Stratigraphic interpretation of the Neogene marine – continental record in the Maaseik well (49W0220) in the Roer Valley Graben, NE Belgium

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(10 figures, 4 tables, 2 photo plates)

Cover illustration : Illustration of sedimentary structures in the lithologically most variable upper part of the Kieseloolith Formation. Different forms of lamination, erosive contacts and eroded clay parts, alternations between clay, sand and lignite are shown. Clockwise from upper left, samples from depths 91,67 m - 68,20 m - 91,55 m - 67,20 m.

STRATIGRAPHIC INTERPRETATION OF THE NEOGENE MARINE – CONTINENTAL RECORD IN THE MAASEIK WELL (49W0220) IN THE RUR VALLEY GRABEN, NE BELGIUM

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Abstract. A 302 m deep, cored reconnaissance well was drilled in 1980, at Jagersborg to the northwest of Maaseik (49W0220). The borehole is located north of the Feldbiss fault system, in the Rur Valley Graben. The top of the section consists of Saalian to Pleni-Weichselian Meuse gravels capped by loam.

The section between 22 and 193 m is identified as the Kieseloolith Formation, consisting mainly of quartzic sands with the intercalation of four lignite and clay intervals. Lithological characteristics and geophysical well logs allow the traditional identification of the Waubach sands and gravels at the base of the Kieseloolith Formation, overlain by the Pey sands between two lignite and clay levels which are interpreted as Brunssum clay; using the same approach, the sands above the upper Brunssum clay are interpreted as the Schinveld/Jagersborg sands. The palynology, however, suggests a Pliocene age, Reuverian, for the entire quartz sand unit although also a Brunssum age could be accorded to the quartz sand below 90 m depth. Two palynozones occur with a boundary around 57.6 m. The top of the lower palynozone A, between 57.6 and 87.5 m, has a similar composition as the Mol sand lignites occurring to the west, outside the Rur Valley Graben. The upper palynozone B between 57.6 m and the top of the sands characterizes the Reuverian C and the clay layers present in this section are consequently interpreted as Reuver clay. The palynozone A represents a landscape covered by dense forest in contrast to the upper palynozone B during which the clearance of the woods had already started, the forest became less dense and enclosed mires more extensive. The top of the Kieseloolith Formation marks the transition to the Praetiglian. All lignites show a rank between the brown coals in the Lower-Rhine exploitations and peats.

The interval between 193 and 198 m is a yellow quartzic, mica-containing marine sand of uncertain stratigraphic position; it might correspond to the Syltian, an uppermost Miocene regional North-Sea stage.

The green glauconitic sands between 198 and 302 m are identified as the Breda Formation and can be further subdivided based on grain size and glauconite content. Dinoflagellates and mollusc fragments allow the identification of a lower part between 302 and about 273 m that is biostratigraphically similar to the upper part of the Antwerpen Member and Zonderschot Member of the Berchem Formation to the west. It is considered as Middle Serravallian in age based on dinoflagellates. An upper part between about 235 and 198 m is biostratigraphically equivalent to the Deurne and Dessel Members of the Diest Formation, based on dinoflagellates, molluscs, benthic foraminifera and ostracods. The age of this upper part is Tortonian. The interval between these lower and upper parts of the Breda Formation has no facies equivalents in the Campine basin to the west.

Key words: palynology, dinoflagellates, molluscs, benthic foraminifera, ostracods.

Introduction

The Maaseik well in northeast Limburg (Fig. 1) was drilled in 1980 as a reconnaissance borehole at the initiative of the Geological Survey of Belgium. The borehole is located about 5 km to the northwest of Maaseik, in the industrial zone named Jagersborg. The Lambert coordinates of the well are 246 636 (x), 200 835 (y) and the topographic height is +33.14 m TAW (z).

The total depth of the well is 302 m. Except for the upper 30 m, the whole borehole was cored with a core diameter of 10 cm. The upper 30 m of the well is cased. Open hole geophysical logs are available between 30 m and total depth, recording resistivity, spontaneous potential, natural gamma ray and caliper (Fig. 2).
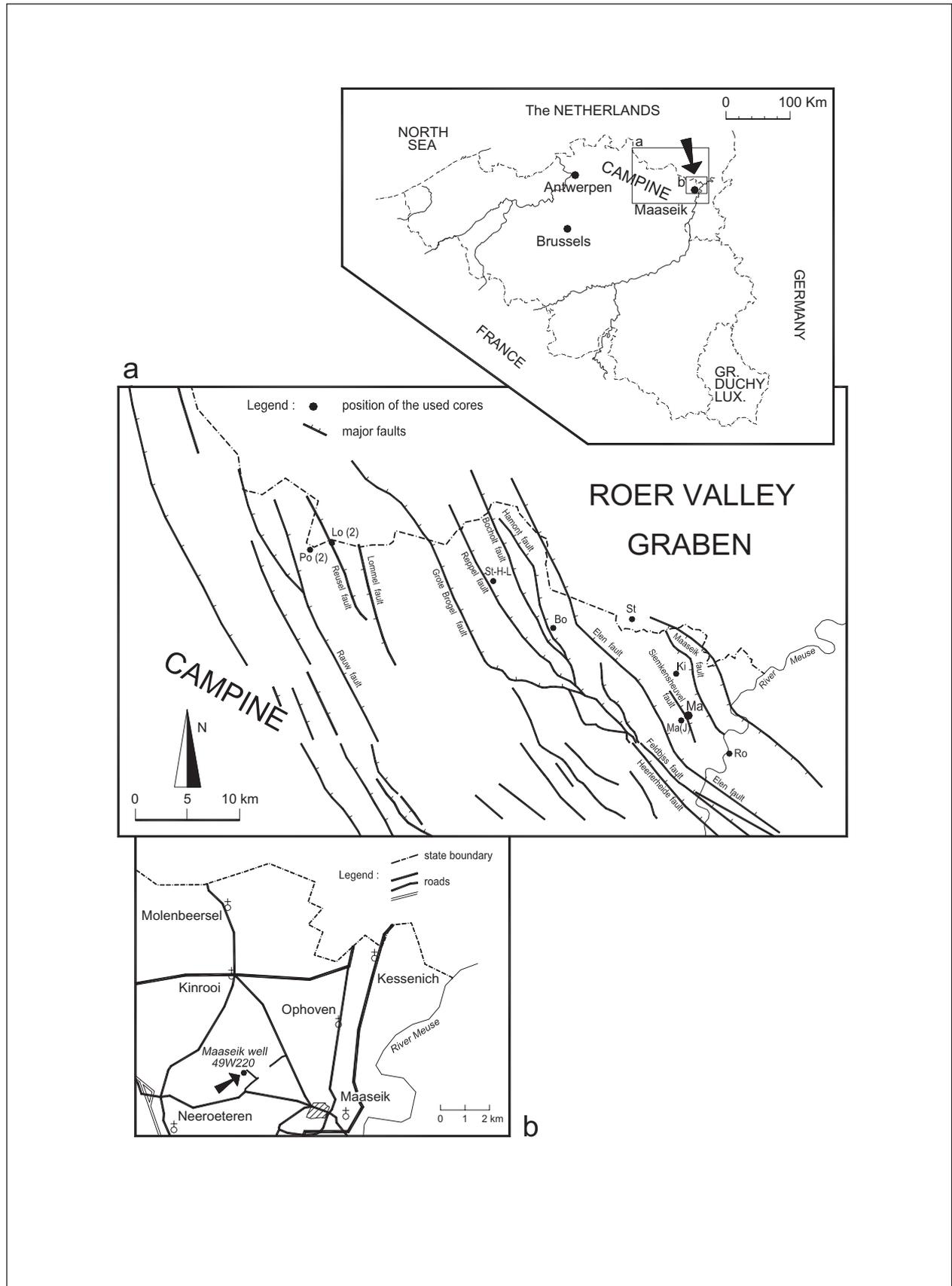
Figure 1. Situation of the Maaseik well (Ma / 49W0220) in northeast Belgium on a regional fault map. All boreholes indicated on the map have been been stratigraphically interpreted and correlated in Figure 10. The faults and their nomenclature have been taken from Gullentops and Vandenberghe (1995), Langenaeker (2000) and Van der Sluys (2000).

Figure 2. Geophysical well logs and synthesis of the stratigraphic results of the Maaseik borehole (49W0220), based on core description, geophysical well logs, sediment analysis and biostratigraphy (palynology, dinoflagellates, molluscs, ostracodes and benthic foraminifera). The stratigraphic interpretations are discussed in the text.

The cores have been described by Vandenberghe, Laga and Vandormael already in 1981 and their full detailed description is kept in the files of the Geological Survey of Belgium by the number 49W0220 (VIII, b). The borehole description is on-line available via the subsurface borehole database of the Flemish Ministry http://dov.vlaanderen.be. A synthetic overview litholog is represented in Fig. 2.

Hammenecker (1980) initiated a regional study of Plio-Pleistocene of the area and Van der Sluys (2000) reviewed the borehole data in the Belgian part of the Rur Valley Graben. The detailed stratigraphy of the borehole Maaseik 49W0220, penetrating through the Pleistocene into the Neogene, however has not been published. Since the cores became available for further research, several paleontological analyses have been carried out and as the Maaseik borehole is one of the few cored wells north of the Feldbiss fault system in Belgium, its stratigraphy can contribute in linking the Belgian and the Dutch traditions in stratigraphic nomenclature (see also Sels et al., 2001).

As the lithological column can be subdivided in Meuse sediments at the top (0-22 m), a quartz dominated sand complex below (22-198 m) and a glauconitic green sand at the bottom (198-302 m), and as the biostratigraphic techniques for the study of the quartz sands and the glauconitic sands are different, the paper is subdivided according to these three lithological types.

1. Pleistocene loam and Meuse gravel (0 – 22 m)

The uppermost 6 m consists of loam. In the area it is known as a usually thinly laminated loam of fluvio-lacustrine to lacustro-eolian origin, the Molenbeersel Member (Kinrooi Formation), of Pleni-Weichselian age. Below the loam occur, till 22 m, Meuse river gravels with loam and carbonate at their base. The higher gamma ray signals (Fig. 2) probably represent clayey intervals. The gravels belong to the Lanklaar Formation and are Saalian and Pleni-Weichselian in age. The lithostratigraphic nomenclature system used here has been developed during the Quaternary mapping organized by the Flemish Ministry (see Beerten et al., 2000).

2. The complex of quartz-rich sands, clays and brown coal (22 – 198 m)

2.1. Lithological description

The 22-50.5 m interval can be individualised on the geophysical logs and it is composed dominantly of a fine-grained to medium-sized sand. The dominant structure in the sand is a horizontal lamination but also oblique stratification and clay drapes over sand ripples occur. Typical mm laminated clays alternate with cm

scale sand laminae between 45 and 46 m. Some levels are coarse grained. Several erosional surfaces interrupt the sedimentation and lignite and clay fragments occur as eroded lumps in the sediment. Small synsedimentary deformational features occur. Clay laminae of over 10 cm thickness occur and some levels have a characteristic gamma ray log clay response (Fig. 2). Clays can be pale grey, pale greenish or black with admixture of plant remains. Sediment transport sometimes concentrated mica flakes. The sand is often purple stained because of the admixture of plant remains. At 34.8 m even a black gyttja type mud occurs.

In the interval between 35.45 m and 37.65 m metallic spherules with diameters between 50 μm and 1700 μm were detected. Mineralogical and chemical analysis in several laboratories concluded that the magnetite spherules are artificial and probably produced by a welding-arc at the well site (see De Geyter, 1989).

Between 50.5 m and 52.5 m grey and bluish clay occurs with some thin lignitic layers. The clay is underlain, between 52.5 m and 56 m, by a thick brown coal layer (lignite 1 on Fig. 2). Wood fragments can still be recognised in this brown coal layer.

The interval between 56 m and 62 m consists of similar grey sands as occur above the overlying clay and brown coal layer. Also the resistivity logs, pointing to permeable sands, and the low gamma-ray log are similar to the sands higher up in the borehole (Fig. 2). Some sands in this interval are laminated and some show the prominent presence of eroded lumps.

The 62 m – 76 m interval consists of less permeable sands, as indicated by the similar resistivity values measured by long- and short-spaced electrodes. This interval is characterised by the systematic presence of thin clay layers of 5 to 10 cm thickness. The clays are coloured green, pale brown and black. The black colour points to the presence of vegetal organic matter and within this interval, at 71 m depth, a 40 cm thick brown coal layer occurs (lignite 2 on Fig. 2). Several erosional surfaces occur and clays are sometimes ripped up into clasts, apparently by strong current activity.

Between 76 m and 88 m clay layers, black clayey brown coal and black gyttja type muds are dominating the lithology. Also some thin sand layers occur and silt layers are present within the clays. This alternation of lithologies explains the rapid changes in the spontaneous potential, the resistivity, caliper and gamma-ray logs (Fig. 2). The two brown coals at the base of this interval are labelled as lignite 3 on Fig. 2.

Geophysical well logs show a permeable sand unit between 88 m and 125 m. The sediment contains milky quartz grains, small transported lignite fragments, thin
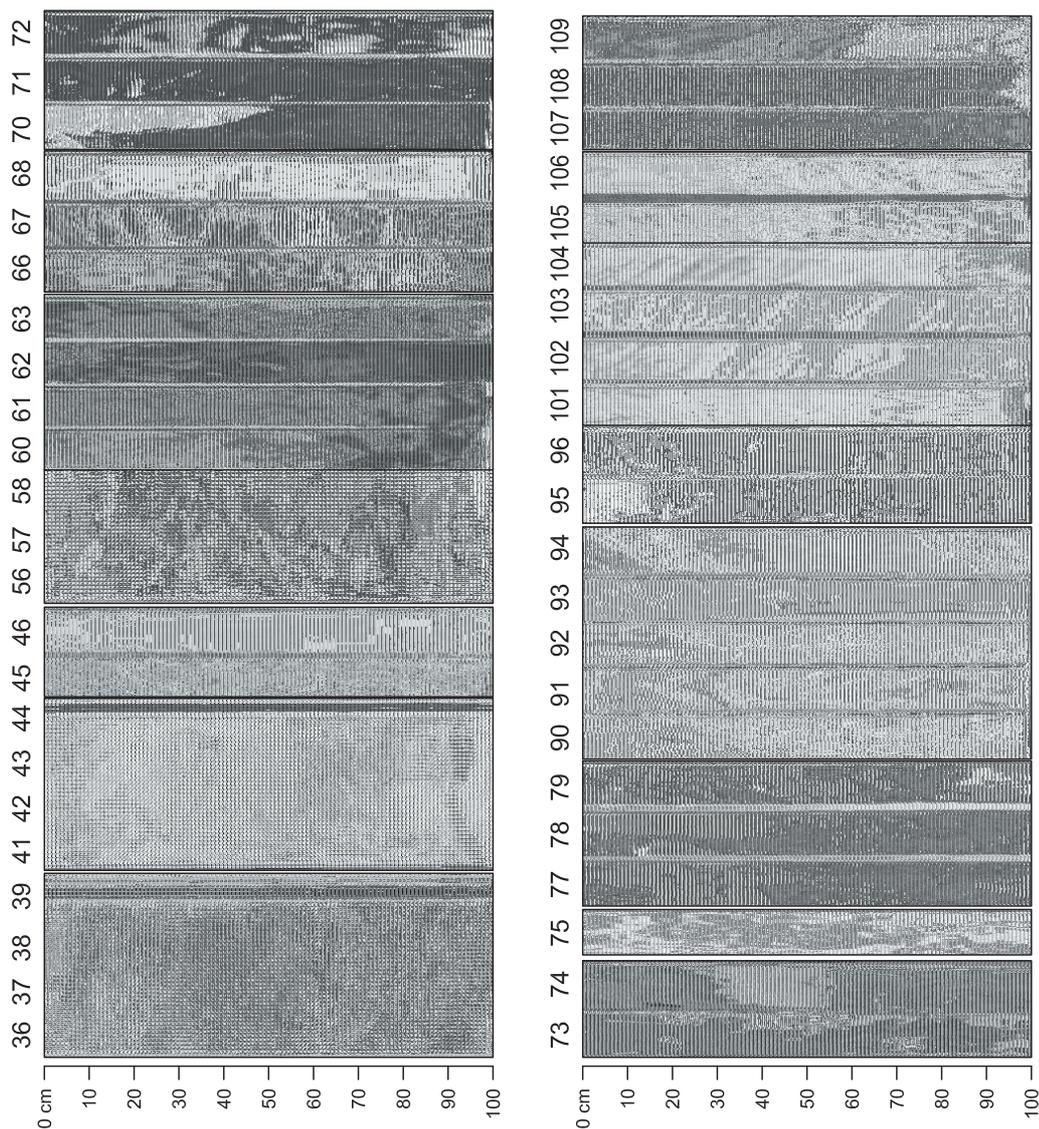
Photo plate 1

Illustration of the sedimentary structures in a selection of cores of the lithologically most variable upper part of the Kieseloolith Formation between 36 and 109 m depth. The number above each core is the depth of the top of the core below surface. The detailed stratigraphic position of each core can be found on Figure 2. Different forms of lamination, erosive contacts and eroded clay parts, alternations between clay, sand and lignite are shown. For details the reader is referred to the original description of the cores kept in the files of the Geological Survey of Belgium.
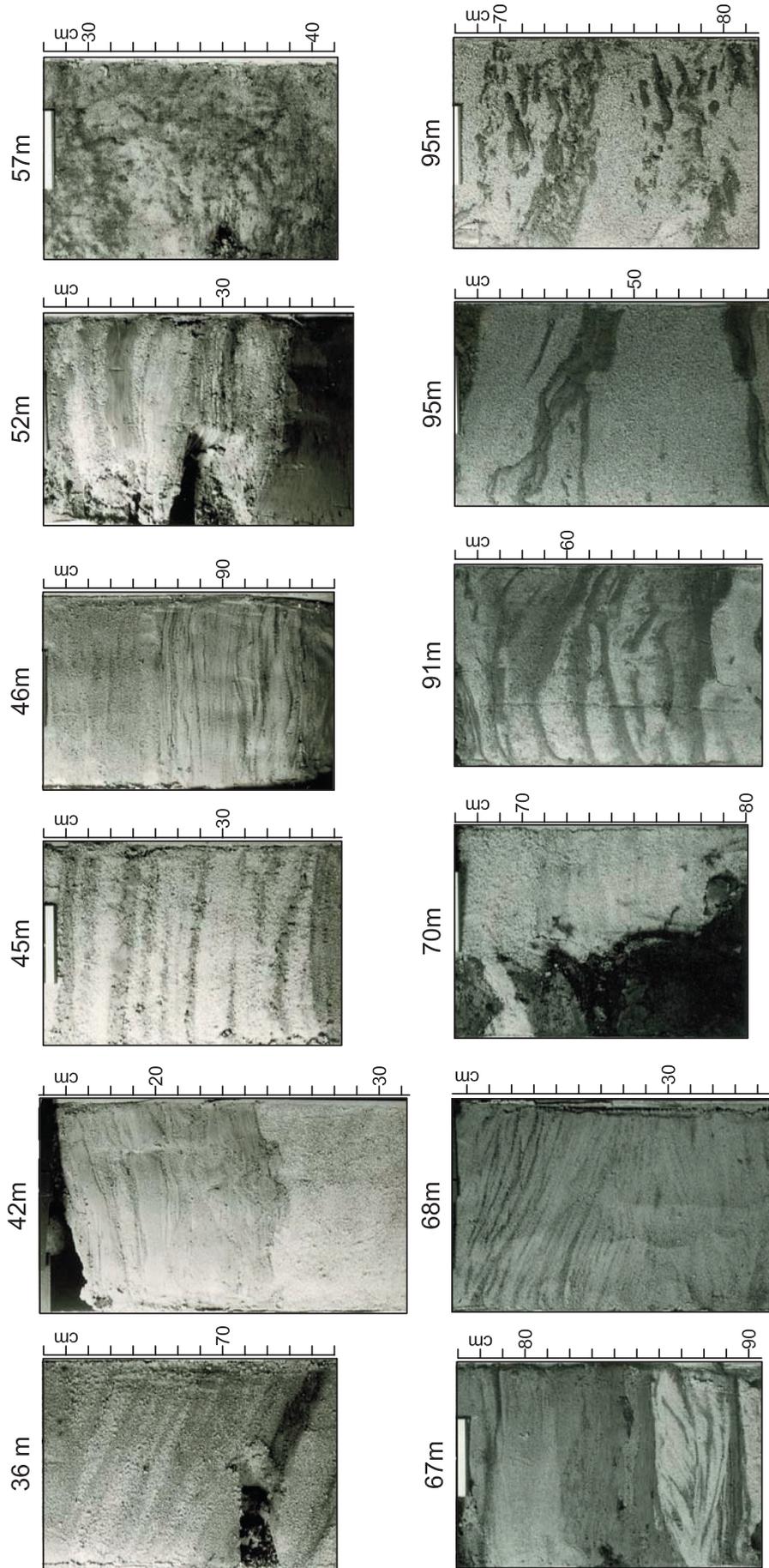
Photo plate 2

Details from the cores in Photo plate 1, displaying different types of horizontal and oblique types of laminations, alternations between clay and sand, erosive contacts and clay pellets derived from disrupted clay laminae. The number above each core is the depth of the top of the core below surface and the cm scale along each core identifies the exact depth of each core fragment shown. The detailed stratigraphic position of each core can be found on Figure 2.

clay laminae, ripped up clay fragments, and concentration of mica flakes in thin laminae. The sands are often purple stained by colloidal organic matter. Lignitic fragments are sometimes washed together in thin laminae; larger lignitic fragments show bio-perforations and several lignite fragments contain pyrite. At 116 m depth a clay horizon occurs. The sand between 88 m and 116 m can be subdivided in two fining upwards cycles which have at about 103 m and 117 m a coarse basal level (Fig. 2, see resistivity log and litholog). Both cycles end in clay and lignite at their top.

Below the clay horizon at 116 m, the sand unit, which extends till 125 m depth, is more homogeneous and has typical low gamma ray intensities compared to higher readings above 116 m. Some of the more variable lithologies above 116 m are shown in two photoplates (Plate 1, 2).

Between 125 m and 127 m a clay and brown coal layer occurs, indicated as lignite 4 on Fig. 2.

The 127 m to 193 m interval consists of pale to whitish grey sands. The top part, down to 148 m is medium grained and very permeable; based on the log data a further subdivision can be made at about 138 m, with a lower part being more clay rich and less permeable. Below 148 m the sand is coarse and even contains gravel, especially between 156 m and 170 m. Several, meter-scale, fining-upward cycles can be distinguished. Many thin clay laminae exist in the sand, often ripped up into clasts. Colloidal organic matter has stained the sand purple. Many lignite fragments occur in the sand, especially in the coarser horizons; also clay fragments occur in the coarse sands. For this reason, the coarse level at 165 m – 166 m appears rather as a more clayey interval on the resistivity and gamma ray logs.

In the relatively coarse sands below 166 m, the change in the patterns of the resistivity and spontaneous-potential logs, without a noticeable change in the accompanying gamma-ray pattern, could suggest a more saline groundwater; however this geophysical log pattern is generally observed in neighbouring water wells without any indication of increasing salinities in the producing water (Van der Sluys, oral.com). Small quantities of glauconite grains or other particularities in the mineralogical composition of the sand could have a similar effect. A few thin clay horizons occur at the base of the interval around 190 m.

The interval between 192.70 m and 198 m is an intermediate to fine pale yellowish grey sand; a modal size between 128 and 174 μm is measured on three samples. It contains small glauconite grains (1.7 to 3.5 % glauconite measured in three samples). The sand is rich in mica flakes, also expressed by the high gamma ray signal. The sand is faintly laminated and contains towards the base greenish clay, peat fragments, some small gravels and a 3 cm large pebble.

2.2. The depositional environment

The mica-rich sediments between 198 and 193 m are interpreted as undeep marine sediments, seen their fine homogeneous nature, the presence of some glauconite grains and also their dinoflagellate content (see further). Between the underlying green sand with abundant glauconite grains and marine molluscs, a continental phase must have occurred as shown by the peat fragments at the base of the unit.

The overlying coarse sediments between 193 and 148 m are interpreted as riverplain deposits. The coarse levels and rip-up clasts represent the stream channel deposits whilst the more clayey and sometimes humic horizons represent floodplain deposits. From the relative proportion of both lithologies, it can be concluded that the landscape was dominated at that time by a high sand load braided river system and some swampy areas in which humic clays were deposited. The repetition of several meter-scale fining-up cycles suggests that the channels were laterally shifting, turning into swampy lakes or ponds when abandoned.

From 148 to 116 m the quartz sands are rather homogeneous compared to the underlying and overlying sands and between 138 and 116 m the sands are characterized by a distinctive low gamma ray signal. The landscape was still dominated by sandy plains but the draining waters had lower energy than before. At 125-127 m the landscape had turned into a swampy vegetated area for a short time (lignite 4).

Coarser river sands are appearing again during a short time at 116 and 106 m, to fine up and fill in the river plain with sand and evolving at the top in a swamp with abundant vegetation. Vegetation must have been fairly widespread seen the many lignitic fragments dispersed in the sand. At the top of the second cycle the swampy vegetation conditions stay for a longer period, from 88 to 76 m (lignite 3).

From that time on, swampy conditions with abundant vegetation dominated the landscape as shown by the regular occurrence of black clay and lignitic layers between 76 and 20 m. Twice, an extensive lignite (lignites 1 & 2) has developed. However a finely laminated clay sand facies, pointing to tidal influences indicates that the sea shore was not very far northwards of the area. Also river channels were crossing the area as indicated by the many erosional surfaces and eroded clasts.

2.3. The lithostratigraphy

The stratigraphic significance of the 193-198 m marine interval is not clear. The unit is not formally named in the area.

In the tradition of the lithostratigraphy in the Rur Valley Graben, the continental quartz sands with a mixture of river, swamp and coastal plain facies and the occurrence of lignite layers between 22 and 193 m belong to the Kieseloolith Formation (Westerhoff et al., 2003).

MAASEIK BOREHOLE 220 (part 1)
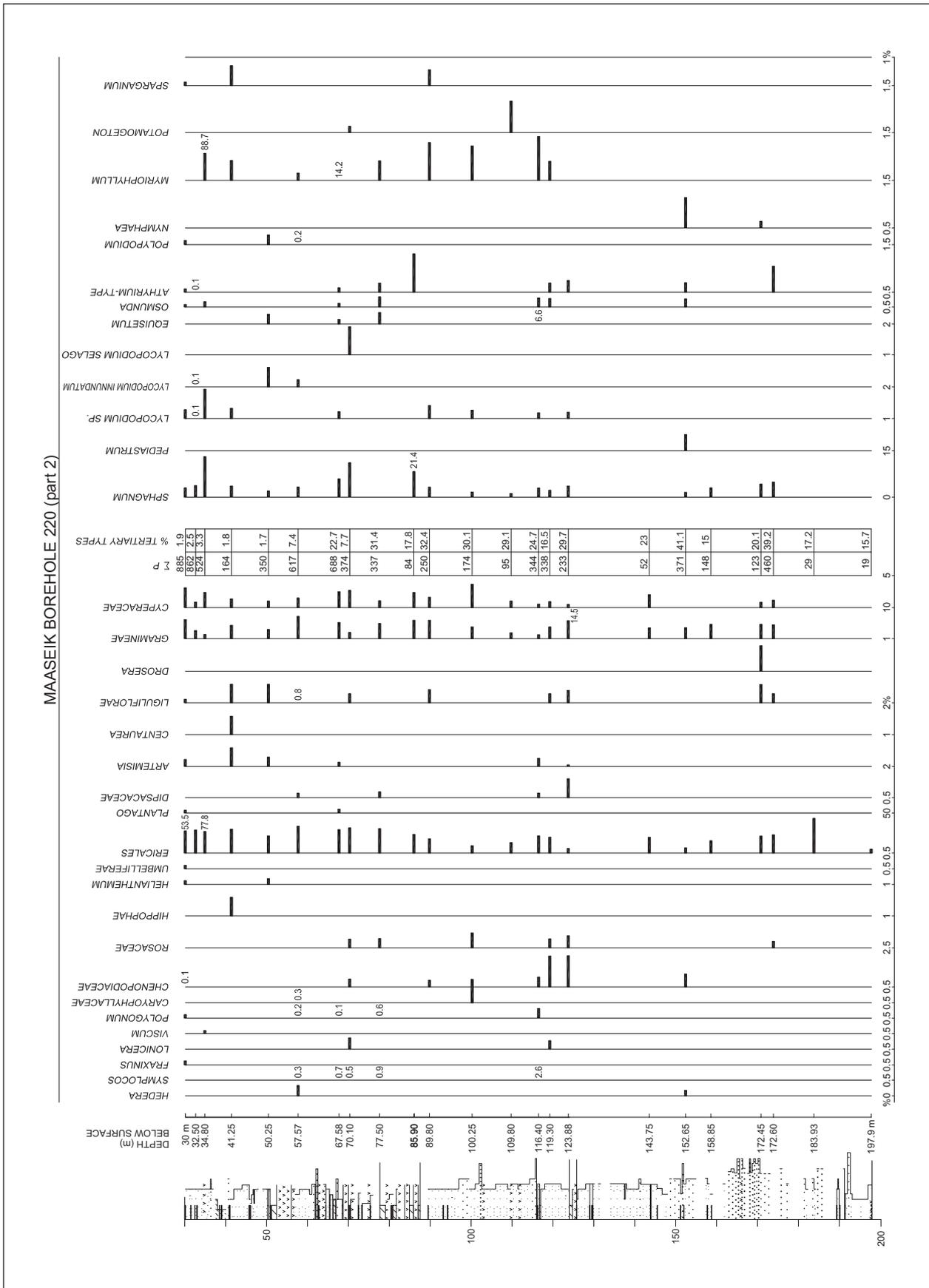
Figure 3. Diagram of the palynological counts (parts 1 & 2) in the section between 30 and 197.9 m. The lithological column and its legend are the same as in Fig.2.

Within this formation several members can be distinguished. The lower coarse gravelly river-facies sands between 193 and 148 m represent the Waubach Member, oldest member of the Kieseloolith Formation (Westerhoff et al., op.cit.). On the 1:50.000 geological map Maaseik, based on the geophysical well log pattern and the correlation with neighbouring wells, Sels et al. (2001, fig. 11 and geological map profile 3) erroneously interpreted the 168 to 193 m section as Kasterlee Sand, a marine sand of earliest Pliocene (Laga et al., 2001).

In the Dutch southern Limburg and the southern part of the Rur Valley Graben, the Brunssum Clay Member occurs above the fluviatile Waubach Member. It has a maximum thickness of some tens of meter (Westerhoff et al., op.cit.). A lithologically similar clay overlies the Brunssum Clay, namely the Reuver Clay occurring in the top of the Kieseloolith Formation and deposited in alluvial plains near the coast; Reuver clay is generally thinner than 10 m thick (Westerhoff et al., op.cit.). Based on lithology alone, it is not possible to precisely differentiate between both clay members. However, as tidal influences are observed towards the top of the section in the Maaseik well, it is expected that the upper clays could belong to the Reuver Member. The lower boundary can not be precisely determined.

In the practice of well descriptions in the southern part of the Rur Valley Graben, a coarse permeable sand between two lignitic clay layers is described and mapped as Pey Sands and the boundary lignitic clays are described as lower and upper Brunssum clay (see Zagwijn and van Staalduinen 1975, fig. 2.1.47; van Adrichem Bogaert & Kouwe 1993, section I, p.33). Although these subdivisions are not precisely defined, the sands between lignite 3 and lignite 4 fit the description of the Pey Sand and therefore lignites 3 and 4 are described as Brunssum I and II clays in the Maaseik well (Fig. 2). Lithologically, the sand below lignite 4 till 148 m, ressembles more the Pey Sand than the Waubach Sand. This regional practice of lithostratigraphic interpretation has also been systematically applied by Van der Sluys (2000).

In the Dutch stratigraphic practice the sands above the Brunssum Clay are called the Schinveld Sands. Vanhoorne et al. (1999) have proposed for the white quartz sands under the Meuse gravel deposits in the area, the name Jagersborg Sand, which they consider as a member of the Mol Formation in the Kieseloolith Group. Unfortunately the base of the Jagersborg Sand was not formally defined. Sels et al. (2001) and Laga et al. (2001, p.146) continue to rank the Kieseloolith as a formation.

2.4. Geophysical log characterisation of the units and their correlation in the area.

This lithostratigraphic interpretation of the Maaseik well leads to a consistent stratigraphic frame in the area, straddling the Dutch-Belgian border (Fig. 10). In figure 10, the lithostratigraphic interpretations are based on geophysical log correlations and calibration of the log signatures with the cored and analysed wells of Maaseik (49W-220) (this paper) and Bocholt (33W-153) (Van der Sluys, 2000), the 1:50.000 Flemish Geological maps of the area and information from NITG-TNO for the Dutch boreholes (Westerhoff, oral com.). The Sterksel Fm (see Gullentops et al., 2001) is characterised by a high gamma-ray signal, the Stramproy Formation (including the former Kedichem) (Westerhoff et al., 2003, p.343-344) by a very low gamma-ray signal, and the Kieseloolith Formation shows characteristic log signatures for its different members; the Jagersborg/Shinveld sands with clay and lignitic horizons have an irregular but relatively high gamma-ray signal with moderate separation between the resistivity logs with different-spacing, the Brunssum clay packages have peak gamma-ray values and the Pey (between Brunssum packages) and Waubach (below lowest Brunssum clay) sands have a more regular gamma-ray signal and a high separation between the resistivity logs with different-spacing. High gamma-ray values in the Jagersborg/Shinveld sands could point to Reuver clays (Westerhoff et al., 2003, p.319). The unit X is the pale yellowish mica rich marine sand between 193 and 198 m in the Maaseik well and characterized by a markedly higher gamma-ray signal. The Breda Formation is characterised by green glauconitic sands and a very low resistivity signal.

2.5. Palynological investigations

2.5.1. The samples and the pollendiagram

In the lignitic seams of the uppermost 200 m fifty samples were taken for palynological investigation, thirty-one of which yielded a reliable pollen assemblage. The chemical treatment of the samples consists of boiling in 10% KOH aqueous solution followed by acetolysis. The results are represented in Fig. 3 and Fig. 4. The taxa percentages are based on a sum containing the pollen grains of trees, shrubs and herbaceous plants except waterplants and spores. The number of pollen grains counted and the percentages of the Tertiary types are arranged in two columns in the middle of the diagram in Fig. 3, separating the summed pollen and the taxa excluded from the sum to the right. The Tertiary types comprise *Tsuga, Sequoia, Taxodium, Sciadopitys, Cupressaceae, Podocarpus, Pterocarya, Juglans, Carya, Ostrya, Castanea, Eucomnia, Liquidamba, Nyssa, Cyrillaceae* and *Symplocos* (Zagwijn, 1960). In Fig. 4 the relative importance of these Tertiary types is indicated with respect to the total vegetation cover unveiled by pollen analysis.

2.5.2. The description of the diagram

The pollen diagram in Figs. 3 & 4 shows a predominance of arboreal pollen (A.P.) except at depths of 85.90 m and 70.10 m as well as at the levels 34.80 m, 32.50 m, 30.00 m where the non arboreal pollen (N.A.P.) are dominant.
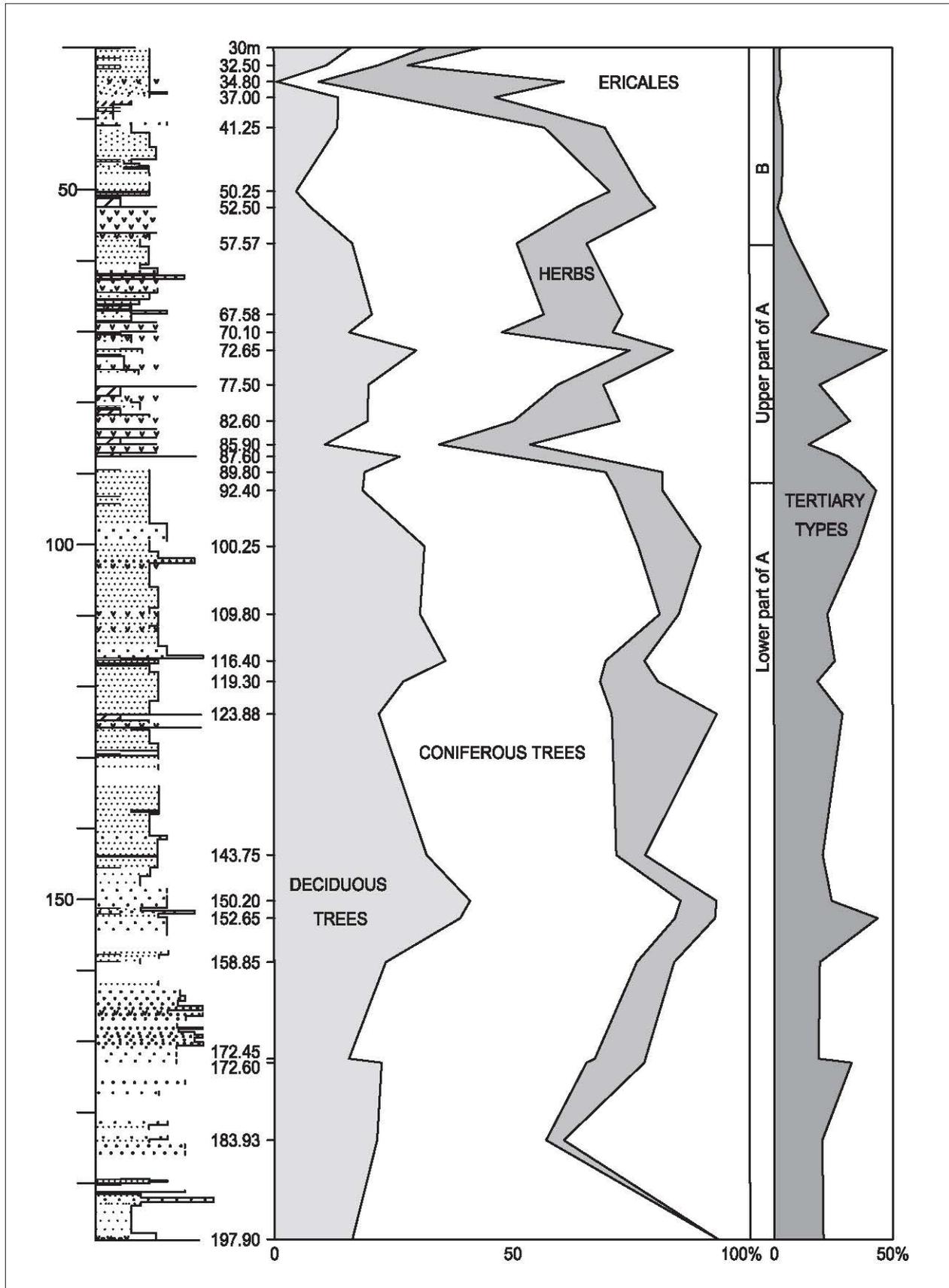
Figure 4. The relative importance of deciduous and coniferous trees, herbs, Ericales and Tertiary types in the section between 30 and 197.9 m. The subdivision in palynozone A, lower and upper part, and B is discussed in the text.The lithological column and its legend are the same as in Fig.2.

The coniferous pollen constitutes the most important component of the A.P. group except at 87.60 m and the levels 32.50 m (only represented in Fig. 4) and 30.00 m where Angiosperm tree pollen are slightly more numerous.

Pinus is the most abundant tree taxon, even at those depths where the Angiosperm trees exceed the Gymnosperm trees, namely 30.00 m and 116.40 m (only represented in Fig. 4). This taxon comprises three differ-

ent species (Fig. 3): *Pinus diploxylon* (*sylvestris*-type) with pollen grains of 60-80 μm total length, *Pinus diploxylon* displaying a total length varying between 80 and 100 μm and a pollen structure at the limit of the *diploxylon* and the *haploxylon* type, and finely the scarcely represented *Pinus haploxylon* where the sacci are attached to the corpus of the pollen grain along a straight line and have the same height as the corpus. Scoring best after *Pinus*, are *Sequoia* and *Cupressaceae* which are especially well represented in the lowermost part of the diagram (Fig. 3).

Pollen of other coniferous trees such as *Abies*, *Tsuga*, *Picea*, *Taxodium*, *Sciadopitys*, *Podocarpus* and *Taxus* are scarce; their frequencies remain below 4%.

Concerning the Angiosperm trees, *Alnus* pollen is an important component of the pollen rain especially between 109.80 m and 158.85 m. Also *Nyssa* is regularly present in the lower part of the diagram (Fig. 3) reaching even more than 15% at 152.65 m depth.

The pollen of other Angiosperm trees, including *Juglans*, *Salix*, *Betula*, *Carpinus*, *Ostrya*, *Fagus*, *Castanea*, *Quercus*, *Ulmus*, *Eucommia*, *Liquidambar*, *Acer*, *Ilex*, *Cornaceae*, *Cyrillaceae* and *Fraxinus* occur in minor quantities.

At 150.20 m (Fig. 4) four pollen grains of *Mastixia* are identified, with a diameter of 31 to 41 μm (type 1 in Fig. 5), while at 183.93 m and 197.90 m one pollen grain of the same genus with a diameter of 45 to 58 μm is found (type 2 in Fig. 5). The pollen spectrum at 150.20 m is not represented in Figure 3. Both types are tricolporate with a perforated tectum and clearly discernible baculae in the ektexine. Endexine and ektexine have about the same thickness. The amb is triangular with slightly convex sides. Each of the long, tapering colpi is bordered by thinnings in the endexine, running parallel to the colpi (Fig. 5). The genus *Mastixia* is abundantly represented in Miocene deposits but is also recorded in small amounts in the Pliocene. This is also the case for *Symplocos* which occurs at 70.10 m depth (Mai, 1995).

The N.A.P. are dominant at the depths of 85.90 m and 70.10 m but especially at the top levels of the diagram in Fig. 3. This pollen group is mainly composed of representatives of *Ericales* except at 123.88 m where herbs, mainly composed of grasses exceed the *Ericales* (Fig. 4). At the top of the diagram, the *Ericales* display high percentages, attaining at two levels more than 70% (Fig. 4). Spores of *Sphagnum* continuously accompany the tetrads of *Ericales* but they are less numerous with maximal percentages of more than 20% at 34.80 m and 85.90 m.

2.5.3. The botanical interpretation

Based on the frequency of the *Ericales*, but especially of the Tertiary types, the pollen diagram can be subdivided into two parts, the limit lying probably just above 57.57 m. In the lower part, called palynozone A, the A.P.-group

Figure 5. Photographs of pollen grains of Mastixia (type 1 & 2). **1a & 1b:** Pollen grain in oblique polar view of Mastixia (Type 1) from depth 150.20 m. Note the endexine thinnings, indicated in 1a by arrows in 1a and the perforate tectum and baculae in 1b. **2a & 2b:** Pollen grain in oblique equatorial view of Mastixia (type 1) from depth 150.20 m. Note the perforate tectum in 2a and the tapering colpi in 2b. **3a, 3b & 3c:** Pollen grains in oblique equatorial view of Mastixia (type 2) from depth 183.93 m. Note the perforate tectum in 3a, the endexine thinnings indicated by an arrow in 3b, the baculae in 3b and the tapering colpi in 3c. **4:** Pollen grain in slightly oblique polar view of Mastixia (type 2) from depth 197.90 m. Note the perforate tectum, the baculae and the rounded triangular amb.

dominates and the Tertiary types are abundantly represented; in the upper part, called palynozone B the N.A.P. group dominates in the upper levels and the Tertiary types undergo a substantial decrease. This subdivision may not be confused with that of Zagwijn, who subdivided the Reuverian into three stages A, B and C (Zagwijn, 1960, fig 5).

The pollen assemblages of the lower palynozone A reflect a mixed, mesophytic forest dominated by coniferous trees, especially *Pinus*. The accompanying *Ericales* tetrads may derive from the undergrowth of the forest, established on the quartz-rich upland or from enclosed oligotrophic mires without or with scattered trees.

The upper palynozone B is characterized by a decrease towards the top of the A.P. percentages and by high frequencies of the N.A.P., of which the great majority is composed of *Ericales*. *Pinus* remains the dominant tree and the thermophilous trees such as *Carpinus*, *Quercus*, *Ulmus* as well as the Tertiary elements including *Tsuga*, *Podocarpus*, *Cupressaceae*, *Pterocarya*, *Carya* and *Ostrya* are still present but in smaller quantities than in the underlying palynozone A. However, the Tertiary types including *Sequoia*, *Sciadopitys*, *Taxodium*, *Nyssa* and *Symplocos* are lacking from 50.25 m till the top of the section.

As the analysed samples are taken in peat layers, the *Ericales* may originate to a large extend from oligotrophic mires in which they throve. On the other hand the presence of thermophilous and some Tertiary types trees which do not grow in such oligotrophic marshes, suggests that the surrounding mineral soils were covered by trees. In order to check if high percentages of *Ericales* in a pollen spectrum are not only owing to a deterioration of the climate, but can also be found in a wooded area with enclosed oligotrophic mires, a comparison is made with the pollen analytical results of peat samples collected in a comparable landscape. For comparison, a Holocene peat deposit is chosen from the coastal plain which developed along the NW European coast from Calais in NW France to Denmark. Along the Belgian coast, this peat was growing between the North Sea and the densely wooded, contiguous, sandy upland from Late Atlantic to Subatlantic times. At some places the peat evolved into a raised bog where the *Ericales* were abundant as demonstrated by the twigs and seeds of *Ericales* in the peat. Published pollen diagrams (Stockmans & Vanhoorne, 1954) cannot be used as such and percentage recalculations have to be made in order to obtain comparable pollen diagrams as used in the present study. Recalculated pollen spectra could be obtained at distances of 7.6 km, 4 km, 3.7 km and 2.3 km from the limit of the wooded upland, and maximal *Ericales* values at these distances are respectively 58%, 54%, 37% and 35%. These percentages, decreasing when approaching the wooded upland, are lower than in the palynozone B in the Maaseik borehole but some exceed the A.P. values. These pollen data indicate that in a wooded area with

contiguous oligotrophic mires, *Ericales* may attain in the peat samples from the mires high percentages exceeding even the A.P. values and may vary as a function of the distance to the wooded upland.

For the two palynozones in the Maaseik borehole it can be concluded that in the upper B zone a wooded landscape existed enclosing oligotrophic mires and that, compared to the older zone A, the forest was less dense and the enclosed mires more extensive.

In the Maaseik section the clearance of the woods had already started as is documented by the presence of two light demanding plants growing on mineral soils: the continuous curve of *Artemisia* from 50.25 m to the top of the section and the appearance of *Plantago* at the very top level of the pollen diagram.

2.5.4. Palyno-stratigraphic interpretation

The tree pollen in the diagram originating from exotic taxa, belong to East Asian genera including *Sciadopitys* and *Eucommia*, to North American genera including *Sequoia* and *Taxodium* and to genera occurring in both regions including *Tsuga*, *Carya* and *Nyssa*. Their coexistence with genera extant in Europe including *Pinus*, *Salix*, *Alnus*, *Betula*, *Carpinus*, *Corylus*, *Fagus*, *Quercus*, *Acer* and *Fraxinus* pleads for a Pliocene age of the deposit. This conclusion is not contended by the occurrence of *Symplocos* and *Mastixia*, appearing a few times in small quantities, as these genera which are abundantly represented in Miocene deposits, are regularly recorded in the Pliocene. The lack of *Tricolporopollenites villensis*, *Tricolpopollinites microhenrici* and *liblarensis*, which are abundantly represented in Miocene deposits, could confirm the Pliocene age.

The palynozone A is characterised by a dominance of tree pollen among which the Tertiary types play an important role. From the A.P. / N.A.P. ratio it may be concluded that the landscape at that time was covered by a dense, mixed, mesophytic forest dominated by coniferous trees, especially *Pinus*. The regular trend of the tree pollen curves shows no major change in the composition and therefore hardly allows any subdivision of the palynozone A. If however the moderate but clear increase of *Sequoia* observed below 87.5 m depth would correspond to the high *Sequoia* values considered by Zagwijn (1960) as characteristic for the Brunssumian, the lower part of the palynozone A could correspond to this stage; if not, the whole palynozone A would correspond to the Reuverian, a possibility supported by the rarity of *Symplocos* and *Mastixia* which occur regularly in the Brunssumian pollen assemblages, as well as by the lack of *Tricolpopollenites liblarensis*, which can attain up to 13% in the Dutch Brunssumian.

The upper part of the palynozone A above 87.5 m resembles fairly well the pollen spectra of the borings 49W0206 and 49W0208 (files Geological Survey of Belgium) near

Depth (m)	Samples	H/C	O/C	N/C
52.5-52.9	95	1.10	0.34	11.02
52.9-53.5	96	1.05	0.34	9.72
53.5-53.9	97	1.13	0.30	9.07
53.9-54.5	98	1.24	0.36	8.49
54.5-55.0	99	1.12	0.39	7.54
55.0-56.0	100	1.16	0.33	7.45
56.0-57.0	101	1.13	0.39	6.57
68.7-69.0	102	1.11	0.27	12.61
69.0-69.4	103	1.16	0.30	11.19
70.2	104	1.27	0.49	1.06
70.8-71.0	105	1.08	0.35	9.43
81.0-81.6	106	1.35	0.50	10.78
82.7-82.8	107	1.09	0.32	7.90
84.1-84.6	108	1.06	0.20	7.58
85.9-86.0	109	1.13	0.33	8.09
86.0-87.0	110	1.31	0.38	7.26

Table 1. The values of the elemental ratios (H,C,O,N) in the lignite 1 (52.5-57.0 m), lignite 2 (68.7-71.0 m) and lignite 3 (81.0-87.0 m) (see also Fig. 6a).

Figure 6. (a) The elemental ratios H/C, O/C and N/C in samples of lignite 1, 2 and 3 (see Fig. 2). (b) Van Krevelen diagram of elemental ratios of H, C, O, showing the Maaseik brown coals intermediate between peat samples and brown coal from Lower Rhine exploitations (Hagemann, 1981).

Maaseik in the Rur Valley Graben and described by Vanhoorne (1979). At the top of borehole 0206 the first signs of climate cooling appear, suggesting that this top level may be considered as the onset of the palynozone B or of the Praetiglian. Outside the Rur Valley Graben to the west, lignite occurring in the Sands of Mol (Gulinck, 1963) also has pollen spectra comparable to the upper part of the palynozone A (Vanhoorne, 1973).

The upper levels of palynozone B are dominated by N.A.P. pollen, mostly consisting of *Ericales* while the lower levels of zone B display 50 % and less. In the A.P. group, *Pinus*, *Alnus* and *Betula* are best represented, while thermophilous trees and Tertiary types are still present but less than in palynozone A. The pollen assemblages evoke a less dense forest with enclosed oligotrophic mires. Notwithstanding the high amounts of NAP, especially at the top, the correlation of the palynozone B with the Late Pliocene or the Reuverian C in the Netherlands is preferred above the Praetiglian, because thermophilous trees and Tertiary types continuously occur and the *Ericales* are considered to originate for a great part from enclosed oligotrophic mires in the forest. Willis et al. (1999) have found a similar zone in an annually layered sequence of the Late Pliocene lake sediments from Pula maar in Central Hungary and considered it as transitional to the next glacial. This zone, characterized by the disappearance of subtropical taxa such as *Sequoia*, *Nyssa*, *Eucommia*, *Pterocarya* and *Sciadopitys* is dated from 2.721 to 2.676 Ma.

The regular occurrence of *Ilex*, *Myrica* and *Osmunda* suggests oceanic climatic conditions, while *Chenopodiaceae* may betray the proximity of the sea. Such conditions could be expected as to the west time-equivalent marine sediments are deposited during the later part of the Reuverian (Merksem Sands, Zandvliet Sands, Sands with *Corbula complanata* SOW., see also Vanhoorne, 1963; Buffel et al., 2001, Vandenberghe et al., 2000). Taking into account the environmental differences, the palynozones B and A seem to correspond reasonably well with the former marine regional stages, respectively the Merksemian and the Scaldisian, sensu de Heinzelin (1963).

2.6. Brown coal characterisation

In the depth ranges 52.5-57 m (lignite 1 on Fig. 2) , 68.7-71 m (lignite 2 on Fig. 2), and 81-87 m (lignite 3 on Fig. 2), 16 brown coal samples of about 50 cm length were taken amongst which 1 xylith sample. During subsampling care was taken to obtain representative samples for the analyses (Hagemann, 1981).

The water content of the samples, at the time of sampling the cores, varied between 29 and 59% whilst the saturation water content varied between 57 and 65%. These figures point to weakly evolved soft brown coal, similar to the Oberflöz–Group in the Lower Rhine brown coal exploitation area at Eschweiler (Kothen & Reichenbach, 1981). The ash content, based on water free coal samples, varied between 10 and 66 weight %. The xylith sample only has 3.1% ash content. These ash contents are generally higher than in the brown coal exploitation area of the Lower Rhine area.

The brown coals of the Maaseik borehole are weakly layered, pale to light coloured and preserving 10 to 35 volume % of plant remains. Generally the coals contain abundant mineral matter, xylith, fusain and resins.

The caloric value of the Maaseik brown coal varies between 8830 to 11.250 J/gr and therefore can be classified as soft brown coal (German rank) or lignite B (ASTM rank). An elemental analysis (Table 1 and Fig. 6a) plotted on a Van Krevelen diagram (Fig. 6b) shows the Maaseik brown coal to be intermediate between soft brown coal from Lower Rhine exploitations and peats.

3. The green glauconitic sands (198 – 302 m)

3.1. The lithological description

The sands below 198 m and till 302 m are generally fine-grained, glauconitic, bioturbated and often containing abundant shell debris, as described for the Breda Formation in this area (see also Westerhof et al., 2003, p.300-303).

Based on the core description, geophysical well-log characteristics, grain-size analysis and glauconite content, several subunits can be approximately delineated (Figs. 2 & 7).

Between 198 m and 225.5 m, the sands are slightly coarser than below. At the base of this unit a coarse level occurs, enriched in glauconite. This upper interval is also characterized by higher glauconite contents than below (Fig. 7). Within this interval, at about 212 m a further subdivision can be made with an uppermost part that is finer-grained, clay-richer, less glauconitic and containing abundant fine shell debris. The lower part has a very loose packing and at its base occur some carbonate-cemented layers. This further subdivision is also expressed on the gamma-ray log (Figs. 2 & 7).

The 225.5 m to 234 m interval contains slightly finer sand than above and is characterized by 5 to 10% clay fraction, as also expressed on the gamma-ray log. The glauconite content is relatively high and increases towards the top. Shell debris is present.

The 234 m to 240 m interval is characterized by a cycle of coarser sand, less than 5% clay fraction and relatively high glauconite contents (Fig. 7).

At about 249-250 m a change in grain-size properties and a glauconite-rich level subdivides a low-glauconite sand interval between 240 m and 261 m, in two parts. The interval between 240 and 248 m is enriched in mica.

The underlying interval between 261 m and 273 m is fine-grained and slightly richer in clay content than the under- and overlying intervals (Fig. 7) as also expressed on the gamma-ray and resistivity logs (Fig. 2).

In the lowest interval, between 288 m and the deepest level of the borehole, the sediment describes a coarser cycle and has relatively higher glauconite contents (Fig. 7).

The depositional environment for the whole Breda sand section in this well must have been marine seen the many marine fossils and the glauconite. Depositional depth was probably deeper than about 10 to 20 meter because of the abundance of glauconite. The two gravelly horizons at 236.9 and 240 m, the abundance of shells and shell debris in several levels, common traces of bioturbation, and also the presence of small wood fragments in several cores all point to a rather shallow depositional environment, situating the depositional depth around the minimal depth limit of 10-20 m given above.

3.2. Dinoflagellate analysis

3.2.1. Introduction

An analysis of marine organic-walled phytoplankton based on a low resolution sampling of the Breda Formation was carried out for the assessment of the stratigraphic position of the sequence and the establishment of its relationship to other Miocene deposits in contiguous areas. Sixteen samples (Tab. 2) were prepared using standard palynological maceration techniques involving demineralisation with HCl and HF. No oxidation or alkali treatments were applied in order to avoid damage (loss of pigment, thinning of cyst walls) and selective loss of species. A better dispersion of fine organic debris was obtained through a short ultrasound treatment for 15 s. A minimum of 250 marine palynomorphs was counted systematically in every sample. The rest of the slide was then scanned for rare specimens. A total of 100 *in situ* organic-walled marine palynomorphs, mainly dinoflagellate cysts and acritarchs, were recorded. Preservation of the palynomorphs is variable. The basal three samples (Tab. 2) yielded a poorly preserved assemblage of dinoflagellate cysts and abundant well preserved specimens
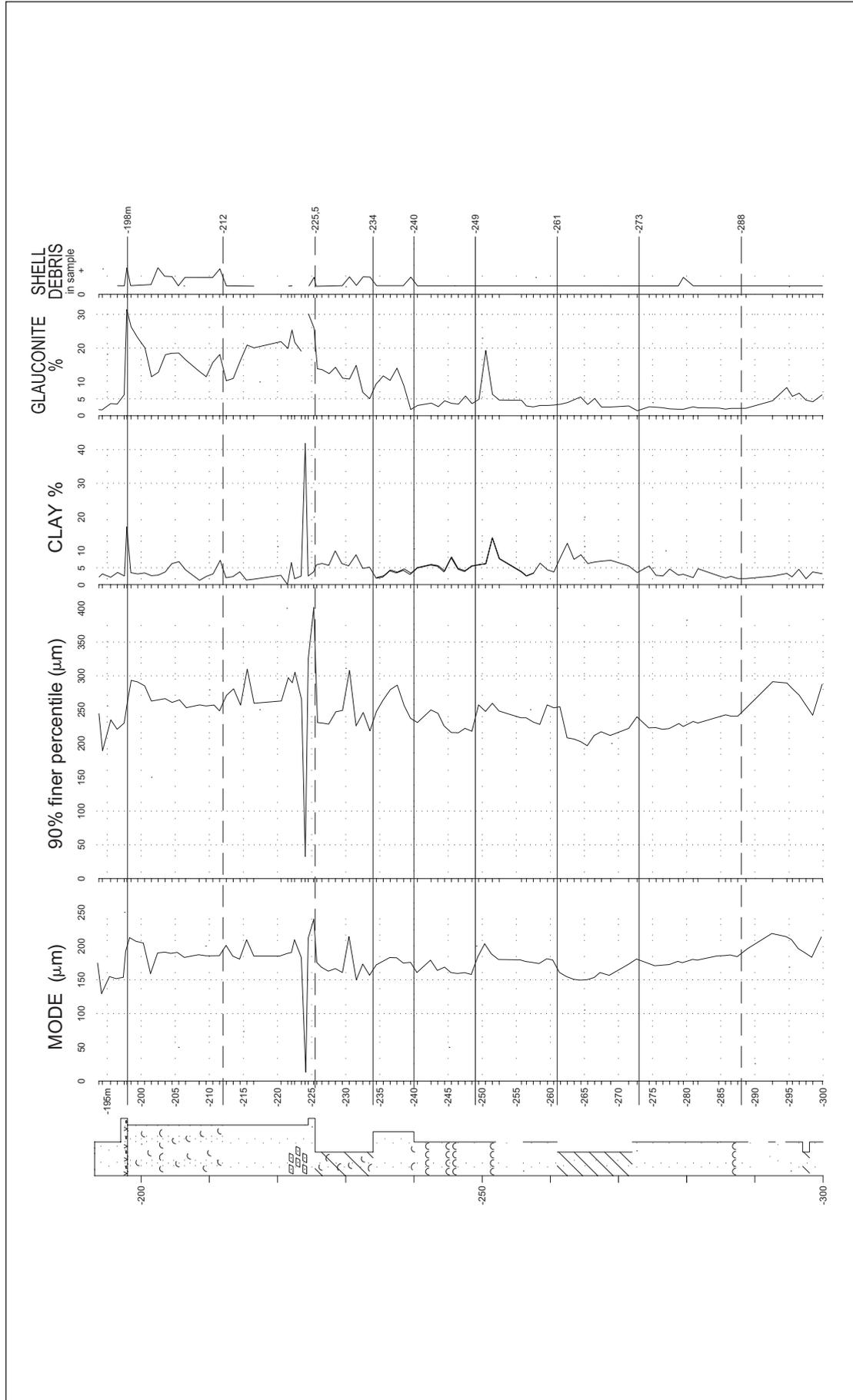
Figure7. Sediment analysis data: modal size, 90% percentile-finest, clay and glauconite content, shell fragments abundance, for the Breda Formation (198-300m) and the overlying unit X (192.7-198m) of possibly Sylt stratigraphic position. Size analysis is carried out by laser diffraction; clay content is therefore defined as < 8 μm, glauconite is separated by an electromagnet and shell debris content is estimated visually in the samples taken from the cores for sediment analysis. Depths are expressed in meters below surface. Sample positions are indicated by the short horizontal lines, left of the zero value line of each parameter. The subdivisions are discussed in the text and the legend of the lithological column is the same as in Fig.2.

Samples	-295.8	-292.4	-285.8	-279.9	-275.8	-270.9	-265.8	-256.3	-245.5	-234.5	-227.5	-220.5	-215.6	-210.8	-201.5	-191.5
Dinoflagellates (n=81)																
Bitectatodinium arborichiarum	1,2	1,1	19,3	9,0	21,3	7,9	3,8		<1	+	1,5	4,4	+	5,4	<1	<1
Dapsilidinium pseudocolligerum	+	+	2,7	<1	1,9		3,0	2,3	1,9	2,5	1,5	1,8	3,1	1,5	1,1	1,9
Labyrinthodinium truncatum truncatum	<1		1,9	1,5	<1	4,8	3,0	2,3	3,3	<1	1,1	1,5	<1		<1	<1
Lejeunecysta sp. 1 Louwye 2002	<1	+	<1	1,5	2,3	+	1,1	<1	1,5	+	+	+	<1	<1	1,5	<1
Lingulodinium machaerophorum machaerophorum	<1		4,9	1,9	2,3	3,1	<1	11,2	1,1	2,1	3,3	6,2	5,2	5,0	9,5	15,6
Operculodinium centrocarpum + O. israelianum	+	+	2,3	+	1,5		1,9	5,8	1,5	2,1	1,9	8,4	7,3	1,9	3,8	
Reticulosphaera actinocoronata	<1		<1		1,9	3,1	<1	<1	1,5	1,3	<1	2,6	2,1	1,2	<1	3,1
Round brown protoperidiniacean cysts	+	+	2,3	<1	1,1	8,8	<1	1,5	1,5	1,7	<1	<1	4,9	1,2	2,3	3,4
Spiniferites spp. / Achomosphaera spp.	3,7	2,2	28,0	6<1	34,6	25,1	63,5	55,6	65,9	21,4	23,4	43,1	29,7	46,2	56,5	37,0
Trinovantedinium spp. ind.	+				<1	+		+	<1						<1	<1
Operculodinium ? eirikianum			+	1,9			1,5	<1	<1	+	<1		<1	1,2	+	<1
Selenopemphix dionaeacysta			<1	<1		1,8		<1	+	+	<1	+	1,0	1,5	+	<1
Selenopemphix quanta			+											+		<1
Tectatodinium pellitum			<1	<1	<1		<1	<1	<1	+	+	<1	+	+	<1	<1
Trinovantedinium ferrugnomatum			<1	+			+			+	<1	+	1,4	5,0	<1	<1
Trinovantedinium variabile			<1		<1		+							<1	<1	<1
Hystrichosphaeropsis obscura								<1		<1	1,9	1,1	+	3,8		15,6
Melitasphaeridium choanophorum				1,5		1,8	1,5	<1	1,1	<1	1,1	1,8	1,0	+		<1
Achomosphaera andalousiensis andalousiensis							2,3		1,1	<1	<1			<1	<1	
Invertocysta lacrymosa													<1	<1		
Barssidinium graminosum													+	+	<1	
Bitectatodinium ? serratum								+					<1	<1	1,5	
Selenopemphix sp. 1 Head et al. 1989														+	+	
Operculodinium antwerpensis																
Lejeunecysta spp. ind.	+	+	3,8	<1		3,1	+		<1	<1	+	<1	+	+	<1	
Selenopemphix nephroides	+		<1	<1	<1	+	+	<1	+	+	+		+	+	+	
Selenopemphix brevispinosa		+	<1	<1		+	<1		<1	<1			+		1,1	
Hystrichokolpoma rigaudiae			<1					2,3	1,1	11,3	+	2,9	2,8	<1		
Barssidinium pliocenicum			<1	<1			<1	<1	<1	<1			1,0			
Habibacysta tectata			1,9	1,1	4,9	26,9	+	2,3	2,2	+	1,1	1,1	+	+	1,5	
Echinidinium euaxum				<1		1,3	+	+	+	+	+		<1	+	<1	
Trinovantedinium glorianum				<1			+	+	<1	<1	<1			+	<1	
Batiacasphaera spp.ind.					1,5	2,6	<1		1,1	<1				+		
Heteraulacacysta campanula							+		+						<1	
Operculodinium borgerholtense									<1				<1		<1	
Gramocysta verricula										42,9					1,1	
Pentadinium laticinctum laticinctum										<1	<1		<1		<1	
Pyxidinopsis tuberculata			1,9	<1					1,1	+	+			+	1,5	
Organic wall of calcareous cyst			1,9	<1						+	<1	<1		+	<1	
Amiculosphaera umbraculum										<1			<1	+	<1	<1
Ataxiodinium zevenboomii																<1
Batiacasphaera minuta			<1		2,3	+	<1	1,2	2,2	<1	<1	<1	+	3,1	<1	

Samples	-295.8	-292.4	-285.8	-279.9	-275.8	-270.9	-265.8	-256.3	-245.5	-234.5	-227.5	-220.5	-215.6	-210.8	-201.5	-191.5
Dinopterygium cladoides													<1	<1		
Trinovantedinium harpagonium				<1		+								+		
Selenopemphix armageddonensis												+	+	+		
Lejeunecysta sp. A														+		
Lingulodinium multivirgatum	<1													<1		
Tuberculodinium vancampoae						+						+	+			
Operculodinium piaseckii	+	+	+	+	<1	<1				+		<1	<1			
Systematophora placacantha			<1		+	<1	<1			<1	+	<1				
Spiniferites pseudofurcatus pseudofurcatus					<1		<1	+	<1			+				
Barssidinium taxandrianum												<1				
Capisocysta wallii												<1				
Operculodinium giganteum					+			<1		<1		<1				
Trinovantedinium sp. A									+			<1				
Palaeocystodinium golzowense	<1					2,2	1,1	3,9		+	+					
Sumatradinium soucouyantiae				<1	<1					<1	+					
Pyxidiniopsis sp. ind.									<1							
Geonettia clineae									+	+	+					
Batiacasphaera deheinzelinii			<1	<1	<1			+	+							
Trinovantedinium? xylochophorum				<1				<1	<1							
Barssidinium olymposum					<1	+		+	1,5							
Palaeocystodinium spp. ind.									+							
Pyxidiniopsis brabantiana									+							
Scaldecysta sp. ind.									+							
Selenopemphix sp. A							+									
Operculodinium sp. ind.								+								
Bitectatodinium tepikiense																
Apteodinium tectatum																
Cerebrocysta? sp. 1 Louwye 2002								1,2								
Pyxidiniopsis cf. *reticulata*								<1								
Cerebrocysta poulsenii							<1									
Sumatradinium druggii						+										
Achomosphaera cf. *andalousiensis andalousiensis*					<1											
Cannosphaeropsis passio					+											
Selenopemphix sp. ind.					+											
Operculodinium sp. 3 de Verteuil & Norris 1996			<1	<1												
Lejeunecysta cf. *marieae*			+													
Selenopemphix conspicua		+														
Tectatodinium cf. *simplex*	<1	+														
Filisphaera microornata	<1															
Marine algae incertae sedis (n=16)																
Cyclopsiella? trematophora	3,3	<1	3,4	3,0	5,3	4,4	1,1	<1	3,3	2,1	5,6	4,7	11,5	8,1	2,7	2,7
Paralecaniella indentata	87,6	89,3	14,4	4,5	5,7	3,1	1,1	1,2	<1	4,6	2,2	11,7	18,5	1,2	3,8	1,9

Samples	-295.8	-292.4	-285.8	-279.9	-275.8	-270.9	-265.8	-256.3	-245.5	-234.5	-227.5	-220.5	-215.6	-210.8	-201.5	-191.5
Incertae sedis 1	<1						<1	+	<1							
Palaeostomocystis globosa	+		1,1		3,8	+	+							<1	<1	
Incertae sedis 2					+			+	<1	<1		<1		<1	<1	
Acritarch sp. 2 Head et al. 1989		+		1,1		<1	<1	<1	<1					<1	<1	
Small spiny acritarchs													<1			
Cyclopsiella elliptica/granosa	+	6,7	1,1		+							1,8	5,9			
Waaslandia gemina												<1				
Algal cluster											+					
Nannobarbophora gedlii				1,1			+			+						
Comasphaeridium sp. ind.										<1						
Incertae sedis 3					<1					<1						
Acritarch sp. 1 Louwye 2002																
Cyclopsiella spp. ind.	<1		<1													
Quadrina condita			<1	4,5				1,5								
Green algae (n=3)																
Tasmanites			<1		<1		+	<1		+						<1
Pterospermella sp. ind.			<1			+	+		<1		+			+		
Pediastrum boryanum					+		+			+	+					
Reworked palynomorphs (n=15)																
Cerebrocysta sp. ind.																
Chiropteridium spp. ind.												+		1,2	+	
Enneadocysta spp. ind.												+		1,2	+	
Wetzeliella sp. ind.																
Homotryblium spp. ind.			3,0		<1		6,8		<1		49,8			4,6		
Areoligera sp. ind.													+			
Cribroperidinium spp. ind.					<1		+		<1				<1			
Areosphaeridium dictyoplokus												<1				
Perisseiasphaeridium sp. ind.												<1				
Raetidinium sp. ind.										+						
Gonyaulacacysta sp. ind.				<1					<1							
Deflandrea sp. ind.						+	+		<1							
Gorgonisphaeridium ambiguum							+									
Oligosphaeridium complex complex							+									
Scriniodinium sp. ind.							<1									
Total number of palynomorphs	241	270	264	266	263	227	266	259	270	238	269	274	286	260	262	262

Table 2. Distribution of marine palynomorphs in the Maaseik borehole: percentages are given for each sample. *: reworked or suspected reworking, +: recorded outside the count, n: number of recorded species.

of *Paralecaniella indentata*. Other samples, e.g. 201.5 m, yielded a very good preserved assemblage with a high species diversity. Reworking of pre-Neogene is moderate, except for sample 227.5 m where high numbers of *Homotryblium* spp. are recorded (Tab. 2). All species of the genus *Spiniferites* are grouped together because of their limited biostratigraphical value, except for *Spiniferites pseudofurcatus* subsp. *pseudofurcatus*, which is a marker species in the northern German Miocene biozonation of Strauss et al. (2001). The nomenclature used is after Williams et al. (1998), Louwye (1999, 2001) and De Schepper et al. (in press).

The assemblage of marine organic-walled palynomorphs from the Breda Formation in the Maaseik borehole compares well to the Middle and Upper Miocene assemblages recovered by de Verteuil & Norris (1996) from the Salisbury Embayment (Atlantic Margin, USA) and by Strauss et al. (2001) from the Nieder Ochtenhausen Research Well in Northern Germany. The dinoflagellate cyst biozonations constructed in both latter areas can readily be applied to our study material, and are discussed below. An overview of the biostratigraphical useful species for correlation and relative dating are given in figures 1 and 2.

3.2.2. Salisbury Embayment, Atlantic Margin, USA - de Verteuil & Norris (1996)

Samples 295.8 m and 292.4 m are strongly dominated (87.6% and 89.3%) by the acritarch *Paralecaniella indentata* (Tab. 2, Fig. 8). This species is a common element in Mesozoic and Cenozoic organic-walled palynomorphs assemblages. *P. indentata* apparently has a broad ecological tolerance since it thrives in marine to marginal marine environments (Elsik, 1977). Noteworthy is that dinoflagellate cysts diversity in these samples is very low - only 19 species were recorded - and the preservation of the cysts is poor. The high abundance of *P. indentata* in this interval indicates a depositional environment highly unfavourable for dinoflagellates, maybe very marginal marine or even brackish. The decrease of *P. indentata* in the above-lying samples (14.4% in 285.8 m and 4.5% in 279.9 m) points to a gradual return to more favourable marine depositional environments for dinoflagellates. Although the dinoflagellate cyst diversity in the two latter samples is higher, the preservation of the cysts remains poor. The increase of the relative abundance of *P. indentata* in a higher interval (234.5 m to 215.6 m) to a maximum of 18.5% testifies of a return to more unfavourable conditions for dinoflagellates (Fig. 8). This is underscored by the relative increase of *Cyclopsiella* species. This interval is furthermore characterised by a pronounced influx of reworked dinoflagellate cysts (Tab. 2).

Poorly preserved specimens of *Systematophora placacantha* are sporadically present in low numbers in some samples. Whether the specimens are reworked or not is unclear and cannot be judged solely from the state of preservation.

However, both de Verteuil & Norris (1996) and Strauss et al. (2001) stress the abrupt last common, and well dated, occurrence of this species in the base of calcareous nannoplankton Zone NN6, an event not recorded in our study material. This implies that the whole studied interval is younger than early Serravallian. The DN6 Zone of de Verteuil & Norris (1996) is defined as the interval from the highest occurrence (HO) of *S. placacantha* to the lowest occurrence (LO) of *Cannosphaeropsis passio*. The LO of *Selenopemphix dionaeacysta* is a diagnostic event for this zone. This zone is recognised in samples 285.8 m and 279.9 m. The DN6 Zone is considered equivalent with part of calcareous nannoplankton Zone NN6 and is thus of middle Serravallian age. *C. passio* is recorded in sample 275.8 m and this points to the presence of the DN7 Zone, defined as the interval from the LO to the HO of the aforementioned species. Based on ODP data, de Verteuil & Norris (1996) propose a chronostratigraphic position of upper Middle Miocene to uppermost Middle Miocene for their *C. passio* DN7 Zone, i.e., equivalent to the upper part of calcareous nannoplankton Zone NN6 to NN8 (late Serravallian). Hardenbol et al. (1998) and Williams et al. (2004) place the HO of *C. passio* at 11.3 Ma (latest Serravallian), just below the Middle - Late Miocene boundary. Strauss et al. (2001) stress the very restricted range of *C. passio* of only a couple of meters in the upper Middle Miocene sequences in the North Sea Basin and the North Atlantic realm (a.o. Brown & Downie, 1985; Lund & Lund-Christensen, 1992; Engel, 1992), which underlines the stratigraphic potential of this species. However, the chronostratigraphic calibration of this event remains uncertain because of the lack of a parallel record of calibration data from other fossil groups. Strauss et al. (2001) furthermore speculate that the short lasting occurrence of *C. passio* might be situated just before the important sea level drop associated with sequence boundary 10.5 Ma sensu Haq et al. (1987) or the major sequence boundary Ser4/Tor1 at 11.7 Ma sensu Hardenbol et al. (1998). The single record of *C. passio*, as *C. utinensis*, in the Mazzapiedi section (Italy) by Zevenboom (1995) in the earliest Tortonian is dissonant vis-à-vis other regions (North Sea Basin and the North Atlantic realm), and thus needs further research.

The interval from 270.9 m to 227.5 m holds the DN8 Zone, which is defined as the interval from the HO of *C. passio* to the HO of *S. soucouyantiae*. Additional diagnostic events are the HO of *C. poulsenii* (sample 265.8 m) within the zone and the HO of *Palaeocystodinium* spp. (sample 227.5 m) near the upper boundary of the zone. *Neogloboquadrina acostaensis* is recorded in the basal beds of the DN8 Zone in the type area. Its appearance, at 10.9 Ma according to Berggren et al. (1995), defines the lower boundary of planktonic foraminifer Zone N16. The upper boundary of the DN8 Zone is close to the calcareous nannoplankton Zone NN10/NN11 boundary. De Verteuil & Norris (1996) estimate that this DN8 Zone spans the time from the beginning of the Late Miocene to the early part of Chron C4r. The HO of *Hystrichosphaeropsis obscura*
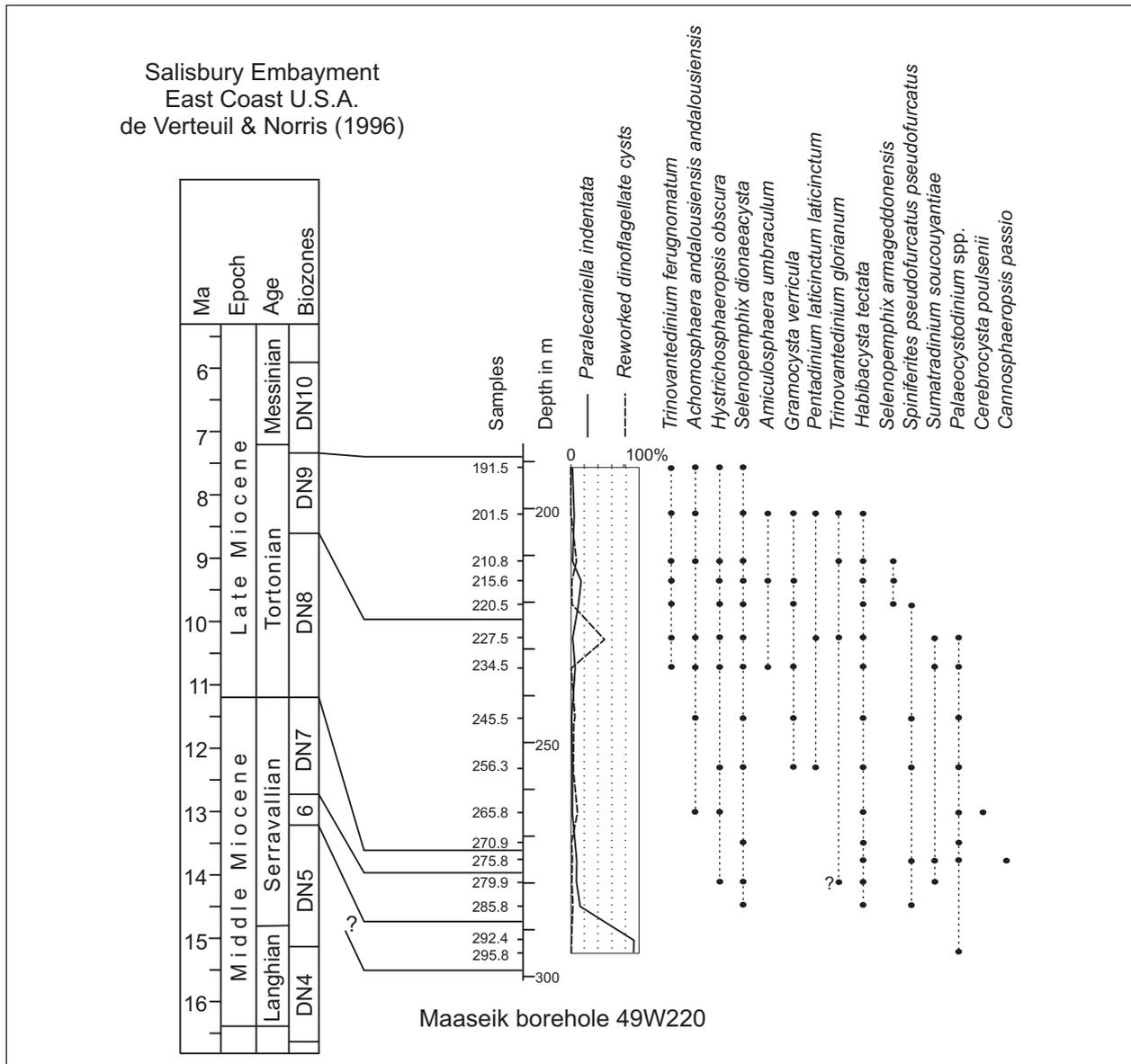
Figure 8. Distribution of selected dinoflagellate cysts in the Maaseik borehole (49W0220) and correlation with the biozonation of de Verteuil & Norris (1996). Depth of samples is given in m below topographic surface.

defines the upper boundary of the DN9 Zone, while its base is defined by the upper boundary of the DN8 Zone. The five uppermost samples of the Maaseik borehole can be accommodated within the DN9 Zone. *Labyrinthod-inium truncatum* occurs in the uppermost sample of our studied section and has its HO at the upper boundary of the DN9 Zone in the Salisbury Embayment. The DN9 Zone is equivalent to the lower part of calcareous nan-noplankton Zone NN11 and has a late Tortonian age. *Selenopemphix armageddonensis* has in our study material an early entry already in the DN9 Zone, while in the type area it only appears in the superjacent latest Tortonian to Messinian DN10 Zone. Hardenbol et al. (1998) place the LO of *S. armageddonensis* at 9.0 Ma, which is before the HO of *H. obscura* at 7.34 Ma.

3.2.3. Nieder Ochtenhausen Research Well, Northern Germany - Strauss et al. (2001)

The low species diversity and poor preservation in samples 295.8 m and 292.4 m hinder the recognition of a biozone. Samples 285.8 m and 279.9 m might hold the Naq Zone, defined as the strata between the LO of *Unipontedinium aquaeductum* to the LO of *Cannosphaeropsis passio* (Fig. 9). According to Strauss et al. (2001), the last common oc-currence of *Systematophora placacantha* and the HO of *U. aquaeductum* are situated high in this zone. *U. aquaeductum* is absent in the Maaseik well and *S. placacantha* occurs only in low numbers (see above). Thus, it is probable that only the uppermost part of the Naq Zone is present in the Maaseik well. Since this zone is correlated with

the middle and upper part of calcareous nannoplankton Zone NN5 (lower to middle Serravallian), samples 285.8 m and 275.8 m could have a middle Serravallian age. Sample 275.8 m holds the Cpa Zone, defined as the interval from the LO to the HO of *C. passio*. Contrary to the findings of de Verteuil & Norris (1996) in the US Atlantic Margin, *Cerebrocysta poulsenii* has a HO within this zone at Nieder Ochtenhausen. Strauss et al. (2001) suggest a correlation with calcareous nannoplankton Zone NN6 (middle to late Serravallian) based on an indirect correlation by means of bolboforms.

The upper boundary of the superjacent San Zone lies just below the LO of *Gramocysta verricula*, recorded in sample 256.3 m. The San Zone, also characterised by the LO of

Achomosphaera andalousiensis andalousiensis, is thus present in samples 270.9 m and 265.8 m. This zone is interpreted by Strauss et al. (2001) to be equivalent to the upper part of NN6 and the lower part of NN7, and to be of (middle to) late Serravallian age. The Gve Zone, defined as the interval from the LO of *Gramocysta verricula* to just below the LO of *Amiculosphaera umbraculum*, is recorded in samples 256.3 m and 245.5 m. The Gve Zone is interpreted to straddle the Middle - Upper Miocene boundary (Strauss et al. 2001). However, this interpretation should be considered tentative since it is based on an indirect correlation, namely the occurrence of *G. verricula* in an interval of the Gross Pampau borehole which is indirectly calibrated with calcareous nannoplankton Zones NN8 and NN9 by means of bolboforms.
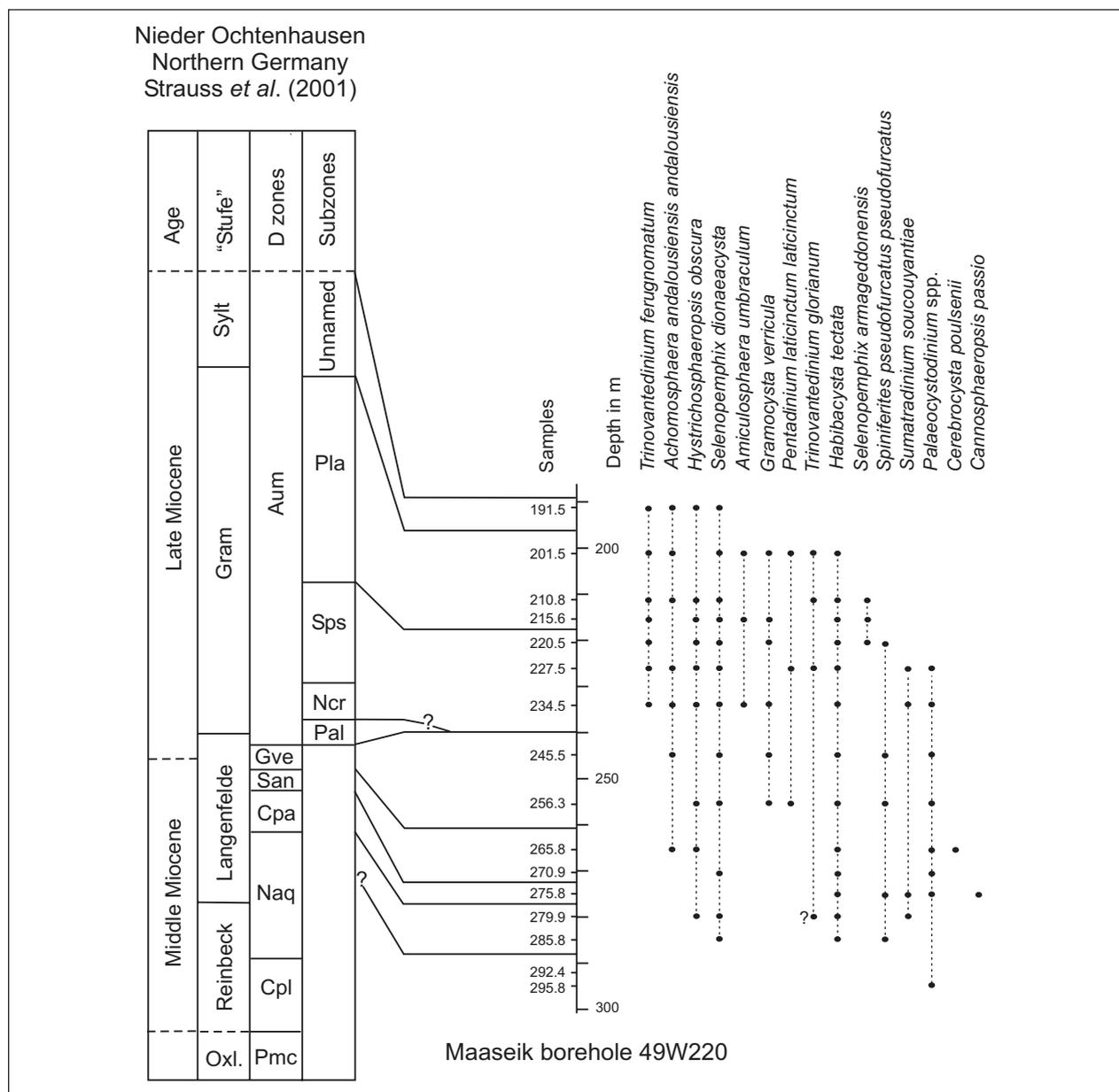
Figure 9. Distribution of selected dinoflagellate cysts in the Maaseik borehole (49W0220) and correlation with the biozonation of Strauss et al. (2001). Depth of samples is given in m below topographic surface.

The above lying Aum Zone covers the greater part of the Upper Miocene and is defined by the LO of *A. umbraculum* (sample 234.5 m) to the LO of *Spiniferites* cf. *pseudofurcatus* sensu Harland (not recorded). The upper part of the studied section from samples 234.5 m to 191.5 m thus holds the Aum Zone. The Aum Zone is subdivided into four subzones and an uppermost unnamed interval (Fig. 9). Recognising these subzones of Strauss et al. (2001) in the interval 234.5 m to 191.5 m is much more difficult.

The lowermost Pal Subzone is defined as the interval from the base of the regular occurrence of *A. umbraculum* to the HO of *Palaeocystodinium* spp. However, the latter species has its highest common occurence in sample 245.5 m. Whether the two single specimens of *Palaeocystodinium* spp. in samples 234.5 m and 227.5 m, recorded outside the counting, are reworked or *in situ* if difficult to assess, and renders the formal recognition of the Pal Subzone difficult (Fig. 9). This interval is furthermore typified by the substantial presence of reworked cysts (see above). The Pal subzone is calibrated against NN8/NN10 and has a supposedly early to middle Tortonian age.

Sample 220.5 m possibly holds the Sps Subzone whose upper boundary is defined by the top of the regular occurrence of *Spiniferites pseudofurcatus*. However, the occurrence of this species is sporadic in the Maaseik borehole and never regular. The Sps Subzone is probably equivalent to calcareous nannoplankton Zones NN10 and NN11 (pars) (middle Tortonian to ?earliest Messinian). The underlying thin Ncr Subzone, defined by the LO and HO of *Nematosphaeropsis crassimuratus*, was most probably not recognised in the Maaseik well because of the low sampling resolution. Furthermore, this Ncr Subzone is difficult to calibrate since *N. crassimuratus* was never recorded outside the type locality Nieder Ochtenhausen. Samples 215.6 m to 201.5 m can possibly be placed within the Pla Subzone, whose upper boundary is defined by the HO of *Pentadinium laticinctum laticinctum*. This species, however, also has a very sporadic occurrence and is never abundant. According to Strauss et al. (2001), this subzone is most probably equivalent to the upper part of calcareous nannoplankton Zone NN11, and they suggest a ?latest Tortonian - early Messinian age.

The uppermost "unnamed" Subzone in the Nieder Ochtenhausen well is characterised by common occurrences of, a.o., *Hystrichosphaeropsis obscura* and *Reticulatopshaera actinocoronata*, a phenomenon also observed in sample 191.5 m.

3.2.4. Comparison with Miocene deposits in northern Belgium

The dinoflagellate cyst assemblages recorded from samples 285.8 m to 275.8 m are comparable to those found in the upper part of the Antwerpen Sands, a member from the Berchem Formation, in the "Borgerhout Rivierenhof" outcrop in the Antwerp area by Louwye *et al.* (2000). This correlation is mainly based on the recognition of the DN6 Zone and DN7 Zone of de Verteuil & Norris (1996). Louwye (2002) recorded a well-preserved and rich dinoflagellate cyst assemblage from the Deurne Sands, a local member of the Upper Miocene Diest Formation. The investigated sequence is located in the Antwerp area and has a thickness of only a few meters. The dinoflagellate cyst assemblage recorded in the Deurne Sands is comparable to the assemblages recorded in samples 234.5 m to 220.5 m of the Maaseik borehole. The comparison is based on the occurrence of species such as *Amiculosphaera umbraculum*, *Lejeunecysta* sp. 1, *Sumatradinium soucouyantiae*, *Spiniferites pseudofurcatus* and *Trinovantedinium glorianum*. The Deurne Sands were correlated with dinoflagellate cyst zone DN8 of de Verteuil & Norris (1996) and the Aum biozone of Strauss et al. (2001), and, more tentatively, with their Sps Subzone. As stressed by Louwye (2002), neither the lower nor upper boundaries of the above mentioned zones were recognised in the unit. The presence of *Impagidinium* species in the Deurne Sands is noteworthy. According to Dale (1996), the presence of this species (and also *Nematosphaeropsis* species), even in very low numbers, is an indication of the influence of oceanic water masses, a phenomenon not recorded in the Maaseik borehole. Striking is the absence of *Gramocysta verricula* in the Deurne Sands, which might be environmentally controlled.

The Dessel Sands and Diest Sands are the two other members of the Diest Formation and are found in the Campine area. Both members are diachronous (Louwye et al.. 1999). The fine-grained Dessel Sands and coarsegrained Diest Sands are genetically related to the formation and infilling of a large gully in the eastern Campine area, which presumably formed at the end of Middle Miocene times or during early Late Miocene times. The Dessel Sands in the vicinity of the gully in the eastern Campine area hold the DN8 Zone of de Verteuil & Norris (1996), while the same sands hold the DN9 Zone in the western Campine area. The above-lying Diest Sands holds, in respectively the same areas, the DN9 and DN10 Zones. The recognition of these biozones in both units allows a correlation with the Maaseik sequence (Fig. 8).

3.2.5. Conclusions

At Maaseik, the deposition of the Breda Formation started in a marginal marine environment unfavourable for dinoflagellate cysts, testified by high numbers of *Paralecaniella indentata* in the very base of the sequence. Decreasing numbers of this species higher up in the sequence indicate that deposition took place in increasingly more marine conditions during middle Serravallian times. An age for the basal section cannot be proposed. According to the biozonation of de Verteuil & Norris (1996), the Middle - Upper Miocene boundary is located between samples 275.8 m and 270.9 m, while according to Strauss et al. (2001) the boundary lies somewhere in

the interval 256.3 m to 245.5 m. The upper Miocene sequence in the Maaseik well was deposited sometime during Tortonian times. The Messinian biozone DN10 of de Verteuil & Norris (1996) was not recognised in the Maaseik borehole, while according to the Strauss et al. (2001) biozonation the uppermost sample could hold their Messinian "unnamed" biozone. The low-resolution sampling does not allow us to draw conclusions regarding changes of the depositional rate. An increase of *P. indentata* and *Cyclopsiella* species in the upper part of the sequence from samples 234.5 m to 215.6 m, and a pronounced influx of reworked species in sample 227.5 m indicate a return to less favourable conditions for dino-flagellate cysts, i.e. much shallower conditions during a period of low sea level or uplift.

3.3. Calcareous microfossils

3.3.1. Benthic foraminifera

The section between 196.50 m and 232.50 m was examined. Below 203.50 m abundant *Florilus boueanus* and some *Elphidium antoninum* are present. In addition, in some samples with abundant foraminifera, also *Uvigerina hosiusi deurnensis* is present. The planktonic forams, the so called *Globigerina pachyderma*, in the samples are generally dextrally coiling (see De Meuter & Laga, 1970 and also Hooyberghs et al., 2004).
This section between 196.50 and 232.50 m can therefore be correlated biostratigraphically to the *Uvigerina hosiusi deurnensis – Elphidium antoninum* assemblage zone (De Meuter & Laga, 1976) or the BFN3 (Belgium Benthic Foraminifera) – FC2 (biozone in the Netherlands) of Doppert et al.(1979). This biozone corresponds in Belgium to the Deurne and Dessel Sands of the Diest Formation; in addition, characteristic foraminifera associations of known over- and underlying lithostratigraphic units are missing in this interval.

3.3.2. The Ostracods

In the approximately same interval between 201.50 m and 235.50 m ostracods are determined. Especially the presence of *Thaerocythere sp.1*, *Sagmatocythere variolata* and *Propontocypris propinqua* are typical for the Sands of Deurne. None of these three species were ever found in other Miocene or Pliocene stratigraphic units in the area. The other species present point to a Miocene rather than Pliocene deposit.
The presence of *Callistocythere sp.1* and *2* and *Leptocythere sp.* is interesting as these species were never recorded in the Deurne Sands of their classical Antwerp Campine occurrence area. It could point to a different palaeoenvironment as the species of both genera preferentially live in shallow environments in association with algae.
Hooyberghs et al. (2004) have recently described the *Bolboforma* zones in the borehole Maaseik and identified

the boundary between Middle and Upper Miocene zones between 228.5 and 237.5 m represented by a hiatus of more than 2 Ma.

3.4. Molluscan fauna

3.4.1. Material and methods

A number of cores, taken between 200 and 298 m depth, were sieved on a 0.5 mm mesh and all identifiable fragments of mollusca were collected (deposited in the IR-ScNB/KBIN collection, Department of Palaeontology, section Invertebrate Palaeontology). The cores sorted out consisted of half of tubes of 1 m long, with a cross section of 10 cm, taken in the intervals 297-298 m, 285-286 m, 279-267 m, 258-248 m, 242-228 m and 218-200 m. This yielded a collection of more than 3000 shells and shell fragments. The highest density was reached between 242 and 228 m, in which several lenses or beds mainly consisting of single valves of the bivalve subspecies *Glycymeris obovata baldii* Glibert & Van de Poel, 1965 occurred. The remaining material was distributed randomly in the cores.
This material was identified using the works of Gürs (2001, 2002), Gürs & Weinbrecht (2001), Janssen (1984), Heering (1950), Hinsch (2000), Menzel et al. (1994), Moths (1989), Van Voorthuysen (1944) and Wienrich (2002). The data are represented in Table 3.

3.4.2. Previous research about the Miocene Mollusca from Belgium

Although already Nyst (1845) described molluscan species from the Miocene of the Antwerp area, the first systematic studies were these of Glibert (1945, 1952, 1954) and Glibert & de Heinzelin de Braucourt (1955). The first three works mentioned treated respectively the bivalves, gastropods (minus Turridae) and Turridae of the Early and Middle Miocene, the last the whole fauna of the Late Miocene Deurne Sand Member. All Glibert's studies however were based on material collected in the nineteenth century, by Nyst and other amateur collectors. A systematic field survey was never attempted, because of lack of exposures before and at the time of the studies of this fauna by Glibert and de Heinzelin. This had however several drawbacks. First of all, a lot of material was collected *ex situ*, so that a number of Pliocene species were included in Middle Miocene fauna lists. This was emphasized by Janssen & Van Der Mark (1969) and confirmed by Marquet (1995, 1997a, b, 2002, in press) regarding the Pliocene malacofauna. Secondly, only part of the Belgian Miocene was known to Glibert: the Early Miocene Houthalen and Edegem Sand Members, the Middle Miocene Antwerpen Sand Member, the Late Miocene Deurne Sand Member and the reworked silicified Bolderberg fauna. Thirdly, in the collection of the IRScNB/KBIN, the material of the

Kattendijk Formation (Early Pliocene) is included in that of the Late Miocene Deurne Sand, (pers. obs.), so that the age of this Member could be underestimated. Lastly, only large shell species were collected, minute ones are underrepresented. So this pre-1960 material is for a large part unsuited for stratigraphic comparisons.

From the 1960's onward, large scale works allowed the collection of a large amount of material from the Belgian Miocene. This material was collected better, including the smaller species, but it has not yet been published completely. The Ring Motorway and Kennedy Tunnel around Antwerp and the Antwerp Metro works contained abundant material from the Edegem, Antwerpen and Deurne Sand Members. In Doel, Oost-Vlaanderen (Deurganckdok) a Miocene fauna preserved in sandstone, of yet unknown age, was discovered. In Deurne (Antwerp, Middelares Hospital), the Deurne Sand Member could be sampled. Furthermore, in Heist-Op-Den-Berg the rich Zonderschot Sand Member was discovered and sampled extensively during several large scale diggings, organized mainly by the "Werkgroep voor Tertiaire en Kwartaire Geologie". Smaller exposures also proved to contain unknown molluscan faunae, especially a clay pit in Ramsel (Antwerp province) with an internal mould fauna and building works in Putte, near Lier (Antwerp province). Last of all, a fauna, preserved in phosphorite nodules, could be studied in Broechem (same province), which seems to represent a Miocene-Pliocene boundary assemblage. Material of all these exposures is conserved in the collection Marquet (to be transferred to the IRScNB/KBIN in Brussels) and the NNM Naturalis in Leiden, The Netherlands, as well as in numerous private collections. Publications however about this new material are scarce: Janssen & Müller (1984) discussed the Ramsel fauna, Marquet (1980) the Broechem fauna and Marquet in Bosselaers et al. (2004) that of the Deurne (Middelares Hospital) section. The bulk of the newly collected material remains however to be described; the doctoral thesis by Ringelé (1974) about the Neogene Bivalvia, unfortunately was never published. A systematic revision of the whole Belgian Miocene molluscan fauna is consequently needed and this would considerably enhance its stratigraphic utility.

3.4.3. Results

Even taking the unpublished material collected after 1960 into account, the Maaseik boring yielded 32 taxa new to the Belgian Miocene fauna, probably representing a part of the Miocene which was not found before in Belgium and therefore not to be correlated with any of the known Members (see Table 3).

A total number of 187 species was found, composed of 75 bivalve, 2 scaphopod and 107 gastropod taxa. Table 3 gives a list of the distribution of these species. Most were represented by few specimens in each core part only. Exceptions are mainly *Glycymeris obovata bal-*

dii Glibert & Van de Poel, 1965, *Modiolula phaseolina* (Philippi, 1844), *Scacchia degrangei* (Cossmann & Peyrot, 1911); *Goodalia waeli waeli* (Glibert, 1945), *Digitaria beyschlageri* (Kautsky, 1925), *Ervilia pusilla* (Philippi, 1836), *Parvicardium scabrum* (Philippi, 1844), *Spaniodontella nitida* (Reuss, 1867), *Gouldia minima* (Montagu, 1803) (Bivalvia), *Hyalia laevigata* (von Koenen, 1882), *Fusiturris duchasteli flexiplicata* (Kautsky, 1925), *Retusa subangystoma* (d'Orbigny, 1852) and *Cylichna cylindracea* (Pennant, 1777) (Gastropoda). All these however are species with a long stratigraphic range, encompassing the whole Miocene and some even reaching till now. A notable exception is *E. pusilla*, an extremely rare species in other Belgian Miocene sediments: it is very common in the upper part of the Maaseik boring, but also occurs rarely in the lower part; before, it has been found in the Early Miocene Edegem Sand Member.

Only a rather low number of taxa - 24 - seem to have stratigraphic significance. First of all, some characterize only part of the section investigated and are well enough represented in the samples. They allow the distinction of two different parts in the section, although there is a considerable overlapping part in their ranges. They are listed in Tables 4a and 4b. The overlapping part is between 239 and 227 m, with one species characteristic of this part by its great abundance, but reaching above as well as below: *Anodontia benoisti* (Cossmann & Peyrot, 1912) found between 268 and 214 m depth. Secondly, other species only were found in one or few samples, but characterize part of the Neogene in other parts of the North Sea Basin.

Of the 14 species characterizing the upper part of the section, only two have been found before in the Belgian Miocene, while of the 10 species in the lower part, only one is new (*A. benoisti*). The upper part of the section apparently contains molluscs new to the Belgian Miocene; only two species in this part are known from earlier research, namely from the Deurne Sand Member, one of which is also found in Pliocene deposits. The lower part of the section contains species found in both the Zonderschot and the Antwerpen Sand Members, so it could be corresponding to both; their general molluscan content only differs slightly.

3.4.4. Notes on systematics

Glossus lunulatus lunulatus (Nyst, 1835) was found in fragmentary condition in the whole section, but the lack of shell sculpture and the shape of the umbo are recognizable in the material collected. This subspecies is only present in the middle part of the Belgian Miocene: the Antwerp and Zonderschot Sand Members. The Deurne Sand Member contains another species, *Glossus (Glossus) forchhammeri* (Beck *in* Ravn, 1907; Marquet, in press), differing by its lower shell and much less protruding umbo.

Aequipecten opercularis (Linnaeus, 1758) s.l. makes part of a group of very similar species and the specimens

Name: Bivalvia	1 Isocrassina f. ariejansseni Marquet, 2005	2 Lentidium turonensis (Cossm. & Peyr., 1914)	3 Arcopagia cf. ventricosa (De Serres, 1819)	4 Callista chione (Linnaeus, 1758)	5 Digitaria beyschlageri (Kautsky, 1925)	6 Glossus lunulatus lunulatus (Nyst, 1835)	7 Scacchia degrangei (Cossm. & Peyr., 1911)	8 Dosinia cf. lupinus (Linnaeus, 1758)	9 Spaniodontella nitida (Reuss, 1867)	10 Aequipecten opercularis (Linnaeus, 1758) s.l.	11 Mactra sp. nov. ?	12 Yoldia glaberrima (von Münster, 1817)	13 Goodallia angulata (Lehmann, 1885)	14 Nucula jeffreysi Bellardi, 1875	15 Leionucula laevigata (Sowerby, 1818)	16 Lucinoma borealis (Linnaeus, 1758)	17 Parvicardium scabrum (Philippi, 1844)	18 Abra antwerpiensis Gilbert, 1945	19 Corbula gibba gibba (Olivi, 1792)	20 Thracia (T.) i. microgranosa Marquet, 2004	21 Glycymeris o. baldii Gl. & V.d. Poel, 1965	22 Angulus benedeni fallax (Beyr. in v. K., 1868)	23 Periploma ariei Gürs, 1996	24 Turneria cylindrica (Wood, 1850)	25 Nucula trigonula Wood, 1851	26 Panopea kazakovae Glibert & V.d.Poel, 1966	27 Ensis	28 Pododesmus squamula (Linnaeus, 1758)	29 Modiolula phaseolina (Philippi, 1844)	30 Hiatella arctica (Linnaeus, 1758)	31 Scapharca diluvii (Lamarck, 1805)	32 Spisula "subtruncata" auct.	33 Acanthocardia hanseata (Kautsky, 1925)	34 Angulus donacinus (Linnaeus, 1758)
297																					X	X												
285																																		
278	X	X												X	X	X															X	X	X	X
277												X		X		X	X	X	X												X	X	X	X
276															X	X			X											X	X	X	X	
275									X							X	X		X												X	X	X	X
274																																		
273																																		
272	X	X														X	X	X	X		X								X				X	
271	X	X							X							X	X	X			X					X			X					
270																																		
269																																		
268																																		
267	X											X				X	X	X	X		X							X	X	X	X			
257							X	X		X				X		X	X	X			X									X	X			
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255										X									X		X									X				
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250							X	X	X					X			X	X																
249	X	X								X		X				X	X	X	X		X									X	X	X		
248	X	X					X	X								X	X	X	X		X							X	X		X	X	X	X
241							X	X						X	X	X	X	X	X		X							X	X		X	X	X	X
240																																		
239																																		
238							X		X			X		X		X	X	X	X		X						X	X	X		X		X	X
237																																		
236					X				X																	X			X					X
235																																		
234								X	X			X				X		X	X		X				X				X		X		X	X
233					X		X							X		X	X	X	X		X								X		X		X	X
232	X			X			X	X	X			X		X		X	X	X	X	X				X	X		X	X	X	X	X		X	X
231													X						X	X														
230	X							X	X			X		X		X	X	X	X		X						X	X	X	X	X		X	X
229					X		X	X								X	X	X	X		X						X	X	X		X		X	X
228	X	X				X	X		X			X		X		X	X	X	X					X			X	X	X		X		X	X
227	X	X				X						X				X	X	X	X		X						X	X	X		X		X	X
226	X	X				X	X					X		X		X	X	X	X		X						X	X	X		X		X	X
225				X	X	X		X	X			X				X	X	X	X		X						X	X	X	X	X		X	X
217																	X		X		X					X					X	X	X	X
216																																		
215	X					X		X						X		X	X	X	X		X						X	X	X	X	X		X	X
214	X			X		X		X				X		X		X	X	X	X		X						X	X	X	X	X		X	X
213																																		
212	X					X	X	X								X	X	X	X								X	X	X	X	X		X	
211												X						X	X															
210			X				X	X								X	X	X	X								X	X	X	X	X		X	X
209							X	X								X	X	X	X								X	X	X	X	X		X	X
208		X			X		X	X					X			X		X									X	X	X		X		X	
207					X		X	X	X							X		X	X								X	X	X		X		X	
206																X	X											X	X		X		X	X
205				X	X	X	X							X		X													X		X		X	X
204						X							X	X								X									X		X	
203				X	X		X	X	X			X				X	X	X	X								X	X			X		X	X
202				X	X	X	X	X		X	X	X				X	X	X	X								X	X			X	X	X	X
201		X																																
200	X																																	
New		N									N																							

Name: Bivalvia	Goodallia waeli waeli (Gilbert, 1945)	Similipecten similis (Laskey, 1822)	Lyonsia	Erycinidae	Teredinidae	Ervilia pusilla (Philippi, 1836)	Timoclea ovata (Pennant, 1777)	Aligena	Lajonkairea lajonkairei ? (Payraudeau, 1826)	Arcoperna sericea (Bronn, 1811)	Mioerycina coarctata (Wood, 1859)	Pandora copiosa Sorgenfrei, 1958	Limopsis anomala auct.	Pitar rudis rudis (Montagu, 1803)	Pseudamussium lilli (Pusch, 1837)	Lepton	Anodontia benoisti (Cossm. & Peyr., 1912)	Bathyarca pectunculoides (Scacchi, 1844)	Cyclocardia scalaris (Leathes in Sow., 1825)	Gouldia minima (Montagu, 1803)	Pseudamussium clavatum (Poli, 1795)	Yoldiella p. wesselinghi Marquet, 2002	Thyasira flexuosa (Montagu, 1803)	Musculus sorgenfreii Anderson, 1967	Axinulus germanicus A.W. Janssen, 1972	Limatula sulcata (Brown, 1827)	Pteria phalaenacea (Lamarck, 1818)	Atrina sp.	Carinastarte anus (Philippi, 1843)	Nuculana westendorpi (Nyst, 1839)	Cuspidaria cuspidata (Olivi, 1792)	Mysella bidentata (Montagu, 1803)	Cardiomya costellata (Deshayes, 1835)	Ostreidae indet.
297	X																										X							
285																																		
278	X												X	X												X	X			X	X			
277												X	X	X									X							X	X	X		
276	X	X													X			X												X	X	X		
275	X	X																												X	X			
274																																		
273																																		
272																								X										
271	X						X															X										X		
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268																																		
267	X	X					X	X							X		X					X					X						
257	X	X					X	X							X		X					X					X						
256																																		
255							X													X														
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249	X	X						X				X			X					X	X	X	X										
248	X	X						X				X			X					X	X	X	X										
241	X	X			X		X	X					X				X			X	X	X					X						
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239																																		
238								X				X	X	X			X			X												X		
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234			X					X				X	X				X			X			X									X	
233			X			X		X		X		X	X	X	X		X			X						X	X					X	X	
232					X		X	X					X	X	X		X			X						X	X			X		X	X	X
231	X												X	X	X		X														X	X	X	X
230	X		X			X		X		X		X	X		X		X			X						X	X				X			
229	X	X	X			X		X				X	X		X			X		X						X	X		X		X			
228	X	X	X			X		X				X	X		X				X		X	X	X			X			X					
227	X	X						X				X	X	X						X	X	X				X								
226	X	X						X					X	X			X			X	X	X					X		X					
225	X	X									X	X	X	X			X			X	X	X							X					
217																																		
216																																		
215	X	X				X								X																				
214	X	X		X		X					X	X				X	X	X	X															
213													X		X																			
212	X	X																																
211	X	X				X					X	X	X																					
210	X	X				X				X		X																						
209	X	X				X			X					X																				
208	X						X																											
207	X		X	X	X	X																												
206																																		
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201																																		
200																																		
New							?		N								N												N					

Name	New	200	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	248	249	250	251	252	253	254	255	256	257	267	268	269	270	271	272	273	274	275	276	277	278	285	297
Name: Bivalvia																																																													
Spaniorinus cimbricus (Kautsky, 1925)																													X																															
Limea strigillata (Brocchi, 1814)																																	X					X																				X X			
Ventricoloidea multilamella (Lamarck, 1818)																												X					X			X																								
Clausinella scalaris (Bronn, 1831)																																							X														X X							
Laevicardium subturgidum (d'Orbigny, 1852)																																																							X	X X	X X			
Mimachlamys angelonii (De St. & P., 1880)																																																								X				
? Callista chionides (Nyst, 1844)																																																												X
Name: Scaphopoda																																																													
Dentalium																																																												X	
Laevidentalium				X												X				X	X										X		X			X																								
Name: Gastropoda																																																													
Sveltia var. paucicostata (Peyrot, 1927)		X	X	X						X			X			X					X		X	X	X		X	X					X																				X								
Ringicula ventricosa (Sowerby, 1824)	N	X			X	X				X	X		X								X		X	X	X		X	X					X					X														X				X				
Ficus conditus (Brongniart, 1823)				X		X		X		X		X	X								X	X	X		X		X	X					X					X							X							X				X			X		
Turritella eryna d'Orbigny, 1852			X	X			X		X			X	X	X		X					X	X	X		X		X	X					X					X X							X							X				X X				
Semicassis bicoronata (Beyrich, 1854)				X												X				X	X							X																	X											X				
Turbonilla sp. nov. ?	N			X						X			X			X					X	X	X	X																																					
Coralliophila bracteata (Brocchi, 1814)				X																				X	X		X						X																												
Calliostoma laureatum (Mayer, 1874)				X			X							X		X								X	X		X				X	X	X																												
Circulus subcirculus (Cossm. & Peyr., 1916)				X					X														X X		X		X X	X X			X X	X X			X																									
Alvania curta nieheimensis Hinsch, 1972	N			X X		X				X											X X	X	X X	X			X X	X X				X	X																					X							
Eulima glabra (Da Costa, 1778)				X								X	X			X X					X X		X X	X X			X	X				X			X																										
Turbonilla gastaldi auct.				X																			X X	X	X		X	X				X																												
Epitonium frondiculum (Wood, 1848)				X								X				X					X X		X	X	X		X					X		X	X																									
Hadriania coelata (Dujardin, 1837)	N			X																			X	X	X		X					X		X	X																									
Brocchinia mitr. parvula (Beyrich, 1856)				X																				X		X	X					X		X	X																									
Turbicauda spinicostata (Bronn, 1831)				X					X		X														X		X					X		X	X			X				X																		
Nassarius prysmaticus (Brocchi, 1814)	N			X																X				X	X		X	X					X		X	X										X			X											
Asthenotoma pannoides (von Koenen, 1872)				X X				X		X X											X		X		X		X	X					X		X	X										X			X											
Sorgenfreispira sorgenfreii (Nordsieck, 1972)				X X			X				X									X				X X	X X		X X	X X					X		X	X										X			X											
Xenophora				X		X X															X		X X	X X	X		X X	X X					X		X	X										X			X											
Euspira helicina protracta (Eichwald, 1830)	N			X X																	X		X	X X	X		X	X					X X		X	X X								X			X										X			
Chrysallida semireticulata Sorgenfrei, 1958	N			X					X															X	X		X	X					X			X																						X		X X			
Daphnobela miocaenica Gürs, 2003	N			X					X															X	X		X	X																														X		X		

Name: Gastropoda

Species columns:
1. *Fusiturris d. flexiplicata* (Kautsky, 1925)
2. *Retusa subangystoma* (d'Orbigny, 1852)
3. *Calyptraea chinensis* (Linnaeus, 1758)
4. *Babylonella fusiformis* (Cantraine, 1835)
5. *Pleurotomella mioweberi* (Nordsieck, 1972)
6. *Roxania utriculus* (Brocchi, 1814)
7. *Cylichna cylindracea* (Pennant, 1777)
8. *Ringicula buccinea* (Brocchi, 1814)
9. *Hyalia laevigata* (von Koenen, 1882)
10. *Asthenotoma obtusangula* (Brocchi, 1814)
11. *Turritella subangulata* (Brocchi, 1814)
12. *Mitrella nana* (Van Voorthuyzen, 1942)
13. *Aporrhais dingdenensis* Marquet et al., 2002
14. *Semicassis miolaevigata* (Sacco, 1890)
15. *Philine aquila* Van Der Linden & A.W. Janssen, 1996
16. *Hyaloscala*
17. *Hermiaclis walleri* (Jeffreys, 1867)
18. *Caecum banoni* (Benoist, 1872)
19. *Calcarata calcarata* (Brocchi, 1814)
20. *Nassarius tenuistriatus* (Beyrich, 1854)
21. *Odostomia conoidea* auct.
22. *Retusa elongata* (von Eichwald, 1830)
23. *Scaphander grateloupi* (Michelotti, 1847)
24. *Circulus hennei* Glibert, 1952
25. *Evalea basistriata* (Etheridge & Bell, 1898)
26. *Crenilabium terebelloides* (Philippi, 1843)
27. *Acteon arnumensis* Sorgenfrei, 1958
28. *Tectonatica miopusilla* (Kautsky, 1925)
29. *Conus dujardini* Deshayes, 1845
30. *Acteon laevigatus* (Grateloup, 1827)
31. *Baryspira obsoleta* (Brocchi, 1814)
32. *Orthosurcula steinworthi* (von Koenen, 1871)
33. *Chrysallida pygmaea* (Grateloup, 1838)
34. *Sinum aquense* (Récluz, 1850)

Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
297									X					X																				
285																																		
278			X	X	X	X		X												X		X	X	X				X		X		X		
277	X	X		X	X	X	X	X				X		X								X	X					X	X	X		X		
276	X	X		X	X	X	X	X	X											X		X							X	X	X	X		
275							X	X	X					X															X	X	X			
274																																		
273																																		
272	X											X		X															X					
271								X																										
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269																																		
268																																		
267	X	X		X		X		X														X	X											
257																					X													
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255	X	X																										X		X				
254	X	X	X																								X							
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251																																		
250	X					X						X	X	X													X							
249				X							X	X	X							X														
248	X	X			X		X	X					X	X																				
241	X	X					X	X				X	X	X																X	X			
240																																		
239	X	X	X	X		X						X	X													X		X	X	X				
238	X	X	X	X		X	X	X				X	X												X	X	X		X	X				
237																	X	X	X															
236	X													X												X		X	X	X				
235																																		
234	X	X		X		X	X												X	X			X											
233	X	X	X	X	X	X	X	X										X	X	X		X	X				X		X	X				
232	X	X	X	X	X	X	X	X			X							X	X	X		X	X										X	
231										X		X													X	X								
230		X	X			X	X	X	X										X	X						X		X		X				
229		X	X	X			X	X	X			X	X						X	X		X	X										X	
228		X	X	X			X	X	X			X	X		X				X	X		X	X					X						
227				X			X	X	X			X	X						X	X		X	X											
226	X					X	X	X	X			X	X						X	X		X	X					X	X					
225	X					X	X		X			X							X	X		X	X				X					X		
217																																		
216																																		
215																																		
214			X			X		X	X							X		X				X	X	X			X							
213																																		
212																																		
211		X	X				X				X																							X
210												X						X													X			
209		X	X			X																	X							X	X	X		
208	X	X	X	X		X	X	X	X			X						X	X	X		X	X	X		X	X	X	X	X				
207				X											X	X							X			X	X	X		X			X	
206				X				X																										
205								X	X																									
204																																		
203	X	X					X	X	X	X		X	X						X	X					X	X	X	X	X	X				
202	X		X		X	X	X	X	X		X	X	X							X														
201																																		
200																																		
New					N								N					N	N						N									

Name: Gastropda	Tornatina bellardii (von Koenen, 1882)	Terebridae	Syrnola neumayri (von Koenen, 1882)	Balcis alba (Da Costa, 1778)	Retusa cf. truncatula (Bruguière, 1792)	Amyclina facki (von Koenen, 1872)	Volvulella acuminata (Bruguière, 1792)	Pyramidella elata (von Koenen, 1882)	Actaeopyramis elatus (von Koenen, 1882)	Trigonostoma umb. pluricostata (Kautsky, 1925)	Turbonilla undulata (von Koenen, 1882)	Lyrotyphis sejunctus (Semper, 1861)	Euspira nysti (d'Orbigny, 1852)	Crassispira borealis (Kautsky, 1925)	Mitrella nassoides (Grateloup, 1832)	Nassarius karinae (Wienrich, 2001)	Natica	Oliva dufresnei Basterot, 1825	Raphitoma spinoreticulatum Gürs, 2001	Pyramidella grateloupi Cossm. & Peyr., 1917	Semibittium duvergieri (Cossm. & Peyr., 1921)	Cerithiopsidae	Erato exmaug. hemmoorensis Schilder, 1929	Latirus rothi (Beyrich, 1856)	Trigonostoma extractrix (Boettger, 1906)	Neverita jos. olla (De Serres, 1829)	Acamptogenotia escheri (Mayer, 1861)	Agatothoma hontensis (Csepreghy-Mezn., 1954)	Ficus simplex (Beyrich, 1854)	Bathytoma c. jugleri (Philippi, 1847)	Nassarius holsaticus (Beyrich, 1856)	Teretia anceps (von Eichwald, 1830)	Genota ramosa (Basterot, 1825)	Alvania antwerpiensis Glibert, 1952
297																																		
285																																		
278						×	×																								×	×	×	×
277																															×	×	×	×
276											×																		×		×	×	×	×
275													×																			×	×	×
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272																																×	×	
271						×					×																				×			
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267		×	×						×																		×		×		×	×		
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248			×	×			×																×								×	×		
241			×	×				×		×												×	×	×	×	×					×	×		
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238			×	×				×															×						×	×	×	×	×	
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232	×		×	×	×	×	×	×		×	×						×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	
231																																		
230		×	×				×	×								×																		
229	×	×	×							×	×			×	×	×																		
228		×	×					×				×	×		×	×																		
227	×	×					×	×	×	×	×		×																					
226	×						×	×																										
225		×																																
217																																		
216																																		
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214				×	×	×		×																										
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Name: Gastropoda	New	297	285	278	277	276	275	274	273	272	271	270	269	268	267	257	256	255	254	253	252	251	250	249	248	241	240	239	238	237	236	235	234	233	232	231	230	229	228	227	226	225	217	216	215	214	213	212	211	210	209	208	207	206	205	204	203	202	201	200
Bela ankae Gürs, 2001	N																																X																												
Nassarius cavatus (Bellardi, 1882)	N				X										X										X	X							X	X																											
Actaeocina spirata (Brocchi, 1814)	N														X																X		X																												
Putilla gottscheana (von Koenen, 1882)																																X																													
Brachystomia	N																															X																													
Acirsa duvergieri (de Boury *in* C. & P., 1912)																													X																															
Hydrobiide																									X																																			
Opalia pertusa (Nyst, 1871)																									X																																			
? *Dorsanum semiplicata* (Van Voorthuyzen, 1944)	N																								X																																			
Trigonostoma apertum (Beyrich, 1856)																									X																																			
Tornus quadrifasciatus (Grateloup, 1832)																								X																																				
Vexillum plicatulum (Brocchi, 1814)																								X																																				
Bittium spina (Hörnes, 1855)														X																																													
Mitra grateloupi (d'Orbigny, 1852)						X																																																						
Spirotropis gramensis R. Janssen, 1993	N				X	X																																																						
Pleurotomoides luisae (von Koenen, 1878)					X	X																																																						

Table 3. Distribution of molluscs (Bivalvia, Scaphopoda and Gastropoda) identified in the Breda Formation arranged according to their depth of first occurrence in the borehole. The depths given in the top of the table are the tops of the core interval in meter below surface. The molluscs described for the first time in the area are indicated with N in the first column.

Species	Minimum depth	Maximum depth
Mactra sp. nov. ?	201-202	211-212
Arcopagia cf. *ventricosa* (De Serres, 1819)	201-202	232-233
Callista chione (Linnaeus, 1758)	201-202	233-234
Lentidium turonensis (Cossm. & Peyr., 1914)	202-203	207-208
Turbonilla sp. nov. ?	202-203	229-230
Turneria cylindrica (Wood, 1850)	202-203	233-234
Caecum banoni (Benoist, 1872)	207-208	237-238
Alvania curta nieheimensis Hinsch, 1972	202-203	238-239
Calcarata calcarata (Brocchi, 1814)	207-208	238-239
Evalea basistriata (Etheridge & Bell, 1898)	207-208	238-239
Lajonkairea lajonkairei ? (Payraudeau, 1826)	209-210	230-231
Anodontia benoisti (Cossm. & Peyr., 1912)	214-215	267-268
Pseudamussium clavatum (Poli, 1795)	226-227	228-229
Turbonilla undulata (von Koenen, 1882)	227-228	276-277
Carinastarte anus (Philippi, 1843)	229-230	230-231
Nuculana westendorpi (Nyst, 1839)	229-230	278-279
Acamptogenotia escheri (Mayer, 1861)	232-233	255-256
Bathytoma c. jugleri (Philippi, 1847)	232-233	276-277
Nassarius holsaticus (Beyrich, 1856)	232-233	278-279
Teretia anceps (von Eichwald, 1830)	232-233	278-279
Genota ramosa (Basterot, 1825)	232-233	278-279
Nassarius cavatus (Bellardi, 1882)	233-234	277-278
Clausinella scalaris (Bronn, 1831)	271-272	276-277
Laevicardium subturgidum (d'Orbigny, 1852)	275-276	278-279

Table 4a. List of the stratigraphic important molluscs in the Breda Formation arranged according to depth of occurrence in the borehole, expressed as the highest (minimum depth) and lowest (maximum depth) core intervals of occurrence, in meter below surface.

encountered belong to a type, slightly deviating from Pliocene to Recent material, described in Marquet & Dijkstra (2000). Further study is needed to ascertain this identification.

Spisula "subtruncata" auct. does probably belong to another species, as do Belgian Pliocene specimens, formerly referred to by the same name, which belong to the extinct taxon *Spisula (S.) obtruncata* (Wood, 1857) (Marquet, in press). *Mactra* sp. probably is a new species, from which unfortunately only fragmentary material was found.

Mitrella nana (Van Voorthuysen, 1944) was originally described as a variety of *Mitrella nassoides* (Grateloup, 1832), with which it can coexist. The differences between both however are clear enough to distinguish both on the species level. *M. nana* remains half as small as *M. nassoides*, for adult specimens with completely developed apertural denticles. Its siphonal canal is shorter and the suture is more distinct. An important difference is the much lower, but broader aperture. It is furthermore only found together with *M. nassoides* in a limited part of its Miocene range and seems to be endemic to the North Sea Basin, while *M. nassoides* has an extremely wide geographic and

stratigraphic distribution. In a number of characteristics, it comes closer to the Pliocene *Mitrella scaldensis* (Van Regteren Altena), with which it could form an endemic evolutionary series.

The material from *Amyclina facki* (von Koenen, 1872) is in general badly preserved; fragments from the upper part of the boring are larger than ordinary specimens from the Antwerpen Sand Member and appear to be relatively broader. These could belong to *Amyclina badensis* (Partsch in Hörnes, 1856); this is a species probably typical of Miocene deposits younger than sediments with *A. facki* (especially Badenian of the Paratethys), but also found by Van Voorthuysen (1944) in the North Sea Basin.

From *Dorsanum semiplicata* (Van Voorthuysen, 1944) only one specimen was found, which is, however, much less slender than the type material and completely lacks spiral ornament. This identification is clearly only provisional.

3.4.5. Comparison with other Miocene molluscan faunas from the North Sea Basin

First, the fauna of the boring can be compared to that of the known Belgian Miocene Formations and Members.

Species	Depth range (m)
Characteristic of upper part	
Pseudamussium clavatum (Poli, 1795)	226-229
Anodontia benoisti (Cossmann & Peyrot, 1912)	214-268
Carinastarte anus (Philippi, 1843)	229-231
Mactra sp. nov.?	201-212
Lajonkairea lajonkairei ? (Payraudeau, 1826)	209-231
Arcopagia cf. *ventricosa* (De Serres, 1819)	201-233
Callista chione (Linnaeus, 1758)	201-234
Turneria cylindrica (Wood, 1850)	202-234
Lentidium turonensis (Cossmann & Peyrot, 1914)	202-208
Alvania curta nieheimensis Hinsch, 1972	202-239
Caecum banoni (Benoist, 1872)	207-238
Calcarata calcarata (Brocchi, 1814)	207-239
Evalea basistriata (Etheridge & Bell, 1898)	207-239
Turbonilla sp. nov.?	202-230
Characteristic of lower part	
Nuculana westendorpi (Nust, 1839)	229-279
Laevicardium subturgidum (d'Orbigny, 1852)	275-279
Clausinella scalaris (Bronn, 1831)	271-277
Nassarius holsaticus (Beyrich, 1856)	232-279
Nassarius cavatus (Bellardi, 1882)	233-278
Bathytoma cataphracta jugleri (Philippi, 1847)	232-277
Teretia anceps (von Eichwald, 1830)	232-279
Genota ramosa (Basterot, 1825)	232-279
Acamptogenotia escheri (Mayer, 1861)	232-256
Turbonilla undulata (von Koenen, 1882)	227-277

Table 4b. List of the molluscs characteristic for the upper and lower part of the Breda Formation with the indication of their depth range in meter below surface.

The upper part (above 239 m) of the Maaseik Miocene deposits cannot be directly correlated with any of the deposits, known from the Antwerp Basin. The molluscan fauna from the Deurne Sand Member in borehole Maaseik differs considerable from the assemblages in the same member in the Antwerp region, especially by the absence of species that are characteristic for the latest Miocene (Langenfeldian and Gramian) such as *Glossus forchhammeri* (Beck in Ravn, 1907) and the scaphopod *Fissidentalium floratum* R. Janssen, 1987. However, ecological differences could also explain differences in mollusc content between time-equivalent units.

The lower part of the boring examined differs only slightly from the Antwerpen/Zonderschot Sand Members, all species indicated in Table 4b as lacking in the upper part of the boring being present in these Members. One species, *Turbicauda spinicostata* (Bronn, 1831), has been found until now in Belgium only in the Ramsel internal mould material. Its range in Maaseik does not include the lowest part of the Miocene, but it reaches well

below 239 m. *Anodontia benoisti* (Cossmann & Peyrot, 1912) also is a species unknown from the Antwerpen/Zonderschot Members, reaching below this limit. It has not been found in Ramsel, but recognizing this species in internal mould material would be very difficult. It could be concluded that the lower Miocene part of the boring could be correlated with the Ramsel fauna, younger than the Antwerpen/Zonderschot Members.

The best match for the boring Maaseik can be found in boreholes from adjacent regions in The Netherlands. Van Rooijen et al (1984) described borings from Broekhuizenvorst and Geldern in the Peel-Venlo area, which they divided into zones using different stratigraphic marker groups: foraminifera, calcareous nanoplankton and molluscs, besides heavy minerals. They introduced a molluscan zone F (see further), which they correlated with the latest part of the German "Reinbek Stufe". Sliggers & van Leeuwen (1987), working with material from the same and other borings, including material

from Dutch Limburg, published a more detailed molluscan and foraminiferal division of the Miocene of the southeastern part of The Netherlands. Several of the species, not encountered in the Miocene of Belgium previously, and found mostly/exclusively in the upper part of the Maaseik boring, seem to be characteristic of their molluscan ecozones. *Astarte fusca "incrassata"* (= *A. f. ariejansseni* Marquet, 1995) is found from Mol F5 to F3, *Caecum banoni* (Benoist, 1872) characterises Mol F4 only, *Ervilia pusilla* (Philippi, 1836), *Lentidium donaciformis* (Cossmann & Peyrot, 1914) and *Actaeocina lajonkaireana* (= *A. spirata* (Brocchi, 1814) here) occur in F4 and reappear in Mol H. This Mol H, however, also contains species, characteristic of older Miocene deposits, such as *Patinopecten brummeli* (Nyst, 1864), *Lembulus emarginatus* (Lamarck, 1819) and *Conus clavatulus* d'Orbigny, 1852. These species are absent from our material. So a correlation with Mol F4 seems most appropriate. Their zone Mol G contains two species, *Eudolium dingdense* Anderson, 1964 and *Aquilofusus festivus* (Beyrich, 1856), (both also marker species for the early Middle Miocene "Reinbek Stufe"), which are absent in borehole Maaseik. For this reason a correlation with Mol F4 seems most appropriate. Mol F4 corresponds with the foraminiferal zone FC2B, which according to Doppert et al. (1979) characterizes the Upper Miocene Diest Formation by the presence of *Uvigerina hosiusi deurnensis*.

Gürs (2002) divided the German Miocene by means of the occurrence of members of the Gastropod family Nassariidae. All species of the genus *Nassarius* present in the Maaseik boring are according to this paper typical of the Reinbekian, Early as well as Late. The Turridae, found in Maaseik and new to the Miocene of Belgium, were however described by Gürs (2001) from the Pinneberger Schichten, which have a Gramian-Syltian or Late Miocene age. Also *Alvania curta nieheimensis* Hinsch, 1972 (Rissoidae) is a Reinbekian species.

Bela ankae (Gürs, 2001) is the first species of its genus to appear in the North Sea Basin, in which it will have a marked evolutionary diversification during the Pliocene (see Marquet, 1997c).

3.4.6. Conclusion

The best match for the upper part (200-239 m) of the Maaseik boring according to its molluscan fauna is the Mol F4 zone in The Netherlands. The lower part, slightly overlapping with the upper part (232-298 m), could correspond to the Ramsel fauna, which is Reinbekian-Hemmoorian in composition and comes close to the Antwerpen-Zonderschot Members.

4. General Conclusions

At the very top of the Maaseik borehole, the Saalian to Pleni-Weichselian Meuse river gravels occur (Lanklaar

Formation), with a thin cover of Pleni-Weichselian fluviolacustrine to eolian loam deposits (Molenbeersel Member). The base of these Pleistocene deposits occurs at 22 m depth.

The main mass of quartzic pale grey sands below, with base at 193 m depth, is known as the Kieseloolith Formation. It contains four lignite and clay-rich lignite horizons. Palynological associations divide this Kieseloolith Formation in two parts at 57.6 m. The upper association shows a wooded landscape with extensive enclosed mires, open enough to allow light demanding plants to grow. The lower association shows a denser forest landscape with less extensive mires.

Clear increase of *Sequioa* deeper than 87.5 m could be linked to the Brunssumian (Pliocene, Zanclean) as characterized by Zagwijn (1960), although according to the palynology also this part of the section is preferably interpreted as Reuverian. The association in the top of palynozone A between 87.5 and 57.6 m is similar to the palynology of the lignites in the Mol Sand lignite to the west.

The upper association A can be correlated with the latest Reuver C (Pliocene, Piacenzian).

Based on the occurrence of the lignite horizons and the grain-size properties of the sands, the Waubach, Pey, Schinveld/Jagersborg units have been identified as well as the Brunssum and Reuver Clays. This traditional lithostratigraphic subdivision of the Kieseloolith Formation in the area, is not entirely corresponding to the palynological interpretation in this study. The palynology suggests a Reuver-Pliocene age for the whole section whilst in the Dutch stratigraphic nomenclature the Waubach Sand unit is considered as Susterian of Upper Miocene age; only the moderate increase in *Sequioa* below 90 m depth is supporting a possible Brunssumian age for this lower part of the Kieseloolith Formation, an interpretation in line with the lithostratigraphic interpretation of Brunssum clays and intercalated Pey Sands in the borehole.

The thin pale yellowish gray mica-rich marine sand unit X between 193 m and 198 m, could not unequivocally be linked to any known lithostratigraphic unit in the area. Based on dinoflagellate content comparison with the Nieder Ochtenhausen borehole a Syltian uppermost Miocene age is proposed.

The marine Breda Formation below extends till the total depth of the borehole at 302 m. Biostratigraphically an upper part, approximately above 235 m, can be distinguished in this formation which based on molluscs, dinoflagellates and calcareous microfossils, ressembles the biostratigraphic content of the Deurne Sand (Diest Formation, Upper Miocene, Tortonian). Similarly a lowest part below approximately 275 m, can be distinguished which based on molluscs and dinoflagellates corresponds to the Berchem Formation, best comparable to the Antwerp, Zonderschot Members; the dinoflagellate zones
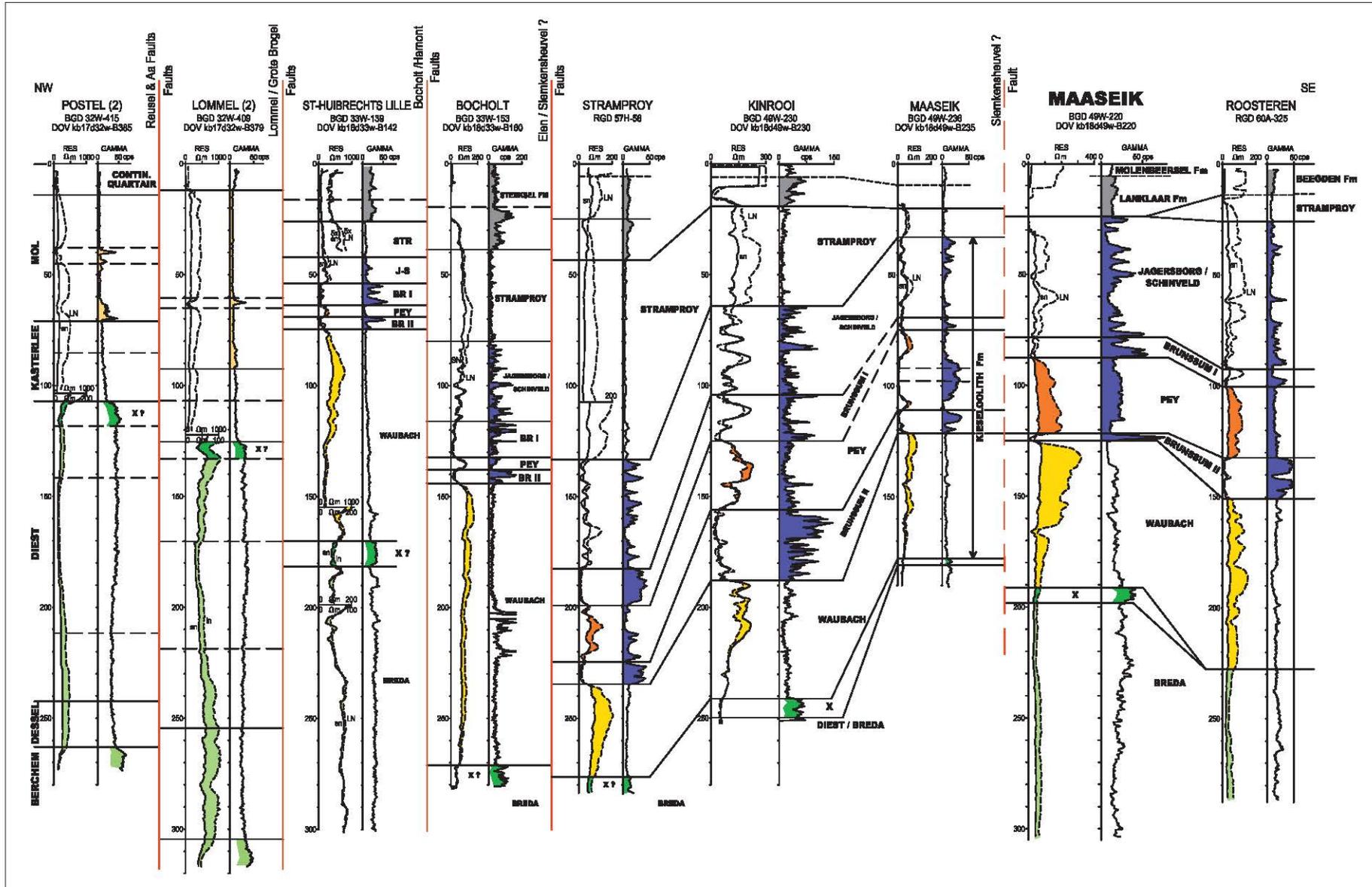
Figure 10. Resistivity and gamma-ray logs in selected boreholes in the Rur Valley Graben in northeast Belgium and the southeast Netherlands, are illustrating the regional correlation of the detailed study in the Maaseik borehole (49W0220). The origin of the different lithostratigraphic names are explained and justified in the text.

recognized in this interval in the Maaseik borehole correspond to a Middle Serravalian age. The interval in between these upper and lower parts in the borehole contains dinoflagellates and molluscs which have not been identified before in the Belgian Campine area.

Acknowledgements

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