is that the interpretation of several shelf breaks from the biostratigraphical perspective usually outlines subbasins mapped by seismic studies.

Palaeoenvironmental Model

The proposed environmental model for fossil distributions is illustrated in Figure 3. On the shelf, calcareous benthic foraminifera dominate micropalaeontological assemblages. A peak in *Spiniferites* spp. is observed directly behind the shelf break. Within the study area, no wells were available which were either non-marine or close to the palaeoshoreline.

Peaks in peridinooids occur just below the shelf break and are associated with peaks in diatoms. This agrees with the findings by BUJAK & BRINKHUIS (1998) indicating that blooms of *Apectodinium* spp. (a peridinooid species) probably fed on blooms of diatoms. This has also been successfully applied to other blooms of peridinooid species within the study interval. Immediately offshore from these peaks, a peak in radiolaria has also been observed. Agglutinating foraminifera dominate benthic assemblages from the upper slope downwards. Within the deepest parts of the basin, dinocyst diversities peak, and their distribution shows a strong correlation with planktonic foraminifera (if the basin was deep and wide enough for the latter).

Also included in the proposed model are the responses of these events within an intraslope/intrashelf basin. It was noted that, in certain areas, the response to upwelling as recorded by palynological and

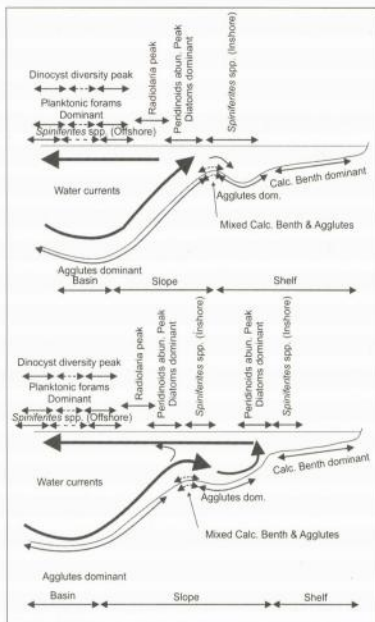


Figure 3: Proposed circulation patterns and microfossil response over an intra shelf basin (top) and a shelf/slope basin (bottom)

micropalaeontological events occurred over a broad area. Occasionally, within this wide region a deeper area is suggested, indicated by the presence of agglutinating foraminifera. It is suggested that the "increased nutrient events" (i.e. peridinioid dinoflagellates and diatoms) show peaks at both topographic highs. Agglutinating foraminifera increase with depth in the subbasins; calcareous benthic foraminifera would be more common on the topographic highs. Fossils would only respond to an intraslope basin if it was at a critical sea depth. For example, if an intraslope basin was located toward the base of slope, water depth would be too deep for calcareous benthic foraminifera to react and too deep for upwelling to occur.

Conclusions

The integration of palynological, micro-

palaeontological and seismic results has allowed a model of fossil distribution across the North Sea Basin in the Palaeogene to be proposed. The main conclusions are summarised below:

Calcareous benthic foraminifera dominate on the shelf. However, these also appear to be reworked out into the deeper basin. *Spiniferites* spp. show an abundance peak at or inshore from the shelf break. Peridinioids peak in abundance immediately offshore from the shelf break. Associated with these are peaks in diatoms. Radiolaria peak on the basinward side of the peaks in diatoms and usually below the peaks in peridinioid species. Agglutinated foraminifera dominate micropalaeontological assemblages from the upper slope downwards. If the basin is deep enough, planktonic foraminifera are most abundant in the most central parts of the basin. Dinocyst diversity shows two peaks, one around the zone of maximum upwelling and the other at the mid-point of the basin. However, in a sufficiently large basin/ocean, diversity would begin to decrease with increasing distance from shore.

The study also revealed that frequently used indices such as P/G ratios, gonyaulacacean ratios and sporomorph ratios are not valid on an industrial dataset. This may be the result of inconsistencies in counting methods for sporomorph ratios. For P/G and gonyaulacacean ratios, this is due to the fact that the technique is flawed. In the latter case, the basic theory is correct (some peridinioids bloom when upwelling occurs) but the forms reacting in this way must be identified.

The study further illustrated how palaeoenvironment interpretations can indicate palaeogeography and basinal changes through time. None of the disciplines used can give a "definite answer" on its own. Therefore, integration between the disciplines is very important.

Acknowledgements

This study was made possible through the work of the Statoil exploration group "Tertiary Central". In particular we would like to acknowledge geologist Bente Bakken for seismic interpretations and valuable discussions of basin morphology. The interpretations expressed in this article are the opinions of the authors.

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The *Bolboforma* Signal

A Distinct Level for Correlating Lower Oligocene Deposits (NP 22), the Melania Clay Formation of Northern Hesse (Hessian Depression) with the Middle Pechelbronn Formation of the Mainz Basin (Rhineland-Palatinate, Germany)

► **Thomas W. Griesemer**

This contribution is dedicated to my teacher in micropalaeontology, Professor Dr. Volker Sonne.

neue Beobachtung kann ein Korrelationsschema für die Melanienton-Formation von Borken mit dem tiefsten Bereich der Mittleren Pechelbronn-Formation aufgestellt werden. Dieses neue Korrelationsschema wird durch die Ostrakoden-Fauna gestützt.

Abstract

The detection of *Bolboforma* in the *Melania* Clay Formation in the former Altenburg IV brown coal open-cast mine near Borken (Hesse) permits a direct correlation with the Middle Pechelbronn Formation of the Mainz Basin, which was exposed in an abandoned clay pit between Bodenheim and Nackenheim, south of Mainz. This study is an excellent example of bed-by-bed correlation with the help of microfossils over a distance of approximately 150 kilometres, with no good exposures in between. It is the first record of *Bolboforma* for the Lower Oligocene of Northern Hesse and the Northern Upper Rhine Graben. With this new observation it is possible to establish a correlation scheme for the *Melania* Clay Formation of Borken with the Middle Pechelbronn Formation in the Mainz Basin (lowest portion). The ostracod fauna supports this correlation scheme.

Kurzfassung

Der Nachweis von *Bolboformen* in der Melanienton-Formation des ehemaligen Braunkohlentagebaus Altenburg IV bei Borken (Hessen) erlaubt die direkte Korrelierung mit der Mittleren Pechelbronn-Formation des Mainzer Beckens, die in der aufgelassenen Tongrube zwischen Bodenheim und Nackenheim südlich Mainz aufgeschlossen war. Diese Arbeit ist ein herausragendes Beispiel für die Korrelierung einzelner Schichten über ungefähr 150 km mit Hilfe von Mikrofossilien, ohne brauchbare Aufschlüsse dazwischen. Sie ist der erste Nachweis von *Bolboforma* für das Unteroligozän von Nordhessen und den nördlichen Oberrheingraben. Durch diese

Keywords

Melania Clay Formation, Middle Pechelbronn Formation, Lower Oligocene, *Bolboforma*, Northern Hesse, Hessian Depression, Upper Rhine Graben, Mainz Basin

Introduction

In northern Hesse (Hessian Depression) the *Melania* Clay Formation has yielded rich microfauna and -flora, which is particularly evident for microfauna influenced by northern elements. Among the ostracods, there are several species which can be observed in sediments of the same age exposed at the Doberg near Bünde further to the north. Further to the south in the Upper Rhine Graben, these lower Oligocene sediments are referred to as the Middle Pechelbronn Formation, named after the small village of Merkwiler-Pechelbronn in northern Alsace. The Middle Pechelbronn Formation is of great importance as mother and source rock for oil, which has been investigated in several oil fields during the last 100 to 150 years (oil fields: Pechelbronn, Landau, Eich; all in the central and northern portions of the Rhine Graben). In the late 1950's the late Dr. Doebl (GRAMANN 1960: 25, 26) was the first to recognize a clear correspondence between microfauna collected by Dr. Franz Gramann (GRAMANN 1960) for his own thesis from the *Melania* Clay Formation of Northern Hesse and those present in the Middle Pechelbronn Formation. At the time, first investigations of the microfauna had begun, but detailed lists were not yet available. Later, the

studies carried out by MALZ (1973), MALZ & TRIEBEL (1970) and TRIEBEL (1963) contributed much to our knowledge of microfauna, particularly ostracoda. Of the foraminifera, only representatives of the *Bolivina* genus have been investigated by MEHRNUSCH (1990, 1998). The *Melania* clay Formation and the Middle Pechelbronn Formation yielded calcareous nannoplankton of zone NP 22 (MARTINI 1973, 1987, 1991, 1998). In 1996 the present author undertook a first detailed attempt (GRIESEMER 1998) to correlate Lower Oligocene sediments in both areas by means of ostracods. New investigations and new samples of presently overgrown exposures permit bed-by-bed correlations between both of these areas with the help of microfossils. Still open is a detailed correlation with Lower Oligocene sediments of the Doberg near Bünde,

where concerted efforts should be made to identify bolboforms in order to locate the *Bolboforma datum* present in a bay of the "proto" "North Sea" in Hesse and Rhine-land-Palatinate.

Methods and Materials

In 1995 Professor Dr. M. Mehrnusch and the author sampled the former Altenburg IV open-cast lignite mine near Borken (Figure 1), which is now a natural reserve. The *Melania* clay Formation was observed in the southeastern portion of the exposure, where two major landslides have taken place. A set of 29 samples and subsamples were collected in Borken. Samples have primarily been taken from slipped material. Near the borders of the landslides more or less in situ sediments were able to be sampled as short sections. Standard micropalaeontological techniques were used for processing the sediments. A sieve with 63- μ m-wide openings was used for washing. Microfossils were extracted only by picking without any enrichment using heavy liquid techniques. Prof. Martini made a complete set of original samples from Ritzkowski available, which he used for his nannoplankton investigations (MARTINI 1987). Each sample was approximately 15 to 20 grams in weight. When looking for microfossils, such a sample size would normally be too small, but the *Melania* Clay Formation and its southern equivalent, the Middle Pechelbronn Formation, are generally extremely rich in microfossils.

In the Mainz Basin, the Middle Pechelbronn Formation was exposed in a now filled and totally overgrown brick pit ("Ziegelwerke Rheinhessen"; previously between Bodenheim and Nackenheim, approximately 8 km south of Mainz). This was the only natural exposure in the northern portion of the Upper Rhine Graben. A first and clear description of these strata was given by STEUER (1910: 43), but without a correct age determination. The first scientist to assign the age correctly was DOEBL in FALKE (1960: 17). His samples (four series) were kindly made available through the courtesy of Wintershall AG (WIAG), Barnstorf. Details on sampling information by the late Doebel were given to the author via letter (by Dr. Wirth and Mr. Bader, dated June 26, 1989). The first set, consisting of only a few samples (sample numbers: 25414–25417: 3 samples (6 slides)), was taken on November 10, 1959. Perhaps this set was taken

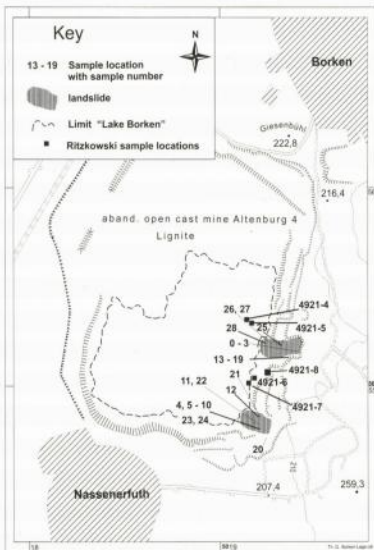
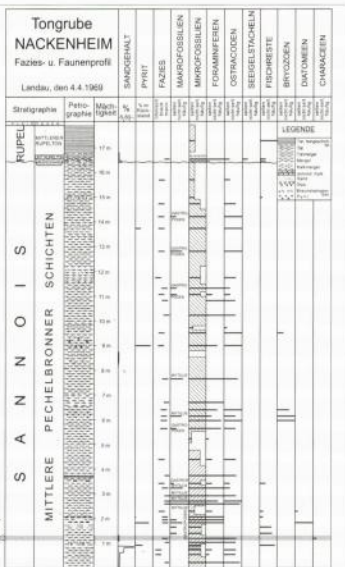


Figure 1: Abandoned Altenburg IV open-cast mine with sampling locations used by Mehrnusch and Griesemer in 1995. In addition, all sample locations used by Ritzkowski have been given. Sample location 4921-8 (Ritzkowski 1965: 134) is identical with 4921-56 (Ritzkowski 1967: 97), where the published section was described (Ritzkowski 1967: Figure 2) and which has been redrawn in Figure 2

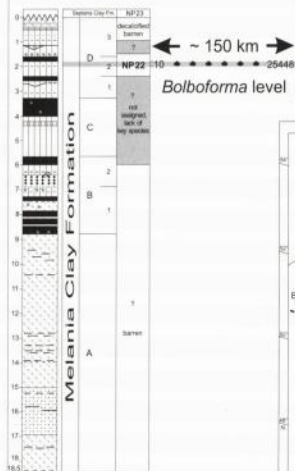
Figure 2: Correlation chart for Borken Melania Clay Formation (Northern Hesse) and Mainz Basin Middle Pechelbronn Formation (Rhine-Palatinate). Borken Lithological section according to RYZKOWSKI (1967; Figure 2; redrawn); nannoplankton data according to Martini 1987. Nackenheim section and faunal distribution chart according to DEBEL 1969; Figure 1 (redrawn). Sections in equal vertical scale.

Geographical setting according to MARTINI 1987 and GRESSEMER 1998; Figure 1 (redrawn).

Abbreviations: Grim. = Grimmeringen, S. J. = Sophia Jakob (mine shaft), B. = Bubenheim, V. = Vardeilsen, Gr. = Großalmerode, M. = Mardorf, L. = Leidenhofen, S. = Sieblos, H. = Helmstedt, Sch. = Schönevalde, Gl. = Glogow.



Borken



just to check microfossil content and age of the sediments. This and/or the second set was just taken shortly before the Falke guide was published, which reports the first outcrop of sediments belonging to the Middle Pechelbronn Formation in the northern Upper Rhine Graben. The second set was sampled in more detail and approximately 10 days later (written communication, WIAG) and comprises 45 samples (WIAG 25442-25487). This set was used approximately 10 years later for a paper (DOEBL 1969) which gives a short lithological description of the section and the sediments as well as a first impression of the distribution of its macro- and microfauna and -flora.

This is the only set of samples for which a description of the sediments together with the correspondent micropalaeontological samples exists. In March 1960 a third set was sampled: B5b – B18, WIAG 25824–25839, 16 slides. No further material (residues) for additional micropalaeontological investigations is available for all three series of samples. On the basis of the richness of the microfauna one would expect that more microfauna (-flora) would be able to be found in the slides. It appears that the microfauna was only investigated for a short survey, particularly for the first sets.

A fourth set (numbers: 30099 – 30145) was sampled in 1969 when this pit was again exposed for the "Oligocene excursion" (ANDERSON et al. 1969). This is the best set of samples, because in addition to each sample a small amount of unpicked material is also available. This set is comparable to one which is kept in the archives of the Rhineland-Palatinate Geological Survey at Mainz, but for all sets taken in 1969 only an incomplete lithological description of the section is available (described by Mowahed in SONNE in ANDERSON et al. 1969: 96, 97), without giving corresponding sample numbers.

Micropalaeontology of the Bolboforma Bed

Bolboforma is found in the *Melania* Clay Formation for the first time. Several samples from the landslide area in the southeastern portion of the Borken exposure have yielded bolboformids: Sample number 23 (ThG 4921/24). For the Borken

section (Figure 2) this bed is number 10, which is located in the middle portion of division D2 (RITZKOWSKI 1967: Figure 2). According to the list by RITZKOWSKI, this bed contains the following ostracoda: *Eucypris entzheimensis*, *Paracypris* aff. *propinqua*, *Cytheromorpha zinndorfi*, *Cytheridea pernota*, *Grinioneis triebeli*, *Schuleridea* (*Aequacyth.*) *perforata*, *Occultocythereis* cf. *mutabilis*, *Paracypris* sp. and *Trachyleberis* sp.. In addition to this list dinoflagellates, fish remains (*Clupea* sp.), molluscs (i.e.: *Corbicula* (*C.*) *tenuistriata*, *Dreissena* sp., *Pseudamnicola* sp., *Melanopsis hassiaca*, *Stenothyra pupa*) and foraminifera are found as well. For details on the foraminifera cf. RITZKOWSKI (1967) (Figure 2).



Figure 3: *Cardobairdia boldi* PIETRZENIUK 1969, left valve (female ?), Borken (*Melania* Clay Formation, presumably division D2; unhorizonted) – SMF Xe 18782

Bolboforma were also detected in some samples personally collected in the southeastern portion of the abandoned open-cast mine. Some of these samples are extremely rich in this microfossil group. In addition, the ostracod species *Cardobairdia boldi* PIETRZENIUK 1969 (Figure 3) was recently observed in some of the Borken samples. In the Mainz Basin the *Bolboforma* bed is located in the basal portion of the Nackenheim clay pit, approximately 1.12 to 1.22 m above the base of the section given by DOEBL (1969: Figure 1). This is sample A12 (WIAG 25448). The ostracod fauna consists of: *Grinioneis triebeli*, *Paracypris* sp. aff. *propinqua*, *Trachyleberis* sp., *Cardobairdia boldi*, *Pseudocandona* sp. (larval stages), *Cytheromorpha* sp., *Ostracoda* sp.1 (indet.). Foraminifera (several species, undetermined) are also present as well as some rare oogonia of charophytes [*Harrisichara tuberculata*; determined by Dr. J. Schwarz, Frankfurt/Main].

The fourth set of samples was taken by Doebl in 1969 before or after the "Oligocene excursion" (ANDERSON et al. 1969). This is the most detailed set of samples available. *Bolboforma* were determined in 4 samples (30134 (sample 9), 30135 (8), 30136 (7), 30138 (5)) which contain the following species of ostracoda (WIAG 30138, sample 5): *Grinioneis triebeli*, *Paracypris* sp. aff. *propinqua*, *Trachyleberis* sp., *Cardobairdia boldi*, *Cytheridea pernota*, *Occultocythereis* sp., *Pseudocandona* sp. (larvae), *Eucytherura* sp. and *Chara* sp.: determined by Dr. J. Schwarz, Frankfurt.

others are column-like in shape. In side view the cyst is somewhat flattened at its base. Broad neck with rounded opening, width around 10 µm. Opening system shows an inner free margin.

Remarks: *Bolboforma* cf. *B. latdorfensis* was figured by SPIEGLER & DANIELS (1991) from the Vibørg Clay (Lower Oligocene) of Ølst, Denmark. The forms from the Melania Clay Formation similar to this show weak reticulation and distally thickened spines. In addition, an unspined area is present around the opening system, which seems

Figure 4: On the left: Subdivision of the Middle Pechelbronn Formation with thicknesses (not to scale) according to the scheme used by geologists in the Pechelbronn oil field first published by GIGNOUX & HOFFMANN (1920). This subdivision was made on the basis of macrofossils. To the right: Subdivision of the Middle Pechelbronn Formation using ostracoda. Note: At present no direct correlation between both systems has yet been possible



Palaeontology

Family BOLBOFORMACEAE SPIEGLER 1987
GENUS *Bolboforma* DANIELS & SPIEGLER 1974
Type species: *Lagena metzmacheri* CLODIUS 1922

Bolboforma cf. *B. latdorfensis* SPIEGLER in SPIEGLER & DANIELS 1991
Plate 1, Figures 1, 2, 3

Material. Sample 10 (original Ritzkowski sample): up to 25 spheres and fragments. Personal collection: approximately one hundred specimens from Borken (collected from slipped material).

Description. Cyst approximately 100 µm wide (without spines). Single (?) chambered sphere, irregularly covered with a rather weak and subordinate reticulation system. Surface covered with spines, sometimes thickened distally. Some spines having a blade-like appearance whereas

lacking in the Danish specimen. This new species lacks the prominent reticulation of *B. latdorfensis*.

Bolboforma sp.1
Plate 1, Figure 4

Some spheres have been found totally lacking in any ornamentation (spines and/or reticulation). All other details (size, width of the opening system) are the same as for the ornamented forms.

Bolboforma sp.2
Plate 1, Figures 5, 6, 6a

The spheres found in the Middle Pechelbronn Formation have been left in open nomenclature due to their preservation. Normally all spines are broken off, so that only the basis of the spines can be seen. The entire surface is covered with clay minerals and nannoplankton.

Stratigraphic Correlation and Interpretation

Bolboforms are recorded here in sediments of Early Oligocene age in Northern Hesse (*Melania* Clay Formation) and in the northern portion of the Upper Rhine Graben for the first time. With these new observations nearly all previous efforts toward correlation must be revised or can at least be refined (Figure 5). It is now possible to establish a direct correlation for the *Melania* Clay Formation with the lower portion of the Middle Pechelbronn Formation (*Mytilus* beds). Arguments for this new correlation scheme are: *Bolboforma* is present only during a very short time span, i.e., they can be observed at one distinct level. No other samples in the Middle Pechelbronn Formation higher up in this sequence have yielded bolboforms until now. This observation can be verified,

particularly on the basis of the distribution of ostracod fauna, which is totally comparable between northern Hesse and the northern Upper Rhine Graben. However, further studies are necessary.

The Middle Pechelbronn Formation can traditionally be subdivided (GIGNOUX & HOFFMANN 1920: 15) from top to base into (Figure 4): "Marls with *Hydrobia*" with *Cyrena* beds at its base, "Marls with *Bryozoa*" and "Marls with *Mytilus*". This subdivision was developed by oil geologists in the type area of the Pechelbronn Group around Pechelbronn in northern Alsace. In general, a three-fold subdivision is used by many authors, thus neglecting the *Cyrena* horizon at the base of the "Marls with *Hydrobia*", but this subdivision still lacks a formal definition in the sense of modern stratigraphy. On the basis of the microfossils, which is extremely rich for the whole sequence, and particularly the ostracods, STOEPIŃSKY (1960) gave a first report as to how to use this group for stratigraphy. This study is based on 12 species, whereas as many as approximately 75 species have been found by the present author. Small-scale foraminifera fauna is present only in the basal portions of the Middle Pechelbronn Formation, whereas higher up in the sequence this type of foraminifera fauna is lacking, or only sporadic occurrences of single species can be observed.

Insofar as ostracods are concerned, a provisional scheme which is still under construction (Figure 4) is presented here. Five zones can be observed in the Rhine Graben which reflect changes in the salinity of the depositional environment. Several characteristic species for each zone have been listed. Due to new sections which have

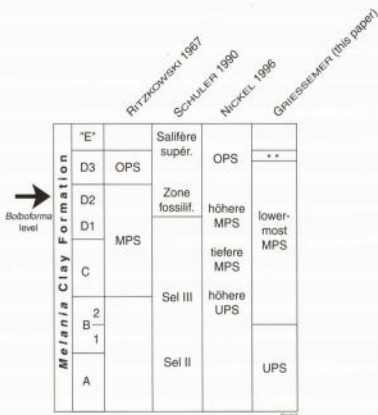


Figure 5: Comparison between various correlation schemes in the literature and the scheme outlined in the present study. Please note: Division "E" was introduced by RITZKOWSKI (in GRAMANN et al. 1986: 105) for a unit found in the Aisfeld "3027" well, approximately 33 km south of Borken. Figure redrawn according to NICKEL (1996: Figure 10). Only samples number 1 and 2 from RITZKOWSKI (1967: Figure 2), marked here with asterisks, may be of the same age as the Upper Pechelbronn Formation. Key: OPS = Upper Pechelbronn Formation, MPS = Middle Pechelbronn Formation, UPS = Lower Pechelbronn Formation; höhere = higher, tiefere = lower

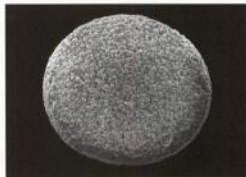


Figure 6: *Coscinodiscus* (?) sp. Pyritized internal mould of a diatom frustule. Altenburg IV open-cast mine, Borken, *Melania* Clay Formation, division B 2 (blackish layer: ~5.65 - 6.00 m; cf. Figure 2)

been sampled in greater detail, byzozoa have been observed in ostracod zone 2 and 3, near its base. Zone 3 is dominated by *Cytheridea pernota* DEITL & KEY 1955, which was described by STOEPIŃSKY as *Haplocytheridea pechelbronnensis* in 1960.

The *Melania* Clay Formation of Borken was subdivided into 4 divisions by RITZKOWSKI. The lowest two divisions (A and B1) represent a limnic to oligohaline environment. Division B2, for which originally an environment similar to B1 was postulated, shows the first marine influences resulting from new observations. *Grinioneis triebeli*, *Hornibrookella* sp., *Hazelina* sp. (n. sp.) and *Cytheromorpha* sp., together with diatoms (*Coccinodiscus*? sp., cf. Figure 6), were observed in the blackish layer at levels of 5.65 to 6.00 m. In divisions C and D, plio- to brachyhaline conditions developed. The highest portions of division D (D3) show reddish colours, which are explained as a soil developing process (RITZKOWSKI 1967: 99). According to his observations, this division still contains ostracods and foraminifera as limonitic internal moulds. These require further investigation, because with the detection of the *Bolboforma* level it seems rather likely to regard division "D3" as a normally developed sequence, perhaps originally (?) reddish in colour, which can be frequently observed in the northern portion of the Upper Rhine Graben. Only the sand layer at the top of the Borken section may represent an equivalent of the Upper Pechelbronn Formation in the northern Rhine Graben, but fossils for dating are lacking. It must be mentioned that the *Melania* Clay Formation is also known in the geological literature from Großalmerode (locality "Gr." in Figure 2, approximately 40 km NE of Borken). According to the palaeontological data available, this unit contains different mollusc fauna and is known as "Cyrenenschluff". The microfauna, particularly the ostracoda, of this unit is similar to ostracod zone 5 of the Middle Pechelbronn Formation. It contains abundant *Hemicypridis gilletae* (?), *Semicytherura dunkeri* and fragments of a large cyprid ostracod. This is the only occurrence of this ostracod zone outside the Rhine Graben which gives good reason for a comparable stratigraphic column in northern Hesse.

Conclusions

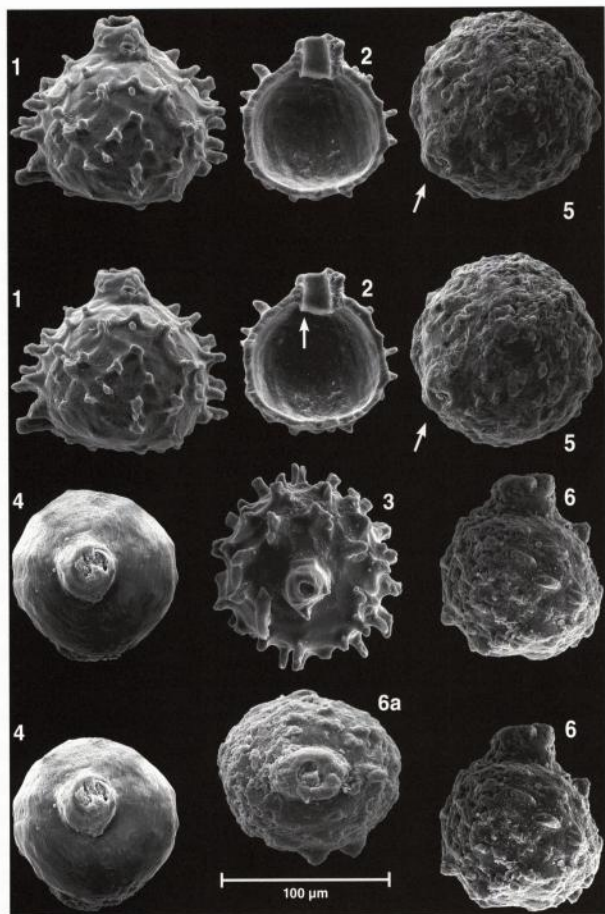
The presence of *Bolboforma* in the *Melania* Clay Formation exposed in the former Altenburg IV open-cast mine near Borken permits a direct bed-by-bed correlation with the lowermost portions of the Middle Pechelbronn Formation ("Mytilus beds") in the northern portion of the Upper Rhine Graben. The similarity of the ostracod fauna in both areas is a further strong indication for such a correlation. For the lowest portion of the Middle Pechelbronn Formation (and the *Melania* Clay Formation), the ostracod fauna is strongly influenced by elements of a northern origin. Compared to the succession of sediments of Early Oligocene age (NP 22) the *Melania* Clay Formation of Borken is rather incomplete, due to erosion during later Oligocene times (i.e. pre-NP 23 times).

Acknowledgements

Prof. Dr. E. Martini (formerly Johann Wolfgang Goethe University, Frankfurt) kindly made a set of samples, originally collected by Ritzkowski, from his nanoplankton collection available. The author is very grateful to the "Obere Naturschutzbehörde, Regierungspräsidium Kassel" (Mr. Herbert) for permitting sampling in the "Borkener See" natural reserve (formerly Altenburg IV open-cast mine). Fieldwork was controlled by Mr. Umbach from forester house Jesberg. Prof. Dr. M. Mehrnusch (Mainz) is thanked for help during sampling and washing the Borken samples. The Wintershall AG (WIAG), Barnstorf, is thanked for loaning slides and residues sampled by the late Dr. Doebl from the former Nackenheim clay pit. Dr. J. Schwarz (Frankfurt), to whom I am also grateful, made some specific determinations of the charophytes. Prof. Dr. V. Sonne (retired Head of Rhineland-Palatinate Geological Survey) and Prof. Dr. K. Rothausen (formerly Johannes Gutenberg University, Mainz) made constructive comments on the manuscript. This contribution is part of the author's research work for a future doctorate thesis at Johannes Gutenberg University, Mainz.

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- Plate 1: Bolboforma of the Melania clay Formation and the Middle Pechelbronn Formation*
- Bolboforma cf. latdorfensis* SPIEGLER in SPIEGLER & DANIELS 1974
Figure 1: (stereo pair): Side view. Note poorly developed ridges between spines. Spines occasionally show blade-like outline. - *Melania* Clay Formation (Lower Oligocene, NP 22); Borken: Sample 10 (collector: Dr. S. Ritzkowski)
Figure 2: (stereo pair): Naturally broken cyst. Note inner free edge of neck-like structure. - *Melania* Clay Formation (Lower Oligocene, NP 22); Borken: Sample 10 (collector: Dr. S. Ritzkowski)
Figure 3: (stereo pair): Oral view. Note smooth area around central opening. Width of opening approx. 10 µm. - *Melania* Clay Formation (Lower Oligocene, NP 22); Borken: Sample 10 (collector: Dr. S. Ritzkowski), specimen lost
- Bolboforma* sp.1
Figure 4: (stereo pair): Oral view of a totally smooth cyst? - *Melania* Clay Formation (Lower Oligocene, NP 22); Borken: Sample 10 (collector: Dr. S. Ritzkowski)
- Bolboforma* sp.2
Figure 5: (stereo pair): Oblique view of a cyst. Arrow points on aperture. Spines broken off, surface covered by nannoplankton and clay minerals. - Middle Pechelbronn Formation [*Mytilus* beds, lower portion], (Lower Oligocene, NP 22); Nackenheim: Sample 25448, A12 (Doebi, WIAG)
Figure 6: (stereo pair): Side view of a cyst. Spines broken off, surface covered by nannoplankton and clay minerals. - Middle Pechelbronn Formation [*Mytilus* beds, lower portion], (Lower Oligocene, NP 22); Nackenheim: Sample 25448, A12 (Doebi, WIAG)
Figure 6a: Apical view of same specimen as shown in Figure 6.
Note: Tilt angles +5° and -5° used for stereo pairs.
- All figured material is kept in the Senckenberg Natural History Museum, Frankfurt (SMF).



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Detailed Analysis of the Rupelian Ru-1 Transgressive Surface in the Type Area (Belgium)

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Abstract

The Rupelian-1 transgressive surface in the type area in Belgium coincides with the NP22/23 boundary. In the direction of the basin, the surface is characterized by a phosphate bed, and by flat black flint pebbles toward the continent. Phosphate concretions cover the fine glauconitic Ruisbroek Sand, whereas the pebbles overlie a group of estuarine, lagoonal and lake deposits. Boom Clay occurs above the phosphate bed, and Berg Sand is found above the pebbles. A detailed palaeontology of the phosphate bed reveals details concerning sedimentary evolution around the transgressive surface.

At the lowest sea-level position, a shallow regional erosional space is cut, whilst soil develops landward. At this stage an estuary had already cut into the underlying sediments. After a slight sea-level rise, lagoonal clays are deposited in the erosional space and swamp clays are deposited landward over the soil. Further slow sea-level rises result in the deposition of the fine glauconitic Ruisbroek Sand with many reworked microfossils and much land-derived organic matter. At the same time, lagoonal and estuarine sediments accumulate landward over the earlier swamp clays. When rates of sea-level change approach the level for the onset of the transgression, sediment influx from land stops and the sea bottom is now colonized by burrowing crustaceans, fishes, Cerianthidae and various other sea worms, large oysters which carry the symbiotic marine pelecypod *Martesia*; and wood fragments perforated by Teredinidae also float in. When sea levels continue to rise, shore erosion begins, and a Berg Sand facies of coastal sand is formed, as indicated by the presence of characteristic large Cyprinidae, often with both valves together. Before transgressive sediments are deposited, phosphate is carried in from the open sea, as shown by the phosphatisation of all previously mentioned organisms and burrows

at the seafloor. The first indication of a new type of transgressive sediment is the presence of numerous mm-sized agate grains and some flat black flint pebbles mixed with the phosphates. These pebbles are much more abundant landward in the top of the estuarine and lagoonal sediments. The new sediments are brought in from the west by marine currents. Continued and increased rates of sea-level rise lead to reworking of the phosphatised sea bottom, forming a lag bed consisting of phosphate-impregnated, slightly transported, fossils and burrows. Further landward, the black pebbles are swept over an abrasive surface formed by transgression. At this time some of the rounded phosphate fragments and admixed pebbles acquire a glauconite staining. Some oysters use the pebbles as a substrate. Before the transgressive silty clay sedimentation spreads over the phosphate bed, a significant number of elasmobranch and teleost fishes strand on the shore, decomposing quietly as indicated by the preservation of nearly intact microbones, articulations and teeth, sometimes even still grouped as though derived from individual specimens. The overlying transgressive silty clay sedimentation initially remains very shallow, as indicated by the presence of oysters colonized by Clionidae sponges, which can tolerate some brackish water, and by the presence of some rare gutters. At the same time coastal erosion continues to produce Berg Sand type coastal sands landward, overlying the black flint pebble layer and containing high levels of Cyprinid valves. Subsequent rapid sea-level rise deposits deeper water Boom Clay over all the former deposits. Pyrite, as observed in the wood fragments, can form rapidly after burial.

Kurzfassung

Die Rupelium-1 Transgressions-Fläche fällt in der Typus-Region in Belgien mit der NP22/23 Grenze zusammen. Beckenwärts wird diese Fläche durch Phosphorit-Füh-

zung, landwärts durch flache, schwarze Flinte charakterisiert. Die Phosphorite bedecken die feinen, glaukonitischen Ruisbroek Sande, wohingegen die Flint-Kiesel eine Gruppe von ästuarinen, lagunären und lakustrinen Ablagerungen überlagern. Über den Phosphoriten folgt der Boom Ton, über den Flint-Kieseln der Berg Sand. Die genaue Paläontologie der Phosphorit-Schichten eröffnet Details über die sedimentologische Entwicklung im Bereich der Transgressions-Fläche.

Während des geringsten Meeresspiegel Standes wird ein flacher regionaler Erosionsraum eingeschnitten, während landwärts Bodenbildung zu beobachten ist. Schon während dieser Phase hat sich ein Ästuar in die unterliegenden Sedimente eingeschnitten. Nach einem geringen Meeresspiegel Anstieg werden lagunäre Tone im Erosionsraum und Überflutungs-Tone landwärts über dem Boden abgelagert. Ein weiterer leichter Meeresspiegel-Anstieg führt zur Ablagerung der feinen, glaukonitischen Ruisbroek Sande mit vielen aufgearbeiteten Mikrofossilien und organischem Material terrestrischen Ursprungs. Gleichzeitig kommt es landwärts zur Ablagerung lagunärer und ästuariner Sedimente über den früheren Überflutungs-Tonen. Als sich der Grad der Meeresspiegel-Änderung der Transgressionsrate annähert, endet der Eintrag von Land her und der Meeresboden wird jetzt von grabenden Crustaceen, Fischen, Ceranithidae und verschiedenen anderen marinen Würmern und großen Austern, die die symbiotische marine Bohrmuschel *Martesia* tragen, besiedelt, und auch von Terebiniden zerbohrte Holzstücke driften herein. Indem der Meeresspiegel weiter steigt, beginnt Küstenerosion und eine Berg-Sand-Fazies von Küstensanden entwickelt sich, wie durch große, oft doppelklappige Isandmuscheln (Cypriniden) angezeigt wird. Bevor Transgressions-Sedimente abgelagert werden, werden Phosphate vom offenen Meer herantransportiert, wie durch die Phosphoritisierung aller bisher genannten Organismen und Spuren am Meeresboden belegt ist. Die ersten Anzeichen einer neuen Generation von Transgressions-Sediment sind in dem Vorkommen zahlreicher mm-großer Achat-Körner und einiger flacher schwarzer Flint-Kiesel zu sehen, die mit den Phosphoriten vermischt sind; Die Flint-Kiesel sind landwärts über den ästuarinen und lagunären Sedimenten deutlich häufiger. Die neuen Sedimente werden vom Westen her durch Meeresströmungen eingetragen. Eine wei-

terhin steigende Rate des Meeresspiegel-Anstiegs führt zur Aufarbeitung des phosphoritisierten Meeresbodens, der zu einer Residual-Lage bestehend aus Phosphorit imprägnierten, wenig transportierten Fossilien und Grabgängen führt; weiter landwärts werden die schwarzen Flinte auf eine Abrasions-Fläche geschwemmt, die durch die Transgression gebildet wurde. Zu dieser Zeit erhalten einige der abgerundeten Phosphorit-Fragmente und untergemischten Flinte einen glaukonitischen Belag. Einige Austern nutzen die Kiesel als Substrat. Bevor sich die siltige bis tonige Transgressions-Sedimentation über die Phosphorit-Lage ausdehnt, strandet eine signifikante Anzahl von Haien und Knochenfischen am Strand und verwest ungestört, wie durch die Erhaltung nahezu intakter Mikroknochen, Gelenkartikulationen und Zähne angezeigt wird, die noch als von einzelnen Tieren stammend angeordnet sind. Die überdeckende transgressive Silt-Ton-Sedimentation bleibt anfangs sehr flach, wie durch das Vorkommen von durch Clioniden (Schwämme) besiedelten Austern, die Brackwasser tolerieren können, angezeigt und seltene Rinnenbildung belegt wird. Gleichzeitig führt die Küstenerosion landwärts weiterhin zur Ablagerung von Küstensanden des Berg-Sand-Typus, die die Flint-Lage überdecken und Lagen mit Cypriniden-Schalen enthalten. Fortschreitender rapider Meeresspiegel-Anstieg führt zur Ablagerung des Boom Tons des tiefern Wassers über allen bisherigen Sedimenten. Pyrit, wie in Holzfragmenten beobachtet, kann sich rasch nach der Sediment-Bedeckung gebildet haben.

Keywords

Sequence stratigraphy, Rupelian, Oligocene, transgressive surface, Belgium

Introduction

The phosphatic gravel layer at the base of the Boom Clay (Rupelian) in the Sint Nikolaas brickyard pit (Waasland, Belgium) (Figure 1) has attracted attention for many years (a.o. VANDENBERGHE 1978), not least because the gravel consists, to a large extent, of fossil moulds. It is obvious that the presence of this rather exceptional level at the base of a major clay deposit has a particular palaeoenvironmental and, hence, stratigraphic significance at the beginning of the Rupelian. VANDENBERGHE et al. (1998)

Figure 1: Location map of the section studied in North Belgium. The schematic profile discussed in Figures 2 to 8 represents the geology between the Waasland, Brabant and Tongeren areas. The inset map shows Belgium and the neighbouring countries



Table 1: Lithostratigraphy of the Waasland-Boom, Brabant and Tongeren areas.

Waasland-Boom area	Brabant area	Tongeren area
RUPEL GROUP		
		Eigenbilzen Formation
Boom Formation	Boom Formation	Boom Formation
Putte Member	Putte Member	Putte Member
Terhagen Member	Terhagen Member	Terhagen Member
Beisele-Waas Member		
		Bilzen Formation
		Kerniel Member
		Kleine-Spouwen Member
		Berg Member
TONGEREN GROUP		
Zelzate Formation		Borgloon Formation
Ruisbroek Member	Heide Horizon	Cude Biezen Member
Watervliet Member	Henis Member	Henis Member
Bassevelde Member	Boutersem Member	
	Kerkom Member	
	Hoogbutsel Horizon	
	Sint-Huibrechts-Hern Formation	
	Kesselberg Member	
	Neerrepn Member	Neerrepn Member
	Grimmertingen Member	Grimmertingen Member

have interpreted the phosphate layer as the transgressive surface of sequence Ru1, sensu HAO et al. (1987) and HARDENBOL et al. (1998).

It is the intention of this paper to describe the composition of the phosphatic bed in detail, to determine its formation conditions and to establish its link to the detailed overall geometry of all the strata around and near the phosphatic bed, leading to an understanding of the stratigraphic meaning of the phosphatic bed. In order to do so, the paper will describe the palaeogeography of the area in a series of narrow consecutive time slices. The lithostratigraphic units used in the text are listed in the stratigraphic table (Table 1).

The time of lowest sea level

Figure 2

The sand unit underlying the phosphatic bed in the Waasland is the Ruisbroek Sand Member of the Zelzate Formation (MARECHAL 1991, 1993). The stratigraphic age of this formation is at the Eocene-Oligocene transition.

The base of the Ruisbroek Sand forms a broad regional erosion level of approximately 10m deep, incised into sands and clays, which have NP21 nannoplankton zonation. The base of the Ruisbroek Sand is characterized by early NP22 nannoplankton content. The erosive nature of the Ruisbroek Sand can be observed on the geological maps 1:25,000 Lokeren (Sheet 14, JACOBS et al. 1993), Antwerp (Sheet 15, JACOBS et al. 2002) and Mechelen (Sheet 23, BUFFEL & VACKER 2002). In the subsurface to the east, the Mol area, core analysis shows the Ruisbroek Sand to have even completely eroded all sediments of the NP21 biozone, either the top of the Bassevelde Sand Member of the Zelzate Formation or the Sint Huibrechts Hern Formation (Tongerense Group), which are both characterized by this same biozone NP21 and otherwise occur continuously over north and northeast Belgium.

To the southeast of the area under erosion, a podzolic soil has developed in the top of a glauconitic marine sand facies, the Neerrepn Sand Member at the top of the Sint Huibrechts Hern Formation (Plate 1, Photo 1). This soil has a widespread regional occurrence and has been studied in detail and described in the Tongeren area as a podzol with a fragipan by BUURMAN &

Figure 2: Schematic representation of the landscape at the beginning of the NP22 biochron during a period of low sea level

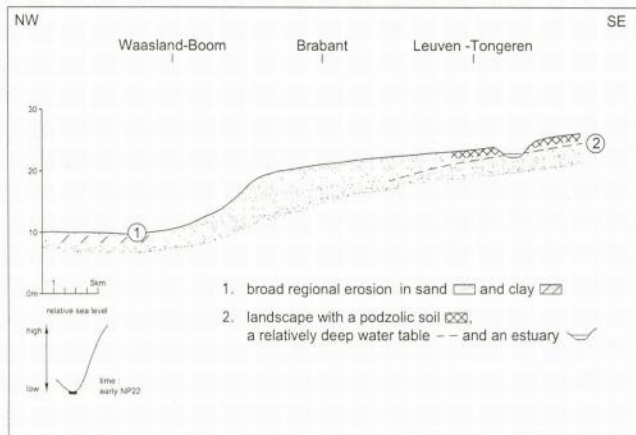


Plate 1

Photograph 1: The succession of podzolic soil developed to the right of and above the shovel (for scale), overlain by a brackish-water white shell-bearing sand with a thin clay layer in the middle. The soil still has black organic matter in its top, a white eluviated horizon below and, at the base (shovel blade), a dark green illuviation horizon with degraded glauconitic clay. At the base of the photograph the unaltered fine glauconitic Neerrepren Sand can be seen. A layered clay complex (Hoogbutsel Horizon) occurs above the white sand, some of the clay layers are greenish, and at the top a black peaty swamp soil occurs. The estuarine Kerkom Sand occurs above the clay



Photograph 2: The base of the silty clay (Belsele-Waas Member of the Boom Clay Formation) with the top of the fine glauconitic sand (Ruisbroek Member) at the very base. The thin marked wash-out horizon between both lithological units is the phosphatic bed level

Photograph 3: A gutter fill in the Belsele-Waas silty clay (shovel blade for scale)



JONGMANS (1975). It overlies in the entire region by the continental deposits of the Tongeren Group, the Borgloon Formation, which have been dated as time equivalent of the NP22 biozone (cf. VANDENBERGHE et al. 1998 for a review). Therefore, erosion underlying the Ruisbroek Sand and soil formation occurred at approximately the same time, around the NP21/NP22 boundary. In the landscape to the south a river channel drained the landscape.

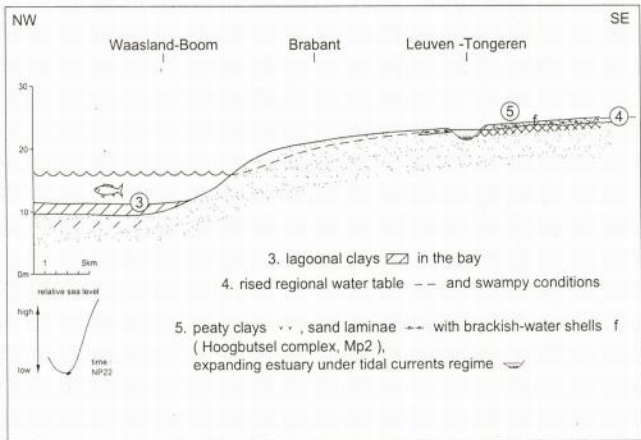
The installation of lagoonal conditions in the Waasland-Boom area and swamps in the Leuven-Tongeren area

Figure 3: Schematic representation of the slowly drowned depression in the northwest and the swampy coastal plain being installed in the southeast during the early part of the NP22 biochron

Figure 3

The first sediments found above the erosive level in the north are a few meters of clays which contain very abundant bisaccate pollen, some dinoflagellates, among which *Gerdicocysta conopea*, *Wetzeliella gochtii* and *Phtanoperidinium* spp., significant amounts of *Pediastrum* fresh water algae, reworked dinoflagellates from Lower Cretaceous through Eocene, but no nannoplankton (VANDENBERGHE et al. 2003).

This association points to a lagoonal or bay depositional environment. A few coarser glauconitic horizons indicate flooding of the lagoonal sediments by marine incursions. The sedimentation indicates a slow rise in sea level. Rising sea levels also caused rises in the regional groundwater table, which led to the installation of swampy conditions in the south, drowning the podzolic soil formed at an earlier stage. In the swamp, peaty clays are formed, and influxes of brackish water are documented by thin shell-bearing sands (Plate 1, Photo 1). In the top of the swamp clays, sepiolite, precipitated in the pores of the desiccating mud, witnesses at least a short period of dry climate (HUGGET et al. 1996, VERBEECK et al. 1998). The swamp and brackish deposits are known under the name of the Hoogbutsel Complex and they contain numerous terrestrial vertebrate fossil remains (SMITH in press). This tetrapod fauna points to the MP21 zone. It is the first assemblage in the area after Stehlin's Grande Coupure. Under coastal conditions, as witnessed by brackish water influxes, it is logical to assume that the river draining the area became a broader estuary, the section of which was being shaped by lateral and also some vertical erosion under the influence of tidal hydraulics.



Slow sea-level rise

Figure 4

Continued slow sea-level rise brings a glauconitic fine sand deposit over the clays in the bay or lagoon in the northwest. Rising sea levels eroded the bay shoreline, moving it gradually to the southeast. The fine glauconitic sands are known as the Ruisbroek Sand. The sands are characterized by many reworked microfossils and by a brownish grey hue, probably due to the presence of tiny black terrestrial plant fragments. The evolution of microfossil associations shows the installation of a more open marine condition toward the top (VANDENBERGHE et al. 2003). Nannoplankton shows the Ruisbroek Sand unit to span the entire NP22 chronozone.

channel are known as the cross-bedded Kerkom Sand Member of the Borgloon Formation.

The beginning of flooding

Figure 5

Apparently at the end of glauconitic Ruisbroek Sand deposition and before the deposition of deeper water Boom Clay just above, sedimentation halted and the shallow seafloor became colonized by a rich fauna, including burrowing decapod crustaceans (Squillidae and Paguridae), Cerianthidae and various other types of sea worms (Plate 2, Photo 2), large oysters which carry the symbiotic marine pelecypod *Martesia* (Plate 2, Photo 3), fishes, etc..

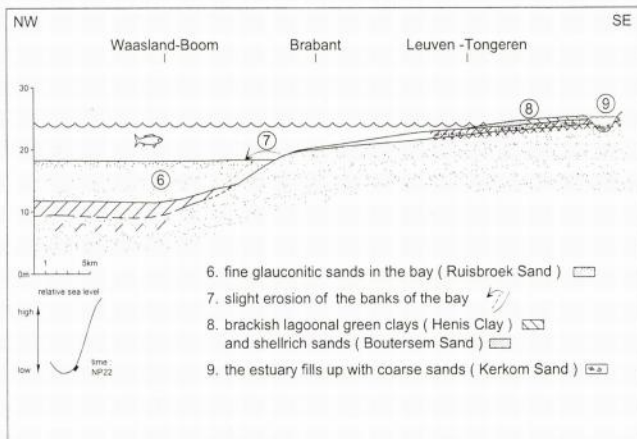


Figure 4: Schematic representation of the infilling of the depression in the northwest by shallow marine sands and the sedimentation in the lagoon and estuary of the coastal plain in the southeast during the NP22 biochron

Raised sea levels bring brackish lagoonal conditions further to the south over the former swamps. These lagoonal conditions form a few well-known facies in the area: the green clay deposit of the Henis Member and the mollusc-rich sands of the Boutersem Member. Both members belong to the Borgloon Formation of the Tongeren Group, also belonging to the NP22 chronozone as mentioned above. Rising sea levels forced the estuary in the area to begin to sediment. The estuarine deposits in the

Rising sea levels continue to erode the shore line in the south, as testified by the influx of wood fragments perforated in sea water by Teridiniidae and other xylophagous molluscs. Newly deposited coastal sediments, including large Cyprinidae, are eroded as the shoreline progresses southward, as shown by the presence of molluscs with both valves still together in the top of the Ruisbroek Sand.

Higher sea levels lead to continuing la-

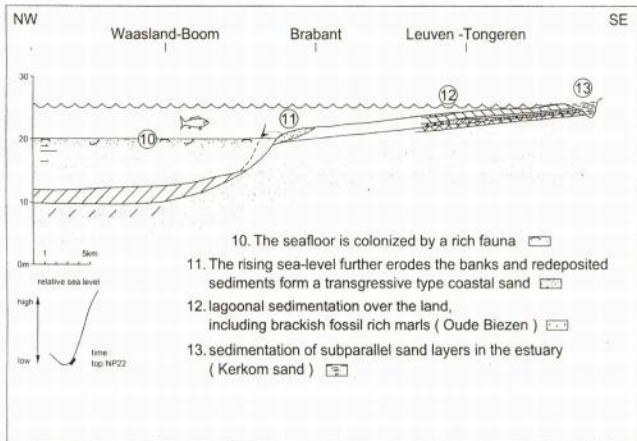


Figure 5: Schematic representation of the sedimentation standstill and the colonization of the seafloor by a rich fauna in the north-west at the end of the NP22 biochron

goonal sedimentation over the land in the south, including the brackish fossil-rich marls of the Vieux Jons or Oude Biezen Member of the Borgloon Formation. The Kerkom Sand estuary is now completely filled with more parallel bedded sands, which more strongly resemble shore facies deposits rather than estuarine sediments.

The phosphate impregnation of the seafloor

Figure 6

Just before the onset of the major transgressive flooding of the land, changes in the palaeoceanic system occurred, and the arrival of new masses of water, probably from deeper levels in the North Sea, brought enough phosphate to cement the top of the seafloor, including bioturbations and many organisms living on the seafloor as described above. XRD analysis characterizes the cement as apatite (main reflections with relative intensities above 50% at 2.79 Å (100), 2.77 Å (50), 2.69 Å (52)). Continuing sea-level rises cut a new profile into the bank, upon which a transgressive sand is deposited with Cyprinidae.

The transgressive surface

Figure 7

When the rate of sea-level rise sharply increases, the phosphate cemented seabottom is broken up, and a phosphate concretionary bed, such as it can be observed today, is formed (Plate 3, Photos 1, 2 and Plate 1, Photo 2). Some of the concretions are slightly rounded and some bear a glauconite staining. Oysters have been observed to be growing over the pebbles.

The lateral transport of new sediment along the coastline is shown by the arrival of some typical flat black flint pebbles in the phosphatic bed, which undoubtedly come from the erosion of Cretaceous chalk cliffs to the west, forming the Anglia-Artois ridge at that time. A counter-clockwise sediment transport in the Rupelian North Sea has already been demonstrated by the study of phytoclasts (VANDENBERGHE 1976). Also indicating a new sediment provenance is the presence of mm-sized agate in the phosphate pebble layer and also some amethyst and jasper grains (Plate 2, Photo 1), logically also occurring from the UK landmass at that time. We suspect that the first arrival of the pebbles occurred at the very beginning of the transgression rate increase, just after phosphatisation

Plate 2

Photograph 1: Selected agate grains from the phosphate bed. The grains are handpicked from the 1- to 3-mm sieve fraction



Photograph 2: Phosphatised worm traces selected from the phosphatic bed. The thickness of the worms is 2 to 3 mm

Photograph 3: Phosphate cemented traces of the pelecypod *Martesia*. The photograph displays a view of the inside part of an oyster shell, now dissolved, into which the pelecypod had bored; the borings were filled with fine glauconitic sand, which was later cemented by phosphate as was the sand in which the oyster shell was buried (the large flat sandstone plate behind the pelecypod borings). The total width of the cemented sandstone plate shown is 7 cm



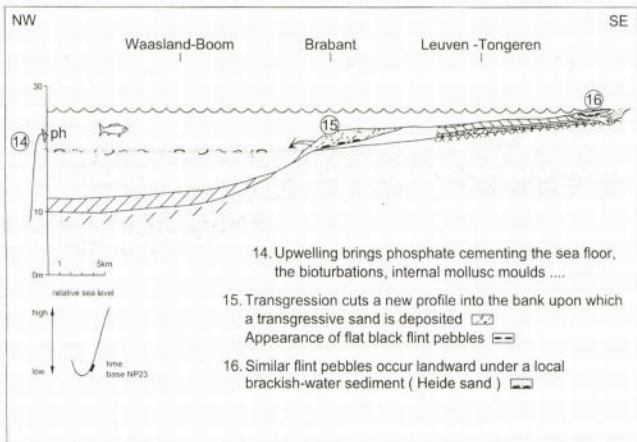


Figure 6: Schematic representation of the formation of a hardground in the sediment top in the northwest and the initiation of a transgressive sand sheet toward the southeast

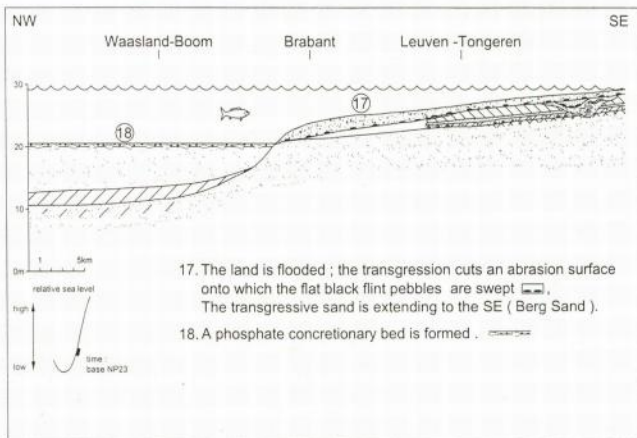


Figure 7: Schematic representation of the effect of the increased rate of sea-level rise with the break-up of the hardground in the northwest and the formation of a transgressive abrasion surface to the southeast at the beginning of the NP23 biochron

Plate 3

Photograph 1: Impregnated block of the phosphatic bed showing slightly rounded phosphate cemented pebbles, and primarily the internal moulds of molluscs. The individual fragments vary from approximately 1 to 3 cm



Photograph 2: Impregnated block of the phosphatic bed showing a few phosphate cemented pebbles and primarily flat phosphate cemented burrows. The burrows are approximately 1 cm in width and several cm long

Photograph 3: Tiny fish-fin bones still in the articulate extracted from the phosphate bed (6 mm long)



halted and the break-up of the hardground began. Indeed the scarce pebbles in the phosphatic layer are never cemented by phosphate to other grains, and in the south the pebbles appear just under the main transgressive abrasion surface (Figure 6). In the south the typical flat black pebbles are found in larger quantities underlying a locally deposited thin white, heavily bioturbated brackish-water to shallow marine sediment in the very top of the Borgloon Formation, namely the Heide Sand Horizon overlying the estuarine channel fill Kerkom Sand. This Heide Sand fills a small local depression, where the top of the Kerkom Sands is cemented either by an oil seepage at that time or a soil (cf. discussion in VAN REUSEN & VANDENBERGHE 1996, 1999). More generally, the Heide Sand is not present, and the flat black pebbles are found underlying the transgressive coastal sand layer containing Cyprinidae, called the Berg Sand Member of the Bilzen Formation, commonly occurring in the south. Apparently, sea-level rises now caused the flooding of landmasses to the south, and marine abrasion cut a large surface onto which the black pebbles were swept.

Initial sedimentation above the transgressive surface

Figure 8

Before new sediment was deposited over the concretionary bed, elasmobranch and teleost fishes stranded, as shown by the intact microbones, articulations and teeth, some associations of which can even be attributed to individual specimens. In the slightly deeper part of the basin in the north, rhythmic silty clays are deposited, namely the Belsele-Waas Member of the Rupelian Boom Clay Formation. Initially, water depths remained very shallow, as indicated by the high silt content and by the presence of rare gutter channels (Plate 1, Photo 3). In addition, the colonization of oysters by Clionidae sponges, which can tolerate brackish water, may confirm a very shallow nearshore depositional environment. Landward, the transgression expands its abrasion plate southward, and reworked and newly arriving fine sands are deposited above in a coastal sand; the sand contains several horizons of large Cyprinidae, swept periodically onto shore together with coarse sand and even some pebbles. This is the Berg Sand Member of the Bilzen

Formation. The large oysters occasionally found in the Belsele-Waas Clay have also been found in the Berg Sand at Viermaal (section in HERMAN 1984). Palaeontological investigations show that the Berg Sand and the Belsele-Waas Member are of similar age; they both contain the lowest NP23 nannoplankton. The Berg Sand displays a cyclicity in grain size of approximately a meter wavelength. These cycles are probably related to the cycles observed in the Belsele-Waas Member (VANDENBERGHE et al. 1997), although it has not been possible to correlate the cycles on a one-by-one basis. Continuing sea-level rises rapidly bring deeper water over the area, and the Terhagen Clay Member on top of the Belsele-Waas Member was deposited at a water depth of 50 to 100 m (VANDENBERGHE 1978, 1981). The level of the sudden appearance of Boom Clay over the Berg Sand in the south can be exactly correlated geophysically and palaeontologically with a horizon of sharp decrease in grain size in the clayey deposits of the Belsele-Waas Member in the north (VANDENBERGHE et al. 2001). The common pyrite in the sediments is a diagenetic mineralisation.

Conclusions

It has been shown that at a position of relative lowest sea level, at the start of the NP22 biochron, an isochronous surface exists in North Belgium, consisting partly of an erosion level and partly of a soil formation level. During the slow rise of sea-levels, lagoonal clays and fine glauconitic sands (Ruisbroek Sand) were deposited, characterized by reworked microfossils and terrestrial plant remains, while sea-level rises installed a landward coastal plain with swamps and lagoons (Borgloon Formation). In sequence stratigraphic terminology, these sediments are classified as lowstand deposits. The increased rate of sea-level rise, occurring toward the end of the NP22 biochron, apparently changed sedimentation and circulation patterns. At that time, sedimentation halted and a rich fauna colonized the seafloor in the marine realm. This fauna is documented by fossil remains, which are to a large extent phosphatised together with the top of the seafloor, which, in turn, was cemented into a hardground. Apparently, the change from primarily land-derived sediment fill from a shallow marine basin during periods of slowly rise of sea levels to the phase of a primarily marine-derived sediment fill

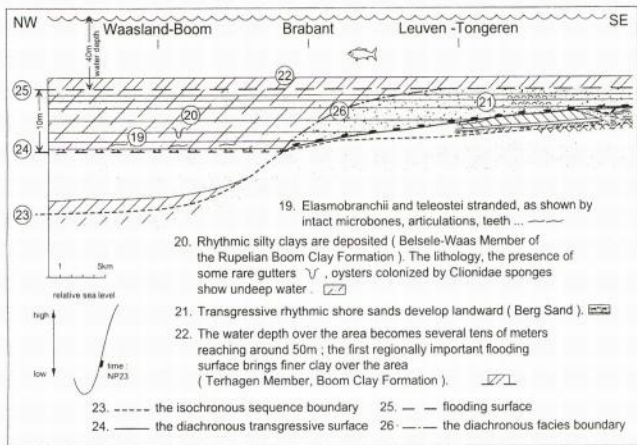


Figure 8: Schematic representation of the initial transgressive phase in the early part of the NP23 biochron, bringing silty clays over the northwest and a coastal transgressive sandsheet over the transgressive surface in the southeast. At the top a new flooding event brings clays also over the south-east area

from a deepening basin was accompanied by changes in current patterns leading to temporary sediment starvation and a supply of phosphate. Subsequently increased sea-level rises at the very beginning of the NP23 biochron form a transgressive sediment, namely a silty clay (Belsele-Waas Member) in the seaward part and a coastal sand layer (Berg Sand) in the landward part. At the base of these transgressive sediments the phosphate hardground is broken up into a pebble bed, and characteristic sediment particles are found, such as agate grains seaward in the phosphate bed and small flat black flint pebbles landward. Both demonstrate a new sediment provenance. The pebbles are swept landward over an abrasion surface. Coastal sand fossils and some flat black pebbles are found reworked in the phosphatic bed as the earliest coastal sands formed are progressively removed by the transgressive erosion.

Acknowledgements

This paper is part of FWO project G.0093.01. We sincerely thank the direction of SVK for granting access to the clay pit, Dr. M. Deliens of the KBIN-IRSNB for the identification of agate grains, M. Vervoenen for taphonomic preparations of the phosphate bed and F. Mollen, L. Anthéunis, T.

Lambrechts for access to their exploration pit in SVK.

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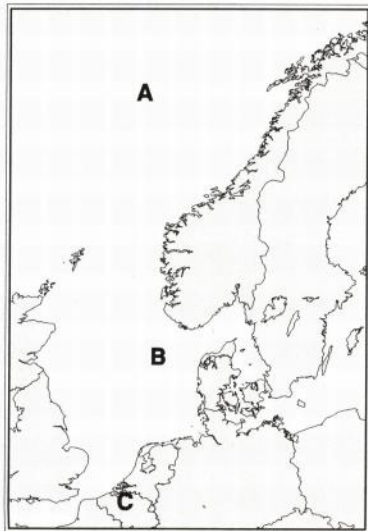
A Lower Oligocene Norwegian Sea Dinoflagellate Cyst Found in the North Sea and in the Rupelian Type Area in Belgium

► Jens J. Lund

Abstract

The large and conspicuous dinoflagellate cyst noted by MANUM et al. (1989) as *Spiniferites* sp.1 from the Lower Oligocene in the Norwegian Sea is described as *Pseudospiniferites manumii* n.gen. n.sp. from onshore sections at the Rupelian type area in Belgium. This species is also illustrated from a Danish North Sea well, where, as is the case in the Norwegian Sea and onshore Belgium, it occurs between the Lower Oligocene top of *Enneadocysta pectiniformis* and the Upper Eocene top of *Areosphaeridium diktyoplokum*. The horizon with *P. manumii* in the Norwegian Sea

Figure 1: Locations (A, B & C) with *Pseudospiniferites manumii* as discussed in the text. Distance approx. 1200 km from A to B, and 650 km from B to C



and onshore Belgium is thin (approx. 5 m) and provides a prime marker for biostratigraphic work in the Lower Oligocene.

Kurzfassung

Die große und auffällige Dinoflagellaten-Zyste, die von MANUM et al. (1989) als *Spiniferites* sp.1 aus dem Unter-Oligozän der Norwegischen See aufgeführt wird, wird als *Pseudospiniferites manumii* n.gen. n.sp. aus einem „onshore“ Profil des Typusgebiets des Rupellium in Belgien beschrieben. Die Art wird ebenfalls aus einer dänischen Nordseebohrung abgebildet, wo sie, wie in der Norwegischen See und „onshore“ Belgien, zwischen dem Top der *Enneadocysta pectiniformis*, Unter-Oligozän, und dem ober-eozänen Top der *Areosphaeridium diktyoplokum* vorkommt. Der Horizont mit *P. manumii* in der Norwegischen See und „onshore“ Belgien, ist nur geringmächtig (ca. 5 m). Er wird als primärer Leithorizont für biostratigraphische Arbeiten im Unter-Oligozän angesehen.

Introduction

From the Norwegian Sea, MANUM et al. (1989) noted the characteristic *Spiniferites* sp.1 from a short interval in the Lower Oligocene. The species occurred between the Early Oligocene top of *E. pectiniformis* and the Late Eocene top of *A. diktyoplokum*. This species has been found by this author at the same stratigraphic position in numerous wells from the Danish and Dutch North Sea, as well from onshore wells in Germany. However, until now, the stratigraphic position of this potentially important fossil has not been calibrated in onshore outcrops.

The aim of this study is to calibrate the occurrence of *Spiniferites* sp.1 of MANUM et al. (1989) in outcrops of Rupel, the type sections of the Early Oligocene in Belgium. Due to the stratigraphic importance of

the species, it is officially described in the binomial nomenclature system as *Pseudospiniferites manumii* n.gen. n.sp. from the latter area.

In the overview map (Figure 1) the Norwegian Sea occurrence is marked with "A" and the outcrop area in Belgium with a "C". A typical occurrence from the North Sea is shown with "B". These are described as follows:

Norwegian Sea Occurrence "A"

P. manumii was noted as *Spiniferites* sp.1 from ODP Site 643 in the Norwegian Sea by MANUM et al. (1989). The location is shown as "A" in Figure 1. MANUM et al. (l.c.) did not describe the species, but provided a photograph (Plate 17, Figure 5). The semi-

quantitative occurrence of this species at ODP Site 643 was given together with data concerning 178 other taxa in their Figures 3 and 4. Data presented by MANUM et al. (l.c.) for *P. manumii*, *E. pectiniformis* (including *E. arcuatum*) and *A. diktyoplokum* are presented in Figure 2. *P. manumii* occurs only in samples at 460.20 m and 461.70 m depth. It is not present uphole from 460.20 m and downhole from 468.40 m. The maximum thickness possible in ODP Hole 643A of the interval with *P. manumii* is thus about 8 m. The observed thickness was only 1.5 m.

An example from the North Sea "B"

In Figure 3, a section is shown with the tops of *E. pectiniformis*, *P. manumii* and *A. diktyoplokum* from a well in the Danish North Sea close to the Danish-Norwegian boundary. The location is noted with a letter "B" in Figure 1. The dinoflagellate cysts noted are displayed in Plate 1. The available samples investigated are "ditch cutting samples", in which only the tops of the fossils mentioned can be located with certainty. The 100 m depths of the samples are not given, and are noted only with "XX", since the data of the well are confidential.

The highest sample with *P. manumii* is "XX30 m", where this fossil is very common with about 50 specimens per palynological slide. The occurrence at this depth is therefore very easy to find, making it a stratigraphically important event. The thickness of the interval with *P. manumii* can not be determined with precision, as the base is indeterminable in "ditch cutting samples". However, since the number of *P. manumii* per slide declines rapidly downhole from "XX30 m", it is likely that the interval with *P. manumii* is thin, as is the case in the Norwegian Sea. The order of the tops of *E. pectiniformis*, *P. manumii* and *A. diktyoplokum* is the same as in Figure 2, illustrating the stratigraphic importance of this fossil succession.

Occurrence at Rupel, the Belgian Lower Oligocene Type Area "C"

Ninety-nine outcrop samples from the Sint

Figure 2a: Succession in the Norwegian Sea, ODP Site 643 (location A in Figure 1) of the index of dinoflagellate cysts used in this study

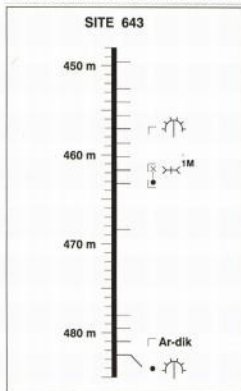
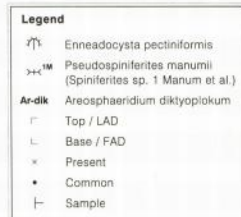


Figure 2b: Legend for figures



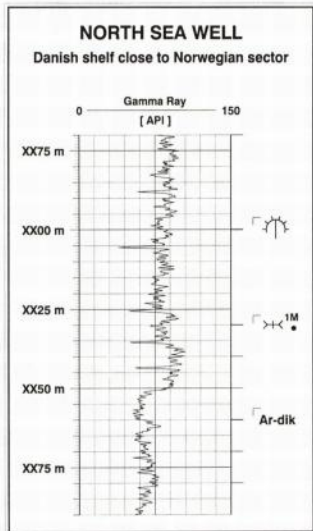


Figure 3: Succession in a Danish North Sea well (location B in figure 1) of the index of dinoflagellate cysts used in this study. For legend cf. figure 2b

Niklas, Rumst-Terhagen and Kruikebe pits in the Rupelian type area, Belgium, were provided by Dr. T. Moorkens, Antwerp. The occurrence of *P. manumii* in these samples is noted in figure 4. The Rupelian type area is noted with "C" in figure 1. Locations and other details of the pits mentioned can be found in VANDENBERGHE et al. (2001).

The samples investigated for the occurrence of *P. manumii* include the Belsele-Waas Clay, Terhagen and Putte Clay members, which form the complete Boom Formation, the lithostratigraphical name of the Rupelian in the type area (Figure 5). The section is subdivided by septarian layers (S10, S20, - S80), and the single beds are numbered, i.e. Beds 17 - 30 in figure 4. This bed numbering system was originally proposed by VANDENBERGHE (1978) and is also used in VANDENBERGHE et al. (2001).

The Kruikebe pit, included here, was also investigated for dinoflagellate cysts by STOVER & HARDENBOL (1993), who did not, however, determine or illustrate *P. manumii*, which at that time was known in the literature as *Spiniferites* sp. 1 of MANUM

et al. (1989). The species must have been present in their samples from Beds 22 and 24 (samples 1739, 1779, and 1850 in Figure 6 in STOVER & HARDENBOL 1993). It is probable that they did not illustrate the species because the "specimens" were fragmented or appeared crushed. This obscured the nature of archaeopyle and made the determination of generic levels difficult.

P. manumii was found only in samples from the Terhagen Member, where it is restricted to Beds 20 to 26 (Figure 4) and thus occurs in less than 5 m within the 35-m-thick Rupelian section investigated. *P. manumii* is consistent to common in Beds 22 to 24, a 1.5-m-thick horizon directly above the red marker horizon is shown in figure 4. In figure 5, the horizon with *P. manumii* is related to the tops of *E. pectiniformis* and *A. diktyoplokum*. The occurrences of the two latter species are noted according to the findings of STOVER & HARDENBOL (1993). The occurrence in the Putte Member was confirmed by the present investigation. However, the top of *A. diktyoplokum* was not able to be located because samples from the Eocene Bassevelde Member were not available.

The succession of *E. pectiniformis*, *P. manumii* and *A. diktyoplokum* in the Rupelian type area in Belgium (Figures 4 and 5) is identical to the succession in the North Sea (Figure 3) and the Norwegian Sea (Figure 2). This illustrates the stratigraphical importance of the new index species *P. manumii* as an addition to the two other species, which are well established index forms. The presence of *P. manumii* in the oceanic North Sea and in Norwegian Sea sections indicates that the horizon in the Belgian sections is more oceanic than the generally non-oceanic Belgian Rupelian.

Pseudospiniferites manumii Relatives in the Paratethys

The diverse palynological literature on the Tertiary of the Paratethys area (Austria, Slovakia, Hungary, etc.) concentrates on pollen and spores, and gives no indication of the presence (or absence) of *P. manumii*. From the Upper Cretaceous, (Lower Maastrichtian) of Bavaria, KRSOČ (1991) described and illustrated a dinoflagellate cyst (*Achomosphaera* sp. B) which resembles *P. manumii* on the basis of size, its thick granulate central body, and relatively

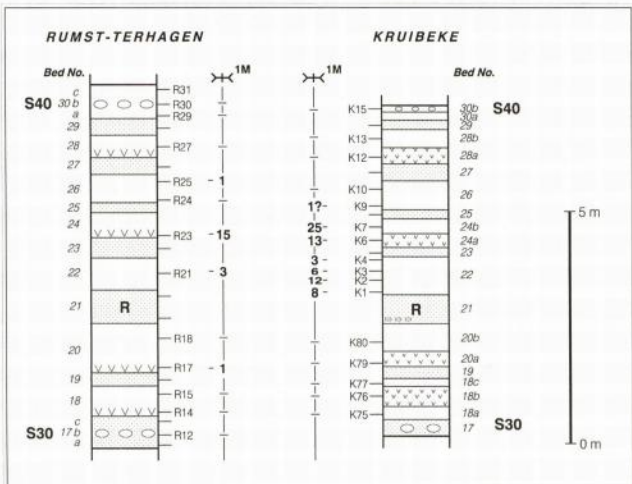


Figure 4: Observed occurrence of *Pseudospiniferites manumii* in the Rupelian of Belgium (location C in figure 1). The occurrence is restricted to the Terhagen Member of the Boom Formation, which is subdivided by means of septarian layers (S30, S40 etc.). For legend cf. figure 2b

long spines with nearly smooth shafts. The outline of the archaeopyle suggests the beginning of rupturing, and septae laying on the granulation can be observed ("five-o'clock" in KASCH Plate 6, Figure 11). The main difference is the presence of shorter trifurcations at the spine ends in the Maas-

trichtian form, which may be considered as a precursor of *P. manumii*.

Due to the precursor form mentioned above, it is considered likely that *P. manumii* existed in the Paratethys over a long period of the Tertiary and that it was able to emigrate to the North Sea during a period with favourable conditions (sea-level highstands and warmer temperatures). Its short presence, combined with a bloom of *P. manumii* in the North Sea and neighbouring areas (Figure 1), suggests that it is an immigrated form and that it died out in the area when the favourable conditions ceased.

N. W. BELGIUM				
SERIES	STAGE	FORMATION	MEMBER	DINOFLAGELLATES
OLIGOCENE	RUPELLIAN	BOOM	PUTTE	
			TERHAGEN	
			BELSELE-WAAS	
			RUISBROEK	
? ?	ZELZATE	WATER-VLIET		
		BASSE-VELDE		
EOCENE				

Figure 5: Succession in the Rupelian of Belgium (location C in figure 1) of the index of dinoflagellate cysts used in this study. For legend cf. figure 2b

Conclusions

The dinoflagellate cyst identified as *Spiniferites* sp. 1 by MANUM et al. (1989) from a short stratigraphic interval in the Lower Oligocene of the Norwegian Sea occurs at the same stratigraphic position (i.e. between the tops of *E. pectiniformis* and *A. diktyoplakum*) in the North Sea and the Rupelian type area in Belgium. It is large and easy to find. Due to this and because it is common, it provides a prime bio-

stratigraphic marker in the Rupelian/Lower Oligocene.

The above-mentioned *Spiniferites* sp.1 of MANUM et al. (1989) is described and named *Pseudospiniferites manumii* n.gen. n.sp..

Pseudospiniferites manumii probably had predecessors in the Paratethys and possibly invaded the North Sea area during a sea-level highstand. The bloom occurrence of *Pseudospiniferites manumii* suggests that the presumed sea-level highstand concurred with favourable conditions, probably warmer climate conditions.

Acknowledgements

The former Wietze Deutsche Texaco college, Dr. T. Moorkens, Antwerp, is thanked for providing the 99 samples from the Rupel type area in Belgium. RWE-DEA is thanked for drawing of Figures 1 - 4 (by Mrs. U. Faust) and for permission to publish this paper. Dr. D. Jutson, RWE-DEA, Wietze is thanked for linguistic advice.

Appendix on systematics of the dinoflagellate cysts used

The systematics of the previously established taxa follow WILLIAMS (1998), where the references can be found.

Areosphaeridium diktyoplokum (KLUMPP 1953) EATON 1971

Enneadocysta pectiniformis (GERLACH 1961) STOVER & WILLIAMS 1995

Pseudospiniferites n.gen.

Type species: *Pseudospiniferites manumii* n.sp.

Diagnosis: *Spiniferites*-like dinoflagellate cysts with granulate to (micro)reticulate ornamented central body surfaces and tendency toward suture break-up around the primary single plate precingular archaeopyle.

Remarks: With "tendency to break up" means that this happens for a consistent portion, not necessarily all, of the individuals of the population of the actual species defined by other characters. Break-up around the archaeopyle may involve only

a neighbouring precingular plate (Plate 1, Figure 5 and ?Plate 1, Figure 6) or sutures to additional plates, which in turn may result in the collapse of the epicyst (Plate 1, Figure 4). Break-up may involve the hypocyst as well as the holotype (Plate 1, Figure 2) and the specimen shown in Plate 1, Figure 7.

Due to the occasionally heavy sculpture of the surface of the central body, the crests connecting the gonal spines may be overlooked, if they are not precisely focused on.

Pseudospiniferites manumii n.sp.

Derivation of name: The species is named after SVEIN B. MANUM, University of Oslo, who led the group (MANUM et al. 1989) which illustrated the species as *Spiniferites* sp.1 from the Norwegian Sea (locality A in Figure 1).

Diagnosis: A large species (central body more than 65 micron) of *Pseudospiniferites* n.gen. with long spines characterized by weak development of the continuation of the spine connecting crests on the spine shafts, which may result in nearly smooth spine shafts.

Holotype and type locality: Specimen in Plate 1, Figures 1 - 2 ("England Finder" coordinates: O46°3', sample R23, Bed 24, locality Rumst - Terhagen from the Belgian Rupelian (Early Oligocene) type area. The holotype is deposited in Niedersächsisches Landesamt für Bodenforschung, Hanover.

Dimensions: Holotype: central body 85 microns, spines max. 48 microns long. Layer 24 in Kruiubeke and Rumst-Terhagen Quarries (six specimens): central body 85-120 (mean 99) microns, spines 40-48 (mean 43) microns. Well "B" (Figure 1) sample "XX30m" (30 specimens): central body 68-90 (mean 77) microns, spines 30-48 (mean 36) microns.

Description: Large central body with two types of sculpture: (a) a low (micro)granulate-reticulate sculpture and (b) a higher sculpture with long, mainly gonal spines connected by low, often indistinct sutural ridges, which continue up the shafts of the spines where they may be hardly visible. The archaeopyle primarily includes the dorsal precingular plate, but primarily sutures radiating from plate break-up, so that the "archaeopyle" ap-

pears to include more plates, and even sutures at a dorsal hypocyst plate may break up.

Remarks: The sculpture of the central body wall varies from minute microreticulate-microgranulate (Plate 1, Figures 1, 2, 4, 7) to more rough reticulate to granulate (Plate 1, Figures 3, 5, 6). It is worth noting that this variation in sculpture occurs both in Belgian and Danish North Sea material, suggesting that it is not valuable for a taxon differentiation.

As noted under the remarks concerning the genus, the break-up around the archaeopyle might involve a varying number of sutures. Plate 1, Figure 4 is an example of extreme degree of break-up. The other extreme with minimal break-up is exhibited in Plate 1, Figure 6 here and by MANUM et al. (1989, Plate 17, Figure 5), where it is doubtful if any sutures radiating from the archaeopyle break up at all.

The strong variation of the "archaeopyle" is unusual within one species or even within one genus of dinoflagellate cysts. However, the other distinctive characters (size, long gonal spines, and sculptured central body) of *Pseudospiniferites manumii* observed in many specimens in the same sample indicate that these belong to one population/species. The variation of the "archaeopyle" is therefore not considered to be useful for taxon differentiation in this particular case.

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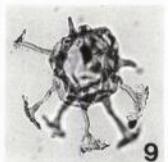
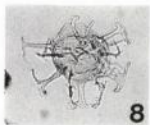
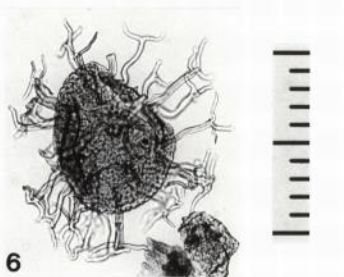
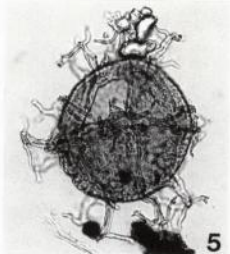
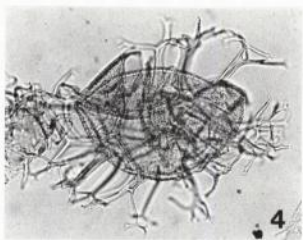
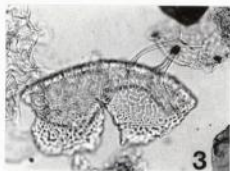
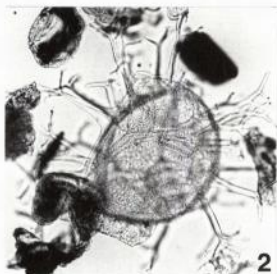
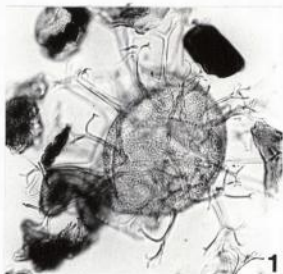
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Plate 1: Magnification approx. x 500. Size meter 100 micron

Figures 1-4: *Pseudospiniferites manumii* n.gen. n.sp. from Belgium, Figures 1-2 holotype, sample R23. Figure 3 sample R17. Figure 4 sample K7
Figures 5-7: *Pseudospiniferites manumii* n.gen. n.sp. from Danish North Sea, all samples "XX30 m"
Figure 8: *Enneadocysta pectiniformis* Danish North Sea sample "XX30 m"
Figure 9: *Areosphaeridium diktyoplakum* Danish North Sea sample "XX30 m"



Miocene Nassariid Zonation

A New Tool in North Sea Basin Neogene Biostratigraphy

► Karl Gürs

Abstract

From 15 drillings taken in Schleswig-Holstein, Lower Saxony, Westphalia and Mecklenburg-Vorpommern (northern Germany), a new biostratigraphic zonation has been developed. For this zonation, gastropods were used from the *Nassarius* (s. lat.) genus, which are, for the most part, highly facies independent. Two new species are described, *N. incisireticulatus* and *N. wieneri*. The new zonation is superior to benthic molluscan zonations used in the past, since it avoids the misinterpretation of facies changes as chronostratigraphical boundaries.

Kurzfassung

Auf Grundlage von 15 Bohrungen aus Schleswig-Holstein, Niedersachsen, Nordrhein-Westfalen und Mecklenburg-Vorpommern (Norddeutschland) wird eine neue biostratigraphische Zonengliederung erarbeitet. Sie basiert auf der Verbreitung der Arten der Gastropodengattung *Nassarius* (s. lat.), die zum größten Teil weitgehend faziesunabhängig sind. Zwei neue Arten, *N. incisireticulatus* und *N. wieneri* werden beschrieben. Die neu eingeführte Zonierung ist den bisher genutzten benthischen Mollusken-Zonierungen überlegen, da sie den Fehler der Interpretation von Fazieswechseln als Zeitgrenzen vermeidet.

Keywords

Mollusca, Gastropoda, Nassariidae, new species, biostratigraphy, Miocene, North Sea Basin

Introduction

Nassariids are marine gastropods which live primarily as scavengers in soft bottom environments. In particular, the members of the *Nassarius* (s. lat.) genus are generally highly facies independent and are, therefore, the most common gastropods found in the Upper Oligocene and Neogene North Sea Basin. Normally, huge

amounts of shells are found, even in small samples. This would predestine Nassariids to become biostratigraphical index fossils. On the other hand, high variability within single populations makes proper identification problematic. In addition, shell characters have been used in the past to distinguish species and even genera, which have proved to vary infraspecifically. Other suitable characteristics, such as the apex or the aperture, were often neglected because they were rarely preserved. WIENER (2002) made a re-evaluation of characteristics of the Nassariids from the time span around the Hemmoorian/Reinbekian boundary from some drillings in the Lower Rhine Embayment and determined evolutionary trends, thus enabling a correlation of boreholes and a determination of the Hemmoorian/Reinbekian boundary.

Research on 18 drilling sections (seven of which have been cored) and two outcrop sections of Miocene strata in northern



Figure 1: Sketch map of localities investigated (*1 cored boreholes, ** outcrop sections, without mark: straight flush drillings): 1 Lübtheen 27/82*, 2 Schwarzenbek 1/96*, Groß Pampau 1*, Groß Pampau**, 3 Schönberg/Mecklenburg, 4 Itzstedt, Heilshoop, 5 Hindorf, Achtrup/Tettwang, Ahrenshöft, 6 Levensau N*, Levensau S**, 7 Wilenscharen, Burg/Dithm., 8 Kaltenkirchen, 9 Borchelhof, 10 Twistringen**, 11 Bochoit KB15*, 12 Rhede*, 13 Obspringen

and western Germany showed that many species have a much shorter range than stated by MOSTAFAVI (1978) or HINSCH (1986) and that many more species existed in the Miocene North Sea Basin than previously recognized. In the following systematic outline, several stratigraphically important species (including two new species) are characterized and their range within North Sea Basin stratigraphy is discussed.

Systematic Outline

Mollusca
Gastropoda
Orthogastropoda
Neogastropoda
Nassariidae

Nassarius schlotheimi (BEYRICH 1854)

Plate 1 Figures 1, 2

N. schlotheimi is the oldest known Miocene species of the genus which was already in existence in the Upper Oligocene. It is interpreted as a descendant of *N. pygmaeus*, an Atlantic immigrant from the beginning of the Chattian, by JANSSEN (1979). It differs from *N. schroederi* by the much broader conical, nearly dome-shaped protoconch. Typical *N. schlotheimi* begins with a teleoconch sculpture of very sharp and dense axial riblets with six spiral furrows only visible in the spaces between. Very soon the riblets become more widely spaced and more rounded, the spiral furrows becoming a more evident feature. The axial ribs become flatter and may vanish in the younger whorls. They are crossed by the spiral furrows on the younger part of the shell. The number of axial ribs per whorl varies from 14 to 26 on younger whorls. On the first teleoconch whorl the number of axial riblets may exceed 40. The number of spiral furrows grows to 10 plus 10 on the base.

BEYRICH (1854) subsumed a wide variety of forms from the Late Oligocene and Early Miocene under the name of *Nassa schlotheimi*. As this species differs stratigraphically, and more than one trend of phylogenetic development can be seen, it is unclear whether further investigations may lead to a splitting of this species into stratigraphical species or subspecies. In this case, the form to which the name should be applied remains a matter of discussion. It can only be stated that Beyrich himself excluded forms with an enlarged spindle plate which developed since the

latest Oligocene and can clearly be separated from *N. schlotheimi* in the late Vierlandian. They are attributed to *N. sulcatus* (KAUTZKY 1925).

Nassarius schlotheimi forma *turbinellus* sensu MOSTAFAVI (1978, Plate 1 Figure 4) (non BROCCHI 1814)

During the Vierlandian a form developed from typical *N. schlotheimi*, differing on the basis of a coarser, more pronounced axial sculpture with a constant number of 14 to 16 ribs per whorl. The protoconch is nearly dome-shaped, as is the case for typical *N. schlotheimi*, but the uppermost part of the teleoconch whorls tends to comprise a right angle. This form leads to *Nassarius coronatus* of the basal Hemmoorian.

Nassarius sulcatus KAUTZKY 1925

Plate 2 Figures 1-3

As mentioned under *Nassarius schlotheimi*, a form developed from this species with a small very high conical protoconch and an enlarged spindle plate exceeding the suture. It also differs from *N. schlotheimi* in its larger dimensions and the increasing number of axial ribs per whorl on the teleoconch. Younger forms from the Hemmoorian have more pronounced axial ribs, but older forms still coexist with *N. schlotheimi* and have somewhat flatter axial ribs, very similar to the ribs found in this species.

Nassarius incisireticulatus n. sp.

Plate 3 Figure 10

1978 *Hinia* (*Hinia*) *holsatica* - MOSTAFAVI (partim, Plate 2 Figure 2) (non BEYRICH 1854)

Holotypus: Plate 3 Figure 10, SMF 323667, ex coll. LANU

Locus typicus: Drilling Heilshoop HL2, 177-180m

Stratum typicum: grey silty fine sand of the Vierlandian

Derivatio nominis: incidere (lat.)=cut in, engrave, from the engraved appearance of the sculpture, reticulatus (lat.)=net sculpture

Diagnosis: A *Nassarius* with a reticulate sculpture, very pronounced spiral grooves, 7 to 8 regular rib-like teeth on the outer lip, none on the inner lip and no enlarged spindle plate.

Differential diagnosis: Differs from all other Miocene *Nassarius* species on the basis of sculpture.

Material: Holotype, Paratypes: Drilling Heilshoop HL2, 198-201 (1), Drilling Brodersdorf, 195-197.5 (3), 200-202.5 (1), 205-207.5 (1) all coll. LANU.

Description: Shell approx. 6 to 7mm high, ovate conical, height/width ratio 1.85. Protoconch smooth of 3.25 to 3.5 whorls, sometimes with growth lines on the last 0.5 whorl, small, conical. Nucleus small, 1/7 of protoconch diameter, slightly prominent. Border to teleoconch sharp. Teleoconch of 3.5 to 4 slightly convex whorls, ratio of height/height of last whorl 1.75. Sculpture of 8 axial ribs on the first quarter whorl without spiral ornamentation, afterwards 22 increasing to 26 small and flat, slightly opisthocline axial ribs per whorl, crossed by 4 to 5 spiral grooves, giving the impression of a reticulation. Base with six additional, wider grooves. Aperture ovate, outer lip not thickened, with 7 to 8 small, rib-like teeth. Inner lip well developed but without teeth. No enlarged spindle plate. Short siphonal canal.

Remarks: This species resembles species of the *Amyclina* genus because of the dominance of the spiral grooves over the axial sculpture and the flat shape of the axial ribs which create the impression of a plain surface cut by a net of small furrows. This pattern is unique among Miocene *Nassarius* species so that it is a very easy to determine species. It is so different from *N. holsaticus* in the form of the first teleoconch whorls, the aperture and the sculpture that it can not be taken to be related or the forerunner of this species.

***Nassarius coronatus* (MOSTAFAVI 1978)**

Plate 1 Figures 8-10

N. coronatus is the most common *Nassarius* species of the lowermost Hemmoorian. It is very easy to determine by a very large broad conical protoconch, an angular shoulder below the suture of the teleoconch whorls, very sharp angular axial ribs (10 to 14 per whorl) ending in short spines or thorns at the shoulder and a nearly reduced spiral sculpture. *N. coronatus* has a very short range and vanishes within the lower Hemmoorian. As stated above, this species develops from *Nassarius schlotheimi* forma *turbinellus* sensu MOSTAFAVI (1978). The very slow character transformation, together with high infraspecific variability of *N. schlotheimi*, leads to the existence of specimens very rarely found in the upper Vierliandian which may

easily be confused with *N. coronatus*. The protoconch of these forms is more conical and the nucleus not as prominent as in *N. coronatus*. Nevertheless, single specimens may have a teleoconch sculpture within the variability of *N. coronatus*. As the point of speciation can not be determined by morphological characters in the range chart, the occurrence of *N. coronatus* is dotted into the Vierliandian.

***Nassarius andersoni* (NORDSIK 1972)**

Plate 1 Figure 11

Another conspicuous species, *N. andersoni*, can be found from the lower Hemmoorian into the upper Hemmoorian. The nomenclature of this species is clarified by WIENRICH (2001). It has a protoconch similar to *N. coronatus*, but convex teleoconch whorls with a very broad subsutural furrow and two other spiral furrows are less dominant below. It may have evolved from *N. coronatus*.

***Nassarius schroederi* KAUTSKY 1925**

Plate 1 Figures 3, 4

Nassarius schroederi was often erroneously made synonymous with *N. schlotheimi*, which it greatly resembles superficially. Surprisingly, *N. schroederi* develops from *N. coronatus*, as is shown by many populations of the early Hemmoorian, where all transitional forms in teleoconch sculpture can be seen. The only remaining distinguishing feature is the protoconch, which is much smaller and more slender in *N. schroederi*. *N. schlotheimi* also differs from *N. schroederi* in the protoconch and, additionally, in a less angular base of the shell. Furthermore, *N. schroederi* has a more unimodal sculpture which does not differ from the older to the younger whorls.

***Nassarius cimbricus* (SORGENFREI 1958)**

Plate 1 Figures 13, 14

N. cimbricus is the classical index fossil of the lower Hemmoorian, although not present in its lower part. It has a very small broad conical protoconch and a conspicuous teleoconch sculpture of 12 sharp, pronounced axial ribs per whorl and two sharp spiral ribs building short spines at the crossing points. At the base there are four additional spiral ribs, weaker and with a shorter distance in between than the others, but also form spines at the crossing points with the axials.

The Tritonella subgroup

Members of this group are easily determined by a round aperture surrounded by a strong lip, a large apertural callus, strong and well-rounded widely spaced axial ribs as well as an even spiral sculpture. The protoconch differs in form from dome-shaped to slender conical and paucispiral with two whorls to multispiral with 3.5 whorls. The spiral sculpture differs from sharp and pronounced, running over the axials, to washed and even absent. There are so many forms that the number of species is much higher than can be judged from the literature. Most authors have different opinions as to how species names should be applied. The following list gives some of the names mentioned in the text and probable synonyms:

N. serraticosta sensu SORGENFREI 1958 non BRÖNN 1831, (Plate 3 Figure 5)
= *N. cattuli* sensu WIENRICH non BELLARDI 1882

N. tenuistriatus sensu SORGENFREI 1958 (Plate 44 Figure 143) non BEYRICH 1854, (Plate 3 Figures 1, 2)
= *N. serraticosta* sensu MOSTAFAVI 1978 non BRÖNN 1831
= *N. sp. 1* WIENRICH (Plate 102 Figure 5)

N. woodwardi sensu SORGENFREI 1958 non HARMER 1913, (Plate 3 Figures 3, 4)
= *N. subobesus* sensu SORGENFREI 1958 non DEGRANGE-TOUZIN 1894?
= *N. woodwardi* sensu MOSTAFAVI 1978 non HARMER 1913
= *N. subobesus* sensu MOSTAFAVI 1978 non DEGRANGE-TOUZIN 1894?

N. woodwardi sensu WIENRICH 2001 non HARMER 1913
= *N. cavatus* sensu ANDERSON 1964 non BELLARDI 1882

This shows part of the confusion within this group and may be enlarged by taking the works of VOORTHUYSEN 1944 and NORDSIEK 1972 into consideration, which must be done if a revision of this group is to be carried out.

Some of the species of this group have stratigraphical value, such as *Nassarius* sp. A (Plate 3 Figure 5) for the lower Hemmoorian, *Nassarius serraticosta* sensu MOSTAFAVI (Plate 3 Figures 1, 2) and *N. woodwardi* sensu SORGENFREI (Plate 3 Figures 3, 4 as *subobesa*) for the lowermost to lower upper Hemmoorian, *N. cavatus* sensu WIENRICH

(Plate 3 Figure 6) for the uppermost Hemmoorian until lowermost Langenfeldian, *N. twistringensis* (Plate 3 Figure 8) for a very short range in the middle of the Reinbekian or *N. sp. B* (Plate 3 Figure 7) for the early Late Miocene. Nevertheless, much work must be completed before this group can be properly integrated into the Nassariid zonation.

Nassarius bochoftensis (BEYRICH 1854)
Plate 1 Figures 6, 7

N. bochoftensis is one of the most common gastropods of the upper Hemmoorian and lower Reinbekian. It is treated in detail by WIENRICH (2001). In the upper Reinbekian, a very conspicuous variety, which comprises nearly no spiral sculpture, exists and characterizes this time interval. In this form the sharp axial ribs build a shoulder and are crossed by one weak spiral furrow just below this shoulder. Above the furrow they form very short spines.

Nassarius tenuistriatus (BEYRICH 1854)
Plate 2 Figure 4

WIENRICH (2001) clarifies the differentiation of *Nassarius tenuistriatus* from the older *N. sulcatus* and gives its stratigraphical range, which can be confirmed here. The species is a good index fossil for the Reinbekian. References of stratigraphically older specimens belong, without exception, to *N. sulcatus*, younger references have not been able to be verified up to now. In the shape of its protoconch, its spiral sculpture and its aperture, this species most resembles *N. wienrichi* described later. It differs on the basis of more convex whorls and more pronounced axial ribs. It seems to be the forerunner of *N. wienrichi*.

Nassarius voorthuysemi (JANSE & JANSSEN 1983)
Plate 1 Figure 12
cf. WIENRICH (2002)

Nassarius karinae WIENRICH 2001
Plate 3 Figures 11, 12
cf. WIENRICH (2001)

Nassarius levensauensis (HINSCH 1987)
Plate 3 Figure 8

Only juvenile and fragmentary specimens from this species were known to HINSCH (1987). Since then, some nearly adult specimens from Lübtheen 27/82 drilling have become available and have been analysed.

***Nassarius wiennrichi* n. sp.**

Plate 2 Figures 5, 6

1987 *Hinia* (*Hinia*) cf. *pseudoturbineola*
- HINSCH, Plate 1 Figure 9 (non MOSTAFAYI
1978)

Holotypus: Plate 2 Figure 6, SMF 323668,
ex coll. GÜRS

Locus typicus: Groß Pampau clay pit, SE
Holstein

Stratum typicum: dark grey, silty fine
sandy clay of the Langenfeldian

Derivatio nominis: After GÜNTHER WIENRICH,
Goch

Diagnosis: A *Nassarius* with six ribbon-like
spiral chords running over 14 to 17 axial
ribs, a small shoulder on the younger teleo-
conch whorls, an aperture with a thickened
outer lip with 13 small, rib-like teeth, interior,
inner lip with only one weak tooth and no
enlarged spindle plate.

Differential diagnosis: Differs from *Nas-
sarius andersoni* on the basis of the higher
number of spiral ribbons and axial ribs per
whorl and a different protoconch, from *N.
tenuistriatus* on the basis of the straight,
shouldered whorls and more spirals per
whorl, from *N. sylvensis* on the basis of
the presence of axial sculpture from the
beginning of the teleoconch sculpture and
the absence of an enlarged spindle plate.
All other Miocene *Nassarius* species look
obviously different.

Material: Holotype, 87 Paratypes (coll.
GÜRS): Ohle clay pit, Groß Pampau; other
material: numerous more or less fragmen-
tary shells from several drillings taken in
Schleswig-Holstein.

Description: Shell approx. 7 to 12mm high,
conical, height/width ratio 1.85 to 2.3.
Protoconch of medium size (approx. 1mm
in diameter), smooth with 2.75 to 3.25
whorls, ovate conical. Nucleus small, 1/8 of
protoconch diameter, prominent. Border to
teleoconch precise. Teleoconch of 3.5 to 4
slightly convex shouldered whorls, ratio of
height/height of last whorl 1.6 to 1.7. Sculpture
of 14 to 17 axial ribs and six spiral rib-
bons with spaces between them as broad
as the ribbons. The first ribbon below the
suture has a space twice as wide as the fol-
lowing space. Between this and the suture,
a small spiral chord intercalates on the
younger whorls. Spirals run well over the
ribs. Axial ribs run well onto the base of
the shell, vanishing very suddenly near the
siphonal canal. Base with 6 to 9 additional,
smaller and more widely spaced spiral rib-
bons. Aperture ovate, outer lip thickened,

with 13 small, regular, rib-like teeth, the
tooth next to the siphonal canal is larger
than the others. Inner lip well developed
with one weak single tooth at the apical
side, one large specimen with three small
teeth below that tooth. Spindle plate not
enlarged. Short but strong siphonal canal.

Remarks: This species is very extraordinary
and most resembles *N. tenuistriatus*, which
is plausibly the ancestor. It has its ribbon-
like spiral sculpture, the shape of the axial
ribs and the broad space between the first
two spiral ribbons below the suture in
common with *N. andersoni*, which was be-
lieved by HINSCH (1987) to be the ancestral
species. Nevertheless *N. wiennrichi* has 2 to
3 additional spiral ribbons at the whorls,
more axial ribs per whorl and, in particu-
lar, a smaller, more conical protoconch. In
Groß Pampau, where this species is most
common, it coexists with a form resem-
bling *N. sylvensis*, and in faunas of the Pin-
neberg Formation one single specimen of
this species was found, indicating that *N.
wiennrichi* and *N. sylvensis* have coexisted
for a long time and are not related. This
species is an index fossil of the middle and
the upper Langenfeldian (sensu SPIEGLER &
GÜRS 1996-Lüneburgian and Langenfeldian
s. str. of HINSCH 1987).

***Nassarius holsaticus* (BEYRICH 1854)**

Plate 3 Figures 13, 14

For distinguishing features cf. WIENRICH
(2001)

***Nassarius sylvensis* (BEYRICH 1854)**

Plate 3 Figures 8-10

This is the most common species of the
uppermost Langenfeldian until the Sylltian,
i.e. the greatest part of the Upper Miocene.
Two drillings, Obspringen and Lübtheen
27/82, show a greater number of individu-
als of this species already in much older
samples. As this species is most common
in sandy facies this is due to the proximal
position of this drilling in the NSB.

***Nassarius silesiawia* (RASMUSSEN 1966)**

In shape and sculpture this species very
much resembles the living type species
of the *Hinia* genus: *Hinia reticulata* (LIN-
NAEUS 1758). It is typical for sandy facies
and has been present since the middle
Langenfeldian but is most common in the
uppermost Miocene developed in the area
investigated. This is due to the shallowing
of sea levels in the area.

Stratigraphical Results

New Zonation

Occurrences of the above-mentioned species in the drillings investigated were plotted against depth and compared with other biostratigraphic data. On the basis of this data, a range chart was developed. In this chart, nine zones and one subzone were defined. These are:

1. *Nassarius schlotheimi* zone

This is the partial range zone of *N. schlotheimi* from its first occurrence, replacing *N. pygmaeus* in the middle Chattian, until the first occurrence of *N. incisireticulatus* in the Vierlandian. This zone may be restricted to a shorter range as there is evidence that more species with possible stratigraphical value existed in the Chattian. Throughout the entire zone, a forma exists with a much smaller and taller protoconch and a different shell form than that of *N. schlotheimi*. This forma has a very similar but more regular sculpture and develops to *N. sulcatus*, but can not clearly be separated as a different species any earlier than in the following zone.

2. *Nassarius incisireticulatus* zone

This is the total range zone of *N. incisireticulatus*. The upper boundary also coincides with the first common occurrence of *N. coronatus*. In addition to *N. incisireticulatus*, *N. schlotheimi* and *N. sulcatus* are common. *N. meyni* is a rare species of this zone. Shouldered forms of *N. schlotheimi*, which were identified as *N. turbinellus* by MOSTAFAVI (1978), exist. *N. schlotheimi* has its last occurrence at the end of this zone.

3. *Nassarius coronatus* zone

This zone begins with a nearly entirely different *Nassarius* fauna. It begins with the last occurrence of *N. schlotheimi* and ends with the first occurrence of *N. cimbricus*. First occurrences of *N. serraticosta* and *N. subobesa* s. MOSTAFAVI as well as first occurrences of *N. schroederi* and *N. andersoni* can be observed in this zone. *N. sulcatus* is common. The species for which this zone is named is the most abundant in all samples examined.

4. *Nassarius cimbricus* zone

This is the total range zone of *Nas-*

sarius cimbricus. Because of its very conspicuous form *N. cimbricus* was established as index fossil of the lower Hemmoorian at a very early date, although it occurs only during a very short time span. *N. coronatus* vanishes in this zone, but other fauna remains the same.

5. *Nassarius schroederi* zone

This is the partial range zone of *N. schroederi* spanning the time from the last occurrence of *N. cimbricus* to the last occurrence of *N. schroederi*. The zone is also limited by the last occurrence of *N. andersoni* and the first occurrence of *N. voorthuyseni*. The first occurrences of *N. karinae* and *N. karinae* lie within the zone. The coexistence of these species with *N. schroederi* indicates upper Hemmoorian or Oxlundian.

6. *Nassarius voorthuyseni* zone

This is the total range zone of *Nassarius voorthuyseni*. The first occurrence of *N. voorthuyseni* seems to be identical with the last occurrence of *N. schroederi*. Also characteristic of this zone are the members of the *N. cattuli* group, with the exception of *N. twistringensis*. First *N. prismaticus* can be observed within this zone.

7. *Nassarius bochohltensis* zone

This zone spans a time from the last occurrence of *Nassarius voorthuyseni* until the last occurrence of *N. bochohltensis*. We know only very little about the fauna of this time, since anoxic sediments, containing nearly no fauna, were deposited throughout greater parts of this interval. Rich faunas from the Twistringen beds are known from the older parts of this zone, thus yielding the index species *N. twistringensis*. In this portion, *N. tenuistriatus* and *N. karinae* are also found. The youngest portion contains highly conspicuous forms of *N. bochohltensis* with a very well-developed spiny shoulder and no spiral ornamentation except one weak furrow shortly below the shoulder. In addition to this species only *N. tenuistriatus* can be observed until the younger part of this zone.

8. *Nassarius levensauensis* zone

This zone is the zone from the last occurrence of *Nassarius bochohltensis*

until the last occurrence of *N. levensauensis*. The oldest parts of this zone, documented in the Hohen Woos mica clay or in the section 248.6 m to 217.4 m of the Lübtheen 27/82 well, had no *N. levensauensis*, but *N. cavatus*. *N. levensauensis* can be observed for the first time in the middle of this zone. Two additional species of the genus were observed in the sediments belonging to this zone i.e. *N. aff. sylvensis* and *N. serraticosta* sensu WIENRICH (2001). Even though *N. prismaticus* was not observed in this zone it should potentially be present as it occurs in strata below and above. It is most likely that it was more facies-bound to coarser sediments and has not been observed in the past because of the rarity of these sediments in this time interval.

9. *Nassarius sylvensis* zone

This is the interval from the last occurrence of *Nassarius levensauensis* until the end of the Miocene. The younger sediments of the "Morsum Kliff" sandstone yield a different, probably lowermost Pliocene, *Nassarius* fauna, indicating that the upper boundary of this zone lies around the Miocene/Pliocene boundary. In the basal portion of this zone *N. sylvensis* is not present, only specimens interpreted as forerunners and identified as *N. aff. sylvensis*. Later on, it becomes common only in sandy facies, and in clay facies it can become extremely rare. Here *N. wiennrichi* is a good substitute marker and at the same time forms a subzone as it becomes very rare in the upper Langenfeldian and disappears around the Gramian/Langenfeldian boundary. *N. slieswicia* is also present in more sandy facies. *N. serraticosta* and other species of the *Tritonella* group can be found only sporadically in addition to *N. sylvensis*. They become more frequent in shallower water. Here, *N. prismaticus* also becomes very abundant. Generally, *N. holsaticus* can be found together with *N. sylvensis*.

9.1 *Nassarius wiennrichi* subzone

This subzone has its lower boundary with the last occurrence of *Nassarius levensauensis* and its upper boundary with the first common occurrence of *N. sylvensis*. During the time around the Upper/Middle Miocene boundary, *N. wiennrichi* is by far the most common

Nassarius species in the faunas observed from clay facies. Nevertheless, the definition of this zone is somehow difficult as *N. sylvensis* coexists together with *N. wiennrichi* and a form best determined as *N. aff. sylvensis*. These are very rare in the clay facies but much more common than *N. wiennrichi* in the sandy facies. Somewhere around the Langenfeldian/Gramian boundary *N. sylvensis* seems to replace *N. wiennrichi* in the clay facies as well. Only single specimens of *N. wiennrichi* are found above the upper boundary of this subzone among thousands of *N. sylvensis* specimens.

Stratigraphic Correlations

Unfortunately no investigations on nanoplankton or dinoflagellate cysts were undertaken in the drillings examined, and correlation data were achieved using pteropods (GÜRS & JANSSEN 2002), bolboforma (zonation after SPIEGLER 1999), planktonic and benthic foraminifera as well as classical molluscan stratigraphy (HINSCH 1988). The correlation results presented here are treated in terms of regional stages based on mollusca.

Vierlandian

The Vierlandian was defined by HINSCH (1986) as the zone of *Lyonsia norvegica*, *Ephora wiechmanni* and *Nassarius meyni*. This definition is not very precise, since the first species is a living species from the northern Atlantic, the second species was encountered in Neochattian deposits as well as fragments of an *Ephora* in classical Hemmoorian faunas and the last species is too rare to be taken as index fossil. *N. meyni* is observed neither in the lower parts of this stage nor in the uppermost parts. Practicable boundary criteria must be found, for example the last occurrence of *N. schlotheimi* or the first common occurrence of *Nassarius coronatus*. On the basis of this criteria, the upper boundary of the *N. incisireticulatus* zone represents the Vierlandian/Hemmoorian boundary. The first appearance of the *Vaginella austriaca* pteropod species, which can be correlated to the Middle Burdigalian, correlates very well with this boundary. The *N. incisireticulatus* zone contains the typical Early Burdigalian pteropod *Diacrolinia aquensis*.

Hemmoorian

The very detailed subdivision of the Hemmoorian into three zones does not reflect

the subdivision in the Behrendorfian and the Oxlundian substage, which is mainly a facies boundary. The upper boundary of the *Nassarius cimbricus* zone is below the Behrendorfian/Oxlundian boundary. The occurrence of typical Langhian pteropods, such as *Diacriolina aurita* or *Vaginella lapugyensis* in Winterswijk-Miste, which belongs to the *N. schroederi* zone, shows a Middle Miocene age for this zone, or at least the upper part of this zone, since the Miste fauna already contains *N. bochohtensis* and therefore belongs to the upper part of this zone. The *N. coronatus* zone and the *N. cimbricus* zone most likely correlate to the late Burdigalian.

Reinbekian

The Hermmoorian/Reinbekian boundary is very well defined by a drastic change in fauna (HINSCH 1986) due to a rapid sea-level rise in the North Sea Basin. Nannoplankton studies from drilling sections in the lower Rhine valley show a nearly perfect fit of this boundary with the NN4/NN5 boundary (MÜLLER internal report for the Geological Survey NRW 2000). The *Bolboforma reticulata* zone begins a little earlier in the *Nassarius schroederi* zone. The *N. voorthuyseni* zone lies entirely in the lower *B. reticulata* zone, while the *N. bochohtensis* zone covers part of the lower and the entire upper *B. reticulata* zone.

Langenfeldian

The Langenfeldian was defined by HINSCH (1986) as the total range interval of *Astarte vetula*. Later the Reinbekian/Langenfeldian boundary was defined by HINSCH (1987) by the first occurrence of *Nassarius levensauensis*. Both boundaries do not fit together, because *Astarte vetula* already occurs in the *Bolboforma danielsi* zone, while the first occurrence of *N. levensauensis* is within the *B. badenensis* zone. No appropriate boundary criteria for the Reinbekian/Langenfeldian boundary have, therefore, been defined thus far. Due to the rarity of macrofauna in this interval, a proposal could be the *B. reticulata*/*B. danielsi* zone boundary. The molluscan range chart of the Schwarzenbek 1/96 drilling shows the first appearance of *N. levensauensis* in the *B. danielsi* zone (GÜRS & SPIEGLER 1999) but this is not confirmed by any other drilling, such as Lübtheen 27/82 or Obspringen, and the fragment on which the occurrence of *N. levensauensis* at 12.00-12.25 m is based is so small and provides such sparse diagnostic information that it might belong to a different species. In the Lübtheen

27/82 drilling *N. levensauensis* covers the stratigraphical range until the lower part of the *B. compressispinosa* zone (HINSCH 2000, GÜRS & SPIEGLER 2000). The boundary of the lower Langenfeldian (Levensauian) and mid-Langenfeldian (Lüneburgian) fits to the *N. levensauensis*/*N. syltensis* zone (subzone *N. wienrichi*) boundary. This boundary lies within the *Bolboforma compressispinosa* zone. The boundary of the *N. wienrichi*/*N. syltensis* zone is high in the upper Langenfeldian and lies within the *Bolboforma laevis/capsula* zone.

Gramian

The Gramian stage is defined by the total range of *Aquilofusus semiglaber* and *Astarte reimersi*. The entire stage lies within the *Nassarius syltensis* zones. It also lies within the *Bolboforma metzmacheri* zone

Syltian

The Syltian stage is defined by the total range of *Aquilofusus eximius* and *Astarte rollei*. The stage lies completely within the *Nassarius syltensis* zone and contains *Bolboforma* floras of both *B. metzmacheri* and *B. intermedia* zone.

Discussion

It is surely not an adequate solution to place all the Nassariid gastropods listed here in one *Nassarius* genus. In fact, after a revision of this group, none of the species would be left in this genus. Unfortunately, in the past, highly contradictory or even infraspecifically varying criteria have been used for the differentiation of genera. By viewing Oligocene "*Nassarius*" species from northern German Chattian strata and operating on the basis of the hypothesis presented by R. JANSSEN (1979) that *N. schlotheimi* is an offspring of *N. pygmaeus*, it is well possible that all "*Nassarius*" species of the North Sea Basin Miocene except *N. prysmaticus*, originate from *N. pygmaeus*. The true connection between the species can only be solved if all the other European species of this group are taken into consideration. This goes far beyond the goal of this work and must be done separately.

Gastropods of the *Nassarius* genus in the sense of this study are a good tool for stratigraphy in the North Sea Basin Miocene. This is due to high evolutionary rates and potential, the abundance of most species and the high level of facies inde-

lower boundary of *A. belgica* zone = lower boundary of *Nassarius coronatus* zone, lower boundary of *A. hinschi* zone = lower boundary of *N. bocholtensis* zone (the sample of the type specimens of *A. hinschi* yielded *N. bocholtensis* and *N. twistringensis* but no *N. voorthuyseni*), range of *A. babylonelliformis* zone = range of *N. levensauensis* zone, range of *A. rischi* zone = range of upper *N. syltensis* zone. Only the lower boundary of the *A. partschi* zone lies within the *N. schroederi* zone, thus permitting a finer resolution in that interval. It is possible that this boundary coincides with the first occurrence of *N. bocholtensis* and/or *N. karinae*.

The comparison of the Nassariid Zonation to the Benthic Mollusc Zonation (BM) of HINSCH (1988) shows that the lower boundary of *N. coronatus* zone = lower boundary BM18A, lower boundary *N. voorthuyseni* zone = lower boundary BM19 and lower boundary *N. syltensis* zone = lower boundary BM20A.

At first glance, the well-fitting boundaries are suspicious, since they appear to result from an imperfectness of fossil record displaying hiatus, but the fauna of the entire Miocene succession is very well documented in several parts of the North Sea Basin and in different facies. Therefore, it is much more likely that an acceleration of the evolutionary rate of several groups is triggered by the same events going back to the factors listed above. Some of these events are already known, such as the massive warming at the Vierlandian/Hemmoorian boundary (HINSCH 1986) or the even more effective cooling at the Reinbekian/Langenfeldian (Levensauian) boundary (HINSCH 1986, GÜRS 2001), but also the dramatic sea-level rise at the Hemmoorian/Reinbekian boundary, whereas others remain unidentified.

Conclusions

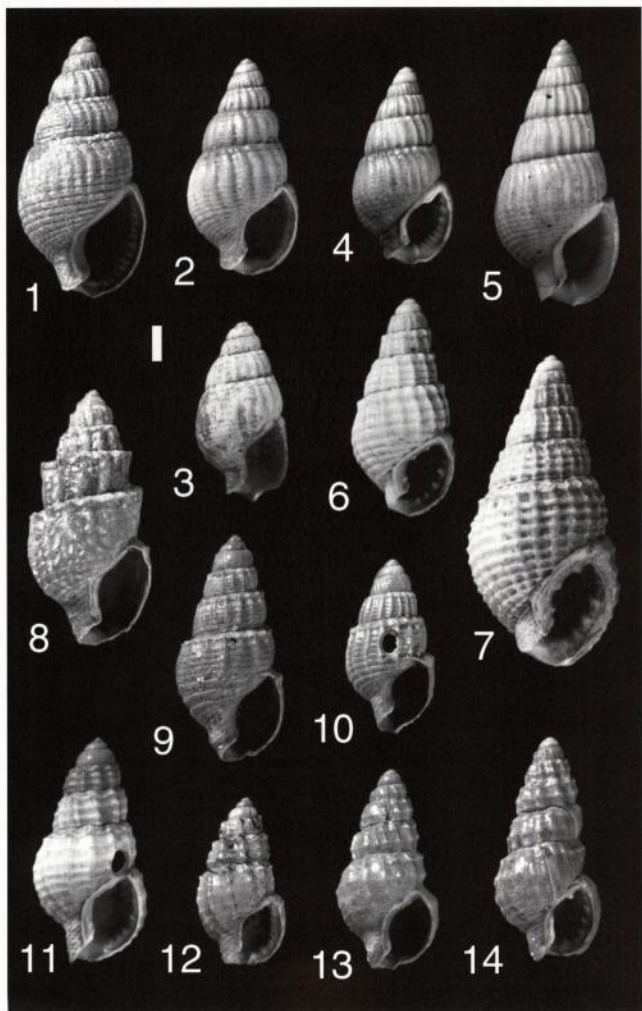
Nine Nassariid zones can be erected from the species of the *Nassarius* genus for the North Sea Basin Miocene. Three zone boundaries can be used for a more precise definition of the regional stage boundaries, i.e. the lower boundary of the *Nassarius coronatus* zone for the boundary between Vierlandian and Hemmoorian, the lower boundary of the *N. voorthuyseni* zone for the boundary between Hemmoorian and Reinbekian and probably the lower boundary of the *N. levensauensis* zone for the

boundary between Reinbekian and Langenfeldian.

Looking at the taxa used, it is fairly obvious that some of them have a phylogenetic connection. Thus, *Nassarius coronatus*, *N. turbinellus* sensu MOSTAFAVI, *N. schroederi* build one complex going back to *N. schlotheimi*, *N. sulcatus*, *N. tenuistriatus* and *N. wienrichi* build one lineage, *N. subobesus*, *N. serraricosta*, *N. woodwardi*, *N. cattuli* all sensu MOSTAFAVI (1978) as well as *N. woodwardi* and *N. cavatus* sensu WIENRICH (2001) belong to one group. This group was attributed to the *Tritonella* subgenus (with *T. incrassata* (MÜLLER 1774) as type) by previous authors; this might be a proper placement, but other species, such as *N. tenuistriatus* and *N. voorthuyseni*, were also included in this subgenus, and they certainly do not belong there.

Plate 1: *Nassarius* species from the North Sea Basin, scale bar = 1mm (Figures 1, 2, 4, 5, 11, 13, 14: LANU collection, all others: author's collection)

- Figure 1: *Nassarius schlotheimi*, Heilshoop HL2 drilling, 192-195 m, Vierlandian
 Figure 2: *Nassarius schlotheimi*, Schönberg/Mecklenburg 3/95 drilling, 229-230 m, Vierlandian
 Figure 3: *Nassarius schlotheimi*, erratic boulder, Damsdorf, Vierlandian
 Figure 4: *Nassarius schroederi*, Viöl 1/96 drilling, 102,5-105 m, upper Hemmoorian
 Figure 5: *Nassarius schroederi*, Viöl 1/96 drilling, 140-142,5 m, upper Hemmoorian
 Figure 6: *Nassarius bocholtensis*, Sunder brickwork pit, Twistingring, lower Reinbekian
 Figure 7: *Nassarius bocholtensis*, Sunder brickwork pit, Twistingring, lower Reinbekian
 Figure 8: *Nassarius coronatus*, form with strong spines, Borchelhof drilling, 108-111 m, lower Hemmoorian
 Figure 9: *Nassarius coronatus*, form with well-developed shoulder, Borchelhof drilling, 108-111 m, lower Hemmoorian
 Figure 10: *Nassarius coronatus*, Borchelhof drilling, 108-111 m, lower Hemmoorian
 Figure 11: *Nassarius andersoni*, Burg 5/90 drilling, 84-87 m, upper Hemmoorian
 Figure 12: *Nassarius voorthuyseni*, Sunder brickwork pit, Twistingring, lower Reinbekian
 Figure 13: *Nassarius cimbricus*, Brokdorf drilling, 246-252 m, lower Hemmoorian
 Figure 14: *Nassarius cimbricus*, Brokdorf drilling, 246-252 m, lower Hemmoorian



The names used on a species level indicate a great amount of confusion within the taxonomy of this group. Many names from different basins and regions are used without the proper consideration of original material. Thus, a revision of this group can only be successful if all the related taxa from all European Neogene strata are involved. Since the scheme presented here seems to work very well within the North Sea Basin it is expected that this revision will open up the possibility of long-distance correlation in some cases.

The new Nassariid stratigraphy shows zone boundaries which may be applicable all over the basin and may proliferate stratigraphic marks to be used in a common sense definition of the North Sea Basin regional stages as demanded by GÜRS & SPIEGLER (2001).

Acknowledgements

I thank D. Spiegler, with whom I enjoyed many hours and days of intensive work on many aspects of North Sea Basin stratigraphy, and also G. Wienrich for many helpful discussions on this special fossil group. I am also very much indebted to W. Weisser, Wild Company, for continuous technical support over many years.

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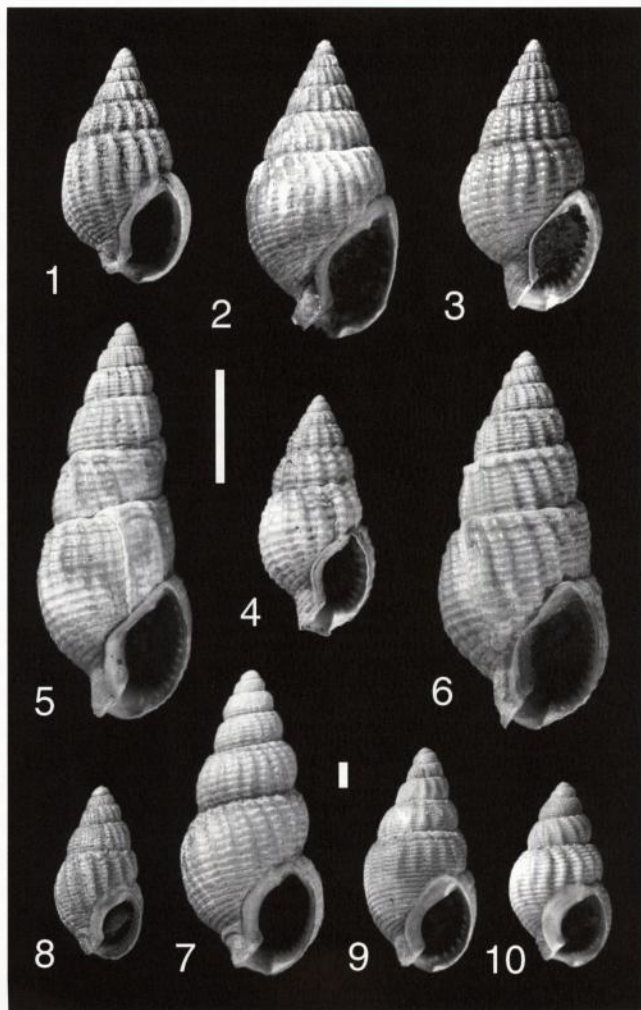
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Plate 2: *Nassarius* species from the North Sea Basin, scale bar Figures 1-6 = 5mm, Figures 7-10 = 1mm, (Figures 1, 8, 9, 10: LANU collection, Figure 6 Senckenberg Museum Frankfurt/Main SMF 323668, all others: author's collection)

- Figure 1: *Nassarius sulcatus*, Heilshoop HL2 drilling, 180-183 m, Vierlandian
 Figure 2: *Nassarius sulcatus*, erratic boulder, Schilke, Vierlandian
 Figure 3: *Nassarius sulcatus*, Borchelhof drilling, 108-111 m, lower Hemmoorian
 Figure 4: *Nassarius tenuistriatus*, Sunder brickwork pit, Twistringen, lower Reinbekian
 Figure 5: *Nassarius wiennrichi*, paratype, Ohle clay pit, Groß Pampau, upper Langenfeldian
 Figure 6: *Nassarius wiennrichi*, holotype, Ohle clay pit, Groß Pampau, upper Langenfeldian
 Figure 7: *Nassarius* cf. *syllentis*, Ohle clay pit, Groß Pampau, upper Langenfeldian
 Figure 8: *Nassarius syllentis*, early form with additional axial ribs, Obspringen drilling, 302-303 m, upper Langenfeldian
 Figure 9: *Nassarius syllentis*, Pinneberg 3040 drilling, 62-66 m, lowermost Gramian
 Figure 10: *Nassarius syllentis*, Pinneberg 3040 drilling, 62-66 m, lowermost Gramian



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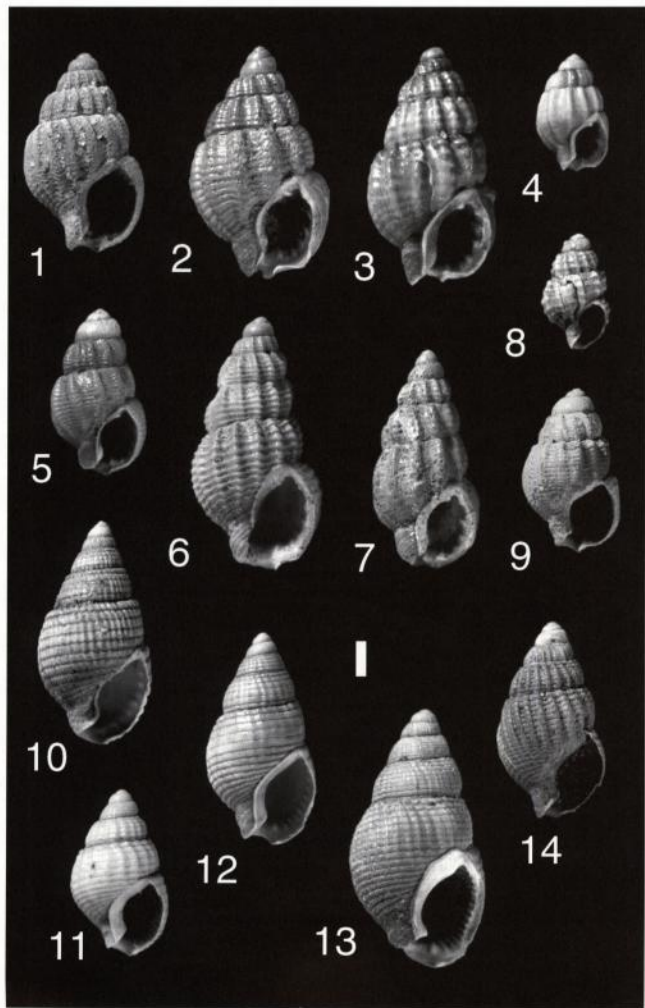
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Plate 3: *Nassarius* species from the North Sea Basin, scale bar = 1mm (Figures 1, 3-9, 11, 13, 14: LANU collection, Figure 10 Senckenberg Museum Frankfurt/Main SMF 323667, Figures 2, 12: author's collection)

- Figure 1: *Nassarius serraticosta* sensu MOSTAFANI 1972, Itzstedt/Nahe 8207 drilling, 426-432 m, lowermost Hemmoorian
Figure 2: *Nassarius serraticosta* sensu MOSTAFANI 1972, Borchelhof drilling, 99-102 m, lower Hemmoorian
Figure 3: *Nassarius woodwardi* sensu SORGENFRIE 1959, Viöl 1/96 drilling, 102.5-105 m, upper Hemmoorian
Figure 4: *Nassarius subobesa* sensu SORGENFRIE 1959, Viöl 1/96 drilling, 127.5-130 m, upper Hemmoorian
Figure 5: *Nassarius* sp. A, Viöl 1/96 drilling, 140-142.5 m, upper Hemmoorian
Figure 6: *Nassarius cavatus* sensu WENIG 2001, Lüththeen 27/82 drilling, 238.4 m, lower Langenfeldian
Figure 7: *Nassarius* sp. B, Obspringen drilling, 302-303 m, upper Langenfeldian
Figure 8: *Nassarius twistringensis*, Ravenhorst E15 drilling, 56-58 m, lower Reinbekian
Figure 9: *Nassarius levensauensis*, Lüththeen 27/82 drilling, 201.8 m, lower Langenfeldian
Figure 10: *Nassarius incisireticulatus*, holotype, Heilshoop HL2 drilling, 177-180 m, Vierlandian
Figure 11: *Nassarius karinae*, Willenscharen 8/79 drilling, 36-42 m, upper Hemmoorian
Figure 12: *Nassarius karinae*, Rhede drilling, 17.7-17.8 m, upper Hemmoorian
Figure 13: *Nassarius holsaticus*, Pinneberg 3040 drilling, 62-66 m, lowermost Gramian
Figure 14: *Nassarius holsaticus*, Obspringen drilling, 302-303 m, upper Langenfeldian



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The Value of the *Nassarius* Gastropod Genus for the Stratigraphy of the Hemmoorian/Reinbekian Boundary

► Günter Wienrich

Abstract

The *Nassarius* (Mollusca, Gastropoda) fauna evident in five drillings from the Lower Rhine district dating from the late Hemmoorian and early Reinbekian regional North Sea Basin stages has been examined for its stratigraphical value. Three of 13 observed species can be used to identify the Hemmoorian/Reinbekian boundary. Six additional species have good stratigraphical potential within the sections. Only four species have a too greatly extended range or are too rare to be used within the stratigraphical range of the drillings.

Kurzfassung

Die *Nassarius* (Mollusca, Gastropoda) Fauna von fünf Bohrungen des Niederrhein-gebietes wird auf ihren stratigraphischen Wert hin untersucht. Die Profile umfassen höheres Hemmoorium und tieferes Reinbekium nach Nordseebecken Regionalstufen. Drei von 13 beobachteten Arten können für die Ermittlung der Grenze Hemmoorium/Reinbekium genutzt werden, sechs weitere besitzen ein gutes stratigraphisches Potenzial. Lediglich vier Arten sind Durchläufer oder zu selten, um im untersuchten Bereich stratigraphisch eingesetzt werden zu können.

Figure 1: Lower Rhine district with classical localities



Keywords

Biostratigraphy, Miocene, Hemmoorian, Reinbekian, Lower Rhine district, gastropods, *Nassarius*

Introduction

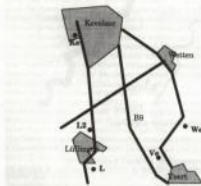
The *Nassarius* genus is one of the most common gastropod groups found in various Late Oligocene and Neogene deposits. At present, the author is in the process of carrying out studies of a fauna and its numerous species which have been gleaned from a number of borings (figure 2) in the Lower Rhine district (figure 1) and which cover the uppermost Hemmoorian and the Reinbekian layers (WIENRICH 1997, 1999, 2001). From this material, thirteen species of *Nassarius* were isolated, some of them containing many thousands of specimens. An intensive study of this group has revealed some surprising and interesting results. In particular, during the analysis of the literature many absurdities provoked by uncritical character evaluation came to light. Until the present, species of this genus have generally been reported from isolated deposits without time coherence (ANDERSON 1964, JANSSEN 1972, 1984). In many cases descriptions were based only on a few specimens. In this manner many evolutionary developments or affinities were either overlooked or incorrectly interpreted (MOSTAFAVI 1978).

Provisionally, the genus name *Nassarius*, and not *Hinia*, has been used for reasons of wider interpretations. In addition, the usage of sub-genus terms has been wavered because the author wishes to avoid any increase in present nomenclature confusion.

Materials and Methods

The material studied comes from five different drillings, the largest distance between these drillings being no more

Figure 2: sketch map of location of drillings

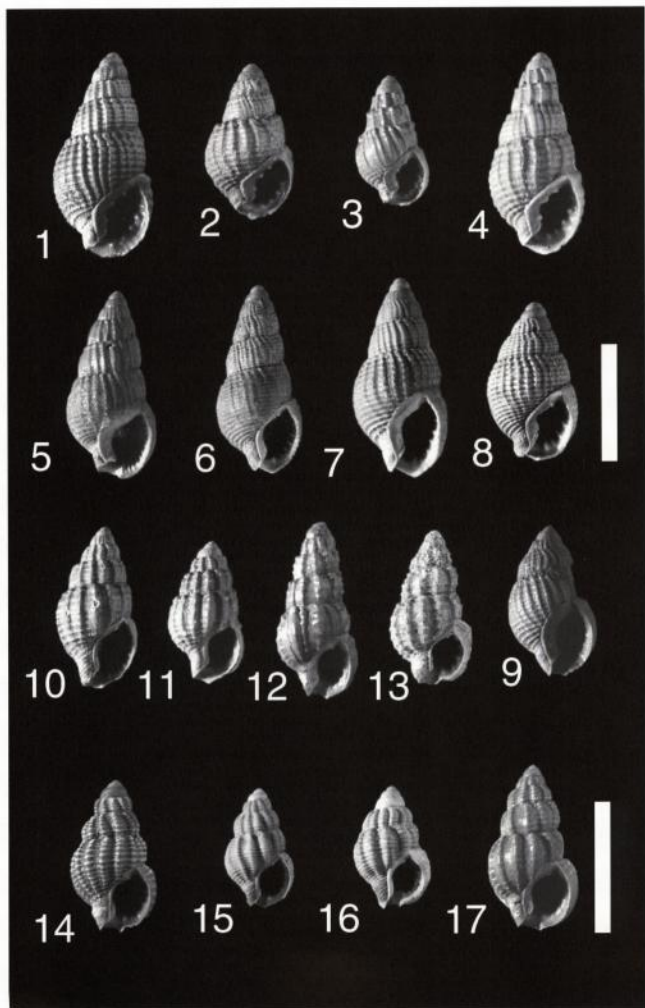


then 8 km. From two of these drillings (Wetten and Veert) only a mixed sample was available, and only the samples provided by the drilling company were able to be used for another drilling (Lüllingen 2). These samples (30 in total) were very small and are, thus, not representative for the completeness of the *Nassarius* fauna. The Kevelaer drilling was brought down for suitable water for a thermal bath. The final depth of this drilling was 553.5 m. In the Wetten, Veert, Lüllingen 1 and Lüllingen 2 drillings, the stratigraphical range covers only Middle Miocene (Reinbekian), with possibly some Upper Miocene on top and without any fossils covered by Pleistocene gravel. Kevelaer covers the same, but contains a few meters of Upper Hemmoorian before it reaches Oligocene strata. The Hemmoorian/Reinbekian boundary was determined by the last occurrence of *Lembulus emarginatus* and *Turritella eryna* [HINSCH 1986]. This is also the zone boundary of Mol H to Mol G after SUGGERS & LEEUVEN (1987). SUGGERS & LEEUVEN additionally mention the last occurrence of "*Hinia*" *schroederi* as a boundary criterion, which is also used here.

While determining the *Nassarius* species, it was ascertained that the criteria of the common appearance, the number of spirals and ribs, together with their apportion, were able to be used only with extreme reservation and restrictions. These characters are so variable that they cannot be used as determining criteria on their own. A useable criterion is, with certainty, the protoconch; however, prior to this, time-consuming statistical research is necessary. The best criterion would appear to be that of the shape of the aperture, the number and shape of the teeth on the inner and outer lip, the thickness of the mouth edge and enlargement of the spindle plate (WIENRIKH 2001).

Plate 1: scale bars 5mm, scale bar besides figure 8 for all figures except figures 9, 15-17

- Figure 1: *Nassarius bochoftensis* (BEYRICH 1854) Kevelaer: 90m, 8.9mm (K-90 75,72,1) Sample with 6 spirals
- Figure 2: *Nassarius bochoftensis* (BEYRICH 1854) Lüllingen 1: 51m, 6.5mm (L-51 75,72,1) Flatter sample, whorls shaped like steps
- Figure 3: *Nassarius bochoftensis* (BEYRICH 1854) Lüllingen 1: 45m, 5mm (L-45 75,72,1) Sample with smoothed whorls
- Figure 4: *Nassarius bochoftensis* (BEYRICH 1854) Lüllingen 1: 21m, 8.7mm (L-21 75,72,1) Sample with very smooth spirals on the oldest whorls
- Figure 5: *Nassarius schroederi* (KAUTSKY 1925) Kevelaer: 90m, 8.5mm (K-90 75,72,4)
- Figure 6: *Nassarius karinae* (WIENRIKH 2001) Lüllingen 1: 57m, 8.4mm (L-45 75,72,3) Paratype, slender sample with finer sculpture
- Figure 7: *Nassarius karinae* (WIENRIKH 2001) Lüllingen 1: 54m, 8.9mm (L-54 75,72,3 - SMF 320979) Holotype
- Figure 8: *Nassarius karinae* (WIENRIKH 2001) Lüllingen 1: 48m, 6.7mm (L-48 75,72,3 - SMF 321962) Paratype, sample with highly pronounced teeth
- Figure 9: *Nassarius holsaticus* (BEYRICH 1854) Kaltenkirchen Ka 18, depth 87-90m, 5.6mm, LANU Schleswig-Holstein, Sample 28665, damaged on the right
- Figure 10: *Nassarius andersoni* (NORDSECK 1972) Kevelaer: 85m, 7.1mm (K-85 75,72,2)
- Figure 11: *Nassarius andersoni* (NORDSECK 1972) Kevelaer: 95m, 5.9mm (K-95 75,72,2)
- Figure 12: *Nassarius voorthuyseni* (JANSSE & JANSSEN 1983) Lüllingen 1: 42m, 8.1mm (L-42 75,72,6)
- Figure 13: *Nassarius twistringensis* (A. W. JANSSEN 1972) Wetten, 6.6mm (We-75,72,8,1)
- Figure 14: *Nassarius cavatus* (BELLARDI 1882) Lüllingen 1: 51m, 6.5mm (L-51-75,72,10)
- Figure 15: *Nassarius serraticosta* (BRONN 1831) Kevelaer: 85m, 4.7mm (K-85-75,72,15)
- Figure 16: *Nassarius catulli* (BELLARDI 1882) Kevelaer: 90m, 4.8mm (K-90-75,72,13)
- Figure 17: *Nassarius woodwardi* (HAMMER 1913) Lüllingen 1: 51m, 6.4mm (L-51-75,72,9)



Short Characterization of

Species

In the following all species determined are briefly characterized. In particular, features which have proved to be well suited for distinguishing species are outlined. For detailed description of the species see WIENRICH (2001).

Nassarius bocholtensis (BEYRICH 1854)

This species has a large and stocky protoconch. It is easiest to determine it by the teeth on the outer lip and the parietal wall. It has six strong knotty teeth on the inside of the outer lip and three strong teeth distributed regularly on the inner lip. The parietal wall is only slightly thickened and spreads only a bit over the base. This species alters remarkably during time. In early populations (Hemmoorian) the whorls are normally smoothly rounded, the spirals remain evenly strong. Later, the whorls become more angular, shaped like steps. The spirals smooth down, sometimes they nearly disappear completely. It is not possible to date a single specimen in a certain age, but if there are more specimens from one fauna, then it should be practicable to date them to the Hemmoorian or Reinbekian. A frequent occurrence always indicates a Reinbekian age. This is one of the most variable species; it changes its appearance from Hemmoorian to Reinbekian very notably, is very common in Reinbekian layers but rare in Hemmoorian layers.

Nassarius andersoni (NOROSIECK 1972)

This species is easy to separate, but it has often been confused with *N. turbinellus*, for example, by VOORTHUYSEN (1944) or JANSSEN (1984). It has nine narrow, elongated teeth on the inside of the outer lip and one tooth at the apical end as well as another tooth at the apertural end of the inner lip. A few small knots can appear between these two teeth. The parietal wall is only slightly thickened and hardly spreads over the base. The whorls are separated by steps. There is a narrow spiral after a concave part under the suture, normally with spikes on it, where the ribs cross. It follows a depressed part and then two or three wide spirals. There are 12-14 ribs on a whorl. This species seems to die out at the end of the Hemmoorian.

Nassarius karinae WIENRICH 2001

This species has always been confused with *N. holsaticus* (BEYRICH 1854), for ex-

ample, by ANDERSON (1964) and MOSTAFAVI (1978), although it is without doubt specifically different. Its general appearance is very similar to that of *N. holsaticus*, but it differs legibly by the characteristics of the aperture. The teeth on the outer lip are much stronger, and there are teeth on the inner lip. *N. holsaticus* has no teeth on the inner lip, apart from a small notch, which occasionally appears at the apical end. The spindle plate of *Nassarius karinae* is not enlarged and does not spread as widely over the base as does *N. holsaticus*. *Nassarius karinae* seems to appear no earlier than late Hemmoorian (there are a few specimens in the material from Winterswijk-Miste in the Naturalis collection in Leiden) and does not exceed over the Reinbekian.

Nassarius holsaticus (BEYRICH 1854)

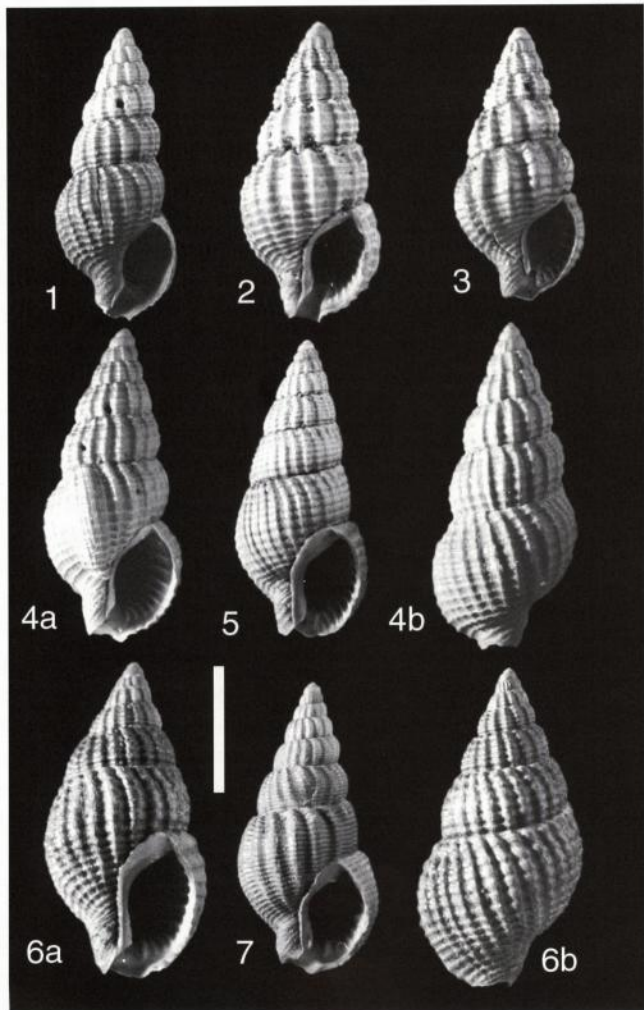
This species is so closely related to *Nassarius karinae*, leading to the conclusion that it must have developed from *N. karinae*. It was first recognized in the mid-Langenfelden (or Lüneburgian sensu HINSCHE 1987).

Nassarius schroederi (KAUTSKY 1925)

The sculpture of this species is very smooth and regular. The spindle plate spreads widely over the base. There are as many as 10 narrow and long teeth on the outer lip and normally none on the inner lip. This species must certainly be sepa-

Plate 2: scale bar 5mm

- Figure 1: *Nassarius tenuistriatus* (BEYRICH 1854) Lüllingen 1: 30m, 11.3mm (L30 75,72,5) Slender sample with highly irregular spirals
Figure 2: *Nassarius tenuistriatus* (BEYRICH 1854) Lüllingen 1: 48m, 9.1mm (L48 75,72,5) Typical sample sensu BEYRICH
Figure 3: *Nassarius tenuistriatus* (BEYRICH 1854) Wetten, 9.4mm (We 75,72,5) Sample with very pronounced ribs and wide spirals
Figure 4: *Nassarius tenuistriatus* (BEYRICH 1854) Lüllingen 1: 42m, 11.1mm (L42 75,72,5) Sample with pronounced varices, a: front view, b: back view
Figure 5: *Nassarius sulcatus* (KAUTSKY 1925) Kevelaer: 85m, 11.8mm (K-85-75,72,11) Slender sample
Figure 6: *Nassarius sulcatus* (KAUTSKY 1925) Kevelaer: 95m, 12.1mm (K-95-75,72,11), a: front view, b: back view
Figure 7: *Nassarius prismaticus* (BROCCO 1814) Lüllingen 1: 45m, 11.6mm (L45-75,72,7)



rated from *N. schlotheimi*, which has no enlarged, even hardly any, spindle plate and is known from older layers (Vierlandian and Late Oligocene). *N. schroederi* is not found in Reinbekian deposits.

***Nassarius tenuistriatus* (BEYRICH 1854)**

This species is very common in Reinbekian deposits. It differs consistently from Hemmoorian populations, which have been described as *N. tenuistriatus* by NORDSIECK (1972) and JANSSEN (1984). The Reinbekian species has a very variable sculpture, specifically in the younger deposits. The number of ribs varies between 12 and 17 on the younger whorls. The spirals can be narrow or wide, occasionally only one or two spirals are wider than the others. There are specimens with secondary spirals and specimens with none. The outer lip has a strong varix, the spindle plate is not reflexed. There are 9 to 10 narrow oblong teeth on the outer lip and only a small knot at the apertural and apical end of the inner lip.

***Nassarius sulcatus* (KAUTSKY 1925)**

This species is remarkable and consistently different from *N. tenuistriatus* from the Reinbekian.

The spiral sculpture of this species is much more even. The spirals have a uniform appearance, they are quite broad. Narrow spirals such as those evident in *N. tenuistriatus* do not exist. The spindle plate is slightly thickened and spreads quite far over the base. This species appears only in the Hemmoorian.

***Nassarius voorthuyseni* (JANSE & JANSSEN 1983)**

This species has 10 to 12 narrow pronounced ribs and three weak spirals, which build knots on the ribs. There are 6 to 7 strong short teeth on the outer lip, on the inner lip on the apical end there is only one knot. *N. voorthuyseni* lived only during the Reinbekian.

***Nassarius twistringensis* (JANSSEN 1972)**

This small species is characterized by the fact that it has only three narrow spirals. There are 10 to 12 ribs on a whorl. The spindle plate covers only a small area. The outer lip comprises 4 to 5 strong teeth, on the inner lip there is a strong tooth at the apical end and a small tooth at the apertural end. This species is restricted to Reinbekian deposits comparable with the so-called "Twistring Schichten".

***Nassarius cf. cavatus* (BELLARDI 1882)**

***Nassarius cf. woodwardi* (HARMER 1913)**

***Nassarius cf. catulli* (BELLARDI 1882)**

***Nassarius cf. serraticosta* (BRONN 1831)**

These species belong to one group and appear only in Hemmoorian (possibly only in late Hemmoorian) and early Reinbekian deposits. Their determination is still uncertain on a species level.

***Nassarius prismaticus* (BROCCH 1814)**

It is nearly impossible to confuse this species with others. It is best recognized by the high number of narrow spirals, which give the whorls a smooth appearance, the narrow spindle plate and the constellation of the teeth. There are eight strong oblong teeth on the inside of the outer lip and one ledge on the apical end of the inner lip. It was very surprising to find this species in older Reinbekian deposits, because it was known only from much younger material until the present.

Stratigraphy

The stratigraphical range studied in the drillings begins with the latest Hemmoorian and covers part of the Reinbekian. The material on top of this is without any fossils; the upper boundary is therefore uncertain.

The boundary between Hemmoorian and Reinbekian may be confirmed by the common composition of molluscan fauna (HINSCHE 1986), the frequency of certain species (e.g. *Turritella eryna* in the Hemmoorian) and the occurrence of certain species (e.g. *Lembulus emarginatus* in the Hemmoorian or *Aquilofusus festivus* in the Reinbekian). In addition, the *Uvigerina* genus (foraminifera) may be used with the same results. As mentioned above, the zone boundary from Mol H to Mol G is the same as the Hemmoorian/Reinbekian boundary because it uses primarily the same criteria.

Three drillings, for which entire sections were able to be investigated, are Lüllingen 1, Lüllingen 2 and Kevelaer. All drillings were straight flush drillings, thus involving the danger of downhole contamination. To study the effect of contamination, a sample from the Late Oligocene Grafenberg beds taken from Kevelaer was studied for Miocene elements. Surprisingly, nearly no Miocene material, which would have been easy to identify because of very different preservation, could be seen in the sample.

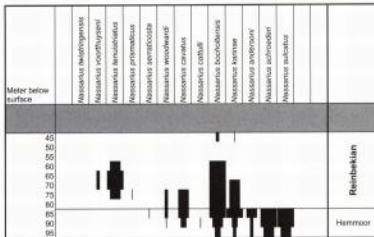
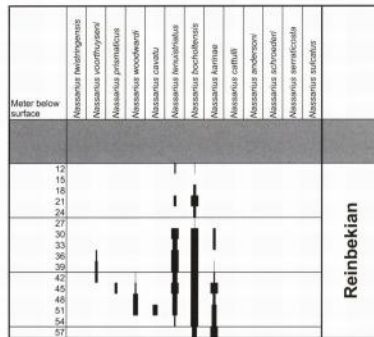


Figure 3: Range chart for species of *Nassarius* genus in Kevelaer drilling, line=very rare, small bar=rare, medium bar=not rare, bold bar=common, extra bold bar=abundant

Figure 4: Range chart for species of *Nassarius* genus in Lüllingen 1 drilling, line=very rare, small bar=rare, medium bar=not rare, bold bar=common, extra bold bar=abundant

Thus, the effects of contamination were very small in the drillings studied.

The range chart for the *Nassarius* fauna of these drillings is shown in Figures 3 to 5. Kevelaer shows the disappearance of four *Nassarius* species at the Hemmoorian/Reinbekian boundary, three of which are stratigraphically relevant, i.e. *N. andersoni*, *N. schroederi* and *N. sulcatus*. No new species appear immediately at the boundary, but *N. tenuistriatus* and *N. prismaticus* appear shortly above, followed by *N. voorthuyseii*. Judging from this drilling, Lüllingen 1 nearly reaches the Hemmoorian/Reinbekian boundary. The deepest sample yields only *N. bochtolensis* and *N. karinae*. After that, *N. tenuistriatus* appears, followed by *N. cavatus* and *N. woodwardi* and then later by *N. prismaticus* and, finally, *N. voorthuyseii*. Lüllingen 2 seems to be stratigraphically somewhat shallower, since *N. bochtolensis* appears together with *N. prismaticus* in the deepest sample one meter above *N. karinae*



and *N. tenuistriatus* and an additional four meters above *N. voorthuyseii*. Because of the small sample amounts and the short distances involved, one can say that the first four species occur simultaneously at the base of the drilling.

Conclusions

These results indicate that the Hemmoorian/Reinbekian boundary in the area investigated is very well defined by *Nassarius* species. While the boundary is precisely characterised by the disappearance of several Hemmoorian species, the new species appear only gradually. A boundary definition on the basis of *Nassarius* species seems more reliable than on the basis of index species used thus far, such as *Lembulus emarginatus*, *Haustator eryna* or even *Sandbergeria wolffi*, *Dorsanum boreobaccatum* and *Donax stoffelsi*, which are very facies-dependent and occur, in part, much later turning out to be Lazarus species. These boundary criteria should bring an end to discussions concerning the diachrony (Bosch 1975) or isochrony (Hiltsch 1972) of the Hemmoorian/Reinbekian boundary.

As shown by Gürs (this volume) these results appear to be valid for western and northern Germany as well as the Netherlands and Denmark. Moreover, the *Nassarius* genus has stratigraphical potential for the entire Neogene of the North Sea Basin (Gürs this volume).

The enormous number of species in this genus in neighbouring marine realms, such as the Atlantic region or the Mediterranean and Paratethys, leads to the conclusion that there is much more stratigraphical potential in this group than known up to now. However, research on this topic demands a taxonomic revision of this group, which is currently taking place.

Acknowledgements

I thank K. Gürs (LANU) for discussions, comments on the manuscript and technical assistance. Special thanks go to my wife, Karin, for the many hours of help and care during my studies; without her help I would never have come so far.

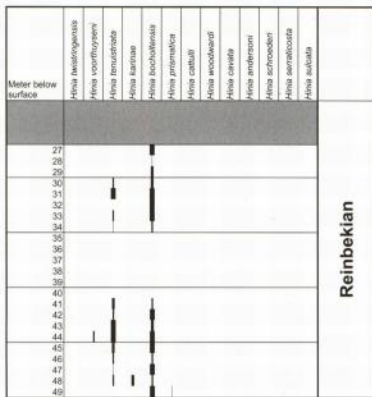


Figure 5: Range chart for species of *Nassarius* genus in Lüllingen 2 drilling, line=very rare, small bar=rare, medium bar=not rare, bold bar=common, extra bold bar=abundant

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Revised Pteropod Biostratigraphy for the Miocene of the North Sea Basin

► Karl Gürs

► Arie W. Janssen

Abstract

A considerably refined biostratigraphic zonation based on pteropoda (Mollusca, Gastropoda, Euthecosomata) is given for the North Sea Basin Miocene. Three of the five zones of JANSSEN & KING (1988) can be further divided, zone 18 into subzone 18a, zone 19 into 19a and 19b, and zone 20 into 20a, 20b and 20c. These zones are correlated with the regional North Sea Basin stages defined by benthic Mollusca and with international nannoplankton and *Bolboforma* standards. From this a correlation with international stages has been completed. This correlation has, in addition, been tested by the ranges of the pteropod species investigated outside the North Sea Basin.

Kurzfassung

Es wird eine deutlich verfeinerte biostratigraphische Zonierung für das Nordsee Becken Miozän nach Pteropoden (Mollusca, Gastropoda, Euthecosomata) vorgestellt. Drei der fünf durch JANSSEN & KING (1988) aufgestellten Zonen können weiter unterteilt werden. Zone 18 erhält die Subzone 18a, Zone 19 wird in 19a und 19b und Zone 20 in 20a, 20b und 20c unterteilt. Diese Zonen werden mit den regionalen Nordseebecken-Stufen korreliert, die über benthische Mollusken definiert sind. Zusätzlich erfolgt eine Korrelation mit den internationalen Nannoplankton- und *Bolboforma*-Standards. Die hierdurch ermittelten Korrelationen wurden zusätzlich anhand der stratigraphischen Reichweite der untersuchten Pteropoden-Arten außerhalb des Nordsee Beckens getestet.

Keywords

Mollusca, Pteropoda, Euthecosomata, biostratigraphy, Miocene, North Sea Basin.

Introduction

JANSSEN & KING (1988, p. 356) gave a first,

preliminary pteropod zonation for the Tertiary of the North Sea Basin. This scheme was already quite detailed for the Palaeocene and Eocene, as many outcrop sections could be studied in the London and Hampshire Basins in England and in Belgium as well. Through the combination of sections, a nearly continuous zonation was able to be achieved. The Oligocene and Neogene, however, showed a completely different picture. Deposits from these ages in the North Sea Basin demonstrate many unconformities, and even most borehole sections display major hiatuses, especially during the very early Miocene and in the younger half of the Middle Miocene. These sedimentary gaps were not very easy to detect, since most international biostratigraphies do not properly correlate throughout the entire North Sea Basin Miocene. With the establishment of an international *Bolboforma* zonation in the 1990's, a tool for the high-resolution biostratigraphy of the higher latitudes was made available, a tool which can be applied without restriction in the North Sea Basin. This enables reliable age controls for borehole sections in the North Sea Basin. Subsequently, the higher resolutions derived permitted the refinement of the succession of pteropod species in the North Sea Basin Miocene. This succession is displayed here as a range chart (Table 7).

Material and Methods

The basis of this study comprises 27 drillings, five of which are cored sections, i.e. Gram I (Denmark, Jutland, LAURSEN & KNISTOFFERSEN 1999), and Groß Pampau I (SPIEGLER & GÜRS 1996), Schwarzenbek 1/96 (GÜRS & SPIEGLER 1999), Nieder Ochtenhausen [MEYER (ed.) 2001] and Lübtheen 27/82 (GÜRS & SPIEGLER 2000), all located in northern Germany. From other boreholes straight flush samples (cuttings) of approx. 10 kg each were taken at intervals of 3 or 6 m, washed, sieved and sorted for Pteropoda and other stratigraphically relevant macro- and microfossils. In addition, erratic boulders of Miocene age and outcrop sections were studied. The stratigraphical interval

of the sections available lies between the Oligocene/Miocene boundary and the Late Miocene, none of them, however, go through sediments at the Mio-/Pliocene boundary in marine facies with fauna. Range charts were compiled for each section and compared to the regional standards for benthic Mollusca and to international *Bolboforma* standards (GÜRS internal reports of the LANU).

Most pteropod specimens are housed in the collections of the National Museum of Natural History (Palaeontology Department), Leiden, the Netherlands (RGM registration numbers). Specimens in pyrite preservation are stored in silicone oil.

Selected Borehole Sections and Exposures

Brodersdorf

The Brodersdorf borehole, situated in the vicinity of Kiel, capital of Schleswig-Holstein [coordinates (Gauß – Krüger) r 35 80807 h 60 29678], was drilled in 1999. It penetrated Quaternary strata until a depth of 44 m, where Middle to Early Miocene estuarine sands were met. They belong to a delta originating from a river coming from the northeast and entering the palaeo-North Sea east of Langeland/Denmark (RASMUSSEN pers. comm.) and are called 'Braunkohlensande' ('lignite sands') in German. According to Danish lithostratigraphy, they belong to the Odderup and Bastrup Formations. This deltaic sand complex is interfingered by a marine transgression horizon: the Frörup Member of the time-equivalent marine Arnum Formation (which yielded no pteropods). Below the sands, at a depth of 172.5 m, the marine

Klintinghoved Formation is encountered, consisting of sediments ranging from fine sand to clay, with a high content of organic matter and rich in macrofossils. The Oligocene is not reached until the final depth of 235 m. Table 1 shows the distribution of pteropods in this borehole.

In the earliest Miocene, two pteropod species, *Limacina valvatina* and *L. miostrostralis*, were encountered. In the interval from 215 m to 230 m only one fragment of *Vaginella depressa* was found, which has a different preservation than the other fossils of the samples and is therefore interpreted as downhole contamination. The two lowermost samples, down to the final depth of 235 m, contain no pteropods. At a depth of 202.50-215 m *V. depressa* occurs, together with *V. cf. tricuspadata*.

The sudden appearance of the common benthic gastropod species *Mitrella attenuata* (BEYRICH 1854) at the depth of 215 m together with *Tornatina bellardii* (KOENEN 1882) shows a faunal incursion with the immigration of new species. In samples 197.50-200 m and 195-197.50 m, the benthic gastropods *Trigonostoma acutangula* (FAUJAS-DE-SAINT-FOND 1817) and *Thatcheria trochlearis* (HOERNES 1856) were found as immigrants. *Vaginella austriaca* does not occur up to the top, the *V. austriaca* zone was thus not reached in this section. In a limited range (202.50-205 m), somewhat above the first occurrence of *V. depressa*, *Clio deflexa* was also observed.

"Holsteiner Gestein", Klintinghoved

The so-called 'Holsteiner Gestein', boulders of presumably local origin found in fluvio-glacial deposits of Schleswig-Holstein, yields six species of pteropods: *Limacina miostrostralis*, *L. valvatina*, *Clio deflexa*,

Table 1: Pteropods in the Brodersdorf borehole

Epoch	Lithostratigraphy	Sample depth [m]	Species	No	Collection
MIOCENE VIERLANDIAN	Klintinghoved Formation	182.50-185	<i>Vaginella depressa</i>	1	RGM 458.707
		190-192.50	<i>Limacina valvatina</i>	3	RGM 458.708
		197.50-200	<i>Vaginella depressa</i>	2	RGM 458.709
		200-202.50	<i>Limacina valvatina</i>	1	RGM 458.710
		202.50-205	<i>Clio deflexa</i>	2	RGM 458.711
			<i>Vaginella depressa</i>	3	RGM 458.712
			<i>Vaginella cf. tricuspadata</i>	1	RGM 458.713
		205-207.50	<i>Limacina valvatina</i>	1	RGM 458.714
		207.50-210	<i>Limacina valvatina</i>	1	RGM 458.715
		210-212.50	<i>Vaginella depressa</i>	1	RGM 457.104
			<i>Vaginella cf. tricuspadata</i>	1	RGM 457.105
		212.50-215	<i>Vaginella depressa</i>	2	RGM 457.106
			<i>Vaginella cf. tricuspadata</i>	1	RGM 457.107
		217.50-220	<i>Limacina valvatina</i>	1	RGM 458.716
		225-227.50	<i>Limacina valvatina</i>	1	RGM 458.717
		227.50-230	<i>Limacina miostrostralis</i>	1	RGM 458.718

Epoch	Lithostratigraphy	Sample depth [m]	Species	No	Collection
LOWER MIOCENE HEMHOORIAN	Arnum Formation	102.50-105	<i>Limacina mirostralis</i>	1	RGM 458.732
			<i>Vaginella austriaca</i>	2	RGM 458.733
		110-112.5	<i>Limacina mirostralis</i>	1	RGM 458.734
			<i>Vaginella austriaca</i>	3	RGM 458.735
			<i>Clio</i> sp.	1	RGM 458.736
		115-117.50	<i>Limacina valvatina</i>	1	RGM 458.737
			<i>Limacina mirostralis</i>	4	RGM 458.738
			<i>Vaginella austriaca</i>	9	RGM 458.739
		127.50-130	<i>Limacina mirostralis</i>	1	RGM 458.719
			<i>Vaginella austriaca</i>	4	RGM 458.720
		140-142.50	<i>Vaginella austriaca</i>	4	RGM 458.721
147.50-150	<i>Limacina mirostralis</i>	1	RGM 458.722		
	<i>Vaginella austriaca</i>	3	RGM 458.723		
155-157.50	<i>Limacina valvatina</i>	1	RGM 458.724		
	<i>Vaginella austriaca</i>	7	RGM 458.725		
	<i>Vaginella austriaca</i>	8	RGM 458.726		
	<i>Vaginella austriaca</i>	3	RGM 458.727		
LOWER MIOCENE VIERLANDIAN	Klintinghoved Formation	220-222.50	<i>Vaginella depressa</i>	1	RGM 458.728
		222.50-225	<i>Vaginella depressa</i>	1	RGM 458.729

Table 2: Pteropods from the Viöl 1/96 borehole

Clio aff. *nielsenii*, *Diacrolinia aquensis* and *Vaginella depressa*. In one boulder of this type from Nehnten, an assemblage including *L. mirostralis*, *V. depressa*, and *D. aquensis* was found. In another such boulder, originating from Damsdorf (leg. A. Montag, RGM 397.000-008), *L. valvatina*, *Clio* aff. *nielsenii* and *V. depressa* were present. For the identification of *Diacrolinia aquensis* cf. JANSSEN & GURS (in press).

The fauna of the foreshore outcrop at Klintinghoved near Sønderborg (coordinates 54°56'40"N 5°49'40"E) in southern Denmark contains *L. mirostralis*, *L. valvatina* and *V. depressa*. These outcrops, traditionally referred to the Vierlandian of the regional stages, contain the same fauna as the Brodersdorf borehole, therefore the same age can be assumed for these outcrops.

Viöl 1/96

The Viöl borehole section, dating from 1996, is situated in the western part of Schleswig [coordinates (Gauß – Krüger): r:35 11514, h: 60 49644]. In this area, Miocene sediments are entirely of marine origin. Quaternary sediments go down to 100 m. The Quaternary sediments overlie fossiliferous Miocene silty fine (but somewhat coarsening upward) sands. They are developed until approx. 210 m, where a clayey to silty facies is reached. Below 230 m Eocene strata are found, separated by an important hiatus. Two Miocene stages of

the regional scale can be recognised, Hemmoorian and Vierlandian. The Vierlandian strata are very poor in fossils and therefore difficult to identify, but apart from *Vaginella depressa* (occurring in samples between 220 and 225 m), another index fossil, the bivalve *Cyclocardia grippi* (ANDERSON 1959), was observed in sample 220-222.50 m. Therefore the interval from 220 to 230 m is considered to belong to the Vierlandian. *V. austriaca* is observed from 220 to 102.50 m. The Last Occurrence Datum (LOD) of *V. depressa* (220 m) fits nearly perfectly together with the Hemmoorian/Vierlandian boundary. Other Pteropoda of this section are *Limacina mirostralis* from 200 to 102.50 m and *L. valvatina* in samples 155-157.5 m and 115-117.5 m. Table 2 gives the pteropod distribution of the samples investigated from this section.

Schwarzenbek

The Schwarzenbek borehole [coordinates (Gauß – Krüger) r: 3597895, h: 5932515], made in 1996, was cored and displayed a Miocene section from 0.80 m – 34.50 m, comprising lignite silt from the Upper Lignite Sands overlain by marine transgressive Reinbek sands and Upper Mica Clay. The section yielded only three species of pteropods, viz. *Limacina gramensis*, *L. valvatina* and *Vaginella austriaca*. The latter was found only in one sample at a depth of 27-27.29 m, together with *L. valvatina*. This sample belongs to the lower *Bolboforma reticulata* zone and to the Early Reinbekian

Table 3: Pteropod distribution in the Schwarzenbek borehole

Epoch	Lithostratigraphy	Sample depth [m]	Species	No	Collection
MIDDLE MIOCENE EARLY LANGENFELDIAN	Upper Mica Clay	3.00-3.25	<i>Limacina gramensis</i>	1	RGM 457.473
			<i>Limacina valvatina</i>	30	RGM 457.474
		4.00-4.25	<i>Limacina valvatina</i>	1	RGM 457.475
		5.00-5.25	<i>Limacina gramensis</i>	7	RGM 457.476
			<i>Limacina valvatina</i>	30	RGM 457.477
		6.00-6.25	<i>Limacina valvatina</i>	1	RGM 457.478
		7.00-7.25	<i>Limacina gramensis</i>	1	RGM 457.479
		7.00-7.25	<i>Limacina valvatina</i>	2	RGM 457.480
		8.00-8.25	<i>Limacina valvatina</i>	3	RGM 457.496
		9.00-9.25	<i>Limacina valvatina</i>	1	RGM 457.481
		10.00-10.25	<i>Limacina valvatina</i>	26	RGM 457.482
		11.00-11.25	<i>Limacina valvatina</i>	23	RGM 457.483
		12.00-12.25	<i>Limacina valvatina</i>	9	RGM 457.484
		13.00-13.25	<i>Limacina valvatina</i>	24	RGM 457.485
MIDDLE MIOCENE REINBEKIAN	Reinbek sand-Fm.	14.00-14.25	<i>Limacina valvatina</i>	10	RGM 457.486
		17.00-17.25	<i>Limacina valvatina</i>	1	RGM 457.487
		19.00-19.25	<i>Limacina valvatina</i>	13	RGM 457.488
		20.00-20.25	<i>Limacina valvatina</i>	26	RGM 457.489
		20.25-20.50	<i>Limacina valvatina</i>	13	RGM 457.490
		21.00-21.25	<i>Limacina valvatina</i>	19	RGM 457.491
		21.25-21.50	<i>Limacina valvatina</i>	16	RGM 457.492
		22.00-22.25	<i>Limacina valvatina</i>	1	RGM 457.493
		27.00-27.29	<i>Limacina valvatina</i>	2	RGM 457.494
			<i>Vaginella austriaca</i>	3	RGM 457.495

after benthic Mollusca. Throughout the entire section *L. valvatina* occurs in large numbers, but in the *Bolboforma badenensis* zone at approx. 3 m above the boundary to the *B. danielsi* zone it is joined by *L. gramensis*.

Groß Pampau I

The Groß Pampau I borehole from 1989 is a cored section. Unfortunately, the pteropods were examined approx. 10 years after the processing of the samples, and pyrite disintegration has ruined much of the material. In particular, a distinction between *Limacina gramensis* and *L. valvatina* was therefore difficult and occasionally impossible. In addition to these species, only *L. ingridae* was found. From 36.00 up to 9.00 m *L. valvatina* was the only pteropod species. Above that depth only *L. ingridae* occurred in coexistence, indicating some intermediate forms. From 6.00 m onward transitional forms from *L. valvatina* to *L. gramensis* occur, and at 2.50-2.75 m at last true *L. gramensis* is present, while in the uppermost 2.50 m only *L. ingridae* is present. Although only parts of the section were able to be dated by *Bolboforma* it can be stated that the exclusive occurrence of *L. ingridae* lies within the *B. laevis/capsula* Zone.

Lübtheen

The cored section of the Lübtheen 27/82 borehole in Mecklenburg-Vorpommern [co-

ordinates (Gauß – Krüger) r 44 49308 h 50 06135] yielded three species of pteropods, *Limacina valvatina*, *L. gramensis* and *L. ingridae*. While from 249.5 up to 203.9 m *L. valvatina* was the only species present, it is joined by *L. gramensis* in short intervals from 203.9 to 201.8 m and at 160.6 m. The first *L. ingridae* was encountered at 161.2 m. From 66.7 m *L. ingridae* becomes more common and is the only species in the uppermost part of the drilling. The first occurrence of *L. gramensis* lies within the *Bolboforma badenensis* zone approx. 28 m above the boundary to the *B. danielsi* zone. The first occurrence of *L. ingridae* lies well within the *B. compressispinosa* zone while the common and exclusive occurrence lies within the *B. laevis/capsula* zone.

Gram I (Jutland, Denmark)

The classical Gram borehole DGU 141.277 at the type locality of the Gram Formation was examined for pteropods by the second author in 1987 and 1991. The material is housed in the Geological Survey of Denmark, Copenhagen. From 35 to 26.5 m *Limacina valvatina* is the only species in the section. Then an interval barren of pteropods is developed up to 22 m. Immediately after that, *L. gramensis* and *L. ingridae* occur, still accompanied by *L. valvatina*. At 21 m *L. gramensis* disappears, and at 20.5 m the remaining species are joined by *L. irisae* and one specimen of *L. wilhelminae*. In the interval from 19 to 18 m all species mentioned, except *L. gramensis*, coexist.

Table 4: Pteropod distribution in the Groß Pampau I borehole, (*ingridae*) and (*gramensis*) indicate the presence of transitional forms

Epoch	Lithostratigraphy	Sample depth [m]	Species	No	Collection
MIOCENE LATE LANGENFELDIAN	Upper Mica Clay	0.05-0.20	<i>Limacina ingridae</i>	32	RGM 457.046
		0.25-0.50	<i>Limacina ingridae</i>	26	RGM 457.047
		0.45-0.65	<i>Limacina ingridae</i>	18	RGM 457.048
		0.65-0.85	<i>Limacina ingridae</i>	3	RGM 457.049
		1.00-1.25	<i>Limacina ingridae</i>	7	RGM 457.050
		1.25-1.50	<i>Limacina ingridae</i>	4	RGM 457.051
		1.50-1.75	<i>Limacina ingridae</i>	8	RGM 457.052
		1.75-2.00	<i>Limacina ingridae</i>	10	RGM 457.053
		2.00-2.25	<i>Limacina ingridae</i>	12	RGM 457.054
		2.25-2.50	<i>Limacina ingridae</i>	5	RGM 457.055
		2.50-2.75	<i>Limacina gramensis</i>	7	RGM 457.057
			<i>Limacina ingridae</i>	14	RGM 457.056
		2.75-3.00	<i>Limacina valvatina (gramensis)</i>	71	RGM 457.059
			<i>Limacina ingridae</i>	1	RGM 457.058
		3.00-3.25	<i>Limacina ingridae</i>	1	RGM 457.060
			<i>Limacina valvatina (gramensis)</i>	41	RGM 457.061
		3.25-3.50	<i>Limacina ingridae</i>	1	RGM 457.062
			<i>Limacina valvatina (gramensis)</i>	51	RGM 457.063
		3.50-3.75	<i>Limacina valvatina (gramensis)</i>	40	RGM 457.064
		3.75-4.00	<i>Limacina valvatina (gramensis)</i>	47	RGM 457.065
		4.25-4.50	<i>Limacina valvatina (gramensis)</i>	21	RGM 457.066
		4.50-4.75	<i>Limacina valvatina (gramensis)</i>	22	RGM 457.067
		4.75-5.00	<i>Limacina ingridae</i>	1	RGM 457.068
			<i>Limacina valvatina (gramensis)</i>	8	RGM 457.069
		5.00-5.25	<i>Limacina valvatina (gramensis)</i>	14	RGM 457.070
		5.25-5.50	<i>Limacina valvatina (gramensis)</i>	46	RGM 457.071
		5.50-5.75	<i>Limacina valvatina (gramensis)</i>	10	RGM 457.072
		5.75-6.00	<i>Limacina valvatina (gramensis)</i>	8	RGM 457.073
		6.50-6.75	<i>Limacina valvatina</i>	9	RGM 457.074
		6.75-7.00	<i>Limacina valvatina</i>	2	RGM 457.075
		7.00-7.25	<i>Limacina valvatina (gramensis)</i>	6	RGM 457.076
		7.25-7.50	<i>Limacina valvatina (gramensis)</i>	15	RGM 457.077
		7.50-7.75	<i>Limacina valvatina (gramensis)</i>	14	RGM 457.078
7.75-8.00	<i>Limacina valvatina (gramensis)</i>	8	RGM 457.079		
8.00-8.25	<i>Limacina valvatina (ingridae)</i>	1	RGM 457.080		
8.25-8.50	<i>Limacina valvatina (ingridae)</i>	6	RGM 457.081		
8.75-9.00	<i>Limacina ingridae</i>	3	RGM 457.082		
9.75-10.00	<i>Limacina valvatina</i>	1	RGM 457.083		
10.00-10.25	<i>Limacina valvatina</i>	1	RGM 457.084		
13.50-13.75	<i>Limacina valvatina</i>	1	RGM 457.085		
14.75-15.00	<i>Limacina valvatina</i>	1	RGM 457.086		
15.25-15.50	<i>Limacina valvatina</i>	5	RGM 457.087		
20.00-20.20	<i>Limacina valvatina</i>	1	RGM 457.088		
22.00-22.25	<i>Limacina valvatina</i>	2	RGM 457.089		
22.25-22.50	<i>Limacina valvatina</i>	10	RGM 457.090		
22.50-22.75	<i>Limacina valvatina</i>	2	RGM 457.091		
22.75-23.00	<i>Limacina valvatina</i>	5	RGM 457.092		
23.00-23.75	<i>Limacina valvatina</i>	2	RGM 457.093		
23.75-24.00	<i>Limacina valvatina</i>	1	RGM 457.094		
24.25-24.50	<i>Limacina valvatina</i>	4	RGM 457.095		
24.75-25.00	<i>Limacina valvatina</i>	1	RGM 457.096		
33.00-33.50	<i>Limacina valvatina</i>	1	RGM 457.097		
33.50-34.00	<i>Limacina valvatina</i>	3	RGM 457.098		
34.00-34.50	<i>Limacina valvatina</i>	5	RGM 457.099		
34.50-35.00	<i>Limacina valvatina</i>	4	RGM 457.100		
35.00-35.50	<i>Limacina valvatina</i>	5	RGM 457.101		
35.50-36.00	<i>Limacina valvatina</i>	12	RGM 457.102		

Higher up, *L. irisa* and *L. valvatina* vanish. Up to 16 m the assemblage consists of *L. ingridae*, slowly decreasing in number, and *L. wilhelminae* becoming more and more abundant. At 16 m *L. atlanta* appears, abruptly replacing *L. wilhelminae* from one sample to the next. From 15.5 m *L. atlanta* is the only remaining species. According to LAURSEN & KRISTOFFERSEN (1999) up to 25.5 m only *Bolboforma reticulata* and *B. sp. D* occur in the section examined. This can thus be attributed to the *B. reticulata* zone. A zone barren in *Bolboforma* follows to 21 m. At that depth, *B. clodiusi* and one specimen of *B. metzmacheri* occur. At 16.5 m *B. metzmacheri* begins to appear in more

reliable numbers and becomes abundant at approx. 13 m. Thus, the *B. metzmacheri* zone, the *L. atlanta* zone and the Gramian stage based on Mollusca (BURGER, this volume) begin nearly simultaneously in this cored borehole.

Faunal Development of Pteropods in the North Sea Basin

In general, two groups of molluscan plankton are found in the sediments of the North

Table 6: Pteropod distribution in the Gram DGU 141.277 borehole

Epoch	Lithostratigraphy	Sample depth [m]	Species	No	Collection
MIOCENE GRAMIAN	Gram-Formation	5.30-5.70	<i>Limacina atlanta</i>	6	Specimens housed in the Geological Survey of Denmark, Copenhagen
		5.70-6.10	<i>Limacina atlanta</i>	3	
		6.10-6.40	<i>Limacina atlanta</i>	17	
		6.40-6.90	<i>Limacina atlanta</i>	15	
		6.90-7.30	<i>Limacina atlanta</i>	27	
		7.30-7.65	<i>Limacina atlanta</i>	9	
		7.65-8.05	<i>Limacina atlanta</i>	32	
		8.05-8.50	<i>Limacina atlanta</i>	18	
		8.50-9.00	<i>Limacina atlanta</i>	26	
		9.00-9.50	<i>Limacina atlanta</i>	13	
		9.50-9.90	<i>Limacina atlanta</i>	49	
		9.90-10.30	<i>Limacina atlanta</i>	23	
		10.30-10.80	<i>Limacina atlanta</i>	55	
		10.80-11.25	<i>Limacina atlanta</i>	12	
		11.25-11.65	<i>Limacina atlanta</i>	27	
		11.65-12.10	<i>Limacina atlanta</i>	6	
		12.10-12.60	<i>Limacina atlanta</i>	46	
		12.60-13.10	<i>Limacina atlanta</i>	47	
		13.10-13.50	<i>Limacina atlanta</i>	27	
		13.50-14.00	<i>Limacina atlanta</i>	30	
			<i>Limacina wilhelminae</i>	1	
		14.00-14.60	<i>Limacina atlanta</i>	32	
		14.60-15.10	<i>Limacina atlanta</i>	33	
		15.10-15.55	<i>Limacina atlanta</i>	30	
		15.55-16.00	<i>Limacina atlanta</i>	10	
			<i>Limacina wilhelminae</i>	21	
		16.00-16.50	<i>Limacina ingridae</i>	17	
			<i>Limacina wilhelminae (atlanta)</i>	50	
		16.50-17.00	<i>Limacina ingridae</i>	2	
			<i>Limacina wilhelminae (atlanta)</i>	30	
		17.00-17.50	<i>Limacina ingridae</i>	4	
			<i>Limacina wilhelminae (atlanta)</i>	68	
		17.50-18.00	<i>Limacina ingridae</i>	3	
	<i>Limacina wilhelminae (atlanta)</i>	36			
18.00-18.50	<i>Limacina ingridae</i>	1			
	<i>Limacina irisae</i>	2			
	<i>Limacina valvatina</i>	1			
	<i>Limacina wilhelminae (atlanta)</i>	5			
18.50-19.00	<i>Limacina ingridae</i>	4			
	<i>Limacina irisae</i>	1			
	<i>Limacina valvatina</i>	5			
	<i>Limacina wilhelminae (atlanta)</i>	8			
19.00-19.50	<i>Limacina ingridae (wilhelm.)</i>	3			
19.50-20.00	<i>Limacina ingridae</i>	1			
	<i>Limacina irisae</i>	1			
	<i>Limacina valvatina</i>	11			
20.00-20.50	<i>Limacina ingridae</i>	14			
	<i>Limacina irisae</i>	5			
	<i>Limacina valvatina</i>	4			
	<i>Limacina wilhelminae</i>	1			
20.50-21.00	<i>Limacina ingridae</i>	17			
21.00-21.50	<i>Limacina gramensis</i>	5			
	<i>Limacina ingridae</i>	8			
	<i>Limacina valvatina</i>	23			
21.50-22.00	<i>Limacina gramensis</i>	2			
	<i>Limacina ingridae</i>	6			
	Glauconite Bed	No pteropods or microfossils present			
MIOCENE REINBEKIAN	Hodde-Formation	26.50-27.00	<i>Limacina valvatina</i>	3	
		27.00-27.50	<i>Limacina valvatina</i>	42	
		27.50-28.00	<i>Limacina valvatina</i>	9	
		28.00-28.50	<i>Limacina valvatina</i>	37	
		28.50-29.00	<i>Limacina valvatina</i>	149	
		29.00-29.50	<i>Limacina valvatina</i>	51	
		29.50-30.00	<i>Limacina valvatina</i>	42	
		30.00-30.50	<i>Limacina valvatina</i>	15	
		30.50-30.95	<i>Limacina valvatina</i>	10	
		30.95-31.35	<i>Limacina valvatina</i>	10	
		31.35-31.65	<i>Limacina valvatina</i>	1	
		31.65-32.30	<i>Limacina valvatina</i>	1	
		32.70-33.05	<i>Limacina valvatina</i>	1	
		33.05-33.40	<i>Limacina valvatina</i>	1	
		33.40-33.80	<i>Limacina valvatina</i>	1	
		33.80-34.25	<i>Limacina valvatina</i>	1	
		34.70-35.00	<i>Limacina valvatina</i>	1	

Sea Basin (NSB) Miocene. The first are Cavoliniidae, a warm-water planktonic assemblage with members evolving mainly outside the basin and immigrating into the basin only sporadically through the Palaeochannel, thus indicating warm-water influx by ocean currents and a relatively high water temperature of NSB surface water. These forms are restricted to the Early to early Middle Miocene, with one Late Miocene exception, *Ireneia marqueti*. Most common in this group are species of the *Vaginella* genus already present in the Late Oligocene (Chattian). They form the evolutionary lineage from *Vaginella chattica*, through *V. depressa* (Plate 1, Figures 1, 2) to *V. austriaca* (Plate 1, Figure 3). Next to this assumed lineage, the species *V. (cf.) tricuspidata* is found in the Late Oligocene and the Early Miocene, and *V. lapugyensis* in the Middle Miocene. The transition from *V. depressa* to *V. austriaca* is quite sudden, and the first occurrence of *V. austriaca* can be interpreted as a zone boundary. In the international Aquitanian and Burdigalian stage type areas, the Aquitaine Basin, *V. depressa* can be found in Aquitanian and Early Burdigalian sediments. In Langhian sediments only *V. austriaca* occurs. Therefore, the hiatus covering the Late Burdigalian in the Aquitaine Basin leaves in doubt the location at which the exact correlation mark must be placed (JANSSEN 2001).

In the earliest Miocene no member of the Cavoliniidae is present in the North Sea Basin. This is probably due to a cooling period at the end of the Chattian and earliest Miocene. Re-immigration begins with *Vaginella depressa* and *V. cf. tricuspidata*, most probably in the Aquitanian, since the latest occurrences of the latter species outside the basin are dated Aquitanian (Malta). *V. tricuspidata* populated the basin during late Early Chattian but then vanished. Later on, *Clio deflexa* (Plate 1 Figure 5), *Clio aff. nielseni* and *Diacrolinia aquensis* (Plate 1 Figure 4) immigrated, but since *C. aff. nielseni* and *D. aquensis* are known only from erratic boulders it is not possible to determine which came earlier and which later. It is very likely that this immigration took place in the Early Burdigalian since *D. aquensis* is known only from the Early Burdigalian of the Aquitaine Basin thus far. It is possible that *C. aff. nielseni* from the 'Holsteiner Gestein' is conspecific with *C. deflexa*, indicating that this species is a descendant from *C. nielseni*, as described from the North Sea Basin Chattian (JANSSEN 1990). Until further evidence has been put forth, both are listed as separate species.

All this took place during the regional Vierlandian stage, while *Vaginella depressa* was replaced by its descendant *V. austriaca* (cf. borehole Viöl) in the Early Hemmoorian and remains the only cavoliniid species apart from two fragments of a large *Clio* species known from a local erratic boulder from Hüllerup near Flensburg. They cannot yet be identified to species level.

Following this, a longer period without observation of any new cavoliniid pteropods in the basin follows until (so called Oxlundian) *Vaginella lapugyensis*, *Clio bellardii*, *C. pauli* and *Diacrolinia aurita* immigrate in the Late Hemmoorian, the assemblage indicating a Langhian age. All of these species are extremely rare and apparently at the northern limit of their area of distribution.

The second group of holoplanktonic Mollusca is that of the *Limacina* genus. *L. valvatina* (Plate 2 Figure 2) is normally a quite common pteropod species known from the Late Oligocene to the Late Miocene, mainly from the North Sea and Central Paratethys basins; dwarf forms are known from the Mediterranean Miocene. In the North Sea area *L. valvatina* is, during the Late Oligocene, accompanied by another *Limacina* species which occurred during the Rupelian, viz. *L. hospes* (ROLLE 1861), and which differs clearly in shell form and apertural structures. During the Early Miocene (from the Vierlandian onwards) another *Limacina* species is found next to *L. valvatina*. This species, *L. miostralis* (KAUTSKY 1925), can easily be recognised by its flat apical side, rapidly increasing whorl diameter and (although normally not developed) the presence of a rostrum on the apertural margin. This latter characteristic makes *L. miostralis* (Plate 2 Figures 7, 8) clearly a forerunner species of the Recent *L. inflata* (ORIGNY 1836).

The morphology of *Limacina valvatina* is quite simple: it approaches the ideal *Limacina* shape, with regularly convex whorls, simple apertural features, and a height/width ratio which is close to 1. During the Vierlandian, populations are known in which specimens occur with relatively flat shells (height/width ratio lower than 1). During the Hemmoorian and Reinbekian, *L. valvatina* demonstrates little variability. During the Reinbekian the accompanying *L. miostralis* species disappears gradually from the North Sea Basin, and *L. valvatina* is the only *Limacina* species there for some time.

Late in the Middle Miocene (Late Reinbeian and Early Langenfeldian, i.e., Levensauian sensu HINSDI 1987), *L. valvatina* suddenly becomes highly variable with respect to its height/width ratio. In addition to the typical form, strikingly depressed specimens are found, in which the whorls tend to be nearly flat, apparently transitional forms to *L. ingridae*. At the same time specimens with a very high height/width ratio of far over 1.10 occur, accompanying typical *L. valvatina*. These higher specimens, indicated as *L. gramensis* (RASMUSSEN 1968) [Plate 2 Figure 1] are found during the Early and Middle Langenfeldian (=Lüneburgian sensu HINSDI 1987) and the early part of the Late Langenfeldian (or Langenfeldian s. str. after HINSDI 1987). Then quite suddenly, at the boundary of Middle and Late Miocene, typical *L. ingridae* (Plate 2 Figure 4) occurs, generally in large numbers and initially still accompanied by *L. valvatina* and *L. gramensis*, but soon it becomes practically the only remaining pteropod species. A short time later it coexists with *L. irisae* (Plate 2 Figure 3), a contemporaneous species, developing either directly from *L. valvatina* or from *L. ingridae*. Towards the end of the Langenfeldian, *L. wilhelminae* (JANSSEN 1989) (Plate 2 Figure 5) develops from *L. ingridae*, to be replaced at the boundary of the Gramian by *L. atlanta* (Plate 2 Figure 6), which remains the only *Limacina* species until the Middle Pliocene.

Stratigraphical Interpretation and Revised Zonation

The developments outlined above permit the construction of a considerably refined Miocene biostratigraphy based on pteropods for the North Sea Basin. While the lowermost Miocene sediments contain no marker species, the sudden common occurrence of *Vaginella depressa* gives a first stratigraphic mark within the Vierlandian of regional stages and the Aquitanian of international stages. The upper boundary of Zone 17 comprises the sudden replacement of *V. depressa* by *V. austriaca* in the middle part of the Burdigalian, also marking the Vierlandian/Hemmoorian boundary. Thus, the *V. depressa* zone is the total range zone of *V. depressa*.

The following is the total range zone of *Vaginella austriaca*. It lasts from the middle part of the Burdigalian, or the Vierlandian/

Hemmoorian boundary, into the Reinbeian. By means of bolboforms the Reinbeian can be subdivided into an early part (lower *Bolboforma reticulata* zone) and a later part (upper *B. reticulata* zone). No *V. austriaca* were able to be observed in the upper *B. reticulata* zone thus far. As *V. austriaca* vanishes together with *Limacina miostralis*, the latter being more abundant in samples, the LOD of *L. miostralis* appears to be a more easily detected upper boundary of this zone. Unfortunately, there is no direct correlation of *Bolboforma* zones and international stages, but in the Paratethys the boundary between lower and upper *B. reticulata* zones lies between the "lower Lagenid zone" and the "upper Lagenid zone" of the early Badenian of Austria (SPIEGLER & ROGL 1992, Plate 1), and the upper *B. reticulata*/*B. danielsi* zone boundary lies within the late Badenian (SZCZECZURA 1997).

The sudden occurrence of various warm-water pteropod species during the late Hemmoorian falls within the *Vaginella austriaca* zone, and is here considered to be Subzone 18a, named after the *Clio bellardii* species.

Following the *Vaginella austriaca* zone, an interval with no stratigraphically relevant pteropods exists, referred to as 19a here, containing only *Limacina valvatina* and one occurrence of *V. lapugyensis*, the latter species occurring up to the end of the Serravallian in the Mediterranean. Towards the top of this interval, *L. valvatina* becomes highly variable, and flat forms are described by TEMBROCK (1989) under the name of *L. weinbrechti*, which can be so flat that it must be considered a transitional form to *L. ingridae*. These specimens should be taken as a form of *L. valvatina*. In the Early Langenfeldian [= Levensauian according to HINSDI 2001] (viz. the *Bolboforma badenensis* zone of the *Bolboforma* biostratigraphy or the Late Serravallian of international stages) the *L. gramensis* species develops from *L. valvatina*, and, as is the case in the Central Paratethys (JANSSEN & ZORN 1993), coexists with it over a long period of time.

The *Limacina gramensis* zone, zone 19b, is a partial range zone and ends with the appearance of *L. ingridae* in great numbers in the *Bolboforma fragorisi/subfragorisi* zone, the early Late Langenfeldian or around the Middle to Late Miocene boundary. *L. gramensis* coexists with *L. ingridae*.

The *Limacina ingridae* zone, 20a, is also a partial range zone since *L. irisae*, the next zone marker, already appears when *L. ingridae* still persists.

The total range of *Limacina irisae* marks the next zone, 20b.

Limacina wilhelminae, the next zone marker of 20c and a clear descendent of *L. ingridae*, develops in the *L. irisae* zone.

The last Miocene zone 21 is marked by *Limacina atlanta*, which in turn develops from *L. wilhelminae*. This zone crosses the Mio-Pliocene boundary.

The *Limacina ingridae* zone, the *L. irisae* zone and the *L. wilhelminae* zone lie within the Late Langenfeldian (Early Tortonian). The latter of these two lies within the *B. laevis/capsula* zone. The boundary of the *L. wilhelminae* zone with the *L. atlanta* zone coincides with the Langenfeldian/Gramian boundary as well as with the boundary between the *B. laevis/capsula* zone and the *B. metzmacheri* zone.

HINSCH (2001) made some puzzling comments on the data concerning long-distance stratigraphic correlations using pteropods by JANSSEN (2001). He says that *Vaginella austriaca* was believed to be a Langhian index fossil by the latter. In contrast, it is stated that *V. austriaca* has a range from post-Early Burdigalian to earliest Serravallian, thus implying that the Vierlandian/Hemmoorian boundary is younger than early Burdigalian. HINSCH also implies that *Vaginella austriaca* occurs in late Vierlandian. No such find is known to us, nor described anywhere in literature. Ultimately, HINSCH (2001) implies that JANSSEN & KING (1988) correlated the Vierlandian and early Hemmoorian with the Aquitanian. JANSSEN & KING integrated the preliminary pteropod zonation into a given chronostratigraphic framework of the time, since too little was then known about the range of the pteropods to use them for international correlations. This former correlation scheme for the North Sea Basin Miocene had very little support from reliable data and must be completely revised due to new data from nannoplankton, bolboforms and pteropods. In addition, it must be updated because of changes made in international time scales and definitions currently in use.

Comparison to Other International Biostratigraphies

Samples taken from dark brown to greenish mica fine sand to silt from a cliff exposure at Johannistal near Heiligenhafen (Holstein) were dated by MARTINI (pers. comm.) as NP 25 and NN1. They yielded only *Limacina valvatina*. For the *Vaginella depressa* zone no reliable nannoplankton dates exist. Samples from the Klintinghoved foreshore outcrop had a dinoflagellate cyst flora of Early Burdigalian age after Dybkjaer (pers. comm.). In the Hemmoorian and its time equivalents, nannoplankton becomes richer, and the NN3 zone is postulated for the Early Hemmoorian (MÜLLER 1986; KÖTHE 1988). An NN4 zone was demonstrated for the younger part of the Early Hemmoorian and the Late Hemmoorian (zone Mol H after SLUGGERS & VAN LEEUWEN 1987). The Hemmoorian/Reinbekian boundary coincides with the NN4/NN5 boundary (MÜLLER 2000, unpublished report for the GLA NRW). Therefore, the *V. austriaca* zone comprises NN3, NN4 and, in part, NN5.

After NN5, nannoplankton data are only very rarely achieved from samples from the North Sea Basin. Instead, bolboforms become more and more abundant and can be used as international markers (SPIEGLER 1999). The next zone boundary, the lower boundary of the *Limacina gramensis* zone, lies within the *B. badenensis* zone. Its upper boundary lies immediately at the boundary from the *B. fragorisi/subfragorisi* zone to the *B. laevis/capsula* zone in the Groß Pampau section but well within the *B. laevis/capsula* zone in the Lübtheen section according to GÜRS & SPIEGLER (2000). Nevertheless it is possible that the *Bolboforma* zone boundary must be placed somewhat higher in the Lübtheen section, since there is an overlap zone of index species in this borehole. It therefore appears as if the zone boundary of the *Bolboforma* zones and the pteropod zones fit together very well at this time. The *L. ingridae* zone has a short range and its upper boundary lies in the *B. laevis/capsula* zone. The *L. irisae* zone has an even shorter range with its upper boundary in the *B. laevis/capsula* zone as well. The upper boundary of the following *L. wilhelminae* zone coincides nearly perfectly with the boundary of the *B. laevis/capsula* zone and with the *B. metzmacheri* zone. The youngest Miocene pteropod zone of *L. atlanta* comprises the *B. metzmacheri* and the *B. intermedia* zone

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Plate 1: *Cavoliniidae* from the North Sea Basin Miocene, scale bar = 5mm; All specimens shown: Nationaal Natuurhistorisch Museum, Leiden (RGM)

- Figure 1: *Vaginella depressa*, erratic boulder, Schilke, Vierlandian, a front view, b side view, c apertural view, RGM 458.740
- Figure 2: *Vaginella depressa*, Brodersdorf drilling, 202.5-205 m, Vierlandian, a front view, b side view, RGM 458.712
- Figure 3: *Vaginella austriaca*, Brodersdorf drilling, 246-252 m, early Hemmoorian, a front view, b side view, c apertural view, RGM 458.741
- Figure 4: *Diacrolinia aquensis*, erratic boulder, Nehnten, Vierlandian, RGM 458.705
- Figure 5: *Clio deflexa*, Brodersdorf drilling, 202.5-205 m, Vierlandian, a front view, b back view, RGM 458.711

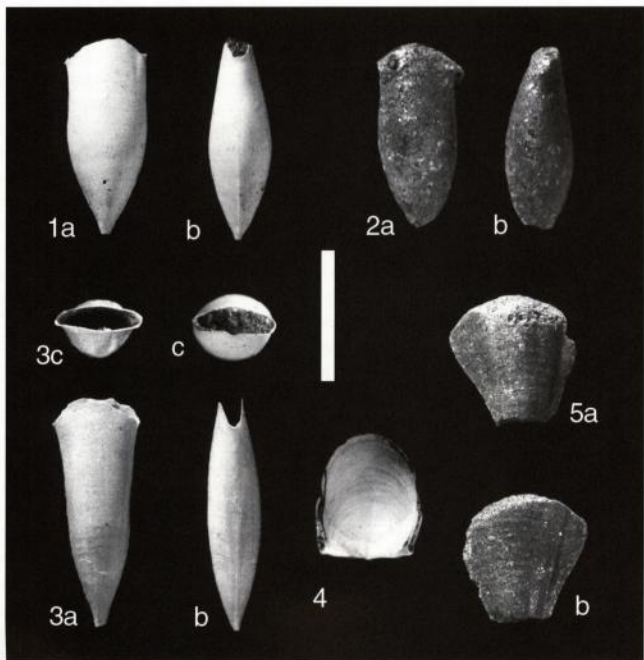
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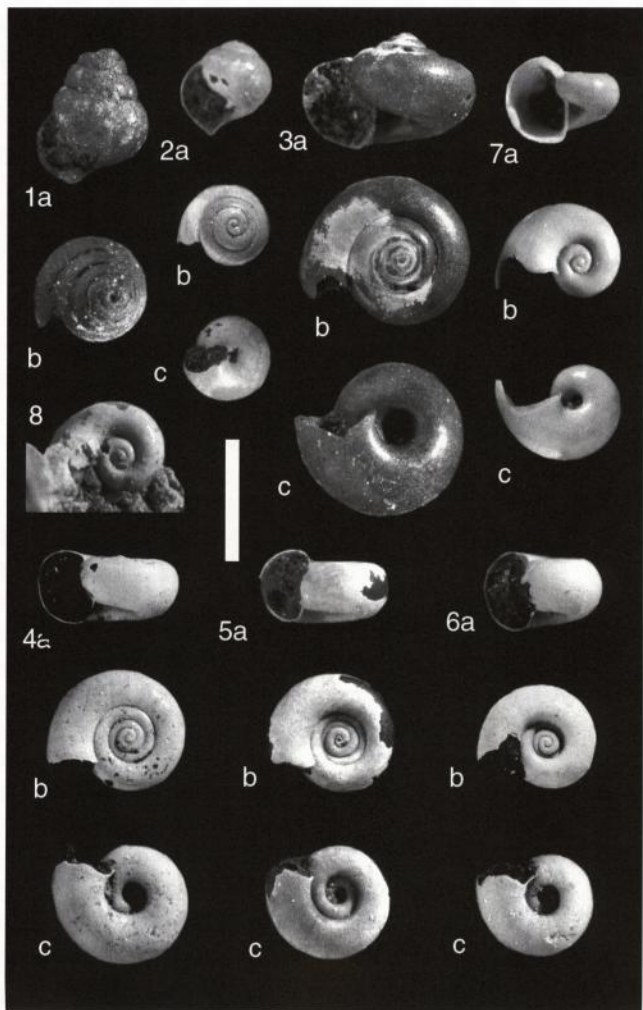
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Plate 2: Limacnidae from the North Sea Basin Miocene, scale bar = 1mm; Figures 7 and 8 coll. Gürs, all other specimens shown: Nationaal Natuurhistorisch Museum, Leiden (RGM)

- Figure 1: *Limacina gramensis*, Karlum A28, 99-102 m, late Langenfeldian, RGM 458.744
Figure 2: *Limacina valvatina*, Reinfeld HL1 drilling, 147-150 m, late Langenfeldian, a apertural view, b apical view, c adapical view, RGM 458.746
Figure 3: *Limacina irisae*, Karlum A28 drilling, 90-93 m, late Langenfeldian a apertural view, b apical view, c adapical view, RGM 458.743
Figure 4: *Limacina ingridae*, Ohle clay pit, Groß Pampau, late Langenfeldian, *Bolboforma laevis/capsula* zone, a apertural view, b apical view, c adapical view, RGM 458.747
Figure 5: *Limacina wilhelmina*, Karlum A28 drilling, 87-90 m, late Langenfeldian, a apertural view, b apical view, c adapical view, RGM 458.742
Figure 6: *Limacina atlanta*, Karlum 1/96 drilling, 80-85 m, Gramian, a apertural view, b apical view, c adapical view, RGM 458.745
Figure 7: *Limacina microstralis*, Borchelhof drilling, 108-111 m, early Hemmoorian, a apertural view, b apical view, c adapical view
Figure 8: *Limacina microstralis*, erratic boulder, Nehnten, Vierlandian, apical view



Correlation of Marine Miocene *Bolboforma* Zonation and *Uvigerina* Zonation in Northern Germany

► Dorothee Spiegelger **Abstract**

Regional *Uvigerina* zonation (benthic foraminifers) is correlated to global *Bolboforma* zonation (incertae sedis) and to Neogene calcareous nannoplankton zonation (NN) in the Nieder Ochtenhausen, Wursterheide, Twistingen, Groß Pampau, Schwarzenbek and Lübtheen Miocene profiles, and in the Lower Rhine area Miocene (Northern Germany). The results enable age determination of *Uvigerina* zones and thus good age control of the marine sequences as well as a determination of nearshore hiatuses and gaps in the area investigated.

Kurzfassung

Gegeben wird die Korrelation der mehr regional anwendbaren biostratigraphischen Gliederung aufgrund von *Uvigerina* (benthische Foraminiferen) zu der globalen *Bolboforma* Zonierung und der neogenen Nannoplankton (NN) Zonierung für das Miozän Norddeutschlands. Ausgewertet wurden die Profile Nieder Ochtenhausen, Wursterheide, Twistingen, Groß Pampau, Schwarzenbek, Lübtheen und Profile vom Niederrhein. Die Ergebnisse führten zu Alterszuordnungen der *Uvigerina* Zonen und damit zu einer genaueren Biostratigraphie für die marinen miozänen Sedimente Norddeutschlands. Sie erlauben die Bestimmung von Schichtlücken in den küstennahen Ablagerungen des Beckens.

Key words

Miocene, biostratigraphy, correlation: *Uvigerina*, *Bolboforma*, calcareous nannoplankton, northern Germany

Introduction

Ever since a definition of the Miocene stages of the North Sea Basin on the basis of molluscs has been under discussion

(VINKEN 1988, DANIELS 2001, GÜRS & SPIEGLER 2001), the most powerful tool for completing a biostratigraphy of marine sediments in northern Germany has been investigations of *Bolboforma* (incertae sedis) and *Uvigerina* (benthic foraminifers).

The stratigraphic value of *Bolboforma* was first described for the Neogene in northern Germany by DANIELS & SPIEGLER (1974). *Bolboforma* zones, partly defined by QVALE & SPIEGLER (1989) and updated by SPIEGLER & DANIELS (1991), are correlated to calcareous nannoplankton (NN) zones and to the palaeomagnetic record (SPIEGLER & MÜLLER 1992) for age control. In the Hatton-Rockall Basin (North Atlantic), Ocean Drilling Program (ODP) Leg 162 recovered a continuous sequence of more than six hundred meters of Neogene sediment (particularly 433 m of Miocene sediment). SPIEGLER (1999) detected an abundance of various *Bolboforma* in this sequence, again documenting the succession of the *Bolboforma* zones. The age of the zones was calculated by interpolation, using the age vs. depth curve of ODP Hole 982 B for age control based on integrated magnetostratigraphy and biostratigraphy of calcareous nannoplankton, planktonic foraminifers, siliceous flagellates and diatoms (JANSEN et al. 1996), and was correlated to the time scale of BERGGREN et al. (1995). The *Bolboforma* biostratigraphy was checked in various drilling sections and outcrops, particularly in middle and higher latitudes in both hemispheres (POAG & KAROWE 1986, SPIEGLER & DANIELS 1991, GRÜTZMACHER 1993, COOKE et al. 2002).

From the eleven *Bolboforma* zones globally identified from Late Miocene to Early Miocene, all zones were recognized in northern Germany.

The regional biozonation of the Miocene sediments in northwest Germany based on the benthic foraminifer *Uvigerina* genus was determined by DANIELS & SPIEGLER (1977, 1979) and updated by DANIELS (1986, 2001).

It is the intent of this paper to correlate both biostratigraphies by summarising the results of the micropalaeontological investigations of the following profiles: Nieder Ochtenhausen (DANIELS 2001, SPIEGLER 2001), Wursterheide (GRAMANN 1989) and Twistringen (SPIEGLER 1986) located in Lower Saxony, Groß Pampau (SPIEGLER & GÜRS 1996) and Schwarzenbek (GÜRS & SPIEGLER 1999) situated in Schleswig Holstein, and several profiles drilled in Mecklenburg (SPIEGLER & RUSBÖLT 1994), particularly the Lüththeen 27/82 well (GÜRS & SPIEGLER 2000). In addition, remarks are made about new biostratigraphical observations of Miocene sediments in the Lower Rhine area (Hess et al. in prep.).

Methods

The preparation method used to obtain *Bolboforma* and *Uvigerina* specimens is the same: wet sieving of sediment through 63- μ m sieves, drying of residues and examination under the binocular microscope. *Bolboforma* are enriched in the sand fraction <200 μ m, *Uvigerina* in the fraction >200 μ m. In older profiles, such as Twistringen and even Wursterheide, where the occurrence of *Bolboforma* was originally not, or not well, described, the residues were again scanned for *Bolboforma*.

Miocene Biostratigraphy

Bolboforma Zonation

The major events used for identifying the Miocene *Bolboforma* zonal boundaries and zones are the same as those used in SPIEGLER & DANIELS (1991) and SPIEGLER (1999). They are reported from youngest to oldest. The base of the younger zone is equivalent to the top of the following zone below it.

***Bolboforma intermedia* zone**, total range (TR) of *B. intermedia*. *B. lockeri* (TR) contained in the upper part of the zone.

Age: NN11; 5.6 - 7.7 Ma

Top: First occurrence (FO) *B. costairregularis*, last occurrence (LO) *B. intermedia*

***Bolboforma metzmacheri* zone**, TR *B. metzmacheri* group (includes *B. metzmacheri metzmacheri*, *B. metzmacheri ornata*, *B. metzmacheri solida*). TR *B. polygonalis* lies in the upper part of the zone.

Age: NN11 - NNS; 7.7 - 9.7 Ma

Top: FO *B. intermedia*, LO *B. metzmacheri*

***Bolboforma capsula* zone**, TR *B. capsula*.

Age: NN9; 9.7 - 10.6 Ma

Top: FO *B. metzmacheri*, LO *B. capsula*

***Bolboforma subfragoris* zone**, TR *B. subfragoris* group (includes *B. subfragoris*, *B. subfragoris magna*, *B. fragori*)

Age: NN8 - NN7; 10.6 - 11.7 Ma

Top: FO *B. capsula*, LO *B. subfragoris*

***Bolboforma compressispinosa* zone**, occurrence of oblate *Bolboforma* specimens. *B. compressispinosa* indicates the upper part and *B. compressibadenensis* the lower part of the zone.

Age: NN6; 11.7 - 11.9 Ma

Top: FO *B. subfragoris*

***Bolboforma badenensis* zone**, very rich in specimens of *B. badenensis*. TR *B. atlantica* lies in the lower part of the zone, together with single *B. platyreticulata*.

Age: NN6; 11.9 - 12.6 Ma

Top: LO *B. badenensis*

***Bolboforma danielsi* zone**, TR *B. danielsi* defines this very distinct marker horizon with an extension of approximately 50 ky, rare *B. platyreticulata* and *B. badenensis*.

Age: NN6; 12.6 - 12.7 Ma

Top: LO *B. danielsi*

The ***Bolboforma reticulata* zone** is subdivided into an upper and a lower subzone:

Upper ***Bolboforma reticulata* subzone**, common *B. platyreticulata*, single *B. badenensis*, no *B. danielsi*.

Age: NN6 - NN5; 12.7 - 14.5 Ma

Top: FO *B. danielsi*, LO *B. platyreticulata*

Lower ***Bolboforma reticulata* subzone**, TR *B. reticulata*, specimens decrease in diameter from top to base of the subzone. *B. bireticulata* common in the upper part of the subzone.

Age: NN5; 14.5 - 15.6 Ma (corrected according Hess et al. in prep.)

Top: FO *B. platyreticulata*, LO *B. reticulata*, LO *B. bireticulata*

***Bolboforma rotunda* zone**, exclusive occurrence of *B. rotunda*

Age: NN4; 15.6 - 18.2 Ma

Top: FO *B. reticulata*, LO of tiny spheroid *Bolboforma* species.

***Bolboforma spinosa* zone**, co-occurrence of *B. rotunda* and *B. spinosa*

Age: NN3; 18.2 - 18.9 Ma

Top: LO *B. spinosa*

***Bolboforma spiralis* zone**, co-occurrence of *B. spiralis* and *B. vulgaris*
 Age: NN2 - NN1; 18.9 - 23.9 Ma
 Top: Rare *B. spiralis* and *B. vulgaris*

***Uvigerina* Zonation**

In northern Germany seven *Uvigerina* zones have been established for the Miocene. They are reported from youngest to oldest with the following definitions:

***Uvigerina saxonica* zone**
 Top: Last appearance (LA) *U. saxonica venusta* group
 Base: LO *U. pygmaea langeri*

***Uvigerina langeri* zone**, TRZ *U. pygmaea langeri*
 Top: LO *U. pygmaea langeri*
 Base: FO *U. pygmaea langeri*

***Uvigerina brunnensis* zone**, TRZ *U. brunnensis*
 Top: LO *U. brunnensis*, *U. semiornata kusteri*, *U. densistriata*, *U. zandii*
 Base: LO *U. macrocarinata*, *U. acuminata*

***Uvigerina macrocarinata* zone**, TRZ *U. macrocarinata*
 Top: LO *U. macrocarinata*
 Base: FO *U. macrocarinata*

***Uvigerina acuminata* zone**, TRZ *U. acuminata*
 Top: FO *U. macrocarinata*
 Base: LO *U. tenuipustulata*

***Uvigerina tenuipustulata* zone**, TRZ *U. tenuipustulata*
 NN5/NN4 boundary lies in this zone (Hiss et al. in prep.)
 Top: LO *U. tenuipustulata*
 Base: FO *U. tenuipustulata*

***Uvigerina hemmooriensis* zone**, NN4/NN3 boundary in this zone (MÜLLER et al. 1979)
 Top: *U. hemmooriensis*

Calcareous Nannoplankton Zonation

Calcareous nannoplankton assemblages occur only sporadically in Miocene sediments in northern Germany. In sediments younger than lower Middle Miocene the associations contain mostly reworked specimens of the Upper Cretaceous, and the zonation according MARTINI (1971) fails. Nevertheless, MÜLLER et al. (1979) observed the NN5 zone in the *Uvigerina brunnensis* zone, NN4 in the lower part of the *U. tenuipustulata* zone, and NN3 in the *U. hemmooriensis* zone. MÜLLER in HISS et al. (in prep.) documented the NN5/NN4 boundary in the Lower Rhine area between the upper and the lower *U. tenuipustulata* subzone, as well as between the lower *Bolboforma reticulata* subzone and the *B. rotunda* zone. MARTINI (2001) observed the NN5 zone in the *U. acuminata* zone and NN4 in the lower *U. tenuipustulata* subzone (Figure 2).

Results

The localities of the sites investigated for *Bolboforma* and *Uvigerina* are outlined in Figure 1. The distribution of the different species at the sites is documented in Table 1. The extension of the profiles in the stratigraphic framework is shown in Table 2.

Lower Saxony

Nieder Ochtenhausen

The Nieder Ochtenhausen cored research well drilled a 99-m-thick sequence of marine Upper and Middle Miocene below 37 m of Quaternary sediment.

Two *Bolboforma* zones were recognized (SPIEGLER 2001).

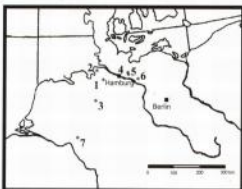
B. metzmacheri zone 39.50 - 101.50 m
B. polygonalis in 88.00 - 89.30 m and
B. capsula in 101.20 m depth
 Lower *B. reticulata* subzone

122.07 - 128.40 m
B. bireticulata in 123.00 - 126.30 m depth)

DANIELS (2001) determined the following six *Uvigerina* zones in the well:

U. saxonica zone 53.90 - 71.60 m
U. langeri zone 72.50 - 102.00 m
U. brunnensis zone 119.50 - 127.60 m
U. macrocarinata zone 128.50 m
U. acuminata zone 129.50 - 134.60 m
U. tenuipustulata zone 135.60 - 136.00 m.

Figure 1: Location map of sites investigated:
 1 - Nieder Ochtenhausen,
 2 - Wursterheide,
 3 - Twistringien,
 4 - Groß Pampau,
 5 - Schwarzenbek,
 6 - Lübtheen,
 7 - Lower Rhine district



Age [Ma]	NN Zone	Bolboforma Zone	Uvigerina Zone	Subseries	
14.50	NN 5	Upper <i>B. reticulata</i>	sparadically <i>U. semiornata</i> <i>U. saprophila</i>	Middle Miocene	
			<i>U. brunensis</i>		
			<i>U. macrocarinata</i>		
			<i>U. acuminata</i>		
15.60	Lower <i>B. reticulata</i>	Upper <i>U. tenuipustulata</i>			
		Lower <i>U. tenuipustulata</i>			
16.40	NN 4	<i>B. rotunda</i>	Lower <i>U. tenuipustulata</i>		Early Miocene
18.30	NN 3	<i>B. spinosa</i>	<i>U. hemmoriensis</i>		

Figure 2: Correlation of the Neogene calcareous nannoplankton, *Bolboforma* and *Uvigerina* zonation in the Miocene in northern Germany

MARTINI (2001) determined the Neogene nannoplankton zone NN5 at 132.00 m and NN4 in 135.5 m depth, meaning that the NN5 lies in the *U. acuminata* zone, and NN4 in the *U. tenuipustulata* zone.

Wursterheide

The Wursterheide well drilled 236 m of marine Upper Miocene and Middle Miocene sediments containing various *Uvigerina* and *Bolboforma* species (GRAMANN 1989). Re-examination of the residues permitted the recognition of two *Bolboforma* zones and six *Uvigerina* zones.

B. metzmacheri zone 111 - 257 m
Lower *B. reticulata* subzone 275 - 280 m
(*B. bireticulata* at 275 - 277 m depth)

U. saxonica zone 111 - 257 m
U. brunensis zone 275 - 277 m
U. macrocarinata zone and
U. acuminata zone 279 - 281 m
U. tenuipustulata zone 285 - 321 m
U. hemmoriensis 323 - 328 m

Twistringen

The approximately seven meters of sediment in the Sunder brickwork pit near Twistringen contained the following *Uvigerina* zones (SIEGLER 1986):

U. brunensis zone Samples 111 - 90
U. macrocarinata zone Samples 50 - 44
U. acuminata zone Samples 43 - 5
Re-examination of the above listed samples showed
no *Bolboforma* Samples 111 - 105
Lower *B. reticulata* subzone
Samples 104 - 45
no *Bolboforma* Samples 44 - 28
Lower *B. reticulata* subzone
Sample 27
no *Bolboforma* Samples 26 - 1

Schleswig Holstein

Groß Pampau

B. laevis/capsula zone, *B. subfragoris* zone, and the *B. compressispinosa* zone were studied in sediments of the Groß Pampau mica clay pit, where an isolated single sample also contained specimens of *B. danielsi*. The benthic foraminifers were studied by DANIELS et al. (1990).

In addition, a 36-meter section of mostly Middle Miocene mica clay in the Groß Pampau 1 well was studied for molluscs and bolboforms (SIEGLER & GÜRS 1996). The following *Bolboforma* zones were recognized:

B. laevis/capsula zone 0.65 - 2.00 m
B. subfragoris zone 2.75 - 5.00 m
B. compressispinosa zone 14.75 - 19.00 m
B. badenensis zone 25.75 - 30.50 m
B. danielsi zone (not recogn.)
Upper *B. reticulata* subzone 30.50 - 35.00 m

No *Uvigerina* specimens were observed, and Neogene nannoplankton was not determined.

Schwarzenbek 1/96

A 33-meter-thick section of Middle Miocene strata from a drilling hole in Schwarzenbek was studied for molluscs, foraminifers and

Table 1: Ranges of *Bolboforma* and *Uvigerina* in the Miocene in northern Germany in order of their LO. Bars indicated with different numbers are used for different profiles: 1 - Nieder Ochtenhausen, 2 - Wursterheide, 3 - Twistringen, 4 - Groß Pampau, 5 - Schwarzenbek, 6 - Lübbtheen, and 7 - Lower Rhine area. dashed line = single specimen, ? = observed in ditch samples only.

Species are grouped:

B. metzmacheri group: *B. metzmacheri metzmacheri*, *B. metzm. ornata*, *B. metzm. solida*
B. contorta group: *B. contorta*, *B. tholiformis*
B. subfragoris group: *B. subfragoris*, *B. subfragoris magna*, *B. fragori*, *B. pseudohystrix*
B. badenensis group: *B. badenensis*, *B. moravica*, *B. pentaspinosa*
U. saxonica group: *U. venusta saxonica*, *U. deumensis*
U. pymaea group: *U. pymaea langeri*, *U. pymaea langenfeldensis*
U. brunensis group: *U. brunensis*, *U. densistriata*, *U. zandii*
U. semiornata group: *U. semiornata semiornata*, *U. sem. kusteri*, *U. sem. karreri*

bolboforms (GÜRS & SPIEGLER 1999). Four *Bolboforma* zones were recognized.

<i>B. badenensis</i> zone	3.00 - 10.25 m
<i>B. danielsi</i> zone	11.00 - 12.25 m
Upper <i>B. reticulata</i> subzone	14.00 - 20.25 m
Lower <i>B. reticulata</i> subzone	20.25 - 32.22 m

Single *Uvigerina semiornata* and *U. saprophiila* occur sporadically in the sequence from 12.00 m through 19.25 m depth. *U. semiornata* is common downhole until 32.22 m. *U. acuminata* is frequent in Samples 20.25 - 20.50 m only.

Neogene nannoplankton was not determined.

Mecklenburg and Brandenburg

The *Bolboforma* associations in marine Miocene sediments deposited beneath the diapirs of Lüththeen (SW Mecklenburg) and Helle (NW Brandenburg) were studied in 13 wells (SPIEGLER & RUSBÖLT 1994). Six *Bolboforma* zones were recognized spanning early Late Miocene (*B. laevis/capsula* zone) to Middle Miocene (upper *B. reticulata* subzone). The same *Bolboforma* zones were observed in the Lüththeen 27/82 well.

Lüththeen 27/82

In the Lüththeen 27/82 well a more than 200-meter-thick section (Pritzierer Schichten) was studied for calcareous microfossils (GÜRS & SPIEGLER 2000). Six *Bolboforma* zones were recognized.

<i>B. laevis/capsula</i> zone	50.70 - 83.90 m
<i>B. subfragoris</i> zone	- 136.30 m
<i>B. compressispinosa</i> zone	- 193.30 m
<i>B. badenensis</i> zone	- 231.90 m
<i>B. danielsi</i> zone	- 240.80 m
Upper <i>B. reticulata</i> subzone	- 250.20 m
(final depth)	

Uvigerina saprophiila and *U. semiornata* occurred only between 242.60 and 248.6 m. Neogene nannoplankton was not determined.

Lower Rhine Embayment

The Miocene *Bolboforma* zones and the *Uvigerina* zones are well documented in several drill holes in the Lower Rhine area (Hiss et al. in prep.). In summary, all Miocene *Bolboforma* zones and *Uvigerina* zones (except for *U. macrocarinata* and *U. hemmooriensis* zone) were recognized. Müller (in Hiss et al. op. cit.) determined the NN5/NN4 boundary between the upper

and the lower *U. tenuipustulata* subzone, as well as between the lower *Bolboforma reticulata* subzone and the *B. rotunda* zone.

Correlation

Different index markers were used as major events to identify *Bolboforma* and *Uvigerina* zones and the zonal boundaries. The profiles containing the markers were numbered as follows: (1) Nieder Ochtershausen, (2) Wursterheide, (3) Twistringen, (4) Groß Pampau, (5) Schwarzenbek, (6) Lüththeen 27/82, and the (7) Lower Rhine area (Figure 2, Tabela 1 and 2).

The *Uvigerina saxonica* zone and the *U. langeri* zone correlate to lower parts of the *Bolboforma metzmacheri* zone. Index marker is *B. metzmacheri* (TR 7.7 - 9.7 Ma) in the localities (1), (2), (7), *B. polygonalis* (TR 8.5- 9 Ma) in (1) and (7), and the LO of *B. capsula* (9.7 Ma) in (1).

Rare *Uvigerina semiornata* and *U. saprophiila* are contained in profiles (5), (6), and (7), whereas in profiles (1), (2), and (4) no *Uvigerina* specimens occur, meaning that in the time spanning the *B. capsula* zone (9.7 Ma) through the Late *B. reticulata* subzone (14.5 Ma) no *Uvigerina* zonation is possible.

The *U. brunensis* zone contains *Bolboforma bireticulata* (TR14.5 - 15.0 Ma) in profiles (1), (2), (3), (7), and *B. reticulata* (LO 14.5 Ma) in profiles (1), (2), (3), (5), (7) and correlates to the upper part of the lower *B. reticulata* subzone.

The *Uvigerina macrocarinata* zone and the *Uvigerina acuminata* zone contain *Bolboforma reticulata* in profile (1), (2), (3), (5), (7) and both correlate to the middle part of the lower *B. reticulata* subzone.

The *Uvigerina tenuipustulata* zone is divided into an upper and a lower subzone. The upper *U. tenuipustulata* subzone still contains *Bolboforma reticulata* (FO 15.6 Ma) in profiles (5) and (7). Therefore, a correlation of the upper *U. tenuipustulata* subzone to the lower part of the lower *B. reticulata* subzone is possible. Calcareous nannoplankton of the NN5 zone (base 15.6 Ma) is obtained in the Lower Rhine area.

The lower *U. tenuipustulata* subzone contains tiny *Bolboforma rotunda* and *B. spinosa* in profiles (5) and (7) and cal-

		Time Scale (Berggren et al., 1995)															
		Epoch		Age in Ma		Nannoplankton Zones (Martini, 1971)		Nannoplankton Zones (Okada & Bukry, 1980)		BOLBOFORMA ZONE		Age in Ma					
		Pliocene		Age in Ma						UWIGERINA ZONE		Age in Ma					
		Late		2		NN18		Barren of <i>Bolboforma</i>		1		Nieder Ochtenhausen					
		Early		3		NN16		CN12		2		Wursterheide					
				4		NN13		CN11		3		Twistringen					
				5		NN12		CN10		4		Gross Pampau					
				6						5		Schwarzenbek					
				7		NN11		CN9		6		Lübbeken					
				8						7		Lower Rhine Area					
				9		NN10		CN8		7.7							
				10		NN9		CN7		9.7							
				11		NN8		CN6		10.6							
				12		NN7		CN5		11.7							
				13		NN6				11.9							
				14						12.6							
				15		NN5		CN4		12.7							
				16						14.5							
				17		NN4		CN3		15.6							
				18						18.2							
				19		NN3		CN2		18.9							
				20													
				21		NN2		CN1									
				22													
				23		NN1											
Miocene		Late		6													
				7		CN9		<i>B. intermedia</i>									
Middle		Late		8						<i>U. saxonia</i> group							
				9		CN8		<i>B. metzmacheri</i>				<i>U. pygmaea</i> group					
				10		CN7		<i>B. capsula</i>									
				11		CN6		<i>B. subfragoris</i>				single					
				12		CN5		<i>B. compressispinosa</i>				<i>U. saprophila</i>					
				13				<i>B. badenensis</i>				and					
				14				<i>B. danewi</i>				single					
				15				CN4		Upper <i>B. reticulata</i>		<i>U. semiornata</i>					
				16				CN4		Lower <i>B. reticulata</i>		<i>U. brunensis</i>					
				17				CN3		<i>B. rotunda</i>		lower <i>U. tenuipustulata</i>					
Early		Middle		18		CN2		<i>B. spinosa</i>		<i>U. hemmooriensis</i>							
				19													
				20		CN1		<i>B. spiralis</i>									
Early		Late		21		CN1		<i>B. spiralis</i>									
				22													
				23		CN1		<i>B. spiralis</i>									
				24		CN1		<i>B. spiralis</i>									

Table 2: Biostratigraphic extension of the profiles investigated

careous nannoplankton of the NN4 zone (top 15.6 Ma) in the Lower Rhine area.

Therefore, the boundary between the NN5/NN4 zones correlates to the lower *B. reticulata*/*B. rotunda* boundary and divides the *Uvigerina tenuipustulata* zone into an upper and a lower subzone.

The *Uvigerina hemmooriensis* zone as observed in profile (2) correlates to NN3 and the *Bolboforma spinosa* zone.

The correlations obtained by an investigation of *Bolboforma* and *Uvigerina* in the same profiles are useful in developing a more precise biostratigraphy of the marine Miocene sediments in northern Germany. The results enable good age control of the marine sequences and the determination of nearshore hiatuses and gaps in the area investigated.

Bolboforma zonal boundaries naturally do not coincide with boundaries between geological series or subseries. The Early Pliocene/Late Miocene boundary (5.3 Ma) lies in the *Bolboforma costairregularis* zone. The Late Miocene/Middle Miocene boundary (11.2 Ma) is determined in the *B. subfragoris* zone, and the Middle Miocene/Early Miocene boundary (16.4 Ma) lies in the *B. rotunda* zone.

Acknowledgements

I am very grateful to Dr. C.H. Daniels for making the *Bolboforma* assemblages of Wursterheide and Twistingring, housed in the Micropaleontological Collection of the BGR/NLFB, Hanover, available.

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The Base of the Gramian Stage in the North Sea Basin

► *Adri W. Burger*

This publication is dedicated to those who introduced me to geology at the Dutch Geological Survey and also taught me that one should look outside ones own discipline: Ing. J.G. Zandstra, Dr. G.H.J. Ruegg and Prof. Dr. W.H. Zagwijn.

Abstract

Criteria for the definition of the base of the local Gramian stage in the younger Miocene of the North Sea Basin are presented and discussed. The original definition by molluscs is checked against the stratigraphic ranges of species of other fossil groups in order to determine if the bivalve criterion is a reliable time marker within the North Sea Basin or whether it follows time-transgressive facies changes.

Comparison of results from boreholes in Denmark, northern Germany and the southern Netherlands leads to the result that the definition for the base of the Gramian using the *Carinastarte* phylogenetic lineage works for the widely distributed "Upper Miocene" mica-clay/silt facies in the North Sea Basin. In shallower, sandy facies, occurrences of *Carinastarte* are too sporadic to provide reliable stratigraphic control. Here, the base of the Gramian falls into the interval between the FO of *Bolboforma metzmacheri* (CLODIUS 1922) and LO of *Palaeocystodinium* spp..

Kurzfassung

Kriterien für die Definition der Untergrenze der lokalen Stufe Gramium des jüngeren Miozäns im Nordsee-Becken werden präsentiert und diskutiert. Die Original-Definition anhand von Mollusken wird mittels der stratigraphischen Reichweite der Arten anderer Fossilgruppen überprüft um festzustellen, ob das Bivalven-Kriterium eine verlässliche Zeit-Marke innerhalb des Nordseebeckens ist oder, ob es zeitabhängigen Faziesänderungen folgt.

Der Vergleich von Ergebnissen aus Bohrun-

gen in Dänemark, Norddeutschland und den südlichen Niederlanden führt zu dem Ergebnis, dass die Definition für die Basis des Gramium anhand der Entwicklungsreihe der Gattung *Carinastarte* für die weit verbreitete "Obermiozäne" Glimmerton- und Glimmerschluff-Fazies anwendbar ist. In der flacheren sandigen Fazies ist das Auftreten von *Carinastarte* zu sporadisch, um verlässliche stratigraphische Kontrolle zu ermöglichen. Hier fällt die Grenze des Gramium in das Intervall zwischen dem FO von *Bolboforma metzmacheri* (CLODIUS 1922) und LO von *Palaeocystodinium* spp..

Introduction

A scheme of local stages for the marine Neogene in the North Sea Basin has been developed during the last century. All of these stages are defined by molluscs. In the last decades the use of these stage names has been well established, particularly in northwestern Germany (HINSCH 1989, 1990, 2000, GRAMANN 1989 and references therein) (Figure 1). The Gramian, one of these stages, is traditionally ascribed to the "Upper Miocene" (the term "Upper Miocene" is used here in the tradition of the North Sea Basin, which does not occupy the same time interval as the Late Miocene in the international stratigraphic scheme). This stage was defined by HINSCH (1952) on the basis of the mollusc fauna found in the type locality in Gram, Jutland, Denmark, i.e., the clay pit of the local brickworks.

HINSCH defines the Gramian as the total range zone of the bivalve species *Carinastarte reimersi* (SEMPER in RAVN 1907) (Figure 2). He suggested an evolution from *Carinastarte vetula* (PHILIPP 1847) as the original form characterising the Langenfeldian, through *Carinastarte reimersi* in the Gramian to *Carinastarte rollei* (SEMPER in RAVN 1907) in the Syltitan. If this holds true, these forms must be well suited to give good time control on faunas. In his publication, HINSCH (1952) defines the Gramian as the lower part of the Syltitan sensu STAESCHE (1930). STAESCHE did not recognise

Staeche, 1926	Hinrich, 1952	Hinrich, 1958	Hinrich, 1967	Hinrich, 2000
3. Sylter Stufe	Sylter Stufe	Sylter Stufe	Syltum IV III II I	Syltum
	Grammer Stufe	Grammer Stufe	Gramium II I	Gramium
2. Langenfelder Stufe	Langenfelder Stufe	Langenfelder Unterstufe	IV III	Langenfeld substage
		Lüneburger Unterstufe	Lüneburger Stufe	Langenfeldium II
1. Gunitz-Moehrenburger Stufe		Lüneburger Unterstufe	I	Lüneburgium Levernau substage Levernium

Figure 1:
Development of
"Upper Miocene"
stage names in the
North Sea Basin

Carinastarte roliei as being different from *Carinastarte reimersi*. In the following discussion the stages are used as defined by HINICH.

Since the introduction of these stages, authors have attempted to recognise and apply these stages throughout the North Sea Basin (cf., e.g., VAN DEN TOORN 1967). Lately

hardly any possibility with characteristic forms and with restricted time ranges. Bolboforms and dinoflagellates seem to provide better possibilities, as they occur regularly in near-coastal deposits.

In the following, a comparison is made between the occurrences of species of different fossil groups in the type area in Gram and four other localities in Denmark, Northwestern Germany and the southern Netherlands. This is done to determine if the base of the Gramian stage as defined by molluscs is reliable as a timeline and to recognise possible substitute markers.

Studies of Localities

Gram

At this locality HINICH (1952) was unable to give an indication of the position of the base of the Gramian stage because the base of the deposits with *Carinastarte reimersi* (SEMPER in RAVN 1907) was not reached in the clay pits. RASMUSSEN (1956) defined the whole of the "Upper Miocene" micaceous clay found at Gram (with a maximum thickness of approximately 35 m) as Gram Clay in the belief that there would be no notable change in the composition of the mollusc faunas throughout its entire thickness. HINICH (1958) presented proof of the superposition of sediments with a lower fauna containing *Carinastarte vetula* and an upper fauna containing *Carinastarte reimersi* from an exposure at Maade near Esbjerg, Denmark. RASMUSSEN (1966) published the results of his studies on mollusc assemblages from a borehole (Gram 1, DGU 141.277) drilled in 1963 at the western rim of the pit, then in use. He found the lowermost occurrence of *Carinastarte reimersi* at 16.50 mbs (meters below surface), preceded by *Carinastarte vetula*, which is considered characteristic for the Langenfeldian Stage.

Samples from the Gram I borehole have also been investigated for **foraminifera** and **bolboforms** by LAURSEN & KRISTOFFER-



Figure 2: *Carinastarte reimersi*
(SEMPER in RAVN
1907) from Gram
Brickworks

some doubts have been expressed as to the usefulness of the local mollusc-defined stages in the later part of the Miocene in the North Sea Basin (GÜRS & SPIEGLER 2001).

A major problem is that *Carinastarte* is not found everywhere in the North Sea Basin in sufficient numbers, particularly in the southern part. It therefore becomes necessary to find substitute markers for the base of the Gramian in other fossil groups. Best suited for basin-wide correlations are planktonic microfossils. Unfortunately, planktonic foraminifera encountered in onshore outcrops and boreholes are rather rare in most of the sediments deposited during the younger parts of the Miocene, so they can hardly be used. Calcareous nannofossils also seem to be rare and therefore offer

Figure 3: Map showing the locations discussed:

- 1=Gram,
- 2=Lille Tønde,
- 3=Nieder Ochtenhausen,
- 4=Wursterheide,
- 5=Cuyk



SEN (1999). The results of their studies of foraminifera show no faunal change at the base of the Gramian at 16.50 mbs (cf. diagram in figure 4). This level is within the interval they interpret as benthic foraminifer zone NSB 12c, which is tentatively characterised by the occurrence of *Uvigerina pygmaea langefeldensis* DANIELS & SPIEGLER 1977, with *Ehrenbergina pupa* (ORRIGNY 1839) as a substitute marker.

The common occurrence of *Uvigerina pygmaea langeri* DANIELS & SPIEGLER 1977 between 5.30 and 17.50 mbs places the whole of the Gramian from this paratype locality inside the *Uvigerina langeri* zone of the northwest German biozonation (DANIELS 1986, 2001).

The base of the Gramian, as defined by bivalves at 16.50 mbs, is found above the acme of *Bolboforma clodiusi* DANIELS & SPIEGLER 1974 (at 17.50 mbs), but below its last regular occurrence at 16.00 mbs. *Bolboforma metzmacheri* has the base of its regular occurrence at 16.50 mbs. The base of the Gramian therefore coincides with the base of the *B. metzmacheri* zone.

PIASECKI (1980) presented the results of a study on **dinoflagellates** from a different borehole at Gram (DGU 141.423), for which no mollusc studies exist. No investigations on foraminifera or bolboforms have taken place. The lithological sequence is identical, but the boundaries are not at the same depth as in borehole Gram 1 (DGU

141.277). PIASECKI did not indicate local stage names.

The new *Dinopterygium verriculum* zone, which reaches from the uppermost sample studied down to 20.0 mbs, probably includes the base of the Gramian. The last occurrence of *Palaeocystodinium golzowense* (ALBERTI 1961) is found at 16.00 mbs. STRAUSS et al. (2001), in their re-evaluation of the dinoflagellate stratigraphy for the Gram 2 borehole, indicate the depth of the base of the Gramian at 16.50 mbs, probably unaware that this identification is done in a different borehole.

Lille Tønde

Investigations on the Lille Tønde borehole (DGU 167.528) drilled in 1968, situated near the Danish/German border (Figure 3), were presented by LAURSEN et al. (1998) and LAURSEN & KRISTOFFERSEN (1999).

Applying the lowermost occurrence of *Carinastarte reimersi*, LAURSEN et al. (1998) put the base of the Gramian stage at 55.05 mbs, (Figure 4). As in Gram 1, the last occurrence of *Carinastarte vetula*, indicative of the Langenfeldian stage, is directly below, with no overlap (Figure 4). Thus, on the basis of the molluscan data, good accordance exists between these two boreholes from southern Jutland. Looking at the dinoflagellates the last occurrence of *Palaeocystodinium golzowense* (ALBERTI 1961) is found at approximately 10 m above the first occurrence of *Carinastarte reimersi*. This means that either a hiatus or strongly condensed sedimentation in borehole Gram 1 exists, which involves the lower part of the Gramian, or that the last occurrence of *Palaeocystodinium golzowense* (ALBERTI 1961) is time-transgressive and not a reliable stratigraphic datum. The latter interpretation is indicated by STRAUSS et al. (2001: 423), who assume a strong sensitivity of the last occurrence of *Palaeocystodinium* to facies changes.

LAURSEN & KRISTOFFERSEN (1999) show that the base of the Gramian stage is to be found, just as in borehole Gram 1, in the foraminiferal zone NSB 12c. The whole of the Gramian belongs to the *Uvigerina langeri* zone. There seems to be good agreement between bivalve and benthic foraminifera stratigraphy at the two localities.

The bolboforms, on the other hand, show a different picture. *Bolboforma clodiusi*

and *Bolboforma metzmacheri* both show an acme, but this time together at the same level and well above the base of the Gramian. According to Dr. G.V. LAURSEN (pers. comm. 2001) acmes of bolboforms do not provide stratigraphical datum levels, but are very local phenomena. The last occurrence of *Bolboforma clodiusi* is found at 45.80 mbs, which is at the same level as the last occurrence of *Palaeocystodinium golzowense*. The first occurrence of *Bolboforma metzmacheri* is found at 60.55 mbs, the base of continuous occurrence is encountered at 48.00 mbs.

Nieder Ochtenhausen

The completely cored Nieder Ochtenhausen borehole (Figure 3), located east of Bremerhaven, was drilled in 1991 to gain more information from the Gramian stage and to try to find data to better define the base. Results are published in a special volume (MEYER (ed.) 2001).

HINSCH (2002) puts the base of the Gramian stage at 101.00 mbs, based on the transition from *Carinastarte vetula* to *Carinastarte reimersi* at this depth. The range of the two species does not overlap (Figure 4). This transition level is positioned in a narrow depth interval with a somewhat higher content of glauconite, possibly indicating some degree of condensation. It is marked in the gamma log by a short and relatively weak maximum with a strong drop in radiation values directly above it (KUSTER 2002: 21).

Looking at the foraminifera (DANIELS 2001), it becomes clear that, as is the case in boreholes Gram I and Lille Tønde, the base of the Gramian is positioned within the *Uvigerina langeri* zone (proved base at 102.00 mbs above a barren zone), with *Uvigerina pygmaea langefeldensis* occurring between 93.90 and 98.00 mbs.

Investigations by SPIEGLER (2001) give a depth of 101.60 mbs as the base of the occurrence of *Bolboforma metzmacheri*, with the base of a continuous and more common occurrence at 96.00 mbs. Its last occurrence is found at 39.50 mbs. *Bolboforma clodiusi* occurs between 98.00 and 40.70 mbs, with a common occurrence range between 96.00 and 89.30 mbs. LEEUWEN (2001) also indicates the presence of *Bolboforma metzmacheri* in the core interval between 40.50 and 95.00 mbs.

Because the lowermost sample of LEEUWEN

above the non-calcareous depth interval is positioned at 100.70 to 100.75 mbs it is not possible to exactly tie the base of the Gramian in this borehole to the standard Dutch foraminiferal zonation. This lowermost sample is interpreted, with some reservations, as belonging to the FC2A2 subzone. An important result of LEEUWEN (2001) using the relative change in the abundance of *Uvigerina* spp. (outer neritic) versus *Bulimina* spp. (middle neritic) versus inner neritic species (*Elphidium* spp., monothalamous species, *Globulina* s.l.) is that he shows a gradual shallowing of the depositional environment from the base of the Gramian upward.

Dinoflagellate studies have been carried out by STRAUSS et al. (2001). The base of the Gramian stage coincides with the base of their *Amiculasphaera umbracula* zone. The last occurrence of *Palaeocystodinium* is given at 97.90 mbs, which is approximately 3 m above the base of the Gramian stage. The lowermost sample containing *Spiniferites andalousiensis* is found at 105.90 mbs; this species is discontinuously found up to the top of the Miocene sediments.

The palaeontological results from this site thus, in general, are in good agreement with the results from the Danish localities described above.

Wursterheide

The Wursterheide research well, near Cuxhaven, was drilled in 1977/1978 and reached the Upper Cretaceous. It provides a continuously cored Miocene section. The results of geophysical and palaeontological studies were published in a special volume (Geologisches Jahrbuch, A 111, 1989). HINSCH (1989), in his study of the molluscs, places the base of the Gramian at 168.00 mbs at the last occurrence of *Carinastarte vetula*. At 152.15 mbs the lowermost occurrence of *Carinastarte reimersi* is encountered (Figure 4). At this site the bivalve datums show the sequence known from other sites in the "Upper Miocene" North Sea Basin. But the microfossil datums that seemed stratigraphically useful at the three sites discussed above do not correlate in the same manner with the bivalve stratigraphy at this site. GRAMANN (1989) places the 168.00 mbs level within a zone defined as *Globobulimina auriculata* + *Siphotextularia sculpturata* zone. The *Uvigerina langeri* zone one would expect at this level is not recognised in this borehole at all.

Instead, the supposedly younger *Uvigerina saxonica* zone is found between 248.00 and 257.00 mbs, i.e. approximately 90 m deeper. If the *Uvigerina* succession were used to define the base of the Gramian it would be placed below 257 mbs.

In the same publication bolboforms are also presented. *Bolboforma metzmacheri* is found between 233.00 and 257.00 mbs together with *Bolboforma clodiusi*. The latter also occurs regularly up to 111 mbs, which again is a different picture compared to the Danish localities treated before, where *Bolboforma metzmacheri* always has its last appearance well above that of *Bolboforma clodiusi*. Heavy-mineral correlation, as presented by BURGER (2001) supports the impression based on foraminiferal results that the base of the Gramian should be put much deeper in the section than the level of the last occurrence of *Carinastarte vetula* (PHILIPPI 1847).

To see how the dinoflagellates correlate with the bivalve, bolboform and foraminifera stratigraphy, the present author requested Dr. J.J. Lund to also investigate the dinoflagellates of the Miocene portions of this borehole. The results, presented in LUND & HEILMANN-CLAUSEN (2001), support the foraminiferal stratigraphy. They indicate a break in the sedimentation between samples at 258.70 and 262.98 mbs (given at 261.00 mbs), which forms the boundary between the *Unopontidinium aquaeductum* (Uaq) zone below, and the *Amiculosphaera umbracula* (Aum) zone above. Correlation with the Nieder Ochtenhausen locality indicates that the lower part of the *Amiculosphaera umbracula* zone, which is present in Nieder Ochtenhausen above 99.90 mbs is missing in Wursterheide, together with the *Cannosphaeropsis passio* (Cpa), *Achomosphaera andalusiensis* (Aan) and *Gramocysta verrucula* (Gve) dinoflagellate zones.

Cuyk 46A/147

The most southern location selected in this study for comparison is borehole Cuyk, 46A/147, on the southern rim of the Miocene North Sea Basin in the southeastern part of the Netherlands (Figure 3). This borehole was drilled in 1976 for the purpose of multi-disciplinary research on glauconite-bearing Miocene deposits and terminated within the "Upper Miocene" at a final depth of 140 mbs. The dominant lithology of the "Upper Miocene" at this site is fine sand.

The results of mollusc and foraminifer studies have been included in a publication by SUGGERS & LEEUWEN (1987). They determined mollusc subzone F2, which is characterised by *Venus imbricata* (SOWERBY 1826) var. and *Astarte beyschlagi* (KAUTSKY 1925), and assumed it to be more or less equal to the Gramian stage. The base of this subzone is placed at 81.00 mbs (Figure 4). Both marker species of the F2 mollusc subzone are absent in Cuyk. They also describe *Carinastarte* as being absent.

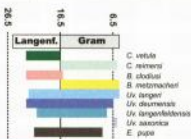
But, studying the range chart of the mollusca (not published, available through the courtesy of Mr. T. MEIJER, NITGTNO), it became clear that *Carinastarte* species did occur, although in small numbers. The striking phenomenon is, however, that the succession of forms is in the opposite order than at all other sites: *Carinastarte rollei*, indicative of the Syltian stage, is mentioned from samples 81.00 to 82.00 mbs and 85.00 to 86.00 mbs, whereas *Carinastarte reimersi* is mentioned higher up from sample 65.00 to 66.00 mbs. The accompanying bivalve assemblage at 65.00 to 66.00 mbs places this depth interval within the Pliocene mollusc zone D (SUGGERS & LEEUWEN 1987). SUGGERS & LEEUWEN (1987) include the three mollusc subzones F1, F2 and F3 in the FC2A foraminifer subzone, characterised by high abundances of *Trifarina angulosa* (WILLIAMSON 1858). In a later internal report, LEEUWEN (1991) presents a refined interpretation of this borehole, assigning the interval 80.90 to 87.25 mbs to the FC2A2 subzone. In the lower part of this depth interval *Uvigerina hosijsi deurnensis* MEIJER & LAGA 1976 is found.

LEEUWEN also uses bolboforms to identify part of his benthic foraminifer subzones. Subzone FC2A1, which has its lower boundary at 78.25 mbs, shows a form of *Bolboforma aculeata* DANIELS & SPEGLE 1974 with platy spine ends together with *Bolboforma intermedia* DANIELS & SPEGLE 1974. Bolboforms found in the interval assigned to the FC2A2 subzone are coarse-spined *Bolboforma aculeata* and *Bolboforma metzmacheri*.

The dinoflagellates of this borehole have been studied by HERNGREEN (1987). Of special interest is the uppermost occurrence of *Palaocystodinium golzowense*, which is found at a depth of 89.00 mbs. This level predates the base of the Gramian stage as indicated by the base of mollusc subzone F2.

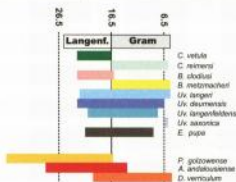
Gram 1

141.277



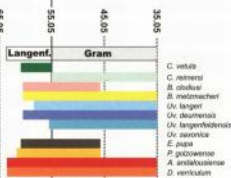
Gram 2

141.423

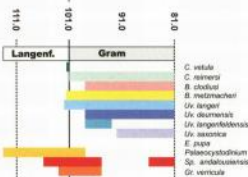


Lilie Tende

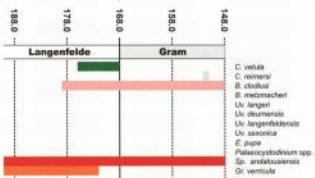
167.528



Nieder Ochtenhausen



Wursterheide



Cuyk, 46A/147

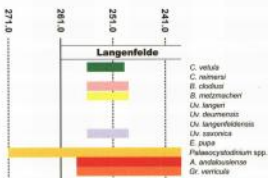
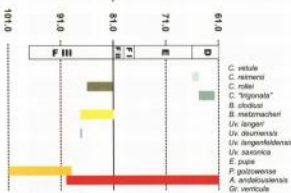


Figure 4: Diagrams of the localities presented, showing ranges of the following selected fossils; depths are indicated in meters below surface

Bivalves:	<i>Carinastarte vetula</i> (PHILIPPI 1847) <i>Carinastarte reimersi</i> (SEMPER IN RAVN 1907) <i>Carinastarte rollei</i> (SEMPER IN RAVN 1907) <i>Carinastarte trigonata</i> auct (non NYST 1881)
Bolboforms:	<i>Bolboforma clodiusi</i> DANIELS & SPIEGLER 1974 <i>Bolboforma metzmacheri</i> (CLODIUS 1922)
Foraminifera:	<i>Uvigerina pygmaea langeri</i> DANIELS & SPIEGLER 1977 <i>Uvigerina hosiusi deurnensis</i> MEUTER & LAGA 1976 <i>Uvigerina pygmaea langenfeldensis</i> DANIELS & SPIEGLER 1977 <i>Uvigerina venusta saxonica</i> DANIELS & SPIEGLER 1977 <i>Ehrenbergina pupa</i> (ORBIGNY 1839)
Dinoflagellates:	<i>Palaeocystodinium golzowense</i> (ALBERTI 1961) <i>Palaeocystodinium</i> spp. <i>Spiniferites andalouisiensis</i> (JAN DU CHÉNE 1977) <i>Gramocysta verricula</i> (PIASECKI 1980)

Based on the results of bolboforms and dinoflagellates, one is inclined to place the base of the Gramian stage at a deeper level than suggested by the mollusc stratigraphy of SLIGGERS & LEEUWEN, although it is hardly possible to pinpoint its exact position. In addition, the lowermost occurrence of *Carinastarte* at 86.00 mbs (although identified as *Carinastarte rollei*) would support the lower positioning of the stage boundary.

Discussion and Conclusions

For the definition of the base of the Gramian stage, which is defined by bivalve stratigraphy, three questions are of interest:

- How widely distributed are the marker species *Carinastarte vetula*, *Carinastarte reimersi* and *Carinastarte rollei* and how facies-dependant is their presence?
- Where the species are present, does the transition from *Carinastarte vetula* to *Carinastarte reimersi* and from *Carinastarte reimersi* to *Carinastarte rollei* occur at the same stratigraphic position as should be expected for events within an evolutionary lineage?

- Which microfossil datum levels at or near the base of the Gramian are of stratigraphical value, and is the sequence of these datum levels the same in the sites discussed?

The palaeontological results from the five localities presented here show that the biostratigraphic results of the Gram, Lille Tønde and Nieder Ochtenhausen sections are in good agreement (Figure 4):

Molluscs – The base of the Gramian stage is marked by the sudden transition from *Carinastarte vetula* to *Carinastarte reimersi* without any overlap and obviously without transitional forms.

Foraminifera – The base of the Gramian stage is positioned within the *Uvigerina langeri* zone.

Bolboforms – The base of the Gramian stage is positioned within the *Bolboforma metzmacheri* zone or at its base.

Dinoflagellates – The base of the Gramian stage is positioned below or near the last occurrence of *Palaeocystodinium* and above the first occurrence of *Spiniferites andalouisiensis*.

The three localities mentioned above have in common the fact that the transition from the Langenfeldian stage to the Gramian stage is positioned within the mica-clay/silt facies, which has a wide distribution in the North Sea Basin "Upper Miocene". *Carinastarte* species seem to favour this deeper-water facies, as does *Uvigerina*.

The two other species which provide the datum levels that show the most consistent stratigraphic position in relation to the *C. vetula* – *C. reimersi* transition are *Palaeocystodinium golzowense* (or *Palaeocystodinium* spp.), which has its last occurrence above, and *Bolboforma metzmacheri*, which has its first occurrence below this bivalve datum.

If one considers these two datum levels, the LOD of *Palaeocystodinium* spp. and the FOD of *Bolboforma metzmacheri* as most reliable, these two indicate that the base of the Gramian stage at the type locality at Gram is a hiatus.

In the other two sites, Wursterheide and Cuyk, the base of the Gramian is positioned within sandy sediments deposited

in a more shallow environment. Here the occurrence of *Carinastarte* species is scarce and patchy. The sequence and position of the selected microfossil datum levels differ in part strongly, in part slightly from that found at the other sites (Figure 4).

If one again views the FOD of *Bolboforma metzmacheri* and the LOD of *Palaeocystodinium* spp. as most reliable, the scarce and patchy occurrences of *Carinastarte* species and their identification from fragments must be considered less reliable. At the Wursterheide site, which is characterised by very high sedimentation rates, reworking of *Carinastarte* must be considered a possibility.

At this site the gamma ray log (REPSOLD 1989), which indicates a shallowing from 264 mbs upwards, and changes in heavy-mineral associations (BURGER 2001), together with the *Uvigerina saxonica* zone as recorded by GRAMANN (1989), also support a position of the base of the Gramian between 258 and 263 mbs.

For the Cuyk borehole, the FOD of *Bolboforma metzmacheri* and the LOD of *Palaeocystodinium golzowense* would place the base of the Gramian between 87.00 and 89.00 mbs. The gamma ray log (ZAGWIJN 1988) places the base of the Gramian at approximately 87 mbs, above which depth gradual shallowing, as already demonstrated for Nieder Ochtenhausen, is observed.

Conclusions

In the widely distributed "Upper Miocene" mica-clay/silt succession the base of the Gramian stage is identified without problems on the basis of the transition from *Carinastarte vetula* to *Carinastarte reimersi*.

In the sandy facies of shallower water deposits, where *Carinastarte* becomes scarce and calcium carbonate dissolution a frequent problem, the base of the Gramian can best be placed using the FOD of *Bolboforma metzmacheri* and the LOD of *Palaeocystodinium golzowense* (or *Palaeocystodinium* spp.).

Independent of its stratigraphical practicality in the mica-clay/silt facies the evolutionary lineage *C. vetula* → *C. reimersi* → *C. rollei* requires further clarification.

It seems advisable to use more quantitative analyses and in this way construct ecological diagrams. This can be used to build a sequence of facies development, which can be correlated throughout the entire basin. Dinoflagellates and, possibly, bolboforms could then be used to tie this scheme to international stratigraphic scales.

Acknowledgements

I would like to thank T. Meijer, Dr. R.J.W. van Leeuwen and Drs. D. Munsterman from the NITGTNO (National Geological Survey), Utrecht, the Netherlands, for their kind willingness to provide me with unpublished data on the Cuyk borehole. Dr. C. Heilmann-Clausen is thanked for providing some unpublished information on the dinoflagellates from the Wursterheide borehole. I am also much indebted to Dr. G.V. Laursen from Statoil, Stavanger, Norway, and Dr. J.M. Fenner from the BGR, Hanover, Germany, for their comments on an earlier draft, which improved the text considerably.

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Lowstand Cycles and Coal Formation in Paralic Environments: New Aspects in Sequence Stratigraphy

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► Jochen Rascher

► Norbert Volkmann

Abstract

The approximately 250-m-thick Tertiary strata of the Lusatian Lignite District (Eastern Germany) show many cyclic changes of shallow water deposits, paralic brown coal seams and estuarine to terrestrial alluvial fans (Spremberg, Brieske, Meuro and Rauno Formation). Due to their palaeogeographical position at the southern margin of the Northwest European Tertiary Basin they are primarily influenced by sea-level changes. The study complex, called the Brieske Formation (Lower/Middle Miocene), is located between the 3rd Miocene Seam Complex at the base and the 2nd Miocene Seam Complex at the top. An example of coal formation during a transgression is seen in the 3rd Miocene Seam Complex, and a further example of a regressive phase is visible in the 2nd Miocene Seam Complex. The Tertiary coal-bearing sequence of the Lower / Middle Miocene Lusatian area reflects significant third-order sea-level changes. Within this major transgressive/regressive phase sea-level oscillations of small-scale order can be recorded in this very marginal palaeogeographical position in the Northwest European Tertiary Basin. Even the finest-scale fluctuations of groundwater levels with a magnitude of only a few decimetres resulted in bog-facial changes in the ancient peat bogs. These fluctuations, which are thought to be related to sea-level trends, can be recorded in typical coal facies successions.

Kurzfassung

Die etwa 250 m mächtige tertiäre Schichtenfolge des Lausitzer Braunkohle-Distrikts (Ost-Deutschland) zeigt mehrere zyklische Abfolgen von marinen Flachwasser-Ablagerungen, paralischen Braunkohlenflözen und ästuarin bis fluviatilen Bildungen (Spremberg-, Brieske-, Meuro-, und Rauno-Formation). Aufgrund ihrer Position

am südlichen Rand der Nordwest-Europäischen Tertiärsenke werden diese Abfolgen hauptsächlich durch Meeresspiegelschwankungen unterschiedlicher Ordnungen bestimmt. Der in dieser Arbeit untersuchte Abschnitt, die sogenannte Brieske-Formation (Unter-/Mittel-Miozän), besteht aus dem basalen 3. Miozänen Flözkomplex, marinen Sanden und Schluffen im mittleren und dem 2. Miozänen Flözkomplex im oberen Teil (Zyklen 3. Ordnung). Der 3. Miozäne Flözkomplex ist ein Beispiel für Kohlenbildung während einer transgressiven Phase, während der 2. Miozäne Flözkomplex beispielhaft für eine Kohlenbildung während einer regressiven Entwicklung dasteht. Die kohlenführende Abfolge des Unter- bis Mittel-Miozäns der Lausitz spiegelt signifikante Meeresspiegelschwankungen 3. Ordnung wider. Durch die paläogeographische Position am Südrand des Ablagerungsraumes können innerhalb dieser Haupt-Oszillationen auch Meeresspiegelschwankungen geringerer Ordnungen nachgewiesen werden (Zyklen 4.-5. Ordnung, z.B. Aquifere, Schluffhorizonte, Flözbänke). Selbst die feinsten Schwankungen des Grundwasserstandes von nur einigen Dezimetern führten zu Veränderungen der Moor-Fazies in den Paläomooren (Zyklen 6. Ordnung). Diese Änderungen, die vermutlich mit Meeresspiegel-Schwankungen in Beziehung stehen, können in der typischen Kohle-Abfolge beobachtet werden.

Keywords

Lusatia, lignite, lithostratigraphy, Miocene, sea-level fluctuations, sequence stratigraphy

Introduction

Most of the world's coal resources were formed in a paralic palaeoenvironmental setting. This means that their origin is strongly related to sea-level fluctuations.

NW-EUROPEAN TERTIARY BASIN



Figure 1: The North-west European Tertiary Basin in the Lower Miocene (adapted from KOCKEL in VINKEN (1988) and PIWOCKY (1987) in: STANDKE et al. (1993)

Previous studies of the formation of paralic bogs have focused only on high-stand periods after transgressive sea-level events. In contrast to this view, the deposition of the 2nd Miocene Seam of the Lusatian Lignite District (Eastern Germany, Figure 1) is interpreted to have taken place during a regressive cycle.

This conclusion was primarily made possible by an increasing abundance of factual material, observations, samples and raw data from numerous outcrops. Outcrop density increased rapidly between 1970 and 1990 due to exploration and production activities (open-cast pits and thousands of wells, Figure 2). It became evident that it is, for instance, necessary to differentiate between single seams as part of coal-bearing strata and the development of the entire seam complex.

The approximately 250-m-thick tertiary strata of the Lusatian Lignite District (Eastern Germany) are, for the most part, characterised by their palaeogeographical position at the southern margin of the Northwest European Tertiary Basin. In this position the influences of transgressive and regressive pulses of different orders are very obvious. Primarily shallow-water

marine sediments with intercalated paralic coal seams and estuarine and partly terrestrial alluvial fans were deposited during these cyclic developments (Spremberg, Brieske, Meuro, Rauno Formation - LOTSCH (1981), ALEXOWSKY et al. (1989), STANDKE (2001), Figure 3.

The 2nd Miocene Seam Complex, including the main coal-bearing strata of the Lusatian Lignite District, is interpreted to have taken place during the regressive phase of a 3rd order cycle.

Facts

The 2nd Miocene Seam Complex was studied in an area covering more than 10,000 sq. km (approximately 3,860 sq. mi., Figure 2). The interpretation of 6,000 to 7,000 boreholes with geophysical well logs resulted in detailed knowledge of very fine-scale lithofacial changes within the layers, and also helped to construct an improved model of sedimentation during the Lusatian Neogene. Palynological investigations supported the identification of sedimentary units and made it possible to correlate sequences of the Lusatian Miocene with the biozonation of the marine basin centre

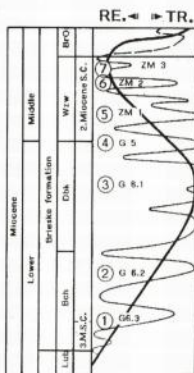
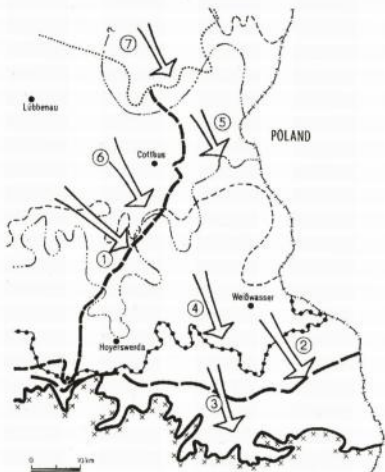


Figure 4: Palaeogeographical distributions of individual sedimentary units in relation to supposed transgressive and regressive sea-level trends (1...7: marine sand layers, aquifers, acc. to: STÄNDKE et al. 1993)

(STRAUß 1991, STÄNDKE et al. 1992, 1993). The area investigated occupies a special palaeogeographical position in the Northwest European Tertiary Basin. Based on global changes in sea level, the Tertiary ocean transgressed from the northwest over the southeastern basin margin several times (Figure 4). This resulted in the deposition of several sand complexes in a marine environment, as well as silt and clay in the lagoons, such as that found in paralic coastal swamps.

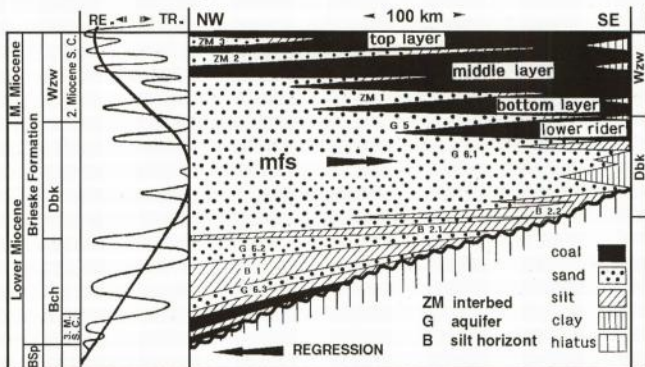
The unit studied, called the Brieske Formation, is located between the older 3rd Miocene Seam Complex at the base and includes the 2nd Miocene Seam Complex at the top (Figure 3). It represents the time span between approx. 19 Ma (Late Lower Miocene) and 15.2 Ma (Early Middle Miocene) according to HAO (1993), or 14.8 Ma according to BERGGREN et al. (1995). In the case of age determination on the basis of spore morphs, the complex represents the zones (SPN) VI C, VII and VIII (KRUTZSCH 2000).

From the viewpoint of sequence stratigraphy, the Brieske Formation forms a symmetric giant cycle, hierarchically in position between the large supercycles and smaller



3rd order cycles according to HAO et al. (1987). It represents the lower part of the TB2 supercycle. From bottom to top it contains a transgressive (TST) cycle (= Buchain Subformation, Bch, including the 3rd Miocene Seam Complex), followed by a highstand cycle (= Drebkau Subformation, Dbk) of maximum flooding surface (=mfs) and, finally, the regressive (LST) cycle (= Welzow Subformation, Wzw, including the 2nd Miocene Seam Complex). These cycles are hierarchically 3rd order cycles, although the boundaries do not completely correspond to those outlined by HAO et al. (1987). They can be subdivided into 4th order cycles (paracycles) on the basis of several transgressive and regressive parts. They correspond to the beds (i.e. aquifers (Figure 4, Units 1 to 7), silt complexes, seam layers etc., STÄNDKE 2001, Figure 5).

The 2nd Miocene Seam Complex is located between the marine Drebkau Subformation (Dbk, aquifer G 6.1 = mfs) and the marine Meuro Formation at the top (Figures 3 and 5). The marine interbeds (ZM 1 to 3) are transgressive units of 4th order during the primarily regressive 3rd order trend of the Welzow Subformation (Figures 6 and 5).



- major eustatic trend
- probably higher order sea level oscillations

Figure 5: Northwest-to-southeast extension of individual sedimentary units of the Brieske Formation in relation to transgressive (TR) and regressive (RE) trends in the Lower / Middle Miocene of the Lusatian Lignite District (southern shelf margin of the Northwest European Tertiary Basin), acc. to STÄNDKE et al. (1993)

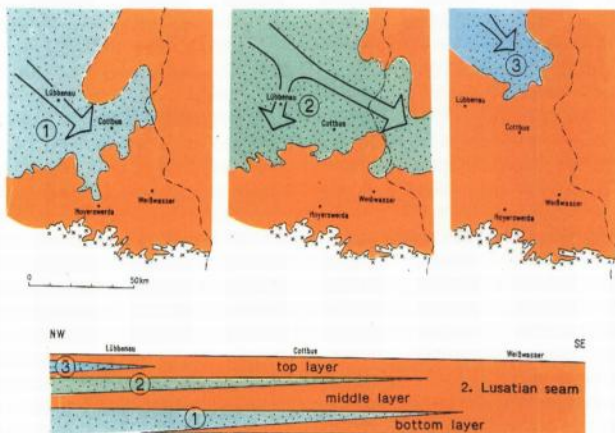


Figure 6: Ranges of the marine interbeds of 2nd Miocene Seam Complex (STÄNDKE 1990, 2001)

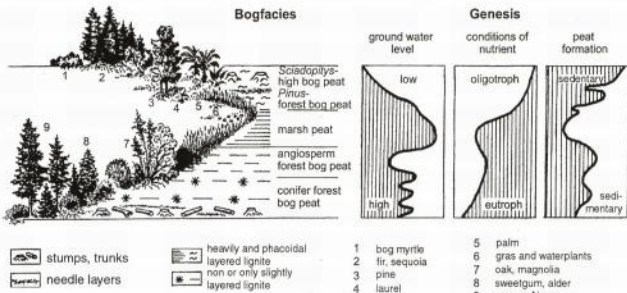


Figure 7: Genetic parameters of a coal facies cycle of the 2nd Miocene Seam Complex (acc. to BRAUSE *et al.* (1989), RASCHER (2001), bog facies acc. to SCHNEIDER (1978, 1990))

Within the paracycles, even smaller oscillations of the coastline can be identified as 5th to 6th order cycles. These oscillations caused groundwater fluctuations which can even be identified in the swamp facies of the separate coal seams. In addition, detailed macro- and micropetrographic studies of the coal seam combined with micropalaeontological analysis (dispersed cuticles) led to the recognition of the characteristic, rhythmic bog (coal-) facies successions and to the reconstruction of palaeogeography during peat formation (Figure 7).

Accordingly, the formation of important seams was primarily controlled, not only during transgressive but during regressive periods as well, by small-scale sea-level fluctuations (Figure 8) and the intensity of alluvial accretion in a coastal-deltaic environment.

This shows that the repeated formation of large peat bogs was established during lowstands of sea-level conditions. The examples show that lignite formation is possible during regressive as well as transgressive phases. In the investigation of these processes it is necessary to differentiate between single seams as part of coal-bearing strata and the development of the entire seam complex.

As shown by the above-mentioned examples, coal formation both during transgressive as well as regressive phases can be observed in Lusatia. During a regressive period the 2nd Miocene Seam Complex developed, whereas the 3rd Miocene Seam Complex was formed during a transgressive phase.

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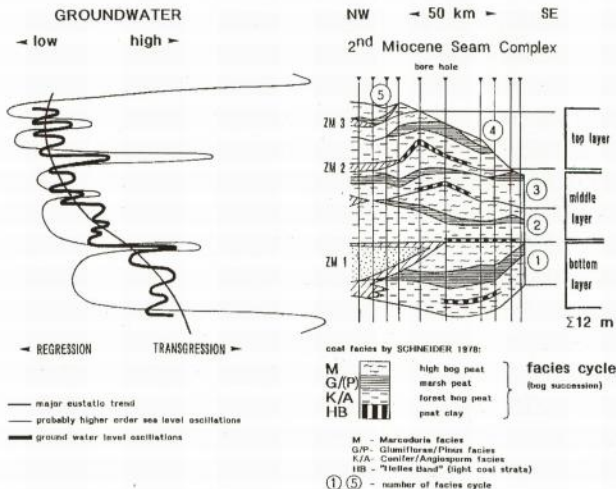


Figure 8: Higher order sea-level trend, bog facies cycles (5th order) and reflected ground water oscillations (6th order cycles, STANDKE 2001) within the 2nd Miocene Seam Complex (acc. to STANDKE et al. 1993)

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Marine-Influenced and Continental Settings of the Poznań Formation (Upper Neogene, Central and SW Poland)

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Abstract

Sedimentological and geochemical studies of the Poznań Formation were carried out on selected well profiles and exposures located in the depositional basin centre in the Konin area and the southwest margin of the basin at the Sudetes in the Wrocław area. Several lithofacies, primarily terrestrial in nature, were distinguished: alluvial fans, deltaic (delta and prodelta), open lacustrine, marsh, and rare facies of brackish/marine character: inlet (inlet and inlet delta) and lagoonal. The Konin area is predominated by terrestrial lithofacies (lacustrine - lake deltaic ones) formed in the lake system fed by numerous rivers. The lithofacies succession results from a rate of water inflow, affected mostly by rainfall during humid periods. This auto-cyclic sedimentation was interrupted with rapid inflows (storm/hurricane surges) of marine waters from the adjacent sea basin, supplying poor microfauna into the former coastal lakes, replaced there for a short time into brackish lagoons. These marine encroaches left discontinuous horizons of sandy-gravel beds, with cross-sets, ripples and erosion scours, marking the position of inlets and inlet deltas, topped by silty-clay series with brackish/marine microfauna. In addition, geochemistry evidenced tripartition of the profiles, particularly confirmed by changes in chemical compositions indicating some disturbances in water chemistry (addition of marine influxes to fresh waters of the river-like system). The Poznań Formation profile from the Wrocław area, situated far away from the sea (apparently occurring in the present Polish Lowlands area), is located within a tectonic depression on the Sudetes Foreland, at the time occupied primarily by a lake basin with an alluvial plain rim and acting as a trap for supplied material. In this area, the Poznań Formation is underlain by weathering wastes/residua of crystalline basement and consists of repeated fluvial-lacustrine-marsh cycles with

coarse cross-stratified alluvial fan units. The character and thickness of the units were controlled by tectonically determined subsidence rates and water/sediment supplies. Concentrations of kaoline as well as lenses of gravels and gravelly sands mark episodes of intensive erosion on depression margins. The tectonic movements of the basement, which were responsible for these episodes, also produced faulting and folding of lacustrine-marsh (clays-lignite-clays) series in the depression centre. The chemical composition of this section is relatively constant, without content peaks, indicating significant changes in water chemistry.

Kurzfassung

Die Poznań Formation wurde an ausgewählten Bohrprofilen und Aufschlüssen im Ablagerungszentrum des Beckens bei Konin und seinem Südwest-Rand an den Sudeten in der Gegend von Breslau sedimentologisch und geochemisch untersucht. Es wurden verschiedene, hauptsächlich terrestrische Lithofazies unterschieden: Alluviale Fächer, deltaische (Delta und Prodelt) und offen lacustrine Fazies, Marschen und selten Fazies mit brackisch/marinem Charakter: „inlet“ (und „inlet“ Delta) und lagunär. Die Gegend von Konin wird bestimmt durch terrestrische Lithofazies (lacustrin - See-Delta), die sich in einem Seensystem, gespeist von zahlreichen Flüssen, bildeten. Die lithofazielle Abfolge wird hauptsächlich bestimmt von Süßwasserzuflüssen durch Niederschläge während humider Perioden. Diese autozyklische Sedimentation wird unterbrochen durch kräftige Überflutungen (Sturm/Hurrikan Ereignisse) mit Meerwasser des benachbarten Meeresbeckens, die eine artenarme Mikrofauna in die ehemaligen Küstenseen eintragen und diese kurzzeitig in brackische Lagunen verwandeln. Diese marinen Einschaltungen haben diskontinuierliche Horizonte aus Sand und Kies hinterlassen

mit Kreuz-Schichtung, Rippelmarken und Erosionskanälen, die die Position von Inlets und Inlet Deltas anzeigen. Sie werden von schluffig-tonigen Lagen mit brackisch/mariner Mikrofauna abgeschlossen. Auch die Geochemie zeigt eine Dreiteilung der Profile an, insbesondere durch den Wechsel der chemischen Zusammensetzung, die auf Störungen im Wasserchemismus hinweist (Zusammentreffen von marinem Einfluss und Süßwasser aus dem flussähnlichen System). Das Profil der Poznań Formation der Gegend von Breslau, fern ab von der See (die sich vermutlich in der heutigen Tiefebene befand), befindet sich in einer tektonischen Depression im Sudesten Vorland, die zu dieser Zeit hauptsächlich durch ein Seebecken mit einem Rand aus alluvialen Fächern eingenommen war und als Sedimentfalle wirkte. In diesem Bereich wird die Poznań Formation unterlagert von verwittertem Schutt und Resten des kristallinen Basements und besteht aus wiederholten fluviatil-lakustrin-Marsch Zyklen mit groben kreuzgeschichteten Einheiten aus alluvialen Fächern. Die Art und Mächtigkeit der Einheiten wurde kontrolliert von tektonisch bestimmter Subsidenz-Rate und Wasser- wie Sedimentzufuhr. Anreicherungen von Kaolin sowie Linsen von Kies und kiesigem Sand zeigen Episoden intensiver Erosion am Rand der Senke an. Die tektonischen Bewegungen des Basements, die für diese Episoden verantwortlich waren, verursachten ebenso Brüche und Faltungen der lacustrin-Marsch-Serien (Ton-Braunkohle-Ton-Serien) im Zentrum der Senke. Die chemische Zusammensetzung dieses Profils ist ziemlich konstant, ohne auffällige Spitzen, die eine signifikante Änderung des Wasserchemismus anzeigen könnten.

Keywords

Poznań Formation, Neogene, Poland, lithostratigraphy, geochemistry

Introduction

The Poznań Formation of Late Miocene-Pliocene age, usually 60-80 m and in some areas as much as 180 m thick within some tectonic depressions, covers nearly the entire Polish Lowlands area. During the Late Neogene, the Polish Lowlands occupied a part of the wide-spread continental basin, extending from central Germany to the lowlands of Belorussia (DYJÓR 1970, BAR-

NECKA 1995, PIWOCKI & ZIEMBIŃSKA-TWORZYDŁO 1997). The Poznań Formation is composed mostly of nearly homogenous, structureless clays and silts with a lignite seam at the bottom (PIWOCKI 1992, 1998). Fine lignite intercalations and dispersed phytogenic matter as well as sandy and gravel interbeds occur within fine clastic series. The Poznań Formation lies directly on the pre-Tertiary basement or it is underlain by the Lower/Middle Miocene terrigenous lignite-bearing association. The top of the formation is erosive and covered by differentiated Quaternary deposits. The presence of rare sedimentary structures, nearly absent fossils (sporadic macro- and microfauna) (GIEL 1971, 1975, 1979a, 1979b, BARANIECKA 1979) and rich but less differentiated vegetation spectra (leaves, spores, pollens plant remains) (LUCZKOWSKA & DYJÓR 1971, ZIEMBIŃSKA-TWORZYDŁO 1974, WAŻYŃSKA 1988, KRAJEWSKA 2001), as well as pelite domination and lignite occurrence also suggest a continental, lacustrine origin of the entire series (DYJÓR 1970, ROŻYCKI 1972, WAGNER 1982, KASIEŃSKI 1995). New complex geological examinations of the series undertaken by the authors permitted a more precise confirmation of the opinions on the age of the Poznań Formation and the evolution of its sedimentary environment.

Geological Setting

The Poznań Formation was formed during the period enclosing the end of Middle Miocene, Late Miocene and Early Pliocene (PIWOCKI 2002). Deposits of this formation developed in the eastern margin of giant Northwest European Tertiary Basin and they occur on nearly the entire area of Polish Lowlands, except for the northernmost part, where they were removed during the Pleistocene. Toward the south, the Poznań Formation extends up to the Central Poland Uplands and to the western part of Carpathian Foredeep, and it also partly covers the Fore-Sudetic Block and the North Sudetic Depression. The extension area of the Poznań Formation is subdivided by the Mid-Polish High into two basins: the Poznań-Wrocław Basin to the west and the Warsaw-Olsztyn Basin to the east (DYJÓR 1987, 1992).

Recently, deposits of the Poznań Formation occupy the area of approx. 75,000 km², and their thickness varies highly, but the average is 60 - 80 m to over 100 m in the Warsaw Depression and to 160 m on the



Figure 1: Location of the Konin and Wrocław areas

Fore-Sudetic Monocline. The maximum thickness above 180 m is noticed in the great tectonic depression of the Wielkopolska Trough, but high values are frequently observed in areas of glaciotectonic disturbances.

The Poznań Formation overlies the older Miocene deposits: quartz sands of the Adamów Formation and sandy silts of the Pawłowice Formation. It is covered with a thick Pleistocene complex and partly with the Ziębice Group (formerly the Gozdnicza Formation), of Pliocene/Quaternary age. However, outcrops of Poznań Formation rocks are rather frequent.

Rare assemblages of Badenian foraminifera (LUCZKOWSKA & DYJON 1971; GIEL 1979a) and paratonstein horizons (MATL & WAGNER 1986), occurring inside the Poznań Formation, permitted the correlation of the Poznań Formation deposits with the

Badenian deposits from the Carpathian Foredeep. Studies on leaf macroflora of the lower part from this formation (KRAJEWSKA 2000) permitted a definition of its age as the equivalent of the X - *Nyssapollenites* pollen/spore horizon, and complex palaeobotanical studies (ZASTAWIAK 1992) displaying their sedimentation during the Pannonian have been undertaken. The Poznań Formation has usually been subdivided into three lithostratigraphic members (ODRZYWOLSKA-BIENKOWA et al. 1981). From the bottom to the top they are: (1) the Grey Clay Member with lignite of the Mid-Polish Seam in its lower part and of the Oczkowice Seam in the upper part, (2) the Green Clay Member with the Orłowo lignite seam, and (3) the Flamy Clay Member. However, differences between individual members of the Poznań Formation are unclear everywhere and their boundaries have to be defined arbitrarily. According to the new stratigraphic scheme (PWOŁOK &

ZEMBIŃSKA-TWORZYŁO 1997), deposits of the Poznań Formation correspond to six Neogene pollen-spore horizons: the Grey Clay Member to the VIII - *Celtipollenites verus* and IX - *Tricolporapollenites pseudocingulum* horizons, and the upper members - to the X - *Nyssapollenites*, XI - *Betulaepollenites*, XII - *Carpinipites Juglandaceae* and XIII - *Sequoiapollenites* horizons.

The **Grey Clay Member** includes the Mid-Polish Lignite Seam in its lowermost part. This seam is recognised nearly commonly in the entire area of the Polish Lowlands. It is 6 m thick on average and up to 20 m at maximum. Coaly middlings (clays and silts) accompanied by lignite are replaced upward by grey and grey/greenish clays and silts. Frequent plant remains, particularly well-preserved leaves, occur in this unit and locally compose thin beds of leaf-lignite (so-called *dysodyl* or *Papierkohle*). In clays and silts small snail shells have been evidenced (PIWOŃSKI 1975, BARANECKA 1995). Poorly preserved foraminifera, bryozoan remains, sponge skeleton elements and dispersed glauconite grains also occur in the upper part of member (DYJÓR 1968, 1970, CIUK 1970). Locally the intercalation of fine-grained quartz and quartz-muscovite sands within clays and silts occurs. The next lignite bench - the Oczkowie Seam - locally occurs in the upper part of the member on the eastern part of the Fore-Sudetic Monocline. It generally consists of one to three discontinuous lignite layers with a total thickness up to 10 m. In the central part of Polish Lowlands, the paratonstein horizon (0.1 - 0.3 m thick on average) was reported inside the uppermost part of Mid-Polish Seam or slightly above it (MATL & WAGNER 1986).

The **Green Clay Member** is developed as green, grey-greenish and bluish clays and silts, including fine and silty sand intercalations. Thin beds of coaly clays and lignite lenses 0.2 - 0.5 m thick (maximum 2.0 m) are also frequent there. The clays contain phytoclasts (mostly gelified xylites) and marly clay intercalations. The latter facies contain concentrations of CaCO_3 and clayey siderite, which form septaria concretions. Poorly preserved foraminifera tests, sponge spicules and glauconite grains have been found in such marly intercalations.

The **Flamy Clay Member** consists of green, grey-greenish and bunter clays with yellow and ochre spots of iron hydroxides. Inter-

calations of silty and fine sands are common in this unit.

Dark to internal mottling (mostly brown) colour staining of the Poznań Formation sediments strongly suggests the presence of dispersed iron. The mineralogical composition of the siliciclastics includes optically identifiable quartz, potash feldspar and plagioclase grains, angular to subangular, well to moderately sorted. Clay minerals predominate, and glauconite, amorphous iron, hematite, siderite micas as well as zircon have been evidenced. Detrital assemblage of clay minerals consists of illite, kaolinite, chlorite and irregularly intrastratified mixed-layer clay (largely beidellite). In the Konin area, beidellite is a substantial component of the deposits (BRAŃSKI 2002, RATAJCEK et al. 2002), and kaolinite predominates in the Wrocław area. Quartz and clay minerals are by far dominant among mineral grains composing sands and disseminated irregularly throughout silts and clays. Other components occur in minor to trace amounts.

Methods of Study

The sedimentological analysis of selected outcrops and well cores with the Poznań Formation deposits concentrated on macroscopic observations including (1) lithology description (mineral composition, fraction, roundness and sorting of components), (2) description of all sedimentary and diagenetic structures, and (3) occurrence of any organic material (this case - primarily phytoclasts due to lack of any macrofauna). Distinctions of lithological units with preserved sedimentary structures permitted a precise determination of environmental provenances and the construction of the synthetic lithological-facies profiles (Figures 3-4 and 7), the illustrating evolution of sedimentary conditions in the sections studied.

Eleven major and twenty-two trace elements of 96 entire-rock samples from two profiles were analysed using a Philips PW 2400 fully automatic, sequential, wavelength-dispersive X-ray fluorescence spectrometer XRF at the Central Chemical Laboratory of the Polish Geological Institute (Warsaw). The elements were measured on glass disks prepared of powdered rock. Detection limits for most major elements were on the order of 0.01 - 0.1 % and was typically 2 - 5 ppm for trace elements. Ma-

chine precision was on the order of 3% for major and 3 - 5% for trace elements. Contents of Fe_2O_3 represent total iron content. Measuring data were then elaborated statistically to reveal geochemical differentiations of the profiles. Since most results for As, Bi, Co, Ta and W contents found in the Konin area section occurred below the limit of detection, i.e. < 3 - 5 ppm, they have not been included in the appropriate list (Table 1) and not statistically examined.

Sedimentological and geochemical investigations on the Poznań Formation profiles were supplemented with the results of palynological (SŁODKOWSKA 2002) and microfauistic (PARUCH-KULCZYCKA & GIEL 2002) data, which permitted a more precise determination of the age of some units within the sections studied. The results also indicate climatic (tropical humid to moderate arid) and environmental conditions (generally continental lacustrine and fluvial), enhancing - as is the case in the section of the Kazimierz Północ open-pit mine near Konin - local fluxes of marine waters. In both the studied outcrops the magnetic properties of deposits were also determined with positive results for the Konin area (KROĆ 2002), where some changes in magnetic polarity have been preliminary registered.

Lithological Characteristics

An analysis of the Poznań Formation lithology carried out in some selected columns in the Konin and Wrocław regions permitted a definition of several lithofacies (Figures 3-4 and 7) representing continental and brackish sedimentary environments (CZAPOWSKI & KASINSKI 2002).

Lithofacies of vari-grained quartz sand and gravel with dissorted pebbles and usually clay addition, structureless, have been deposited by a short-distance mass-flow processes. This lithofacies was observed on the Fore-Sudetic Block in the Wrocław region. It has been interpreted as a sedimentary record of mud flows (mF), frequently found within Neogene deposits. The Neogene series have infilled semi-isolated satellite basins, extending along the margins of the major sedimentary basin, particularly in the Sudetic Foreland (OSIŁUK & PŁOCKI 1972).

Lithofacies of vari-grained quartz sand and fine gravel with clay addition, poorly

sorted and structureless, infills erosional scours and/or interfingers laterally with silty sand and silt. This lithofacies has been also evidenced in the Wrocław region within an isolate satellite basin and is interpreted as an alluvial fan deposit (AF). The geometry of these lithosomes of this facies reflects a shape of alluvial fan, and their size is decimetres to meters in order.

Lithofacies consisting of vari-grained quartz sands and silts, poorly to medium sorted, with large-scale cross- and trough bedding, with thin layers or "pocket" of fine gravels, are interpreted as a fluvial channel facies (chF). Fine gravel layers are a channel lag, and "pocket" gravel concentrations accumulated at the toes of lee slopes of point bars and megaripples. The geometry of this facies closely corresponds to a river network, and its dimension is decimetres to meters.

Monotonous complexes of structureless clay/clayey silt lithofacies were interpreted as open-lake (L) or lagoonal (Lg) deposits. A precise distinguishing of these facies on the basis of sedimentary features is rather difficult and requires additional data (e.g. biological and chemical markers). The observed thickness of both these facies is up to a few meters. Locally thin (decimetres to meters) bodies of fine to medium sands bordered with erosional surfaces were found. They are closely related to a lagoonal facies and probably represent an inlet facies (In), and structureless silts (frequently with clay addition) accompanying them among typical lagoonal deposits - an inlet delta (InD) facies.

Locally described units of predominant silts and subbordered clays, with sand and pebbles addition (dispersed or as thin lenses/layers, decimetres to meters thick), are frequently characterised by horizontal lamination and small ripples. Coaly middling intercalation and bioturbations have been evidenced there. This lithofacies represents lacustrine nearshore (Ls) deposits.

Coaly lithofacies consist of some types of lignite (xylic, detrital and bituminiferous coals) and coaly middling (mostly clays) with flooded plant detritus and phytoclasts. They are few decimetres to several meters thick and, because they extend widely, they act as good correlation horizons. Such deposits are interpreted as marsh-peatland deposits (M).

Lithosomes of fine to medium sands, frequently with silt addition and with single quartz pebbles, more or less sorted, usually structureless or with low-angle cross bedding, have been defined as deltaic sediments (D). Similar lithofacies with higher silt content and frequent clay laminae or intercalations, frequently horizontally laminated, with fine ripples, are interpreted as prodelta deposits (pD). Both the facies have a rather narrow extent and thickness (decimetres to meters).

Weathering residua (WR), described from the Wrocław area only, consist of structureless yellow silts and clays with dispersed angular quartz grains (CZAPOWSKI et al. in print). They occur at the bottom of sedimentary series. These lithosomes usually infill morphological depressions of crystalline basement and their top surface is erosional.

Characteristic two-component lithofacies of iron-cemented bed with knobby structure overlying a layer with lower iron oxides content represent **sub-soil** sediments (sS). The bed of rich iron oxides content corresponds to the aerated zone above a groundwater table, and its knobby structure is affected by root penetration. Layers depleted in iron oxides represent a saturated zone. Multiple successions of both these layers have recorded fluctuations of the groundwater table during diagenetic stages.

Profile Description

Konin Area

In the Konin area, located nearly in the centre of the Miocene continental basin of Poland (Figure 1), three sections (KASIKSKI & CZAPOWSKI 2002) were selected for detailed studies of the Poznań Formation deposits. The wall of the Kazimierz North open-pit mine, exploited for lignites, is the best basis for investigations. There is also a section of the Poznań Formation over 30 m thick (Figure 2). Other sections containing the formation are cores of two boreholes BK-110 and BK-117 (Figures 3 and 4) with thicknesses of Poznań Formation deposits equal to 23.1 m and 18.8 m correspondingly. Lithological and sedimentological observations permitted the determination of 42 lithological complexes, representing facies varieties but mostly uncorrelatable. Microfaunistic and microfloristic studies

(SŁOCKOWSKA 2002, PARUCH-KULCZYCKA & GIEL 2002) documented a rich floral association in the lower part of these successions, which is nearly lacking upward in the section, as well as a local occurrence of poor but undoubtedly *in situ* foraminifera fauna

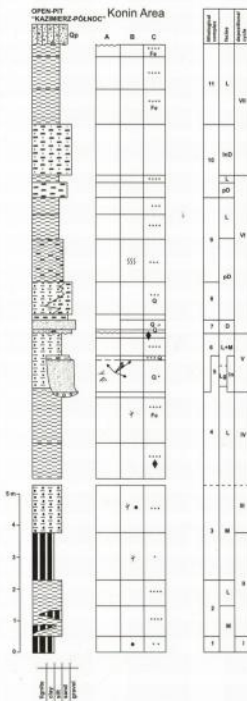


Figure 2a: Sedimentological profile of the upper (fine-clastid part) of the Poznań Formation, Kazimierz-Pólnoc open-pitmine, Konin area. Facies explanations: AF - aluvial fan, D - delta, FL - fluvialite, In - inlet, InD - inlet delta, L - open lake, Lg - lagoon, M - marsh, MF - mudflow, pD - prodelta, S - palaeosol, WR - weathering waste/residua

Explanations:	lithology	
till	silty clay	clayey/silty sand
detrital lignite	sandy clay	silty sand
xylitic lignite	clayey silt	sand
clay	silt	gravely sand
coaly clay	coaly silt	gravel
coaly silty clay	clayey sand	kaoline clay
sedimentary and erosional structures	biogenic structures	mineral composition
erosional surface	bioturbation	clay minerals (predominating)
erosional channel	plant detritus	clay minerals (rich)
horizontal lamination	phytoclast	clay minerals (secondary)
diagonal stratification	structural xylem (coalified wood-tissue)	clay minerals (in addition)
lenticular stratification	coaly dust	hematite
ripple stratification	palaeosol	iron hydroxides
flame stratification	rhizoid	silica cementation
stratification dip		pyrite
pebbles with diameter in mm		quartz
loadcast		muscovite
syndimentary fault		carbonate concretion
syndimentary fold		manganese dendrites
		markasite concretion

Figure 2b: Explanations for profiles

suggesting episodes of marine water invasions.

Kazimierz-Pólnoc Open-Pit Mine

The section of the Poznań Formation exposed in the northern open-pit mine wall is subdivided into 11 lithological complexes (Figure 2) and has been sampled for palynological (18 samples), microfauanal (12 samples) and geochemical (9 samples) studies. These complexes constitute eight depositional cycles, representing lacustrine to lagoonal environments.

The lower part of profile is built of detrital Lignite Seam, with numerous less coalified xylites and fine grey clay interbeds. This lignite corresponds to the 1st Mid-Poland lignite seam. The lignite seam is overlain by an approx. 1.8-m-thick complex of clay-lignite sediments, consisting of fine interbeds of dark coaly clay and detrital lignite in the lowermost part. This coaly series represents a pit-bog facies (M). The upper part of the entire complex is built of dark-grey clay, interpreted as a lacustrine deposit (facies L). The next complex is over 4.1 m thick and similarly developed. It consists of the bed, 1.5 m thick, of detrital

lignite overlain by lacustrine clays (approx. 2.6 m), celadon in the base and motley at the top.

This lacustrine/bog succession is incised by a lens (6.0 m wide and 1.3 m thick) of siliciclastics. The lens base is covered with fine quartz gravel (pebbles up to 3 cm) and coarse sand, and fine and medium clayey sands, medium sorted, with ripple and cross bedding, occur above. This series has been subdivided by dark clay fine layers into four units. In uppermost two, large (up to 15 cm high) aggradational cross-sets, with set inclinations primarily indicating transport toward the northeast, are visible. The clastic lens was interpreted as the infill of a storm inlet (facies In), due to the infrequent presence of forams. Upward, these sands are continuously replaced by beige-brownish sandy clay.

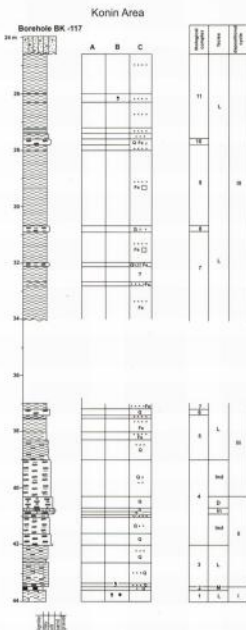
The next pelitic complex primarily represents the lagoonal-deltaic succession (facies Lg and D). Its lower part is built of black to celadon clays, 1.8 m thick, with dispersed iron sulphides, corresponding to facies transition from lagoonal to lacustrine environments. The top of clays is erosional and covered with 0.4-m-thick beds of silty to fine quartz sands, interpreted as deltaic sediments (facies D). Overlying complexes of grey-greenish clays and sandy silts, 1.0 m thick, together with the lower, silty part of next sandy-clay complex, containing numerous phytoturbations, represent the prodelta (pdD) facies. The upper, clayey part of this complex was interpreted as a lacustrine facies. The lowermost part of following complex (2.4 m thick) is composed of grey-greenish silt (0.5 m thick), representing the prodelta facies. This series has been separated upward by a fine layer of lacustrine clay from the thick (1.7 m) unit of light-grey sandy silt, containing rare forams and interpreted as an inlet delta deposit (facies InD).

The Poznań Formation is covered by the Pleistocene glacial till series.

BK-110 Well

The Poznań Formation deposits studied in the BK-110 well profile were subdivided into 20 lithological complexes (Figure 3), clayey and clayey-silty in the lower part of section and more sandy in the upper part. Similarly to the former section, the lowermost part of profile is built of lignite layer (complex # 1, over 0.4 m thick), primarily xylitic and detrital with abundant plant

Figure 4: Sedimentological profile of the upper (fine-clastic) part of the Poznań Formation, BK-117 borehole, Konin area. Explanations: cf. Figure 2



trations as well as a very fine sand layer at the top. This complex corresponds to a return of lacustrine conditions.

Geochemical Characteristics

Generally, most elemental content (including SiO_2 , TiO_2 , Al_2O_3 , Fe_2O_3 , P_2O_5 , MgO , CaO , K_2O , Ba , Co , Mo , Nb , Pb , Rb , Sr , Th , U , V and Zn) varies irregularly, remaining relatively stable throughout the BK-110 well sequence studied. Contents of other elements, such as SO_3^{2-} , Ce , Cu , Ga , La , Ni and Y , show a tendency to decrease upwards, and As , Cr and Zr - to increase upwards. TOC decreases sharply in the lowermost part of the profile and shows steady content above. The MnO , Na_2O and Hf content increases from base to the middle part of the series and decreases upwards. Both interfacies and intrafacies variations in whole-rock abundance of major and trace elements (Table 1, Figure

5) as well as the relationships between the constituents in samples from the region (Figure 6) permit the distinction of three geochemical units.

The **Lower Unit** occurs from 56.0 m to 59.5 m depth and is characterised by relatively high average contents of TOC , SO_3^{2-} , TiO_2 , Ga , La , Mo and Sr , while the abundance of SiO_2 , Fe_2O_3 and Zr is the lowest. The range of TOC , SiO_2 , TiO_2 , Ba , Ga , Nb and Sr concentration is the highest, and that of Fe_2O_3 , As , Hf , V and Zn is the lowest. This unit is clearly defined by changes in TOC , TiO_2 , Fe_2O_3 , Na_2O , K_2O , As , Ce , Co , Cu , Ga , La , Mo , Pb , Sr , Y and Zn content as well as reflected by $\text{V}/\text{Al}_2\text{O}_3$, $\text{U}/\text{Al}_2\text{O}_3$, Ce/La , $\text{Fe}_2\text{O}_3/\text{Al}_2\text{O}_3$, $\text{SiO}_2/\text{Fe}_2\text{O}_3$, As/Zr , $\text{Al}_2\text{O}_3/\text{Zr}$, $\text{Fe}_2\text{O}_3/\text{As}$, $\text{Fe}_2\text{O}_3/\text{MgO}$ and $\text{Fe}_2\text{O}_3/\text{Sr}$ ratios. For this unit, TOC content is particularly indicative.

The **Middle Unit** is the thickest one (from 40.0 to 56.0 m and from 40.5 to 56.5 m depth) and, in comparison to other units of the profile, it is very differentiated chemically. It has the highest average content of MnO , P_2O_5 , Ba , Ce , Co , La , Y and Zn and the lowest content of TiO_2 . The range of abundance of SiO_2 , Al_2O_3 , Fe_2O_3 , MnO , MgO , Na_2O , CaO , SO_3^{2-} , As , Ba , Ce , Co , Cr , Cu , Ga , Hf , La , Mo , Nb , Ni , Pb , Rb , Sr , Th , U , V , Y , Zn and Zr is also high. This unit may be distinguished as well by relatively high contents of TiO_2 , MgO , K_2O , Hf and Rb as $\text{Co}/\text{Al}_2\text{O}_3$, MnO/TiO_2 , $\text{Fe}_2\text{O}_3/\text{Sr}$, As/Sr , Sr/Ba , Cr/Ni and Pb/Zn ratios.

The **Upper Unit** occurs between 36.5 m and 40.0 - 40.5 m depth intervals. It is substantially enriched in Fe_2O_3 , As and Cr , and has the lowest content of K_2O , SO_3^{2-} , Ba , Ce , Co , Cu , La , Mo , Ni and Sr . The range of Hf concentration is highest, and changes in the abundance of TOC , SiO_2 , TiO_2 , CaO , Na_2O , K_2O , SO_3^{2-} , Ba , Co , Ga , La , Mo , Nb , Ni , Rb , Sr , Y and Zr are the lowest in the entire profile. The tendency toward an upward increase in the content of TiO_2 , Ce , Cr , Nb , Sr , U and Y as well as an upward decrease in Al_2O_3 , Fe_2O_3 , MgO , CaO , K_2O , As , Cu , Ga , Ni , Pb , Rb , Th , V , Zn and Zr is typical for this unit. This part of the profile is also well constrained by $\text{Co}/\text{Al}_2\text{O}_3$, Ce/La , $\text{SiO}_2/\text{Fe}_2\text{O}_3$, $\text{Fe}_2\text{O}_3/\text{CaO}$ and $\text{Fe}_2\text{O}_3/\text{Sr}$ ratios.

Sedimentary History

In the Konin area, the deposits of the Poznań Formation have originated on a broad alluvial plain, with local shallow lakes, abandoned oxbows and ponds. The underlain lignites of the 1st Mid-Polish

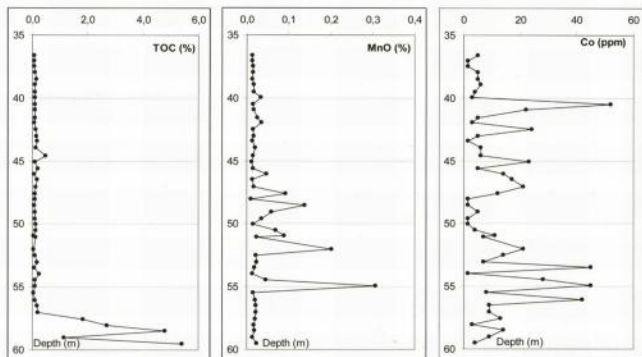


Figure 5: TOC, MnO and Co concentrations in the section from the Konin area

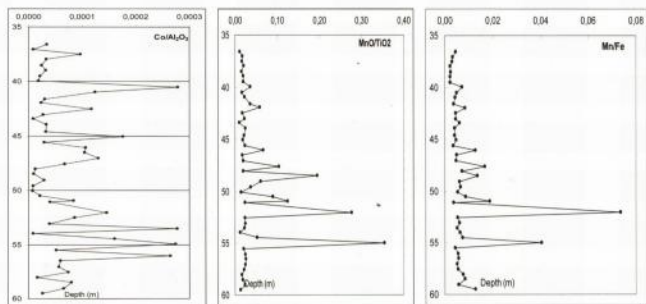


Figure 6: Selected element ratios in the section from the Konin area

Lignite Seam correspond to the end of intensive phytogenic accumulation, dated as the Early Langenfeldian (equivalent of Late Badenian-Early Sarmatian; IX spore-pollen horizon – *Tricolporopollenites pseudocin-gulum sensu* PIWOCKI & ZEMBIŃSKA-TWORZYDŁO 1997), caused by decisive climatic changes, providing cooling and drying (PIWOCKI 1998). The deposition of phytogenic material was replaced by siliciclastics, primarily pelite, in a low-energy lacustrine environment of high water level stages (facies L). Locally in the lower part of the Poznań Formation profile, peat-bog sediments have developed (facies M). Episodes of intense transport of clastic material from lake margins have been reflected when small deltaic lobes invaded the lakes (D and pD) composed of silts and fine sands, with coarse-upward sequences. The succession of lacustrine, peat-bog and deltaic sediments was determined by authocyclic processes (primarily wet and dry seasons).

Authocyclic deposition was interrupted sporadically by tectonic regional events. The oldest event affected the generation of the characteristic horizon, called "a re-deposition correlating horizon" (Figure 10) and also noticed outside the Konin region (SŁODKOWSKA 2002). It has been defined in the lowermost part of the supralignite deposits studied, about 0.2 - 2.0 m above the top of 1st Mid-Polish Lignite Seam and, except for Middle Miocene pollens, also contain abundant redeposited older spore material of Upper Cretaceous/Palaeocene age. This horizon reflects regional redeposition, resulting from intensive erosion caused probably by a tectonic lowering of the erosional base.

The next regional event in the sections of the Poznań Formation studied has been recorded by a series of coarser, primarily silty sediments with benthic foraminifera (PARUCH-KULCZYCKA 2001, PARUCH KULCZYCKA & GIEL 2002): *Lobatula lobatula* (WALKER & JACOB), *Spirillina vivipara* EHRENBERG and *Glomospira charoides* (JONES & PARKER). The same foraminifera specimens were also evidenced earlier in the marine units of the Poznań Formation (DYJÓR 1968, GIEL 1971, 1975, 1979a, 1979b, ŁUCZKOWSKA & DYJÓR 1971). However, foraminifera generally did not occur frequently in Poznań Formation deposits. Foraminifera of the *Spirillina* genus are characteristic of deeper waters and always co-occur with other marine indicators, such as sponge spicules and glauconitic grains. Foraminifera of the

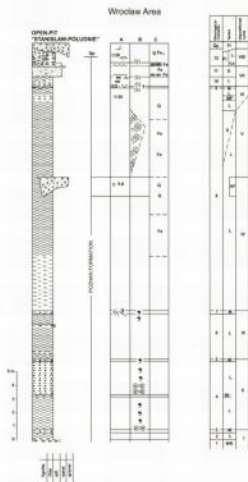
shallow marine species *Lobatula lobatula*, easily adapting to environmental changes and commonly inhabiting plants of shallow basin bottoms, are accompanied by numerous mineralised fragments of plants, being probably the remains of "subaqual meadows" (ODRZYWOLSKA-BIENKOWA & OLSZEWSKA 1996). Foraminifera tests are well preserved, without rounding and infilled with different material. However, their small size and low amount may suggest unfavourable conditions, for instance – removal of marine foraminifera by storm waves into brackish lagoons or freshwater coastal lakes. In the "Kazimierz-Północ" open-pit mine profile (Figure 2), the series mentioned is developed as a sandy unit (complex # 5), interpreted as an inlet deposit, accumulated during storm surges, which invaded marine waters into coastal lakes.

The next storm-generated marine event may be evidenced by the unit of coarser deposits - an inlet delta (InD) facies (upper part of complex # 9) - in the same section. This complex contains numerous glauconitic grains and sponge spicules (also in the BK-110 well profile – PARUCH-KULCZYCKA & GIEL 2002).

Wrocław Area

The Poznań Formation on the Fore-Sudetic Block primarily overlay the older, tectonically dislocated crystalline basement or - such as within the tectonic grabens - they are underlain by clastics and lignites dated as the Lower and Middle Miocene (SADOWSKA 1995a, SZYKIEWICZ 2002). The Poznań Formation sediments are from 20 m to 160 m thick, and their southern extent is limited by the Janowskie Hills, composed of Lower Palaeozoic crystalline rocks and Variscan granites. Chemical weathering of the uplifted basement has permitted the generation of regolithic covers. This material was then resedimented and became a valid component of the Poznań Formation deposits. The entire series of the Poznań Formation deposits is overlain by the Quaternary series or locally by sands and gravels of the Ziemskie Group (DYJÓR 1995, KRZYŻKOWSKI 2001), dated for the time interval: Sarmatian - Upper Pliocene (ZASTAWIAK et al. 1992, SADOWSKA 1995b), or by others up to the Eopleistocene. The age of the deposition of the Poznań Formation was determined after palynological data for the Sarmatian/Lower Pannonian interval - according

Figure 7: Sedimentological profile of the upper (fine-clastic) part of the Poznań Formation, Stanisław-Południe open-pitmine, Wrocław area. Explanations: cf. Figure 2



to the Paratethys stratigraphic scheme (ZASTAWIAK et al. 1992, SADOWSKA 1995b), i.e., Middle/Upper Langefeldian (PIWOCKI & ZIEMBIŃSKA-TWORZYDŁO 1995).

Complete profile of the Poznań Formation, approx. 30 m thick, is exposed in the open pit mine of ceramic clays at Jarosów near Wrocław (Figure 7). The formation is underlain by the crystalline basement and covered by the Quaternary series (SZYNKIEWICZ 2002). This profile was subdivided into 12 lithological complexes, representing seven facies of fluvial-lacustrine environments (CZAPOWSKI et al. 2002).

At a base of the section, the yellow kaoline clays (complex # 1), as redeposited weathering wastes of crystalline basement, occur locally. They directly overlay the regolithes, which cover the kaolinised pre-Tertiary basement metamorphic shales (SZYNKIEWICZ 2002). The next several complexes (# 2, 4, 6, 8 and 10) consist of grey and beige clays, and silts with kaoline admixture are interpreted as a lacustrine facies (L). This complex locally includes zones of dispersed angular quartz gravels, considered as mud flow/slump (MF) deposits. Grey pelites are separated by

four decimetre-thick levels of black and brownish coaly clays (complexes # 3, 5, 7 and 9) and xylite fragments are interpreted as a peat-bog facies (M) developed at a stage of low water level. The upper part of profile (complexes # 11-12) consists of grey and coaly pelites and is interbedded with sands and gravelly sands. They represent the fluvial sediments, i.e., F1 facies with channel (Ch) and deltaic (D) varieties invading due to increased clastics supply to the lake. Locally in the southern part of the open-pit mine, near the basement exposures, the clays of complex # 8 contain few palaeosol horizons (sS facies). The top of the Poznań Formation is locally deeply erosively incised, covered by the fluvial sandy-gravel series, comparable to the Ziembińskie Group, or by the fluvial sand and gravels of Quaternary age.

The Poznań Formation from the Wrocław area was formed on the southeast margin of a giant tectonic depression, extending from the Sudetes to the North Sea (LUBIŃ & SCHWAB 1995). In the lower part of the section (complexes # 2-7) mineralised fragments of arthropods, megaspores of aquatic ferns and seeds of herbaceous plants were found without remains of marine or brackish organisms (KASIEŃSKI et al. 2001), which confirms a continental character of the deposition. In the upper part of the profile, the absence of organic remains probably results from dissolution by humic acids.

Geochemical Characteristics

The elementary distribution of the Poznań Formation in the Wrocław area displays different pattern from that of the Konin area. MgO, K₂O, Na₂O, Ba, Cr, Ga, Rb and V contents decrease upwards linearly, and TOC, Al₂O₃ and Ni concentration decreases upwards hyperbolically from the profile base. The content of Fe₂O₃, P₂O₅, Ce, Cu, La and Th increases hyperbolically from base to top of the profile, and the content of CaO, Hf, Pb, Sr, Ta, U and Zr fluctuates irregularly without any trends. SiO₂, TiO₂, Mo, Nb, Y and Zr content exhibits a gradual increase in the lower part and decrease in the upper part of the profile. Variation in both elementary contents (Table 2, Figure 8) and ratios (Figure 9) of the profile, such as in the Konin area, reflect its geochemical tripartition.

The **Lower Unit** occurs from the approx. 27 m to 29 m depth. This unit has relatively the highest average content of TOC, TiO₂,

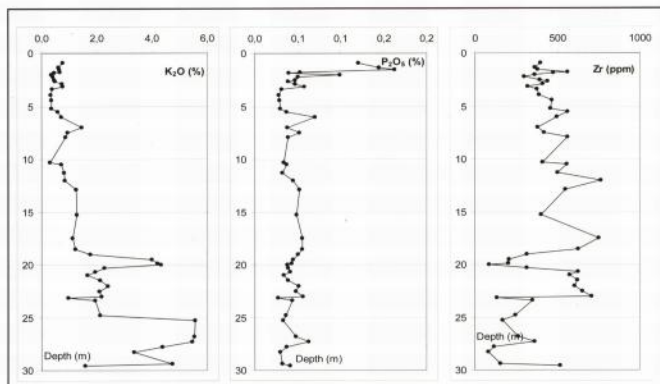


Figure 8: K_2O , P_2O_5 and Zr concentrations in the section from the Wrocław area

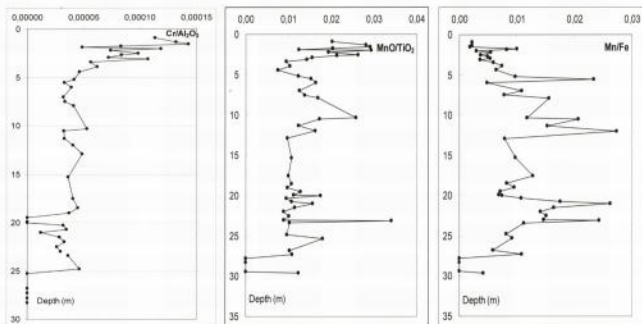


Figure 9: Selected element ratios in the section from the Wrocław area

Al₂O₃, MgO, CaO, Na₂O, K₂O, Ba, Ga, Pb, Rb, Sr and V. The ranges of SiO₂, Fe₂O₃, P₂O₅, Th and U content are the lowest, while the ranges of MnO, Na₂O, Ga, Ni and Pb are slightly lower than the corresponding values in other units. This part of the profile is also well marked by changes in U/Al₂O₃, SiO₂/TOC, Ce/La, Fe₂O₃/Sr, SiO₂/Al₂O₃, SiO₂/Fe₂O₃, Al₂O₃/Zr, TiO₂/Al₂O₃ and Cr/Al₂O₃ ratios as well as by sharp decrease in the content of SiO₂, TiO₂, Al₂O₃, K₂O, P₂O₅, Ba, Ca, Cr and Y to the relatively lowest values.

The **Middle Unit** is the thickest unit and most differentiated with regards to its geochemical composition. It comprises the interval located between ca 3 m and 27 m depth of the profile. The average values of SiO₂, TiO₂, MgO, Na₂O, Cr, La, Nb, Sr, Y and Zr content compared to other units are the distinctly higher and the average Fe₂O₃ content value is lower. The ranges of content of TOC, SiO₂, TiO₂, Al₂O₃, MnO, MgO, CaO, Na₂O, K₂O, Ba, Ce, Ga, Hf, La, Nb, Ni, Pb, Rb, Sr, Th, U, Y and Zr are the highest among the units of this section. In comparison to others, the middle unit is also marked by generally higher values and distinctly higher variability of the V/Al₂O₃, Co/Al₂O₃, U/Al₂O₃, SiO₂/TOC, Ce/La, SiO₂/Al₂O₃ and TiO₂/Al₂O₃ ratios.

The **Upper Unit** extends from the Quaternary bottom down to the 3 m depth interval and is characterised by the highest average content of Fe₂O₃, P₂O₅, Cu, Th and Zr as well as by the significantly lowest values of TOC, TiO₂, MgO, CaO, Na₂O, K₂O, Ba, La, Nb, Rb, Sr and V content. This unit is also characterised by the highest ranges of content of Fe₂O₃, P₂O₅, Cr and Cu as well as the lowest contents of TOC, TiO₂, Al₂O₃, MnO, Na₂O, K₂O, La, Nb, Ni, Pb, Rb, Sr and Zr. The upper unit is also well displayed by the V/Al₂O₃, Co/Al₂O₃, U/Al₂O₃, SiO₂/TOC, Ce/La, SiO₂/Al₂O₃, Fe₂O₃/Al₂O₃, Fe₂O₃/CaO, Fe₂O₃/Sr, SiO₂/Fe₂O₃, Rb/Th, TiO₂/Al₂O₃, Cr/Al₂O₃ and Pb/Zn ratios.

Sedimentary History

Tectonic activity of the basement has determined the character of material and the mode of deposition. Periods of increased subsidence permitted the accumulation of thick pelitic lacustrine facies (corresponding to high water level stages) as well as episodic rapidly accumulated mud flow deposits after slumps initiated by torrent floods or seismic triggers. Decreasing or halting of subsidence - as well as climatic

changes - has caused lowering of water levels in the lake and the expansion of vegetation (at that time peat-bog sediments predominated). These types of fluctuations were responsible for eight depositional cycles distinguished in the section (Figure 7). The first (I) cycle corresponded to flooding of the basement depression, infilled by weathering wastes and gradual accumulation of lacustrine sediments and later - due to subsidence uncompensated by the sediment infill of depression - generation of peat-bogs with soils. Cycles II-VI, with similar facies successions, reflect repeated phases of increased activity of tectonic basement zones, ending with an environmental stabilisation and the development of peat-bog deposits. Longer periods of intensive tectonic activity (cycle IV) are responsible for the remobilisation of weathering wastes from the far basin margins (distinct kaoline content in the cycle bottom): coarse material was supplied into the depression at Jarosów by braided rivers, invading the existing lake there as several alluvial fans. The top cycles (VII and VIII) represent gradual decreases in a large lacustrine basin and the expansion of fluvial sediments, probably due to stabilisation of the depot surface.

Apparently the lower part of the section studied (cycles I-III) may be correlated with the period of early removal of weathering wastes and development of synsedimentary trenches near the Marginal Sudetic Fault, dated for the Miocene and the Early Pliocene (Wojewoda et al. 1995). The end of this section, recording the closing of the lacustrine basin and the expansion of fluvial and alluvial fan sediments, may be compared with the late (end of Pliocene) development of a fluvial network in the entire Fore-Sudetic area. Fluvial sedimentation was accompanied with the increasing supply of very coarse material.

Comparison of Sedimentary Sections

Both the open-pit mine and the well profiles from the Konin area (Figures 2-4) evidence a dominance of terrestrial lithofacies (lacustrine - lake deltaic - mud flows), formed on the large alluvial plain with numerous constant and ephemeral lakes. The Konin succession, characterised by three to nine cycles primarily representing deltaic-lacustrine-marsh sequences, was

Upper level	SiO ₂		FeO		CaO		MgO		K ₂ O		Na ₂ O		P ₂ O ₅		Al ₂ O ₃		TiO ₂		MnO		ZnO		CuO		NiO		V ₂ O ₅		Cr ₂ O ₃		
	%	wt	%	wt	%	wt	%	wt	%	wt	%	wt	%	wt	%	wt	%	wt	%	wt	%	wt	%	wt	%	wt	%	wt	%		
Mean	61.18	19.92	0.87	1.91	0.84	0.01	1.92	0.24	0.16	0.12	0.04	0.01	16.29	16.22	15.13	1.88	10.25	0.15	0.88	0.50	0.25	1.81	1.83	0.41	0.02	0.02	0.02	0.02	0.02	0.02	0.02
S.D.	0.05	0.07	0.02	0.06	1.80	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	
Range	0.86	0.87	0.71	2.77	0.87	0.01	0.82	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	
Maximum	62.07	20.06	0.97	3.21	1.92	0.01	2.23	0.26	0.17	0.13	0.05	0.02	17.00	17.00	16.24	2.00	11.00	0.16	0.90	0.26	2.00	2.00	0.42	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Minimum	61.18	19.92	0.76	0.84	0.83	0.01	1.62	0.23	0.15	0.11	0.04	0.01	15.38	15.38	14.02	1.76	9.50	0.14	0.70	0.24	1.62	1.62	0.40	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Median	61.18	19.92	0.84	1.91	0.84	0.01	1.92	0.24	0.16	0.12	0.04	0.01	16.29	16.22	15.13	1.88	10.25	0.15	0.88	0.50	0.25	1.81	1.83	0.41	0.02	0.02	0.02	0.02	0.02	0.02	0.02
95% N	62.07	20.06	0.97	3.21	1.92	0.01	2.23	0.26	0.17	0.13	0.05	0.02	17.00	17.00	16.24	2.00	11.00	0.16	0.90	0.26	2.00	2.00	0.42	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03

Table 1: Main statistical parameters of the chemical composition of the Poznań Formation in the Kolin area

controlled by a rate of water inflow into lacustrine basins related to rainfalls, humid periods, etc. Open-lake deposits (L) and nearshore deposits (Ls) created seasonally shallow lakes developed on a wide-spreading alluvial plain as well as in isolated small perennial lacustrine basins (pools) located along the basin margins. These deposits are characterised by maximum extension and higher thickness (up to tens of meters). They interfinger with alluvial fan deposits (AF) and channel facies, representing a set of fluvial facies.

The succession described for the Poznań Formation has been subdivided into eight depositional cycles, indicating water level fluctuations within the sedimentary basin. Most of the cycles begin with coarser deposits - lacustrine, deltaic or inlet, corresponding to high water levels (cycles V and VII), and finish with pelitic lacustrine or phytogenic pit-bog sediments, accumulated at lower water level conditions (cycles I, II, IV, VI).

In the basin centre, this autocyclic sedimentation was interrupted several times by rapid inflows (storm/hurricane surges) of marine waters from the adjacent marine basin. Two of these episodes had been recorded by poor brackish/marine microfauna (PARUCH-KULCZYCKA & GIEL 2002) evidenced into the former coastal lakes, which have been transformed into brackish lagoons. These marine inflows have produced discontinuous horizons of sandy-

gravel beds, with cross-sets, ripples and erosion scours indicating positions of inlets and inlet deltas, topped by silty-clay series with microfauna.

The section from the southwest basin of the Wroclaw region (Figure 5) is situated very far from an open sea. It is located within a tectonic depression on the Sudetes foreland, at that time primarily occupied by small lacustrine basins with an alluvial plain rim. The Poznań Formation series in this area is underlain by weathering wastes/residua (WR) of crystalline basement and consists of eight repeated fluvial-lacustrine-marsh cycles, with coarse, cross-stratified alluvial fan (AF) units. Lithofacies and thickness of the series were controlled by a subsidence rate (tectonically determined) and a water/sediment supplying ratio. Concentrations of kaoline as well as lenses of gravels and gravelly sands reflected episodes of intensive erosion of the depression margins. Tectonic movements of the basement responsible for these processes have also produced faulting and folding of lacustrine-marsh (clay/lignite and clay) series in the depression centre. Chemical characteristics of the section studied (Figures 5 and 6) are relatively constant.

A comparison of the facies distribution in the central and southwestern parts of the Poznań Formation sedimentary basin (Figure 11) suggests that marine influences may be related not only (and even

Table 2: Main statistical parameters of the chemical composition of the Poznań Formation in the Wroclaw area

Upper level	SiO ₂		FeO		CaO		MgO		K ₂ O		Na ₂ O		P ₂ O ₅		Al ₂ O ₃		TiO ₂		MnO		ZnO		CuO		NiO		V ₂ O ₅		Cr ₂ O ₃	
	%	wt	%	wt	%	wt	%	wt	%	wt	%	wt	%	wt	%	wt	%	wt	%	wt	%	wt	%	wt	%	wt	%	wt	%	
Mean	61.18	19.92	0.87	1.91	0.84	0.01	1.92	0.24	0.16	0.12	0.04	0.01	16.29	16.22	15.13	1.88	10.25	0.15	0.88	0.50	0.25	1.81	1.83	0.41	0.02	0.02	0.02	0.02	0.02	
S.D.	0.05	0.07	0.02	0.06	1.80	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Range	0.86	0.87	0.71	2.77	0.87	0.01	0.82	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Maximum	62.07	20.06	0.97	3.21	1.92	0.01	2.23	0.26	0.17	0.13	0.05	0.02	17.00	17.00	16.24	2.00	11.00	0.16	0.90	0.26	2.00	2.00	0.42	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Minimum	61.18	19.92	0.76	0.84	0.83	0.01	1.62	0.23	0.15	0.11	0.04	0.01	15.38	15.38	14.02	1.76	9.50	0.14	0.70	0.24	1.62	1.62	0.40	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Median	61.18	19.92	0.84	1.91	0.84	0.01	1.92	0.24	0.16	0.12	0.04	0.01	16.29	16.22	15.13	1.88	10.25	0.15	0.88	0.50	0.25	1.81	1.83	0.41	0.02	0.02	0.02	0.02	0.02	0.02
95% N	62.07	20.06	0.97	3.21	1.92	0.01	2.23	0.26	0.17	0.13	0.05	0.02	17.00	17.00	16.24	2.00	11.00	0.16	0.90	0.26	2.00	2.00	0.42	0.03	0.03	0.03	0.03	0.03	0.03	0.03

not primarily) to the Paratethys area, as they were hitherto considered (DYJOR 1968, 1992, LUCZKOWSKA & DYJOR 1971), but also to the North Sea area. This conclusion substantially changes the position of the basin borders that time.

The chemical composition of Poznań Formation deposits confirms that terrigenous silicate (primarily quartz) and clay minerals are main components (Tables 1 and 2). This is reflected by the relatively high average content of SiO_2 and Al_2O_3 as well as by admixture of some minor components such as Fe_2O_3 , K_2O and TiO_2 . The allochthonous provenance of these elements may be also supported by positive/negative moderate to strong correlation between the content of SiO_2 and Al_2O_3 , CaO , Fe_2O_3 , K_2O , MgO , Na_2O , TiO_2 , Ba , Ce , Cr , Cu , Ga , Hf , Mo , Nb , Ni , Pb , Rb , Sr , V , Y , Zr . The main components show very high differentiations in their distribution. The clay fraction predominates mineral composition of the entire series. In the Konin area, the content of this fraction oscillates from 25 to 60 %, usually approx. 40 % (KLAFYTA 1972), and in the Wrocław area it is even higher. This fraction is marked by moderate to strong positive correlations ($R^2 > 0.80$) between the content of SiO_2 , Al_2O_3 , Na_2O , K_2O , MgO , CaO , MnO , P_2O_5 and Ce , Cr , Ga , Rb , V . Moreover, a positive correlation between the content of major elements and Ba , Sr , U , Th , Y also suggests that the later elements are linked to clay matter. A distinct positive correlation between Zr content and SiO_2 and a negative correlation between Zr and Cu , Pb , Rb , Sr suggests the detrital provenance of this element, probably deposited along with quartz sands. Moderate to distinct correlation between TiO_2 and SiO_2 , MnO , Na_2O , Ce , Cr , V , Zr shows the same origin of Ti . Detrital origin (as substitution in transported minerals) may be also indicated for Hf and Sr . Organic matter is particularly concentrated in the lowermost part of the sections near underlying lignite seams. Part of this, according to distinct correlation between TOC and MgO , K_2O , TiO_2 , Ga may also be detrital in origin.

The presence of iron is a distinctive macroscopic feature of Poznań Formation sediments. It is expressed with grey, green and mottled colours, particularly when stained by iron oxides and/or hydroxides. Pyrite is also a common mineral, especially in dark rocks rich in organic matter, where it occurs as isolated and, in places, ag-

gregated small micronodules. Iron oxides and hydroxides are particularly abundant in the upper part of the series as a result of epigenetic weathering oxidation of iron sulphides and thus impregnation by iron oxides. The presence of sulphides (primarily pyrite) is confirmed by the distinct correlation between the content of Cu , Ni , Pb and Zn . Some of iron released from detritus may contribute to rare glauconite grains in the sandy/clayey deposits.

Both the profiles - near Wrocław and Konin - of the Poznań Formation analysed are very depleted in CaO and Na_2O content. These values are 0.33 % and 0.08 % in the Konin area, and 0.61 % and 0.17 % in the Wrocław area. This suggests extremely low contents of calcium carbonates in both the sedimentary piles. This is also confirmed by very low Mn/Fe average ratios (0.008 in the Konin area and 0.010 in the Wrocław area), which indicate there are practically no carbonates dispersed in a matrix, and the entire Mn content is absorbed onto clay matter. However, carbonates (in the form of calcareous or marly beds and horizons of calcareous, dolomitic and sideritic concretions) have been found in clayey deposits of the Poznań Formation in many localities of the Polish Lowlands (WYRZYCKI & MALISZEWSKA 1977). The bedded and mottled olive-grey clays and silts of the examined sections also do not contain intrasedimentary gypsum crystallites. This mineral occurs in sediments of the Poznań Formation and is originated due to weathering processes. Therefore, sulphur content, as exemplified by SO_4^{2-} , was originally bound in the organic matter and sulphides, and was an artefact of analytical procedure. This is in accord with TOC content decreasing upward in the same fashion.

Following the chemostratigraphic method, three geochemical units have been defined in the Poznań Formation profiles in both areas on the basis of the analysis of elementary-content curves (GASIEWICZ 2002). The transitions between these are generally distinct and short. These geochemically different units suggest that slightly different depositional settings developed during the sedimentation of the Poznań Formation. The distinct depletion of Ca and Na as well as the distinct predominance of elements related to detrital fraction clearly indicate that they were supplied from weathering of crustal rocks. Other elements, such as Ca , Mg , Na , Ba , Sr and some siderophile

elements, may be sourced from basinal (sea) floods.

The **Lower Unit** is marked by a general depletion in the contents of many elements and concomitant distinctive enrichments in TOC content. Substantial abundances of TOC evidence the intense accumulation of organic matter and then its diagenetic transformation into lignite beds. The downprofile increase in TOC content coupled with increases in pyrite amounts suggests that these deposits were produced by unusual or non-steady-state processes developing near the sediment surface (Bozkurt et al. 2001). The organic matter accumulation associated with iron in abundant terrigenous detritus supplied to the basin is subjected to more reducing conditions when deposited at the basin floor. These conditions are evidenced in the sediments investigated primarily in the form of abundant pyrite (as noted above) and were similar in both regions.

The **Middle Unit** of the Poznań Formation in both sections studied is relatively much thicker than other units and typically characterised by high variation in chemical composition and the highest average values of element contents. Shifts in the abundance of most of these elements are irregular and point to a non-systematic change in the source material or unidirectional mineral fractionation. This is exemplified by downprofile variations in ratios of total iron to aluminium (Co/Al₂O₃ or Mn/Fe), which show a high variability in the middle part of the sections (Figures 6 and 9), while pyrite abundance seems to remain similar. This suggests qualitative differences in both the elements and/or the composition of clay matter or simply clastic inputs. Different patterns in the ratio found in this unit imply various sedimentary conditions in these settings. Moreover, one may interpret low iron abundance (and thus lower Fe/Al ratio) in lower part of both sections as being due to leaching of iron from detrital minerals in anoxic waters and then, in consequence, relatively higher pyrite precipitation. Yet distinct, either enrichment (Wrocław area) or depletion (Konin area) in Fe of the upper part of the sequence could result of local shifts in terrigenous material, higher in more proximal and lower in more distal areas.

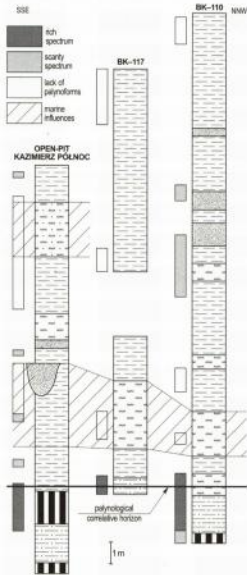
The **Upper Unit** is marked by a substantial increase in Fe₂O₃, Al₂O₃ and (locally) P₂O₅ and Th contents. This enrichment is

accompanied by a consistent decrease in CaO, K₂O, Ba, La, Rb, Sr, and Y abundance. This seems to reflect a relatively increased detrital input to the basin. However, enrichment in Fe₂O₃ and Al₂O₃ means a change in major element composition in this unit relative to the other units. This increase indicates a high percentage of ferromagnesian silicate minerals, possibly chlorites and iron oxides, as compared with other insoluble components such as quartz and feldspars. These features, together with concomitant depletion (more distinct in the Wrocław area) in K₂O, CaO, Rb and Y (?) thus suggest a decrease in illite content (which is regarded as being the most significant K-bearing mineral). This may be true because K-feldspar content in the Poznań Formation beds is generally low, and, in parallel, there is no evidence for a substantial increase in the plagioclase content at all. P₂O₅ content remains relatively stable throughout the series of the Konin area and both the lower and middle units of the Wrocław area. However, in the upper unit of the latter area, in grey argillaceous material and sands, it increases sharply. This increase is attributed to amorphous phosphatic components, which, on the other hand, may be more common and dispersed in sediments of the coastal setting.

Conclusions

Clayey deposits of the Poznań Formation generally occurred within some continental environments: fluvial (predominated by flood-plain facies), lacustrine and, locally, tethymic environments. The material was supplied from different directions, and a belt of the southern uplands, Sudetes Mountains and Scandinavia were the main alimentary areas (Pwocik 1998). In addition, other areas, such as Belorussia Antecline and uplifting Carpathian Orogen, may be important. Some deposits from the upper part of Middle Miocene in southwestern Poland probably originated in brackish/marine embayments connected with Paratethys (LUCZKOWSKA & DYJOR 1971). Clayey deposits of the Grey Clay Member originated in warm-temperate conditions. After sedimentation of this series, general climatic cooling took place, and the Wielkopolska Member deposits were formed in temperate and periodically even cold-temperate conditions (STUCHLIK 1998). Humid and very humid conditions predominated generally during the time of sedimentation

Figure 10: Regional correlation of the Poznań Formation deposits and pollen/spore frequency in the Konin area (after: SŁODKOWSKA 2002)



of the Poznań Formation, but gradual aridisation proceeded during the last period of sedimentation (Flamy Clay Member).

In the Konin area, typical facies succession related to the development of peat-forming vegetation in lacustrine basins was interrupted with overflowing of marine water, which transformed periodically nearshore lakes into brackish lagoons. These inflows, probably affected by storm surges, are indicated by scarce marine mixed microfauna (deep- and shallow-water microfauna) and small amounts of glauconite.

The depositional cycles related to the deepening and shallowing of the basin were controlled by water-level oscillations and storm surges in the Konin area. Sedimentary record of the surges depends on basin bottom morphology, and, therefore, comparison of the numerous profiles from the Polish Lowlands should be useful for detail reconstruction of this area.

Microfloristic studies (SŁODKOWSKA 2001) of coaly middlings displayed the predominance of foristic assemblages of riparian forest with *Pterocarya*, *Liquidambar*, *Ulmus*, *Carya*, and swamp forest with *Nyssa*, *Alnus* and ferns. Plants of the mesophilous mixed forest with *Pinus*, *Quercus*, *Fagus*, *Betula*, *Carinus*, *Tilia*, *Araliaceae*, *Engelhardtia*, with infrequent palaeotropical taxa (*Itea*) were also significant there. Contents of bush peat land elements with *Ericaceae*, *Ilex* and *Myrica* were lower. Temperate climates predominated distinctly in the spectra of lower part of the profiles. However, wide taxonomical differentiation and important content of plants related to humid settlements show rather mild warm-temperate climate, which was favourable for the development of coal-forming swamps. The pollen/spore spectra are rich and pollen grains are well-preserved, confirming organic matter accumulation in a stagnant thelmatic basin.

In the overlying clayey sediments, organic matter, including palynomorphs and phytoclasts, is generally lacking. Infrequent sporomorphs occurring in this series are not index species, and this feature is typical for large areas of the Polish Lowlands. During sedimentation of the clay deposits of the Poznań Formation, the basin frames were probably covered with vegetation. However, the sedimentary, diagenetic and erosional processes, primarily oxidation, which affected the periodical drying of the basin, involved plant remains (those consisting of sporopollenite) thus not preserved in the sediments.

The geochemical element variations of the Poznań Formation from the two localities of the Polish Lowland permit the establishment of three geochemical units in both the sections: lower, middle and upper. The lower and upper units are relatively thin (up to few metres in thickness) compared to the middle unit (several to a few tens of metres thick). This tripartition is however not clearly reflected in the lithological pattern, although is in an accord with the generally assumed tripartite subdivision of the series into: upper - mottled clays, middle - green clays, and lower - grey clays.

Geochemical features of the units from both the sites suggest: (1) environmental evolution in the same sedimentary basin of the Polish Lowlands characterised by (2) differentiated (with regard to the composition and content of transported material)

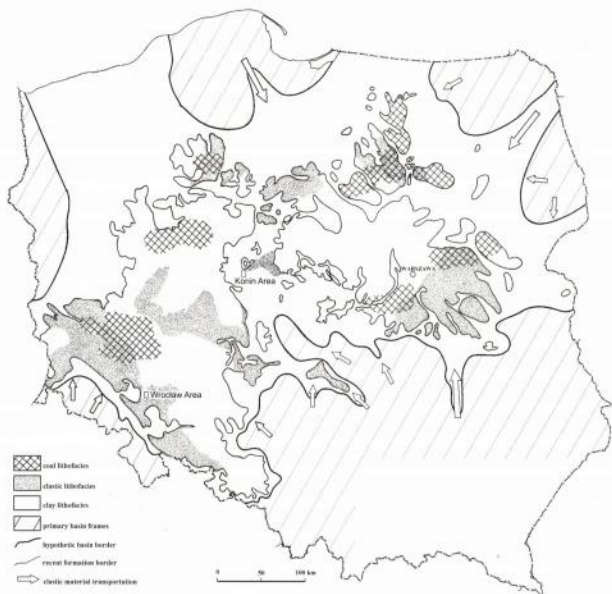


Figure 11:
Palaeogeographic/
lithofacies map of
the Poznań Forma-
tion sedimentary ba-
sin (after: CZAPOWSKI
& KASINSKI 2002)

inputs of allochthonous material, (3) similar (tripartite) short-term evolution of both the depositional environments and their different geochemical associations may easily be explained by (4) slightly different depositional systems with a general short-term instability of their sedimentary regimes and a distance from coastline of the basin whose (5) surficial (marine) waters were frequently diluted by increased contributions of rainwater or river discharges from near land, especially in the Wrocław region.

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The Impact of Political Borders on Stratigraphic Nomenclature of the Palaeogene and the Neogene

Examples from the Easternmost Areas of the Netherlands and the German Emsland Area

► Franz Gramann

Abstract

Sedimentary bodies which form lithostratigraphic units of uniform origin may be subject to name and even rank changes when they are traced across political borders. These nomenclatural problems comprise man-made complications in the reconstruction of geological history in uniform sedimentary areas. The extent of possible differences is demonstrated on the basis of a comparison of national stratigraphical schemes across national borders between the Netherlands and westernmost Lower Saxony. A special problem arises from the use of six regional stages and two substages for the Miocene in the literature for northwestern Germany.

Kurzfassung

Sedimentkörper gleicher Entstehung haben meist verschiedene Namen und gelegentlich unterschiedlichen Rang innerhalb der Nomenklatur-Hierarchie, wenn sie politische Grenzen überschreiten. Dies kann ein Hindernis sein für das Verständnis der geologischen Geschichte. Das Ausmaß solcher Unterschiede wird anhand eines Vergleichs der stratigraphischen Gliederungen beiderseits der Grenze zwischen den östlichen Provinzen der Niederlande und dem niedersächsischen Emsland aufgezeigt. Ein besonderes Problem besteht im Gebrauch von sechs regionalen Stufen und zwei Unterstufen für das Miozän in der nordwestdeutschen Literatur.

Keywords

Lithostratigraphy, chronostratigraphy, Palaeogene, Neogene, Emsland area, the Netherlands, political borders

The Problem

It is a common belief that lithostratigraphic units should be sedimentary bodies of uniform physical origin. A single name for each unit should surely be very convenient. But what happens when lithostratigraphical units run across political borders? In the early days of the geological sciences, scientists were very pleased to be able to trace the course of London Clay from southwestern England to northern Germany, where its original name was simply translated as "Londonton". The same procedure was favoured by HINSON (1986) for some units of the Palaeogene in Schleswig-Holstein by the use of stratigraphic names from Denmark. The political border between the easternmost provinces of the Netherlands and the Emsland area of Lower Saxony runs primarily from north to south, whereas the sedimentary bodies of Palaeogene and Neogene ages trend roughly east-west, as does the present coastline of the North Sea. Nevertheless many lithostratigraphic units have received discrete national names. These may even differ in rank within the nomenclatural hierarchy. The current state of affairs, as can be compiled from publications and reports from both sides of the border, is given here in Figure 1.

For instance, the continuation of the Delden Member of Late Miocene age into the Emsland area has been seen there recently in the same glauconite sand body with shell fragments of *Lingula* sp., as described by BOSCH et al. (1975) from the neighbouring Hengelo area of Overijssel. This unit is regarded there as a member of the Breda Formation. The Breda Formation comprises a sedimentary column of entirely Miocene age in the stratigraphic nomenclature of the Netherlands, in the updated

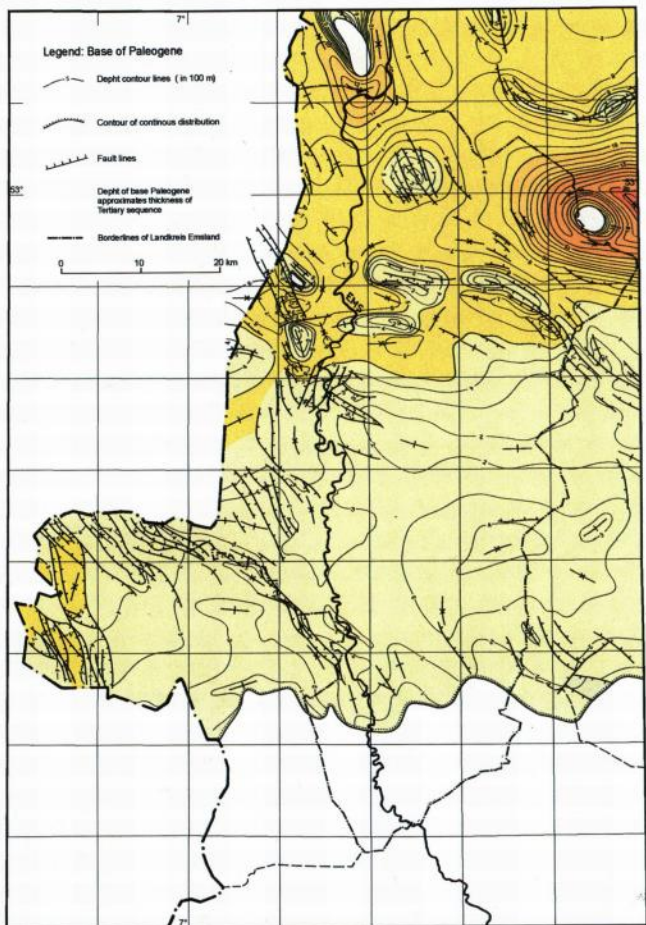


Figure 3: Base of Palaeogene. Depth of base Palaeogene approximates thickness of Tertiary (Palaeogene and Neogene) sequence. Average thickness of Pleistocene cover plus Holocene beds approximately 50 m in areas without meltwater channels and glaciotectonic deformation

calcareous microfauna, the FI of DOPPERT & NEELE (1983), offers the possibility of long-distance correlations to clay units of Ypresian age in Belgium and England. The UE4 assemblage zone in the Emsland area is represented by a sand unit, with sponge spicules and globular radiolaria. It is the southern equivalent of the "Heiligenhafener Kieselgestein" in Schleswig-Holstein, in which siliceous microfossils comprise rock-forming constituents. Largely dated as Late Ypresian, it may also be partly equivalent to the Brussels Sand Member within the Dongen Formation. Stratigraphic names for some members of the Dongen Formation, which comprise the entire Eocene sedimentary column in the Netherlands, have been borrowed from Belgium. This is rather reasonable, as there is little difference across the border, though they have formation rank in Belgium and may not be fully coeval, as indicated by VAN ALDRICHEM et al. (1997) for the Brussels Sand. The same lithostratigraphic units in the Netherlands, with Belgian names, are equally present in the Emsland province of Lower Saxony and much farther beyond as well. Calcareous sands and marly clays with Ledian-Wemmelian microfossils (FH1), including small and primitive *Nummulites* of the *variolaris* species group, have been encountered in the extreme western part of Lower Saxony, in the Emlichheim region, as described by ELLERMANN (1963), but also in the area farther northeast, at Lingen and beyond the river Ems, where they are contained in a cored section at Haselünne.

Contrary to previously published findings indicating a position within the Late Eocene, these calcareous sediments are mainly of Middle Eocene = Lutetian age. This has been proved on the basis of the biozonation of calcareous nannoplankton of MARTINI (1971). Sediments of true Late Eocene = Priabonian age are as yet unknown in the Emsland. If present, they must be searched for in borehole sections with extreme thickness in Palaeogene sediments.

The Ootmarsum Formation in Twente, present on both sides of the border within the Emsland province, refers to a transgressive glauconitic sand unit with rolled phosphatic sandstone concretions, reworked Eocene fossils, including the crab *Coeloma balticum* (SCHLÜTER 1879), figured from there by DE NEVE (1945), and selachian teeth. This assemblage of fossils has been compared with the collections

of teeth from the Middle to Late Eocene Gehlberg Formation found around Helmstedt, in easternmost Lower Saxony by LERICHE (1936). BOSCH (1964) has found teeth of six shark species of Oligocene age together with 26 others which are reworked from the Eocene. GAEMERS (1993) derives the green phosphorites of the Ootmarsum Formation from the Brussels Member of the Dongen Formation. The Ootmarsum Formation in Twente, its German equivalent, referred to as "Klastischer Fuß" by ELLERMANN (1963), and also the Afzetting van Ratum as described by BOSCH et al. (1975) must be regarded as the coarse transgressive base of a nearly ubiquitous marine rhythmic sequence of more or less silty clays with carbonate septaria. The old German formation name refers to these septaria type concretions. The Septaria Clay Formation is an eastern continuation of the Belgian Boom Clay Formation of Rupelian Age. It can be traced across the entire region at least as far as the lowlands of Poland, but has received a total of nine different lithostratigraphic names in the area on both sides of the national border alone. The geological history during the Oligocene may thus be obscured by purely nomenclatural differences. The upper part, still regarded as belonging to the Rupelian Stage, figures as the Winterswijk Member in BOSCH & HAGER (1984). The lower part has been named there as the Brinkheurne Formation, with Kotten and Woold Members. In the column for the Emsland, R1, R2, R3, R4 are the symbols for the stratigraphy by foraminiferal assemblages by SNEGLER (1966) within the Septaria Clay Formation. The R1, R2 and R3 foraminiferal assemblages can be traced, according to VON DANIELS et al. (1994), as far to the west as to the Waasland province of Belgium. The Woold Member, rich in organic matter and with elevated gamma radiation, seems to be the equivalent of the R3 unit. The Winterswijk Member contains the R4 foraminiferal assemblage in samples provided by A.W. JANSSEN. In the Emsland area, much younger sediments have been frequently found on top of Rupelian Clay with R2 microfauna, and clay beds with the R3 and R4 assemblages are eroded.

The gap below the Ootmarsum Formation, and later gaps above the Rupel Formation members as well, seem to be characteristic, at least for the southern part of the Emsland area. In accordance with ELLERMANN (1963), and contrary to older publications, the marine Veldhoven Formation or

similar Chattian equivalents of the Late Oligocene are missing there as well as across the border. The Veldhoven Formation is preserved according to BERG et al. (2000) only in a downfaulted rift structure farther southwest. HAGER & PROFERT (1988) indicate a presence in the northern part of the Rhine Embayment, where the Chattian Sands equivalent is known as the "Grafenberger Schichten".

Neogene

A glauconite sand unit on top of the Septaria Clay Formation, and here in the west at the base of the Neogene sequence, has received the name "Grenzglaukonit" in Lower Saxony. It has most recently been demonstrated to be diachronous by KREUZER & HARRÉ (1989). The glauconite sand "Laag van Miste" (Miste Bed) of BOSCH et al. (1975) in the lowermost part of the Aalten Member within the Breda Formation, in the Achterhoek of the Gelderland province, is its equivalent west of the national border. Apart from an autochthonous mollusc fauna, it contains reworked shells and shark teeth of Late Oligocene origin. The next lithostratigraphic unit in the Emsland area above the "Grenzglaukonit" is known as the "Unterer Glimmerfeinsand".

In some well sections, for instance, in the Emlichheim 74, but also in cored holes at Lingen, the "Unterer Glimmerfeinsand" has been identified as silt with the zonal marker *Uvigerina tenuipustulata* on top of the Grenzglaukonit layer and gradually emerging from it. This indicates the presence of the foraminiferal biozone FD of DOPPERT (1980) of Late Hemmoorian=Burdigalian age. The same age has been attributed to the "Laag van Miste" due to the description of its autochthonous Oxlundian Substage mollusc fauna by A. JANSSEN (1984). In Lower Saxony, on the Danish Jutland peninsula, but also in the Lower Rhine Embayment, a fully marine mica clay formation, named "Oberer Glimmertert" in Lower Saxony, should follow. It has been traced only sporadically in the northern Emsland area. The same may be the case in the Overijssel province. Thus, the equivalent of the Reinbek-Hoddedingden sedimentary and faunal complex, well known for instance from the Lower Rhine Embayment, seems to be undersized or truncated there. It has been encountered more frequently in the southeastern part of the Emsland and in its eastern neighbour-

ing areas near Quakenbrück. In the Winterswijk area, it is contained in the Aalten Member above the Miste Bed, according to BOSCH et al. (1975). Their description of the non-calcareous Eibergen Member with its whale bones in the same publication resembles the suboxic Tostedt Beds in the Oldenburg Münsterland, between the Ems and Weser rivers.

The presence of sediments with Late Miocene microfauna (FB) has been proved many times in the Emsland area since ELLERMANN (1963). Sand units of this age, informally named "Oberer Glimmerfeinsand", are known in the south around Nordhorn. Marine clastics of Late Miocene age form a transgressive blanket, covering much of the area. In the extreme they may directly cover the Septaria Clay = Boom Clay unit. The stratigraphy within the up to 2,000 m of Tertiary (Paleogene and Neogene) sediment in the rim sink of the Lathen salt plug in the north is not sufficiently known to exclude stratigraphic gaps. The presence of the Delden Member, the uppermost member of the Breda Formation on both sides of the national border, has already been mentioned. Normally, its coarse glauconite grains are partly transformed into brown goethite. Remnants of the calcareous mollusc fauna are represented by moulds and fills, as shown by BOSCH et al. (1975, Pl. 19). Subaeric weathering during a pre-Pleistocene time of denudation may be the reason for this.

The last clearly marine sediment in the area has been observed by VORHUYSEN & TOERING (1969) in the Gelderland and Overijssel provinces and by GRAMANN (1987) in the Emsland. It is a widely distributed, slightly glauconitic and micaceous silt unit with the foraminifera *Monspeliensis pseudotepida* (VAN VORHUYSEN 1950) and *Bolboforma costairregularis* (VORHUYSEN & TOERING 1969). The foraminiferal assemblage can be ascribed to a FB/FC transition within the DOPPERT zones, as demonstrated by LEEUVEN in BERG & GAEMERS (1993) in a sample from the Peize well on the Assen Oost map sheet. This unit may belong to the same transgression, which deposited the Kattendijk Sand in the Antwerp area. In the Netherlands, the Kattendijk Sand is regarded as a basal member of the Pliocene Oosterhout Formation. The introduction of a Kattendijkian Stage for the Early Pliocene has been attempted by GAEMERS (1993) and has been followed by HINSCH (2001).

North Sea Stages for the Neogene

A most serious complication, which also greatly puzzles outsiders, is the presence of local names for the stages of the Neogene. Though much in use in German papers and recognizable as names meant to denote stages by the Latin ending -ium, little has previously been known about their chronostratigraphic values. They have their roots in characteristic mollusc assemblages, described in the years from 1919 to 1952. The history of their successive introduction by various authors has been compiled for the first time by ANDERSON (1961), later also by HINSCH in TOBIEN (1986: 679-699). A correlation to sequence stratigraphy has recently been attempted by HINSCH (2001). At least for the stages younger than the Reinbekian, which represents a time of widespread marine environmental conditions in large areas of northern Germany and offshore, correlations to international stages may still be tentative. Seismically recorded sections from the coast and extending into the North Sea display prograding reflectors, typical of deltaic sedimentation, as indicated in Figure 266 in VINKEN (1988). Therefore, this area may be a difficult region for the definition of chronostratigraphic units for the Late Neogene. Promising attempts towards better knowledge of the Neogene in northern Germany have been published recently by BÜLOW (2000) or are under way within the framework of multidisciplinary studies, for instance, on the Nieder Ochtenhausen cored borehole section outside the Emsland area by C.H. VON DANIELS and others in volume A 152 of *Geologisches Jahrbuch*, Hanover (2001).

Conclusions

Differing stratigraphic codes, together with a predominance of independent national names for basically identical interregional sedimentary units, have, until recently been used quite normally by various European scientists. This is largely a consequence of differences in the history of geological science and language barriers. Nevertheless, the aim should now be to reveal geological history to the public in spite of nomenclatural problems. Insiders may keep their personal stratigraphic dictionaries in their memories, but in order to assist the broader scientific community, identical sedimentary units should receive

single names across the entire area of their distribution.

Acknowledgements

Since the informative contribution of ELLERMANN (1963) on the Tertiary in the oilfields in the southwestern part of the Emsland area, many shallow and several deeper boreholes have been sunk through the total cover of Pleistocene sediments in the westernmost part of Lower Saxony, including the Emsland area, together with the *Grafenschaft Bentheim*. The Neogene, and eventually also Palaeogene, formations encountered there were sampled. The majority of these shallow wells were sunk for regional groundwater surveys. Other samples were taken during subsurface mapping activities. As a routine, micropalaeontological methods were applied to obtain as much stratigraphic information as possible. In the course of time, my fellow palaeontologists, P. Cepek, C.H. von Daniels, A. Köthe, K.J. Meyer, U. Staesche, and myself were active in these investigations. To my colleagues, including those who have provided the samples, and to the Niedersächsisches Landesamt für Bodenforschung, I wish to express my thanks for their permission to use data from internal palaeontological reports. A discussion of the stratigraphy of the Miocene on the German side with von Daniels resulted in a necessary revision of the names of lithostratigraphical units. Information on subsurface geology in the Emsland area by F. Kockel, who has contributed a depth contour map on the base of the Tertiary, was very helpful.

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Figure 10 Dinoflagellates from the Lingen B1 borehole).

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