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Reinvestigation of the invertebrate fauna of the Boom Clay Formation and the Ruisbroek Sand Member (Oligocene, Rupelian) of Belgium, with the description of a new lithostratigraphic unit: the Sint Niklaas Phosphorite Bed

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The Rupelian stage, defined in Belgium, is recognized now as a global chronostratigraphic unit. Rupelian deposits in Belgium have been studied extensively in the past. More recently in-depth studies have been carried out on its stratigraphy, sedimentology, micropalaeontology and vertebrate fossils. Gastropods, however, have not been revised since the work of Glibert (1957). Most invertebrate data predate the stratigraphic synthesis of Vandenberghe (1978), that enabled identification of different members and sedimentary cycles in the Boom Clay Formation. Other parts of the Rupelian sequence (such as the Ruisbroek Sand Member, Kerniel Sand Member and the Sint Niklaas Phosphorite Bed) have only been recognized or adequately dated since Glibert (1957) in the mid-1980s and their malacofauna is not yet described. Here some preliminary results of numerous recent samplings of Rupelian deposits in Belgium are presented and analyzed. Special focus is given to the Boom Clay Formation and the Sint Niklaas Phosphorite Bed. It is concluded that the molluscan fauna of the Boom Clay Formation can be used to delimit its various members and levels. The composition and diversity of the fauna could possibly be linked to successive sea level changes. The Sint Niklaas Phosphorite Bed 2.5 to 3 m below the base of the Boom Clay Formation is formally introduced as a new stratigraphic unit within the Ruisbroek Sand Member.

KEY WORDS: Oligocene, Rupelian, Mollusca, Invertebrata, new lithostratigraphic unit

L'étage Rupélien, défini en Belgique, est reconnu maintenant comme une unité chronostratigraphique mondiale. Il a été étudié en détail dans le passé. Depuis lors, de nombreuses études approfondies furent consacrées à sa stratigraphie, sa sédimentologie, à son contenu micropaléontologique et à sa faune de vertébrés. Les gastéropodes au contraire n'ont plus été révisés depuis le travail de Glibert (1957), publié avant la synthèse stratigraphique fondamentale de Vandenberghe (1978). Certaines entités constitutives du Rupélien marin (comme le Membre de Ruisbroek, Membre de Kerniel, Phosphorites de Sint-Niklaas) n'ont été découvertes ou datées convenablement qu'après l'étude de Glibert (1957), et leurs faunes malacologiques respectives n'ont jamais été décrites. Quelques résultats des nombreux échantillonnages effectués récemment dans le Rupélien sont présentés et analysés. Une attention particulière est accordée à la révision des faunes malacologiques de l'Argile de Boom et à celle du nouvel horizon nommé Horizon des Phosphorites de Sint Niklaas. Les conclusions sont que la faune malacologique de l'Argile de Boom peut être utilisé pour distinguer les différents lits et membres, et que la composition et la diversité de cette faune peut être liées aux variations successives du niveau marin. Le conglomérat phosphoritique qui se trouve 2,50 m à 3m sous la base de l'Argile de Boom à Sint Niklaas (Membre du Ruisbroek Sand) est introduit formellement comme une unité stratigraphique nouvelle.

MOTS-CLEFS: Oligocène, Rupélien, Mollusca, Invertebrata, unité lithostratigraphique nouvelle

Introduction

The denomination Rupelian, introduced by Dumont (1850) to specify a series of sedimentary rocks outcropping along the river Rupel cuesta in northern Belgium, was officially accepted as the first stage of the Oligocene by the International Subcommission on Paleogene Stratigraphy of the International Commission on Stratigraphy (ICS) in 1989 (Jenkins & Luterbacher, 1992; Steurbaut, 1992; van Simaeys & Vandenberghe, 2006). The GSSP for the Eocene-Oligocene boundary, and consequently the Priabonian-Rupelian boundary, was designated at the 19 m level in the

Massignano section, near Ancona (Italy), because of its continuity, accessibility, good micropalaeontological record, and a series of other criteria (ratified in 1992: Premoli-Silva & Jenkins, 1993), with the distribution of the foraminifer genus *Hantkenina* as a major criterion. This genus, however, does not occur in the Rupel area.
Cross-correlation with the North Sea Basin, essentially based on dinoflagellate cysts, has shown that this boundary, as defined by its GSSP, is situated somewhere in the time interval between the deposition of the Bassevelde-2 and Bassevelde-3 sequences (Vandenberghe *et al*., 2003). This means that the upper part of the Bassevelde Sand Member and its correlative the Grimmertingen Sand Member, as first evidenced by Steurbaut (1986, fig. 8), are definitely of Oligocene age. The currently adopted stratigraphic subdivision of the Belgian Oligocene and the terminology used by older authors like Glibert (1957) is given by Marquet (2010, figs. 1, 2) and repeated here in Tables 1 and 2.The present paper aims at a preliminary inventory of invertebrate assemblages present in Belgian Rupelian rocks, more especially those of the Boom Clay Formation and the locally underlying phosphorite bed in the Ruisbroek Sand Member. For the phosphorite bed a new lithostratigraphical unit name is formally introduced herein: the Sint Niklaas Phosphorite bed.
This paper is the third of a series on the systematic revision of the invertebrate fauna of the marine Rupelian of Belgium, which will be carried out by the authors. It presents an overview of the first results of the palaeontological work after 1960, based on material collected at 16 different sampling sites (see Marquet, 2010, fig. 3 for exact locations), and outlines some new stratigraphical and palaeoecological observations. Attention has been paid in particular to the invertebrate faunas of the Boom Clay Formation, most of which are almost unknown to date. Many identifications in this paper are only provisional, because of the lack of sufficient comparative material or because of preservation artefacts. Table 2 allows a precise positioning of the different invertebrate finds, mentioned in text, tables and plates.

Abbreviations

RGM Netherlands Centre for Biodiversity Naturalis, Palaeontology Department, Leiden (The Netherlands), formerly Rijksmuseum van Geologie en Mineralogie.

RBINS Royal Belgian Institute of Natural Sciences (Koninklijk Belgisch Instituut voor Natuurwetenschappen; Institut royal des Sciences naturelles de Belgique, Brussels (Belgium).

The Rupelian stage in Belgium

During the earliest Oligocene sea level was relatively high in the southern part of the North Sea Basin, probably also covering parts of the Ardennes (Vandenberghe *et al.,* 2004). These high sea levels led to the deposition of the upper part of the Bassevelde Sand Member and the Watervliet Clay Member (together making up sequence Ba-3, see Vandenberghe *et al.,* 2003) in western Belgium, and the Grimmertingen Sand Member in eastern Belgium. The Grimmertingen Sand Member molluscan fauna is currently being revised. Preliminary results show more affinity with Oligocene faunas than with those of late Eocene (Priabonian) age. After deposition of the Grimmertingen Sand Member sea level dropped slightly and led to the formation of the shallow Wintham Member in northwestern Belgium and the coastal Neerrepen Sand Member. The presence of the Neerrepen Soil (Buurman & Jongmans, 1975) in the top of the Neerrepen Sand Member demonstrates the existence of dry land conditions. The euryhaline to terrestrial Borgloon Formation in the east and the marine Ruisbroek Sand Member in the west of Belgium, represent higher sea levels and a second depositional sequence, named NS-Oli-2 by van Simaeys (2004), was laid down. Decreasing sea level during the time span between sequences NS-Oli-1 en NS-Oli-2, is believed to result from major ice sheet formation on Antarctica, known as the Oi-1 glaciation (Zachos *et al.*, 2001). This Oi-1 glaciation, estimated to have occurred at 32.8 Ma, was recognized in the Belgian Basin on the basis of oxygen isotopes (de Man *et al.*, 2004). The overlying Boom Clay, term introduced by de Koninck (1838) in a paper on the Boom Clay molluscs, is the most widely distributed and thickest unit of Oligocene age in Belgium. It was designated as a formal formation by Vandenberghe (1988) and subdivided into three members, in ascending order the Belsele-Waas Member, the Terhagen Member and the Putte Clay Member, which were fully described by Laga *et al.* (2001).
During deposition of the Boom Clay the sea gradually deepened, with cyclic oscillations in lithology, which were for the first time systematically described and linked to sea level fluctuations by Vandenberghe (1978). Gullentops & Vandenberghe (1985) suggested that these successive clay/silt alternations in the Boom Clay were sedimentary cycles, comparable to glacial/interglacial periods following a 100 kyr eccentricity cycle. Recently it has been demonstrated that these alternations reflect glacio-eustatic sea level variations, primarily driven by the 41-kyr obliquity cycle with additional influence of the 100- and 405-kyr eccentricity cycles (Abels *et al.,* 2007). This cyclic sedimentation pattern can be traced over long distances in the southern North Sea Basin, as it has been identified in a series of Dutch and German borehole sections (Vandenberghe *et al.*, 2001). Geomagnetic polarity reversals during the deposition of the Boom Clay Formation permitted age estimates for the boundary between the Terhagen and Putte Clay members, established at 30.95 Ma (Lagrou, 2001; Lagrou *et al.*, 2004; Vandenberghe *et al*., 1997).
Additional age indications were obtained through pinpointing several FAD's and LAD's of microfossils, identified in the Boom Clay Formation, on the geomagnetic polarity timescale of Berggren *et al.* (1995) (van Simaeys, 2004). During the last decade the palaeoclimatic conditions during the Oligocene also became better understood. De Man & van Simaeys (2004) reconstructed water temperatures during the deposition of the Boom Clay Formation on the basis of mean temperature ranges of benthic foraminiferal taxa and concluded that these varied between 5 and 10° C, with minimum values during the Rupelian-Chattian transi-

tion. At the end of the Rupelian, sea level dropped and major erosion occurred, as the result of tectonic uplift. It was followed at the start of the Chattian by a strong subsidence in the Lower Rhine area (Vandenberghe *et al.,* 2004).

According to de Man & van Simaeys (2004), based on benthic foraminiferal data, water temperature during the earliest Chattian increased to 25° C, but, progressively decreased again, to stabilize around 10° C near the end of the Chattian.

Etages	***Horizon*** **(Vlaams Brabant and Antwerpen provinces)**	***Horizon*** **(Limburg province)**
Chattien		Sables de Voort
Rupélien	Assise de Boom	
	Horizon à *Nucunella taxandrica*	Horizon à *Nucula comta*
	Sables de Berg	Sables de Berg
Tongrien	Sables de Kerkom	Sables de Vieux-Joncs
	Sables de Bautersem	Glaises de Henis
	Horizon à Vertébrés de Hoogbutsel	
		Sables de Neerrepen
		Sables de Grimmertingen

Table 1. Stratigraphic subdivision of the Oligocene, after Glibert & de Heinzelin (1954) and Glibert (1957).

Age	**Chrono-stratigraphy**			**Waasland-Boom area**	**Brabant area**	**Tongeren area**
23.0	OLIGOCENE	late	Chattian			**Voort Formation**
28.4	OLIGOCENE	early	Rupelian	**Rupel Group**	**Rupel Group**	**Rupel Group** – **Eigenbilzen Formation**
				Boom Formation: Putte Member, Terhagen Member, Belsele-Waas Member	**Boom Formation**: Putte Member, Terhagen Member, Berg Member	**Boom Formation**: Putte Member, Terhagen Member
						Bilzen Formation: Kerniel Member, Kleine-Spouwen Member, Berg Member
				Tongeren Group	**Tongeren Group**	**Tongeren Group**
				Zelzate Formation: Ruisbroek Member, Watervliet Member, Bassevelde Member (Ba3)	**Borgloon Formation**: Heide Horizon, Henis Member, Boutersem Member, Kerkom Member, Hoogbutsel Horizon	**Borgloon Formation**: Alden Biesen Member, Henis Member
33.9					**Sint Huibrechts-Hern Formation**: Kesselberg Member, Neerrepen Member, Grimmertingen Member	**Sint Huibrechts-Hern Formation**: Neerrepen Member, Grimmertingen Member

Table 2. Present stratigraphic subdivision of the Belgian Oligocene. Estimated absolute ages in 10^6 year. After Marquet (2010).

The Rupelian of Belgium has been studied extensively in the past. Recently, most attention has been paid to lithostratigraphy, sedimentology, micropalaeontology and vertebrate fossils. Major contributions to invertebrate paleontology date as far back as Glibert & de Heinzelin (1954) and Glibert (1957) who investigated the mollusc fauna, whereas studies of most other invertebrate groups go even further back in time. The stratigraphic terminology used by Glibert & de Heinzelin (Table 1) to define the origin (*stratum typicum* and *locus typicus*) of their collected material, specified on the RBINS collection labels, is given in Marquet (2010, fig. 1), repeated here in Table 2. Only a few papers were published subsequently on the invertebrates of the Boom Clay: a revision of the decapod crustaceans (Verheyden, 2004) and a detailed study of the bivalves (Marquet, 2010). Jagt *et al.* (2010) described a decapod from the Bilzen Formation. Van den Bosch & Janssen (1990) compared the planktonic gastropods with those of The Netherlands, suggesting a substantial hiatus in the top of the Boom Clay Formation section at Kruibeke. Herein, the nomenclature of Vandenberghe *et al.* (2001) for the various beds is used.

Origin of the material

Ruisbroek Sand Member – Rupel Canal Tunnel, Ruisbroek (Antwerpen province)

A fairly rich mollusc fauna in the Ruisbroek Sand Member was collected by the present authors during the construction of the Rupel Canal Tunnel at Ruisbroek (map-sheet 23/3-4; x = 148.875, y = 196.875). This material is housed in RBINS and consists of well- preserved shells. No bulk samples were taken, because of the low density of small-sized species. The same locality was sampled between 1973 and 1975 by A.W. Janssen who produced an internal report, including a preliminary list of species and some details of the sections (Janssen, 1980b; RGM collections).

Phosphorite bed below base of the Boom Clay Formation – SVK clay pit, Sint-Niklaas (Oost Vlaanderen province)

In the SVK (Scheerders-Van Kerckhoven Company) clay pit (map-sheet 15/5-6; x = 132.725, y = 205.000) the lowermost part of the Boom Clay Formation is exposed. In an earlier, now abandoned clay pit of the same company a sandy level with abundant well-preserved specimens of the oyster *Pycnodonte callifera* (Lamarck, 1818) was formerly observed, just below the base of the Boom Clay (Boekschoten, 1967; Janssen, 1980b), in what is now called the top of the Ruisbroek Sand Member (Steurbaut, 1986). The occurrence of the bivalve species *Nucunella taxandrica* Vincent, 1922, recorded by Boekschoten from the oyster layer, could also point to correlation with the Wintham deposits. Correlation with the deposits in the nearby Sint-Niklaas borehole (Steurbaut, 1992) shows that it belongs to the extreme top of calcareous nannofossil zone NP 22. Today, a phosphoritic conglomerate is exposed in a new clay pit at Sint Niklaas, *c*. 2 m down section, below the base of the Boom Clay Formation. Preliminary lists of molluscs from both levels were given by Boekschoten (1967) and Janssen (1980a, 1981). The present authors paid particular attention to the fossil contents of the phosphoritic conglomerate (RBINS collection), using data of many private collectors (see acknowledgements); materials from the same bed housed in the RGM will be taken into account in a paper now in preparation.

Kerniel Sand Member – Albertkanaal, Lanaken (Limburg province)

Fossiliferous Kerniel Sands were discovered for the first time and exhaustively sampled during works on the Albertkanaal at Lanaken (map-sheet 34/1-2, between x = 239.000, y = 175.400 and x = 235.100, y = 175.500). Molluscs were collected from bulk samples, processed on a 1 mm mesh. The shells are brittle, but well preserved. However, because of the fragmentary state of preservation, identifiable gastropod species are probably underrepresented (RBINS and RGM collections).

Boom Clay Formation – various localities

The Boom Clay Formation was sampled at six quarries:

- SVK clay pit at Sint Niklaas (Belsele, Oost-Vlaanderen province; coordinates see above);
- Gralex clay pit at Kruibeke (Oost-Vlaanderen province); map-sheet; coordinates 15/3-4; x = 146.500, y = 208.540;
- Wienerberger clay pit at Rumst (Antwerpen province); map-sheet 23/3-4; coordinates x = 353.550, y = 197.870;
- Steendorp clay pit (Oost-Vlaanderen province); map-sheet 15/5-6; coordinates x = 142.380, y = 202.110;
- Ceulemans clay pit at Niel (Antwerpen province); map-sheet map-sheet 15/5-6; coordinates x = 149.150, y = 199.850;
- Roelants sand and clay pit at Lubbeek (Pellenberg, Vlaams-Brabant province); map-sheet 32/3-4, x = 181.750, y = 173.100.

At each of these localities the present authors, together with Messrs K. Hoedemakers and L. Dufraign took bulk samples from the exposed septaria levels (S-levels) only, as the clay strata between these levels contain hardly any macrofossils. Samples were dried, soaked in hot water and processed on 0.5 and 1 mm meshes until only pyrite and fossils remained. It was thus possible to reduce the sampled sediments from about 100 kg for the richest levels (S41 and S50) to not more than 450 grams of clean residue. In total, more than 8 tons of sediment were processed.

Top Boom Clay – Mol (Antwerpen province); shaft digging for the Study Centre of Nuclear Energy

A single rather small sample, taken by S. Goolaerts (Katholieke Universiteit, Leuven) in the Mol laboratory shaft (map-sheet 17/1-2; x = 198.350, y = 211.750), at a depth of -225 m, was washed on a 0.5 mm mesh. A similar small sample is in coll. RGM.

The localities discussed in the text are shown in Marquet (2010, fig. 3).

Provisional results

Only invertebrate and plant macrofossils from the Boom Clay and the Phosphorite Bed in the Ruisbroek Sand Member are discussed here. Sharks, rays and bony fishes from the Rupelian have already been treated extensively by Leriche (1910), Steurbaut & Herman (1978), Bor (1990) and Hovestadt & Hovestadt-Euler (1995); the microfossils by Hooyberghs (1983, 1992), Steurbaut (1992), Stover & Hardenbol (1994), van Simaeys (2004) and de Man *et al*. (2004).

Non-molluscan invertebrates and plant remains from the Boom Clay and the phosphorite bed

Plant remains, ichnofossils and invertebrate fossils belonging to the following groups have been encountered: Anthozoa, Hydrozoa, Bryozoa, Annelida, Echinodermata, Mollusca, Crustacea and Insecta. Van Beneden (1883) gave a review of some of these groups, but most of them have not subsequently been revised. Trace fossils, which are very common in the Boom Clay, and plant fossils, encountered in both the Boom Clay and the underlying phosphorite bed, are commented upon here for the first time.

Ichnofossils – Through processing 100 kg of Boom Clay from the S50 bed at Kruibeke, a residue of 450 grams remained, of which pyritized trace fossils represent about 90%. Field observations have shown that these occur dispersed in the sediment, without preferential orientation. The bulk of this material consists of round tubes about 1 mm in cross-section and 1 cm in length, without any structures or branching (Plate 2, fig. 6). A second type of trace fossil is also circular in cross-section, but showing irregularly situated holes, which are sharply delimited (Plate 2, fig. 7). A third type consists of tubes with an elliptical transverse section, showing concentric rings (Plate 2, fig. 8). These ichnofossils occur in all levels sampled between S20 and S60.
Also calcareous trace fossils occur in the Boom Clay. They have been observed in septaria-level S60 in the Kruibeke clay pit. These tubiform, often branched structures with tubercles occur on eroded septaria, both on their upper and lower surfaces. Their length does not exceed 20 cm, their width is less than 2 cm. They might belong to the ichnogenus *Ophiomorpha*.
In the Herselt clay pit (Vlaams-Brabant province) an ichnofossil occurs, consisting of large (*c.* 20 cm length) cylindrical siderite concretions, with a core filled by pyrite (exact level of origin unknown). These have been described as S*ideritichnium herseltensis* Vochten, Geys & Bauten, 1975 (see also Marquet, 1984). In shape, they are not unlike the trace fossil *Tasselia ordamensis* de Heinzelin, 1964, which occurs abundantly in the late Pliocene Merksem and Zandvliet Sand Members (Lillo Formation) around Antwerp. In shape and structure similar concretions, but consisting of sandstone, occur in the late Miocene Deurne Sand Member (Diest Formation) more to the east in the same region and in the Zanclean Oosterhout Formation at Langenboom (Mill, The Netherlands) (F.P. Wesselingh pers. comm.).

Hydrozoa – In the past few very large complete specimens of the benthic hydroid polyp *Delheidia proxima* (Delheid, 1898) were found in the Boom Clay. In our material every sample above S40 contains fragments of these colonies, consisting of irregular small (to 1 cm) blocks, pierced with sharply delimited and thin-walled holes (Plate 2, fig. 5). Complete specimens were described by Delheid (1898, 1899).

Annelida – Small shells of coiled serpulids are rarely found in the Boom Clay, mainly in level S50. From the Latdorfian (early Rupelian) of Germany similar fossils were described as *Vermetus varicosus* von Koenen, 1891. The genus *Vermetus*, however, belongs to the Gastropoda and is not a serpulid and therefore these fossils have to be transferred to another genus. Cadée (1969) also identified the species *Serpula septaria* Giebel, 1866. This was one of the index fossils used by van den Bosch *et al.* (1975) in their biozonation of the septaria clay in The Netherlands and Belgium.

Anthozoa, Hexacorallia – Tubes of *Cerianthus* sp. (family Cerianthidae) are found in the Sint Niklaas phosphorites, associated with possible sponge and/or calcareous algae remains.

Anthozoa, Octocorallia – Fragments of stalks of what could be an unidentified pennatulid are found rather frequently, especially so in S50 (Plate 1, fig. 1). These could be taken for fragments of sea urchin spines, but differ by the lack of the calcite crystals typical for echinoid spines.

Bryozoa – Very large cupuliform colonies of an unidentified species of the family Lunulariidae, probably genus *Lunulites* occur in the Sint Niklaas phosphorites.
Remains of Bryozoa are rare in the Boom Clay; possibly two species have been found, one of which is relatively more common (Plate 1, fig. 3). Only small, isolated fragments of colonies occur, especially in and above S41.

Brachiopoda – At least one brachiopod species occurs commonly in the upper parts of the Boom Clay, from S41 to S50 (Plate 1, fig. 2). Possibly this species is also known from the early Oligocene of the province of Limburg (Belgium), but the identification is uncertain. It probably belongs to the genus *Terebratulina*. Von Koenen (1894) illustrated very similar specimens from the German Latdorfian, applying a large number of probably synonymous names; a revision of these species is presently in progress (A. Müller, pers. comm.).

Echinodermata – Small fragments of irregular sea urchins occur rarely throughout the Boom Clay.

Arthropoda, Crustacea – Completely new was the discovery of numerous Stomatopoda, some with perfectly preserved pereiopods, belonging to the family Lysiosquillidae, genus cf. *Lysiosquilla* in the Sint Niklaas Phosphorite Bed (Plate 2, fig. 9). Furthermore, very rare isopods of the family Cirolanidae or Limnoriidae, some as free specimens, some preserved in their own galleries in silicified wood fragments (Plate 2, fig. 10) occur in the same level. Both groups are extremely rare in the fossil record and no further identification can be given.

At least five species of Decapoda were encountered in the phosphorites. These are: *Ciliopagurus obesus* van Bakel, Jagt & Fraaije, 2003, *Homarus* sp., cf. *Linuparus* sp., probably a new species of cf. *Dromilites* (*Basinotopus*) and *Coeloma* sp. Several unidentified chelipeda or dactyli, some of which seem to be attributable to Parthenopidae (Lambriformes) of uncertain genus. A study of these remains by H. van Bakel is in preparation.

Complete specimens of the crab species *Coeloma rupeliense* Stainier, 1887 were found in the 19th and early 20th century in the Boom Clay, preserved in small septaria but the exact collection level was never recorded. Nowadays the species is rarely found in the clay proper. They are relatively common, reworked in Miocene (Rumst, Wienerberger clay pit) or Pliocene (Kallo and Doel dock works) basal gravels on top of the clay. Probably the crabs occurred in the upper parts of the clay that are eroded in most localities. The first author found small septaria, one of them with a crustacean cast (Plate 1, fig. 5), at Kruibeke, above level S70, about 0.5 m below the top of the Boom Clay. The second author observed in the now abandoned and levelled clay pit of Hemiksem, near Antwerp, two distinct levels, 2 m apart, with crab nodules. The upper level was found between S50 and S60.

Claws of a very large shrimp were also found in the Boom Clay during the 19th century. These are described as *Homarus percyi* van Beneden, 1872. A thorough redescription of both species was published recently by Verheyden (2002).

An earlier unreported small crab is rather common in S41 and S50. Only chelae are found (Plate 1, fig. 4). Similar specimens were illustrated by Moths (2000), from the Rupelian clay of Malliß, Germany, identified as *Ctenocheles rupeliensis* Beurlen, 1939. Comparison with the original publication of this species from the Oligocene of Hungary however shows that this identification is doubtful. Some claws of a more plump form were found in the sieving residue collected around a piece of driftwood in the S30 level at Niel. These certainly belong to a third crab species, but all specimens are strongly eroded.

Part of the pyritised carapace with appendages of an undescribed species of marine isopod or amphipod was collected at Kruibeke in the S50 septaria level (Plate 3, fig. 1). Isopoda are characterised by the occurrence of identical appendages on all except the last segments; that, however, are not preserved. Also the head segments are lacking in the specimen. The compressed body is reminiscent of an amphipod. These animals usually have a curved body (pers. comm. d'Udekem d'Acoz), but the fossil illustrated herein is straight. This could also be a preservation artefact.

Finally, Cirripedia were represented by very rare fragments of scalpellids and other barnacles which were only found on a piece of driftwood. Ostracod carapaces occur rarely in the lower part of the Boom Clay (S20-S30).

Insecta – The occurrence of three-dimensionally preserved insects in all parts of the Boom Clay is remarkable. These have only been found during the last decades, by processing large quantities of rock. The first specimen was found by the second author and published by Hovestadt & Hovestadt-Euler (1995). All remains are pyritised and they only consist of head, thorax and abdomen, and consequently identification is very difficult owing to the lack of appendages. At least one unidentified species of Hymenoptera (Plate 1, fig. 8) and two Coleoptera (Plate 1, figs 6, 7) have been found. Their occurrence might point to the presence of land near the deposition sites of the Boom Clay or, alternatively, they could have been transported on driftwood. Preservation chances of such insects is higher in an anoxic environment. Insects are also present in the RGM collections (A.W. Janssen, pers. comm. 2012).

Plantae – Silicified wood fragments of Conifera were found in the Sint Niklaas Phosphorite Bed. One seed of Cornales (family Mastixiaceae, genus *Eomastixia* or *Mastixia*) was encountered. Concretions occur, enveloping roots of cf. Posidoniaceae (all plants remains identified by H. d'Outrelepont, pers. comm.).

An unidentified seed of a plant (Plate 2, fig. 4) was found in the Boom Clay at Lubbeek, near Leuven (Vlaams-Brabant province, Belgium). Small fragments of wood are present at the same locality (Plate 2, fig. 3). At Niel, below the Red Band (= Bed 21, below S40), large pieces of driftwood were collected; these apparently formed a small local slack water environment, assembling a much richer assemblage of fossils than usual at any level (Plate 3, figs 2a, b). Furthermore, floating or submerged wood is known to harbour very specific species assemblages not usually found in soft bottom environments. Several molluscan species, claws of a crab species and balanids were found exclusively in material around such blocks of wood.

History of the study of the Oligocene molluscan fauna in Belgium

The first list of fossil Mollusca from the Boom Clay is from de Koninck (1838). Glibert (1957) revised this fauna systematically and added a large number of records. In his monograph he also included the Mollusca from the Chattian Voort Sand in the Antwerpen and Limburg provinces, Belgium. However, the Boom Clay samples were taken by visual surface collecting, so that Glibert (1957) studied only the larger species, usually lacking protoconchs. The exact stratigraphical position of these samples is not known. Bulk sample collecting at specified levels started only after the publication of Vandenberghe (1978) and added a large number of species to the fauna known to Glibert (1957). These were mainly identified by comparing with the more or less contemporaneous faunae of Malliß, Germany, described by Moths (2000), from the Dutch Oligocene near Winterswijk and Ootmarsum, studied by Cadée (1961), Bosch (1967) and van den Bosch *et al.* (1975), and with older publications on German Oligocene

occurrences by von Koenen (1867, 1868). In addition, some authors revised a part of the Boom Clay fauna: Janssen (1989, pteropods), Gürs & Janssen (2004, pteropods), Cadée & Janssen (1994, part of the gastropod family Fasciolariidae) and R. Janssen (1989, Scaphopoda).
Glibert & de Heinzelin (1954) studied the molluscan fauna of the earliest Rupelian in the Belgian province of Limburg, from the Grimmertingen Sand Member to the Berg Sand Member. The very species-poor fauna of the Neerrepen Sand Member, preserved mainly as casts, was studied by Deville (1996) (further as yet unstudied material is present in the RGM collections from Valkenburg, The Netherlands and Membruggen, Belgium). Marquet *et al.* (2007) revised the molluscan fauna of the euryhaline to continental Borgloon Formation, Marquet (2010) systematically reviewed the Boom Clay Bivalvia.
Several members, however, were not known to contain molluscan fossils at the time of the publications of Glibert & de Heinzelin (1954) and Glibert (1957). The Ruisbroek Member was only found during construction works near Boom (Rupel Canal Tunnel, 1973-1975) and Wintham (of a different age?) between 1979 and 1980. Several taxa described by Glibert & de Heinzelin (1954) from the Campine coal mines at Eisden, Zwartberg, Houthalen and Voort (Zolder) were found later in the Rupel Canal Tunnel at Ruisbroek and especially at Wintham. Further material was found below the Boom Clay at Sint Niklaas (Belsele) in a level with the oyster *Pycnodonte callifera* (Lamarck, 1818), which also contained a small number of other molluscan species with shell preservation. A fauna of phosphorite casts was sampled between 1995 and 2005 in a nearby clay pit *c.* 2 m lower in the section. This phosphorite cast fauna is discussed further below. Fossiliferous Kerniel Sand was found for the first time around 1980 during works at the Albertkanaal at Lanaken, Limburg province. Transitional layers between Rupelian and Chattian were discovered at Mol, in a shaft digging.
Furthermore, sampling by staff members of the NCB Naturalis at Leiden, The Netherlands, considerably improved the known fauna of the Berg Sand Member and the overlying *Nucula comta* horizon (= Kleine Spouwen Clay Member) (A.W. Janssen, 1979).

The Oligocene molluscan fauna in general

The molluscan fauna of the Belgian Oligocene shows clear changes in composition and diversity. The first trend is the disappearance of taxa with Eocene affinities and a general impoverishment of the fauna after deposition of the Grimmertingen Sand Member. Secondly, changes in sea level caused transitions from marine to euryhaline and fresh water assemblages and subsequently back to marine conditions. Third, the composition of the marine faunas is clearly related to water depth. However, the differences in the number of species can be partly linked to preservation conditions and partly to differences in sampling density. Some faunas, such as those from the Kerniel Sand Member, from the Ruisbroek Sand Member and from the transitional strata between Rupelian and Chattian have not yet been described systematically. The species numbers observed so far are summarized in Fig. 1.

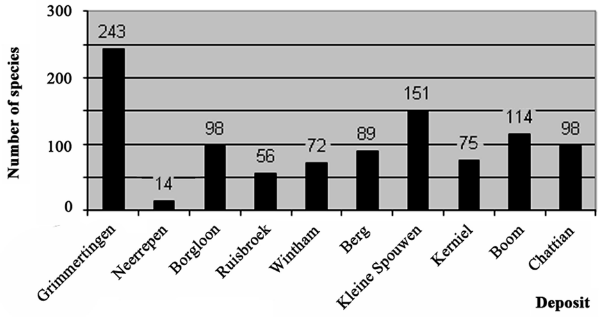


Figure 1. Number of molluscan species in the various Oligocene deposits in Belgium.

The earliest fauna considered, from the Grimmertingen Sand Member, shows a high diversity, with 243 known mollusc species from one small locality near the village of Grimmertingen; these were listed by Glibert & de Heinzelin (1954). The faunal composition is partly comparable to that of the Eocene, with shallow marine species, deposited during a warm climatic phase. The Grimmertingen Sand fauna suddenly and completely disappears. The overlying Neerrepen Sand Member is usually barren of macrofossils. Only from a sand pit near Sint Truiden, a limited shallow marine molluscan fauna of Pectinidae and casts of other molluscan species was collected (Deville, 1996). Some further samples from other localities are in coll. RGM. The species number is not representative of the original fauna diversity, because of decalcification.
Mollusc species numbers rise considerably during the deposition of the marine Ruisbroek (56) and Bassevelde (72) Sand members. These faunas have not yet been published, but data were taken from Janssen (1980b) and from personal observations; one species was mentioned by Marquet (1995). Data about the Sint Niklaas phosphorites bed are discussed below.
During deposition of the Borgloon Formation sea level dropped, leaving an euryhaline to freshwater fauna in the Limburg and Vlaams-Brabant provinces. These faunas were revised recently by Marquet *et al.* (2007) and consist of 99 species, some of which had possibly been introduced from nearby marine deposits.
The Berg Sand Member reflects the return of shallow marine conditions in the same provinces. Most shell material in the basal deposit, called the 'Horizon à *Callista kickxi*' by Glibert & de Heinzelin (1954) is reworked from the underlying Borgloon Formation. Then follows a level with abundant Glycymerididae shells, with a rather rich molluscan fauna, studied by Glibert & de Heinzelin (1954). Their list seems fairly complete and only few species have been added after recent research. Further identification of material will undoubtedly enlarge this list, in spite of the often rather poor preservation of the smaller species. More than 250 samples from the type locality are in coll. RGM, and these have not yet been published.
The Kleine Spouwen Member, formerly called 'Argille à *Nucula comta*' by Glibert & de Heinzelin (1954) (or '*Nucula* Clay'), is a sandy clay, deposited in rather deep water, with a fauna of mainly small molluscan species. In

the field, this unit looks very poor in fossils, but species lists from large samples taken by A.W. Janssen (1979) contain the highest number of molluscan species after the Grimmertingen Sand Member. This undoubtedly is the result of sample size.
The last deposit in this series is the Kerniel Sand Member, the molluscan fauna of which still remains undescribed; the number of species is provisionally estimated at 75, based on the collections of the first author in the RBINS and on the RGM collections, but will undoubtedly turn out to be richer. The fauna of the Boom Clay is discussed below.

General observations on the Mollusca from the Sint Niklaas Phosphorite Bed and the Boom Clay Formation

In a former Sint Niklaas clay pit, a fauna in shell preservation was collected around 1960-1970, mainly consisting of very large specimens of the oyster *Pycnodonte callifera* (Lamarck, 1814), accompanied by sparse specimens of other, mainly bivalve species. The occurrence of the bivalve species *Nucunella taxandrica.*Vincent, 1922 in the oyster layer, could point to a correlation with the Wintham deposits. The phosphorites found now in a newer clay pit *c.* 2 m lower in the section, show a more diverse assemblage, dominated by gastropods and by the bivalve *Arctica islandica rotundata* (Agassiz, 1845).
Mollusca are the most common fossils of the Boom Clay, but the number of specimens is restricted compared to Eocene or Neogene deposits. All species are rather small (less than 5 cm), except for the nautiloid *Aturia* sp. In the 19th century, large groups of *Aturia* specimens were collected, amongst others in a former clay pit at Edegem (near Antwerp). It is, however, not known in which member of the Boom Clay Formation these fossils occurred. Van den Bosch & Janssen (1990) supposed the occurrence of *Aturia* to be restricted to the S70-S80 interval, acknowledged by some finds in the same interval of the Putte Clay Member, exposed at Kallo (Oost Vlaanderen province, 'Vierde Havendok' construction pit).
A list of the material in RBINS and in the first authors collection is given in Table 3.

	Name	Ph. Bed	Belsele-Waas Member			Terhagen Member		Putte Member		T.
	Bivalvia		**S'0'**	**S10**	**S20**	**S30**	**S41**	**S50**	**S60**	
	Glycymeris sp.	?				?				
	Limopsis goldfussi (Nyst, 1843)	?								
	Hilberia stettinensis (von Koenen, 1868)	?								
	Aulacomya subfragilis (d'Orbigny, 1852)	?								
	Pycnodonte callifera (Lamarck, 1819)	x								
	Cyclocardia omaliana (Nyst, 1845)	?								
	Astartidae indet.	x								
	Laevicardium tenuisulcatum (Nyst, 1836)	?								
	Laevicardium subturgidum excomatulum Glibert & van de Poel, 1970	?								
	Arctica islandica rotundata (Agassiz, 1845)	x	x					x		
	Glossus subtransversus (d'Orbigny, 1852)	?								
	Callista splendida (Deshayes, 1857)	?								
	Panopea sp.	x								
	Corbula gibba (Olivi, 1792) *s.l.*	?	x	x	x	x	x	x		x
	Martesia perroni Cossmann & Lambert, 1888	?								
n	Teredinidae	x				x				x

Table 3. Bivalve molluscan taxa present in the Sint Niklaas Phosphorite Bed (Ph.), compared to their occurrence in the Boom Clay Formation. T. = 'Transitional layers' to the Chattian from the Mol shaft digging; n = new for the Rupelian of Belgium; x = occurring, ? = possibly occurring, but identification uncertain (most phosphorite species).

Molluscs are much more commonly present in more sandy parts of the Boom Clay Formation, which form the septaria levels, not in the clay levels proper. Sampling was consequently restricted to these levels, but the RGM collection at Leiden contains also material from between these levels, collected in the Kruibeke clay pit. It is not yet possible to make a complete list of the Boom Clay Mollusca. Even the most common species, the small scaphopod *Gadilina ottoi* (Pilsbry & Sharpe, 1898) (Plate 1, fig. 9) and the bivalve *Yoldiella pygmaea pygmaea* (von Münster, 1837), were just recently recorded for the first time from the Belgian Oligocene. A number of the larger species recorded in the older literature have not yet been found during recent sampling, so it is not known in which bed or member they occur. A provisional list is given in Table 4.
As shown in Fig. 2 (number of species in the different septaria levels of the Boom Clay, and the Campine transitional layers), the number of species recorded diminishes after the phosphorite level to an absolute minimum in the S10 septaria level of the Boom Clay. Then it increases again fol-

lowing the subsequent septaria levels, especially from S41 upwards, to reach a maximum in S50. The samples from S60 are too scant to give a realistic idea of the fauna and the same applies to the transitional layers.

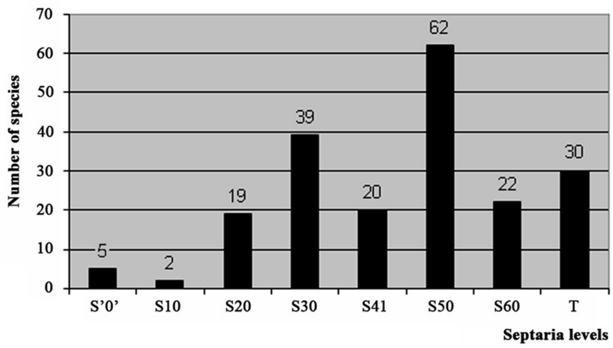


Figure 2. Number of molluscan species in the various septaria levels of the Boom Clay and the Campine transitional layers (T).

Distribution of the species

The Sint Niklaas phosphorite bed yielded a fauna of shallow marine species. Not more than 27 species were recorded by the authors and by Janssen (1981), but this number is an underestimate, because small species are not preserved. The fauna is dominated by a gastropod species, *Arrhoges speciosus speciosus* (Schlotheim, 1820) and a bivalve, *Arctica islandica rotundata* (Agassiz, 1845). Of the last species, it is remarkable that isolated fossilized ligaments were detected. The bivalve species *Hilberia stettinensis* (von Koenen, 1868) was in Belgium only found commonly at the Rupel Canal Tunnel works at Ruisbroek in the Ruisbroek Sand Member, confirming that the phosphorites are part of this member. Material of this species is also present in the RGM collections from the Neerrepen Sand Member. Earlier records of *H. stettinensis* by Glibert (1957) from the Boom Clay at Hoboken, near Antwerp exist, but these can for the moment not be confirmed by later findings and it is not known to what part of the Boom Clay this locality belonged. Deville (1969) cited it also from the Neerrepen Sand. Janssen (1981) gave a list of the species collected by him from the Sint Niklaas Phosphorite Bed, housed in RGM. A preliminary list of the molluscan fauna collected by the present authors is given in Table 3.
The Belsele-Waas Member, found at Sint Niklaas, contains isolated shells only. In the lowermost part, the bivalve species *Arctica islandica rotundata* (Agassiz, 1845) is very characteristic.This species occurred in Belgium before deposition of the Boom Clay in the Berg Sand Member (possibly two species of the genus present: A.W. Janssen, pers. comm.) and in the phosphorite bed. In Germany, however, it is found only in the later Rupelian (A. Müller, pers. comm.). It recurs during the Chattian and the subspecies *Arctica islandica islandica* (Linnaeus, 1758) is present from the early Miocene until today. It is a species occurring in shallow (0-500 m), well oxygenated and probably rather cold water (in its deepest parts) with sandy sediment.
The stratigraphic range of six species is restricted (or nearly so) to the Terhagen Clay Member: the scaphopod *Fissidentalium novaki pseudacutum* R. Janssen, 1989, the bivalves *Patinopecten hoeninghausi* (Defrance, 1825), *Pycnodonte paradoxa* (Nyst, 1835), *Cyclocardia kickxi* (Nyst, 1835), *Astarte kickxi* (Nyst, 1835) and the pteropod *Clio blinkae* Janssen, 1989 (Plate 1, fig. 11). The last species is only known from the 'Red Band', the base of bed 21 below S40. Apart from the Boom Clay, *Patinopecten hoeninghausi* (Defrance, 1825) is also found in the Berg and Kerniel Sand members. Shells are often heavily pyritised, especially on the outside. The most common species is the gastropod *Arrhoges speciosus speciosus* (Schlotheim, 1820), a species found throughout the Boom Clay Formation, continuing into the early Miocene Edegem Sand Member as the subspecies *Arrhoges speciosus margerini* (de Koninck, 1838). In the Boom Clay, specimens are often completely covered by pyrite (Plate 1, fig. 13).
The base of the Putte Clay Member (S40-S61), is characterized by the pteropod *Heliconoides hospes* (Rolle, 1861) (Plate 2, fig. 1), although this species occurs only in isolated groups and not in every locality; its range continues into the Chattian (A.W. Janssen, pers. comm.).
The highest number of species is recorded in S50. The dominant fossil species in S41 and S50 is a small, nearly straight scaphopod, *Gadilina ottoi* (Pilsbry & Sharpe, 1898). The fauna of the Putte Clay Member is furthermore characterized by species adapted to an oxygen-poor environment below the euphotic zone, such as the bivalves *Thyasira benedeni* (de Koninck, 1835) and *Axinulus obtusus* (Beyrich, 1848). It was observed that in S41 and S50 not only adult specimens of the larger species occur, but also protoconchs, whereas these embryonic shells are missing in the underlying levels. It appears that the molluscan fauna by that time had developed a stable population, which was able to reproduce at the sites studied. Nearly all species found are carnivores or suspension feeders, while grazing species are absent. This also is characteristic for an environment below the euphotic zone.
A highest number of species in S50, however, could be misleading, because S60 was sampled less intensively than the underlying septaria levels. Level S60 only occurs at Kruibeke and even there it is not easy to recognize, being mostly covered by displaced Miocene sediments sliding downsection. Furthermore, between the septaria of this level, clay is present instead of sand, which makes sampling much more difficult. Protoconchs still occur, but the small species mentioned above, characterizing S41 and S50 are absent. Instead, a species of the Terhagen Clay Member reappears: *Fissidentalium novaki pseudacutum*. Other species, characteristic of S60 are *Ancilla karsteni* (Beyrich, 1853) and the bivalve *Thyasira obtusa* (Beyrich, 1848).
Levels S70 and S80, as indicated by Vandenberghe (1978) at Kruibeke, can only be observed occasionally and were even supposed to be absent here by van den Bosch & Janssen (1990). Few mollusc species, however, were found until now in levels overlying S70, from which the last mentioned authors recorded the pteropod species *Limacina umbilicata* (Bornemann, 1855).

	Name	Ph. Bed	Belsele-Waas Member			Terhagen Member		Putte Member		T.
	Gastropoda		**S'0'**	**S10**	**S20**	**S30**	**S41**	**S50**	**S60**	
	Margarites m. margaritula (Sandberger, 1859)	?								
	Solariella bernaysi Glibert, 1950							x		
n	*Bivonia* sp.							x		x
n	*Alvania* cf. *multicostata* (Speyer, 1864)									x
n	*Alvania* cf. *rupeliensis* Tembrock, 1969							x		
n	*Putilla* sp.				x					
n	*Cirsope multicingulata* (Sandberger, 1868)							x		
n	*Cirsope ovula* (Philippi, 1844)							x		
	Capulus elegantulus Speyer, 1864									x
	Lunatia achatensis (de Koninck, 1838)				x	x	x	x	x	x
n	*Naicarius* sp.				x					
u	*Sigatica hantonensis* (Pilkington, 1804)									
n	*Ampullinopsis crassatina* (Lamarck, 1804)	?								
	Naticidae indet.	x								
	Arrhoges s. speciosus (Schlotheim, 1820)	?	x		x	x	x	x	x	
	Charonia flandrica (de Koninck, 1838)	?				x		x		
	Tugurium scrutarium (Philippi, 1843))	?		x		x				
	Ficus concinnus (Beyrich, 1856)							x	x	x
	Echinophoria rondeleti (Basterot, 1825)							x	x	
u	*Cassidaria depressa* von Buch, 1831	?								
u	*Typhis pungens* (Solander *in* Brander, 1766)									
u	*Lyrotyphis cuniculosus* (Nyst, 1836)									
	Eotyphis scalaris (Braun, 1850)							x		x
	Hexaplex pauwelsi (Basterot, 1837)							x	x	x
	Aspella deshayesiana (Nyst, 1836)					x				
	Pisanella semiplicata (Nyst, 1843)					x			x	
	Liomesus danicus (von Koenen, 1880)							x		
u	*Scalaspira erratica* (de Koninck, 1838)									
u	*Keepingia suturosa* (Nyst, 1836)									
u	*Searlesia konincki* (Nyst, 1843)									
	Aquilofusus deshayesi (Basterot, 1837)					x		x		
	Aquilofusus biformis (Beyrich, 1856)							x		
u	*Aquilofusus ravni* Glibert, 1955									
	Aquilofusus waeli (Nyst, 1852)					x		x	x	
	Streptolathyrus m. multisulactus (Nyst, 1843)					x	x	x	x	x
	Fusinus elatior (Beyrich, 1856)							x	x	
	Streptodictyon subelongatus (d'Orbigny, 1852)					x				
u	*Streptodictyon sowerbyi* (Nyst, 1836)									
	Streptodictyon impiger Cadée & Janssen, 1984					x		x		x
	Conomitra soellingensis (Speyer, 1864)							x		
	Bonellitia evulsa postera (Beyrich, 1858)					x				
	Babylonella fusiformis (Cantraine, 1835)						x	x		x
	Ancilla karsteni (Beyrich, 1850)								x	
	Neoatletha rathieri (Hébert, 1849)							x		
	Scaphella siemsseni (Boll, 1851)					x				
	Turridae sp. 1	x								
	Turridae sp. 2	x								
	Drilliola bicingulata (Sandberger, 1860)							x		
	Genota morreni (Basterot, 1837)					x				
	Bathytoma crenata (Nyst, 1843)					x		x	x	x
n	*Asperodaphne* n. sp.							x		x
	Turricula regularis (Basterot, 1837)				x	x	x	x	x	
u	*Oxytropa pseudovolgeri* Glibert, 1955									
	Oxytropa konincki (Nyst, 1843)					x		x	x	x
n	*Cochlespira volgeri* (Philippi, 1847)									x
	Gemmula laticlavia (Beyrich, 1848)					x	x	x	x	
	Fusiturris d. duchasteli (Nyst, 1843)					x		x	x	x
	Fusiturris selysi (Basterot, 1837)					x	x	x	x	
u	*Glibertturricula vervoeneni* Cadée & Janssen, 1998									
n	*Niso incrassata* (von Koenen, 1867)							x	x	

	Name	Ph. Bed	Belsele-Waas Member			Terhagen Member		Putte Member		T.
			S'0'	**S10**	**S20**	**S30**	**S41**	**S50**	**S60**	
u	*Rudiscala subangulata* (Speyer, 1864)									
	Opalia pusilla recticostata (Sandberger, 1863)									x
n	*Cirsotrema* cf. *insigne* (Philippi, 1843)						?			
n	*Aclis vetusta* Wiechmann, 1871							x		
n	cf. *Menestho semistriata* (Speyer, 1864)							x		
n	*Odostomia acutiuscula* (Braun, 1850)							x		
	Tornatellaea simulata (Solander *in* Brander, 1766)	?				x				
n	*Ringicula semperi* Koch, 1860					x		x		
n	*Scaphander lignarius distinctus* Koch, 1867								x	
n	*Cylichna laurenti* (Bosquet, 1859)							x		
n	*Crenilabium terebelloides* (Philippi, 1844)							x		
n	*Philine kochi* von Koenen, 1880							x		
	Clio blinkae A.W. Janssen, 1989				x					
	Limacina umbilicata (Bornemann, 1855)									x
	Limacina hospes Rolle, 1861							x		
	Creseis berthae A.W. Janssen, 1989									x
n	*Vaginella* sp.							x		
Scaphopoda										
n	*Gadilina ottoi* (Pilsbry & Sharpe, 1898)				x			x		x
	Gadila rupeliensis R. Janssen, 1989									x
n	*Cadulus cylindrulus* R. Janssen, 1989				x			x		
	Fissidentalium novaki pseudacutum R. Janssen, 1989				x	x		x	x	
n	*Dentalium pseudofissura* R. Janssen, 1989							x		x
	Dentalium sp.	x								
Cephalopoda										
u	*Aturia* sp.									

Table 4. Distribution of the gastropod taxa over the different levels in the Boom Clay. Ph. = Sint Niklaas Phosphorites Bed; T. = 'Transitional layers' to the Chattian from the Mol shaft digging; n = species, new for the Rupelian of Belgium; x = occurring, ? = possibly occurring, but identification uncertain (most phosphoritic species); u = unknown.

Transitional layers to the Voort Sand Member, demonstrated to be present in the Campine (Mol) shaft digging, also possess a species-rich molluscan fauna, but could only be studied in small samples. The dominating species is the same pteropod species, *Limacina umbilicata* (Plate 2, fig. 2), recorded above from the Kruibeke top level. The tubiform pteropod *Creseis berthae* Janssen, 1989 (Plate 1, fig. 10) is much rarer, it has been found in the present survey only in these layers, but seems to occur also at Kruibeke. However, the sample size is so small that the estimated number of species is certainly too low.

Discussion

The molluscan fauna listed here could be compared to that of foreign localities. From The Netherlands, the Rupelian fauna of Winterswijk (De Vlijt) and Ootmarsum (Kuiperberg) has been described by Boekschoten (1954), Cadée (1961), Bosch (1967) and van den Bosch *et al.* (1975). From Germany lists of Rupelian Mollusca from Amsdorf (Sachsen Anhalt) by Gründel (1997) and by Welle (1998), and from Malliß (Mecklenburg-Vorpommern) by Moths (2000) are available. We feel, however, that it is premature to make a detailed comparison, because a thorough systematic revision and comparison of Belgian material has to be made first.

Starting from the Sint Niklaas Phosphorite Bed and from the lowermost beds of the Boom Clay one could suppose a gradual deepening of the sea; in the last stages of the clay only species living in a deep, anoxic environment are present. Towards the Chattian, water depth decreases again and the diversity becomes greater and remains high during the Miocene. The evolutionary lineages of the Miocene molluscan species seem to start in the Berg Sand Member, the Boom Clay or the Voort Sand Member. During the Chattian to late Miocene interval, the water depth and lithology of fine glauconitic sand, remains largely the same.

Formal description of the Sint Niklaas Phosphorite Bed

As the sedimentological characteristics and preservation of the phosphorite bed repeatedly referred to above, differ strongly from those of the type locality of the Ruisbroek Sand Member, of which it forms a part, a formal lithostratigraphical denomination is here introduced.

Name – Sint Niklaas Phosphorite Bed, named after the city of Sint Niklaas.

Locus typicus – SVK clay pit, Belsele village at Sint Niklaas, Oost-Vlaanderen province, Belgium; Geological Survey number 42W394, at about +4 m TWA. Coordinates: x = 146.500, y = 208.540.

Lithology – Level consisting of greyish coarse sand (mean grain size 0.5 mm) with phosphorite nodules. This conglomerate consists of a local, very restricted, lenticular concentration of phosphoritic elements: small pebbles, gravel, diverse types of concretions, various indurated burrows and complex galleries, scattered or more or less concentrated silicified wood fragments (some bored by mycelia), casts of various invertebrates and vertebrate remains. Minute (mm-sized) varicoloured polished agates with concentric structure occur in the phosphorite level. Its maximal thickness 25 to 30 cm. The conglomerate is sometimes split up into two distinct layers separated by fine sands. The lower layer is always the coarser and contains the heavier elements.

Stratigraphy – Part of the Ruisbroek Sand Member, Zelzate Formation, Tongeren Group, Rupelian, early Oligocene. In the northern part of the outcrop, the new unit lies 3 m below the base of the Boom Clay, in the southern part 2.5 m and in the south-east 2.5-2.8 m.

Geographic distribution – Only present at the type locality. The extension of this deposit seems to be smaller than 5 km².

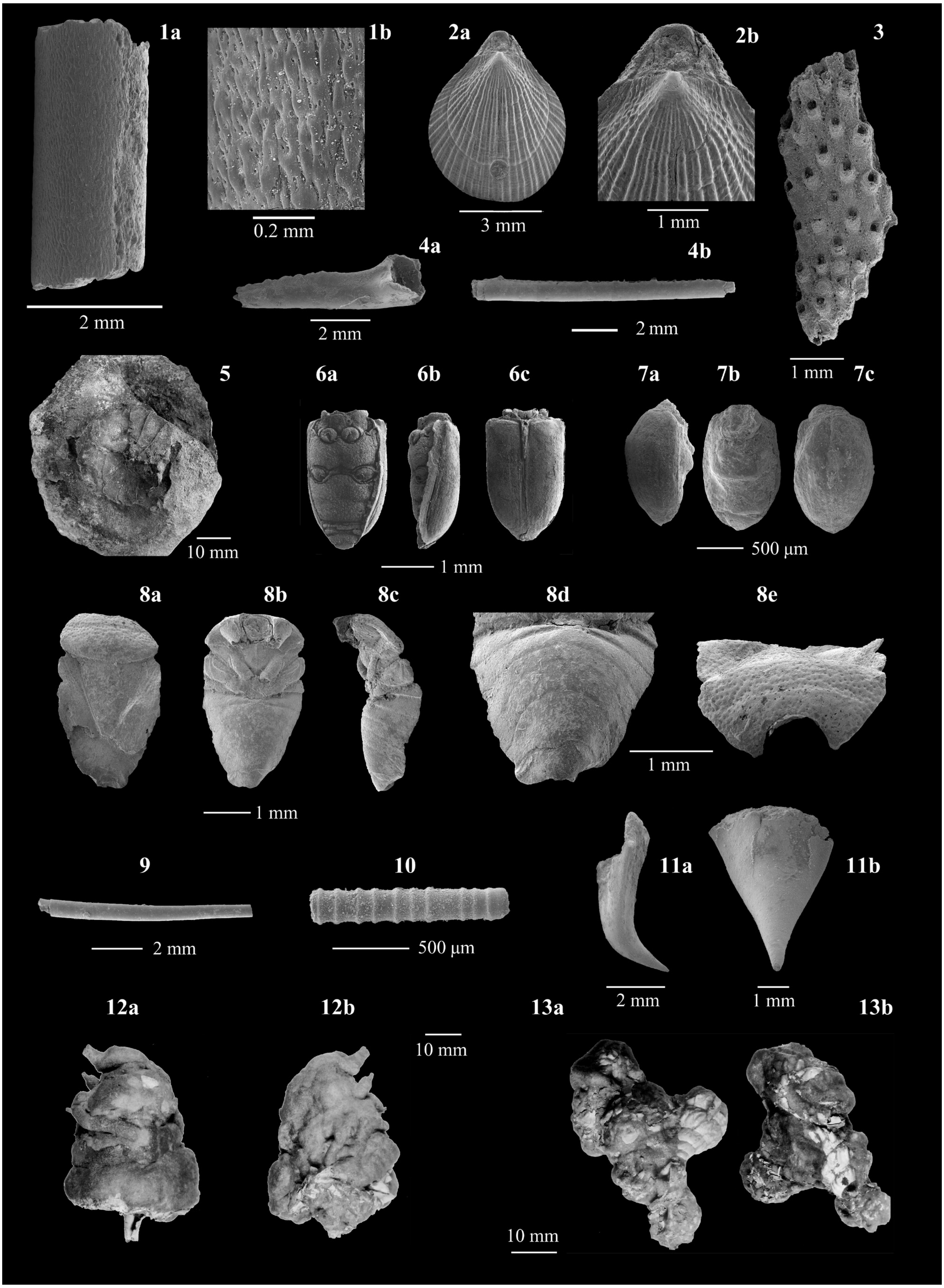
Singularities – Presence of marine Stomatopoda and Isopoda; all fossils preserved as phosphorite casts.

Conclusions

The invertebrate and especially the molluscan fauna changed considerably during the Oligocene. After deposition of the Grimmertingen Sand Member, the molluscan fauna preserved in the Belgian Oligocene deposits decreased dramatically in diversity. A gradual recovery followed before the end of the Rupelian stage, but the number of species, as recorded now, seems to reflect sampling density rather than true biodiversity. Another factor in the decreasing number of molluscan species after the Grimmertingen Sand Member could be the effect of poor preservation. A decreasing number of species was also observed in Germany by Müller (2008, 2011), Welle (2003), (2009) and Welle & Nagel (2003), but seems to depend rather on preservation conditions (A. Müller, pers. comm.). The members of the Boom Clay Formation all contain a characteristic molluscan assemblage. The molluscan faunal composition and the trophic levels as observed here seem to reflect gradual deepening of the sea, until septaria level S60. The preservation of soft bodied organisms, like insects, can be linked to lack of oxygen during deposition. More material still has to be collected from the different levels of the Boom Clay in order to have a complete insight into the distribution of the species: a large number of previously recorded species have not been found again and the protoconchs, in many cases essential for a reliable identification, have not yet been collected for some of the gastropod species, especially those occurring in the septaria levels below S41. Remarkably preserved fossils of invertebrates, especially arthropods, occur in the phosphorites as well as in the Boom Clay, but these have yet to be studied by specialists. The phosphorite bed differs sufficiently in lithology as well as in fauna from the other known occurrences of the Ruisbroek Sand Member to consider it a separate stratigraphic unit.

Plate 1.

1. Unidentified pennatulid. Kruibeke, Oost Vlaanderen province, Belgium, Argex clay pit. S50 septaria level, Putte Clay Member, Boom Clay Formation, Rupelian, early Oligocene. RBINS IST 7236.
2. *Terebratulina* sp. Data as for fig. 1. RBINS IST 7237.
3. Unidentified bryozoan colony. Niel, Antwerpen province, Belgium, Ceulemans clay pit. S30 septaria level, Terhagen Clay Member, Boom Clay Formation, Rupelian, early Oligocene. RBINS IST 7238.
4. Chela of '*Ctenocheles rupeliensis* Buerlen, 1939'. Data as for fig. 1. RBINS IST 7239.
5. *Coeloma rupeliense* Stainier, 1887. Counter cast of telson of female individual. Kruibeke, Oost Vlaanderen province, Belgium, Argex clay pit. S70 septaria level, Putte Clay Member, Boom Clay Formation, Rupelian, early Oligocene. RBINS IST 7240. Photograph J. Laporte.
6. Unidentified beetle. Oost Vlaanderen province, Belgium, Argex clay pit. S41 septaria level, Putte Clay Member, Boom Clay Formation, Rupelian, early Oligocene. Archeological Museum St. Niklaas (not registered).
7. Unidentified beetle. Kruibeke, Oost Vlaanderen province, Belgium. Data as for fig. 6. L. Dufraign collection.
8. Unidentified hymenopterid. Oost Vlaanderen province, Belgium. Data as for fig. 1. RBINS IST 7241.
9. *Gadilina ottoi* (Pilsbry & Sharpe, 1898). Data as for fig. 1. RBINS IST 7242.
10. *Creseis berthae* A.W. Janssen, 1989. Mol, Antwerpen province, Belgium, shaft digging sample -225 m. Transitional layers to Chattian, Rupelian, early Oligocene. RBINS IST 7243.
11. *Clio blinkae* A.W. Janssen, 1989. Kruibeke, Oost Vlaanderen province, Belgium, Argex clay pit. Bed 21 below septaria level S40, Terhagen Clay Member, Boom Clay Formation, Rupelian, early Oligocene. RBINS IST 7244.
12. Pyrite covered specimen of *Arrhoges speciosus speciosus* (Schlotheim, 1820). Rumst, Antwerpen province, Belgium, Wienerberger clay pit. S30 septaria level, Terhagen Clay Member, Boom Clay Formation, Rupelian, early Oligocene. RBINS IST 7245. Photograph M. Wagenaar.
13. Specimen of *Arrhoges s. speciosus* (Schlotheim, 1820), partly covered with pyrite. Data as for fig. 12. RBINS IST 7246. Photograph M. Wagenaar.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2 mm
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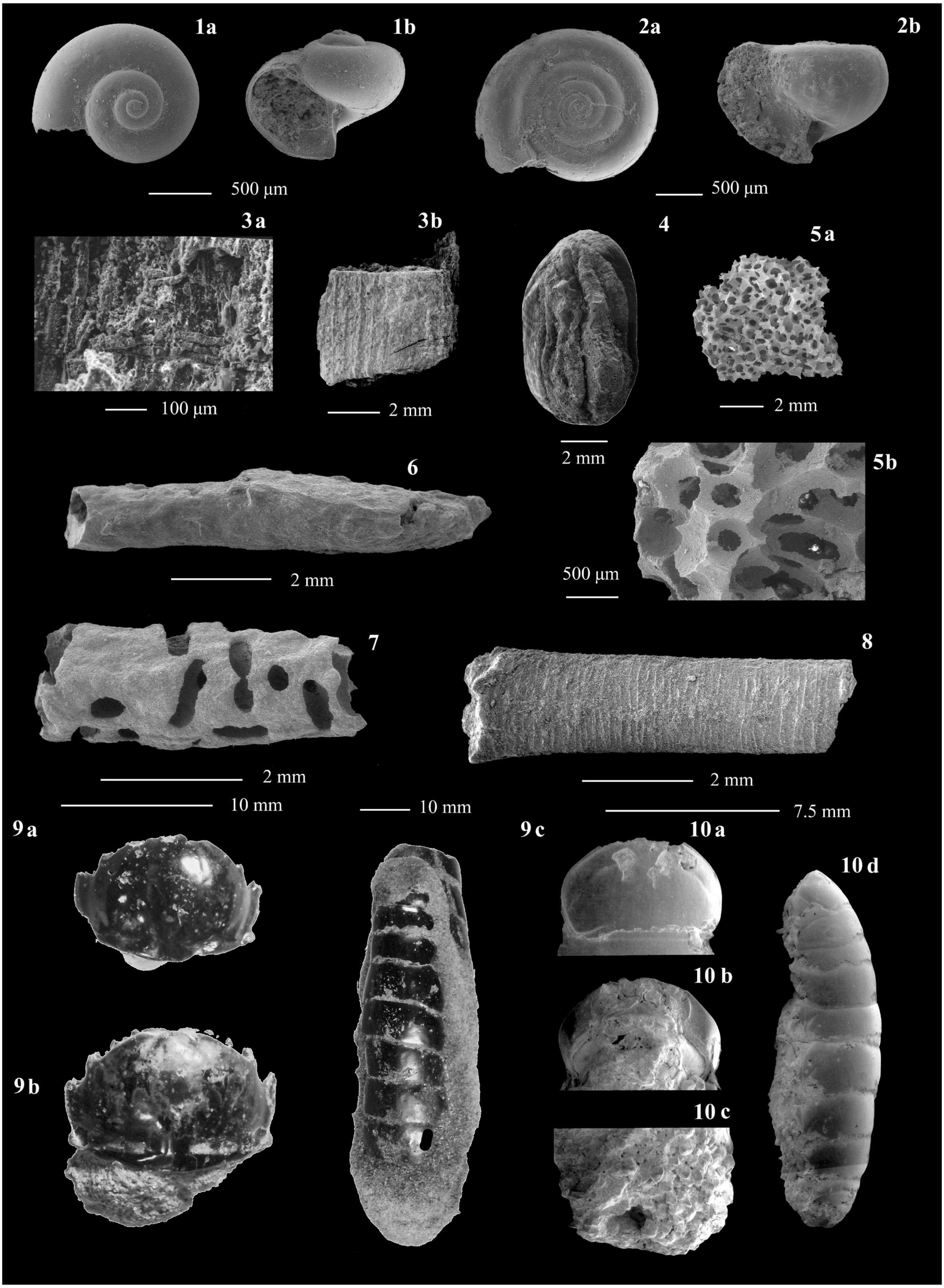
12a
12b
10 mm
13a
13b
10 mm

Plate 1.

Plate 2.

1. *Heliconoides hospes* (Rolle, 1821). Kruibeke, Oost Vlaanderen province, Belgium, Argex clay pit. S50 septaria level, Putte Clay Member, Boom Clay Formation, Rupelian, early Oligocene. RBINS IST 7247.
2. *Limacina umbilicata* (Bornemann, 1855). Mol, Antwerpen province, Belgium, shaft digging, - 225 m. Transitional layers to Chattian, Rupelian, early Oligocene. RBINS IST 7248.
3. Unidentified wood fragment. Lubbeek, Vlaams-Brabant province, Belgium, Roelants clay pit. S20 septaria level, Terhagen Clay Member, Boom Clay Formation, Rupelian, early Oligocene. RBINS b5174.
4. Unidentified fruit. Data as in fig. 3. RBINS b5175.
5. *Delheidia proxima* (Delheid, 1898). Niel, Antwerpen province, Belgium, Ceulemans clay pit. S41 septaria level, Putte Clay Member, Boom Clay Formation, Rupelian, early Oligocene. RBINS IST 7249.
6. Ichnospecies 1. Kruibeke, Oost Vlaanderen province, Belgium, Argex clay pit. S50 septaria level, Putte Clay Member, Boom Clay Formation, Rupelian, early Oligocene. RBINS IST 7249.
7. Ichnospecies 2. Data as in fig. 6. RBINS IST 7250.
8. Ichnospecies 3. Data as in fig. 6. RBINS IST 7251.
9. *Lysiosquilla* sp. 9a: Last segment, 9b: head segment, 9c: middle segments. Sint Niklaas (Belsele), Oost Vlaanderen province, Belgium, Scheerders-Van Kerckhove clay pit. Phosphorite layer below Boom Clay, Rupelian, early Oligocene. G. van den Eeckhaut collection.
10. Cirolanidae or Limnoriidae; 10a: head segment dorsal view, 10b: head segment, ventral view, 10c: tail segment, 10d: complete specimen. Data as in fig. 9. B. d'Haeze collection.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10 d
10 b
9 b
10 c

Plate 2.

Plate 3.

1. Marine isopod or amphipod; 1a: lateral view right side, 1b: ventral view, 1c: dorsal view. Kruibeke, Oost Vlaanderen province, Belgium, Argex clay pit. S50 septaria level, Putte Clay Member, Boom Clay Formation, Rupelian, early Oligocene. B. d'Haeze collection.

2a: Concentration of fossil Mollusca and shark teeth around a piece of driftwood; 2b: driftwood in clay. Niel, Antwerpen province, Belgium, Ceulemans clay pit. S30 septaria level, Terhagen Clay Member, Boom Clay Formation, Rupelian, early Oligocene. L. Dufraign collection.

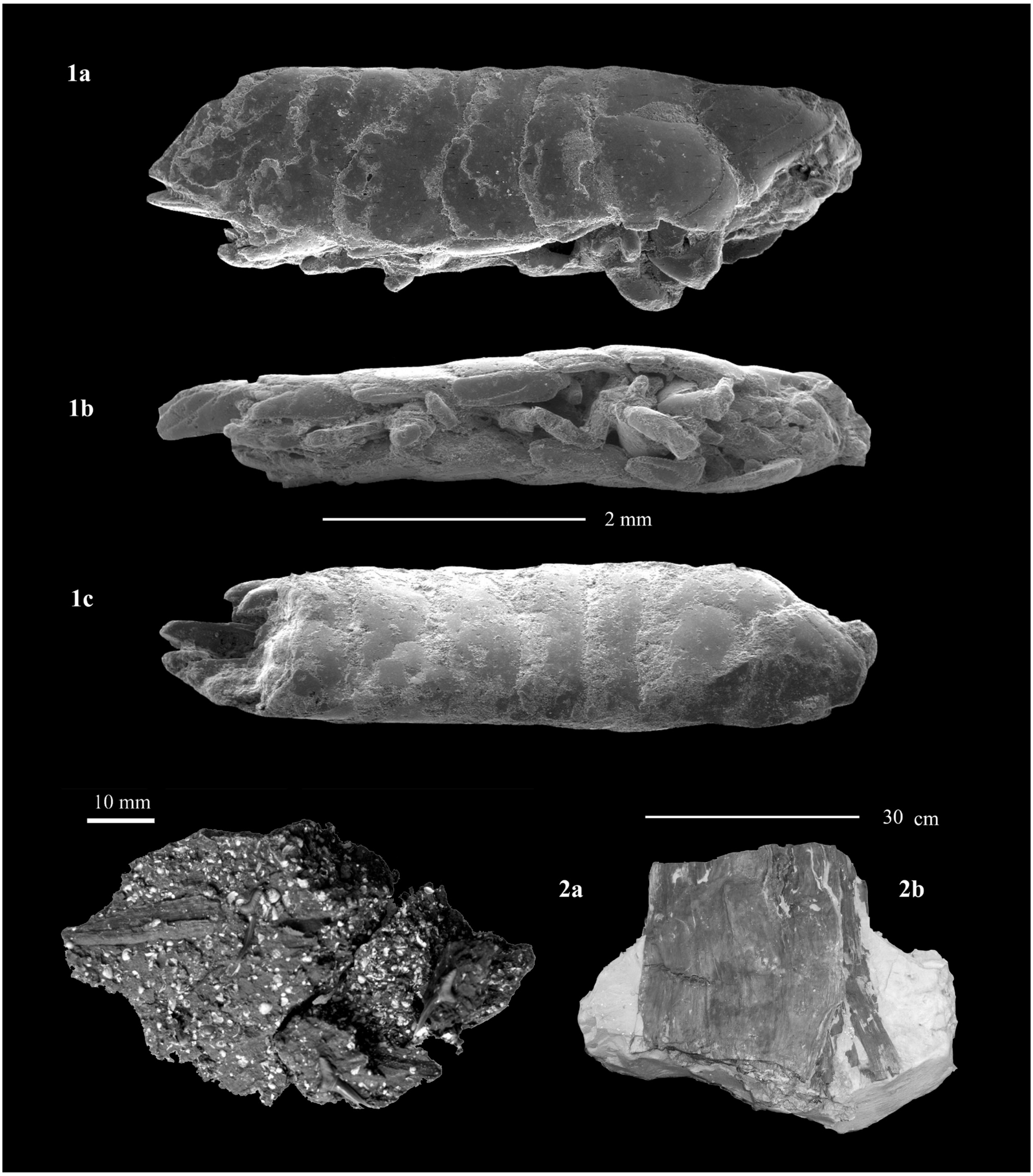

Plate 3.

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