

# Notes on Late Cretaceous – earliest Paleocene xenophorid gastropods from Denmark, Belgium and the Netherlands

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In Late Cretaceous and earliest Paleocene gastropod assemblages from Denmark, north-east Belgium and the south-east Netherlands, originating from white chalk and biocalcarenic facies alike, xenophorids or ‘carrier shells’ constitute merely a minor component. The main interest of these marine gastropods lies in the fact that they attach foreign objects, such as bivalve shells, serpulid worm tubes, bryozoans, fragments of echinoid tests and spines, as well as gastropod shells to their conchs. The first specimens of xenophorid shells, with attached foreign objects, from the lower upper Maastrichtian white chalk of Hillerslev (Jylland) are here presented, assigned to *Xenophora nilssoni* for the time being and compared with coeval and younger material from Belgium and the Netherlands. It appears that more than one species is represented in the latter lot, but this requires more detailed assessment of larger populations. *Xenophora nilssoni* is here recorded to range from the lower Campanian to upper Maastrichtian in the Netherlands-Belgium border region, while *Xenophora* sp. 1 refers to a population from the Meerssen Member, subunit IVf-7 (lowermost Paleocene) in southern Limburg, the Netherlands. Wherever possible, attached foreign objects are identified to genus and/or species.

**Keywords:** Gastropoda, Stromboidea, Xenophoridae, carrier shells, attachments, taxonomy, palaeoecology.

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In north-west Europe, the small- to medium-sized, low conical, trochospiral shells of ‘carrier shells’, or xenophorids, constitute only a minor component of Late Cretaceous and early Paleocene gastropod assemblages. Although more than one species appears to be represented, the name *Xenophora onusta* (Nilsson, 1827) has been used by nearly all previous authors for forms of Santonian(?), Campanian and Maastrichtian age. Pacaud (2016, p. 50) has recently noted that the name *Trochus onusta* Nilsson, 1827 is invalid, being preoccupied by *Trochus onusta* Lightfoot, 1786, an extant species, and itself a junior synonym of *Trochus conchyliophora* von Born, 1780, and suggested *Xenophora nilssoni* Pacaud, 2016 as a replacement name. Nilsson’s (1827) original material came from the coarse-grained, calcarenitic Köpings Sandstone (“calcarenosa” of Nilsson 1827) in south-

ern Sweden, which equates with the *basiplana-roemeri* Zone (*sensu germanico*) in the lower upper Campanian (Kennedy & Christensen 1997).

Here, we present the first Danish examples of xenophorid shells, with attached foreign objects such as gastropods, bivalves and a primary spine of a cidaroid echinoid, from white chalk facies at Hillerslev, northern Jylland (Fig. 1), dated as late early to early late Maastrichtian (*tenuicostata-semiglobularis* and *semiglobularis-humboldtii* brachiopod zones; Møns Klint Formation) (Fig. 2). In the extended type area of the Maastrichtian Stage (Fig. 3) in the south-east Netherlands and north-east Belgium, xenophorids have been recorded from the mid-nineteenth century onwards, mostly in faunal lists and invariably referred to as *Xenophora onusta* (Nilsson, 1827). Bosquet (1860, 1868) noted this form from strata dated as

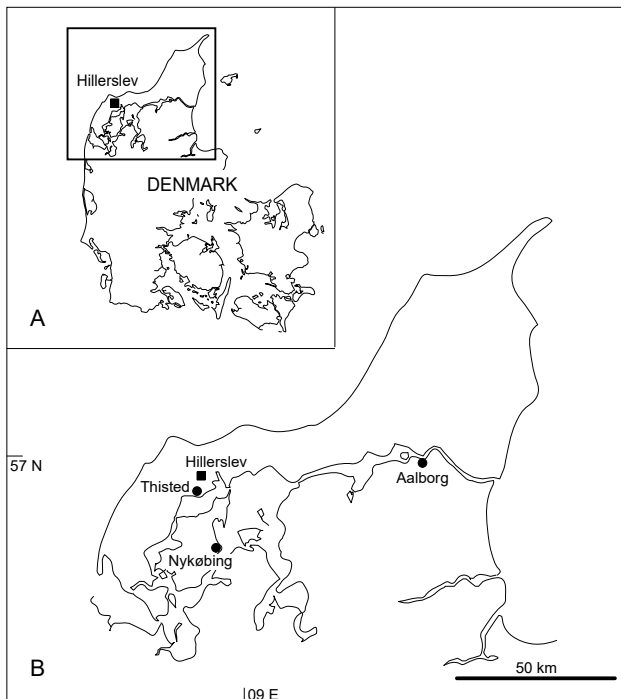


Fig. 1. Map of Denmark, showing the locality of Hillerslev in northern Jylland.

‘Hervien’ (= Vaals Formation in current terminology; lower Campanian) and ‘Maastrichtien’ (= Maastricht and Kunrade formations in current terminology; upper Maastrichtian). Binkhorst van den Binkhorst (1861-1862) was the first to illustrate a specimen in internal mould preservation from the ‘calcaire de Kunraed’ (= Kunrade Formation, in current terminology), while his material was subsequently revised by Kaunhowen (1898), who also provided details of the stratigraphical provenance, recording specimens from the Nekum Member (Maastricht Formation; Fig. 4). In both papers, the name *Xenophora onusta* is used.

It is highly likely that more than one species is involved in the material studied herein. Specimens from indurated levels, such as the top of the Emael Member and the overlying base of the Nekum Member (Maastricht Formation) in the Maastricht area (the Netherlands) are more or less three-dimensionally preserved, so that the apical angles may be measured.

For the time being, we use the name *Xenophora nilssonii* for the Danish specimens and for two composite moulds from the Vijlen Member (interval 6) and numerous silicified shells as well as external and internal moulds from the Gronsveld, Emael, Nekum and Meerssen (subunits IVf-1 to IVf-6) members (Fig. 4). Under the name of *Xenophora* sp. 1, an earliest Paleocene population (Meerssen Member, subunit IVf-7) from the Geulhem area (the Netherlands) is listed here. These forms are distinguished on overall shell

proportions, apical angle and ornament, where preserved.

Below, a brief overview of the stratigraphy of the levels that have yielded the present xenophorid material is given, first for Denmark, and secondly, for the Liège-Limburg area (Belgium, the Netherlands).

## Localities and stratigraphy

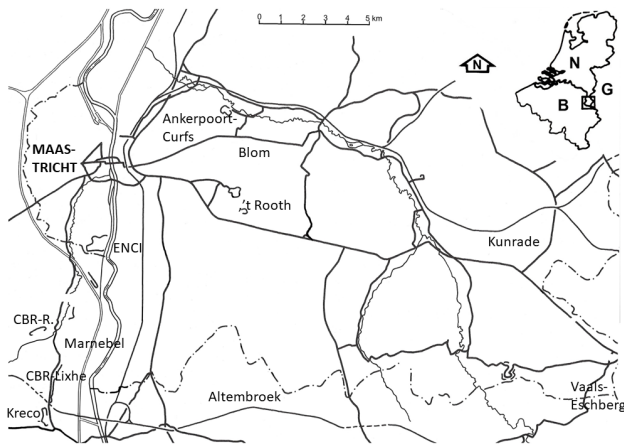
### Denmark

The Hillerslev chalk quarry is situated in north-west Jylland, north of Limfjorden (Fig. 1), c. 5 km north of Thisted (co-ordinates: 57.008°N, 8.72°E); it covers an area of approximately 600 × 700 metres.

This locality is situated in the Danish Basin, immediately south of the tectonically significant Tornquist Zone, more precisely on the Thisted Dome, a salt-influenced structure extending between Thisted and Hanstholm (Hansen & Håkansson 1980). Fracturing is widespread at the site and quarry faces reach over 10 metres in height, although most are less high. The non-indurated chalk excavated is assigned to

| Ma   | Thibault <i>et al.</i> (2025) |                   | Surlyk <i>et al.</i> (2013) |                  | Birkelund (1957)           | Surlyk (1984, 2025) |                                    |
|------|-------------------------------|-------------------|-----------------------------|------------------|----------------------------|---------------------|------------------------------------|
|      | Stages                        | Boreal sub-stages | Litho-stratigraphy          |                  | Belemnite zones            | Brachiopod zones    |                                    |
| 66.0 | Maastrichtian                 | upper upper       | Mons Klint Formation        | Høj. Mb.         | <i>Bln. casimirovensis</i> | 10                  | <i>stevens-chitoniformis</i>       |
|      |                               |                   |                             | Sigerslev Member |                            | 9                   | <i>humboldtii-stevens</i>          |
| 67.0 |                               |                   |                             | Rørdal Mb.       | <i>Blt. junior</i>         | 8                   | <i>semiglobularis-humboldtii</i>   |
| 68.0 |                               | lower upper       |                             |                  |                            |                     |                                    |
| 69.0 |                               |                   | Hvidskud Mb.                |                  |                            | 7                   | <i>tenuicostata-semiglobularis</i> |
| 70.0 | Camp.                         | upper lower       |                             |                  | <i>Bln. occidentalis</i>   | 6                   | <i>pulchellus-tenuicostata</i>     |
| 71.0 |                               |                   |                             |                  |                            | 5                   | <i>pulchellus-pulchellus</i>       |
|      |                               |                   |                             |                  |                            | 4                   | <i>subtilis-pulchellus</i>         |
|      |                               |                   |                             |                  |                            | 3                   | <i>spinosa-subtilis</i>            |
| 72.0 |                               | lower lower       | Mandehoved Formation        | Boesdal Mb.      | <i>Bln. lanceolata</i>     | 2                   | <i>acutirostris-spinosa</i>        |
| 73.0 |                               |                   |                             |                  |                            | 1                   | <i>jasmundi-acutirostris</i>       |

Fig. 2. Lithostratigraphy (formations, members and horizons; Surlyk *et al.* 2013; Thibault *et al.* 2025) and belemnite and brachiopod zonation (Birkelund 1957; Surlyk 1984, 2025) of uppermost Campanian and Maastrichtian strata in Denmark.



**Fig. 3.** Map of the extended type area of the Maastrichtian Stage (southern Limburg, the Netherlands, and contiguous areas in Belgium and Germany), showing localities that have yielded xenophorid material described herein.

the Møns Klint Formation (Surlyk *et al.* 2013) and is light grey to white in colour, being almost entirely composed of biogenic material, primarily abundant calcareous coccolith remains interspersed with skeletal fragments of bryozoans, brachiopods, bivalves, sponges and echinoderms. The dominant lithofacies is bioturbated pelagic chalk mudstone.

Macrofossil and ichnofossil assemblages from Hillerslev have received attention in numerous papers, including Birkelund (1979, 1993), Surlyk (1970, 1984), Jagt *et al.* (1999), Machalski (2005) and Vallon *et al.* (2020). Surlyk (1984, 2025) correlated strata exposed at Hillerslev quarry with the *tenuicostata*-*semiglobularis* and *semiglobularis*-*humboldtii* brachiopod zones, dated as latest early to earliest late Maastrichtian. Associated ammonites include *Hoploscaphites constrictus constrictus* (J. Sowerby, 1817), *H. tenuistriatus* (Kner, 1848), *Saghalinites wrighti* Birkelund, 1965 and *Pachydiscus neubergicus* (von Hauer, 1858), support this dating (Birkelund 1993; Machalski 1996, 2005). Even if dating of strata exposed at Hillerslev quarry awaits to be determined in detail, currently an age of between 69 and 67 Ma may be proposed (see Thibault *et al.* 2025).

### North-east Belgium and south-east Netherlands

In the extended type area of the Maastrichtian Stage (Fig. 3), the Upper Cretaceous succession has been subdivided into five formations, with numerous members and horizons (omission surfaces, hardground, fossil hash levels; see Jagt 1999), only few of which have yielded xenophorid gastropods in various states of preservation (*i.e.* composite moulds, internal/external moulds and silicified shells). These units are as follows:

*Vaals Formation* (Fig. 4). Within the lower part of this glauconitic, sandy/silty unit, the so-called 'Müller's Bed' (Gemmenich Member) has yielded a highly diverse silicified macrofauna, including numerous molluscs, in particular near Vaals-Eschberg (W.M. Felder & Bosch 2000). This bed is named after a local headmaster, Johannes Müller, who collected such silicified macrofossils and described and named these (Müller 1847, 1851, 1859). This fauna was subsequently revised by Holzapfel (1884, 1885, 1887–1888, 1889). Albers & Felder (1979) showed 'Müller's Bed' to have been situated within their 'sandy silt biotope' of silty, glauconitic, extensively bioturbated, fine-grained sands, with the bed itself representing an original biocoenosis of high diversity, including many gastropod species suggestive of rich thallopiphyte growth. Xenophorids, here assigned to *Xenophora nilssoni*, are rare in these assemblages (Table 1).

Within the Vaals Formation important index biota such as inoceramid bivalves and ammonoid and coleoid cephalopods are comparatively rare.

### Houthem Formation

|  |                          |                 |
|--|--------------------------|-----------------|
|  | Vroenhoven Hz            |                 |
|  | Meerssen Mb, IVf-7       |                 |
|  | Berg en Terblijt Hz      | 66.02 Ma (K/Pg) |
|  | Meerssen Mb, IVf-1/-6    |                 |
|  | Caster Hz                | 66.13 Ma        |
|  | Nekum Mb, IVe-3/4-4      |                 |
|  | Kanne Hz                 | 66.25 Ma        |
|  | Nekum Mb, IVe-1/2-2      |                 |
|  | Laumont Hz               | 66.35 Ma        |
|  | Emael Mb                 |                 |
|  | Romontbos Hz             | 66.55 Ma        |
|  | Schiepersberg Mb         |                 |
|  | Schiepersberg Hz         | 66.60 Ma        |
|  | Gronsveld Mb             |                 |
|  | St. Pieter Hz            | 66.90 Ma        |
|  | Valkenburg Mb            |                 |
|  | Lichtenberg Hz           | 67.00 Ma        |
|  | Lanaye Mb                |                 |
|  | Nivelle Hz               | 67.80 Ma        |
|  | Lixhe 3 Mb               |                 |
|  | Boirs Hz                 | 68.60 Ma        |
|  | Lixhe 2 Mb               |                 |
|  | Halembaye 1 Hz           | 69.20 Ma        |
|  | Lixhe 1 Mb               |                 |
|  | Wahlwiller Hz            | 69.70 Ma        |
|  | Vijlen Mb, interval 6    |                 |
|  | Zonneberg Hz             |                 |
|  | Vijlen Mb, interval 5    |                 |
|  | Böckler Hz               | 70.40 Ma        |
|  | Vijlen Mb, intervals 0-4 |                 |
|  | Bovenste Bos Hz          | (Camp/Mstr)     |
|  | Beutenaken Mb            |                 |
|  | Froidmont Hz             | 72.60 Ma        |
|  | Zeven Wegen Mb           |                 |
|  | Zeven Wegen Hz           |                 |

### Vaals Formation

**Fig. 4.** Lithostratigraphy (formations, members and horizons) of Upper Cretaceous-lowermost Paleocene strata in the type area of the Maastrichtian Stage, and dating of horizons (after Vellekoop *et al.* 2022; see also Keutgen 2018). The Kunrade Formation (not shown) is considered to be the lateral, near-shore equivalent of the upper Gulpen Formation (Lanaye Member) to the Emael Member of the Maastricht Formation (P.J. Felder & Bless 1989; Jagt 1999).



**Fig. 5.** *Xenophora nilssoni* Pacaud, 2016 (DK 1076), upper lower to lower upper Maastrichtian, Hillerslev (northern Jylland, Denmark). **A:** Entire slab with the two parts of DK 1076 and *Saghalinites* sp. (bottom left-hand side). **B:** Base of DK 1076 with attached molluscs: indeterminate gastropod (a), indeterminate bivalve with adnate juvenile oyster (b), smooth pectinid valve (c), large specimen of *Amaea aliciae* T. Hansen, 2019 (d), *?Serrifusus binkhorsti* (Kaunhowen, 1898) (e), *?Pseudotoma danica* T. Hansen, 2019 (f). **C:** Apex of DK 1076 with attached molluscs: *?Dolicholatirus* sp. (a), *?volutid* (b, c), *?fasciolariid* (d), indeterminate gastropod (e), fragment of oyster? (f). Microconch of *Hoploscaphites constrictus constrictus*, associated, but apparently not attached (g), and spine of cidaroid echinoid (h).

Albers (1976) recorded the belemnitelids *Gonioteuthis granulataquadrata* (Stolley, 1897), *G. quadrata* (de Blainville, 1827) and *Belemnitella praecursor* Stolley, 1897 and, on this basis, favoured correlation with the North German *granulataquadrata*, *lingualquadrata* and *pilula* zones (lower lower Campanian; see Niebuhr 2006). The base of the *granulataquadrata* Zone had previously been shown to correspond to the United States Western Interior *Scaphites leei* III Zone, dated at  $83.5 \pm 0.5$  Ma (McArthur *et al.* 1993). Ammonite taxa particularly suited for both trans-Atlantic and European correlations include *Scaphites hippocrepsis* II-III (*sensu* Cobban 1969) and *Baculites vaalsensis* Kennedy & Jagt, 1995. In the Western Interior, the *Scaphites hippocrepsis* II Zone has been dated at 81 Ma (McArthur *et al.* 1994). Other, non-heteromorph ammonites from the Vaals Formation corroborate such an age assignment for the lower part of this unit (Jagt & Jagt-Yazykova 2019). However, the upper part has yielded a different ammonite assemblage, typical of the lower upper Campanian, the most important index being

*Hoplitoplacenticeras marroti* (Coquand, 1859). Other macrofaunal groups that may be used as proxies comprise inoceramid bivalves (Sornay 1982), with direct links to assemblages from the Münsterland Basin in north-west Germany (Walaszczyk 1997).

*Gulpen Formation, Vijlen Member* (Fig. 4). This highly complex unit of glauconitic limestone has been subdivided into intervals 0 to 6 (P.J. Felder & Bless 1994; P.J. Felder 1997), with correlations relying on benthic foraminifera and bioclast-based ecozones, as well as inoceramid bivalves, ammonites and belemnites. Only from the Haccourt-Lixhe area (Fig. 3) are xenophorids known to date. Amongst the rich macrofaunal assemblages from the Altembroek section, described in detail by Jagt *et al.* (1995), there are none. At that locality, various belemnite-rich levels within interval 4 were distinguished, but repeated reworking across a channelised sea floor must have occurred to explain associations of various taxa of early (*obtusum*, *sumensis* and *cimbricum* zones) and early

**Table 1.** Xenophorid records from the Campanian to lowermost Danian of the extended type area of the Maastrichtian Stage (north-east Belgium, south-east Netherlands), with indications of attached foreign objects.

| Formation  | Member             | Age                      | Locality                         | Registration number (MHMM-) | Preservation style | Attachments                                                                                        | Illustration | Taxon                      |
|------------|--------------------|--------------------------|----------------------------------|-----------------------------|--------------------|----------------------------------------------------------------------------------------------------|--------------|----------------------------|
| Vaals      | Gemmenich          | early Campanian          | Vaals-Eschberg                   | 899                         | silicified         | fragments of irregular echinoid tests, bivalves                                                    |              | <i>Xenophora nilssonii</i> |
| Gulpen     | Vijlen, interval 6 | late early Maastrichtian | CBR-Lixhe quarry                 | M2146                       | composite mould    | scars of bivalves, single gastropod spire                                                          | Fig. 7       | <i>Xenophora nilssonii</i> |
| Gulpen     | Vijlen, interval 6 | late early Maastrichtian | Kreco quarry (formerly CPL SA)   | M2343                       | composite mould    | scars of bivalves                                                                                  |              | <i>Xenophora nilssonii</i> |
| Gulpen     | Vijlen, interval 6 | late early Maastrichtian | Kreco quarry (formerly CPL SA)   | JJ 7301                     | composite mould    | fragments of irregular echinoid test, pectinoid bivalves and brachiopods                           | Fig. 19      | <i>Xenophora nilssonii</i> |
| Maastricht | Gronsveld          | late Maastrichtian       | ENCI quarry                      | M180                        | silicified         | fragments of irregular echinoid test, cheilostome bryozoans                                        |              | <i>Xenophora nilssonii</i> |
| Maastricht | Gronsveld          | late Maastrichtian       | ENCI quarry                      | M196                        | silicified         | scars only                                                                                         |              | <i>Xenophora nilssonii</i> |
| Maastricht | Gronsveld          | late Maastrichtian       | ENCI quarry                      | M1509                       | silicified         | faint scars only                                                                                   | Fig. 14      | <i>Xenophora nilssonii</i> |
| Maastricht | Gronsveld          | late Maastrichtian       | ENCI quarry                      | M1524                       | silicified         | scars only                                                                                         |              | <i>Xenophora nilssonii</i> |
| Maastricht | Gronsveld          | late Maastrichtian       | ENCI quarry                      | M1606                       | silicified         | fragment of cheilostome bryozoan                                                                   |              | <i>Xenophora nilssonii</i> |
| Maastricht | Emael              | late Maastrichtian       | Marnebel quarry, Eben Emael      | M186                        | silicified         | fragments of serpulids and bivalves                                                                | Fig. 14      | <i>Xenophora nilssonii</i> |
| Maastricht | Emael              | late Maastrichtian       | Marnebel quarry, Eben Emael      | M187                        | silicified         | fragments of irregular echinoid test, serpulids and decapod crustaceans                            |              | <i>Xenophora nilssonii</i> |
| Maastricht | Emael              | late Maastrichtian       | Marnebel quarry, Eben Emael      | M1436                       | silicified         | vague scars only                                                                                   |              | <i>Xenophora nilssonii</i> |
| Maastricht | Emael              | late Maastrichtian       | ENCI quarry                      | M1533                       | silicified         | fragments of serpulids and irregular echinoid tests                                                |              | <i>Xenophora nilssonii</i> |
| Maastricht | Emael              | late Maastrichtian       | Marnebel quarry, Eben Emael      | M1798                       | silicified         | fragments of serpulids and bivalves                                                                |              | <i>Xenophora nilssonii</i> |
| Maastricht | Emael              | late Maastrichtian       | Marnebel quarry, Eben Emael      | M2077                       | silicified         | scars, mostly of bivalves                                                                          | Fig. 14      | <i>Xenophora nilssonii</i> |
| Maastricht | Emael              | late Maastrichtian       | Marnebel quarry, Eben Emael      | M2094                       | silicified         | fragment of irregular echinoid test                                                                |              | <i>Xenophora nilssonii</i> |
| Maastricht | Emael              | late Maastrichtian       | Marnebel quarry, Eben Emael      | M2158                       | silicified         | fragments of serpulids and bivalves                                                                |              | <i>Xenophora nilssonii</i> |
| Maastricht | Emael              | late Maastrichtian       | Marnebel quarry, Eben Emael      | M2251                       | silicified         | fragments of ostreid bivalves, serpulids, ?decapod crustaceans                                     |              | <i>Xenophora nilssonii</i> |
| Maastricht | Emael              | late Maastrichtian       | Marnebel quarry, Eben Emael      | M2386                       | internal mould     | vague scars only                                                                                   |              | <i>Xenophora nilssonii</i> |
| Maastricht | Emael              | late Maastrichtian       | CBR-Romontbos quarry, Eben Emael | M2538                       | silicified         | vague scars only                                                                                   |              | <i>Xenophora nilssonii</i> |
| Maastricht | Nekum              | late Maastrichtian       | Blom quarry, Berg en Terblijt    | M129                        | silicified         | fragment of bivalve, scars                                                                         |              | <i>Xenophora nilssonii</i> |
| Maastricht | Nekum              | late Maastrichtian       | Blom quarry, Berg en Terblijt    | M130                        | silicified         | fragments of bivalves and irregular echinoid test, cyclostome bryozoan                             |              | <i>Xenophora nilssonii</i> |
| Maastricht | Nekum              | late Maastrichtian       | Blom quarry, Berg en Terblijt    | M308                        | silicified         | fragments of serpulids and ostreid bivalves                                                        |              | <i>Xenophora nilssonii</i> |
| Maastricht | Nekum              | late Maastrichtian       | Blom quarry, Berg en Terblijt    | M476                        | ext + int moulds   | fragments of irregular echinoid test, bivalves and serpulids                                       |              | <i>Xenophora nilssonii</i> |
| Maastricht | Nekum              | late Maastrichtian       | Blom quarry, Berg en Terblijt    | M545                        | external mould     | fragments of irregular echinoid test                                                               |              | <i>Xenophora nilssonii</i> |
| Maastricht | Nekum              | late Maastrichtian       | Blom quarry, Berg en Terblijt    | M609                        | ext + int moulds   | fragments of irregular echinoid test, ostreid bivalves and serpulids                               |              | <i>Xenophora nilssonii</i> |
| Maastricht | Nekum              | late Maastrichtian       | Blom quarry, Berg en Terblijt    | M610                        | ext + int moulds   | fragments of echinoid test, bivalves and serpulids                                                 | Fig. 12      | <i>Xenophora nilssonii</i> |
| Maastricht | Nekum              | late Maastrichtian       | Blom quarry, Berg en Terblijt    | M611                        | ext mould          | fragments of echinoid test, pectinoid bivalves, single gastropod                                   |              | <i>Xenophora nilssonii</i> |
| Maastricht | Nekum              | late Maastrichtian       | Blom quarry, Berg en Terblijt    | M1200                       | ext + int moulds   | fragments of ostreid, ?cardiid and veneroid bivalves                                               | Fig. 13      | <i>Xenophora nilssonii</i> |
| Maastricht | Nekum              | late Maastrichtian       | Blom quarry, Berg en Terblijt    | M1473                       | ext + int moulds   | fragments of decapod crustaceans, single turritellid gastropod                                     |              | <i>Xenophora nilssonii</i> |
| Maastricht | Nekum              | late Maastrichtian       | ENCI quarry                      | M1705                       | ext + int moulds   | fragments of bivalves and serpulids                                                                |              | <i>Xenophora nilssonii</i> |
| Maastricht | Nekum              | late Maastrichtian       | Blom quarry, Berg en Terblijt    | M1753                       | ext + int moulds   | fragments of irregular echinoid test, astarid bivalves and cheilostome bryozoans, single gastropod |              | <i>Xenophora nilssonii</i> |
| Maastricht | Nekum              | late Maastrichtian       | t Rooth quarry, Bemelen          | M1969                       | ext mould          | fragments of irregular echinoid test and bivalves                                                  |              | <i>Xenophora nilssonii</i> |

Table 1. Continued

| Formation  | Member          | Age                  | Locality                                  | Registration number (MHMM-) | Preservation style | Attachments                                                                                   | Illustration                          | Taxon                      |
|------------|-----------------|----------------------|-------------------------------------------|-----------------------------|--------------------|-----------------------------------------------------------------------------------------------|---------------------------------------|----------------------------|
| Maastricht | Nekum           | late Maastrichtian   | Marnebel quarry, Eben Emael               | M1986                       | ext + int moulds   | fragments of irregular echinoid test, bivalves and serpulids                                  |                                       | <i>Xenophora nilssonii</i> |
| Maastricht | Nekum           | late Maastrichtian   | CBR-Romonbos quarry, Eben Emael           | M2940                       | silicified         | fragments of bivalves, serpulids and cheilostome bryozoans                                    |                                       | <i>Xenophora nilssonii</i> |
| Maastricht | Nekum           | late Maastrichtian   | CBR-Romonbos quarry, Eben Emael           | M3347                       | silicified         | fragments of astarid bivalves and serpulids                                                   |                                       | <i>Xenophora nilssonii</i> |
| Maastricht | Nekum           | late Maastrichtian   | ENCI quarry                               | JJ 15993                    | ext and int moulds | fragments of serpulids, astarid bivalve, irregular echinoid test                              | Fig. 16                               | <i>Xenophora nilssonii</i> |
| Maastricht | Nekum           | late Maastrichtian   | ENCI quarry                               | JJ 15832                    | ext + int moulds   | fragments of bivalves and irregular echinoid test, cyclostome bryozoan                        | Fig. 17                               | <i>Xenophora nilssonii</i> |
| Maastricht | Nekum           | late Maastrichtian   | ENCI quarry                               | JJ 14685                    | ext + int moulds   | fragments of bivalves and irregular echinoid test                                             | Fig. 18                               | <i>Xenophora nilssonii</i> |
| Maastricht | Meerssen        | late Maastrichtian   | Blom quarry, Berg en Terblijt             | M595                        | ext + int moulds   | fragments of irregular echinoid test, bivalves, cheilostome bryozoan; single gastropod        | Fig. 11                               | <i>Xenophora nilssonii</i> |
| Maastricht | Meerssen        | late Maastrichtian   | Ankerpoort-Curfs, Geulhem                 | M2967                       | ext + int moulds   | fragments of irregular echinoid test and veneroid bivalves                                    |                                       | <i>Xenophora nilssonii</i> |
| Maastricht | Meerssen        | late Maastrichtian   | Ankerpoort-Curfs quarry, Geulhem          | M3345                       |                    | fragments of irregular echinoid test and pectinoid bivalves                                   |                                       | <i>Xenophora nilssonii</i> |
| Maastricht | Meerssen        | latest Maastrichtian | Ankerpoort-Curfs quarry, Geulhem          | JJ 13048                    | internal mould     | scars only                                                                                    |                                       | <i>Xenophora nilssonii</i> |
| Maastricht | Meerssen, IVf-7 | early Danian         | Ankerpoort-Curfs quarry, Berg en Terblijt | M1715                       | ext + int moulds   | fragments of cheilostome (lunuliform) bryozoans, arid and veneroid bivalves and echinoid test | Fig. 8                                | <i>Xenophora</i> sp. 1     |
| Maastricht | Meerssen, IVf-7 | early Danian         | Ankerpoort-Curfs quarry, Berg en Terblijt | M1723                       | ext mould          | fragment of bivalves                                                                          | Fig. 8                                | <i>Xenophora</i> sp. 1     |
| Maastricht | Meerssen, IVf-7 | early Danian         | Ankerpoort-Curfs quarry, Berg en Terblijt | M1730                       | ext + int moulds   | fragments of irregular echinoid test, ostreid bivalves and ?gastropods                        |                                       | <i>Xenophora</i> sp. 1     |
| Maastricht | Meerssen, IVf-7 | early Danian         | Ankerpoort-Curfs quarry, Berg en Terblijt | M1924                       | ext + int moulds   | fragments of cheilostome bryozoans, nuculanid bivalves and echinoid test; single gastropod    | Fig. 9                                | <i>Xenophora</i> sp. 1     |
| Maastricht | Meerssen, IVf-7 | early Danian         | Ankerpoort-Curfs quarry, Berg en Terblijt | M1925                       | ext + int moulds   | fragments of irregular echinoid test, cheilostome bryozoans, bivalves and ?serpulid           |                                       | <i>Xenophora</i> sp. 1     |
| Maastricht | Meerssen, IVf-7 | early Danian         | Ankerpoort-Curfs quarry, Berg en Terblijt | M2280                       | ext + int moulds   | fragments of echinoid test, cheilostome bryozoans, ostreid and pectinoid bivalves             | Fig. 10                               | <i>Xenophora</i> sp. 1     |
| Maastricht | Meerssen, IVf-7 | early Danian         | Ankerpoort-Curfs quarry, Berg en Terblijt | M3058                       | ext + int moulds   | fragments of irregular echinoid test, cheilostome bryozoans and arid bivalves                 |                                       | <i>Xenophora</i> sp. 1     |
| Maastricht | Meerssen, IVf-7 | early Danian         | Ankerpoort-Curfs quarry, Berg en Terblijt | M3059                       | ext + int moulds   | fragments of irregular echinoid test, cheilostome bryozoans and bivalves                      |                                       | <i>Xenophora</i> sp. 1     |
| Maastricht | Meerssen, IVf-7 | early Danian         | Ankerpoort-Curfs quarry, Geulhem          | 2002 025                    | ext + int moulds   | fragments of bivalves and irregular echinoid test                                             |                                       | <i>Xenophora</i> sp. 1     |
| Maastricht | Meerssen, IVf-7 | early Danian         | Ankerpoort-Curfs quarry, Geulhem          | 2002 060                    | ext + int moulds   | fragments of bivalves and irregular echinoid test                                             |                                       | <i>Xenophora</i> sp. 1     |
| Maastricht | Meerssen, IVf-7 | early Danian         | Ankerpoort-Curfs quarry, Geulhem          | 2002 078                    | ext + int moulds   | fragments of bivalves and irregular echinoid test                                             |                                       | <i>Xenophora</i> sp. 1     |
| Maastricht | Meerssen, IVf-7 | early Danian         | Ankerpoort-Curfs quarry, Geulhem          | 2002 087                    | ext + int moulds   | fragments of bivalves and irregular echinoid test                                             |                                       | <i>Xenophora</i> sp. 1     |
| Maastricht | Meerssen, IVf-7 | early Danian         | Ankerpoort-Curfs quarry, Geulhem          | 2002 091                    | ext + int moulds   | fragments of bivalves and irregular echinoid test                                             |                                       | <i>Xenophora</i> sp. 1     |
| Maastricht | Meerssen, IVf-7 | early Danian         | Ankerpoort-Curfs quarry, Geulhem          | 2002 099                    | ext + int moulds   | fragments of bivalves and irregular echinoid test                                             |                                       | <i>Xenophora</i> sp. 1     |
| Maastricht | Meerssen, IVf-7 | early Danian         | Ankerpoort-Curfs quarry, Geulhem          | 2002 103                    | ext + int moulds   | fragments of bivalves and irregular echinoid test                                             |                                       | <i>Xenophora</i> sp. 1     |
| Maastricht | Meerssen, IVf-7 | early Danian         | Ankerpoort-Curfs quarry, Geulhem          | 2002 104                    | internal moulds    | fragments of bivalves and irregular echinoid test                                             |                                       | <i>Xenophora</i> sp. 1     |
| Maastricht | Meerssen, IVf-7 | early Danian         | Ankerpoort-Curfs quarry, Geulhem          | 2002 128                    | ext + int moulds   | fragments of bivalves and irregular echinoid test                                             | Jagt <i>et al.</i> , 2013, fig. 7-1/O | <i>Xenophora</i> sp. 1     |
| Maastricht | Meerssen, IVf-7 | early Danian         | Ankerpoort-Curfs quarry, Geulhem          | 2002 131                    | ext + int moulds   | fragments of bivalves and irregular echinoid test                                             |                                       | <i>Xenophora</i> sp. 1     |
| Maastricht | Meerssen, IVf-7 | early Danian         | Ankerpoort-Curfs quarry, Geulhem          | 2002 189                    | ext + int moulds   | fragments of bivalves and irregular echinoid test                                             |                                       | <i>Xenophora</i> sp. 1     |
| Maastricht | Meerssen, IVf-7 | early Danian         | Ankerpoort-Curfs quarry, Geulhem          | 2002 193                    | ext + int moulds   | fragments of bivalves and irregular echinoid test                                             |                                       | <i>Xenophora</i> sp. 1     |
| Maastricht | Meerssen, IVf-7 | early Danian         | Ankerpoort-Curfs quarry, Geulhem          | 2002 197                    | ext + int moulds   | fragments of bivalves and irregular echinoid test                                             |                                       | <i>Xenophora</i> sp. 1     |
| Maastricht | Meerssen, IVf-7 | early Danian         | Ankerpoort-Curfs quarry, Geulhem          | 2002 247                    | ext + int moulds   | fragments of bivalves and irregular echinoid test                                             |                                       | <i>Xenophora</i> sp. 1     |

Table 1. Continued

| Formation  | Member          | Age                | Locality                         | Registration number (MHMM-) | Preservation style | Attachments                                       | Illustration                        | Taxon                     |
|------------|-----------------|--------------------|----------------------------------|-----------------------------|--------------------|---------------------------------------------------|-------------------------------------|---------------------------|
| Maastricht | Meerssen, IVf-7 | early Danian       | Ankerpoort-Curfs quarry, Geulhem | 2002 052                    | ext + int moulds   | fragments of bivalves and irregular echinoid test | Jagt <i>et al.</i> 2013, fig. 7-1/N | <i>Xenophora</i> sp. 1    |
| Maastricht | Meerssen, IVf-7 | early Danian       | Ankerpoort-Curfs quarry, Geulhem | 2002 266                    | ext + int moulds   | fragments of bivalves and irregular echinoid test |                                     | <i>Xenophora</i> sp. 1    |
| Maastricht | Meerssen, IVf-7 | early Danian       | Ankerpoort-Curfs quarry, Geulhem | 2002 286                    | external mould     | fragments of bivalves and two gastropods          |                                     | <i>Xenophora</i> sp. 1    |
| Maastricht | Meerssen, IVf-7 | early Danian       | Ankerpoort-Curfs quarry, Geulhem | 2002 317                    | ext + int moulds   | fragments of bivalves and irregular echinoid test |                                     | <i>Xenophora</i> sp. 1    |
| Maastricht | Meerssen, IVf-7 | early Danian       | Ankerpoort-Curfs quarry, Geulhem | 2003 143                    | ext + int moulds   | fragments of bivalves and irregular echinoid test |                                     | <i>Xenophora</i> sp. 1    |
| Maastricht | Meerssen, IVf-7 | early Danian       | Ankerpoort-Curfs quarry, Geulhem | 2003 151                    | ext + int moulds   | fragments of bivalves and irregular echinoid test |                                     | <i>Xenophora</i> sp. 1    |
| Maastricht | Meerssen, IVf-7 | early Danian       | Ankerpoort-Curfs quarry, Geulhem | 2003 155                    | ext + int moulds   | fragments of bivalves and irregular echinoid test |                                     | <i>Xenophora</i> sp. 1    |
| Maastricht | Meerssen, IVf-7 | early Danian       | Ankerpoort-Curfs quarry, Geulhem | 2004 122                    | ext + int moulds   | fragments of bivalves and irregular echinoid test |                                     | <i>Xenophora</i> sp. 1    |
| Maastricht | Meerssen, IVf-7 | early Danian       | Ankerpoort-Curfs quarry, Geulhem | 2004 124                    | ext + int moulds   | fragments of bivalves and irregular echinoid test |                                     | <i>Xenophora</i> sp. 1    |
| Maastricht | Meerssen, IVf-7 | early Danian       | Ankerpoort-Curfs quarry, Geulhem | 2004 137                    | ext + int moulds   | fragments of bivalves and irregular echinoid test |                                     | <i>Xenophora</i> sp. 1    |
| Maastricht | Meerssen, IVf-7 | early Danian       | Ankerpoort-Curfs quarry, Geulhem | 2004 138                    | ext + int moulds   | fragments of bivalves and irregular echinoid test |                                     | <i>Xenophora</i> sp. 1    |
| Maastricht | Meerssen, IVf-7 | early Danian       | Ankerpoort-Curfs quarry, Geulhem | JJ 14030                    | external mould     | base                                              |                                     | <i>Xenophora</i> sp. 1    |
| Maastricht | Meerssen, IVf-7 | early Danian       | Ankerpoort-Curfs quarry, Geulhem | KUL2006 001                 | internal moulds    | fragments of bivalves and irregular echinoid test |                                     | <i>Xenophora</i> sp. 1    |
| Maastricht | Meerssen, IVf-7 | late Maastrichtian | Ankerpoort-Curfs quarry, Geulhem | KK 16-                      | internal mould     | scars only                                        |                                     | <i>Xenophora nilssoni</i> |
| Kunrade    |                 |                    | Kunrade area                     | Renkens-Zijlstra            |                    |                                                   | Fig. 15                             |                           |

late Maastrichtian age. The sections exposed in the Haccourt-Lixhe area (Kreco [formerly CPL SA] and CBR-Lixhe quarries) are referred to the uppermost part of interval 5 and the entire interval 6 (Keutgen *et al.* 2010). The prime index fossils in this part of the succession are scaphitid ammonites, belemnite shells and inoceramid bivalves, including 'tegulated' species (Jagt *et al.* 1999; Walaszczyk *et al.* 2010). Overall, intervals 0–6 of the Vijlen Member correlate with the *obtusa* to *tegulatus/junior* zones of the North German subdivision (Niebuhr 2006). Xenophorid material is currently known only from interval 6 of this member and is here assigned to *X. nilssoni* (Table 1).

*Maastricht Formation, Gronsveld to Meerssen members* (Fig. 4). The Gronsveld Member comprises poorly indurated, fine- to coarse-grained biocalcarenes, with two horizons (St. Pieter and ENCI) clearly distinguishable in the basal portion, in particular at the former ENCI-Heidelberg Cement Group quarry. Storm-generated echinoderm Lagerstätten have been described from this level, as have silicified macrofaunal elements in proximity of crumbly flint bodies with a dark-coloured core. These faunules comprise scaphitid and baculitid ammonites, serpulid polychaetes, a sepiid, various species of gastropods and bivalves, as well as teleost otoliths and sea grass stems and roots (Hewitt & Jagt 1999; Van der Ham *et al.* 2017; Schwarzhans & Jagt 2021). Keutgen (2018) dated the St. Pieter Horizon at 66.7 Ma; Vellekoop *et al.* (2022) noted 66.9 Ma.

The Emael Member is a poorly indurated, fine-to coarse-grained, homogeneous biocalcarene, typically with large, regular flat and pipe-shaped flint bodies near the base. For the lower part of the Maastricht Formation (*i.e.* the Valkenburg, Gronsveld, Schiepersberg and Emael members), Villain (1977) assumed regional currents constant enough to transport sediment particles over the entire platform, at shallow palaeodepths of 20 to 40 metres, without oceanic influence and a relatively firm sea floor and clear waters. On microfossil evidence, Liebau (1978) and Sprechmann (1981) characterised this setting as fully marine (middle sublittoral, lagoon-like with near flat coastline and low hinterland), invariably above wave base in the euphotic zone, under subtropical temperatures, with seagrass communities and rich thallopiphyte assemblages, inclusive of washed-in terrestrial plants. The Lava Horizon within the upper Emael Member was dated at 66.5 Ma by Keutgen (2018). We follow P.J. Felder & Bless (1989) in considering the 'Kunrade Chalk' (now Kunrade Formation) to be the nearshore lateral equivalent of the Lanaye Member (uppermost Gulpen Formation) up to, at least, the base of the Emael Member (Maastricht Formation), to the west of the River Maas (Meuse; Fig. 3).

The Nekum Member comprises a poorly indurated

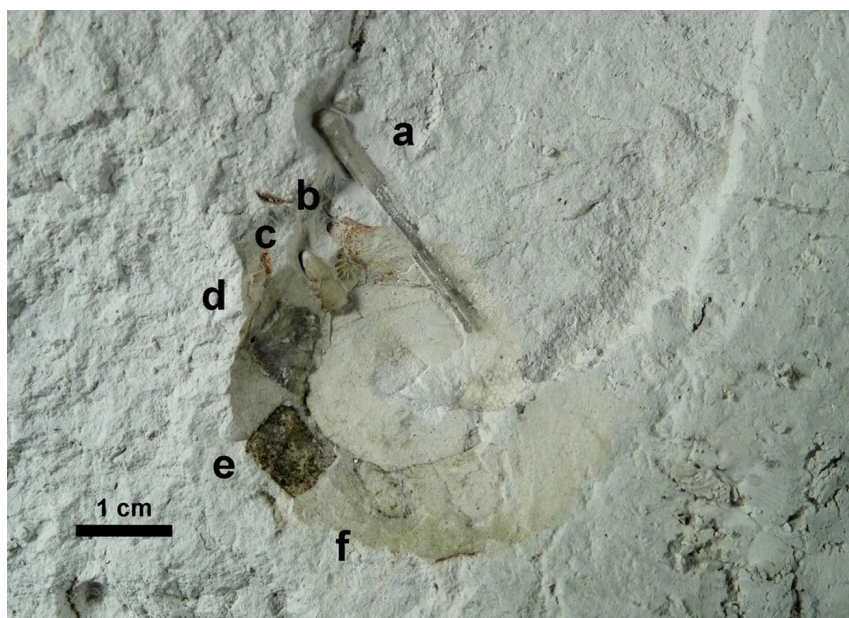
ed (except for a strongly cemented level above the Laumont Horizon, dated at 66.35 Ma by Vellekoop *et al.* (2022), coarse-grained, homogeneous limestone. Both the indurated uppermost portion of the Emael Member and the overlying 20 to 30 centimetres of the Nekum Member are replete with internal and external moulds of molluscs (bivalves, gastropods, scaphopods, nautiloids and heteromorph and non-heteromorph ammonites), as well as two species of serpulid polychaetes. These levels may be considered current-winnowed, time-averaged lumachelle or coquina beds. Locally coarse-grained fossil hash lenses and beds occur in the middle and upper part of this member, while the top corresponds to an omission surface (hardground), the Caster Horizon, dated at 66.2 Ma by Keutgen (2018) and at 66.13 Ma by Vellekoop *et al.* (2022).

The Meerssen Member consists of poorly indurated, coarse- to very coarse-grained limestones with clearly developed hardgrounds and fossil hash lay-

ers, with bryozoan remains and large benthic foraminifera. Liebau (1978) characterised these strata as high-energy deposits, with a marked production of carbonate detritus leading to the establishment of a broad, shallow, well-lit, warm carbonate platform with rich phytal association, and water temperatures of 20 to 25°C, allowing the growth of scleractinian corals and hippuritid/radiolitid rudists. The uppermost portion of subunit IVf-6 of the Meerssen Member is replete with external and internal moulds of molluscs, testifying to current winnowing leading to chaotic concentrations of empty shells (Vellekoop *et al.* 2020). The top of IVf-6 equates with the Bergen Terblijt Horizon, which coincides with the Cretaceous–Paleogene (K/Pg) boundary. Xenophorid material, both silicified and in external/internal mould preservation, is known, with the largest individuals recorded from the basal Nekum Member. For the time being, all specimens, except those from Meerssen Member subunit IVf-7 (see below), are here as-

**Table 2.** Late Cretaceous xenophorid records on the basis of literature sources, and indications of the nature of attached foreign objects.

| Species name used                                       | Reference                               | Country           | Attachments <i>in situ</i>                                                 |
|---------------------------------------------------------|-----------------------------------------|-------------------|----------------------------------------------------------------------------|
| <b>Maastrichtian</b>                                    |                                         |                   |                                                                            |
| <i>Xenophora nilssoni</i> Pacaud, 2016                  | This study                              | Denmark           | Gastropods, bivalves, echinoids                                            |
| <i>Xenophora nilssoni</i> Pacaud, 2016                  | This study                              | Netherlands       | Gastropods, bivalves, echinoids, serpulids, decapod crustaceans, bryozoans |
| <i>Xenophora onusta</i> (Nilsson, 1827)                 | Blank (1974)                            | Ukraine           |                                                                            |
| <i>Xenophora onusta</i> (Nilsson, 1827)                 | Bakayeva (2011)                         | Ukraine           |                                                                            |
| <i>Xenophora onusta</i> (Nilsson, 1827)                 | Kutscher & Kullessa (2010)              | Germany           | Bivalves, echinoids                                                        |
| <i>Xenophora onusta</i> (Nilsson, 1827)                 | Kaunhowen (1898)                        | Netherlands       |                                                                            |
| <i>Xenophora onusta</i> (nobis)                         | Binkhorst van den Binkhorst (1861-1862) | Netherlands       |                                                                            |
| <i>Xenophora onusta</i> (Nilsson, 1827)                 | Abdel-Gawad (1986)                      | Poland            |                                                                            |
| <i>Xenophora onusta</i> (Nilsson, 1827)                 | Tzankov & Motekova (1981)               | Bulgaria          |                                                                            |
| <i>Xenophora hermax</i> Squires & Saul, 2001            | Squires & Saul (2001)                   | USA               |                                                                            |
| <i>Xenophora leprosa</i> (Morton, 1834)                 | Richards (1962)                         | USA               |                                                                            |
| <i>Acanthoxenophora sinuosa</i> Perrilliat & Vega, 2001 | Kiel & Perrilliat (2001)                | Mexico            | Gastropod                                                                  |
| <i>Xenophora vasconcellosi</i> Oliveira, 1957           | Ponder (1983)                           | Brazil            |                                                                            |
| <i>Xenophora</i> sp.                                    | Darragh & Kendrick (1994)               | Australia         | Bivalves                                                                   |
| <i>Xenophora trangahinsis</i> Basse, 1931               | Ponder (1983)                           | Malagasy Republic |                                                                            |
| <i>Xenophora madagascariensis</i> Collignon, 1951       | Ponder (1983)                           | Malagasy Republic |                                                                            |
| <b>Campanian</b>                                        |                                         |                   |                                                                            |
| <i>Trochus onustus</i> Nilsson, 1827                    | Nilsson (1827)                          | Sweden            |                                                                            |
| <i>Xenophora nilssoni</i> Pacaud, 2016                  | This study                              | Netherlands       | Bivalves, echinoids                                                        |
| <i>Trochus onustus</i> Nilsson, 1827                    | Goldfuss (1841, in 1826-1844)           | Germany           |                                                                            |
| <i>Xenophora onusta</i> Nilsson sp.                     | Andert (1934)                           | Czech Republic    |                                                                            |
| <i>Xenophora onusta</i> (Nilsson, 1827)                 | Arnold (1968)                           | Germany           |                                                                            |
| <i>Xenophora onusta</i> (Nilsson, 1827)                 | O. Schneider (2007)                     | Germany           |                                                                            |
| <i>Xenophora onusta</i> (Nilsson, 1827)                 | Kollmann & Odin (2001)                  | France            |                                                                            |
| <i>Endoptygma umbilicata</i> Tuomey, 1854               | Richards (1962)                         | USA               |                                                                            |
| <i>Xenophora carnatica</i> Stoliczka, 1868              | Stoliczka (1868)                        | India             |                                                                            |
| <i>Xenophora leprosa</i> (Morton, 1834)                 | Dockery (1993)                          | USA               | Gastropods, bivalves                                                       |
| <i>Xenophora canaliculata</i> (d'Orbigny, 1842)         | Ponder (1983)                           | France            |                                                                            |
| <i>Xenophora willisi</i> Webster, 1983                  | Webster (1983)                          | Mexico            |                                                                            |
| <b>Coniacian</b>                                        |                                         |                   |                                                                            |
| <i>Xenophora onusta</i> Nilsson sp.                     | Andert (1934)                           | Czech Republic    |                                                                            |
| <b>Turonian</b>                                         |                                         |                   |                                                                            |
| <i>Xenophora grasi</i> Roman & Mazeran, 1920            | Ponder (1983)                           | France            |                                                                            |
| <i>Xenophora simpsoni</i> Stanton, 1894                 | Perrilliat & Vega (2001)                | USA               |                                                                            |
| <b>Cenomanian</b>                                       |                                         |                   |                                                                            |
| <i>Xenophora</i> sp.                                    | Stephenson (1952)                       | USA               |                                                                            |



**Fig. 6.** *Xenophora nilssoni* Pacaud, 2016, upper lower to lower upper Maastrichtian, Hillerslev (northern Jylland, Denmark). Potential Danekræ PD66 (currently under evaluation by the Danekræ committee), with attached foreign objects: cidaroid spine (a), bryozoan? (b), sponge (c), fragment of bivalve (d), indeterminate fragment (e) and indeterminate gastropod (f).

signed to *X. nilssoni* (Table 1).

On palynological and molluscan evidence, the entire Maastricht Formation has been dated as late Maastrichtian, with the exception of the highest subunit (IVf-7) of the Meerssen Member, between the Bergen Terblijt and Vroenhoven horizons (Fig. 4), which is of earliest Danian age (Jagt & Jagt-Yazykova 2012; Jagt *et al.* 2013; Vellekoop *et al.* 2020). Principal index macrofossils of correlative value include various heteromorph and non-heteromorph ammonites, belemnite coleoids and ‘tegulated’ inoceramid bivalves (Keutgen *et al.* 2017; Jagt & Jagt-Yazykova 2018, 2019). These allow correlations with both Boreal and Tethyan sections in northern/north-eastern and southern Europe, respectively. Smit & Brinkhuis

(1996) integrated sedimentological, biostratigraphical, geochemical and palaeomagnetic analyses of the marginal-marine boundary section in the Geulhemmerberg underground quarries, close to Geulhem (Fig. 3). The base of subunit IVf-7 of the Meerssen Member is an undulating hardground (palaeorelief), with depressions up to 1.5 m deep, in heavily bioturbated calcarenites of subunit IVf-6, marking a brief period of non-deposition. Above this, initially coarse-grained sediments filling the depressions of palaeorelief represent a thinning-up and fining-up sequence, culminating in the 10–15 cm thick E clay. This would correspond to the Fiskeler Member (Rødvig Member; Surlyk *et al.* 2006).

On the basis of microfossils, in particular dinoflagellates and benthic foraminifera, and to a lesser de-



**Fig. 7.** *Xenophora nilssoni* Pacaud, 2016, with attached ?fusiform gastropod; NHMM M2146, CBR-Lixhe quarry, Lixhe (Liège, north-east Belgium), Gulpen Formation, Vijlen Member, interval 6 (upper lower Maastrichtian). Scale bar equals 10 mm.



**Fig. 8.** *Xenophora* sp. 1, with pieces of irregular echinoid test, cheilostome bryozoans and bivalves attached, former Ankerpoort-Curfs quarry, Geulhem (A: NHMM M1715) and veneroid and arcid bivalves (B: NHMM M1723), Maastricht Formation, Meerssen Member, subunit IVf-7 (lowermost Danian). Scale bars equal 10 mm.

gree sporomorphs, the K/Pg boundary equates with the Berg en Terblijt Horizon and not, as traditionally thought, with the overlying Vroenhoven Horizon, which separates the Maastricht and Houthem formations and would seem to be correlatable with the top of the Cerithium Limestone Member (Rødvig Formation) in eastern Denmark (Surlyk *et al.* 2006). Just below the Berg en Terblijt Horizon, very low, yet relatively slightly elevated Ir-contents have been observed. According to Smit & Brinkhuis (1996), the time span between the IVf-6 and IVf-7 strata, separated by the Berg en Terblijt Horizon, involved deposition of uppermost Maastrichtian calcarenites, followed by K/Pg storm or hypercane-related ‘washing’ of the palaeoshelf and erosion of uppermost Maastrichtian and lowermost Danian deposits, inclusive of an Ir-bearing layer. The xenophorid ‘population’ (some 50 specimens) from subunit IVf-7 of the Meerssen Member at Geulhem comprises merely small-sized specimens, here referred to as *Xenophora* sp. 1 (Table 1).

## Material and methods

### Danish material

Currently, the two specimens of xenophorid from Hillerslev quarry are the only ones on record from the white chalk facies in Denmark. One of these has

been declared Danekræ, namely DK 1076 (Fig. 5) and is housed in the collections of the Natural History Museum Denmark at Copenhagen. A second specimen, collected in 2021 (Fig. 6), awaits formal Danekræ evaluation and numbering.

### Dutch–Belgian material

All material was collected over recent years either by splitting rocks, taken directly from quarry faces or from scree slopes after quarry blasting, or by wet sieving of matrix samples (up to several kilogrammes in weight). Only from subunit IVf-7 of the Meerssen Member have xenophorids been recovered that may be considered preserved *in situ*. This is indicated clearly by the fact this unit has also yielded co-occurring articulated bivalves, those preserved in butterfly position, as well as those documented undoubtedly *in situ*, such as poromyids and clavagellids (Jagt *et al.* 2013). Other occurrences reflect deposition in current-winnowed levels, resulting in coquina- or lumachelle-like levels, with rather chaotic structures and no real size sorting.

Wet sieving was favoured for samples from ‘early’ flint nodules in the Gronsveld and Emael members; only tap water was used.

**Institutional abbreviations.** NHMD, Natural History Museum Denmark, Copenhagen (with DK, Danekræ material); NHMM, Natuurhistorisch Museum Maas-



**Fig. 9.** *Xenophora* sp. 1, with nuculanid and indeterminate gastropod attached, former Ankerpoort-Curfs quarry, Geulhem; NHMM M1924), Maastricht Formation, Meerssen Member, subunit IVf-7 (lowermost Danian). Scale bar equals 10 mm



**Fig. 10.** *Xenophora* sp. 1, with fragments of irregular echinoid test, bryozoans and bivalves attached, former Ankerpoort-Curfs quarry, Geulhem; NHMM M2280, Maastricht Formation, Meerssen Member, subunit IVf-7 (lowermost Danian). Scale bar equals 10 mm.

tricht, Maastricht, the Netherlands (with several prefixes: JJ – J.W.M. Jagt Collection; KUL – Katholieke Universiteit Leuven Collection; see Vellekoop *et al.* (2020); M – P.H.M. van Knippenberg Collection; RZ – S. Renkens and J.J.P. Zijlstra Collection).

## Systematic part

**Remarks.** The higher-level classification adopted here follows Ponder (1983), Bandel (2007) and Irwin *et al.* (2024).

Superfamily Stromboidea Rafinesque, 1815

Family Xenophoridae Troschel, 1852

**Genus *Xenophora* Fischer von Waldheim, 1807**

Type species. *Xenophora laevigata* Fischer von Waldheim, 1807 (= *Trochus conchyliophora* von Born, 1780) (ICZN Opinion 715, 1964).

***Xenophora nilssoni* Pacaud, 2016**

Figs. 5–7, 11–19

Selected synonyms (exclusively Danish, Belgian and Dutch records)

1851 *Trochus onustus* Nilsson; Müller, p. 44.

1860 *Xenophora onusta* Bosquet †; Bosquet, p. 376.

1861 *Xenophora onusta*, Nobis; Binkhorst van den Binkhorst, p. 38, pl. 3, fig. 14a–c.

1868 *Xenophora onusta*, Nilsson; Bosquet, p. 8.

1888 *Xenophora onusta* Nilss. sp.; Holzapfel, p. 152, pl. 14, fig. 28.

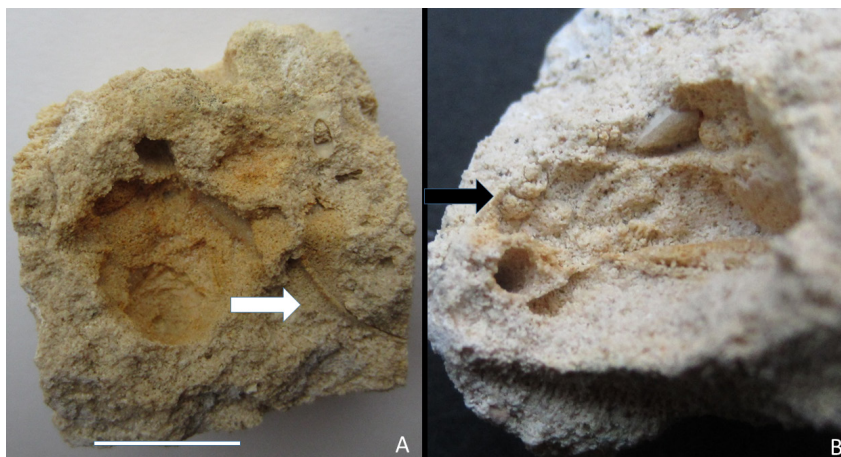
1898 *Xenophora onusta* Nilsson sp.; Kaunhowen, p. 50, pl. 3, fig. 15.

1943 *Xenophora onusta* (Nilsson); Van der Weijden, p. 107.

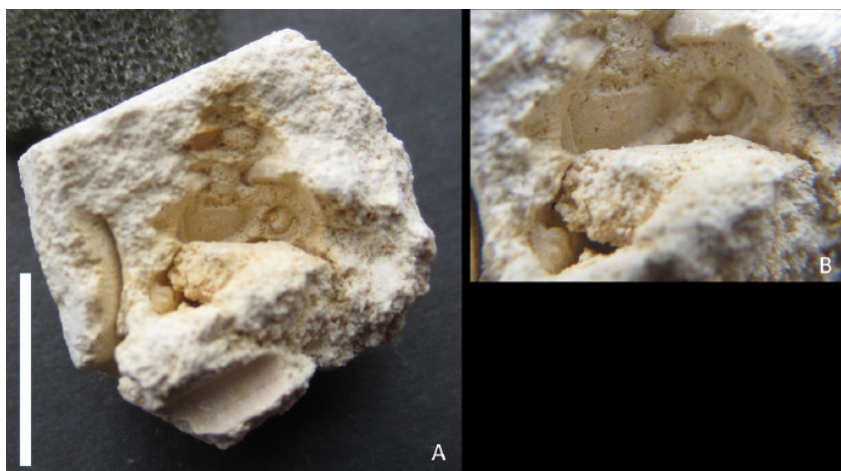
\*2016 *Xenophora nilssoni* Pacaud, p. 50, fig. 5.

**Material.** See Tables 1 and 2.

**Description of Danish specimens.** DK 1076 (Fig. 5A–C): fairly large, low conical, width 85 mm and estimated height 80 mm; apical angle c. 85°; specimen consisting of two parts, presumably representing predator- or scavenger-cut shell; base, with lobed marginal flange and indistinct curved growth lines, lying with concave side up. Whorls medium convex, separated by distinct suture; low and with irregular surface. Aper-



**Fig. 11.** *Xenophora nilssoni* Pacaud, 2016, with gastropod spire attached (black arrow: turritellid or aporrhaid?), NHMM M595, former Blom quarry, Berg en Terblijt, Maastricht Formation, Meerssen Member (IVf-1 to -6). Scale bar equals 10 mm. The white arrow in A points to part of an aporrhaid digitation, in close proximity, but not attached to the xenophorid shell.



**Fig. 12.** *Xenophora nilssoni* Pacaud, 2016, with gastropod spire, as well as fragments of echinoid test and bivalves, NHMM M611, former Blom quarry, Berg en Terblijt, Maastricht Formation, Meerssen Member (IVf-1 to -6). Scale bar equals 10 mm.

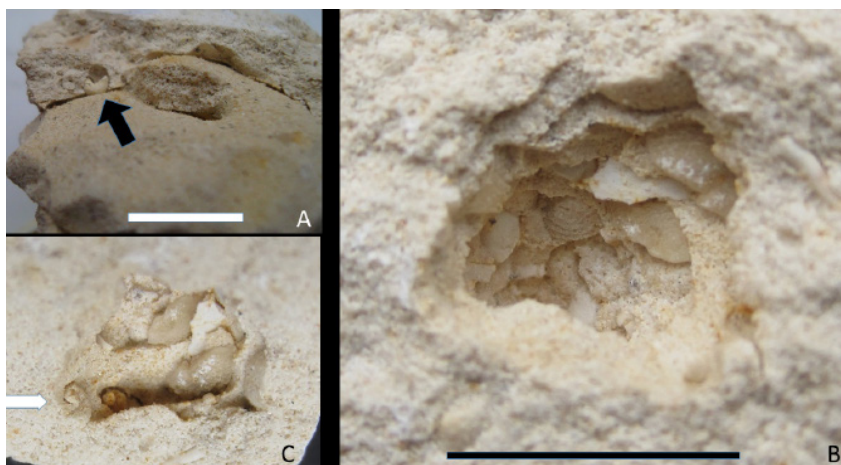
ture not visible; umbilicus apparently absent; some weak spirals on adaxial part of base. Small cheilostome bryozoan colony on base. On visible portions of two last whorls are attached shells, preserved *in situ*. In all, nine gastropods and two bivalves recognised. Identifications of gastropods tentative because of state of preservation.

On base (Fig. 5B) attachments as follows: a juvenile indeterminate gastropod (letter **a**), attached by apex and preserved as composite mould). Indeterminate bivalve with adnate juvenile oyster (letter **b**), with quite prominent ribbing, attached by tip with convex side down. Left valve of smooth pectinid (letter **c**), attached by hinge margin, convex side down. Large (length >30 mm) specimen of *Amaea aliciae* T. Hansen, 2019 (letter **d**), preserved as composite mould, obliquely attached by apex but also reminiscent of '*Cerithium*' *imbricatum* Münster in Goldfuss, 1842 (see Säbele & Krupp 2013). Another gastropod (letter **e**), preserved as external mould and attached by periphery of two last whorls, tentatively assigned to *Serrifusus binkhorsti* (Kaunhowen, 1898), based on shell outline, similar position of spirals and rather similar axial ribs. External impression (letter **f**) of gastropod,

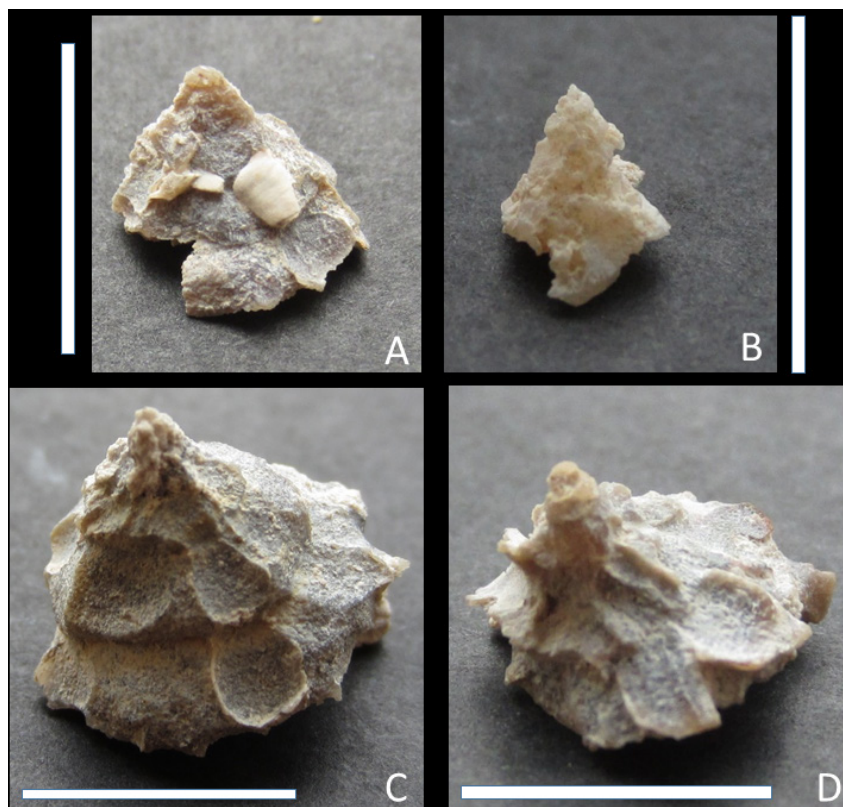
obliquely attached by apex and with sculpture similar to that of *Pseudotoma danica* T. Hansen, 2019.

Apex (Fig. 5C) with attached molluscs, as follows: poorly preserved external gastropod mould (letter **a**), tentatively assigned to *Dolicholaturus* sp., attached by periphery of all whorls. Another poorly preserved impression of gastropod attached by apex (letter **b**), tentatively interpreted as volutid based on outline and weak axial ribs, as another poorly preserved possible volutid (letter **c**). A possible fascioliid (letter **d**), preserved as impression and attached by apex, and indeterminate gastropod, attached by periphery of all whorls (letter **e**). Also attached fragment of oyster(?) (letter **f**) and cidaroid spine (letter **h**). A microconch scaphitid, preserved as external mould (letter **g**) is associated, but apparently not attached.

The potential danekræ PD66, currently under evaluation (Fig. 6), is preserved as an impression of apex and seen from below, with attached cidaroid spine (letter **a**), ?bryozoan (letter **b**), sponge (letter **c**), bivalve fragment (letter **d**), indeterminate fragment (letter **e**) and indeterminate gastropod (letter **f**). The specimen awaits formal Danekræ evaluation and numbering.



**Fig. 13.** *Xenophora nilssoni* Pacaud, 2016, with indeterminate gastropod attached, NHMM M1753, former Blom quarry, Berg en Terblijt, Maastricht Formation, Nekum Member (IVe-1/2-2). Scale bar equals 10 mm. **A:** NHMM M1473; **B:** NHMM M1753.



**Fig. 14.** *Xenophora nilssoni* Pacaud, 2016, silicified shells: **A:** NHMM M186A; **B:** NHMM M1509; **C:** NHMM M2077; **D:** NHMM M186C. Marnebel quarry, Eben Emael, Emael Member (**A, C, D**) and Gronsvelt Member, former ENCI quarry, Maastricht (**B**). Scale bars equal 10 mm.

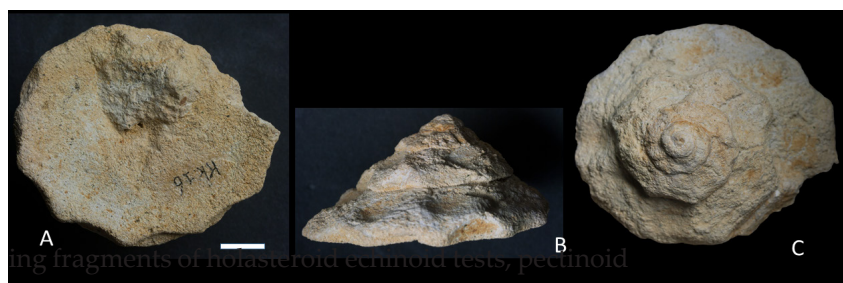
*Description of Dutch and Belgian material.* Shells of small to medium size, ranging from a few millimetres in diameter, to around 50 mm; up to five whorls, but top part of shell preserved only in silicified material. Shell low, trochospiral; whorls flattened, sutures clearly impressed. Base apparently smooth, or with weak, curved spirals. Apical angle 76–100°, in most specimens around 90°. Attached foreign objects including serpulid polychaetes, mostly *Pyrgopolon mosae* (de Montfort, 1808), a common constituent in macrofossil assemblages of the middle and upper portions of the Maastricht Formation (Jäger 2005, 2012), as well as pectinoid, arcid, nuculanid, ?limopoid and ostreid bivalves, plus fragments of irregular echinoid tests (holasteroids; see Jagt 2000).

Single composite mould (NHMM JJ 7301) large sized, low and trochospiral, greatest diameter, as preserved c. 80 mm, apical angle c. 120°, also referred here, for now. Recognisable attached objects includ-

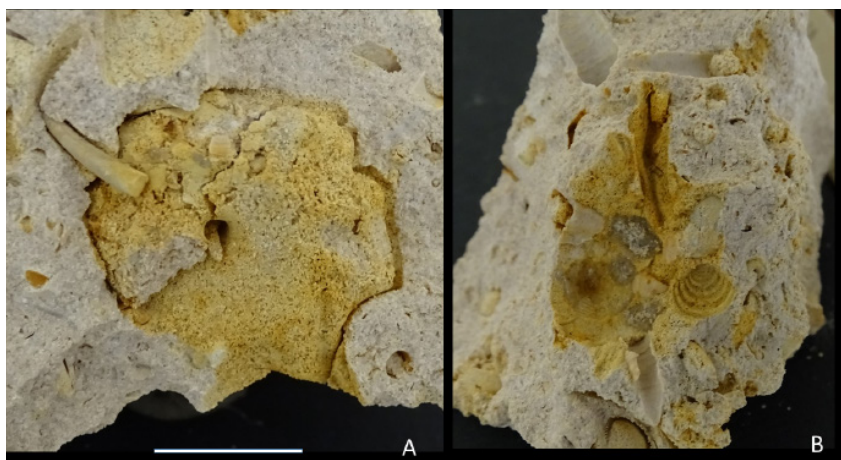
valves and brachiopod shell; close to shell margin on final whorl wrinkled ornament visible in places.

*Discussion.* Binkhorst van den Binkhorst (1861, p. 39) indicated an apical angle of 110° and his illustration of a large-sized internal mould shows curved growth lines on the base and even a furrow close to the umbilicus. Whether or not these features are indeed this clearly developed can only be judged on the basis of the original specimen.

For now, we use the name *Xenophora nilssoni* Pacaud, 2016 for this form, although the absence of shell material in the Maastricht Formation makes it impossible to assess the ornament, if any, of these particular specimens. In silicified specimens (NHMM Van Knippenberg Collection) traces of ornament, comparable to that seen in NHMM JJ 7301, are occasionally seen, both on whorls and on the base of the shell. Janssen (1984, pp. 188–190, pl. 53, fig. 5; pl. 54, fig. 1)



**Fig. 15.** *Xenophora nilssoni* Pacaud, 2016, internal mould, NHMM KK 16 (Renkens-Zijlstra Collection), Kunrade area, Kunrade Formation, upper part. Scale bar equals 10 mm.



**Fig. 16.** *Xenophora nilssoni* Pacaud, 2016, internal and external moulds, NHMM JJ 15993; former ENCI quarry, Maastricht, Maastricht Formation, basal Nekum Member. Attached foreign objects include serpulid polychaetes, a fragmentary ostreid shell, an astartid bivalve and pieces of irregular echinoid test. Scale bar equals 10 mm.

demonstrated that two co-occurring Middle Miocene species, *Xenophora burdigalensis* (de Grateloup, 1847) and *X. deshayesi* (Michelotti, 1847) from the Winterswijk area (eastern Netherlands), could only be distinguished on the basis of shell ornament, in particular on the base.

**Stratigraphical range.** Vaals Formation (Gemmenich Member); Gulpen Formation (Vijlen Member, interval 6), Gronsveld, Emael, Nekum and Meerssen (up to IVf-6) members of the Maastricht Formation and Kunrade Formation in the south-east Netherlands and north-east Belgium; Møns Klint Formation in northern Jylland, Denmark, and elsewhere in Europe (Table 2).

***Xenophora* sp. 1**  
Figs. 8–10

2013 *Xenophora onusta* auct. (? non Nilsson, 1827); Jagt *et al.*, p. 202, fig. 7-1/N, O.

2020 *Xenophora nilssoni*; Vellekoop *et al.*, p. 7, fig. 8L.

**Material.** Around 50 specimens in external and internal mould preservation, all from the Geulhem area, southern Limburg, the Netherlands (NHMM collections; Table 1).

**Description.** Small sized, not exceeding 20 mm in greatest diameter; low, trochospiral. Attached foreign objects include serpulid polychaetes, pectinoid, arcid and ostreid bivalves, plus fragments of irregular echinoid test and cheilostome bryozoans.

**Discussion.** For the time being, this is considered different from ‘populations’ from the Gronsveld, Emael and Nekum members (Maastricht Formation) and the Kunrade Formation, mostly on the basis of smaller size and base with close-set, curved growth lines.

**Stratigraphical range.** Lowermost Paleocene (lower Danian), Maastricht Formation, Meerssen Member, subunit IVf-7.

## Records of Late Cretaceous xenophorids with attached gastropods

In contrast to other attached foreign objects, such as pieces of echinoid test, bivalve shells (entire or partial), serpulid worm tubes and cheilostome bryozoans, xenophorid shells with attached gastropod shells appear to be very rare. In the literature, only a handful of finds from the lower Campanian of the Hannover area (northern Germany; C. Schneider



**Fig. 17.** *Xenophora nilssoni* Pacaud, 2016, partial external and entire internal moulds, NHMM JJ 15832; former ENCI quarry, Maastricht, Maastricht Formation, basal Nekum Member. Merely scars of attached foreign objects left. Scale bar equals 10 mm.



**Fig. 18.** *Xenophora nilssoni* Pacaud, 2016, external and internal moulds, NHMM JJ 14865; former ENCI quarry, Maastricht, Maastricht Formation, basal Nekum Member. Attached foreign objects include larger bivalves (aragonitic) and flat pieces of irregular echinoid test. Scale bar in centimetres and millimetres.

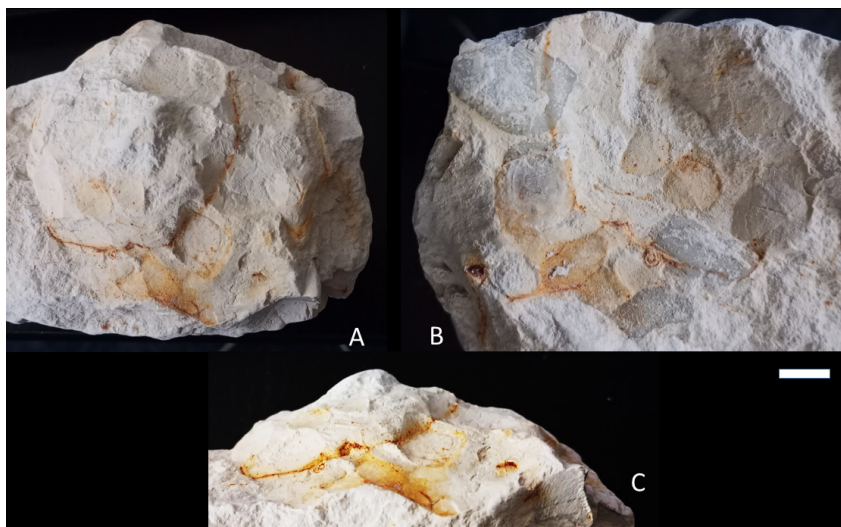
2024), the Campanian of Mississippi, southern USA (Dockery 1993) and the Maastrichtian of Mexico (Kiel & Perrilliat 2001) have been recorded (Table 2).

## Palaeoecological interpretations

Darragh & Kendrick (1994, p. 5, table 3), who recorded comparatively large-sized internal moulds of xenophorids from the upper Maastrichtian Miria Formation in the Carnarvon Basin (north-west Australia), considered *Xenophora* to be an ‘unspecialised

omnivore’ and pointed out that extant xenophorids were cryptic (Ponder 1983), preferring either grazing on fine algae, or microfauna collected from the substrate beneath the widened shell periphery. As far as attached foreign objects on xenophorid shells are concerned, phosphatic particles and inoceramid shell fragments were recorded by Darragh & Kendrick (1994, fig. 6).

Of note in the Meerssen Member, subunit IVf-7, is the fact that the commonest gastropod taxa are aporhaides and xenophorids. Shells of both families are found ‘floating’ in the biocalcarenitic matrix, in con-



**Fig. 19.** *Xenophora nilssoni* Pacaud, 2016, composite mould, NHMM JJ 7301; Kreco (formerly CPL SA) quarry, Haccourt, Vijlen Member, interval 6, base + c. 4.5 m, with echinoid test fragments, a pectinoid bivalve and a brachiopod shell attached. Scale bar equals 10 mm.

trast to material from the underlying subunit IVf-6, and are considered to be preserved *in situ* (see also Jagt *et al.* 2013; Vellekoop *et al.* 2020).

## Significance of the Danish gastropod fauna

In view of the fact that they possess aragonitic shells, the great majority of gastropods generally are very rare and/or poorly preserved in the Danish white chalk, comparable to other white chalk occurrences throughout Europe, with few exceptions (Kollmann & Odin 2001; Kutscher & Kullessa 2010). The best material is either that which became silicified early during diagenesis or 3D-preserved material from hardgrounds, with both internal and external moulds available. Gravesen & Jakobsen (2013) presented an overview of gastropod faunas from the upper Maastichtian white chalk in eastern Denmark, while T. Hansen (2019) described and illustrated gastropod assemblages from a hardground in the uppermost Maastichtian white chalk (zone 10, *stevensis-chitoniformis* brachiopod zone) and the lower Danian Cerithium Kalk facies along Stevns Klint (Sjælland, eastern Denmark).

The two specimens from Hillerslev are the only xenophorids known to date from the Danish white chalk. Specimen DK 1076 in particular provides an important contribution to our knowledge of gastropod faunas from the Maastichtian of Denmark in brachiopod zones 8 (*semiglobularis-humboldtii* Zone) and 9 (*humboldtii-stevensis* Zone), represented in the Hillerslev quarry succession.

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