# A late Oligocene molluscan fauna and Oligocene coastal outcrops from Vilsund, NW Denmark

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A rich late Oligocene molluscan fauna from a coastal cliff at Vilsund on the island of Mors, Jylland, Denmark, was studied. A summary of the upper Palaeogene sedimentary sequence in NW Jylland is given and lithostratigraphical and biostratigraphical correlations are suggested. The molluscan fauna contains 120 species, and the non-molluscs are briefly mentioned. The new species *Mitromorpha (Mitrolumna) danica* n. sp. and *Cerithiopsis vilsundensis* n. sp. are established. *Mitromorpha (Mitrolumna) danica* n. sp. is the first representative of the gastropod genus *Mitromorpha* Carpenter, 1865 and subgenus *Mitrolumna* Bucquoy, Dautzenberg & Dollfus, 1883 from the Cenozoic of Denmark. *Eubela* (s. lat.) *zetes* (Kautsky, 1925) represents the oldest record of the genus *Eubela* Dall, 1889. *Andersondrillia* Schnetler & Beyer, 1990 is considered to be a junior synonym of *Benthomangelia* Thiele, 1925. The bivalve genus *Cubiostrea* Sacco, 1897 is recorded from the upper Oligocene of the North Sea Basin for the first time. In the systematical part, several species are treated, including 16 species which have not been recorded previously from the Danish upper Oligocene; a synopsis of the representatives of the genus *Streptodictyon* Tembrock, 1961 in the Danish Oligocene is also given. *Aphanitoma ingerae* Schnetler & Palm, 2008 is transferred to the genus *Mitromorpha,* subgenus *Mitrolumna*. The fauna is compared with other Danish and German late Oligocene faunas and palaeoecological interpretations are suggested. As many of the mollusc species have not previously been illustrated from the Danish upper Oligocene, the fauna is extensively illustrated.

Dinocyst assemblages have been studied to help date the investigated successions. The assemblages indicate that the glauconitic clay from Vilsund should be assigned to the provisionally named stratigraphical Unit X in Śliwińska *et al.* (2012) or the lowermost Brejning Formation. Unit X was previously only known from the interval 61.5–67.5 m in the Harre-1 borehole. Schnetler & Beyer (1990) assigned the glauconitic clay in the coastal cliff at Mogenstrup to the Brejning Formation, but dinocyst studies herein indicate that these strata should be assigned either to Unit X, most likely the upper part, or the lowermost Brejning Formation (see Appendix). This interpretation is supported by the foraminifers and the pectinid species *Palliolum hausmanni* (Goldfuss, 1835).

The occurrence of other nearby outcrops of differing Oligocene ages is demonstrated. The outcrops are described and dated by means of dinocysts and foraminifers and include a section showing a depositional contact between the lowermost Rupelian Viborg Formation and Chattian Branden Clay. The age of the Mogenstrup section is also demonstrated by means of dinocysts.

*Keywords*: Mollusca, taxonomy, biostratigraphy, dinocysts, palaeontology, Brejning Formation, Viborg Formation, Oligocene, Denmark, North Sea Basin.

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The Danish land area is situated in the eastern part of the Cenozoic North Sea Basin (*e.g.*, Knox *et al.* 2010). Oligocene sediments from Denmark crop out in cliffs and clay-pits in rather limited parts of Jylland, but they presumably originally had a much wider distribution toward the east, where they have been removed as a result of late Oligocene and Quaternary erosion. To the west, the Oligocene sediments are covered by younger deposits and continue under the North Sea. Recent stratigraphic overviews of the Oligocene in Denmark are given in Ulleberg (1987), Rasmussen & Dybkjær (2005), Rasmussen *et al.* (2010) and Śliwińska *et al.* (2012, 2014).

In the Limfjorden area, Oligocene sediments have been encountered at several localities. Ravn (1907) recognised the Branden Clay, which he considered to be middle Oligocene, at Branden, Lambjerg and Gjærup. The clay at the localities Nordentoft, Silstrup, Agger in Thy and Sundby on Mors was considered to be upper Oligocene. The Branden Clay is now referred to the lower upper Oligocene (Schnetler & Palm 2008, Śliwińska *et al.* 2012), and Agger (Lodbjerg) to the lower Miocene (Rasmussen *et al.* 2010). The non-glauconitic Skive Clay is known from Hesselbjerg near Skive and is considered to be a facies of the Branden Clay (Heilmann-Clausen 2006; Śliwińska *et al.* 2012).

Ravn (1909) described the clay-pit of Vilsund Brickworks on the island of Mors, where two different sedimentary facies were exposed: black micaceous clay with numerous spherical calcitic concretions that contain crab fossils, and greenish, glauconitic clay with sideritic concretions. Based on the molluscs, Ravn (1909) considered both the black micaceous clay and greenish, glauconitic clay to be of late Oligocene age. Beyer (1987) studied upper Oligocene and Miocene localities in NW Jylland for sedimentology and magnetostratigraphy. Schnetler & Beyer (1990) studied the coastal cliff at Mogenstrup, north of Skive, and recorded 197 mollusc species from a greenish, glauconitic clay with sideritic concretions. They assigned this clay to the Brejning Clay Member of the Vejle Fjord Formation (now the Brejning Formation) of late Oligocene (Chattian B) age, based on molluscs and foraminifer zonation (Ulleberg, pers. comm. 1987). Schnetler & Palm (2008) assigned the greenish, glauconitic clay in the clay-pit of the former Vilsund Brickworks to the Branden Clay. The greenish, glauconitic clay at Mogenstrup is either Unit X or the lowermost Brejning Formation (see Appendix), and

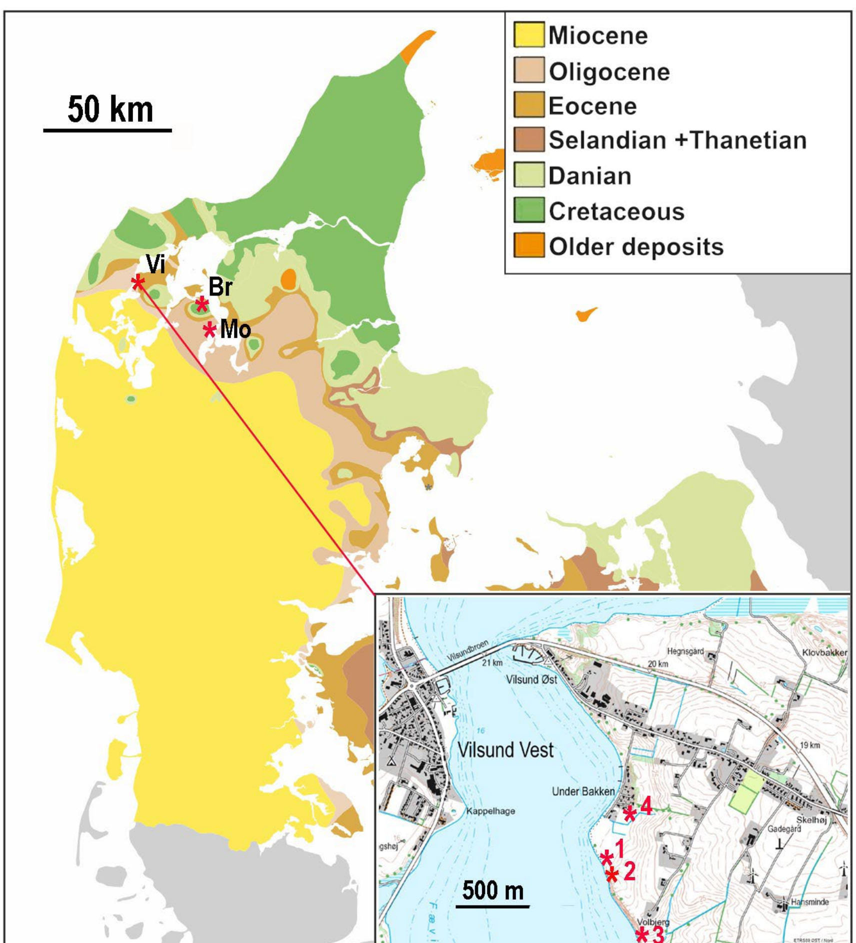



**Fig. 1.** Pre-Quaternary geology of Denmark. Modified after Jensen (1974) and Håkansson & Pedersen (1992). Inset: Detailed map with the Vilsund localities indicated with asterisks. Vi: the localities near Vilsund. Br: the former Branden Brickworks. Mo: the coastal cliff at Mogenstrup. 1: Vilsund 1 (= Sundby Nord, sampled 2006), 2: Vilsund 2 outcrop, sampled 2022–2023, 3: Vilsund 3, (= Sundby Syd, sampled 2006), 4: Vilsund 4, the location of the former Vilsund Brickworks. © Styrelsen for Dataforsyning og Infrastruktur.

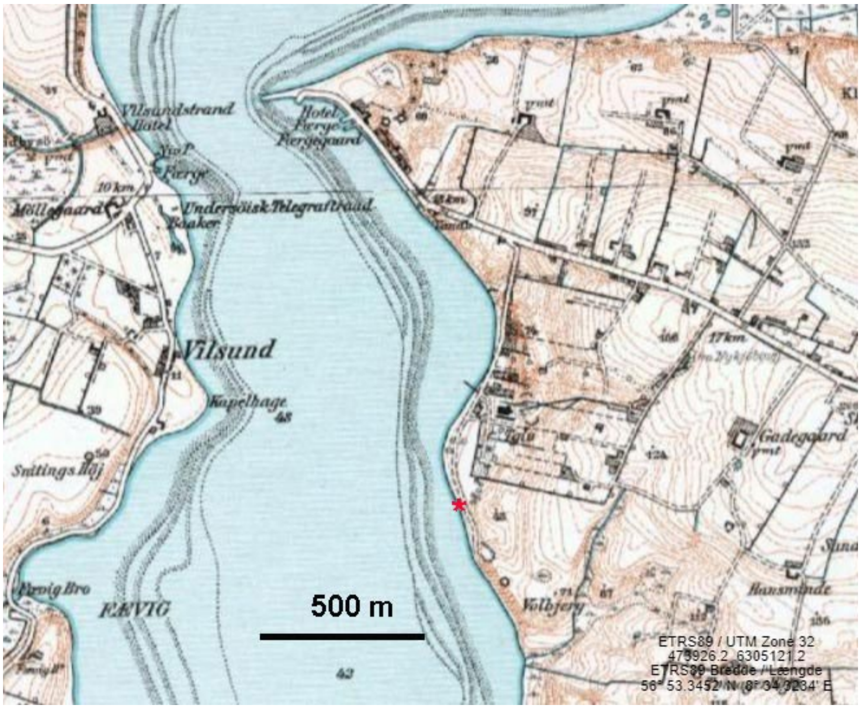



**Fig. 2.** Map from *c*. 1920, showing the location of the former Vilsund Brickworks (teglværk, Tglv). The studied locality Vilsund 2 is indicated by an asterisk (*). © Styrelsen for Dataforsyning og Infrastruktur.

**Fig. 3.** An excavated profile 13 m north of Vilsund 2 in 2022, showing the siderite horizons.

the glauconitic clay in the former clay-pit of Vilsund Brickworks is probably of the same age.

Coastal cliffs at northern Vilsund on the west coast of Mors expose Oligocene sediments of varying age (Fig. 1). One of these outcrops has revealed a rich Chattian mollusc fauna. The purpose of the present study is to describe this new fauna and discuss its palaeoecology, stratigraphic context and age, and to compare it with previously known faunas. For this purpose, a dinoflagellate cyst (dinocyst)-based dating of the section as well as of the rich mollusc fauna from Mogenstrup (Schnetler & Beyer 1990) is provided. Another purpose is to describe and biostratigraphically date (dinocysts and foraminifers) other Oligocene outcrops at Vilsund, including a section showing a disconformity (depositional contact) between lowermost Rupelian Viborg Formation and lower Chattian Branden Clay.

### Mollusc-bearing locality

The locality Vilsund 2 sampled for molluscs is a low coastal cliff *c.* 1500 m south of the Vilsund Bridge (56°52′22.74″N and 8°38′39.69″E). The locality has been known by one of us (HM) for several years, but the sampling of sediment did not begin until 2022. The outcrop has a length of *c.* 21 m and exposes a stratigraphic thickness of *c.* 1 m. The sediment is glauconitic and greenish, very dark when wet. Fragments of molluscs and brachiopods are visible because of their whitish shells. Three horizons of sideritic concretions occur, and numerous sideritic concretions are scattered on the beach. The section is referred to the middle Chattian (either Unit X or lowermost Brejning Formation, see below). The locality was briefly described by Madsen & Schnetler (2023).

### Other Oligocene outcrops at Vilsund

Two other profiles, Vilsund 1 (formerly Sundby Nord) and Vilsund 3 (formerly Sundby Syd), north and south of Vilsund 2, respectively (Fig. 2), were sampled in 2006 for the study of dinocysts and foraminifers; for details, see the appendix. Vilsund 1 was a small outcrop a little north of Vilsund 2, and dinocysts in glauconitic clay at this outcrop indicate assignment to the lower Chattian Branden Clay. Vilsund 3, *c.* 400 m south of Vilsund 2, is a prominent section at Volbjerg exposing the lowermost Rupelian Viborg Formation in depositional contact with the lower Chattian Branden Clay. HM has recently found typical Viborg Formation gastropods here. The section was included in the study by Beyer (1987). The former Vilsund Brickworks and the nearby clay-pit were located *c.* 500 m north of Vilsund 1, but Ravn (1909) gave no information on the exact location of the clay-pit.

## Material and methods

The present paper is based on material collected in 2022 and 2023. Numerous fossils have been found, especially molluscs and brachiopods. Almost all mollusc specimens could be identified to genus or species. Larger specimens are very rare and have been collected by handpicking, but the bulk of the material has been obtained by sediment processing. Smaller molluscs are generally well preserved, but many specimens are worn or fragmented, especially thin-walled bivalves such as pectinids. Many species are found in small numbers only.

The bulk of the material was collected in 2022 and a total of approximately 900 kg of clay was processed. The clay was dried, dispersed in water three times, and screen washed through sieves of two different mesh sizes (2.0 mm and 0.5 mm). The residue contains abundant glauconite, some pyrite, grains of sand and fossils. The residues were examined for fossils by HM using a binocular microscope (Euromex). Fossils larger than 5 mm were photographed with a Nikon D7000. Smaller fossils were photographed with a binocular microscope using the Image Stacking Software – Combine ZM.

Among the non-molluscs, abundant specimens and fragments of a terebratulid brachiopod were collected; such remains are frequently visible in the field due to their size and light color. They may be assigned to the family Terebrataliidae Richardson, 1975, subfamily Terebrataliinae Richardson, 1975 (von der Hocht, pers. comm. 2022). The brachiopod genus *Terebratulina* is represented by a few specimens. Teleost otoliths are rather rare, whereas shark teeth are more common. Noteworthy are the teeth of *Pristiophorus* sp., which are also known from Mogenstrup (Schnetler & Beyer 1990). Anthozoa are regularly found (*Ceratocyathus* and *Flabellum*) and serpulids are rather common.

The mollusc taxa from Vilsund are listed in Table 1. The bivalves are arranged following Bouchet & Rocroi (2010), and the gastropods are arranged following Bouchet & Rocroi (2017). WoRMS Editorial Board (2014), World Register of Marine Species, has also been consulted. Taxa recorded from the Danish upper Oligocene for the first time are indicated with an asterisk. Because the fauna is the first recorded from Unit X or the lowermost Brejning Formation, and because many species have not previously been illustrated from the Danish upper Oligocene, almost all species are illustrated on Figs 6–14. The illustrated fossils are housed in the Fossil and Mo-Clay Museum, Nykøbing Mors, and registered in the Specify database with an MM prefix, but some specimens have been declared Danekræ (prefix DK) and will

**Table 1.** Mollusc taxa from the locality Vilsund 2

| Taxon | Number of specimens | New Denmark |
|---|---|---|
| *Nucula* sp. | 5 fr. | |
| *Nuculana westendorpi* Nyst & Westendorp, 1839 | 4, 7 fr. | |
| cf. *Barbatia glimmerodensis* R. Janssen, 1978 | 1 fr. | * |
| *Acar* aff. *dentiens* (Cossmann & Peyrot, 1912) | 52, 67 fr. | |
| *Bathyarca bellula* (Wiechmann, 1874) | 4 | |
| *Aspalima chattica* (Schnetler & Beyer, 1990) | 1 | |
| *Limopsis parva* Harder, 1913 | 160, 100 def., 50 fr. | |
| *Cosmetopsis retifera* (Semper, 1861) | 1, 1 fr. | |
| *Oblimopa vonderhochti* (Schnetler & Beyer, 1990) | 55, 18 def., 21 fr. | |
| *Ostrea* sp. | 1 | |
| *Cubiostrea* sp. | 2, 5 fr. | * |
| *Hilberia bifida* (Münster, 1835) | 4 fr. | |
| *Palliolum limatum* (Goldfuss, 1833). | Numerous fr. | |
| *Cyclocardia grossecostata* (Koenen, 1884) | 18 def. | |
| *Astarte gracilis* Goldfuss, 1837 | 12 def., 3 fr. | |
| *Digitaria koeneni* (Speyer, 1866) | 1 | |
| *Parvicardium kochi* (Semper, 1861) | 2 fr. | |
| *Varicorbula gibba* (Olivi, 1792) | 1 | |
| Teredinidae, gen. et sp. indet. | 1 | |
| *Hiatella arctica* (Linnaeus, 1767) | 1 | |
| *Poromya* sp. | 1 fr. | |
| *Antalis geminata* (Goldfuss, 1841) | 2 fr. | |
| *Fissidentalium polypleurum* (Seifert, 1959) | Numerous fr. | |
| *Perotrochus* aff. *sismondai* (Goldfuss, 1844) | 1, 1 fr. | * |
| *Emarginula punctulata* (Philippi, 1843) | 2, 1 fr. | |
| *Scissurella koeneniana* R. Janssen, 1978 | 1 | |
| *Steromphala chattica* R. Janssen, 1978 | 2 | * |
| *Collonia troelsi* Schnetler & Beyer, 1990 | 3 fr. | |
| *Homalopoma (Boutillieria) simplex* (Philippi, 1843) | 141 | |
| *Margarites margaritula* (Sandberger, 1859) | 3 | * |
| *Astraea (Lithopoma) pustulosa* (Münster, 1844) | 61 | |
| *Haustator goettentrupensis* (Cossmann, 1899) | 2 | |
| *Cirsotrema insigne* (Philippi, 1843) | 1 | * |
| *Cirsotrema crispata* Harder, 1913 | 2 | |
| *Cirsotrema (?Opaliopsis)* aff. *koeneni* A.W. Janssen, 1967 | 1 | |
| *Opalia pusilla* (Philippi, 1843) | 1 | |
| *Leptonotis planatus* (Speyer, 1864) | 2 | |
| *Euspira helicina protracta* (Eichwald, 1830) | 38 | |
| *Norephora elatior* (Koenen, 1891) | 36 | |
| *Cerithiopsis henckeliusii* (Nyst, 1836) | 2 | |
| *Cerithiopsis jutensis* Schnetler, 1985 | 1 | |
| *Cerithiopsis serrula* R. Janssen, 1978 | 6 | |
| *Cerithiopsis* aff. *dautzenbergi* Glibert, 1949 | 5 | * |
| *Cerithiopsis* (s. lat.) *ariejansseni* R. Janssen, 1978 | 2 | |
| *Cerithiopsis vilsundensis* n. sp. | 6 | * |
| *Cerithiella bitorquata* (Philippi, 1843) | 6 | |
| *Cerithiopsida boelschei* (Koenen, 1891) | 2 | |
| *Laeocochlis supraoligocaenicus* Schnetler & Beyer, 1990 | 13 | |
| *Thereitis angusta* (Tembrock, 1965) | 26 | |

**Table 1 continued**

| Taxon | Number of specimens | New Denmark |
|---|---|---|
| *Seila* (s. lat.) *koeneni* R. Janssen, 1978 | 2 | |
| *Alvania semperi* Wiechmann, 1871 | 1 | |
| *Rissoa karsteni* R. Janssen, 1978 | 1 | |
| *Cirsope multicingulata* (Sandberger, 1859) | 2 | |
| *Polygireulima pseudonaumanni* (R. Janssen, 1978) | 6 | |
| *Niso minor* Philippi, 1843 | 11 | |
| *Aporrhais speciosa* (Schlotheim, 1820) | 5 | |
| *Echinophoria rondeleti* (Basterot, 1825) | 3 | |
| *Pseudosassia flandrica* (Koninck, 1838) | 25, 1 fr. | |
| *Onustus scrutarium* (Philippi, 1843) | 2, 1 fr. | |
| *Euroscaphella siemssenii* (Boll, 1851) | 2 | |
| *Admetula postera* (Beyrich, 1856) | 2 | |
| *Unitas granulata* (Nyst, 1845) | 2 | |
| *Babylonella pusilla* (Philippi, 1843) | 2 | |
| *Searlesia dentifera* Vermeij, 1991 | 1 | |
| *Aquilofusus elegantulus* (Philippi, 1843) | 4 | * |
| *Aquilofusus waeli* (Nyst, 1852) | 5 | |
| *Aquilofusus aequistriata* (Speyer, 1863) | 2 | |
| *Boreosiphopsis danicus* (Schnetler, 1985) | 5 | |
| *Streptodictyon cheruscus* (Philippi, 1843) | 57 | |
| *Streptodictyon soellingensis* (Tembrock, 1965) | 4 | |
| *Streptodictyon schnetleri* Cadée & Janssen, 1994 | 24 | |
| *Tritia schlotheimi* (Beyrich, 1854) | 3 | |
| *Pterynotus (Pterochelus) tristichus* (Beyrich, 1854) | 2 | |
| *Murexsul kochi* (Beyrich, 1854) | 2 | |
| *Eopaziella deshayesi* (Nyst, 1836) | 1 | |
| *Eopaziella capito* (Philippi, 1843) | 6 | |
| *Trophonopsis angustevaricata* (Gripp, 1915) | 12 | |
| *Siphonochelus sejunctus* (Semper, 1861) | 11 | |
| *Siphonochelus fistulatus* (Schlotheim, 1820) | 1 | * |
| *Lyrotyphis cuniculosus* (Nyst, 1836) | 2 | |
| *Hirtotyphis pungens* (Solander, 1766) | 1 | * |
| *Metula (Daphnobela) scabricula* (Philippi, 1843) | 4 | |
| *Vexillum hastatum* (Karsten, 1849) | 1 | |
| *Conomitra soellingensis* (Speyer, 1864) | 7 | |
| *Ancilla karsteni* (Beyrich, 1856) | 16 | |
| *Conus semperi* Speyer, 1862 | 10 | |
| *Bathytoma leunisii* (Philippi, 1843) | 5 | |
| *Drilliola speyeri* (Koch & Wiechmann, 1872) | 2 | |
| *Microdrillia ingerae* Schnetler & Beyer, 1990 | 109 | |
| *Orthosurcula regularis* (Koninck, 1838) | 4 | |
| *Cochlespira volgeri* (Philippi, 1843) | 11 | |
| *Fusiturris selysii* (Koninck, 1838) | 3 | |
| *Fusiturris duchastelii* (Nyst, 1836) | 35 | |
| *Fusiturris enodis* R. Janssen, 1979 | 3 | |
| *Boreodrillia undatella* (Speyer, 1867) | 2 | |
| *Benthomangelia brejningensis* (Schnetler & Beyer, 1990) | 2 | |
| *Benthomangelia holzapfeli* (Koenen, 1890) | 1 | |
| *Splendrillia koeneni* (Speyer, 1867) | 16 | |

**Table 1 continued**

| Taxon | Number of specimens | New Denmark |
|---|---|---|
| *Stenodrillia obeliscus* (des Moulins, 1842) | 3 | |
| *Amblyacrum roemeri* (Koenen, 1867) | 1 | |
| *Mitromorpha (Mitrolumna) danica* n. sp. | 1 | * |
| *Polystira koninckii* (Nyst, 1845) | 6 | |
| *Glibertturricula ariejansseni* Schnetler & Beyer, 1987 | 8 | |
| *Acamptogenotia morreni* (Koninck, 1838) | 2 | |
| *Gemmula geinitzi* (Koenen, 1890) | 3 | |
| *Pleurotomella rappardi* (Koenen, 1867) | 2 | * |
| *Pleurotomella margaritata* R. Janssen, 1978 | 2 | |
| *Rimosodaphnella lappanni* Schnetler & Beyer, 1990 | 1 | |
| *Eubela* (s. lat.) *zetes* (Kautsky, 1925) | 1 | * |
| *Nipteraxis bimonilifera* (Sandberger, 1859) | 2 | |
| *Graphis hosiusi* (Lienenklaus, 1891) | 7 | |
| *Mathilda bicarinata* Koch & Wiechmann, 1872 | 2 | * |
| *Crenilabium terebelloides* (Philippi, 1843) | 2 | |
| *Acteon punctatosulcata* (Philippi, 1843) | 1 | |
| *Odostomia ventriosa* (Speyer, 1870) | 2 | * |
| *Odostomia* sp. | 2 | |
| *Syrnola subcylindrica* (Philippi, 1843) | 4 | |
| *Syrnola laevissima* (Bosquet, 1859) | 1 | |
| *Turbonilla jeffreysi* Koch & Wiechmann, 1872 | 5 | |
| *Chrysallida* sp. | 5 | |

fr.: fragment, def.: defective

ultimately be stored in the Natural History Museum of Denmark (Copenhagen, NHMD prefix).

A sample of ‘glauconitic clay with brachiopods’ collected by one of us (IS; 18 March 2022) from the Vilsund 2 locality was analysed for dinocysts. The sample consists of medium grey clay with scattered, well-rounded quartz and quartzite grains ranging from coarse sand to fine sand (up to 3 mm). The sample is very rich (estimated ~50%) in light and dark green, sand-sized glauconite, giving the sediment a greenish colour and grainy texture. The sample is furthermore very rich (estimated ~25%) in shells and shell fragments of molluscs and brachiopods.

For the dinocyst analysis, a sample of 31 g of clean material was processed for palynology at the Department of Geoscience, Aarhus University (as ch-c lab. no. 3283) using a standard technique, which involves successive treatments with HCl, HF, and again HCl and $H_2O$ to dissolve and remove calcium carbonate and siliceous compounds. This procedure was followed by sieving on a 20 $\mu$m mesh. The sieved residue was treated briefly (7 min) with cold, concentrated $HNO_3$ in order to oxidise amorphous organic matter and pyrite. Following oxidisation, the residuum was mounted with gelatine-glycerine on slides for light-microscopy.

# Geological setting and stratigraphy

The pre-Quaternary geology of the western Limfjorden area consists of strata ranging from the Danian to the Miocene. The presence of salt diapirs and pillows have resulted in exposure of Upper Cretaceous chalk over the Mors and Batum diapirs (Håkansson & Pedersen 1992), and strata of Danian, Thanetian and Eocene age are found flanking these diapirs. The lowermost Eocene Fur Formation is exposed in several coastal cliffs on Fur and Mors and at Ertebølle north of Hvalpsund and Silstrup south of Thisted. The only existing outcrop in NW Jylland of the lowermost Rupelian Viborg Formation is the high cliff section at Volbjerg (this study Vilsund 3 section, see Appendix). Here the Viborg Formation is in undisturbed depositional contact with the overlying lower Chattian Branden Clay, demonstrating a major intra-Oligocene hiatus in this area. The Oligocene Branden Clay was formerly exposed at Branden near the northern tip of Salling. Originally, Ravn (1907) assigned the Branden Clay to the middle Oligocene, and recently Schnetler & Palm (2008) and Śliwińska *et al.* (2012) stated an early Chattian age. Ravn (1907) also assigned the clay at Gjærup to the middle Oligocene, whereas Schnetler

& Palm (2008) assigned it to the Branden Clay. Ravn (1909) assigned the sediments in Vilsund Brickworks to the upper Oligocene. The uppermost Oligocene Brejning Formation is exposed at Lyby (Beyer 1987; Rasmussen *et al.* 2010) and at Mogenstrup (Beyer 1987; Schnetler & Beyer 1990; Rasmussen *et al.* 2010; present study). The present study indicates that the greenish, glauconitic clay with siderite layers at the Vilsund 2 locality and at Mogenstrup should be assigned to either Unit X (Śliwińska *et al.* 2012) or the Brejning Formation, see Appendix. At Silstrup a depositional contact is exposed between lowermost Eocene Fur Formation and the Brejning Formation (Gry 1979; Heilmann-Clausen 1997; Rasmussen *et al.* 2010; Schulz *et al.* 2020), demonstrating a local *c.* 30 Ma hiatus possibly related to movement in salt diapirs.

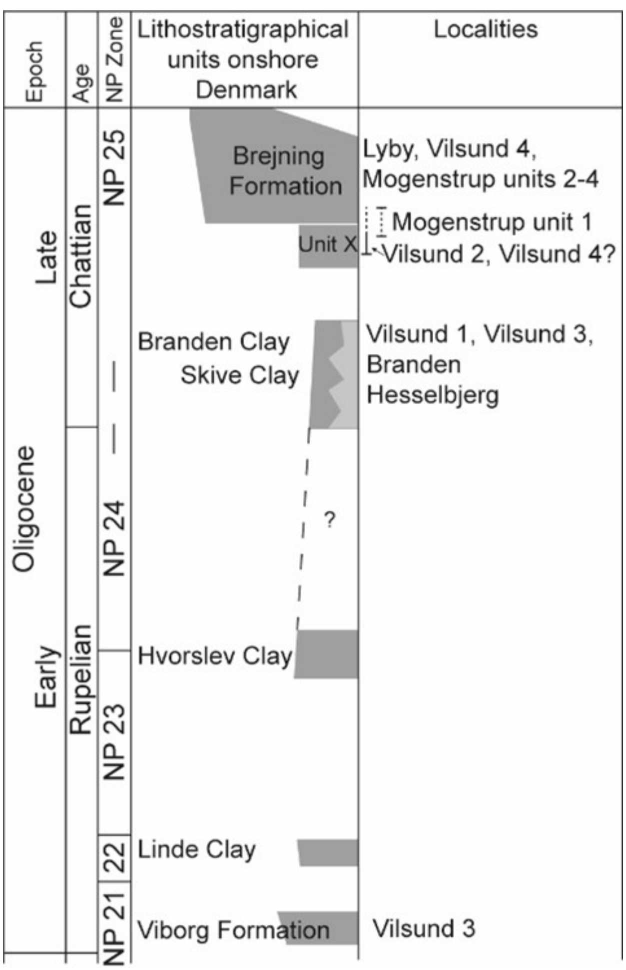



**Fig. 4.** Composite lithological column illustrating the upper Oligocene sequence in NW Jylland. The stratigraphical positions of the localities at Vilsund, Mogenstrup, Lyby, Branden and Hesselbjerg are indicated. Vilsund 1–3 are coastal exposures, Vilsund 4 is the former Vilsund Brickworks. Modified from Śliwińska *et al.* (2012).

# Biostratigraphy and Age

## Molluscs

A late Oligocene (Chattian) age is clearly apparent from the molluscan fauna at the Vilsund localities studied herein. Anderson (1958, 1961) and R. Janssen (1979b) suggested a biostratigraphy of the Chattian, based on pectinids. Numerous fragments of pectinids have been collected, viz. abundant *Palliolum limatum* (Goldfuss, 1833) and a few *Hilberia bifida* (Münster, 1835), indicating a Chattian A age. At Mogenstrup, *Hilberia bifida*, *Hilberia soellingensis* (Koenen, 1868) *Palliolum limatum ambignum* and *Palliolum hausmanni* (Goldfuss, 1835) are present (Schnetler & Beyer 1990), and the first two species are probably reworked. The gastropod species *Tritia schlotheimi* (Beyrich, 1854) indicates, according to R. Janssen (1979b), a Chattian B or younger age. This species has been encountered at Mogenstrup, indicating a Chattian B age. However, three specimens were also found at Vilsund.

In the Vilsund fauna, the pectinid *Palliolum hausmanni* is absent, suggesting a Chattian A age. Several species, *e.g. Palliolum limatum*, *Acar* aff. *dentiens*, *Scissurella koeneniana*, *Steromphala chattica*, *Homalopoma simplex* and *Streptodictyon soellingensis* are only known from Chattian A (lowermost upper Oligocene) strata in Germany. The latter species is also known from the lower upper Oligocene (Chattian A) at Branden (Schnetler & Palm 2008), and the occurrence in the Vilsund fauna also supports a Chattian A age.

Ravn (1909) listed the mollusc faunas from the two different sedimentary facies in the clay-pit of Vilsund Brickworks. The senior author studied this material in the Geological Museum, Copenhagen (now NHMD), in 1982 and 2022. The black micaceous clay contained numerous spherical concretions with crabs and a typical late Oligocene fauna. The greenish, glauconitic clay with sideritic concretions contained a rather limited fauna, *e.g. Limopsis goldfussi* (= *Limopsis parva*), *Mitra* sp. (= *Conomitra soellingensis*) and *Parvicardium kochi*. We conclude, based on the molluscs, that both the black micaceous clay and the greenish, glauconitic clay in the clay-pit of the former Vilsund Brickworks are of late Oligocene age. The greenish, glauconitic clay with sideritic concretions is presumably the same unit as the sediments at the Vilsund 2 locality and Mogenstrup, and the black micaceous clay with spherical concretions is assigned to the glauconite-free upper part of the Brejning Formation, as at Mogenstrup.

## Dinocysts and foraminifers

*Palynofacies.* The organic particles in the processed sample from Vilsund 2 ('Glauconitic clay with brachiopods') include palynomorphs (estimated 70–75%), light brown structured woody material (20–25%) and few percent foraminifer-inner linings. Palynomorphs are well preserved and dominated by dinocysts (approximately 50 % of the organic particles). Pollen and spores (mainly bisaccate pollen) make up 20–25% of the organic particles. Non-saccate pollen and spores are underrepresented in residues sieved on 20 $\mu$m.

*Dinocyst analysis and age of the sample.* The dinocyst assemblage is well preserved and diverse. A full account of the assemblage is given in the Appendix. In brief,

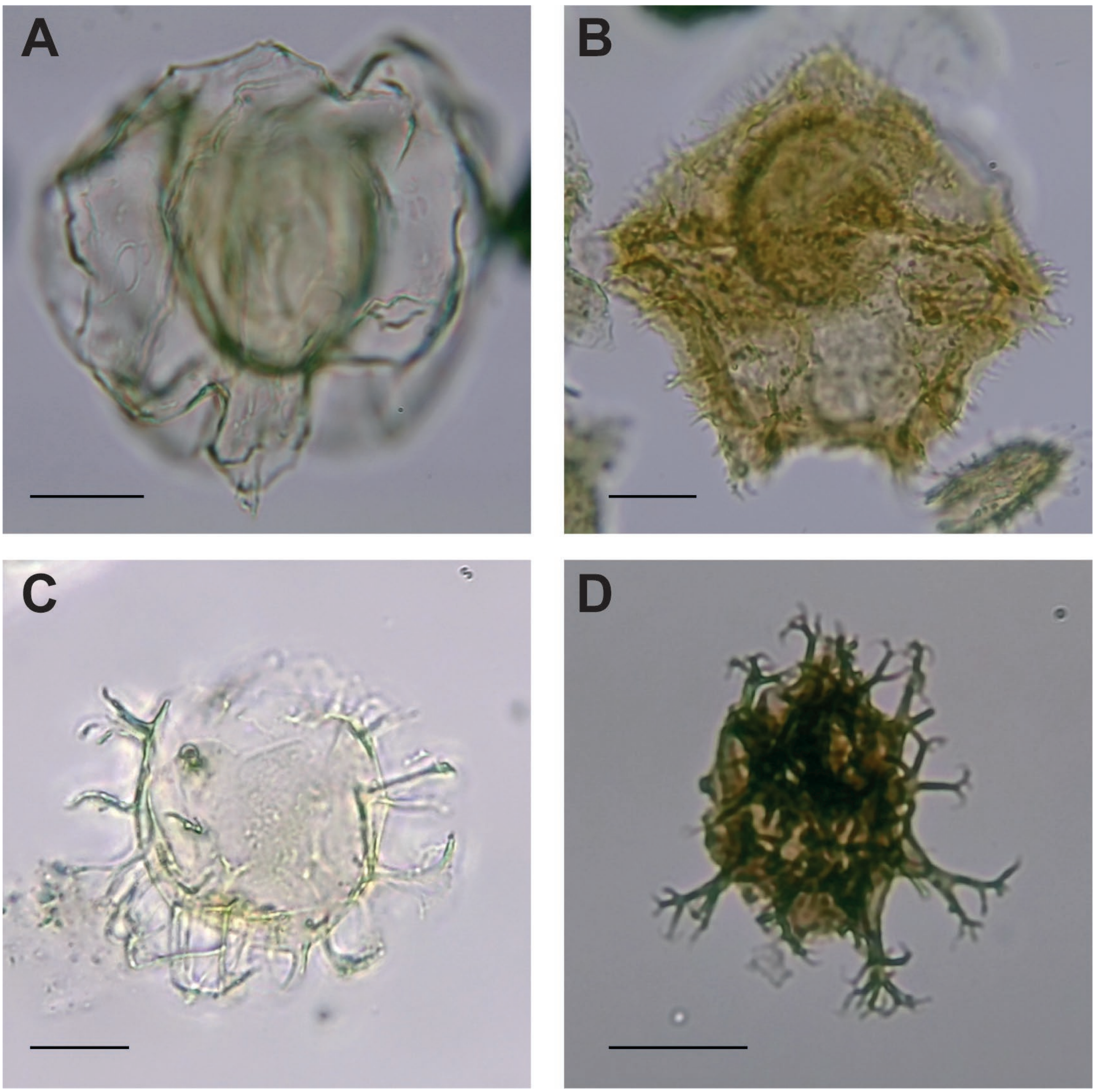



**Fig. 5.** Selected key dinocysts and an acritarch from the studied outcrops. Scale bars: 20 µm. Microscope coordinates (MC) are taken following the method described by Śliwińska (2019), with A-point coordinates 100.7×0.6. **A,** *Triphragmadinium demaniae* Vilsund 2, Lab. No. 3283, Slide J-2; England Finder Coordinates V19-2. **B,** *Lejeunecysta tenella* Vilsund 2, Lab. No. 3283 Slide J-4, MC 15.5 x 158. **C,** cf. *Licracysta? semicirculata* Vilsund 2, Lab. No. 3283 Slide J-4, MC 20.2 x 152. **D,** acritarch *Artemisiocysta cladodichotoma* Mogenstrup Unit 1, Lab. No. 1143 Slide H-1; MC 18 x 141.

the assemblage contains several long ranging taxa (*e.g.*, *Spiniferites* spp., *Lingulodinium machaerophorum* and *Reticulatosphaera actinocoronata*). The sample yields rare *Chiropteridium galea*, *Lejeunecysta tenella* (Fig. 5 B), the acritarch *Artemisiocysta cladodichotoma* (Fig. 5 D) and cf. *Licracysta*? *semicirculata* (Fig. 5 C, see taxonomic remarks in the Appendix). Notably, several specimens of *Triphragmadinium demaniae* (Fig. 5 A) were recovered, a species (see taxonomic remarks in the Appendix) that has previously only been recorded in the ?upper Eochattian of the Netherlands, Belgium and Germany (Van Simaeys *et al.* 2005; King *et al.* 2016). In the dinocyst zonation of the North Sea Basin (King 2016), the first occurrence of *T. demaniae* indicates the base of dinocyst Subzone DO7b (King 2016, p. 603); note that the base of the subzone is erroneously shown as the *last* occurrence of *T. demaniae* in King (figs 13, 20). The processed sample from Vilsund 2 lacks the following stratigraphically significant taxa: *Deflandrea* spp., *Saturnodinium pansum*, *Wetzeliella gochtii*, *W. symmetrica*, *Rhombodinium draco*, and typical ?*Licracysta semicirculata*. The absence of these taxa, combined with the presence of *T. demaniae*, indicates probable assignment to Subzone DO7b of King (2016), i.e., a late Chattian age. In terms of Danish lithostratigraphic units, the sample should probably be assigned to Unit X of Śliwińska *et al.* (2012), although the lowermost Brejning Formation cannot be excluded (see Appendix).

## Systematical part

*Abbreviations and repositories.* ISL: MNO: Collection of Mogens Stentoft Nielsen, (Odense, Denmark); LSJ: Collection of Lone Sortkjær (Juelsminde, Denmark); MM: Collection of the Fossil and Mo-Clay Museum (Skarrehagevej 8, Nykøbing Mors, Denmark); NHMD: Collection of the Natural History Museum of Denmark (Copenhagen, Denmark); DK: prefix for specimens in the Danekræ Collection (NHMD, Copenhagen). This published work and the nomenclatural acts it contains have been registered in ZooBank: http://zoobank.org:pub

### Class Bivalvia Linnaeus, 1758

### Autobranchia Grobben, 1894

### Infraclass Pteriomorphia Beurlen, 1944

### Order Arcida Stolictzka, 1871

### Superfamily Arcoidea Lamarck, 1809

### Family Arcidae Lamarck, 1809

Genus *Barbatia* Gray, 1842

Type species: *Arca barbata* Linnaeus, 1758 accepted as *Barbatia barbata* (Linnaeus, 1758) (type by subsequent designation).

**cf. *Barbatia glimmerodensis* R. Janssen, 1979**
Fig. 6f

1979b *Barbatia (Barbatia) glimmerodensis* R. Janssen, p. 24, pl. 1, figs 6–7.

*Material*. One fragmentary valve. Height 1.7 mm.

*Remarks*. The sculpture of the fragment matches the description and illustration by R. Janssen well.

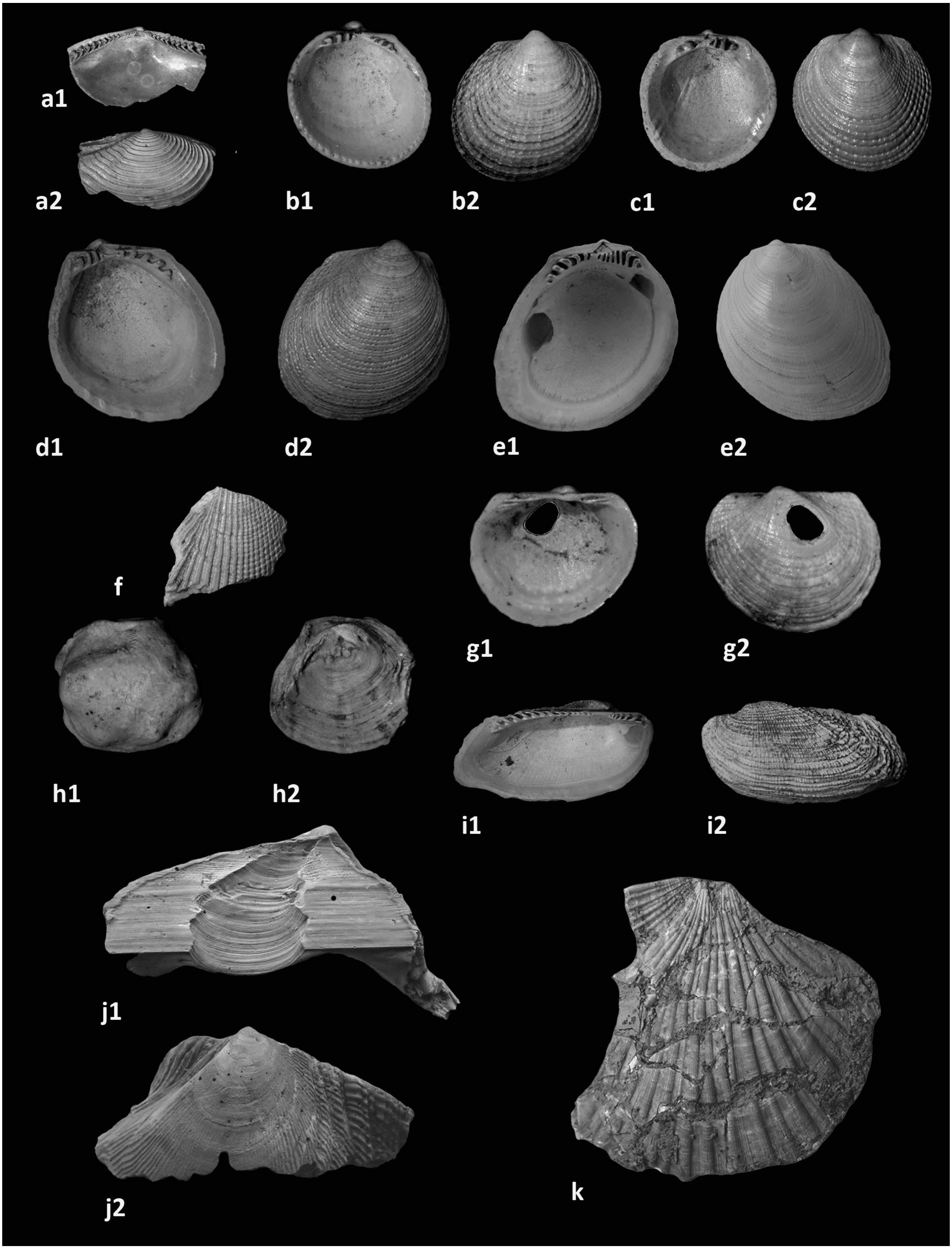
Genus *Acar* Gray, 1857

Type species: *Byssoarca divaricata* G. B. Sowerby I, 1833 accepted as *Acar plicata* (Dillwyn, 1817) (type by subsequent designation).

***Acar* aff. *dentiens* (Cossmann & Peyrot, 1912)**
Fig. 6i

1979b *Barbatia (Acar)* aff. *dentiens* Cossmann & Peyrot, 1912 – R. Janssen, p. 25, pl. 1, figs 8–9.
1990 *Barbatia (Acar)* aff. *dentiens* Cossmann & Peyrot, 1912 – Schnetler & Beyer, p. 46, pl. 1, figs 1a–b.

▼ **Fig. 6. a,** *Nuculana westendorpi* Nyst & Westendorp, 1839. Right valve, length 4.2 mm. **a1,** interior view, **a2,** exterior view. MM-13589. **b,** *Aspalima chattica* (Schnetler & Beyer, 1990). Right valve, length 2.8 mm. **b1,** interior view, **b2,** exterior view. MM-13590. **c,** *Cosmetopsis retifera* (Semper, 1861). Right valve, length 2.0 mm. **c1,** interior view, **c2,** exterior view. MM-13591. **d,** *Oblimopa vonderhochti* (Schnetler & Beyer, 1990). Right valve, height 7.2 mm. **d1,** interior view, **d2,** exterior view. MM-13592. **e,** *Limopsis parva* Harder, 1913. Left valve, height 11.0 mm. **e1,** interior view, **e2,** exterior view. MM-13593. **f,** cf. *Barbatia glimmerodensis* R. Janssen, 1979. Fragmentary right valve, height 1.7 mm. NHMD 1651691 (ex MM-13594), DK 1264. **G,** *Bathyarca bellula* (Wiechmann, 1874). Left valve, length 1.6 mm. **g1,** interior view, **g2,** exterior view. MM-13595. **h,** *Ostrea* sp. Height 1.7 mm. **h1,** interior view, **h2,** exterior view. MM-13596. **i,** *Acar* aff. *dentiens* (Cossmann & Peyrot, 1912). Left valve, height 6.0 mm. **i1,** interior view, **i2,** exterior view. MM-13597. **j,** *Cubiostrea* sp. Right valve, length 41.0 mm. **j1,** interior view, **j2,** exterior view. NHMD 1651688 (ex MM-13598), DK 1261. **k,** *Palliolum limatum* (Goldfuss, 1833). Left valve, height 28.0 mm. MM-13599.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*Material*. 52 specimens and 67 fragments.

*Remarks*. The specimens are generally broken and worn, but the few complete valves match the illustrations in R. Janssen (1979b) well. The species is less common at Mogenstrup (Schnetler & Beyer 1990) and is also found at Brejning (collected by K. Eriksen, unpublished, NHMD). The species is common in the German upper Oligocene at Glimmerode and furthermore reported from Doberg and Söllingen (R. Janssen 1979b).

## Order Ostreida

## Superfamily Ostreoidea Rafinesque, 1815

## Family Ostreidae Rafinesque, 1815

Genus *Cubiostrea* Sacco, 1897

Type species: *Ostrea virginica* Gmelin, 1791 accepted as *Crassostrea virginica* (Gmelin, 1791) (type by original designation).

***Cubiostrea* sp.**
Fig. 6j, Fig. 14a

*Material*. Three large fragmentary specimens and fragments from the glauconitic clay. A valve in a sideritic concretion has a height of 128 mm and a width of 103 mm.

*Description*. The illustrated fragmentary right valve has a width of 41.0 mm and a height of 20.3 mm. The other fragmentary specimen has a width of 90 mm. The valve is large and rather fragile. It has numerous rather irregular radial ribs, which are strongest on the margins. There is a large highly triangular and curved ligament pit on the internal of the valve.

*Further material*. One adult specimen, preserved in a sideritic concretion, one defective valve in clay and a few fragments.

*Discussion*. The specimen is very similar to the illustration in Cox in Moore 1971 (p. N1141, fig. J117).

*Remarks*. The species *Cubiostrea digitalina* (Dubois de Montperreux, 1831) was reported from the Hemmoorian at Miste (A.W. Janssen 1984, p. 58, pl. 27, figs 1a–b, 2a–b). The genus is represented in the Eocene of England by three species (*fide* Alan Morton: https://www.dmap.co.uk/index.htm). The Eocene of France contains six species of the genus (*fide* Le Renard & Pacaud 1995). The genus was not previously known from the upper Oligocene of the North Sea Basin.

## Class Gastropoda Cuvier, 1795

## Subclass Vetigastropoda Salvini-Plawen, 1980

## Order Pleurotomariida Cox & Knight, 1960

## Superfamily Pleurotomarioidea Swainson, 1840

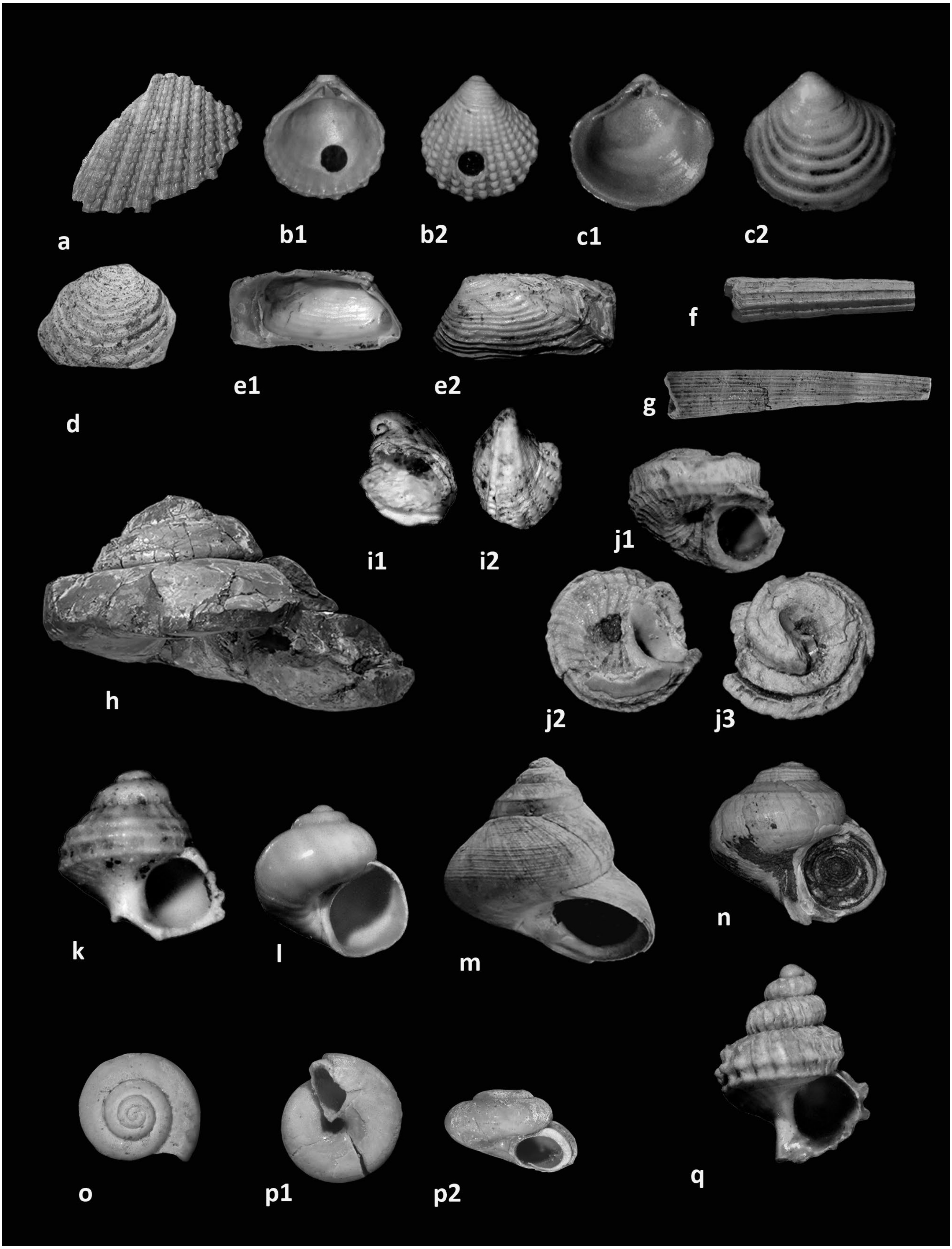
## Family Pleurotomariidae Swainson, 1840

Genus *Perotrochus* P. Fischer, 1885

Type species: *Pleurotomaria quoyana* P. Fischer & Bernardi, 1856, accepted as *Perotrochus quoyanus quoyanus* (P. Fischer & Bernardi, 1856) (type by monotypy).

***Perotrochus* aff. *sismondai* (Goldfuss, 1844)**
Fig. 7h

▼ **Fig. 7. a,** *Hilberia bifida* (Münster, 1835). Length 3.5 mm. MM-13600. **b,** *Cyclocardia grossecostata* (Koenen, 1884). Right valve, height 1.4 mm. **b1,** interior view, **b2,** exterior view. MM-13601. **c,** *Astarte gracilis* Goldfuss, 1837. Right valve, height 1.1 mm. **c1,** interior view, **c2,** exterior view. MM-13602. **d,** *Digitaria koeneni* (Speyer, 1866). Right valve, height 3.5 mm. MM-13603. **e,** *Hiatella arctica* (Linnaeus, 1767). Left valve, height 3.0 mm. **e1,** interior view, **e2,** exterior view. MM-13604. **f,** *Antalis geminata* (Goldfuss, 1841). Length 14.5 mm. MM-13605. **g,** *Fissidentalium polypleurum* (Seifert, 1959). Length 40.3 mm. MM-13606. **h,** *Perotrochus* aff. *sismondai* (Goldfuss, 1844). Height 5.0 cm, width 8.5 cm. MM-13607. **i,** *Emarginula punctulata* (Philippi, 1843). Length 1.8 mm. **i1,** oblique apertural view, **i2,** apical view. MM-13608. **j,** *Scissurella koeneniana* R. Janssen, 1978. Width 1.1 mm. **j1,** lateral view, **j2,** umbilical view, **j3,** apical view. MM-13609. **k,** *Steromphala chattica* (R. Janssen, 1978). Height 0.8 mm. NHMD 1651683 (ex MM-13610), DK 1256. **l,** *Collonia troelsi* Schnetler & Beyer, 1990. Height 1.0 mm. MM-13611. **m,** *Homalopoma simplex* (Sandberger, 1859). Lateral view, height 10.0 mm. MM-13612. **n,** *Homalopoma simplex* (Sandberger, 1859). Specimen with operculum *in situ*. Lateral view, height 3.0 mm. MM-13613. **o,** *Margarites margaritula* (Sandberger, 1859). Apical view, diameter 1.1 mm. NHMD 1651687 A (ex MM-13615), DK 1260. **p,** *Margarites margaritula* (Sandberger, 1859). Height 1.0 mm. **p1,** umbilical view, **p2,** lateral view. NHMD 1651687 B (ex MM-13616), DK 1260. **q,** *Astraea (Lithopoma) pustulosa* (Münster, 1844). Height 2.0 mm. MM-13617.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1978b *Pleurotomaria* aff. *sismondai* (Goldfuss, 1844) – R. Janssen, p. 141.

*Description*. The large almost complete specimen has a height of 50 mm and a width of 85 mm. The H/W ratio is 0.59. The shell has *c.* 3.5 whorls preserved as internal molds with parts of the nacreous layer preserved. The whorls are almost flat with a narrow shoulder and are separated by a deep suture. The aperture is rather large and almost ellipsoidal, and the umbilicus is rather narrow and deep. No ornament is visible.

*Remarks.* The species was not recognised by Schnetler & Beyer (1990). Later, several incomplete specimens have been found at Mogenstrup, some of them rather large. The species is elsewhere only known from the upper Oligocene at Doberg (Germany).

## Family Scissurellidae Gray, 1847

Genus *Scissurella* d'Orbigny, 1824

Type species: *Scissurella laevigata* d'Orbigny, 1824, accepted as *Scissurella costata* d'Orbigny, 1824 (type by subsequent designation).

***Scissurella koeneniana* R. Janssen, 1978**
Fig. 7j

1978a *Scissurella (Anatoma) philippiana* – R. Janssen, p. 17 [*non* Semper].
1978b *Scissurella (Anatoma) koeneniana* R. Janssen, p. 142, pl. 9, fig. 6.

*Remarks*. The only specimen found has a coarser sculpture than the illustrated holotype. However, as the range of variation of the taxon is unknown, the specimen has been assigned to this species, which is also known from Mogenstrup.

## Order Trochida

## Family Trochidae Rafinesque, 1815

## Subfamily Cantharidinae Gray, 1857

Genus *Steromphala* Gray, 1847

Type species: *Trochus strigosus* Gmelin, 1791, accepted as *Gibbula cineraria* (Linnaeus, 1758), accepted as *Steromphala cineraria* (Linnaeus, 1758) (type by original designation).

***Steromphala chattica* (R. Janssen, 1978)**
Fig. 7k

1978a *Jujubinus (Strigosella) chatticus* n. sp. R. Janssen, p. 23, pl. 1, fig. 8, pl. 4, fig. 2.
1978b *Jujubinus (Scrobiculinus) chatticus* R. Janssen, 1978 – p. 147, pl. 10, fig. 14.

*Material*. One juvenile specimen, NHMD 1651683 (ex MM-13610), DK 1256.

*Description*. The shell is very small and conical, a little higher than wide. The last whorl equals 0.85 of the total shell height, the aperture about 0.46. The aperture is rounded quadratic, the columella concave and the labrum is broken.

The protoconch is paucispiral and consists of one smooth whorl. The nucleus is small and depressed and the protoconch whorl is planspiral. There are 2½ teleoconch whorls, which are separated by a deep suture. On the first medium whorl there is a rather distinct edge on the middle of the whorl, which divides the whorl into an adapical flat part and an abapical part. On the next teleoconch whorl a further spiral appears below the edge, which also becomes a distinct spiral. On the flat adapical part of the whorl an indistinct spiral appears. The flat base is demarcated by a distinct spiral rib. There are *c.* 20 weak axial ribs which gradually get weaker on the terminal whorl. The axial ribs continue on the base, where they are very weak.

*Discussion*. The specimen is similar to the juvenile specimen illustrated by R. Janssen (1978a, pl. 1, fig. 8), but the aperture on the German specimen is more rectangular. According to WoRMS Editorial Board (2014), *Jujubinus (Strigosella)* Sacco, 1896 is a junior synonym of *Steromphala* Gray, 1847.

*Remarks*. The species is very common in the fauna from Glimmerode (R. Janssen 1978a), but only two additional specimens are known from Doberg (R. Janssen 1978b).

Genus *Margarites* Gray, 1847

Type species *Margarites diaphana* Gray, 1847 accepted as *Margarites helicinus* (Phipps, 1774) (type by monotypy).

***Margarites margaritula* (Sandberger, 1859)**
Fig. 7o, 7p

1959 *Tiburnus (margaritula) margaritula* (Sandberger, 1859) – Anderson, p. 55, pl. 2, fig. 4.
1978a *Margarites margaritula* (Sandberger, 1859) – R. Janssen, p. 23 [here extensive synonymy].

1978b *Margarites margaritula* (Sandberger, 1859) – R. Janssen, p. 146, pl. 9, fig. 12.

*Material.* The poor material of five specimens includes only defective and fragmentary remains.

*Description*. The shell is small and low conical. The height/ width ratio is *c.* 0.8. The protoconch consists of 1½ smooth whorls and the nucleus is small. There are *c.* 3½ convex and smooth teleoconch whorls, which are separated by a deep suture and quickly increasing in diameter. The height of the last whorl equals more than half the shell height. The transition into the slightly convex base is gradual. The umbilicus is deep and rather narrow. The labrum is broken, and the columella is thickened. Neither sculpture nor growth lines could be observed due to poor preservation.

*Remarks.* The specimens match the description and illustrations in the literature well.

## Subclass Caenogastropoda Cox, 1960

## Order Caenogastropoda Cox, 1960

## Superfamily Triphoroidea Gray, 1847

## Family Cerithiopsidae H. Adams & A. Adams, 1853

### Genus *Cerithiopsis* Forbes & Hanley, 1850

Type species: *Murex tubercularis* Montagu, 1803, accepted as *Cerithiopsis tubercularis* (Montagu, 1803) (type by monotypy).

***Cerithiopsis* aff. *dautzenbergi* Glibert, 1949**
Fig 8p

1978a *Cerithiopsis (Cerithiopsis) 'henckeliusi'* auct. (pars) sp. 3 – R. Janssen, p. 57, pl. 5, fig. 8.
1978b *Cerithiopsis* (s. lat.) aff. *dautzenbergi* Glibert, 1949 – R. Janssen, p. 167, pl. 12, fig. 43.

*Material.* Three fragmentary specimens.

*Remarks*. The rather poor specimens match the descriptions and illustrations well (R. Janssen 1978 a, b). The medium whorls have three spiral cords, of which the adapical two are more narrowly spaced. On the base a weak spiral is situated close to the demarcating spiral rib.

***Cerithiopsis vilsundensis* n. sp.**
Fig. 8n

*Type material*. Holotype: Fig. 7o, NHMD 1177238 (ex MM-13631), DK-1202. leg. Henrik Madsen.
*Additional material*. ISL, three defective specimens.

*Etymology*. This species is named after the type locality.

*Type locality*. Coastal cliff at Vilsund.

*Type strata*. Unit X, upper Oligocene.

*Diagnosis*. A *Cerithiopsis* with three primary spirals and 16 slightly opisthocline axial ribs without knobs. The suture is slightly undulating.

*Description*. The shell is slender turriculate with a height/width ratio of 3.5. The largest specimen has the last 3½ protoconch whorls and six teleoconch whorls preserved. The last whorl equals 0.33 of the total shell height, the aperture and canal 0.20. The aperture is rounded ovate, with a rather short canal, which is turned to the left. The columella is slightly concave. The first three teleoconch whorls are very convex, the following medium convex.

The initial 1½ protoconch whorls are broken off. The terminal three whorls are convex and separated by a deep suture. They have about 25 axial ribs on the two first whorls and 20 on the terminal whorl. These ribs are slightly flexuous and become stronger on the terminal protoconch whorl. Two very delicate spiral ribs are present on the abapical part of the whorl, and they continue as the abapical two primary spirals. The transition into the teleoconch is gradual.

There are three primary spiral cords; the adapical is placed immediately under the suture, the second at one third of the whorl, and the third at one quarter above the abapical suture. On the following whorls this number continues. The spiral cords are weaker than their interspaces and are sharpest adapically. On the last whorl a fourth distinct spiral demarcates the flat base, which has a few weak spiral ribs at the transition of the neck of the canal.

The teleoconch whorls have slightly opisthocline axial ribs, which are of almost the same width as their interspaces. On the first two teleoconch whorls there are about 18 ribs, on the following 16 ribs. On the last whorl the ribs are more indistinct. The spiral cords run slightly undulating across the axial ribs but cause no knobs.

*Discussion*. The new species has some resemblance to *Cerithiopsis serrula* R. Janssen, 1978, but differs by having no knobs on the spirals, opisthocline and stronger axial ribs, a more ovate aperture, and a relatively higher last whorl.

## Superfamily Epitonioidea Berry, 1910 (1812)

## Family Epitoniidae Berry, 1910 (1812)

Genus *Cirsotrema* Mörch, 1852

Type species: *Scalaria varicosa* Lamarck, 1822, accepted as *Cirsotrema varicosum* (Lamarck, 1822) (type by monotypy).

***Cirsotrema insigne* (Philippi, 1843)**
Fig. 8b

1978b *Cirsotrema (Cirsotremopsis) insigne* (Philippi, 1843) – R. Janssen, p. 175, pl. 13, fig. 61 [here extensive synonymy].

*Material.* One defective specimen.

*Remarks.* The specimen matches the description and illustrations in the literature well.

Genus *Pseudosassia* Vicián & Kovács, 2022

Type species: *Triton flandricum* Koninck, 1838 by original designation.

***Pseudosassia flandrica* (Koninck, 1838)**
Fig. 9i

1913 *Tritonium flandricum* – Harder, p. 75, pl. 6, fig. 3.
1979b *Charonia (Sassia) flandrica* (Koninck, 1837) – R. Janssen, p. 199 [herein extensive synonymy].
1987 *Charonia (Sassia) flandrica* (Koninck, 1837) – Schnetler & Beyer, p. 204.
1990 *Charonia (Sassia) flandrica* (Koninck, 1837) – Schnetler & Beyer, p. 48.
2022 *Pseudosassia flandrica* (Koninck, 1838) – Vicián & Kovács, p. 29.

*Remarks*. Vicián & Kovács (2022) assigned this species to their new genus and selected it as the type species.

The year of the publication of the paper by Koninck is in literature given as 1837 or 1838. Koninck (1838) dated it as ''Liege, 29. January 1837', but the paper was first published 1838 in Nouveaux Mémoires de l'Académie des Sciences et Belles-Lettres de Bruxelles. Consequently, 1838 is the correct year.

## Order Neogastropoda Wenz, 1938

## Superfamily Buccinoidea Rafinesque, 1815

## Family Buccinidae Rafinesque, 1815

Genus *Aquilofusus* Kautsky, 1925

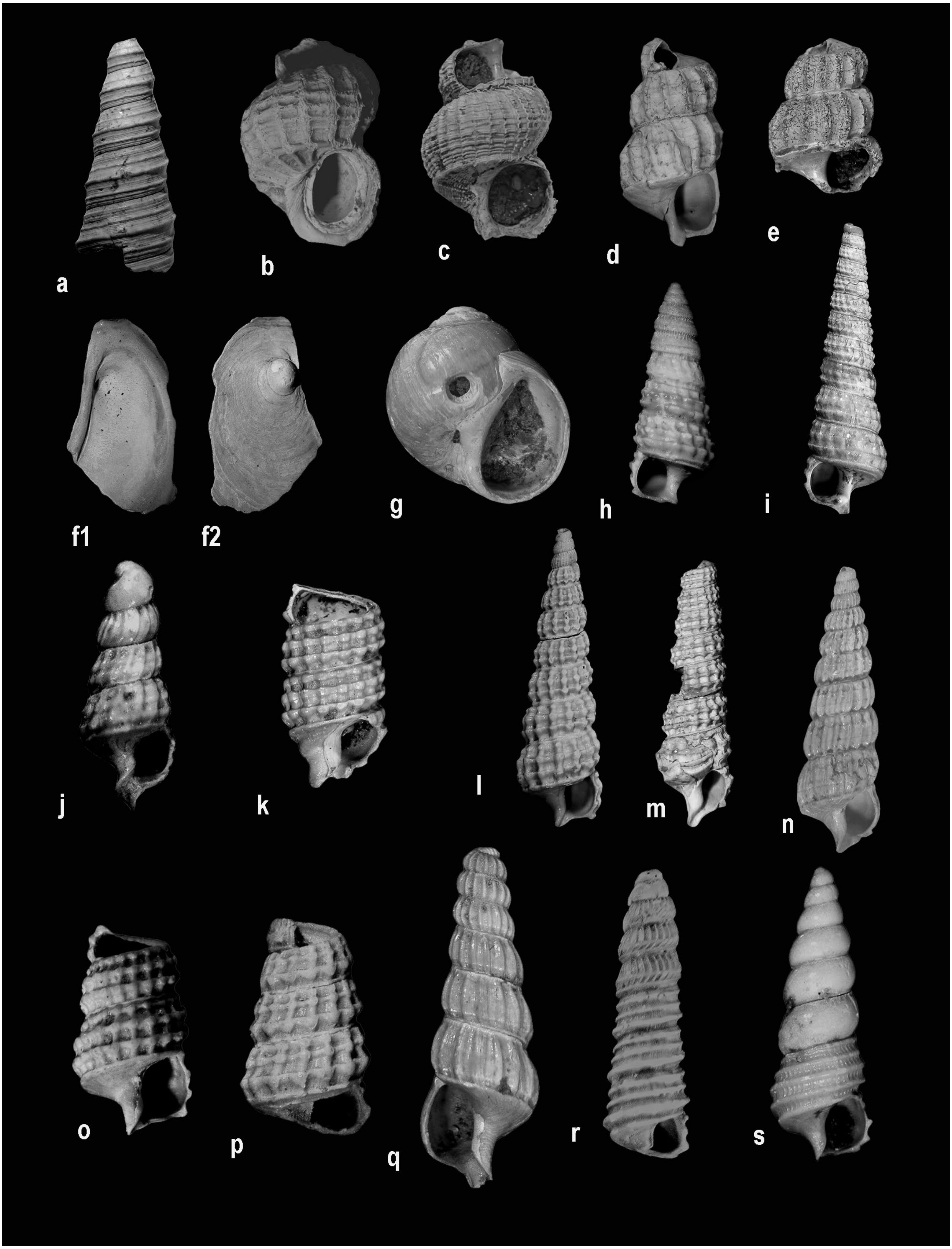
Type species: *Fusus waeli* Nyst, 1852 by original designation.

***Aquilofusus elegantulus* (Philippi, 1843)**
Fig. 10a

1843 *Fusus elegantulus* Philippi, p. 59, 76, pl. 4, figs 16, 16a.
1968 *Scalaspira (Scalaspira) elegantula elegantula* – Tembrock, p. 216, pl. 1, figs 2–5. pl. 3, figs 2–7, pl. 5, figs 6–7, pl. 6, figs 7–7a, pl. 7, fig 11.
1967 *Aquilofusus elegantulus* – Rasmussen, p. 187, fig. 171, 12 [*non* Philippi, 1843].
1968 *Aquilofusus elegantulus* – Rasmussen, p. 72, fig. 12 [*non* Philippi, 1843].
1979 *Scalaspira (Scalaspira) elegantula elegantula* (Philippi 1843) – R. Janssen, p. 286, pl. 286, pl. 15, fig. 7 [here extensive synonymy].

*Material*. Four specimens.

▼ **Fig. 8. a,** *Haustator goettentrupensis* (Cossmann, 1899). Height 14.0 mm. MM-13618. **b,** *Cirsotrema insigne* (Philippi, 1843). Height 3.0 mm. NHMD 1651689 (ex MM-13619), DK 1262. **c,** *Cirsotrema crispata* Harder, 1913. Height 3.8 mm. MM-13620. **d,** *Cirsotrema (?Opaliopsis)* aff. *koeneni* A.W. Janssen, 1967. Height 3.2 mm. MM-13621. **e,** *Opalia pusilla* (Philippi, 1843). Height 3.5 mm. MM-13622. **f,** *Leptonotis planatus* (Speyer, 1864). Length 5.8 mm. **f1,** apertural view, **f2,** apical view. MM-13623. **g,** *Euspira helicina protracta* (Eichwald, 1830). Height 5.5 mm. MM-13624. **h,** *Norephora elatior* (Koenen, 1891). Height 2.1 mm. MM-13625. **i,** *Norephora elatior* (Koenen, 1891). Height 4.0 mm. MM-13626. **j,** *Cerithiella bitorquata* (Philippi, 1843). Height 1.5 mm. MM-13627. **k,** *Cerithiopsis henckeliusii* (Nyst, 1836). Height 2.4 mm. MM-13628. **l,** *Cerithiopsis serrula* R. Janssen, 1978. Height 4.8 mm. MM-13629. **m,** *Cerithiopsis* (s. lat.) *ariejansseni* R. Janssen, 1978. Height 6.3 mm. MM-13630. **n,** *Cerithiopsis vilsundensis* n. sp. Height 3.0 mm. Holotype, NHMD 1177238 (ex MM-13631), DK 1202. **o,** *Cerithiopsis jutensis* Schnetler, 1985. Height 1.4 mm. MM-13632. **p,** *Cerithiopsis* aff. *dautzenbergi* Glibert, 1949. Height 1.0 mm. NHMD 1651690 (ex MM-13633), DK 1263. **q,** *Laeocochlis supraoligocaenicus* Schnetler & Beyer, 1990. Height 5.0 mm. MM-13634. **r,** *Thereitis angusta* (Tembrock, 1965). Height 3.5 mm. MM-13635. **s,** *Seila* (s. lat.) *koeneni* R. Janssen, 1978. Height 1.7 mm. MM-13636.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Remarks. The species is characterised by two strong spirals on the first teleoconch whorls. R. Janssen (1979, p. 287) considered *Aquilofusus cochleata* (Speyer, 1863) and *A. tricarinata* (Koch & Wiechmann, 1872) to be extreme forms of *A. elegantulus*. *A. elegantulus* has not previously been recorded from the Danish upper Oligocene. The species illustrated in popular scientific books has a spiral ornament, consisting of many spirals of the same strength. These features thus match *Aquilofusus elegantulus aequistriatus*, which R. Janssen (1979, p. 287) interpreted as an independent species, although he did not exclude an assignment to *A. elegantula*.

## Superfamily Buccinoidea Rafinesque, 1815

## Family Fasciolariidae Gray, 1853

## Subfamily Fusininae Wrigley, 1927

Genus *Streptodictyon* Tembrock, 1961

Type species: *Streptochetus (Streptodictyon) elongatus* Tembrock, 1961 [*non* Nyst = *Streptodictyon sowerbyi* (Nyst, 1836) emend].

**The Danish Oligocene species of *Streptodictyon***
Ravn (1907) and Harder (1913) assigned all specimens of *Streptodictyon* fom the middle Oligocene (= the lower Oligocene Viborg Formation and the lower upper Oligocene Branden Clay), as well as in the upper Oligocene (= the upper Oligocene Brejning Formation) to *Fusus elongatus* Nyst, 1836.

Cadée & Janssen (1994) assigned the early Oligocene specimens to *Streptodictyon subelongatus* (d'Orbigny, 1852) or *Streptodictyon impiger* Cadée & Janssen, 1994, both with a query. Almost all late Oligocene specimens were assigned to *Streptodictyon cheruscus* (Philippi, 1843). They introduced the new species *Streptodictyon schnetleri* and assigned two specimens (from Nørre Vissing and Brejning) to *Streptodictyon cheruscus* forma *fascilaroides* (Nyst, 1861), which was predominantly found in the Miocene. They considered *S. soellingensis* and *S. schnetleri* as parts of a lineage, as the latter species was only known from Chattian B at that time.

Schnetler & Palm (2008) monographed the lower upper Oligocene (Chattian A) Branden Clay fauna and found *S. soellingensis* (Tembrock, 1965) and *S. schnetleri*. As these species co-occur a lineage relationship is not supported. *S. cheruscus* is very common in the Brejning Formation but absent in the Branden Clay.

The present study has recorded *S. cheruscus*, *S. soellingensis* (Tembrock, 1965) and *S. schnetleri* from Unit X of early late Oligocene age. *S. cheruscus* is very common, but all specimens except one are juvenile. Only one juvenile specimen of *S. soellingensis* and 11 specimens of *S. schnetleri* have been found.

## Family Muricidae Rafinesque, 1815

## Subfamily Muricopsinae Radwin & D'Attilio, 1971

Genus *Murexsul* Iredale, 1915

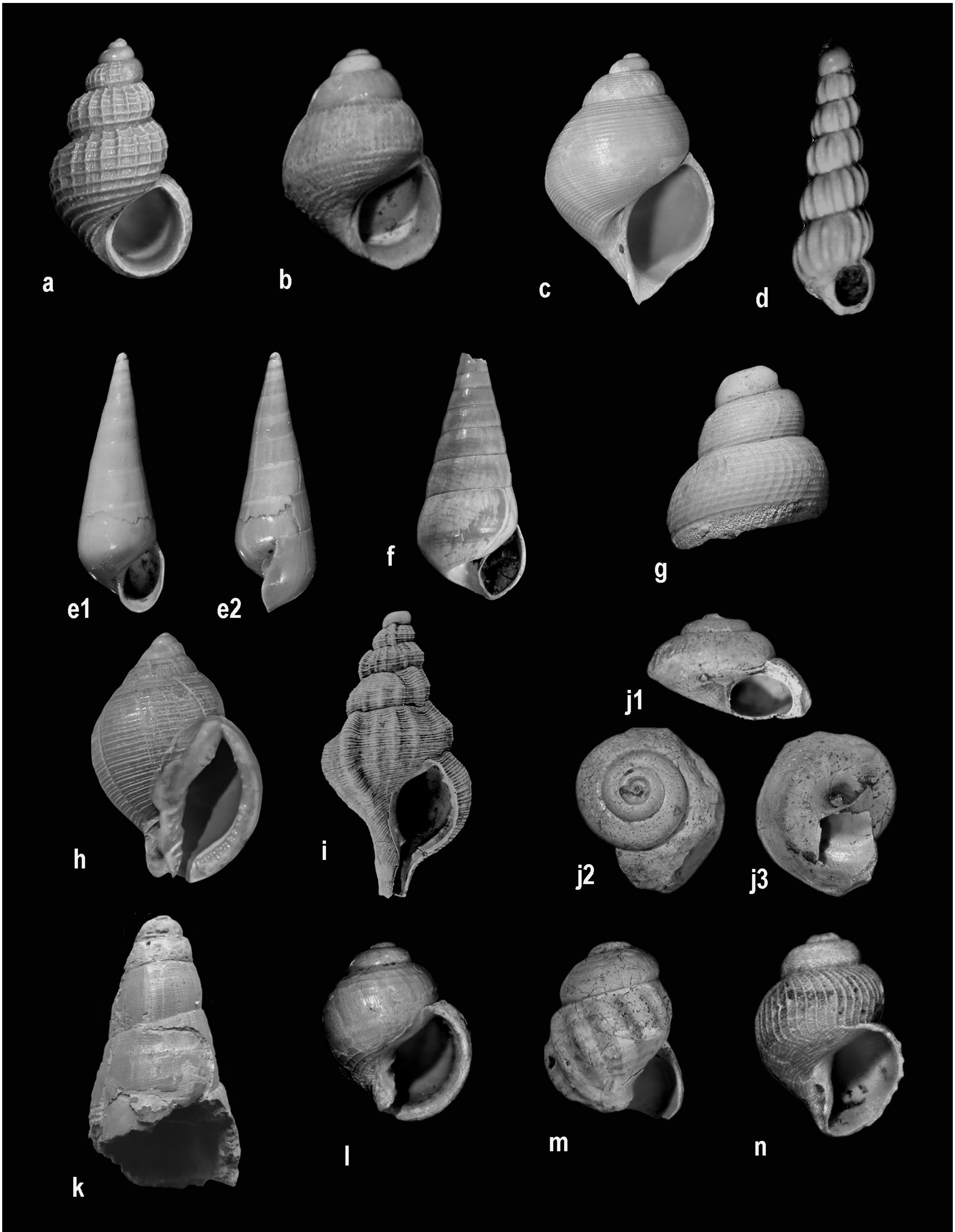
Type species: *Murex octogonus* Quoy & Gaimard, 1833 (type by original designation).

***Murexsul kochi* (Beyrich, 1854)**
Fig. 10m

1854 *Murex kochi* Beyrich, p. 759.
1872 *Murex kochi* – Koch & Wiechmann, p. 13, pl. 1, figs 2a–c.
1963 *Coralliophila (Hirtomurex) kochi* Beyrich, 1854 – Tembrock, p. 323, pl. 2, fig. 9, pl. 3, figs 12–13, pl. 4, fig. 9.
1990 *Coralliophila (Hirtomurex) kochi* Beyrich, 1854 – Schnetler & Beyer, pl. 2, figs 15a–b.

*Remarks*. Lozouet (1998) questioned the assignment to *Coralliophila* because of the smooth, multispiral protoconch and suggested an assignment to *Murexsul* (P. Lozouet, pers. comm. 2023). The species was not mentioned by Merle *et al.* (2022).

▼ **Fig. 9. a,** *Alvania semperi* Wiechmann, 1871. Height 1.3 mm. MM-13637. **b,** *Rissoa karsteni* R. Janssen, 1978. Height 1.7 mm. MM-13638. **c,** *Cirsope multicingulata* (Sandberger, 1859). Height 3.0 mm. MM-13639. **d,** *Graphis hosiusi* (Lienenklaus, 1891). Height 2.2 mm. MM-13640. **e,** *Polygireulima pseudonaumanni* (R. Janssen, 1978). Height 4.0 mm. **e1,** apertural view, **e2,** lateral view. MM-13641. **f,** *Niso minor* Philippi, 1843. Height 3.1 mm. MM-13642. **g,** *Aporrhais speciosa* (Schlotheim, 1820). Height 4.4 mm. MM-13643. **h,** *Echinophoria rondeleti* (Basterot, 1825). Height 18.0 mm. MM-13644. **i,** *Pseudosassia flandrica* (Koninck, 1838). Height 20.0 mm. MM-13645. **j,** *Onustus scrutarium* (Philippi, 1843). Height 2.5 mm. **j1,** lateral view, **j2,** apical view, **j3,** umbilical view. MM-13646. **k,** *Euroscaphella siemssenii* (Boll, 1851). Height 36.0 mm. MM-13647. **l,** *Admetula postera* (Beyrich, 1863). Height 2.8 mm. MM-13648. **m,** *Unitas granulata* (Nyst, 1845). Height 2.0 mm. MM-13649. **n,** *Babylonella pusilla* (Philippi, 1843). Height 1.5 mm. MM-13650.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## Subfamily Typhinae Cossmann, 1903

Genus *Siphonochelus* Jousseaume, 1880

Type species: *Typhis arcuatus* Hinds, 1843 (type by original designation). Synonym: *Eotyphis* Tembrock, 1963; type species *Typhis sejunctus* Semper, 1861 (type by original designation).

***Siphonochelus fistulatus* (Schlotheim, 1820)**
Fig. 10s

1963 *Lyrotyphis (Lyrotyphis) fistulatus* (Schlotheim, 1820) – Tembrock, p. 318, pl. 7, fig. 3, pl. 8, figs 6, 12a–b, 13, pl. 10, figs 5–6.
1979a *Lyrotyphis (Eotyphis) fistulatus* (Schlotheim, 1820) – R. Janssen, p. 283 [here extensive synonymy].

*Material.* One defective specimen.

*Remarks*. R. Janssen (1979a, p. 284) suggested that this form might be a hybrid of *Lyrotyphis sejunctus* and *L. cuniculosus*, as it co-occurs with these species, which are also present in the Vilsund fauna. The species is very rare at German localities and has not previously been recorded from the Danish upper Oligocene, because the predominantly juvenile specimens have been confused with *L. cuniculosus*. *Siphonochelus fistulatus* is now known from Nørre Vissing, Jensgård, Kirstinebjerg Skov and the localities Boestholt and Fakkegrav on the northern coast of Vejle Fjord, Denmark (all occurences unpublished, coll. ISL, MNO and LSJ). Houart *et al.* (2021) stated that *Eotyphis* Tembrock, 1963 is a junior synonym of *Siphonochelus* Jousseaume, 1880.

Genus *Hirtotyphis* Jousseaume, 1880

Type species: *Murex horridus* Brocchi, 1814 (type by original designation).

***Hirtotyphis pungens* (Solander, 1766)**
Fig. 10t

1963 *Typhis (Typhis) pungens* (Solander, 1766) – Tembrock, p. 328, pl. 7, figs 9–10; pl. 8, figs 8, 17a–b; pl. 10, figs 9a–b.
1979a *Typhis (Typhis) pungens* (Solander, 1766) – R. Janssen, p. 282 [here extensive synonymy].

*Material.* One defective specimen.

*Remarks.* Lozouet (2023) discussed the genus *Hirtotyphis*, especially the different protoconchs, and questioned the distribution from the Eocene to the late Miocene of the species *Hirtomurex pungens*. The late Oligocene and Miocene species from the North Sea Basin have traditionally been assigned to this species. The only specimen found at Vilsund is defective and has no protoconch preserved but matches the descriptions and illustrations in the literature well. The species is very rare in Denmark and only known from Boestholt (coll. LSJ).

## Superfamily Conoidea J. Fleming, 1822

## Family Mitromorphidae T.L. Casey, 1904

Genus *Mitromorpha* Carpenter, 1865

Type species: *Daphnella filosa* Carpenter, 1864, *non* Dujardin, 1837 (= *Mitromorpha carpenteri* Glibert, 1954) by monotypy.

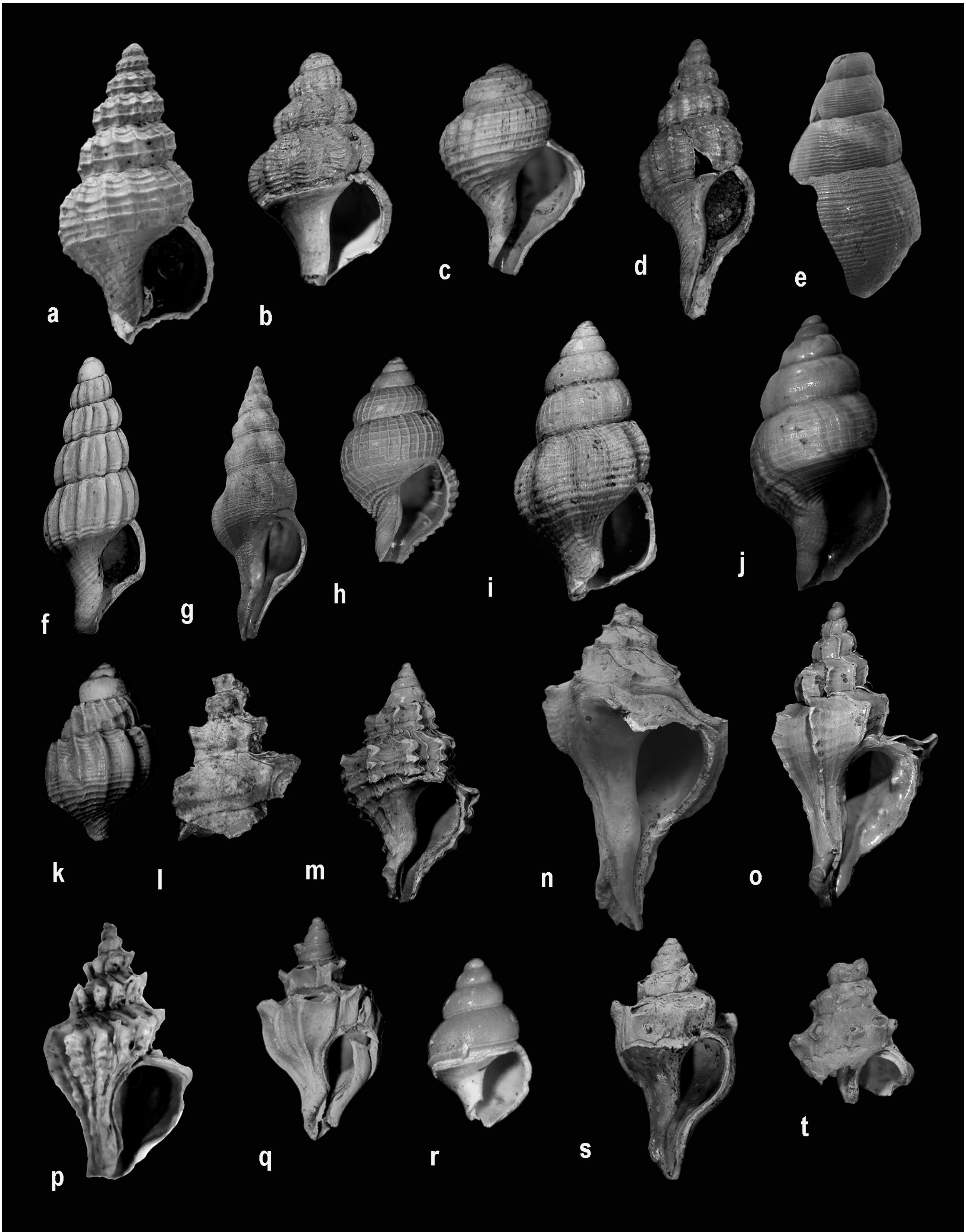
Subgenus *Mitrolumna* Bucquoy, Dautzenberg & Dollfus, 1883

Type species: *Mitra columbellaria* Scacchi, 1836 [*Mitra olivoidea sensu* Bucquoy, Dautzenberg & Dollfus, 1883, *non* Cantraine, 1835] by original designation.

***Mitromorpha (Mitrolumna) danica* n. sp.**
Fig. 12j

*Type material*. Holotype: NHMD 1177239 (ex MM-13692), DK-1203 (Fig. 10). Leg. Ulla Marcussen.

▼ **Fig. 10. a,** *Aquilofusus elegantulus* (Philippi, 1843). Height 20.0 mm. NHMD 1651692 (ex MM-13651), DK 1265. **b,** *Aquilofusus waeli* (Nyst, 1852). Height 8.2 mm. MM-13652. **c,** *Aquilofusus waeli* (Nyst, 1852). Height 3.2 mm. MM-13939. **d,** *Aquilofusus aequistriata* (Speyer, 1863). Height 22.0 mm. MM-13653. **e,** *Searlesia dentifera* Vermeij, 1991. Height 35.0 mm. MM-13614. **f,** *Boreosiphopsis danica* (Schnetler, 1985). Height 6.3 mm. MM-13654. **g,** *Streptodictyon cheruscus* (Philippi, 1843). Height 40.0 mm. MM-13657. **h,** *Streptodictyon cheruscus* (Philippi, 1843). Height 2.8 mm. MM-13655. **i,** *Streptodictyon schnetleri* Cadée & Janssen, 1994. Height 3.1 mm. MM-13656. **j,** *Streptodictyon soellingensis* (Tembrock, 1965). Height 2.3 mm. MM-13789. **k,** *Tritia schlotheimi* (Beyrich, 1854). Height 3.2 mm. MM-13658. **l,** *Pterynotus (Pterochelus) tristichus* (Beyrich, 1854). Height 6.5 mm. MM-13659. **m,** *Murexsul kochi* (Beyrich, 1854). Height 4.5 mm. MM-13660. **n,** *Eopaziella deshayesi* (Nyst, 1836). MM-13661. Height 41.0 mm. **o,** *Eopaziella capito* (Philippi, 1843). Height 9.5 mm. MM-13662. **p,** *Trophonopsis angustevaricata* (Gripp, 1915). Height 11.0 mm. MM-13663. **q,** *Siphonochelus sejunctus* (Semper, 1861). Height 6.4 mm. MM-13664. **r,** *Lyrotyphis cuniculosus* (Nyst, 1836). Height 1.5 mm. MM-13665. **s,** *Siphonochelus fistulatus* (Schlotheim, 1820). Height 8.5 mm. MM-13666. **t,** *Hirtotyphis pungens* (Solander, 1766). Height 4.0 mm. MM-13667.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*Etymology*. Danica (latin) = Danish.

*Type locality*. Coastal cliff at Vilsund.

*Type strata*. Unit X, upper Oligocene.

*Diagnosis*. A *Mitromorpha (Mitrolumna)* with three primary spirals, 12–14 slightly opisthocline axial ribs and almost flat whorls. The spiral cords and axial ribs are fading gradually out on the teleoconch.

*Material*. Only the holotype. Height 5.3 mm.

*Description*. The shell is small and subfusiform. The height/width ratio is 2.3. The protoconch is paucispiral and has 1½ smooth and convex whorls, which are separated by a deep suture. The nucleus is large and almost semiglobular and the transition into the teleoconch is sharp and opisthocline.

The only specimen provides a little more than three almost flat whorls, which are separated by a distinct and slightly undulating suture. The last whorl equals 0.75 of the total shell height, the aperture 0.58. The base is slightly concave and regularly constricted into a rather short siphonal canal. There is a small pseudoumbilicus. The narrow aperture is elongated oval and acute posteriorly and goes into the rather short and straight canal. The columella is oblique to the axis and has two folds near the middle. The callus is well defined. The labrum is slightly thickened and partly broken. Growth lines are visible. They are slightly flexuous adapically and prosocyrt across the whorl, with a wide sinus.

The spiral ornament starts with three spiral bands, separated by much narrower interspaces. The abapical band is the strongest. On the next whorl a secondary spiral band is inserted and demarcated by deep spiral furrows on the following whorls. On the last whorl the spiral furrow between the middle and the anterior spiral bands is almost invisible, and the most prominent spiral ornament are the two spiral furrows demarcating the secondary spiral band, which remains narrow. The adapical spiral equals about one quarter of the whorl height, the middle and abapical spiral bands together a little more than the half. The spirals run slightly undulating across the axial ribs. On the neck of the canal there are about 15 rather distinct spirals.

The axial sculpture consists of 12–14 slightly opisthocline ribs, separated by interspaces of almost the same width. The axial ribs fade out on the last whorl. The shell has a rather smooth appearance because of the fading out of the sculptural elements.

*Discussion*. *Mitrolumna raulini septemtrionalis* R. Janssen, 1978 from the upper Oligocene of Glimmerode (Germany) is less slender and has more convex whorls with 25–30 weak axial ribs, which continue on the last whorl. The spiral cords are prominent on all teleoconch whorls. *Mitrolumna rupeliensis* Moths, 2000 (p. 28, pl. 10, fig. 5) from the lower Oligocene at Malliss (North Germany) has 7–10 spiral ribs and *c.* 20 opisthocline axial ribs. The aperture is wider and the folds on the columella are weaker. *Mitrolumna hortiensis* Lozouet, 1999 from the upper Oligocene at Peyrehorade (France) has a similar outline as the new species, but differs by having four narrow and sharp spirals, which run across 17–18 slightly opisthocyrt axial ribs. At the intersections between the spiral ornament and the axial ribs there are rather sharp knobs. The interior of the labrum has seven lirae. *Mitromorpha (Mitrolumna) panaulax* Cossmann, 1901 from the lower Pliocene of northwest France (see Ceulemans *et al.* 2018) is less slender and has narrow spiral cords, separated by groves, 7–8 on the penultimate whorl, axial sculpture restricted to the first two teleoconch whorls, outer lip arcuated in profile and denticulate within. Lozouet (2015) established four *Mitrolumna* species from the Oligocene and lower Miocene of Aquitaine (southwest France). *Mitrolumna ventriosa* Lozouet, 2015 has five primary spirals, 17–18 slightly opisthocline axial ribs, which together with spiral cords cause granules. The adapical spiral cord is wider than the other spiral cords and form a cord without granules. Furthermore, the columellar folds are stronger. *Mitrolumna peyroti* Lozouet, 2015 has 6–7 spiral cords on the first teleoconch whorl and 10–12 on the following whorls. The spiral cords run over numerous flattened axial ribs, which fade out on the last whorls, so the spiral ornament is dominating. *Mitrolumna oligomiocaenica* Lozouet, 2015 has three spiral cords, crossed by 16 opisthocyrt axial ribs on the first teleoconch whorl, and five cords, crossed by 20–21 axial ribs. The cords are granulated.

*Mitrolumna*? *atypica* Lozouet, 2015 has five spiral cords, and 14 slightly opisthocyrt axial ribs.

Schnetler & Palm (2008, p. 51; pl. 7, figs 15a–b, 16a–b, pl. 9, fig. 12) established *Aphanitoma ingerae* from the upper Oligocene Branden Clay of Denmark. We cannot maintain this generic assignment, as the species in outline, sculpture and aperture fits the subgenus *Mitrolumna* much better. Thus, we transfer the Branden Clay species to *Mitrolumna* and suggest the name *Mitromorpha (Mitrolumna) ingerae* (Schnetler & Palm, 2008) for it. This species has four primary spiral cords, arising to seven on the following whorls. There are 18–20 opisthocline axial ribs, which fade out on the last whorl.

According to Landau & Harzhauser (2022), species in the subgenus *Mitromorpha* lack well defined columellar folds, whereas species in *Mitrolumna* have two columellar folds. *Mitrolumna* was relegated to being a subgenus of *Mitromorpha* Carpenter, 1865 by Kilburn (1986) and Drivas & Jay (1986), based on having similar radula formulae.

## Family Mangeliidae P. Fischer, 1883

Genus *Benthomangelia* Thiele, 1925

Type species: *Surcula trophonoidea* Schepman, 1913, accepted as *Benthomangelia trophonoidea* (Schepman, 1913) (type by original designation).

***Benthomangelia brejningensis*** **(Schnetler & Beyer, 1990)**
Fig. 11p

1990 *Microdrillia (Andersondrillia) brejningensis* n. sp. Schnetler & Beyer, 1990, p. 66, pl. 3, figs 9a–b, 10.

*Material*. Two juvenile specimens.

*Discussion*. The material consists of a specimen with a complete protoconch and one half of the first teleoconch whorl and a specimen with two teleoconch whorls and the protoconch broken off. Both specimens match the description and illustrations in Schnetler & Beyer 1990 completely. The type species of *Andersondrillia* n. subgen. Schnetler & Beyer, 1990 is *Microdrillia grippi* Anderson, 1964. This species was assigned by Wienrich (2007) to the genus *Benthomangelia*, and Moths *et al.* (2010, p. 694, pl. 111, fig. 10, pl. 146, figs 3a–b, 4–5) discussed and illustrated the species. Lozouet (2017, p. 50) stated that *Andersondrillia* is a junior synonym of *Benthomangelia* and briefly discussed the Danish species. He questioned the assignment to *Benthomangelia* because of the more shouldered whorls and the muricoid outline. However, the Danish species has a protoconch with axial riblets and carinated whorls with growth lines having their sinus above the carina. It has some resemblance to *Benthomangelia venusta* (Peyrot, 1931) as illustrated by Lozouet (2017, pl. 21, figs 1–9). The Danish species differs from species of *Benthomangelia* by having a more concave adapical ramp and knobs on the intersections between spirals and axial ribs. However, we find the assignment to *Benthomangelia* most suitable.

## Family Raphitomidae Bellardi, 1875

Genus *Eubela* Dall, 1889

Type species: *Pleurotoma limacina* Dall, 1881, accepted as *Eubela limacina* (Dall, 1881) (type by original designation, 1889, p. 102).

***Eubela*** **(s. lat.)** ***zetes*** **(Kautsky, 1925)**
Fig. 13a

1925 *Daphnella (Eubela) Zetes* Kautsky, p. 190, pl. 12, figs 19a–b.
1958 *Eubela* sp. – Sorgenfrei, p. 293.
2010 *Eubela zetes* (Kautsky, 1925) – Moths *et al*., p. 68, pl. 42, figs 6a–b.

*Material.* One specimen. NHMD 625416, DK-1176. Ex MM-13695.

*Measurements.* Heigh 3.9 mm, width 2.2 mm.

*Description.* The shell is rather small and biconical and the teleoconch whorls are carinated and separated by a distinct suture. The height/width ratio is 1.8, the last whorl equals 0.67 of the total shell height, the aperture and canal 0.45 of the total shell height. The only specimen available has a well preserved protoconch and almost three teleoconch whorls. The last whorl has a fracture, but the aperture is well preserved, except for the labrum, which is broken off. There are *c.* four protoconch whorls, which are medium convex and separated by a distinct suture. The nucleus is small. The last three protoconch whorls have a diagonally cancellated sculpture. At the transition into the teleoconch this sculpture disappears. The terminal protoconch whorl has its greatest diameter abapically and the adapical part of the whorl is flat. On the first teleoconch whorl an unsharp carina appears on the abapical part of the whorl and on the following teleoconch whorls the carina is situated a little above the middle of the whorl. The carina divides the whorls into an adapical concave part and a straight to convex abapical part. The aperture is lengthened ovate, with a very short canal, which is slightly turned to the left. The smooth columella is almost straight. The spiral ornament is very weak. There are no spirals on the adapical concave part of the whorls, but a weak subsutural band is suggested. Another very weak spiral demarcates the concave part of the whorl from the smooth carina. Under the carina there are c. 10 very weak spiral bands, of which one is wider and indistinctly demarcated and situated, where the following whorl is attached. On the neck of the canal there are c. 8 spiral bands, which are decreasing in strength abapically and separated by narrow spiral furrows. An axial sculpture is absent, except for the growth lines, which are most prominent on the concave adapical part of the whorl. On the subsutural band they cause small knobs, in a number of c. 40 on each whorl. In the concave part of the whorls the growth lines have a rather swallow sinus and, on the carina, they run almost horizontal and then, below the carina, they have a wide sinus. The shell has a glossy look because of the very weak ornament.

*Discussion.* The illustration in Kautsky (1925, pl. 12, figs 19a–b) is poor. Moths *et al.* (2010, p. 68, pl. 42, figs 6a–b) described and illustrated a specimen from the Hemmoorian in the gravel-pit Krinke. They stated that there was in fact a very weak spiral ornament, whereas Kautsky found no spiral ornament. The Danish specimen has a slightly more prominent spiral ornament and the carina situated above the middle of the whorl. On the German specimens, the carina is situated almost at mid-whorl, and the adapical ramp is concave from the first teleoconch whorl. However, these differences are small and, as the range of variation of the two populations is not known, we consider them to be conspecific.

Wenz (1943, p. 1456) mentioned only a few Recent species of *Eubela* from the Atlantic Sea and considered the fossil records as very dubious. Powell (1966) stated that the Recent species of Eubela live at depths of 250–1270 fathoms and have been recorded from Florida to Brazil, off Panama, and in the Indo-Pacific from East Africa to Japan and Hawaii. He stated two miocene species from New Zealand and *Eubela* ? *zetes* from Germany.

A literature review provides the following results: *Eubela limacina* (Dall, 1881) (p. 55), the type species of the genus, from the Western Atlantic, is rather slender and has only 16 subsutural knobs. *E. aequatorialis* Thiele, 1925 (p. 253, pl. 29, figs 13, 13a) 191 is rather slender and has no carina and *c.* 25 subsutural knobs. *E. distincta* Thiele, 1925 (p. 253, pl. 29, figs 15, 15a) is slender and has almost flat whorls and *c.* 30 subsutural knobs. *E. plebeja* Thiele, 1925 (p. 253, pl. 29, figs 16, 16a) has rather convex whorls and no subsutural knobs visible. *Eubela* sp. (Thiele 1925, p. 253, fig. 14) has *c.* 15 subsutural knobs. *E. mcgintyi* Schwengel, 1943 (p. 76, pl. 7, figs 4, 5) from Florida has rather convex whorls, no carina and no subsutural knobs visible. *E. nipponica* Kuroda, 1938 from Japan is slender and has a narrow ramp, and *c.* 25 subsutural knobs.

*Eubela woodrowi* Ladd, 1982 (p. 69, pl. 23, figs 7, 8) from the Pliocene of Fiji (Western Pacific Islands) is not carinated and has only 12 knobs on the subsutural band. *E. monile* Marwick, 1931 (p. 146, figs 310, 311) from the lower Miocene of New Zealand has a weaker shoulder.

All Recent species and the species from the lower Miocene of New Zealand and the Pliocene of Fiji are not carinated. As the species from the lower Miocene of Germany and the upper Oligocene of Denmark are carinated, they might belong to a separate genus. For the time being, we prefer to use the denomination s. lat.

Sorgenfrei (1958) assigned *Clinura trochlearis* (Hörnes, 1854) from the lower Miocene Klintinghoved Formation to the genus *Eubela*, and furthermore assigned a specimen from the Arnum Formation to the same species. According to his description and illustrations, these specimens have a biconical outline and distinct spirals under the carina and thus cannot be assigned to the genus *Eubela*. Sorgenfrei furthermore described another specimen as *Eubela* sp., one that seems to be conspecific with *Eubela* (s. lat.) *zetes*. The specimen from the Arnum Formation may be assigned to *Clinura circumfossa* (Koenen, 1872) (p. 100, pl. 2, figs 11a–b).

Genus *Pleurotomella* A.E. Verril 1872

Type species: *Pleurotomella packardii* A. E. Verrill, 1872 (type by monotypy).

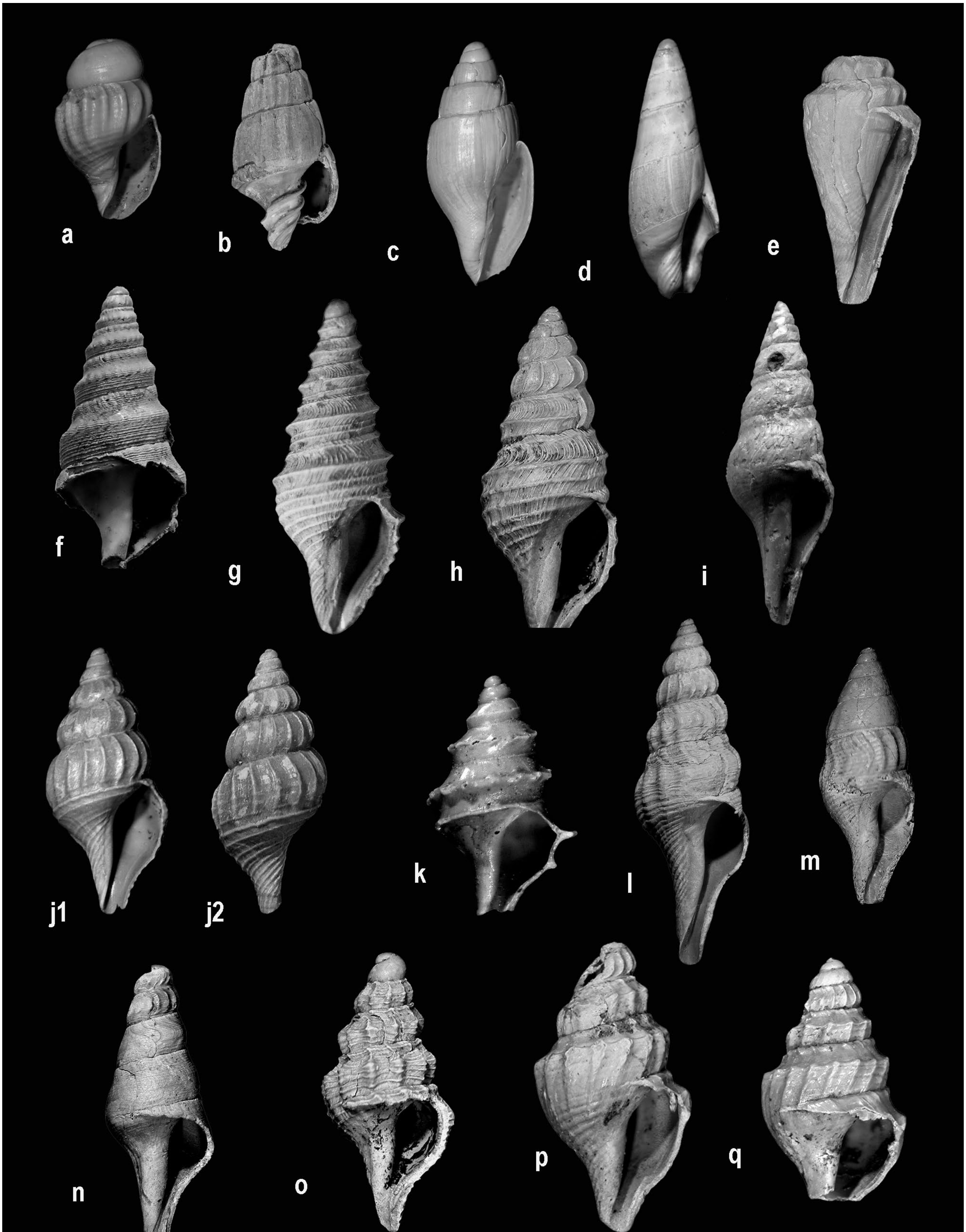
***Pleurotomella rappardi*** **(Koenen, 1867)**
Fig. 12g

1979a *Pleurotomella (Pleurotomella) rappardi* (Koenen, 1867) – R. Janssen, p. 327, pl. 18, fig. 74 [here extensive synonymy].

*Material.* One juvenile specimen.

*Description.* The specimen has the protoconch and half of the first teleoconch whorl preserved. The protoconch is multispiral with *c.* 4½ whorls, which are medium to very convex and separated by a distinct suture. The nucleus is small and the last four whorls have a diagonally cancellated microsculpture. On

▼ **Fig. 11. a,** *Metula (Daphnobela) scabricula* (Philippi, 1843). Height 2.7 mm. MM-13668. **b,** *Vexillum hastatum* (Karsten, 1849). Height 6.8 mm. MM-13669. **c,** *Conomitra soellingensis* (Speyer, 1864). Height 6.0 mm. MM-13670. **d,** *Ancilla karsteni* (Beyrich, 1856). Height 12.0 mm. MM-13671. **e,** *Conus semperi* Speyer, 1862. Height 5.5 mm. MM-13672. **f,** *Bathytoma leunisii* (Philippi, 1843). Height 20.6 mm. MM-13673. **g,** *Drilliola speyeri* (Koch & Wiechmann, 1872). Height 3.0 mm. MM-13674. **h,** *Microdrillia ingerae* Schnetler & Beyer, 1990. Height 2.3 mm. MM-13675. **i,** *Orthosurcula regularis* (Koninck, 1838). Height 15.2 mm. MM-13676. **j,** *Glibertturricula ariejansseni* Schnetler & Beyer, 1987. Height 4.0 mm. **j1,** apertural view, **j2,** rear view. MM-13688. **k,** *Cochlespira volgeri* (Philippi, 1843). Height 2.2 mm. MM-13677. **l,** *Fusiturris selysii* (Koninck, 1838). Height 7.7 mm. MM-13678. **m,** *Fusiturris duchastelii* (Nyst, 1836). Height 5.9 mm. MM-13679. **n,** *Fusiturris enodis* R. Janssen, 1979. Height 8.0 mm. MM-13680. **o,** *Boreodrillia undatella* (Speyer, 1867). Height 5.0 mm. MM-13681. **p,** *Benthomangelia brejningensis* (Schnetler & Beyer, 1990). Height 4.8 mm. MM-13682. **q,** *Benthomangelia holzapfeli* (Koenen, 1890). Height 4.4 mm. MM-13683.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the terminal protoconch whorl a distinct spiral keel occurs below the middle of the whorls and soon a further spiral keel occurs below the first. These two keels continue as the primary spirals. On the terminal half of the protoconch fine axial riblets occur below the adapical suture and the transition into the teleoconch whorl is indicated by the disappearance of the diagonal cancellation. A secondary spiral rib is inserted between the two primary spirals and soon is of the same strength as the primary spirals. Fine knobs occur at the intersections between the spiral ribs and the axial ribs. On the slightly convex base and the neck of the canal an additional eight spirals are present, and they are diminishing in strength towards the end of the canal. The aperture is rounded oval and constricted into the rather short canal, which is slightly turned to the left.

*Remarks*. The species has not previously been recorded from the Danish upper Oligocene. Two juvenile specimens have been found in material from a glacial floe at Skanderborg and three juvenile specimens at Kirstinebjerg Skov (coll. ISL, unpublished). In the German upper Oligocene, the species is rather common at Söllingen, Niederkaufungen and in Sternberger Gestein, but elsewhere very rare or absent (R. Janssen 1979a).

## Subclass Heterobranchia Burmeister, 1837

## Grade 'Lower Heterobranchia'

## Superfamily Mathildoidea Dall, 1889

## Family Mathildidae Dall, 1889

Genus *Mathilda* Semper, 1865

Type species: *Turbo quadricarinatus* Brocchi, 1814, accepted as *Mathilda quadricarinata* (Brocchi, 1814) (type by subsequent designation).

***Mathilda bicarinata* Koch & Wiechmann, 1872**
Fig. 13d

1872 *Mathilda bicarinata* Koch & Wiechmann, p. 107, pl. 2, figs 5, 5a–c.
1978b *Mathilda (Fimbriatella) bicarinata* Koch & Wiechmann 1872 – R. Janssen, p. 183, pl. 13, fig. 69.

*Material.* One very juvenile specimen and one fragment.

*Remarks*. The species was not previously recorded from the Danish upper Oligocene. A single complete adult specimen is known from Kirstinebjerg Skov (coll. ISL, unpublished).

## Family Pyramidelliidae Gray, 1840

Genus *Odostomia* J. Fleming, 1813

Type species: *Turbo plicatus* Montagu, 1803, accepted as *Odostomia plicata* (Montagu, 1803) (type by subsequent designation).

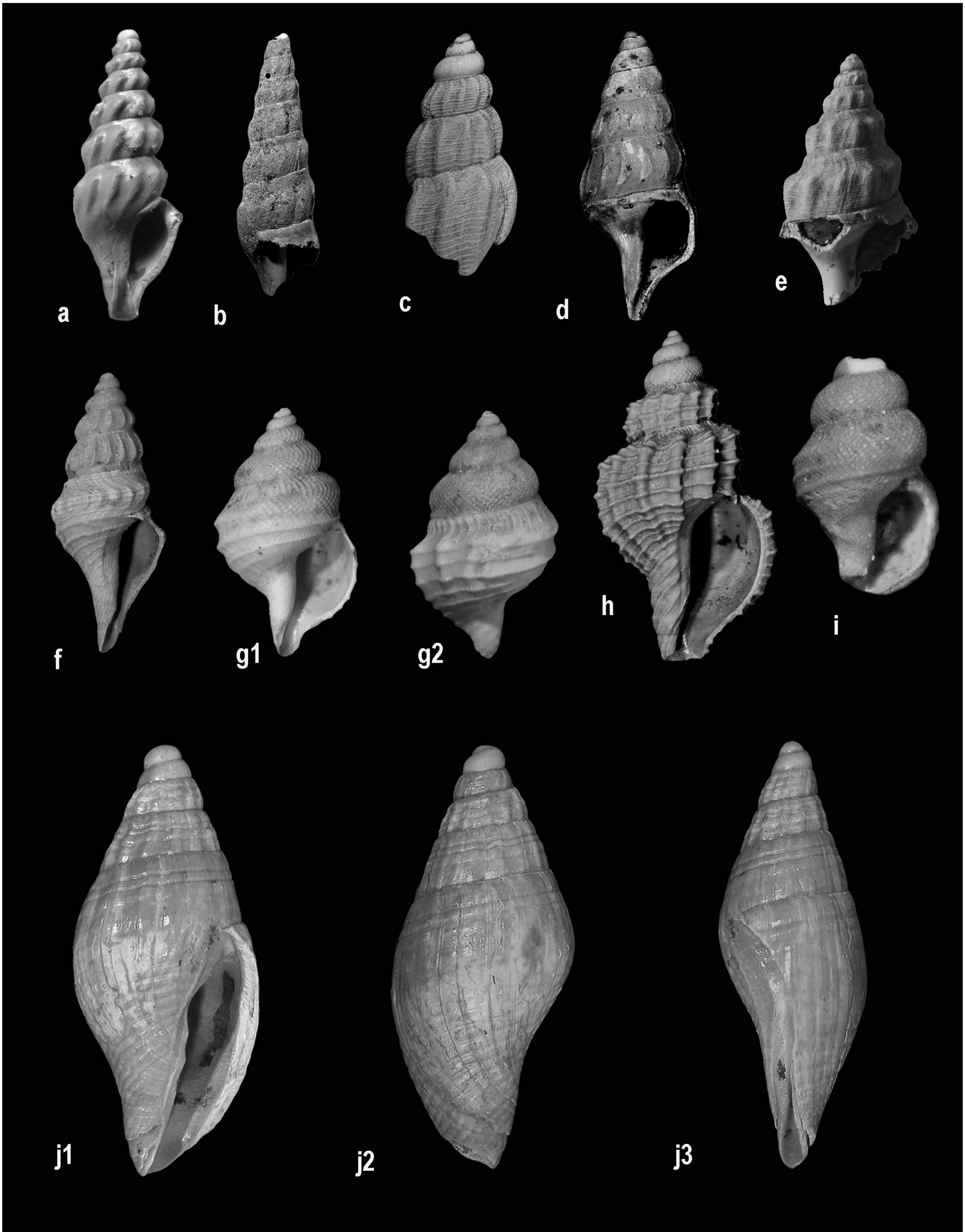
***Odostomia ventriosa* (Speyer, 1870)**
Fig. 13f

1870 *Odontostoma ventriosum* Speyer, p. 53, pl. 10, fig. 7.
1978a *Odostomia (Cyclodostomia) ventriosum* – R. Janssen, p. 141.
1979 *Odostomia (Cyclodostomia) ventriosa* – R. Janssen, p. 333, pl. 18, fig. 83.

*Material*. Two specimens.

*Remarks*. The specimens have a characteristic angulated last whorl, a rather thick walled shell and a distinct columellar fold and match the description in R. Janssen 1979 well. The species is very rare in the German upper Oligocene. R. Janssen (1979) only mentioned one specimen each from Glimmerode and Ahnetal.

▼ **Fig. 12. a,** *Splendrillia koeneni* (Speyer, 1867). Height 10.8 mm. MM-13684. **b,** *Stenodrillia obeliscus* (des Moulins, 1842). Height 17.0 mm. MM-13685. **c,** *Amblyacrum roemeri* (Koenen, 1867). Height 3.6 mm. MM-13686. **d,** *Polystira koninckii* (Nyst, 1845). Height 3.0 mm. MM-13687. **e,** *Acamptogenotia morreni* (Koninck, 1838). Height 18.5 mm. MM-13689. **f,** *Gemmula geinitzi* (Koenen, 1890). Height 5.4 mm. MM-13690. **g,** *Pleurotomella rappardi* (Koenen, 1867). Height 2.2 mm. **g1,** apertural view, **g2,** rear view. NHMD 1651684 A (ex MM-13691), DK 1257. **h,** *Pleurotomella margaritata* R. Janssen, 1978. Height 3.8 mm. MM-13693. **i,** *Rimosodaphnella lappanni* Schnetler & Beyer, 1990. Height 1.3 mm. MM-13694. **j,** *Mitromorpha (Mitrolumna) danica* n. sp. Height 5.3 mm. **j1,** apertural view, **j2,** rear view, **j3,** lateral view. Holotype, NHMD 1177239 (ex MM-13692), DK-1203.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## Comparisons with other late Oligocene mollusc faunas

*Mogenstrup (Schnetler & Beyer 1990)*
The fauna contains 197 species and the Vilsund fauna shares 109 (80.9 %) with it. However, there are some differences in the frequencies of Limopsidae species. The two small species *Aspalima chattica* and *Cosmetopsis retifera* are very common in the Mogenstrup fauna, but extremely rare at Vilsund, and *Limopsis parva* is generally much larger at Vilsund (maximum size 20 mm). The gastropod species *Homalopoma simplex* is very common at Vilsund and represented by full-grown specimens as well as juvenile specimens but is very rare at Mogenstrup. There is a higher diversity of Muricidae at Vilsund. *Gemmula* species are only represented by a single *Gemmula geinitzi* at Vilsund but are more common at Mogenstrup. Pteropods are absent in the Vilsund fauna but present in the Mogenstrup fauna. *Laeocochlis supraeoligocaenicus* is present, but not as common as in the Vilsund fauna. This species is only known from Mogenstrup and Vilsund.

*Nørre Vissing (Schnetler & Beyer 1987)*
The fauna contains 144 species and the Vilsund fauna shares 73 species (60.3 %) with it. Of the Limopsidae only *Limopsis parva* is common, whereas *Cosmetopsis retifera* and *Aspalima chattica* are rare and *Oblimopa vonderhochti* absent. Typical Vilsund species such as *Acar* aff. *dentiens*, *Homalopoma simplex* and *Astraea pustulosa* are absent, as are several Cerithiopsidae species. Muricidae are less diverse and *e.g., Trophonopsis angustevaricata* and *Murexsul kochi* are absent.

*Aarhus (Harder 1913)*
The classical Danish fauna contains 87 species and the Vilsund fauna shares 50 (41.3 %) with it. The family Muricidae is less diverse and many small species, *e.g.* Cerithiopsidae, are absent. Characteristic Vilsund species such as *Acar* aff. *dentiens*, *Homalopoma simplex*, *Astraea pustulosa*, *Trophonopsis angustevaricata* and *Murexsul kochi* are absent. The pteropod species *Ireneia tenuistriata* (Semper, 1861) is rather common. The number of species from Aarhus is somewhat lower, as the clay samples were not processed.

*Cilleborg (Ravn 1907)*
The classical fauna contains 49 species and the Vilsund fauna shares 28 (22.6 %) with it. The occurrence of the species *Searlesia dentifera* is noteworthy.

*Brejning (Eriksen 1937 and unpublished material in coll. ISL, coll. MNO and NHMD)*
The fauna contains *c.* 100 species and the Vilsund fauna shares 67 species (55.0 %) with it. The occurrence of the species *Oblimopa vonderhochti*, *Acar* aff. *dentiens*, *Aspalima chattica*, *Searlesia dentifera* and *Benthomangelia brejningensis* are noteworthy.

*Skanderborg (highway excavation 1976, unpublished, coll. ISL)*
The fauna contains *c.* 120 species and the Vilsund fauna shares 77 species (63.6 %) with it. The occurrence of the species *Pleurotomella rappardi* and *Trophonopsis angustevaricata* are noteworthy. The pteropod species *Ireneia tenuistriata* (Semper, 1861) is very common, but is absent in the Vilsund fauna.

*Kirstinebjerg Skov (coastal cliff, unpublished, coll. ISL and coll. MNO)*
The fauna contains *c.* 120 species and the Vilsund fauna shares 63 species (52.1 %) with it. Noteworthy species are *Pleurotomella rappardi* and *Mathilda bicarinata*. The pteropod species *Ireneia tenuistriata* (Semper, 1861) is rather common, but is absent in the Vilsund fauna.

*Branden (Denmark)*
The fauna of the lower upper Oligocene Branden Clay was studied by Schnetler & Palm (2008). This fauna contains 78 species but shares only 46 species (38.3 %) with the Vilsund fauna.

The mollusc faunas from Vilsund and Mogenstrup are very similar and contain several species which are absent at other Danish localities. However, the noteworthy species mentioned above may suggest that part of the glauconitic clay at the Cilleborg, Brejning, Skanderborg and Kirstinebjerg Skov localities might be of the same age as at Vilsund and Mogenstrup. Unit X is only present at Vilsund, Mogenstrup and in the Harre borehole (Śliwińska *et al.* 2012). Ulleberg (1987, p. 198) presumed, based on Troelsen (1955), that the Branden Clay might be present at Cilleborg. Further studies are necessary.

▼ **Fig. 13. a,** *Eubela* (s. lat.) *zetes* (Kautsky, 1925). Height 3.9 mm. **a1,** apertural view, **a2,** rear view, **a3,** lateral view. NHMD 625416 (ex MM-13695), DK 1176. **b,** *Acteon punctatosulcata* (Philippi, 1843). Height 1.1 mm. MM-13699. **c,** *Nipteraxis bimonilifera* (Sandberger, 1859). Height 3.4 mm. **c1,** lateral view, **c2,** apical view, **c3,** umbilical view. MM-13696. **d,** *Mathilda bicarinata* Koch & Wiechmann, 1872. Height 0.8 mm. NHMD 1651686 A (ex MM-13697), DK 1259. **e,** *Crenilabium terebelloides* (Philippi, 1843). Height 3.4 mm. MM-13698. **f,** *Odostomia ventriosa* (Speyer, 1870). Height 1.5 mm. NHMD 1651685 A (ex MM-13700), DK 1258. **g,** *Odostomia* sp. Height 2.2 mm. MM-13701. **h,** *Syrnola subcylindrica* (Philippi, 1843). Height 4.1 mm. MM-13702. **i,** *Syrnola laevissima* (Bosquet, 1859). Height 4.6 mm. MM-13703. **j,** *Turbonilla jeffreysi* Koch & Wiechmann, 1872. Height 1.6 mm. MM-13704. **k,** *Chrysallida* sp. Height 1.8 mm. MM-13705.

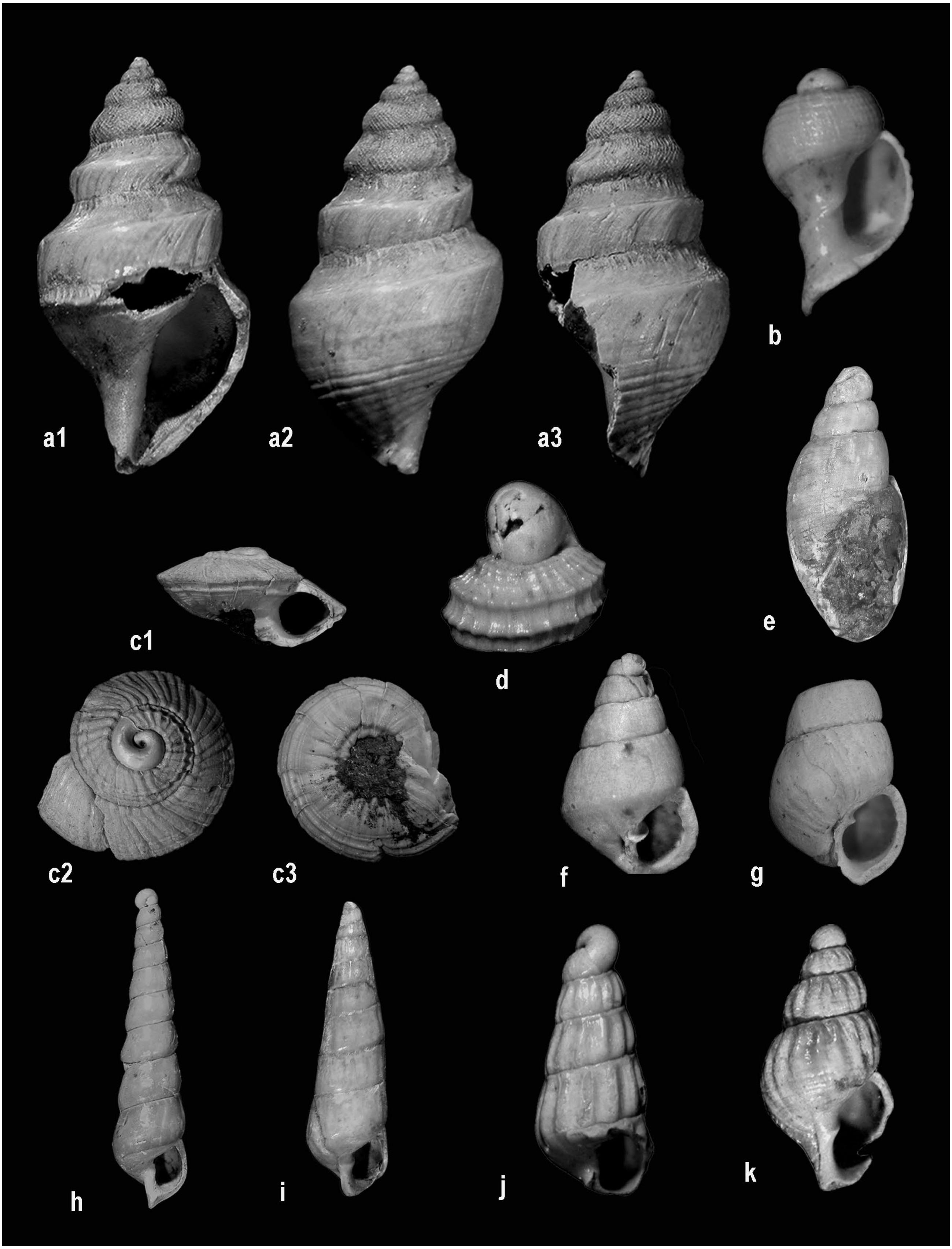
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**Fig. 14. a,** *Cubiostrea* sp. in siderite. Height 128 mm, width 103 mm. MM-13707. **b,** Fossilised wood with borings by Teredinidae. Length of specimen 7 cm. MM-13706. **c,** Glauconitic clay with concentration of Terebrataliidae. Height of largest brachiopod specimen 10 mm. MM-13914. **d,** Glauconitic clay with *Pseudosassia flandrica*. Height of gastropod 35 mm. MM-13915.

Faunas of the same age from Germany have been described by R. Janssen (1978a, 1978b, 1979a, 1979b).

*Glimmerode*
The Vilsund fauna shares 95 species (77 %) with the fauna from Glimmerode, Germany. Many characteristic species are in common, *e.g.* Cerithiopsidae, *Acar* aff. *dentiens*, *Homalopoma simplex*, *Steromphala chattica* and *Astraea pustulosa*. Of the Limopsidae only *Cosmetopsis retifera* is common, whereas *Aspalima chattica*, *Limopsis parva* and *Oblimopa vonderhochti* are absent.

*Freden*
77 species (63.6 %) are in common with the Vilsund fauna, among which are *Limopsis parva* and *Astraea pustulosa*. Almost all Cerithiopsidae, *Drilliola speyeri* and *Oblimopa vonderhochti* are absent.

*Krefeld*
81 species (61.9 %) are in common with the Vilsund fauna. Among these are *Limopsis parva*, *Oblimopa vonderhochti*, *Cirsope multucingulata*, *Cirsotrema crispata*, *Conomitra soellingensis* and *Drilliola speyeri*.

*Söllingen*
Only 59 species (48.8 %) are in common with the Vilsund fauna. Among these are *Acar* aff. *dentiens*, *Scissurella koeneniana*, *Astraea pustulosa* and *Pterynotus tristichus*.

## Palaeoecological interpretation

Many mollusc species are very rare, and several species are represented by juvenile specimens only, whereas others occur as both adults and juveniles. With a few exceptions, larger species are rare. Numerous sharp-edged fragments of *e.g. Limopsis parva* are most likely due to compaction of the sediment.

The bivalve assemblage is dominated by the Limopsidae species *Limopsis parva* and *Oblimopa vonderhochti* and the Arcidae species *Acar* aff. *dentiens*. Limopsidae are epibenthic and byssate and live in a sublittoral environment (Schnetler & Beyer 1990). Fragments of the pectinid species *Palliolum limatum* are abundant. Less common are the endobenthic species *Nuculana westendorpi*, *Cyclocardia grossecostata* and *Astarte gracilis*.

*Limopsis parva* is found as large specimens when compared to other Danish upper Oligocene localities, *e.g.*, Nørre Vissing, Aarhus and Skanderborg (largest specimen 20.0 mm), This finding suggests that good conditions existed for the species at Vilsund. *Oblimopa vonderhochti* is known from Mogenstrup (Schnetler & Beyer 1990), where large specimens were also found. This species has also been found in unpublished material from Brejning (coll. K. Eriksen, NHMD), but is absent at all other Danish upper Oligocene localities.

*Acar* aff. *dentiens* is very common and most specimens are rather large. Almost all specimens are worn or crushed. This species has also been recorded with lower frequency from Mogenstrup and a single unpublished specimen was found in the K. Eriksen collection from Brejning (NHMD); the species is absent at all other Danish upper Oligocene localities. The species is very common in the near-shore assemblage at Glimmerode, Germany (R. Janssen 1979b).

The abundant fragments of *Palliolum limatum* and a few of *Hilberia bifida*, as well as the worn specimens of the Limopsidae, indicate reworking or transport. Recent species of *Bathyarca* live in deep water (MolluscaBase 2022) and the presence of *Bathyarca bellula* might indicate deeper water, *e.g.* at least deeper sublittoral. Overall, the bivalve assemblage indicates littoral to deeper sublittoral conditions.

Gastropod species, such as *Microdrillia ingerae*, *Streptochetus cheruscus* and *Fusiturris duchastelii*, are almost exclusively found as juvenile specimens, whereas *Astraea pustulosa*, *Homalopoma simplex* and *Bathytoma leunisii* are found as juveniles and adults. *Astraea pustulosa* and *Steromphala chattica* indicate littoral conditions (R. Janssen 1978a), whereas *Pseudosassia flandrica* indicates deeper water (R. Janssen 1978a). Recent species of the gastropod genus *Homalopoma* are generally sublittoral to bathyal (*e.g. Homalopoma sanguinem* (Linnaeus, 1758): 200 m; *H. eoa* Azuma, 1972: 300–400 m, and *H. laevigata* Sowerby, 1914: 50–200 m, see Poppe 2008). The genus *Eubela* indicates bathyal conditions (Wenz 1943). Species of the families Cerithiopsidae and Triphoridae are generally indicators of shallow water, whereas the family Newtoniellidae is associated with the deep sea (Fernandes & Pimenta 2017). The rather common species *Laeocochlis supraeoligocaenicus* (Newtoniellidae) thus indicates deep water, whereas the diversity of the family Cerithiopsidae and the rather common *Norephora elatior* indicate shallow water. In all, the gastropod assemblage indicates littoral to sublittoral conditions, except for *Eubela* (s. lat.) *zetes*, *Pseudosassia flandrica*, *Laeocochlis supraeoligocaenicus* and *Homalopoma simplex*.

Schnetler & Beyer (1990) studied the fauna from Mogenstrup and found a mixed mollusc fauna with elements indicating deep marine conditions and others indicating more shallow water. They suggested that some species, *e.g.,* the Chattian A pectinids *Hilberia soellingensis* and *Hilberia bifida* and the shallow marine fauna, are most likely reworked. Rasmussen *et al*. (2010) suggested that the shallow marine fauna was transported down the delta or shelf slope to the basin floor. The mixed faunal assemblage from Mogenstrup thus seems to be a thanatocoenosis.

In all, the mollusc assemblage at Vilsund also indicates that the fauna is a thanatocoenosis. The presence of rolled quartz grains in the residues also indicates periods with littoral conditions, and erosion and transport of the molluscs from the littoral zone to the basin floor.

Schwarzhans (pers. comm. 2022) gave a preliminary overview of the otoliths from Vilsund and Mogenstrup and concluded that the Vilsund species indicated rather deep water (100–200 m), deeper than the Mogenstrup species.

# Conclusions

A mollusc fauna of 120 taxa has been studied and compared with other faunas of late Oligocene age. Sixteen species have been recorded from the Danish upper Oligocene for the first time, and a synopsis of the representatives of the genus *Streptodictyon* Tembrock, 1961 in the Danish Oligocene is given. Two new species *Mitromorpha (Mitrolumna) danica* n. sp. and *Cerithiopsis vilsundensis* n. sp. are established. The species *Eubela* (s. lat.) *zetes* (Kautsky, 1925) is the oldest representative of a predominantly Recent genus. The bivalve genus *Cubiostrea* Sacco, 1897 has been encountered in the upper Oligocene of the North Sea Basin for the first time. *Andersondrillia* Schnetler & Beyer, 1990 is considered a junior synonym of *Benthomangelia* Thiele, 1925. The environment of the mollusc fauna was most likely sublittoral, but the bivalve species *Bathyarca bellula* (Wiechmann, 1874), the extremely rare gastropod species *Eubela* (s. lat.) *zetes*, the very common gastropod species *Homalopoma simplex*, and the rather common species *Laeocochlis supraeoligocaenicus* and *Pseudosassia flandrica* indicate deeper water (sublittoral to bathyal conditions). The reworked molluscs indicate that the shallow marine fauna was transported down the delta or shelf slope to the basin floor. The mollusc fauna is presumed to be a thanatocoenosis.

The fauna is compared with other upper Oligocene Danish and German faunas and palaeoecological interpretations are suggested. The fauna has the closest affinities to the faunas from Mogenstrup and Glimmerode. As many of the mollusc species have not previously been illustrated from the Danish upper Oligocene, the fauna is extensively illustrated.

Dinocyst and foraminifer studies were carried out on samples from the Oligocene sections at Vilsund and Mogenstrup. The studied assemblages indicate that the greenish, glauconitic clay with siderite at the Vilsund 2 locality and Mogenstrup should be assigned to Unit X in Śliwińska *et al.* (2012) or the lowermost Brejning Formation, whereas a similar lithology at the Vilsund 1 locality is referred to the Branden Clay. The high Vilsund 3 section at Volbjerg exposes an undisturbed depositional contact between the Viborg Formation and Branden Clay, thus demonstrating a 6 Ma hiatus with most of the Rupelian missing in this area. The dark glauconite-free micaceous clay in the former clay-pit of Vilsund Brickworks is referred to the upper part of the Brejning Formation and the greenish, glauconitic clay in the clay-pit should most likely be assigned to Unit X or the lowermost Brejning Formation. The mollusc faunas from Vilsund and Mogenstrup are the first recorded from Unit X or the lowermost Brejning Formation.

# Acknowledgements

We are indebted to Erik Skovbjerg Rasmussen (GEUS, Copenhagen) for discussions and advice concerning the stratigraphy and lithology. Ronald Janssen, (Frankfurt a. Main, Germany), Jean-Michel Pacaud (MNHN, Paris), and Thomas Darragh (Victoria, Australia), are thanked for taxonomical advice and help with literature. Pierre Lozouet (MNHM, Paris) kindly gave his opinion of *Murexsul kochi*. Fritz von der Hocht (Kerpen, Germany) kindly commented on the brachiopods. Werner Schwarzhans (Hamburg, Germany) kindly provided his opinion on the otoliths. Mogens Stentoft Nielsen (Odense, Denmark) and Lone Sortkjær (Juelsminde, Denmark) kindly placed material at our disposal.

Samples for foraminifera and dinocysts from Vilsund 1 and 3 were collected during field work in northern Jylland in the summer 2006. The palynological analysis of the samples was carried out by Kasia K. Śliwińska as a part of her PhD project, but the results have not been published before. The PhD project was fully funded by Aarhus University. Annette Ryge and Dorthe Samuelsen prepared the palynological slides.

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# Appendix: micropalaeontology of samples from the Vilsund area and Mogenstrup

## Mogenstrup

A section (UTM coordinates NH 074 814) in the coastal cliff at Mogenstrup was studied for molluscs by Schnetler & Beyer (1990). According to the authors a *c.* 20 cm thick green glauconite-sand layer at the top of an at least 2 m thick light-greenish clayey silt with three horizons of siderite concretions in the upper meter yielded an abundant and diverse mollusc assemblage. This part of the profile was described as Unit 1 by Schnetler & Beyer (1990), who assigned the unit to the Brejning Clay Member (previously a member in the lower part of the Vejle Fjord Formation, but now defined as the Brejning Formation by Rasmussen *et al.* (2010)). Schnetler & Beyer (1990) assigned the glauconitic sand at the top of Unit 1 to the late Oligocene (Chattian B) based on molluscs. Foraminifers were studied in two samples, one from the glauconitic sand and one from a lower level in Unit 1. The samples were referred to the *Angulogerina gracilis* Zone, previously identified in the Brejning Formation (Ulleberg, pers. comm. 1987).

The mollusc-rich glauconitic layer is overlain, with a sharp boundary, by dark brown micaceous silts and clays, described as units 2-4 by Schnetler & Beyer (1990). This part of the section was referred to an interval of the Vejle Fjord Formation above the Brejning Clay Member and provisionally dated as Chattian C (late Oligocene).

The succession was sampled for palynological analyses in a slightly different position of the coastal cliff in 1987 by C. Heilmann-Clausen and C. Beyer. Palynological preparations ch-c lab. nos. 1141-1142 from Unit 1 below the glauconite-sand, ch-c no. 1143 from the glauconite-sand in the top of Unit 1, and ch-c nos. 1144 and 1145 from Units 2-4 were studied here. Ch-c no. 753 from a spherical calcitic concretion with parts of a skull case from a small cetacean from Lyby Strand (6 km SW of Mogenstrup) was studied as well. The characteristic spherical calcitic concretions at Lyby occur in a similar lithology as Unit 4 at Mogenstrup, and the concretions were also observed by Schnetler & Beyer (1990) within Unit 4. Information on this sample is therefore relevant for the dating of Unit 4 at Mogenstrup. No information based on these dinocyst samples has previously been published.

### Palynology

*Samples ch-c 1141-1143 (Unit 1).* The organic matter in the palynological slides is dominated by terrestrial particles: mainly degraded woody debris and bisaccate pollen. The dinocysts are moderately well preserved, and assemblages are poor in stratigraphically significant species. The most characteristic *in situ* species include *Artemisiocysta cladodichotoma* (Fig. 5 D) and *Distatodinium paradoxum*, both of which are common in all three samples, *Chiropteridium lobospinosum* (1 specimen in slide 1141), questionable *Chiropteridium galea*, *Reticulatosphaera actinocoronata*, *Polysphaeridium zoharyi*, *Dapsilidinium pseudocolligerum*, *Lejeunecysta acuminata*, *Lejeunecysta* cf. *fallax*, *Lejeunecysta tenella*, *Gerlachidinium aechmophorum*, *Selenopemphix nephroides*, *Selenopemphix* cf. *armata*, *Palaeocystodinium teespinosum* or *P. golzowense*, *Homotryblium floripes/plectilum* and *Cordosphaeridium cantharellum*. Mesozoic and older Palaeogene reworked dinocysts are present, but sporadic.

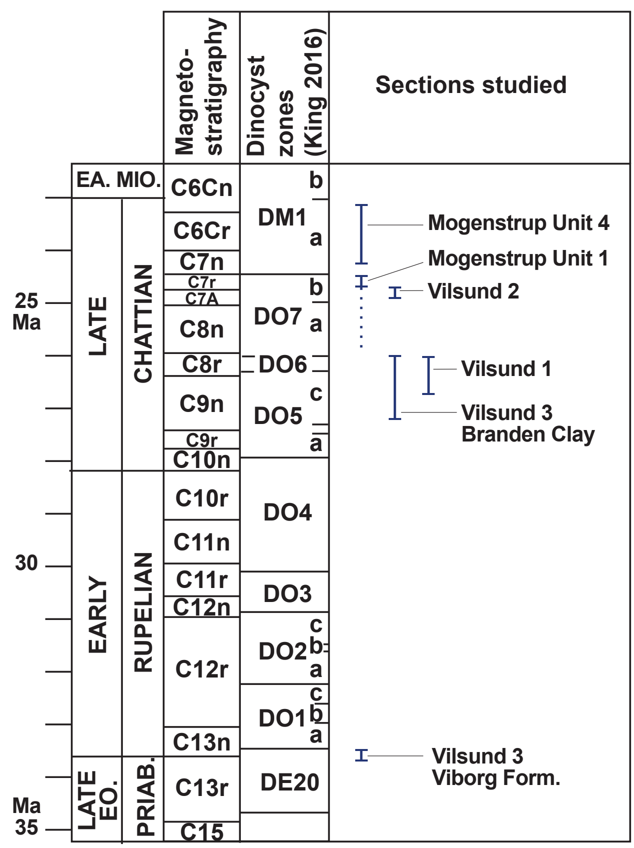


**Fig. 15.** Age and zonal assignment of sections analysed for dinocysts. Dinocyst zones, magneto- and chronostratigraphy are according to King (2016). Note that the Priabonian/Rupelian boundary definition used in King (2016) differs from the current global definition (see discussion in King 2016, p. 15–16). The Global Time Scale (GTS 2020; Gradstein *et al.* 2020) places the Priabonian/Rupelian boundary slightly deeper, in the upper part of Chron C13r. Following the GTS 2020, the upper part of dinocyst Subzone DE20b (with Viborg Formation in Vilsund 3) is therefore in the basal Rupelian.

*Samples ch-c 1144 and 1145 (both from the interval spanning units 2-4).* Organic particles consist mainly of brown, degraded lignitic debris. Bisaccate pollen are relatively common. Dinocysts are poorly preserved and very sporadic. The few observed specimens include a significant proportion of reworked Mesozoic and older Palaeogene dinocysts (*e.g*, *Chatangiella* sp., *Areoligera* sp. and *Enneadocysta pectiniformis*). *In situ* species include, in particular: *Artemisiocysta chladodichotoma*, *Palaeocystodinium golzowense*, a single questionable specimen of *Deflandrea phosphoritica*, *Reticulatosphaera actinocoronata*, *Cleistosphaeridium* cf. *diversispinosum*, *Distatodinium paradoxum* and few fragments of questionable *Chiropteridium galea*.

*Sample ch-c 753 (Unit 4 equivalent).* The sample includes a well preserved dinocyst assemblage characterised by common *Deflandrea phosphoritica*, *Homotryblium floripes/plectilum* and *Distatodinium paradoxum*, fairly common *Thalassiphora pelagica*, and the presence of *Chiropteridium galea* and *Cordosphaeridium cantharellum*.

**Comparison with previous Chattian dinocyst studies from Denmark and age determination**

The lower and middle Chattian of Denmark was studied by Sliwinska *et al*. (2012). According to these authors, the distinctive acritarch *Artemisiocysta cladodichotoma* (relatively common in all three samples of Unit 1) is present (but very rare) in Denmark in the lower Chattian (lower part of the Branden Clay). However, its last occurrence is not well constrained in the North Sea Basin. Notably, in the southern North Sea Basin this species ranges at least to near the top of the Oligocene (Van Simaeys *et al.* 2005). Furthermore, a lower Miocene (Aquitanian) reappearance of *Artemisiocysta cladodichotoma* is observed in the North Atlantic (Egger *et al.* 2016), suggesting that the range extends into the Miocene in northern middle latitudes. Accordingly, *A. cladodichotoma* can only have been intermittently present in Danish waters during the Chattian. This may explain its absence in the few previously studied samples from the upper part of the Branden Clay and the overlying Unit X of Śliwińska *et al.* (2012).

As shown by Śliwińska *et al.* (2012), several stratigraphic markers range through the Branden Clay-basal Unit X succession, including *Licracysta*? *semicirculata*, *Wetzeliella* spp., *Rhombodinium draco*, *Saturnodinium pansum* and *Pentadininum imaginatum*. None of these markers are recorded at Mogenstrup, indicating that the Mogenstrup section should be correlated with a higher level than basal Unit X. This conclusion is supported by the finding of the *Angulogerina gracilis* Zone in Unit 1 (see above). The lowest level for this zone is the upper part of Unit X (Śliwińska *et al.* 2012) and the top of the zone coincides with the top of the Brejning Formation (Ulleberg 1987).

The Oligocene – Miocene transition onshore Denmark (the boundary between the Brejning and the Vejle Fjord formations) was studied by Śliwińska *et al.* (2014). According to these authors, *Deflandrea phosphoritica* is common throughout the Brejning Formation in the Harre-1 borehole, except for the few metres thick, glauconitic basal part of the formation. *D. phosphoritica* is absent in Unit 1 at Mogenstrup. In conclusion, these features suggest a correlation of Unit 1 with the lowermost glauconitic part of the Brejning Formation or upper part of the underlying Unit X. In terms of the North Sea Basin zonation provided by King ( 2016), Unit 1 can be referred to the upper Chattian Zone DO7, and possibly the upper part, Subzone DO7b as discussed below in connection with the sample from Vilsund 2.

Unit 4 can be confidently correlated with the uppermost Chattian *Deflandrea phosphoritica* Zone of Dybkjær & Piasecki (2010) and DM1a Subzone of King (2016) based on the common *D. phosphoritica* in sample 753. This allows a correlation of Unit 4 to the non-glauconitic upper part of the Brejning Formation in the Harre-1 borehole (cf. above). The *D. phosphoritica* Zone is very thick (33 m) in the Harre-1 borehole and consists of a dark brown micaceous silty clay similar to Unit 4 at Mogenstrup.

## Vilsund 2

A sample collected by IS in 2022 from the mollusc-rich strongly glauconitic layer at the Vilsund 2 locality was processed for palynology (ch-c lab.no. 3283). For lithology, preparation and palynofacies, see the main text.

The well-preserved dinocyst assemblage is dominated by *Spiniferites* spp. (including *S. pseudofurcatus*), *Achomosphaera* spp., and *Lingulodinium machaerophorum*. Other common dinocyst taxa include: *Dapsilidinium pseudocolligerum*, *Reticulatosphaera actinocoronata*, *Chiropteridium galea*, and *Cleistosphaeridium diversispinosum*. The acritarch *Cyclopsiella elliptica* is also fairly common. Less common are *Thalassiphora pelagica*, cf. *Licracysta*? *semicirculata* and *Triphragmadinium demaniae* (see Taxonomic remarks to the latter two taxa). Present, but not rare, taxa include *Hystrichokolpoma cinctum* (4 specimens), *Artemisiocysta cladodichotoma* (3, possibly 4 specimens), *Homotryblium floripes/plectilum*, *Distatodinium paradoxum* and *Hystrichokolpma rigaudae*. Rare taxa include *Membranophoridium aspinatum*, *Lejeunecysta tenella* (Fig. 5 B), *Lejeunecysta hyalina* and *Selenopemphix nephroides*.

The diversity is high, which is partly due to a considerable proportion of reworked cysts from the Lower Cretaceous and Palaeogene (Eocene – Oligocene). The most common reworked dinocysts include *Areosphaeridium diktyoplokum* (mainly forms with entire margins of process-platforms from upper Eocene –

lowermost Oligocene) and *Enneadocysta arcuatum/pectiniformis* (middle Eocene – lower Oligocene). Further reworked taxa include, among others *Heteraulacacysta porosa* (several specimens), *Dracodinium* cf. *similis* (1 specimen), *Phthanoperidinium comatum* (1 specimen), several specimens of cf. *Tenua* sp. (Lower Cretaceous). A single questionable *Wetzeliella* sp. is also considered to be reworked.

**Comparison with samples from Mogenstrup and age**
The palynofacies suggests a more open marine environment than at Mogenstrup, which is heavily dominated by degraded woody material. The dinocyst assemblage shows similarities with Unit 1 at Mogenstrup (presence of *Artemisiocysta cladodichotoma* and *Lejeunecysta tenella*, and absence of the genus *Deflandrea* as well as absence of nearly all stratigraphic markers for the Branden Clay, such as *Saturnodinium pansum*, *Rhombodinium draco* and *Pentadinium imaginatum*). The main difference is the presence of *Triphragmadinium demaniae* and cf. *Licracysta*? *semicirculata* at Vilsund.

According to the data in Van Simaeys *et al.* (2005), *T. demaniae* occurs only in a narrow interval in the lower part of their Zone NSO-8. Zone NSO-8 is identical to Subzone DO7b of King (2016). The Vilsund 2 sample may hence correlate with this narrow interval in the lower part of the upper Chattian Subzone DO7b.

It can be speculated that cf. *Licracysta*? *semicirculata* only occurs a short distance above proper *Licracysta? semicirculata,* the last occurrence of which marks the top of the mid-Chattian Zone DO6 of King (2016) and is absent above the lower part of Subzone DO7b with *T. demaniae*. If so, the Mogenstrup sample, without *Triphragmadinium demaniae* and cf. *Licracysta*? *semicirculata,* should be referred to a higher part of Subzone DO7b than the Vilsund 2 sample.

## Sections from the Vilsund area sampled for micropalaeontology in 2006

Two outcrops, Vilsund 1 and Vilsund 3 (during field work named Sundby Nord and Sundby Syd, respectively), were studied for micropalaeontology (dinocysts and foraminifers). The profiles were described, and all samples were collected, during field work in the summer 2006.

**Vilsund 1 (formerly Sundby Nord)**
The Vilsund 1 section is a *c.* 1.5 m high cliff, which in 2006 was exposed very close to, and probably north of, the Vilsund 2 section. The lower part of the outcrop consists of black, sticky micaceous clay. The middle part exposes a 15–20 cm thick very glauconite-rich layer with siderite concretions. The upper part consists of brown, sticky glauconitic clay. Three sediment samples were collected from the outcrop. Sample no. 1 (GEUS Lab. no. 20.226) was taken *c.* 45 cm below the glauconitic layer with siderite. Sample no. 2 (GEUS Lab. no. 20.227) was collected from the glauconitic unit with siderite. Sample no. 3 (GEUS Lab. no. 20.228) was taken *c.* 70 cm above sample 2. All samples were prepared at the Geological Survey of Denmark and Greenland (GEUS) for dinoflagellate cysts following the methods described in Śliwińska *et al.* (2014). All samples yielded well preserved dinoflagellate cyst assemblages of low to high diversity.

Sample no. 1 (GEUS no. 20.228_6) yields typical early Chattian dinocyst assemblages with *Chiropteridium galea*, *Chiropteridium lobospinosum*, *Pentadinium imaginatum*, *Saturnodinium* cf. *pansum* and *Wetzeliella gochtii*. Sample no. 2 (GEUS no. 20.227_6) has the least diverse dinocyst assemblage. The only useful age indicative dinocyst is *Licracysta? semicirculata.* Sample no. 3 (GEUS no. 20.226_6) yields *Distatodinium biffii*, *Licracysta? semicirculata*, *Saturnodinium* cf. *pansum*, *Wetzeliella symmetrica* and the acritarch *Artemisiocysta cladodichotoma*. *Areosphaeridium diktyoplokum* (with ragged clypeate process terminations, see Śliwińska (2019) for details) and *Areosphaeridium michoudii* (sample no. 3), as well as *Enneadocysta pectiniformis* (sample no. 1), are rare and are considered to be reworked. The dinocyst assemblages in the Vilsund 1 section are typical for the Branden Clay (Śliwińska *et al.* 2012), and can be assigned to the dinocyst D14nb Zone (Köthe 1990), the lower part of the NSO-5b Subzone (Van Simaeys *et al.* 2005) and the upper part of Subzone DO5c or Zone DO6 of King (2016).

**Vilsund 3 (formerly Sundby Syd)**
The cliff section at Vilsund 3 (registered as the Sundby Syd section in the palynological database at GEUS) is situated at 56° 52′ 12″ N, 8° 38′ 50″ E. at Volbjerg *c.* 2 km south of the Vilsund Bridge. The section was included in a master's thesis on the magnetostratigraphic and sedimentology of the upper Oligocene and Miocene in NW Jylland (Beyer 1987, unpublished). The following description is based on the present study. The site exposes a *c.* 14 m high cliff section, with a thin layer of undifferentiated Quaternary till on top. The interval from the beach level (marked as 0 on Fig. 16) up to *c.* 13.2 m consists of dark brown micaceous silty clay with sporadic lenses of silt and fine sand. From *c.* 10 m above the beach level, the sediments become more sandy. The uppermost *c.* 90 cm of the unit consists of fine sand and silt and is more yellow in appearance. Around level 13.2 m there is a sharp boundary and a shift to green, glauconitic clay. Fifteen sediment samples were collected in total: 14 sediment samples were collected from the lower unit. One sample was collected from the upper unit, *c.* 30 cm above the lithological change.

Seven samples (nos. 1, 4, 7, 10, 12, 14 and 15, see sample position in Fig. 16) were prepared for micropalaeontology (foraminifers) at Aarhus University following methods described in Śliwińska *et al.* (2012). In the interval from 0.0–10.8 m (samples no. 1 to 12), *Turrillina alsatica* is the most dominant species. The other common species are *Nonion affine, Pullenia bulloides, Gyroidinoides* spp. and *Cibicides* spp. The lowermost sample also contains a few *Globigerinacea* spp. The faunal assemblage is typical for the *Turrillina alsatica* Zone. The two uppermost samples (no. 14 and 15) are barren in foraminifers.

All 15 samples were processed at the Geological Survey of Denmark and Greenland (GEUS) for dinoflagellate cysts (sample codes 20.211–20.225) following the method described by Śliwińska *et al.* (2014). Palynological slides are stored at GEUS. All samples yielded well preserved and diverse dinocyst assemblages. The interval from 0.0 m – 12.8 m (sample no. 1 to 14; 20.211-20.224) contains a typical earliest Oligocene dinocyst assemblage with *Areosphaeridium diktyoplokum* (both ragged and entire clypeate process terminations; see Śliwińska 2019), *Cerebrocysta bartonensis, Enneadocysta pectiniformis, Glaphyrocysta semitecta, Lentinia serrata, Phthanoperidinium comatum, Rhombodinum draco,* and *Thalassiphora reticulata* (*e.g.*, Köthe 1990; Van Simaeys *et al*. 2005; Köthe & Piesker 2007; Śliwińska *et al*. 2012). Rare occurrences of *Areosphaeridium michoudii, Eatonicysta ursulae, Diphyes colligerum*, and *Thalassiphora delicata* in the interval are considered to be reworked.

The foraminifera and dinocyst assemblages are very typical for the Viborg Formation (Śliwińska *et al*. 2012), which can be assigned to the dinocyst D12nc Zone (Köthe 1990), the NSO-1 Zone (Van Simaeys *et al*. 2005) and Subzone DE20b of King (2016).

From the uppermost *c.* 1.5 m thick interval only one sample was studied for dinocysts (20.225). The sample contains *Licracysta? semicirculata*, *Chiropteridium galea, Chiropteridium lobospinosum*, *Distatodinium biffii* and *Saturnodinium pansum*. The assemblage is typical for the Branden Clay (Śliwińska *et al.* 2012), and can be assigned to the dinocyst D14nb Zone (Köthe 1990), the NSO-5b Subzone (Van Simaeys *et al.* 2005) and DO5c or DO6 of King (2016).

The biostratigraphy shows that the sharp boundary at level 13.2 m is a major disconformity (erosional

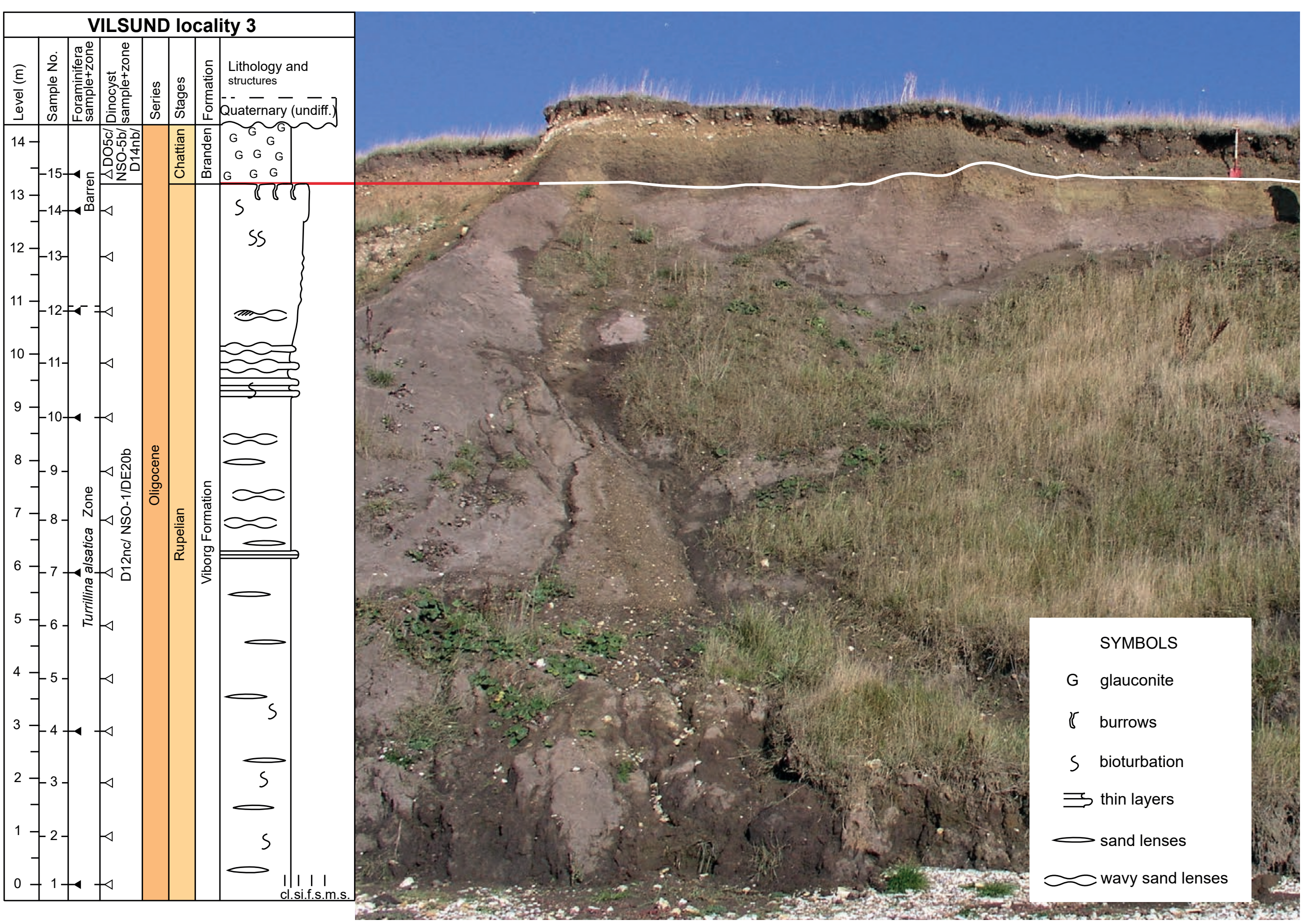


**Fig. 16.** The Vilsund 3 outcrop section in 2007. cl.: clay; si.: silt; f.s.: fine-grained sand; m.s.: medium-grained sand. Spade for scale. Photo Kasia K. Śliwińska.

unconformity) between the Viborg Formation and the 6 Ma younger Branden Clay. The short section of Branden Clay at Vilsund 1 does not show the contact to the Viborg Formation and must represent a higher level of the Branden Clay.

The Vilsund 3 section is the thickest and most northerly exposure of the Viborg Formation. Accordingly, and because of the sedimentary contact (undisturbed by glacial tectonics) between the Viborg Formation and Branden Clay, the section is of particular interest for education and future research.

**Taxonomic remarks**

*Triphragmadinium demaniae* (Fig. 5 A)

This dinocyst was used as a zonal marker by Van Simaeys *et al.* (2005) and King (2016) and is present in the Vilsund sample (ch-c 3283). *Triphragmadinium demaniae* was described relatively recently by Van Simaeys *et al.* (2005) and has rarely been recorded since. Comments on its morphology in the present material are therefore appropriate.

At least 10 specimens were observed. The general shape and structure of the cyst is similar to the type material from the southern North Sea Basin. A number of distinctive characters are also identical to the type material; these include the wrinkled, very thin and hyaline periphragm with a variable number of distinctive small round holes (claustra) in parts of the surface, the antapical invagination of the periphragm surrounding a hollow process (outgrowth of the periphragm), and the contact between peri- and endophragm at the margin of the apical archaeopyle.

The mesophragm described in the type material as a low suturocavate feature on the surface of the endocyst is difficult or impossible to ascertain in our specimens. At least in one specimen (Fig. 5 A) low folds or ridges of thin material on the surface of the endocyst may reflect sutures, thus probably representing the mesophragm. Considering the identity in most characters, we consider the lack of a clearly recognizable mesophragm as an intraspecific variation in *Triphragmadinium demaniae.*

cf. *Licracysta*? *semicirculata* (Fig. 5 C)

This dinocyst is present in the Vilsund sample (ch-c 3283) and may be of stratigraphic significance as discussed above. Approximately 10 specimens were observed; they differ from the type material of *Licracysta*? *semicirculata* by having shorter processes, which are less ribbon-like and more cylindrical.

**Storage of palynological preparations**

Preparations with ch-c-numbers are stored at the Department of Geoscience, Aarhus University. Preparations with GEUS-numbers are stored at GEUS.

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