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REFINED CORRELATIONS BY MEANS OF LITHOSTRATIGRAPHY AND GADID OTOLITH ZONATION OF THE RUPELIAN OF THE NORTH SEA BASIN : A PROGRESS REPORT

by

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ABSTRACT

The otolith zonation for the Rupelian (in wide sense, including the Late Tongrian Ruisbroek Sands) has been extended with five zones, comprising nine zones now. The new zones are mainly based on new members of the *Parvicolliolus* lineage. The frequency of otoliths in Rupelian sediments is usually low due to poor conditions in most marine environments. A high abundance of otoliths is often remarkable in horizons within the septaria clay with the highest concentrations of calcium carbonate in calcareous intervals and in calcareous beds intercalated in lime-free intervals. These highly calcareous beds usually also contain septaria nodules. The large numbers of otoliths in these beds are strong evidence of very reduced sedimentation rates and are additional proof of an originally carbonate rich sedimentation in levels containing septaria.

Correlation of the septaria levels has been established between the borehole for the storm weir and the boreholes for the underground railway under the River Scheldt at Antwerp. By this the "standard" septaria numbering system in Belgium is enlarged to 20 beds comprising S10 up to and including S160. Based on litho- and biostratigraphical data a new correlation between the "standard" septaria numbering and the septaria levels in the Winterswijk area in the eastern part of the Netherlands is proposed.

The changes in the correlations lead to several conclusions, including the absence of a supposed hiatus between S70 and S80 at Kruibeke, the stratigraphically higher position of the probably larger local hiatus of the *Aturia* horizon at Winterswijk, the stratigraphically more extensive development of the septaria clay at Winterswijk and the lower sedimentation rates in the higher part of this clay there, and the clearly older age of the Kleine Spouwen Member (Nucula Clay) with respect to the base of the Terhagen Member.

KEY WORDS

North Sea, Rupelian, lithostratigraphy, otolith zonation, correlation, type area, eastern extension.

1. INTRODUCTION

During most of Rupelian (Middle Oligocene) time the North Sea Basin was occupied by an extensive sea in which special circumstances prevailed. Comparable environmental conditions existed in this basin during the Ypresian (Early Eocene) and Langenfeldian (late Middle Miocene) stages. Sedimentation of clays, marls and silts occurred over large areas, not only in deeper, but also in shallower parts of the shelf area. These fine-grained deposits are relatively rich in organic matter. From this it can be concluded that only weak tidal and other currents existed, and that large parts of the basin had stagnant water conditions, causing stratification in the water column. As a result low oxygen levels occurred at and near the sea floor, also in relatively shallow water (see Moorkens for a more comprehensive treatment of the subject). Consequently most of the sea could yield only a low productivity of nearly all kinds of benthonic life including the (sub)top of the food pyramid, the near-bottom fishes. These

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fishes did not only occur in relatively small numbers, but most species remained also small in size.

Only along the edges of the sea, in the shallowest waters, there was enough oxygen and food available for abundant benthonic life and near-bottom fish production. One such a prolific, shallow marine deposit is the Kleine Spouwen Clay Member in Belgian and Dutch Limburg, formerly called Nucula Clay, which has been formed in sheltered circumstances. This very silty and fine-sandy deposit contains a peculiar otolith assemblage which is much richer in species than known from the literature (Nolf, 1977 ; Gaemers, 1985b). Species typical for very shallow waters, viz. the grunt Pomadasyidarum *pouwi* (Van Hinsbergh, 1980) and the shad "*Alosa*" *atuatucae* (Van Hinsbergh, 1980), occur together with species of which recent relatives live near the bottom of the continental slope, such as the hake *Palaeogadus compactus* Gaemers & Van Hinsbergh, 1978 and the scabbard-fish Trichiuridarum *wongratanai* Nolf, 1977. Apart from many normal, near-bottom shelf species further constituents of this fish fauna are the silver smelt *Argentina parvula* (Koken, 1891), a common species of which recent relatives live mesopelagically above the continental slope, and a barrelfish, "*Mupus*" *neumanni* (Schwarzhans, 1974), a member of the pelagic and oceanic centrolophid family.

This strange otolith assemblage can impossibly be the result of mixing of different biocoenoses due to transportation of otoliths from various environments, because deposition took place in quiet, protected circumstances. This still largely unpublished fish fauna probably is the best evidence of oxygen-poor and even anoxic conditions deeper in the Rupelian sea. Deeper (near-) benthonic and deeper mesopelagic species apparently could not live at their normal depth during the Rupelian and were forced to live much shallower due to the low oxygen concentrations.

The presence of molluscs, foraminifera, etc., of which recent relatives live in deep to very deep seas has misled many palaeontologists in the past and has given rise to much too high estimates for the depth of the Rupelian North Sea. Brouwer (1977) for instance came up with estimates of more than 300 up to 500 m depth of this sea in the southeastern part of the Netherlands based on foraminifera. For a more elaborate discussion on Rupelian palaeodepths see Gaemers & Van Hinsbergh (1978, p. 40).

2. MATERIAL AND METHODS

The above explains why otoliths (and other meso- and macrofossils) are usually rather rare in Rupelian sediments. Septaria clays often contain less than one otolith per kilogram of dry sediment. Large samples of at least 20-25 kilogram therefore are necessary to discover and define biozones. It is not easy to process large quantities of the heavy Rupelian clays. Therefore one has to put fresh lumps of the clay in buckets of high quality plastic which are in use with construction works. The lumps must be so fresh that they still contain the pore water. The buckets are placed in a deep freezer for about 24 hours, so that all the pore water becomes ice, its expansion destroying the structure of the clay. Thawing the sample goes best by putting the clay under tap water for about one day. Finally the clays are sieved with a 0.3 mm mesh. If the desintegration of the clay has not yet been completed the process should be repeated.

The continuous sampling of large samples from the Gralex clay pit at Kruibeke, south of Antwerp in Belgium, provided the material for a good base of a more detailed and more accurate biozonation of the Rupelian. The zonation was extended by studying otoliths from older and younger, often partly overlapping sections from borings and exposures in the eastern part of the Netherlands and Belgium.

Otoliths belonging to the *Parvicolliolus* lineage are far the most common ones in Rupelian shelf deposits. They are only absent in the oldest sediments of this stage because the lineage apparently started some time after the beginning of the Rupelian. Combined with the fact that this lineage underwent rapid evolution the successive members of the lineage are very good index fossils.

Because of low sedimentation rates during deposition of the septaria clay, samples of short intervals are prefered. As a starting point samples from each half metre seem to be sufficient, but when the beds introduced by Vandenberghe (1978) are thinner, a sample from each bed is more appropriate, although from boreholes a large sample might only be available every meter.

It is very important to collect really fresh septaria clay samples. This clay always contains a lot of fine-crystalline pyrite, present in aggregates or dispersed through the sediment, which oxidizes rapidly when exposed to the air. The disengaged sulphuric acid rapidly dissolves (or at least severely attacks) the calcareous fossils, thus also the aragonitic otoliths. Therefore, in exposures samples should always be taken from walls where excavation of the clay is in progress.

3. IDENTIFICATION AND EVOLUTION OF INDEX SPECIES

The otoliths which are best suited for setting up a biozonation for the northwestern European Rupelian belong to the genus *Parvicolliolus*. The otoliths of this genus are small : their known maximum length ranges from 1.8 mm to about 3.5 mm. The ratio between otolith length (OL) and total fish length (TL) in living small cod species is of the order of magnitude of 1:15 to 1:20. It is therefore unlikely that fishes belonging to *Parvicolliolus* would have exceeded a total lenght of about 3.5 to 7 cm. So they were very small cods with about the lowest position in the food webb possible for fish. Therefore it is not surprizing that they could afford to be so numerous compared to other Rupelian fishes. In unweathered clay samples *Parvicolliolus* otoliths rarely account for less than 50 % of the specimens in a Rupelian otolith assemblage, and their share can rise to more than 90 %. Apart from being relatively very abundant, their rapid evolution, their widespread distribution in Rupelian shelf seas and the good fossilisation potential of their otoliths make *Parvicolliolus* otoliths a very good biostratigraphic tool.

All *Parvicolliolus* otoliths belong to one gradually evolving lineage which at this moment can be splitted into eight successive evolutionary stages within the Rupelian. There is of course always some problem to assign intermediate forms to a certain evolutionary stage, and populations of each evolutionary stage always display a certain variability, but experience has shown that there are no serious difficulties with the identification of most specimens.

Conventionally the successive evolutionary stages are called species by most palaeontologists and I followed this practice up to now. But from a taxonomic point of view it is probably better to regard a whole lineage as one species, and the successive stages as subspecies or morphotypes. This is however a matter of definition which is not really important for biostratigraphy.

How do we recognize the different evolutionary stages ? Shape and size are both important, because both are changing through time. Moreover, otoliths always grow allometrically, so they also change their shape during growth. Therefore it is necessary to study and to illustrate all specimens of a species at the same

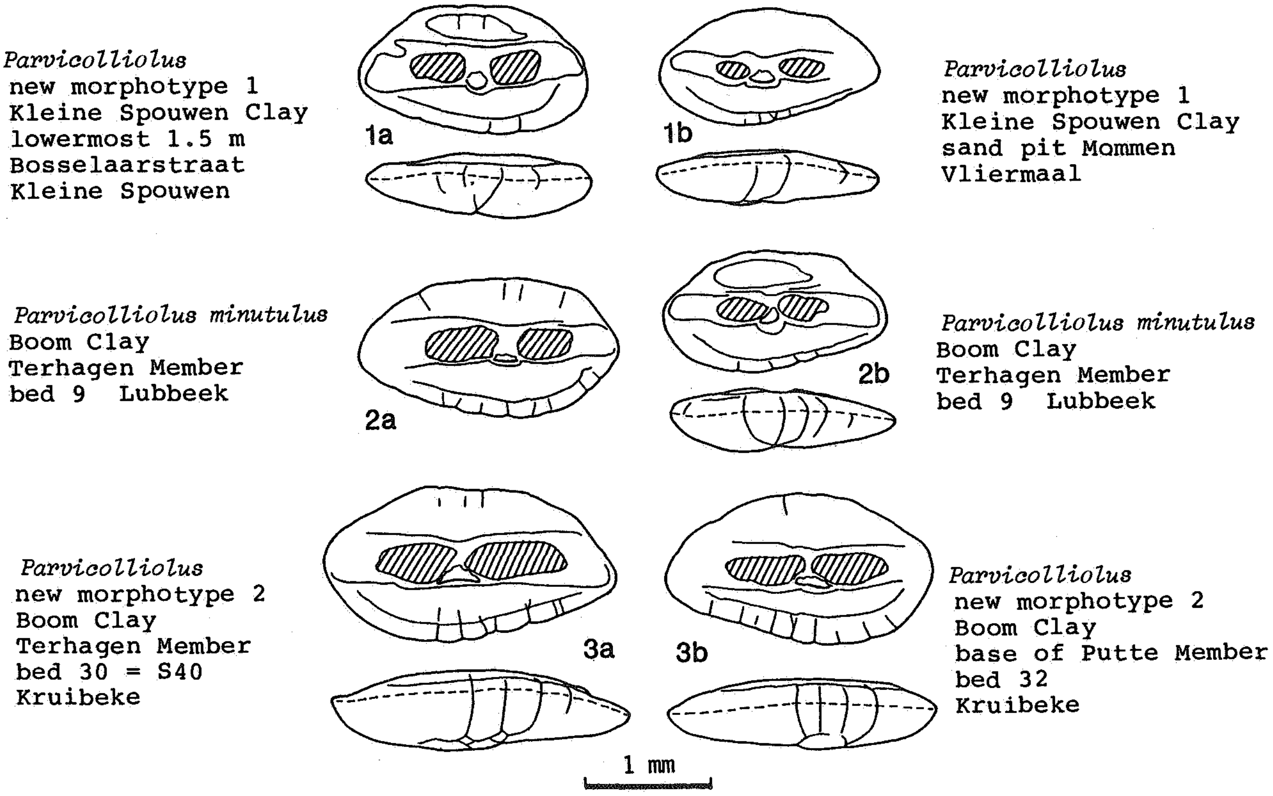

Figure 1. Comparison of full-grown otoliths of *Parvicolliolus* new morphotype 1 and *P. minutulus* (specimens 1a, 2a) with somewhat smaller ones of the same species (specimens 1b, 2b). Note the changes in overall shape and in shape and size of the colliculi (hatched areas).
Example of infraspecific variability in *Parvicolliolus* new morphotype. Specimen 3a is a full-grown, relatively slender otolith ; specimen 3b is a nearly full-grown, but more thickset otolith.
Specimens 1, 2b and 3 give inner surfaces and ventral views of the otoliths, specimen 2a only the inner surface.

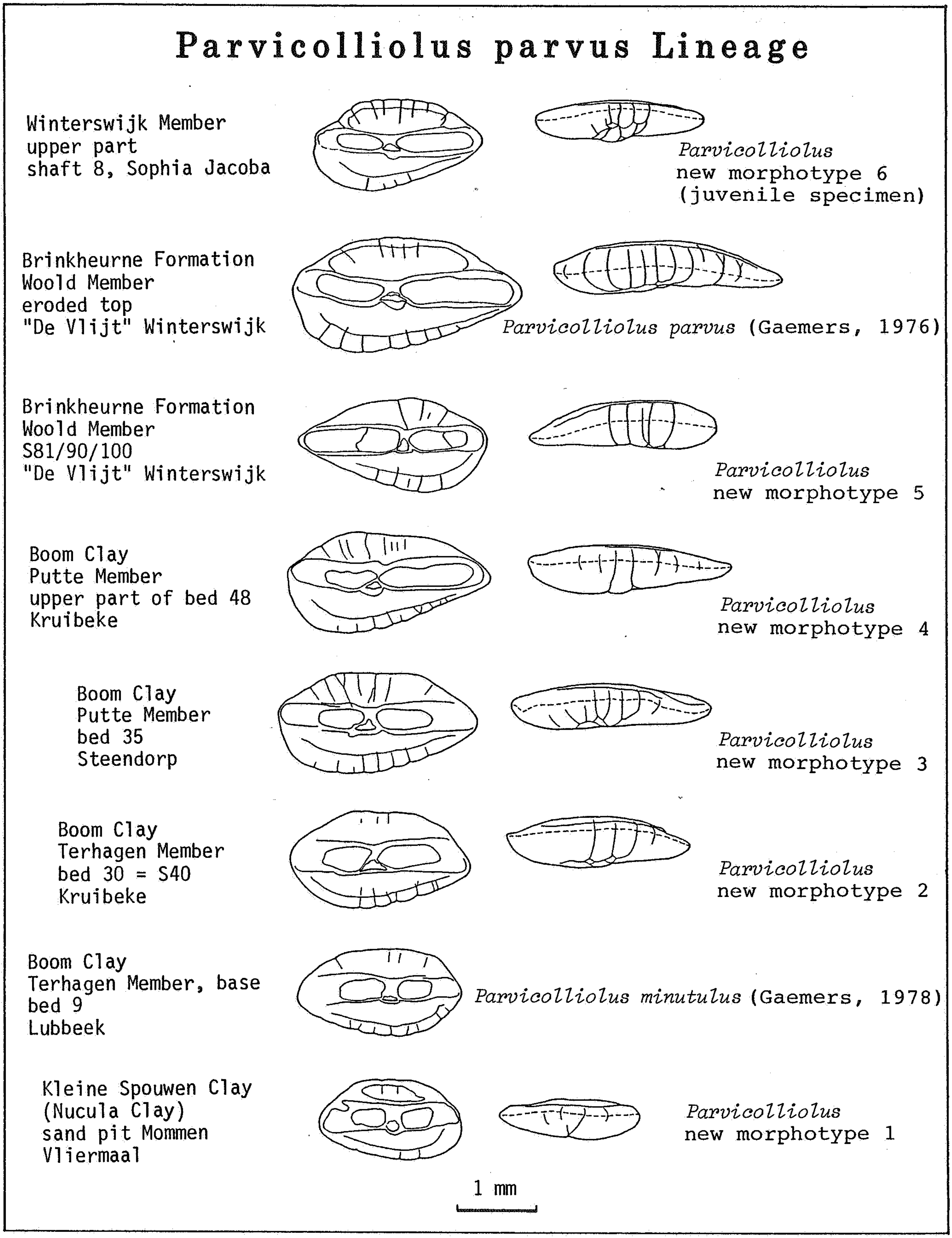

Figure 2. Schematic illustration of the evolution of the *Parvicolliolus parvus* lineage. Inner surfaces of the otoliths to the left of the ventral views of the same specimens. Entirely on the left are the lithostratigraphic data belonging to the illustrated otoliths.

magnification.
Absolute size is one important factor. Every evolutionary stage has its own characteristic maximum size. When several hundreds of specimens are available the largest ones that are present are usually close to the maximum size. It is fortunately possible to find a good approximation of the maximum size through another channel requiring much less specimens. Not only the overall shape is changing during growth, but also several details on the surface of otoliths. The best criteria to recognize full-grown otoliths are the proportionally greater width of the sulcus acusticus and the comparatively larger and better developed colliculi in the sulcus compared to earlier ontogenetic stages.

Shape at various sizes is another important factor. Allometrical growth necessitates the study of otolith growth series of each evolutionary stage of the lineage. Comparison of otoliths of the same size, but belonging to different evolutionary stages (= successive species) always show important differences in overall shape and in details on the surface of the otoliths. Only the smallest otoliths can not be distinguished and identified at the species level, but such tiny specimens rarely fossilize. Due to their relatively larger surface with respect to their volume and due to their small mass they dissolve much more rapidly in stomachs of predators or afterwards in the sediment (Gaemers, 1977).

The evolution of the *Parvicolliolus* lineage is illustrated in figs. 1, 2 where inner surfaces and ventral views of otoliths of the successive morphotypes are given. As yet only two species have been described. For a good comparison of the successive morphotypes and a clear picture of the general trend in the evolution it should be the best to figure only full-grown otoliths, but this is unfortunately not yet possible for each morphotype. *Parvicolliolus* morphotypes 5 and 6 are half-grown otoliths ; only up to half-grown specimens of morphotype 5 are available and the illustrated juvenile specimen of morphotype 6 is the only known otolith of this species at present.

The general trend in the evolution of *Parvicolliolus* agrees with that in most other cod lineages. The lineage starts with the smallest, most compactly built otoliths. Up to and including morphotype 4 they change into larger, more slender morphotypes. The descendants of the latter species do not seem to change essentially in size anymore, but they become more thickset again. The rate of evolutionary change is high from morphotype 1 to morphotype 5 and diminishes strongly after that.

Another general trend can be seen in the size and shape of the colliculi, the small cushions in the sulcus. They are small and rounded to oval in shape in the oldest stages of the lineage changing into larger, longer and more elongate shapes. There is a fairly rapid change in this development between morphotypes 3 and 4, so that the oldest four *Parvicolliolus* species can easily be distinguished from the youngest four by means of the colliculi.

4. RUPELIAN OTOLITH ZONATION

In the last published version of the gadid otolith zonation (Gaemers *in* Vinken, 1988) the Rupelian taken in the wide sense, including the Ruisbroek Sands, was subdivided in four zones : the *Palaeogadus ruisbroekensis* Range Zone and the *Parvicolliolus minutulus, P. biocellatus* and *P. parvus* Lineage Zones. The species *P. biocellatus* has not yet been published and is identical with *Parvicolliolus* morphotype 3 in this paper.

It is possible now to recognize nine otolith zones within the same Rupelian interval, mainly thanks to the recognition of five new species belonging to the *Parvicolliolus* lineage. Full description and definition of the new otolith zones will be presented in a coming paper together with the description of the new species. The provisional zones are given in table 1 in which the known lithostratigraphic intervals of the otolith zones in Belgium and the Netherlands are indicated, as well as the intervals from which the index fossils are still unknown.

A continuous record of *Parvicolliolus* otoliths is known from a large part of the Kruibeke section. Large samples taken from every half meter of this section in the Gralex clay pit furnished identifiable *Parvicolliolus* otoliths from bed 23 up to and including bed 63, covering the *Parvicolliolus* morphotype 2-4 zones. Bed numbers are, as always, according to Vandenberghe's beds and some beds are thinner than half a meter. Establishment of the zonation is still impossible for beds 34 and 40 ; new samples from the Kruibeke pit from these levels are necessary.

The *Parvicolliolus minutulus* Zone is known from the Sint-Niklaas clay pit in the province of East Flanders in Belgium, from the Roelants sand pit at Lubbeek (province of Brabant in Belgium) and from several boreholes in the Winterswijk area (Achterhoek, province of Gelderland in the Netherlands). The Kleine Spouwen Clay (=Nucula Clay) in the Tongeren area in the province of Limburg in Belgium and in southern Limburg in the Netherlands belongs to the *Parvicolliolus* morphotype 1 zone. From the Berg Sands in

Lithology zoned	Gadid otolith zones	Lithology not yet zoned
upper part of Winterswijk Member at least 14 m (409-423 m of Sophia Jacoba shaft 8	*Archaegadiculus* n. sp. Range Zone	
		large, unknown thickness
Boom Clay/Brinkheurne Fm. 0.5 m above S110 - at least 1.5 m of base Winterswijk Member	*Parvicolliolus parvus* Lineage Zone	
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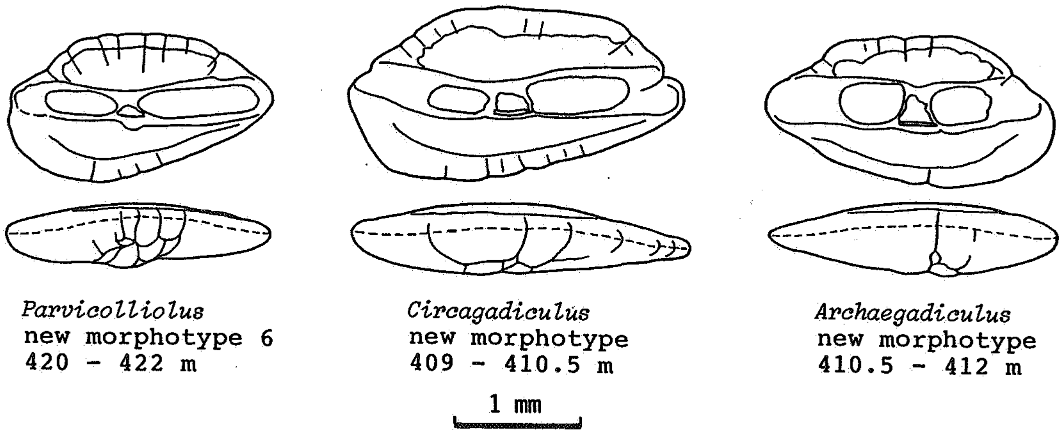
Boom Clay/Brinkheurne Fm. bed 68 (just below S80) - 0.5 m above S110	*Parvicolliolus* morphotype 5 Lineage zone	
		beds 64 - 67 (ca. 2 m)
Boom Clay/Brinkheurne Fm. beds 41 - 63	*Parvicolliolus* morphotype 4 Lineage zone	
		bed 40 (ca. 50 cm)
Boom Clay/Brinkheurne Fm. beds 35 - 39	*Parvicolliolus* morphotype 3 Lineage zone	
		bed 34 (ca. 20 cm)
Boom Clay beds 23 - 33	*Parvicolliolus* morphotype 2 Lineage zone	
		beds 15 - 22 (ca. 6 m)
Boom Clay beds 9 - 14	*Parvicolliolus minutulus* Lineage zone	
		beds 1 - 8 (ca. 8 m)
Kleine Spouwen Clay	*Parvicolliolus* morphotype 1 Lineage zone	
Berg Sands	?	Berg Sands
Ruisbroek Sands	*Palaeogadus ruisbroekensis* Range zone	

Table 1. Gadid otolith zonation and its relation to Rupelian lithostragigraphy as far as presently known.


Parvicolliolus new morphotype 6 420 - 422 m

Circagadiculus new morphotype 409 - 410.5 m

Archaegadiculus new morphotype 410.5 - 412 m

Figure 3. Comparison of inner surfaces and ventral views of gadid otoliths from the upper part of the Winterswijk Member in shaft 8 of coal mine Sophia Jacoba at Erkelenz, Lower Rhine District, Germnay. Depths below surface are indicated for each otolith.

Belgian Limburg only two *Parvicolliolus*-like otoliths were found. Unfortunately these specimens are trackless at this moment, and their former identification as *Parvicolliolus* is questionable. The *Parvicolliolus* morphotype 5 and *P. parvus* zones are best known from clay pit "De Vlijt" at Winterswijk and from boreholes in the Achterhoek. Finally the *Archaegadiculus* morphotype zone at present is only known from shaft 8 of the Sophia Jacoba coal mine near Erkelenz ; *Parvicolliolus* morphotype 6 has not been used as the index fossil for this zone, because it is much more rare than *Archaegadiculus* morphotype which is now the oldest known member of that lineage.

The presence of *Archaegadiculus* and *Circagadiculus* (fig. 3) in the youngest known Rupelian deposits belonging to the Winterswijk Member gives hope for a complete and well-defined otolith zonation across the Rupelian-Chattian boundary in the future, because these two genera are represented in large parts of the Chattian sequence.

The duration of the Rupelian otolith zones can differ to a large degree. The *Parvicolliolus* n. sp. 3 Lineage zone covering only a few beds of Vandenberghe's numbering system probably comprises the shortest time interval. The *P. parvus* Lineage zone covers a very long period of time due to the low evolutionary rate in this part of the lineage.

5. CORRELATIONS

Correlations by means of otolith zones and reconsideration of lithological correlations between Belgium and the eastern part of the Netherlands make it necessary to revise earlier correlations by Van den Bosch (1984), Gaemers (1985a) and Van den Bosch & Janssen (1990).

The septaria clay consists of an alternation of more clayey and more silty to fine-sandy beds. On this alternation Vandenberghe (1978) has based his bed numbering system. Another, much more irregular alternation apparently not related to the former one is formed by more or less bituminous beds. A third important variability is the calcium carbonate content of the sediment (calcareous fossils not included !). The highest concentrations of calcium carbonate are in the beds containing septaria. Vandenberghe (1978) introduced a septaria numbering system which was extended by Vandenberghe & Laga (1986). Observations by Vandenberghe (1978), Van den Bosch (1984) and Vandenberghe & Laga (1986) made it clear that many, if not all, septaria levels have their own, special characteristics. The septaria nodules can be recognized by means of differences in size, shape, colour and hardness, numbers per surface unit, presence or absence of pyrite, calcite and siderite crystals in the shrinking fissures, burrows, fossil content, etc. The septaria maintain their specific features over large distances, so that they can be used as first-class lithostratigraphical markers. A nice example is the presence of the S40 in a clay pit at Vechta (Lower Saxony, Germany) containing the same large septaria with yellow to brownish ferroan calcite as in the type area around Boom in Belgium. The uniformity of deposition of septaria clays and silts within the North Sea Basin can be demonstrated by the possibility to recognize many of the beds numbered by Vandenberghe over large distances, at least from the type area in Belgium to the eastern part of the Netherlands (Van den Bosch, 1984), but probably even much farther. Septaria beds are always in the same place of this microstratigraphical sequence in carbonate-rich beds and may therefore also be considered chronostratigraphical markers.

There is, however, only a small chance to find fragments of septaria in borehole samples, so that precise correlations by means of septaria characteristics are usually restricted to exposures. The position and approximate number of septaria levels in boreholes in most cases can only be demonstrated by a high content of calcium carbonate of the sediment in closely spaced samples, preferably from every 25 cm. Since the detailed stratigraphy of the Rupelian in the Winterswijk area necessarily had to be based mainly on borehole sections (Van den Bosch, 1984), the transmission of large parts of the numbering system of septaria levels from the type area in Belgium to the Winterswijk region remained difficult.

Another serious difficulty is the absence of exposures in the Boom Clay in Belgium above septaria level S80. Hence the alternation of more clayey and silty beds is less well-known above this horizon (Vandenberghe's bed numbering system does not stop by accident just below the S80 with bed 68 !), and also the characteristics of the higher septaria nodules are poorly known in Belgium. When preparing this paper I discovered a great problem : there are large discrepancies between the Boom Clay section in the River Scheldt near Antwerp published in Van den Bosch (1984 ; see enclosure 3 in that paper) which was also used for the composite section in Van den Bosch and Janssen (1990), and the reconstruction of the septaria levels by Vandenberghe and Laga (1986) compiled of 50 boreholes made for the underground railway under the River Scheldt at Antwerp : two different septaria numbering systems were used. The Boom Clay section given in Van den Bosch (1984) was drawn from a cored borehole made for a storm weir in that same river some-

Correlation of Rupelian Septaria levels

"Standard" Septaria Numbering System in Belgium (enlarged after Vandenberghe 1978 and Vandenberghe & Laga 1986)	Septaria numbering in Winterswijk area (Van den Bosch & Janssen 1990)	Septaria numbering in borehole for storm weir in River Scheldt near Antwerp (after Vandenberghe, in Van den Bosch 1984)
S160	= unknown	= S12
S150	= unknown	= unknown
S140	= S10	= S11
S130	= calcareous level between S9 and S10 (in: Van den Bosch, 1984)	= unknown
S120	= S9	= S10
S110	= calcareous level between S8 and S9	= unnumbered S-level between S9 and S10
S100	} S8	= S9
S90		= unknown
(S81)	= S7	= unknown
S80	= calcareous level between S7 and unnumbered S-level between S6 and S7	= S8
(S71)	= unknown	= unknown
S70	= unnumbered S-level between S6 and S7	= S7
S61	= S6	= unknown
S60	= unnumbered S-level between S5 and S6	= S6
S50	= S5	
S41	= (S41)	
S40	= S4	
S30	= S3	
S20	= S2	
S10	= S1	

Table 2. Correlation of septaria levels in the Rupelian of Belgium and The Netherlands. The "standard" septaria numbering system from S60 up to and including S150 has been based on the boreholes for the underground railway under the River Scheldt at Antwerp published by Vandenberghe & Laga (1986) ; from S10 to S60 this system has been based on Vandenberghe (1978) ; S71, S81 and S160 are numbers introduced here for the first time.

what to the north of the boreholes for the underground (Vandenberghe, personal communication).

There is a good fit between the S60, S70 and S80 of both sections. The correlation of the basal part of both sections made it possible to fix their mutual position entirely. By this the S9(0), S10(0) and S11(0) in the storm weir section proved to correlate surprizingly well with the S100, S120 and S140 in the underground boreholes, respectively. The intermediate septaria levels S90 and S130, as well as the S150, apparently had not been recognized in the storm weir section. In this section the S110 was found between the S9 and S10, but it did not receive a number. The S12 in the same section proved to be a higher, younger septaria level which is absent in the sections for the underground. This septaria level did not yet receive a number in the "standard" septaria numbering system, so I give it number S160 here. The full correlation scheme is presented in table 2.

The detailed otolith zonation now available makes it possible to check earlier septaria level correlations between Belgium and the Netherlands. Combined with the vertical distribution of bituminous horizons, the distance between the septaria horizons, and known characteristics of septaria nodules, the correlations between Belgium and the Netherlands given in table 2 seem the most likely ones. The highly bituminous interval between S120 and S140 at Antwerp and between the former S9 and S10 at Winterswijk, as well as the (nearly) complete absence of bituminous horizons between the S100 and S120 at Antwerp and between the former S8 and S9 at Winterswijk, were especially helpful as markers.

The correlation of septaria levels S10 up to and including S50 (or S1 to S5) is correct, but above the S50 a shift occurs leading to a leap of up to four levels. It appears that several septaria levels in the Winterswijk area which were less known and did not receive a number had already been included in the Belgian numbering system. On the other hand, one septaria level, the former S7 in the Winterswijk area, has not yet got a number in the Belgian series and has therefore been placed between brackets in table 1. It is introduced here as the S81 and it is considered to be identical with the septaria level indicated between S80 and S90 in Vandenberghe and Laga (1986, fig. 4). The same authors indicate an unnumbered septaria level between S70 and S80. I give it number S71, and it is between brackets for the same reason as the S81. Septaria level S41 has not yet been indicated in publications of Van den Bosch in the Winterswijk area (therefore it is also between brackets), but a level with a high content of calcium carbonate is known in the right place between S4 and S5 in several boreholes in that area.

The result of the changes in the correlations is that the septaria clay in the Winterswijk area turns out to comprise a larger time span than thought before. Another consequence is that between levels S50 and S140 the distances between successive septaria levels in that area is more reduced than earlier indicated.

The local hiatus in the Winterswijk area apparently is situated between S81 and S100, not between S70 and S80 (S7 and S8) as published by Van den Bosch and Janssen (1990). The levels S70 and S80 in Belgium are characterized by small septaria nodules, with few septaria in S70 and many in S80 (Vandenberghe and Laga, 1986) , in contradistinction to the so-called S7 and S8 in the Winterwijsk area which both contain many large and thick septaria (Van den Bosch, 1984) ; the characteristics of the corresponding S81, S90 and S100 in Belgium are, however, still unknown.

The absence of the nautiloid *Aturia* sp. in Kruibeke is not due to a hiatus immediately above S70 as assumed by Van den Bosch and Janssen (1990), but simply because the *Aturia* horizon which in the Winterswijk area corresponds with the interval between S81 and S100, is situated above the highest Rupelian beds exposed in the Gralex clay pit at Kruibeke. The lowest known occurrence of the pteropod *Limacina umbilicata* in the Winterswijk area turns out to be around the S90, not at the S80 as assumed by Van den Bosch and Janssen (1990). The lowest find of this pteropod in the Kruibeke section somewhat above the S70 by the same authors is not a valid argument for the presence of a hiatus between S70 and S80 there. The earlier start of *L. umbilicata* at Kruibeke probably is the result of deeper water or better current conditions than at Winterswijk. The only reason why this pteropod has not been found starting in the same horizon probably is that it is rarer at Winterswijk in the lowest levels. All palaeontological arguments put forward by Van den Bosch and Janssen (1990) thus fail to prove the existence of an important hiatus above S70 at Kruibeke. Although it is difficult to recognize all beds numbered by Vandenberghe between S60 and S70 at Kruibeke, solid lithological data for an important hiatus do not exist in the Kruibeke section. This section is considered a continuous series in which no septaria levels are missing, what is in agreement with Vandenberghe's earlier conclusions.

The thicknesses of the intervals between S30 and S40 and between S50 and S70 have been clearly reduced at Kruibeke in comparison with all known sections in the Winterswijk area. On the other hand reductions in thickness occur in the Winterswijk area between S70 and S120 as compared with the Scheldt boreholes at Antwerp (Vandenberghe and Laga, 1986). In its most extreme case this reduction leads to amalgamation of septaria levels S81, S90 and S100 (of which only two are visible) into only one septaria level which has been observed at some places in the clay pit "De Vlijt" at Winterswijk (Van den Bosch, 1984). The same author noticed a distance of about 1.5 m between these septaria levels in restricted parts of the same clay pit. Where these septaria have been fused to one level, a hiatus or at least a strongly condensed sequence exists. A strong paleontological argument for very slow sedimentation rates at this point of the section is that the sediment between the numerous septaria is extremely rich in otoliths and fish bones.

Also in the case of normal development of septaria levels, when no fusion of septaria horizons has taken place, it is striking that one can often find distinctly higher numbers of fish otoliths in the sediment between the septaria nodules than in other beds without septaria. Strikingly high numbers of otolihts are for instance known from the S10 (bed 9) in the Roelants pit at Lubbeek (Gaemers, 1985a), from the S40 (bed 30) in the clay pit at Putte in Belgium (S. Ritzkowski, personal communication), from the S41 (top of bed 41) in the clay pits at Terhagen and Schelle (Steurbaut and Herman, 1978) and at Kruibeke (own observations), and from the S50 (bed 49) in the same three clay pits (Steurbaut and Herman, 1978, and own observations). In bed 35 in the clay pits at Steendorp, Terhagen and Schelle (Steurbaut and Herman, 1978) and at Kruibeke (own observations) very large numbers of otoliths were found too. Septaria nodules have not yet been found in this bed, but the calcium carbonate content is high there

(Van den Bosch and Janssen, 1990). It would not be a surprise when somewhere septaria nodules in this level will be found.

The relatively high concentrations of otoliths in septaria beds and some other beds rich in calcium carbonate are good evidence for very low sedimentation rates during deposition of these beds. This reinforces the conclusion of Vandenberghe and Laga (1986) that these carbonate rich beds represent an originally carbonate rich sedimentation which has not been generated by diagenetic precipitation horizons. The reason why these beds are so rich in calcium carbonate simply must be the temporarily very low supply of clay and silt in the basin.

A distinct calcium carbonate content, however, is not automatically an indication for low sedimentation rates. The lower part of the Kotten Member in the Netherlands and its equivalence, the lower part of the Terhagen Member in Belgium, as well as the lower part of the Woold Member in the Netherlands and, to a much lesser degree, its counterpart, the lower part of the Putte Member in Belgium, show a more or less continuous presence of calcium carbonate of which only the highest concentrations are representative of septaria levels (Van den Bosch, 1984). According to M. van den Bosch (personal communication) the calcium carbonate content in these intervals in most cases is only an indication of shallower sea depths opposed to deeper water conditions in intervals in which only the septaria horizons are calcareous. The deposition of calcium carbonate in detectable quantities while sedimentation rates are normal or even rather high, can be explained by clearly higher water temperatures in shallower depths. Due to the stratification of the water column much older water is occurring not very much deeper. The trend in water depth changes suggested by Van den Boch is comparable, but not exactly the same, as the trend found by Van Echelpoel (1991, fig. 3.29) using a smoothed curve of the percentage of sediment grains larger than 32 µm.

The absence of septaria levels S150 and S160 in the Winterswijk area can be explained by a distinct hiatus between the Woold Member and the Winterswijk Member (Van den Bosch, 1984 ; Van den Bosch and Hager, 1986). It is highly likely that the top of the Woold Member and at least at many places also the base of the Winterswijk Member are missing there.

The correlation of the base of the Boom Clay at Lubbeek, the S10 (bed 9), with the top of the Nucula Clay by Gaemers (1985a) proves to be incorrect. In the basal beds of the Boom Clay in the Roelants sand pit at Lubbeek *Parvicolliolus minutulus* occurs from the S10 up to and including the S20 (i.e. beds 9-14, not 9-12 as published by Gaemers, 1985a). The Nucula Clay (=Kleine Spouwen Clay) appears to contain *Parvicolliolus* morphotype 1, the oldest known member of the *P. minutulus* lineage. The conclusion can be drawn that the Kleine Spouwen Member is clearly older than the base of the Terhagen Member in spite of some lithological and faunistical resemblances.

The attribution of the youngest Rupelian beds in shaft 8 of the Sophia Jacoba mine (near Erkelenz in the Lower Rhine District in Germany) to only the uppermost part of the Winterswijk Member, and the missing of the lower part of this member, based on lithological characteristics (M. van den Bosch, unpublished data), is supported by otoliths. The oldest known beds belonging to the Winterswijk Member, found in clay pit "De Vlijt" at Winterswijk, contain otoliths of *Parvicolliolus parvus* which are unknown from shaft 8.

It can be expected that the new, more detailed otolith zonation for the Rupelian will be a useful tool to solve more correlation problems. It is for instance likely that the uncertainty about the correlation of the Kleine Spouwen Member in Belgium and the Netherlands with the Ratingen or Hamborn Clay in Germany can disappear when otoliths are available from the German lithological units.

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REFERENCES

BROUWER, J., 1977 - Depositional environment of the Oligocene Rupel Clay in well Grashoek-1, Peel Region, the Netherlands. *Geol. Mijnbouw*, **56/1**: 25-30.

GAEMERS, P.A.M., 1977 - Recente en jong-kwartaire visresten van het Long Forties gebied, noordelijke Noordzee. *Med. Werkgr. Tert. Kwart. Geol.*, **14/1**: 21-40.

GAEMERS, P.A.M., 1985a - Fish otoliths from the Rupelian of sand-pit Roelants at Heide-Boskant (municipality of Lubbeek, Belgium) and the stratigraphy of the Early Rupelian. 1. General part. *Med. Werkgr. Tert. Kwart. Geol.*, **22/3**: 143-151.

GAEMERS, P.A.M., 1985b - Fish otoliths from the Rupelian of sand-pit Roelants at Heide-Boskant (municipality of Lubbeek, Belgium) and the stratigraphy of the Early Rupelian. 2. Systematic part. *Med. Werkgr. Tert. Kwart. Geol.*, **22/4**: 155-172.

GAEMERS, P.A.M., 1988 - Fishes, introduction. Otoliths (Gadidae). The description of the interregional zonation (otolith zones) and its stratigraphical consequences. The regional distribution of otolith assemblages ; correlation of the interregional zonation with the regional lithostratigraphic formations. *In* : Vinken, R., compiler. The Northwest European Tertiary Basin. Results of the Intern. Geol. Corr. Programme Project n° 214. *Geol. Jb*, **A(100)**: 368-390.

GAEMERS, P.A.M. & VAN HINSBERGH, V.W.M., 1978 - Rupelian (Middle Oligocene) fish otoliths from the clay pit "De Vlijt" near Winterswijk, The Netherlands. *Scripta Geol.*, **46**: 1-77.

MOORKENS, Th. L., 1975 - Palökologische Bedeutung einiger Vergesellschaftungen von sandschaligen Foraminiferen aus dem NW europäischen Alttertiär und ihre Beziehung zu Muttergesteinen. *Compendium 75/76. Ergänzungsband Zeitschr. Erdöl u. Kohle, Erdgas, Petrochem.*, 77-95.

NOLF, D., 1977 - Les otolithes des téléostéens de l'Oligo-Miocène belge. *Ann. Soc. roy. Zool. Belg.*, **106/1**: 3-119.

STEURBAUT, E. & HERMAN, J., 1978 - Biostratigraphie et poissons fossiles de la Formation de l'Argile de Boom (Oligocène moyen du Bassin Belge). *Geobios*, **11/3**: 297-325.

VANDENBERGHE, N., 1978 - Sedimentology of the Boom Clay (Rupelian) in Belgium. *Verhand. Kon. Acad. Wetensch., Lett. schone Kunsten Belg. Kl. Wetensch.*, **40/147**: 1-137.

VANDENBERGHE, N. & LAGA, P., 1986 - The septaria of the Boom Clay (Rupelian) in its type area in Belgium. *Aardkund. Med.*, **3**: 229-238.

VAN DEN BOSCH, M., 1984 - Lithostratigraphy of the Brinkheurne Formation (Oligocene, Rupelian) in the eastern part of the Netherlands. *Med. Werkgr. Tert. Kwart. Geol.*, **21/2**: 93-113.

VAN DEN BOSCH, M. & HAGER, H., 1984 - Lithostratigraphic correlation of Rupelian deposits (Oligocene) in the Boom area (Belgium), the Winterswijk area (The Netherlands) and the Lower Rhine District (F.R.G.). *Med. Werkgr. Tert. Kwart. Geol.*, **21/3**: 123-138.

VAN DEN BOSCH, M. & JANSSEN, A.W., 1990 - Application of planktonic gastropods ("Pteropods") in biostratigraphy and interregional correlation of Rupelian deposits in Belgium and The Netherlands. *Veröff. Übersee-Mus.*, Bremen, **A10**: 3-10.

VAN ECHELPOEL, E., 1991 - Kwantitatieve cyclostratigrafie van de Formatie van Boom (Rupeliaan, België). De methodologie van het onderzoek van sedimentaire cycli via Walshanalyse. PhD Thesis, Catholic University Leuven, 164 p.

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