

The youngest Maastrichtian ‘true’ inoceramids from the Vijlen Member (Gulpen Formation) in northeast Belgium and the Aachen area (Germany)

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Abstract

The youngest representatives of ‘true’ (= non-tegulated) inoceramid bivalves (Inoceramidae) are described from intervals 3-6 of the Vijlen Member (Gulpen Formation), of late early and early late Maastrichtian age, as exposed at quarries and temporary sections in northeast Belgium (CPL SA-Haccourt and CBR-Lixhe quarries) and the Aachen area (Germany), i.e. the extended type area of the Maastrichtian Stage. In total, twelve taxa are recognised from levels which are correlative with the Calcaire à *Baculites* of Manche (France), as well as with the Tercis les Bains section in southwest France, the Wisła (Vistula) River sections (central Poland) and the Western Interior of the United States. Associated cephalopods allow a detailed correlation between biozones based on those groups and on inoceramid bivalves.

Keywords: Bivalvia, Inoceramidae, Maastrichtian, Maastrichtian type area, correlation

Introduction

Recent studies of Late Cretaceous (Campanian-Maastrichtian) inoceramid bivalve faunas have documented their general succession, ranging up to the ‘*Inoceramus*’ *ianjonaensis* Assemblage, the youngest association of what are often referred to as ‘true’ inoceramids. This assemblage is characterised by a fairly wide geographical distribution, having been recorded to date from Europe, Africa and Madagascar, as well as from the United States Western Interior (Walaszczyk et al., 2009). This implies that the ‘*Inoceramus*’ *ianjonaensis* Assemblage will likely become the prime biocorrelative tool for the mid-Maastrichtian (Walaszczyk et al., 2008). Until recently, correlation of this inoceramid assemblage with the standard Maastrichtian coleoid (belemnite) succession in northwest Europe was unclear. Although belemnites are associated with ‘*I.*’ *ianjonanensis morgani* in the Calcaire à *Baculites*, Kennedy (1986, p. 76) noted that only fragments from Fresville and Orglandes were available which, according to Christensen (in Kennedy, 1986), on the basis of Schatzky Distance and alveolar

angle, were referable to *Belemnitella*, and due to their small fissure angle resembled *Belemnitella junior*. Thus, this provides but a very rough estimate.

Although inoceramids should be quite abundant throughout Europe, also in areas where belemnites are common, we know of no other reasonably large inoceramid and belemnite collections from the lower/upper Maastrichtian interval (in terms of belemnite stratigraphy) outside the Maastricht-Aachen-Liège area. The present faunules originate from the Vijlen Member, the depositional history of which has been unravelled by members of the so-called ‘Vijlen Groep’ during the past decade. The Vijlen Member occurs in the area between the Roer Valley Graben in the north and the Brabant Massif in the southwest. According to Felder (1997), the thickness of the unit generally varies between 0 and 30 m between Maastricht, Aachen and Liège, with the exception of two channel structures which are more or less parallel to the Roer Valley Graben, and in which thicknesses of up to 70 m have been noted. The Vijlen Member is developed in its entirety only within these channels, while at the channel margins and outside these, usually only the higher

intervals are preserved. At the (extended) type locality, which comprises the Mamelis sunken road (outcrop 62D-79) and the Mamelis borehole (62D-168) sections close to the Netherlands-Germany border, the Vijlen Member is complete, with a subdivision on the basis of bioclasts, foraminifera and ostracods into seven (0-6) intervals (Felder & Bless, 1994). The foraminifera in the 1-2.4 mm sieve fraction show c. twelve distinct peaks, which have proved useful in the correlation of various sections. Furthermore, peaks in belemnites and bivalves have been used for the same purpose (Felder, 2001). In addition, Felder & Bless (1994) interpreted changes in the relative frequency of molluscan and echinoderm bioclasts at the Mamelis type section to be indicative of sea level fluctuations and combined these with the appearance of characteristic horizons (i.e., pebble beds, glauconitic layers). The sea level fluctuations can be recognised in the bioclast composition at several outcrops and represent a helpful tool for the correlation of sections.

Based on the established subdivision of the Vijlen Member, its fauna has now been re-evaluated in order to establish a biozonation. However, this approach is hampered by the fact that remanié fossils, especially belemnites, may locally be frequent (Felder, 2001; Keutgen et al., 2010). As a consequence, only the first appearance datum (FAD) of species is considered a reliable bio-event.

Within the Vijlen Member, foraminifera zones C and D of Hofker (1966) have been distinguished, with the latter characterised by the FAD of *Bolivinooides draco draco* (Marsson, 1878) and restricted to the uppermost 7 m of this unit at the type locality (Felder & Bless, 1994). Locally, Zone E may appear within the uppermost Vijlen Member (Robaszynski et al., 1985). Zone C of the Vijlen Member may be further distinguished, as follows. The lowermost part of this zone is characterised by the FAD of *Bolivinooides delicatulus regularis* Reiss, 1954 (compare Felder & Bless, 1994). In the Maastricht-Aachen-Liège area, this taxon has so far only been identified from a few levels within the Vijlen Member, whereas in northern Germany its acme encompasses the uppermost Campanian to lowermost Maastrichtian. Felder & Bless (1994) also noted that Zone C might be subdivided into a lower portion with *Bolivinooides draco militaris* Hiltermann & Koch, 1950 and *Neoflabellina permutata* Koch, 1977 and an upper with *Nonionella troostae* (Visser, 1951). At Mamelis, the boundary between the subzones C_{lower} and C_{upper} corresponds roughly to the base of interval 4 of the Vijlen Member and this level is also characterised by a significant change in macrofauna. The first unequivocal records of two index belemnitellids of the upper Maastrichtian, *Belemnitella junior* Nowak, 1913 and *Belemnitella lwowensis* Naidin, 1952, are known from slightly above the base of interval 4 (Keutgen et al., 2010).

To date, the most easily applied macrofossil subdivision of the Vijlen Member is based on scaphitid ammonites (Keutgen et al., 2010). However, ammonites have not yet been recorded from intervals 0-2, because these levels are only rarely exposed. Interval 3 has yielded well-preserved specimens of

Acanthoscaphites (*A.*) *tridens* (Kner, 1848); fragments of this species have also been recorded from interval 4. The range of *A.* (*A.*) *tridens*, as currently documented, is uppermost Campanian (*Belemnella lanceolata* Zone (sensu germanico) to the mid-lower Maastrichtian (*Belemnella sumensis* Zone (sensu germanico)) (see Niebuhr, 2003; Kin, 2010). However, for material from the Maastricht-Aachen-Liège area, a late early Maastrichtian age (*Belemnella cimbrica* Zone (sensu germanico)) has been proposed (Jagt et al., 1992). Of note is that the age assignment (early Maastrichtian) of interval 3 is based mainly on the presence of this ammonite species. Within interval 4, *Hoploscaphites constrictus* (J. Sowerby, 1817) and *H. tenuistriatus* (Kner, 1848) make their first appearance. While the former is long-ranging (i.e., uppermost Campanian *Belemnella lanceolata* Zone (sensu germanico) to lowermost Danian; see Machalski, 2005; Machalski et al., 2009), the latter appears confined to the interval between the mid-lower Maastrichtian *Belemnella sumensis* Zone and the upper Maastrichtian *Spyridoceras tegulatus/Belemnitella junior* Zone (sensu germanico) (see Machalski, 2005). Close to the base of interval 6 of the Vijlen Member appears *Acanthoscaphites* (*Euroscaphites*) *varians blaszkiewiczzi* Jagt, Kennedy & Machalski, 1999. At Hemmoor (northern Germany), this subspecies is recorded from equivalents of the upper lower Maastrichtian *Belemnella cimbrica* Zone to the upper Maastrichtian *Tenuipteria argentea/Belemnitella junior* Zone (sensu germanico) (see Machalski, 2005). The presence of an interspecies hybrid of *Hoploscaphites*, which exhibits typical features of the North American *Jeletzkytes dorfi* Landman & Waage, 1993 and the European *H. constrictus*, allows correlation of the lower portion of interval 6 with the *Hoploscaphites birkelundae* Zone of the United States Western Interior (Machalski et al., 2007).

The record of *Belemnitella junior* and *Blt. lwowensis* from intervals 4-6 of the Vijlen Member indicates these to correspond with the *Spyridoceras tegulatus/Belemnitella junior* Zone (sensu germanico), whereas the top of the member may extend into the lowermost *Tenuipteria argentea/Belemnitella junior* Zone (sensu germanico) (Keutgen et al., 2010). While belemnites from intervals 0-2 are not available, those collected from interval 3 seem to favour correlation with the mid- to upper lower Maastrichtian *Belemnella sumensis* Zone (upper part) or *Belemnella cimbrica* Zone (sensu germanico). However, the latter interpretation of belemnite data is equivocal (Keutgen et al., 2010).

Keutgen & Jagt (2009) proposed correlation of the sea level lowstand at the base of interval 4 with Ma3, a major sequence boundary dated at 69.42 Ma by Wornardt (2002) and Vandenberghe et al. (2004) and at 69.23 Ma by Ogg (in litt., June 2009). For comparison, Keutgen & Jagt (2009) dated the FAD of *Belemnitella junior* at Hemmoor at 69.2 Ma on the basis of data supplied by Niebuhr (2006), which is well in line with the first unequivocal records of that species from interval 4 in the Maastricht-Aachen-Liège area, slightly above the sequence boundary. Using a sequence-stratigraphic approach, the base

of the Vijlen Member was correlated with a level which was either close to the base of the *Belemnella cimbrica* Zone (sensu germanico) (Vandenberghé et al., 2004) or within the *Belemnella sumensis* Zone (sensu germanico) (Keutgen & Jagt, 2009).

In summary, the following picture for the Vijlen Member arises from currently available data. Intervals 0-3 are probably of mid- to late early Maastrichtian age, while intervals 4-6 are of early late Maastrichtian age. In comparison with the Krons Moor-Hemmoor sections in northern Germany, those Vijlen Member intervals that have recently yielded inoceramids (i.e., intervals 3-6) can be dated as follows:

- Interval 3: early Maastrichtian(?), probably upper *Belemnella sumensis* or *Belemnella cimbrica* zones;
- Intervals 4-6 (lower portion): *Spyridoceramus tegulatus/Belemnitella junior* Zone;
- Interval 6 (upper portion): lowermost *Tenuipteria argentea/Belemnitella junior* Zone

Until now, inoceramids from the Vijlen Member in northeast Belgium and the Aachen area have only been treated in a few papers. Dhondt & Jagt (1987) listed and illustrated a single species, referred to as *Inoceramus* spec. cf. *I. balticus* Böhm, from the CPL-SA quarry (Haccourt, Liège, Belgium), which is here reassigned to '*Inoceramus*' *ianjonaensis*. A more complete, albeit still preliminary, study was made on a faunule from the Altembroeck section (Voer, northeast Belgium), where inoceramids were listed and their stratigraphic potential briefly discussed (Dhondt in Jagt et al., 1995). Keutgen (1995, 1996) carried out further work on faunules from the Vijlen Member, inclusive of inoceramid species from the Aachen area. The succession of 'teguled' inoceramids, *Spyridoceramus tegulatus* and *Tenuipteria argentea*, in the Maastrichtian type area, and their stratigraphical importance, has been briefly discussed by Jagt (1999).

The aim of the present paper is to describe inoceramid faunules that have been collected during recent years from strata assigned to the Vijlen Member (Gulpen Formation; sensu Felder, 1975) in northeast Belgium (CPL SA-Haccourt and CBR-Lixhe quarries, province of Liège) and in the Aachen area (Germany) and to integrate them into the existing inoceramid zonation (Fig. 1; Walaszczyk et al., 2009). The inoceramid specimens described herein can also be tied in with well-established belemnite zones (Christensen, 1997; Christensen et al., 2004) and the Maastrichtian macrofossil biozonation for northern Germany (Schulz, 1979; Schulz & Schmid, 1983). As such, they contribute significantly to our understanding of correlations between the chalk facies which is extended over northwest Europe and which is subdivided mainly by means of belemnites, and other rock types elsewhere in Europe (i.e., the Tethyan realm) which do not yield index belemnitellids.

Localities

Inoceramid studied herein come from intervals 3-6 of the Vijlen Member as exposed at various localities in the area which has also yielded the belemnite faunules described by Keutgen et al. (2010), to which paper reference is made. The ranges of inoceramid species recognised herein are illustrated in Fig. 2.

Schneeberg near Lemiers (Vaals)

At the Schneeberg near Lemiers, close to the Netherlands-Germany border (see Keutgen et al., 2010, fig. 8), several small outcrops were accessible during the nineteenth century, where the so-called 'Bakovensteen van Lemiers', a pure, white, fine-grained marly limestone, was quarried. Specimens in museum collections, such as *Trochoceramus* cf. *radiosus* (Quaas, 1902) may stem from this locality. At present, fossils can still be

	BISCAY REGION	AACHEN-MAASTRICHT	INOCERAMID ZONATION	MIDDLE VISTULA		BELEMNITE ZONATION	
MAASTRICHTIAN Upper	<i>Anapachydiscus fresvillensis</i>	' <i>Inoceramus</i> ' <i>ianjonaensis</i> ----- <i>Trochoceramus radiosus</i>	6 5 4 3	<i>'Inoceramus</i> ' <i>ianjonaensis</i>	MAASTRICHTIAN Upper	<i>Belemnitella junior</i>	<i>Belemnitella junior/S. tegulatus</i>
			MAASTRICHTIAN Lower				<i>Pachydiscus neubergicus</i>
CAMP.	<i>Nostoceras hyatti</i>	<i>'Inoceramus</i> ' <i>redbirdensis</i>		<i>'Inoceramus</i> ' <i>redbirdensis</i>	<i>Belemnella lanceolata</i>	<i>Belemnella obtusa</i>	
			<i>'Inoceramus</i> ' <i>costaecus</i>			<i>'Inoceramus</i> ' <i>costaecus</i>	<i>Belemnella lanceolata</i>
CAMP.	<i>'Inoceramus</i> ' <i>inkermanensis</i>	<i>'Inoceramus</i> ' <i>inkermanensis</i>		CAMP.			

Fig. 1. Correlation of inoceramid/ammonite/belemnite schemes for the uppermost Campanian, lower and lowermost upper Maastrichtian. Correlation with the Bay of Biscaye area is based on Ward & Kennedy (1993); with the Wista sections (central Poland) on Walaszczyk (2004) and Remin (2007).

?LOWER MAASTRICHTIAN				UPPER MAASTRICHTIAN			SUBSTAGES
				<i>Spyridoceramus tegulatus</i> / <i>Belemnitella junior</i>		<i>T. arg.</i> / <i>Blt jun.</i>	
<i>Acanthoscaphites tridens</i> --- <i>Hoploscaphites constrictus</i> <i>Hoploscaphites tenuistriatus</i> <i>Belemnitella junior</i> <i>Belemnitella lwowensis</i>				<i>A. varians blaszkiewiczzi</i> <i>Hoploscaphites</i> sp.			Ammonite and belemnite species
Vijlen 0	Vijlen 1	Vijlen 2	Vijlen 3	Vijlen 4	Vijlen 5	Vijlen 6	Vijlen units
Schneeberg				Mamelis			Stratigraphic range of localities studied
Schurzelterstrasse				Hans-Böckler-Allee			
Altembroeck				CPL Haccourt			
				Wilkenberg			
<i>Cataceramus barabini</i>				●			Inoceramid species/subspecies
<i>Cataceramus ghadamesensis</i>				●		●	
<i>Cataceramus glendivensis</i>				●	●		
<i>Cataceramus cf. oviformis</i>				●			
<i>Cataceramus cf. subcircularis</i>				●			
<i>Endocostea cf. jolkicevi</i>				●			
<i>Platyceramus stephensoni</i>					●		
<i>Platyceramus cf. salisburgensis</i>				●			
' <i>Inoceramus</i> ' <i>ianjonaensis morgani</i>						●	
<i>Endocostea coxi</i>					●	●	
' <i>Inoceramus</i> ' sp.				●			
<i>Spyridoceramus tegulatus</i> forma A				●			
<i>Spyridoceramus tegulatus</i> forma B					●	●	
<i>Spyridoceramus tegulatus</i> forma C						●	
				<i>Trochoceramus radiosus</i>		' <i>Inoceramus</i> ' <i>ianjonaensis</i>	Inoceramid zones

Fig. 2. Stratigraphic distribution of inoceramid material from intervals 3-6 of the Vijlen Member (Gulpen Formation) in the Haccourt-Lixhe (CPL SA and CBR-Lixhe quarries) and Aachen areas.

collected from nearby fields. From material contained in the collections of the Rheinische Friedrich-Wilhelms-Universität Bonn or formerly on exhibit in the students' collections of the Institute of Palaeontology (Rheinisch-Westfälische Technische Hochschule, Aachen), studied by one of us (NK), we assume that these outcrops exposed at least intervals 3 and 4 and, most probably, older intervals (1 and 2) as well. Worthy of note is that at the Schneeberg also intervals 5 and 6 have been documented, and these are overlain by the late Maastrichtian Orsbach Member, a local facies equivalent of the Lixhe Member (Van der Ham & Van Birgelen, 1992).

Schurzelterstraße and Hans-Böckler-Allee

The temporary section Schurzelterstraße (Aachen) was first described by Keutgen & van der Tuuk (1991). It comprised several short-term exposures, accessible between 1978 and 1981 during construction of houses at numbers 460-565. Towards its top, the Schurzelterstraße section is complemented by the Hans-Böckler-Allee section (8.4 m), which comprised the construction sites of houses at numbers 40-42. While the deposits of Schurzelterstraße exposed a yellow-grey, marly limestone, those at Hans-Böckler-Allee revealed an alternation of glauconite-rich beds and marlstones or marly limestones

with low glauconite content. Felder & Bless (1994) analysed a bioclast sample from Hans-Böckler-Allee and correlated it with their interval 4. Hence, the underlying deposits formerly exposed at Schurzelterstraße are correlated with interval 3. The locality Schurzelterstraße yielded well-preserved specimens of *A. (A.) tridens*, while the locality Hans-Böckler-Allee yielded the first specimens of *H. constrictus*.

Vaalserstraße

This temporary section at Aachen exposed the transition between intervals 3 and 4 (see Keutgen et al., 2010, fig. 8). *Spyridoceramus tegulatus* (Von Hagenow, 1842) was collected from the lower portion of the section exposed, from which also a well-preserved specimen of *A. (A.) tridens* has been recorded (Jagt et al., 1999). It may thus have come from interval 3.

Wilkenberg

Near the RWTH Aachen computer museum (Melatener Straße), the top of the Vijlen Member (uppermost metres of interval 5, plus interval 6) were exposed temporarily. These strata are correlated with the upper *Spyridoceramus tegulatus/Belemnitella junior* Zone and the lowermost *Tenuipteria argentea/Belemnitella*

junior Zone (sensu germanico) (Keutgen et al., 2010). At this locality, the index scaphitid *A. varians blaszkiewiczzi* was collected.

Haccourt-Lixhe area

The former Ciments Portland Liégeois (CPL) quarry, Haccourt, and the nearby CBR-Lixhe quarry, are situated on the left bank of the River Maas, about 10 km south of Maastricht, in the Belgian province of Liège (see Keutgen et al., 2010, fig. 8). These quarries expose the uppermost portion of interval 5, plus interval 6, and biota collected here are coeval with those from the Wilkensberg near Aachen, as indicated by records of *A. varians blaszkiewiczzi*.

Discussion

Inoceramid succession

The inoceramid species recognised to date (Figs 3-9) represent two stratigraphical assemblages, referred to herein as the *Cataceramus* Assemblage (which characterises intervals 3, 4 and the lower portion of interval 5) and the '*Inoceramus*' *ianjonaensis* Assemblage, typical of the upper portion of interval 5, in addition to interval 6. These assemblages are dominated by their index taxa; additionally, nearly the entire Vijlen Member succession, with the exception of interval 4, is characterised by the occurrence of a tegulated species, *Spyridoceramus tegulatus*.

The *Cataceramus* Assemblage is dominated by *Cataceramus glendivensis*; other associated taxa are rare and/or taxonomically equivocal. Amongst other taxa are: *Cataceramus barabini*, *C. ghadamesensis*, *C. cf. oviformis*, *Platyceramus cf. salisburgensis*, '*Inoceramus*' sp. and *Endocostea cf. jolkicevi*. A single specimen of *Trochoceramus cf. radiusus* (Fig. 5), from a locality near Vaals (?Schneeberg) which probably exposed the lower portion (i.e., below interval 3) of the Vijlen Member, is contained in the collections of the Rheinische Friedrich-Wilhelms-Universität Bonn.

The younger lot, referred to herein as the '*I.*' *ianjonaensis* Assemblage, is well represented in both the Haccourt-Lixhe and Aachen areas. It is represented by '*Inoceramus*' *ianjonaensis morgani*, a geographical subspecies, and by *Endocostea coxi*. Although the latter species is poorly represented in our material (three specimens only), it is the form that is coeval with '*I.*' *ianjonaensis* in other stratigraphically equivalent faunas, having been recorded from Zululand (Walaszczyk et al., 2009), France (Calcaire à *Baculites*) and Nigeria (Reyment, 1955; López et al., 2004).

A more detailed analysis of the inoceramid succession reveals that species richness in Vijlen Member interval 3 is comparatively high. The six specimens of 'true' inoceramids collected from this interval are assigned to six different species. For interval 3,

the presence of *Cataceramus ghadamesensis*, which was first described from a level just below the first occurrence of '*Inoceramus*' *ianjonaensis* Sornay, 1973 (see Tröger & Röhlich, 1981), supports the proposed dating as *Belemnella cimbrica* Zone of these deposits. *Spyridoceramus tegulatus* is represented by forma A, which is characterised by an axially elongated, slender form with concentric rugae that dominate the pattern of ornament, and radial elements that form lines of nodes at the intersection with the concentric rugae.

Interval 4 as exposed at Hans-Böckler-Allee yielded six specimens of 'true' inoceramids, representing merely three species. With four specimens, *Cataceramus glendivensis* dominates this impoverished assemblage. *Spyridoceramus tegulatus* is notably absent from this assemblage, indicating that this species might have temporarily become absent in the study area, near the lower/upper Maastrichtian boundary as defined by the FAD of *Belemnitella junior* at the base of interval 4 (see Keutgen et al., 2010).

Based on inoceramid faunas, interval 5 should be subdivided into a lower and an upper portion. The lower portion, as exposed at Hans-Böckler-Allee, has yielded an assemblage that differs from that of the upper levels as exposed at Wilkensberg and in the Haccourt-Lixhe area. The fauna of the lower portion of interval 5 clearly is transitional between the *Cataceramus* Assemblage and the '*Inoceramus*' *ianjonaensis* Assemblage. While the last representatives of the former, such as *C. glendivensis* and *Platyceramus stephensoni*, are still present in significant numbers, a typical element of the latter assemblage, *E. coxi*, appears for the first time. However, the index, '*I.*' *ianjonaensis*, is missing. Of note is the fact that representatives of *S. tegulatus* re-appear at this level, but they belong to forma B, a less slender morphotype with an ornament composed almost exclusively of concentric rugae.

Typical representatives of '*I.*' *ianjonaensis* and *E. coxi* are found in the uppermost portion of interval 5 and in interval 6. Twelve 'true' inoceramid specimens have been collected, nine of them assignable to the index taxon, while only a single member of the *Cataceramus* Assemblage, *C. ghadamesensis*, has been recorded from these levels, which correspond roughly to the upper *Spyridoceramus tegulatus*/*Belemnitella junior* Zone of northern Germany (Schulz & Schmid, 1983). In the Maastricht-Aachen-Liège area, this youngest fauna of 'true' inoceramids is further impoverished. *Spyridoceramus tegulatus* forma B is still present, but in the Haccourt-Lixhe area rare representatives of forma C, with very strong radial ornament, co-occur with it. Of note is a similar drop in species-level variability in this youngest inoceramid assemblage in Zululand (Walaszczyk et al., 2009).

Inoceramid stratigraphy and correlations

Three successive inoceramid zones, defined as interval range zones of the index taxa (see Fig. 1), have recently been

recognised in the Maastrichtian of the Euramerican biogeographic region and Africa (Walaszczyk et al., 1996, 2001, 2002a, b; Walaszczyk, 2004; Walaszczyk et al., 2009). These are, in ascending order, the *Endocostea typica*, *Trochoceramus radiosus* and '*Inoceramus*' *ianjonaensis* zones.

The base of the *Endocostea typica* Zone is situated slightly above the Campanian/Maastrichtian boundary as currently defined, i.e. above the average level of twelve bio-events as recognised in the stratotype at Tercis les Bains, Landes (France; see Odin, 2001; Odin & Lamaurelle, 2001; Walaszczyk et al., 2002b). Consequently, the Campanian/Maastrichtian boundary, in inoceramid terms, should be placed somewhere within the underlying '*Inoceramus*' *redbirdensis* Zone, as discussed by Walaszczyk et al. (2002a, b) and Odin & Walaszczyk (2003). As demonstrated at Tercis les Bains and, in part, in the Wisła (Vistula) River sections (central Poland), both the *E. typica* and *T. radiosus* zones correspond to the *Pachydiscus neubergicus* Zone, defined as an interval from the FAD of the index taxon to the FAD of *Menuites fresvillensis* (Seunes, 1890) (see Walaszczyk et al. 2002b, 2009). The base of the successive zone of '*Inoceramus*' *ianjonaensis* and its European equivalent, the '*Inoceramus*' *ianjonaensis morgani* Zone, as documented in successions in Spain and Zululand (Ward et al., 1991; Ward & Kennedy, 1993; MacLeod, 1994), approximates the lower boundary of the *Menuites fresvillensis* Zone.

The correlation between ammonites and inoceramids thus seems well established. However, correlation of the inoceramid zonation and the northwest European belemnite scheme is still poorly constrained. In the chalk succession of Hemmoor-Kronsmoor (northern Germany), where the lower Maastrichtian belemnite standard was established (Schulz, 1979; Schulz & Schmid, 1983; Schulz et al., 1984; Schönfeld et al., 1996), true inoceramids are only known from unidentifiable fragments (Dhondt, 1982). In contrast, both groups are well represented in the Wisła River section, central Poland (Walaszczyk, 2004). A renewed study of late Campanian and early Maastrichtian belemnites, documented almost 50 years ago by Kongiel (1962), has recently been carried out by Remin (2007). According to these data, the base of the *E. typica* Zone falls within the *Belemnella pseudobtusa* Zone, and the zone itself spans the upper part of that zone and ranges into the succeeding *Belemnella obtusa* Zone. Unfortunately, the higher part of the succession, corresponding to the *Trochoceramus radiosus* to '*Inoceramus*' *ianjonaensis* zones, is not exposed along the Wisła River. The present inoceramid material from the Maastricht type area is thus of prime importance for belemnite-inoceramid intercorrelation. The data presented here correlate the base of the '*Inoceramus*' *ianjonaensis* Zone to a level within the *Spyridoceramus tegulatus/Belemnitella junior* Zone (see Schulz & Schmid, 1983; Jagt, 1999) (Fig. 1). According to data from the Wisła River section, the *Endocostea typica* Zone spans the upper *Belemnella pseudobtusa* and *Belemnella obtusa* zones, implying that the *Trochoceramus radiosus* Zone is equivalent to

the *Belemnella sumensis*, *Belemnella cimbrica* and *Belemnella fastigata* zones, which in turn would correspond to the traditional *Belemnella occidentalis* Zone and lower *Spyridoceramus tegulatus/Belemnitella junior* Zone. Keutgen & Jagt (2009), on the basis of a correlation between northern Germany (combined Kronsmoor-Hemmoor sections) and the United States Western Interior, plus the documented range of *Trochoceramus radiosus* in the latter area, proposed that this taxon could be expected to occur in most of the *Belemnella sumensis* Zone as well as in the lower *Belemnella cimbrica* Zone. This implies an informal subdivision of the *Trochoceramus radiosus* Zone into a lower assemblage with the index and related taxa (*Trochoceramus* Assemblage) and an upper one without these (*Cataceramus* Assemblage).

Inoceramid zonation in the Maastricht-Aachen-Liège area

Based on the stratigraphic ranges of inoceramid assemblages recognised in the area, two successive inoceramid zones are distinguished in the interval studied; the *Trochoceramus radiosus* Zone (spanning intervals 3, 4 and the lower portion of 5) and the '*Inoceramus*' *ianjonaensis* Zone, encompassing the upper portion of interval 5, plus interval 6 (Figs 1, 2). The distinction of the latter zone is straightforward, and it comprises the stratigraphic interval of the '*I.*' *ianjonaensis* Assemblage. It is defined by the FAD of the index species, here represented by its geographic subspecies, '*I.*' *ianjonaensis morgani*. The upper boundary of the zone is defined by the last occurrence of '*I.*' *ianjonaensis*. The *T. radiosus* Zone comprises the stratigraphic interval of the *Cataceramus* Assemblage. The distinction of *T. radiosus* Zone is based on its stratigraphic position below the '*I.*' *ianjonaensis* Zone and on a single questionable (cf.) specimen of the index species. Based on the inoceramid fauna alone it is impossible to state which part of the zone is actually represented in the succession studied.

Systematic palaeontology

Our material is quite rich, consisting of a total of sixty-three specimens. Preservation, however, is variable. Most specimens are internal moulds of a single, usually incomplete, valve. Only a few specimens are articulated; some specimens are external moulds. In addition, most are usually deformed, commonly having suffered lateral or oblique compression.

Morphological terms and measurements applied herein follow Harries et al. (1996), and are as follows: Δ – anterior hinge angle; δ – angle between growth axis and hinge line (obliquity); h – axial length; l – length perpendicular to h; H – valve height; L – valve length; HL – hinge line; B – convexity.

With one exception, all material is housed in the collections of the Natuurhistorisch Museum Maastricht (abbreviation: NHMM; JJ – J.W.M. Jagt Collection; NK – N. Keutgen Collection).

Three specimens are contained in collections at the Museen der Stadt Aachen (abbreviation: MSA). Other abbreviations are as follows: UB – Rheinische-Friedrich-Wilhelms University, Bonn; NHM – The Natural History Museum, Department of Palaeontology, London; USNM – United States National Museum, Washington DC; YPM – Peabody Museum, Yale University, New Haven.

Family *Inoceramidae* Giebel, 1852

Genus *Cataceramus* Heinz, 1932

Type species

Inoceramus balticus Böhm, 1907.

Cataceramus barabini (Morton, 1834) *sensu* Meek, 1876

Figs 3/5, 4/5.

Compare:

1876 *Inoceramus Cripsii?*, var. *Barabini* Morton; Meek, p. 49, pl. 12, fig. 3; text-figs 1-4 (?pl. 13, fig. 1).

1995 *Inoceramus (Endocostea) balticus* subsp. Böhm; Keutgen, p. 298, pl. 7, fig. 1.

Material

Two specimens: NHMM NK 23 (Schurzelterstraße, interval 3) and NHMM NK 5 (Hans-Böckler-Allee, interval 4).

Description and remarks

Both specimens are internal moulds of single left valves. NHMM NK 23 is a large ($h_{\max} = 107$ mm), adult specimen, secondarily compressed perpendicular to the commissural plane, which results in a higher valve inflation. NHMM NK 5 is a juvenile fragment ($h_{\max} = 48.6$ mm), with posterior and postero-ventral parts missing. Both specimens are of a '*balticus*'-like morphotype, with high obliquity ($\delta = 30^\circ$), a distinct posterior elongation, a long and straight hinge line and a short and convex anterior margin. The ornament is composed of regularly/subregularly spaced commarginal rugae.

Both specimens closely resemble *Inoceramus Cripsii?*, var. *Barabini* Morton as interpreted by Meek (1876, p. 49, pl. 12, fig. 3; text-figs 1-4), from the lower Maastrichtian of the United States Western Interior. The relationship of Meek's form to Morton's is unclear.

Occurrence

The present specimens are from intervals 3 and 4. Meek's type is from the lower Maastrichtian of the United States Western Interior.

Cataceramus ghadamesensis (Tröger, in Tröger & Röhlich, 1981)

Figs 3/2, 3.

1981 *Inoceramus (Selenoceramus) ghadamesensis* Tröger, in Tröger & Röhlich, p. 170, pls 1, 2; text-fig. 2.

1991 *Inoceramus (Selenoceramus) ghadamesensis* Tröger et Röhlich; Tröger & Röhlich, p. 1368, pl. 3, figs 1-5, 8-10.

non2000 *Endocostea* cf. *ghadamesensis* (Tröger & Röhlich, 1981); Dhondt in Robaszynski et al., p. 414, pl. 11, fig. 3; text-fig. 43.

Type

Holotype, by original designation, is specimen no. 1285-II-B-4/22, the original of Tröger, in Tröger & Röhlich (1981, pl. 2, fig. 1), from the Lower Târ Member (Zimam Formation; lower Maastrichtian) near Ghadames, Libya.

Material

Two specimens: NHMM JJ 8636 (CBR-Lixhe quarry, interval 6) and NHMM NK 36 (Schurzelterstraße, interval 3).

Description

Small- to moderate-sized ($h_{\max} = 55$ mm in NHMM JJ 8636 and 65 mm in NHMM NK 36), equivalve, strongly inequilateral species. Valves show two growth stages, separated by a more or less distinctly developed geniculation; the juvenile stage is small (approximately 20 mm in h length in both specimens), subrounded in outline, and ornamented with regularly and finely spaced commarginal rugae. The adult stage is elongated strongly postero-ventrally (adult δ values reach about 20°), weakly ornamented with irregular, low rugae or is almost smooth. The hinge line is long and straight; the umbo small, not projecting above hinge line. A 'hohlkehle' usually is present, starting in the median part of the juvenile stage and continuing onto the adult.

Remarks

Juveniles are indistinguishable from those of small-sized '*I. ianjonensis morgani*', but these species differ in the adult stage; *C. ghadamesensis* has a strongly posteriorly extended shell in the adult stage, and the juvenile stage is weakly separated; moreover, its adult ornament is composed almost entirely of growth lines, with rare irregular rugae in the ventralmost parts. None of the specimens illustrated and referred to *C. ghadamesensis* by Dhondt (in Robaszynski et al., 2000) can be confirmed as conspecific; one of her specimens (text-fig. 43) is a transitional form between '*Inoceramus gandjaeformis*' and '*Inoceramus alaeformis*', well represented in the uppermost Campanian (see Walaszczyk, 2004, fig. 44A, C, D, F); the one in pl. 11, fig. 3 is difficult to determine, but may be close to '*Inoceramus oblongus*'.

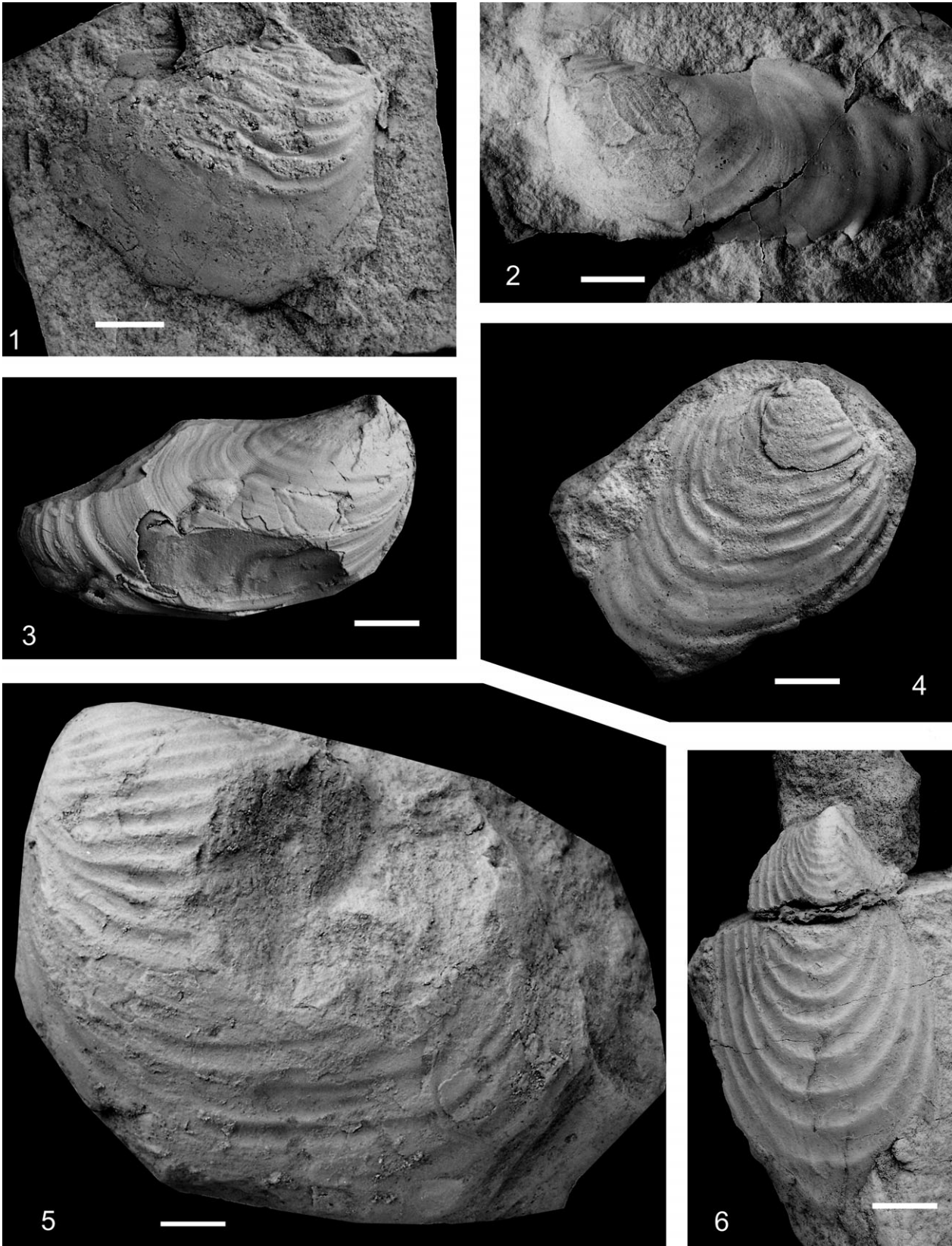


Fig. 3. *Inoceramids* of the *Vijlen Member*; 1. *Endocostea* cf. *jolkicevi* Walaszczyk, Odin & Dhondt, 2002 (NHMM NK 17; Schurzelterstraße, interval 3); 2, 3. *Cataceramus ghadamesensis* (Tröger, in Tröger & Röhlich, 1981) (NHMM NK 36; Schurzelterstraße, interval 3, and NHMM JJ 8636; CBR-Lixhe quarry, interval 6); 4. *Cataceramus glendivensis* Walaszczyk, Cobban & Harries, 2001 (NHMM NK 3; Hans-Böckler-Allee, interval 4); 5. *Cataceramus barabini* (Morton, 1834) *sensu* Meek, 1876 (NHMM NK 23; Schurzelterstraße, interval 3); 6. *Cataceramus* cf. *subcircularis* (Meek, 1876) (NHMM NK 18 II; Hans-Böckler-Allee, interval 4). All scale bars represent 10 mm.

Occurrence

In the Maastricht-Aachen-Liège area, this species is known from intervals 3 and 6, which, in belemnite terms, equate with the upper *Belemnella cimbrica* and *Belemnitella junior* zones (Fig. 2). *Cataceramus ghadamesensis* was first described from the lower Maastrichtian of northwest Libya, from a level just below the first occurrence of *Inoceramus ianajonaensis* Sornay, 1973 (see Tröger & Röhlich, 1981). The late Campanian-early Maastrichtian forms (Abiod and basal El Haria formations) referred to this species from western Tunisia (Dhondt in Robaszynski et al., 2000) represent different species.

Cataceramus glendivensis Walaszczyk, Cobban & Harries, 2001

Figs 3/4, 4/2, 3, 7.

2001 *Cataceramus?* *glendivensis* Walaszczyk et al., p. 170, pl. 42, figs 2, 11; pl. 44, figs 2, 4.

Type

Holotype, by original designation, is YPM 191001, the original of Walaszczyk et al. (2001, pl. 42, fig. 2) from the upper part of the *Baculites baculus* Zone (lower lower Maastrichtian) of the Glendive section, Montana (USA).

Material

Six specimens: NHMM NK1 (Schurzelterstraße, interval 3); NHMM NK 2 (+ corresponding outer mould, NHMM NK 29), NHMM NK 3, ?NHMM NK 8 and NHMM NK 38 (all Hans-Böckler-Allee, interval 4); NHMM NK 24 (+ corresponding counterpart, NHMM NK 26) (Hans-Böckler-Allee, interval 5).

Dimensions

(linear; in mm):

	valve	h_{max}	h	l	H	L	HL	Δ	δ
NHMK NK 24	LV	49	48	42	39.5	40	21.5*	108	55
NHMK NK 38	LV	65	55	47	47	50	27	110	55
NHMK NK 2	RV	71	-	-	-	-	-	-	-
NHMK NK 3	RV	46*	-	-	-	-	-	-	45*

Description

These specimens represent medium-sized forms, weakly inflated, inequilateral, presumably equivalve or nearly so. The species is moderately oblique, with the δ angle between 45 and 55°. The anterior margin is moderately long, straight or slightly convex, and passes into a long, broadly convex antero-ventral margin. The ventral margin is rounded, the hinge line moderately long and straight.

Ornament consists of subregular, low and delicate, concentric rugae; growth lines are rarely observed; these are better preserved in NHMM NK 24 (+ 26), in which they are oblique to the rugae.

Remarks

Cataceramus glendivensis is similar to *Inoceramus bebahoensis*, described by Sornay (1973) from the Maastrichtian of Madagascar. Although one of the specimens illustrated by Sornay (1973, pl. 3, fig. 2) closely resembles the North American *C. glendivensis*, the Madagascan material is represented by rather massive, moderately inflated specimens.

Occurrence

This North American species was described from the lower Maastrichtian (*Baculites baculus* Zone) and from the successive *Baculites grandis* Zone. It has subsequently been recorded from the lower Maastrichtian of Piesting (Austria; Tröger et al., 2001, p. 151, pl. 1, fig. 1; text-fig. 7). In the study area, it is known from intervals 3, 4 and 5 in the Aachen area, corresponding to the *Belemnella cimbrica* Zone and lower *Belemnitella junior* Zone (= *Spyridoceramus tegulatus/Belemnitella junior* Zone).

Cataceramus cf. oviformis Walaszczyk, Cobban & Harries, 2001

Fig. 4/4.

Material

A single specimen: NHMM NK 37 (Schurzelterstraße, interval 3).

Description and remarks

This species is represented by a single internal mould of a left valve, of moderate size ($L_{max} = 55$ mm). The valve is incomplete, lacking the postero-ventral portion. The specimen shows a characteristic valve outline, with the beak located more dorso-centrally, and with a strongly convex anterior margin. The valve is covered with regular concentric rugae, with their size and interspaces increasing gradually ventrally. The posterior auricle is not separated; the hinge line is long and straight.

The specimen closely corresponds to the typical features of *Cataceramus oviformis*, an early Maastrichtian species from the United States Gulf Coast and Montana (Walaszczyk et al., 2001, p. 166, pl. 41, fig. 3). On account of incomplete preservation, specific assignment is tentative.

Occurrence

Cataceramus oviformis occurs widely in the lower Maastrichtian of the Euramerican region; it is known from the United States Western Interior, Gulf Coast, from the *Endocostea typica* Zone at Tercis les Bains and from the Maastrichtian (possibly lower) of Daghestan (Caucasus).

Cataceramus cf. subcircularis (Meek, 1876)

Fig. 3/6.

1995 *Inoceramus* sp. 2; Keutgen, p. 309, pl. 8, fig. 3.

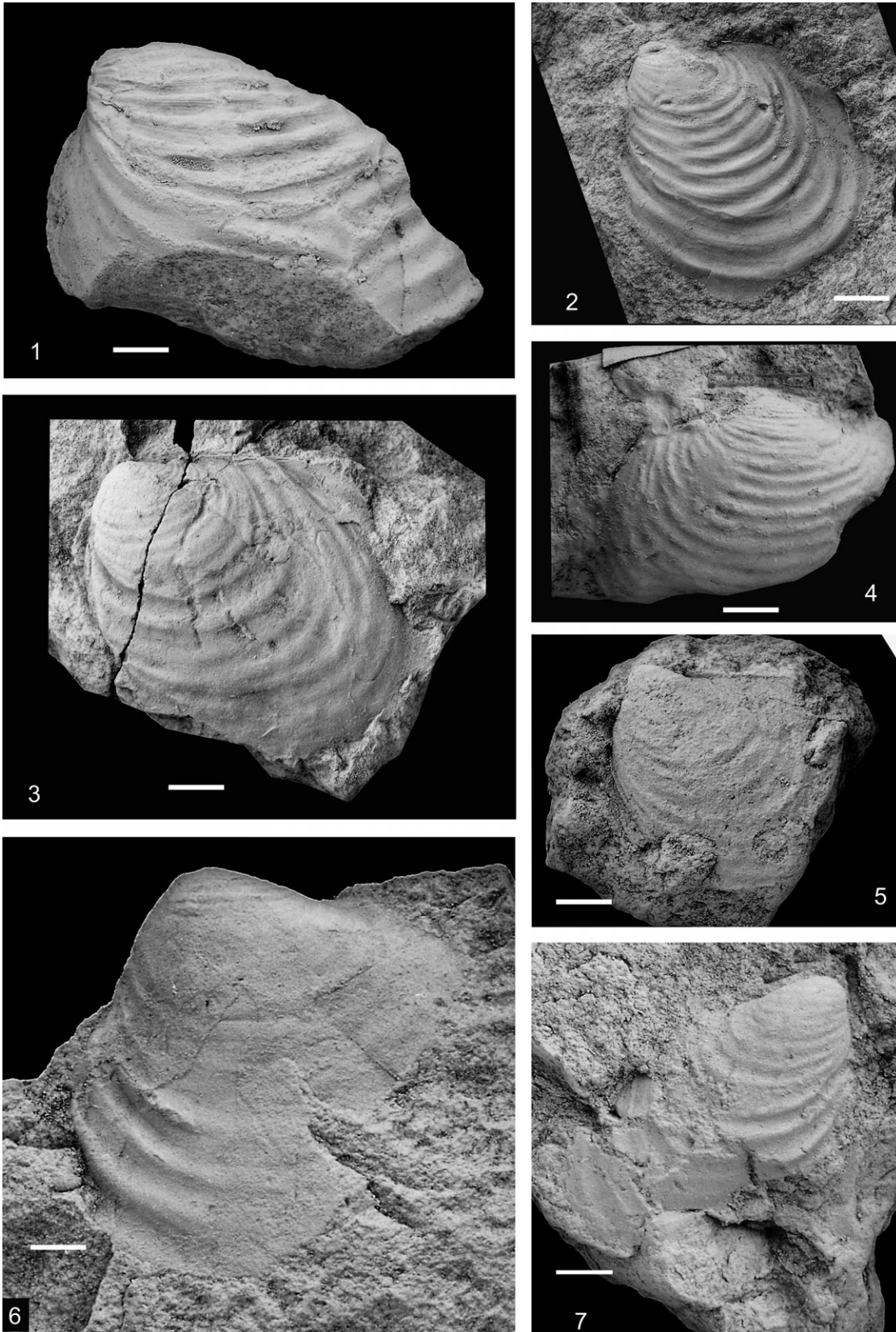


Fig. 4. *Inoceramids* of the Vijlen Member; 1. '*Inoceramus*' sp. (NHMM NK 35; Lemiers-Schneeberg, ?interval 3); 2, 3, 7. *Cataceramus glendivensis* Walaszczyk, Cobban & Harries, 2001 (NHMM NK 24; Hans-Böckler-Allee, interval 5; NHMM NK 38; Hans-Böckler-Allee, interval 4; NHMM NK 2; Hans-Böckler-Allee, interval 4); 4. *Cataceramus* cf. *oviformis* Walaszczyk, Cobban & Harries, 2001 (NHMM NK 37; Schurzelterstraße, interval 3); 5. *Cataceramus barabini* (Morton, 1834) *sensu* Meek, 1876 (NHMM NK 5; Hans-Böckler-Allee, interval 4); 6. *Platyceramus* cf. *salisburgensis* (Fugger & Kastner, 1885) (NHMM NK 4; Schurzelterstraße, interval 3). All scale bars represent 10 mm.

Material

A single specimen: NHMM NK 18 II (Hans-Böckler-Allee, interval 4).

Description and remarks

This specimen, of moderate size ($h_{\max} = 64$ mm), is deformed, but its regular commarginal rugae, regularly spaced, and apparently regular original outline allow it to be referred to this species, albeit questionably. The *subcircularis* morphotype is quite common at most localities exposing lower Maastrichtian strata. Based on observations within the Euramerican biogeographical region, early representatives of the taxon (in the uppermost Campanian and lowermost Maastrichtian) are small sized and then display a gradual size increase, at least up to the mid-lower Maastrichtian, within the *Trochoceras* *radiosus* Zone (Walaszczyk et al., 2001). The larger representatives from the upper lower Maastrichtian have invariably been referred to a number of other species, e.g. *Cataceramus buguntaensis* (Dobrov & Pavlova, 1959), *Endocostea (Selenoceras) semaili* Morris, 1995 or '*Inoceramus*' *mandembataensis* Sornay, 1973. All these names were synonymised with *C. subcircularis* by Walaszczyk et al. (2001); however, more detailed studies may reveal that a subdivision of the *subcircularis* lineage into two (?or three) chronosubspecies is possible, for which these names would then be available.

Genus Endocostea Whitfield, 1877

Type species

Endocostea typica Whitfield, 1877 (see Walaszczyk et al., 2001, for comments on the genus).

Endocostea cf. jolkicevi Walaszczyk, Odin & Dhondt, 2002

Fig. 3/1.

Material

A single specimen: NHMM NK 17 (Schurzelterstraße, interval 3).

Description and remarks

This is an internal mould of a single right valve, with L and H approximately 50 and 43 mm, respectively. The valve lacks the umbo and is rather poorly preserved in the dorsal and posterior portions. It shows two distinct growth stages; the juvenile, about 28 mm in H and the adult, growing at the same obliquity angle (with δ about 45°), but being distinctly geniculated, with an angle about 45° . The valve has a well-separated, narrow, elongated posterior auricle, at least in the adult stage. The juvenile part is weakly inflated, trapezoidal in outline; its anterior margin is straight, slightly concave below the umbo, then it passes at almost right angle into broadly rounded ventral margin, and then into short, almost straight posterior margin. The juvenile ornament is composed of distinct, closely

spaced commarginal rugae, with narrow and deep interspaces. The outline of the rugae shows the presence in the juvenile part of a distinct radial sulcus, located approximately in the axial part of the valve. The adult stage is almost smooth; the radial sulcus does not continue, or at least is not visible at this stage.

In outline and character of the juvenile rugae, and the inferred presence of the radial sulcus in the juvenile stage, this specimen approaches *E. jolkicevi*, first described from the lower Maastrichtian (lowermost *E. typica* Zone) at Tercis les Bains (Walaszczyk et al., 2002b, p. 39, pl. 13, fig. 9). Although the French specimen lacks the two growth stages, it is readily apparent in an American specimen (*Baculites baculus* Zone), here referred to this species, as illustrated by Walaszczyk et al. (2001, pl. 39, fig. 9), under the name of *Endocostea* sp.

Occurrence

This species is also known from the lower lower Maastrichtian of Tercis les Bains, as well as from Aimaki, Daghestan (Caucasus; see Walaszczyk et al., 1996, pl. 4, fig. 1, as '*Inoceramus*' ex gr. *impressus*) and from the United States Western Interior (Walaszczyk et al., 2001).

Endocostea coxi (Reyment, 1955)

Fig. 8/1(?), 2-3.

1955 *Inoceramus coxi* Reyment, p. 140, pl. 3, fig. 4.

2009 *Endocostea coxi* (Reyment, 1955); Walaszczyk et al., p. 72, figs 41A, G; 44C-E, G; 46A-F, ?G; 47A-F (with additional synonymy).

Type

Holotype, by original designation, is NHM L82963, from the Maastrichtian of Auchy, Nigeria.

Material

Three specimens: NHMM NK 25 (Hans-Böckler-Allee, interval 5) and NHMM NK 6 and NK 27 (Wilkenberg, uppermost portion of interval 5, plus interval 6).

Description and remarks

The species is represented by three specimens of variable preservation. The best preserved is NK 6 (with $h_{\max} = 82$ mm), an internal mould of a single, complete right valve, composed of a juvenile stage comparable with that of the type of the species, followed by extended ventrally adult stage (Fig. 8/3). The specimen is moderately laterally compressed and, moreover, it lacks the postero-ventral part of the juvenile stage. The juvenile stage is a posteriorly elongated part (H/L ratio at the juvenile/adult stage boundary is 0.6), with typical *Endocostea*-type morphology. It is strongly inflated in the umbonal part, with the beak located antero-posteriorly. The posterior auricle

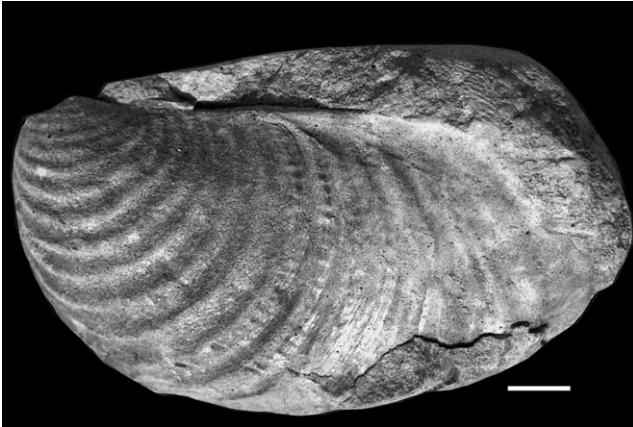


Fig. 5. *Trochoceramus cf. radiosus* (Quaas, 1902), from 'Kalkstein von Vijlen' near Vaals; UB, unregistered specimen. Scale bar represents 10 mm.

is well separated from the disc. In the adult stage, the valve starts growing postero-ventrally; the adult δ value is estimated at about 60° ; the adult valve outline becomes trapezoidal (with H/L ratio about 1). The anterior margin is relatively long with relatively high anterior face. The juvenile ornament is composed of closely and quite regularly spaced, sharp-edged rugae; in the adult stage the rugae are more widely spaced, with interspaces increasing subregularly ventrally.

The two other specimens (NHMM MK 25 and 27) are juvenile fragments. MK 25 (Fig. 8/1) is represented by the external mould of the juvenile and small part of the adult stages of a left valve, whereas MK 27 (Fig. 8/2) is a deformed juvenile fragment of a left valve, which shows its original inflation. Although, for the time being, MK 25 is referred herein to *E. coxi*, it is possible that it represents '*I. ianjonaensis*' with strong concentric ornament in the juvenile stage and with much more distinct ornament in the adult, similar to specimen NHMM JJ 2812 (Fig. 7/9).

Occurrence

In the study area, this species is confined to intervals 5 and 6, corresponding to the lower *Belemnitella junior* Zone (= *Spyridoceramus tegulatus/Belemnitella junior* Zone). The species is known from equivalent horizons in Nigeria (Reyment, 1955; López et al., 2004) and Zululand (Walaszczyk et al., 2009).

Genus *Platyceramus* Heinz, 1932

Type species

Inoceramus mantelli (De Mercey) Barrois, 1879.

Platyceramus stephensoni (Walaszczyk, Cobban & Harries, 2001)

Fig. 6.

- pars 1994 *Inoceramus (Platyceramus) aff. I. (Pl.) cycloides* Wegner, 1905; MacLeod, p. 1061, figs 7.1, 8.2, 9.5, 9.6, 12.5 (non 11.3, '*Inoceramus*' sp.).
- 1995 *Inoceramus (Platyceramus) sp.*; Keutgen, p. 300, pl. 7, fig. 2.
- 2001 '*Inoceramus*' *stephensoni* Walaszczyk et al., p. 223, pl. 41, fig. 6; pl. 42, fig. 5, pl. 44, fig. 3.

Type

Holotype, by original designation, is USNM 507487, the original of '*Inoceramus*' *stephensoni* in Walaszczyk et al. (2001, pl. 44, fig. 3), from the *Baculites grandis* Zone of Weston County, Wyoming.

Material

One specimen, illustrated by Keutgen (1995, pl. 7, fig. 2), and reillustrated herein (Fig. 6), plus two additional specimens (not illustrated) from the same locality and level (Hans-Böckler-Allee, interval 5). These specimens (unregistered) are now contained in the collections of the Museen der Stadt Aachen (MSA).



Fig. 6. *Platyceramus stephensoni* (Walaszczyk, Cobban & Harries, 2001) (MSA unregistered; Hans-Böckler-Allee, interval 5). Scale bar represents 10 mm.

Description

The illustrated specimen is a single right valve. It is a huge specimen, with $h_{\max} = 135$ mm. It is nearly flat; only the umbo is weakly inflated. The valve outline is subrectangular, almost twice as long along h than along b . The beak is small, projecting slightly above the hinge line. The hinge line is moderately long and straight. The anterior margin is long, broadly convex, then it passes into rounded ventral margin. The posterior margin fragmentarily preserved. The disc is separated from the posterior auricle only in the peri-umbonal region.

Both the juvenile and adult valve stages are covered with quite regular concentric rugae, which increase in size and in interspaces ventrally. The gerontic stage is covered with irregular, low, widely spaced rugae and with growth lines, well seen on the shelly fragments.

Remarks

These specimens are indistinguishable from forms referred to *Platyceramus cycloides* group in the Santonian and lower lower Campanian (illustrated and described at length by Seitz, 1961); the temporal gap separating the two occurrences is the basis for referring such forms in the upper lower Maastrichtian to another species.

Occurrence

This species was described from the upper *Baculites baculus* and from the *Baculites grandis* Zones of the United States Western Interior (Walaszczyk et al., 2001) and has also been recorded from the lower Maastrichtian of Austria (Tröger et al., 2001), and is well represented in the upper lower Maastrichtian of Zululand (Walaszczyk et al., 2009).

Platyceramus cf. salisburgensis (Fugger & Kastner, 1885)

Fig. 4/6.

Compare:

1970 *Inoceramus (Platyceramus) salisburgensis* Fugger & Kastner; Seitz, p. 125, pl. 24, fig. 1; pls 25-27; text-fig. 11.

Material

A single specimen: NHMM NK 4 (Schurzelterstraße, interval 3).

Description and remarks

This is an internal mould of a single, incomplete left valve, with an estimated maximum h of 74 mm and with $L = 72$ mm. It shows the small, raised umbonal portion and a flat, extended adult stage; the hinge line itself is only partially preserved, and its characteristics cannot be described. The anterior margin is straight. The antero-ventral and ventral margins are rounded. The valve is weakly oblique, with $\delta = 68^\circ$. The ornament is composed of commarginal rugae. The rugae are fine and closely spaced in the umbonal part. The adult rugae are relatively

widely spaced and irregular, best developed in the anterior part of the disc.

The specimen corresponds well to the Zululand material from equivalent upper lower Maastrichtian strata (see Walaszczyk et al., 2009, figs 32, 33, 36, 37, 38A, F, 39A). It is left in open nomenclature due to its incomplete preservation.

Occurrence

This species is known from the lower Maastrichtian of Austria, Rügen (northeast Germany) and Zululand; the present material is from interval 3, *Belemnella cimbrica* Zone.

Inoceramids referred to the genus *Inoceramus* (*sensu lato*)

Species with unknown generic affiliation are referred to the genus *Inoceramus (sensu lato)*; to distinguish them from forms representing genuine *Inoceramus (sensu stricto)*, quotation marks are used in generic assignment.

'Inoceramus' ianjonaensis Sornay, 1973

Type

Holotype, by original designation of Sornay (1973, pl. 1, fig. 3), is specimen no. 13-10 from the lower Maastrichtian of Mandembata, Madagascar.

Remarks

'*Inoceramus' ianjonaensis*, best characterised as a 'balticus'-like form with additional radial ornament, was one of the forms commonly referred to the genus *Trochoceramus*. The number of radially ribbed forms from an interval spanning the topmost Campanian-basal upper Maastrichtian, which could potentially be referred to *Trochoceramus*, has grown markedly, and the group has been shown to occur at least in Europe, West Asia, Africa, and North and South America. The progress in the stratigraphic recognition of the topmost Campanian and lower Maastrichtian has enabled a refinement of our knowledge of the group's record. More precise stratigraphy and better knowledge of particular species within the group have aided in constraining its evolutionary interpretation, and consequently also its taxonomy.

The group first appeared in the uppermost Campanian (topmost *Nostoceras pozaryskii* = *N. hyatti* Zone) (Walaszczyk et al., 2002a, b; Walaszczyk, 2004) and persisted until the final disappearance of the so-called 'true' inoceramids in the lowermost upper Maastrichtian (somewhere in the *Belemnitella junior* Zone, as shown herein). Furthermore, the group does not occur continuously throughout the entire interval, but, instead, is found in three distinct, stratigraphically narrow intervals. These are:

1. a level in the uppermost Campanian (upper, but not the topmost *Nostoceras hyatti* Zone);

2. the mid-lower Maastrichtian, lower *Trochoceramus radiosus* Zone; and
3. basal upper Maastrichtian (as demonstrated herein), '*Inoceramus*' *ianjonaensis* Zone, in the *Belemnitella junior* Zone; no representatives of the group occur in the intervals between.

Moreover, the morphotypes from particular intervals are closer morphologically to time-equivalent, non-radially ribbed forms than to members of the group from other intervals. Consequently, it is proposed that what is called the *Trochoceramus* group does not actually represent a single clade, which consequently could be referred to a single genus, but is rather composed of three independent, iteratively appearing lineages, in three successive time intervals. In ascending stratigraphic order these are:

1. the '*Inoceramus*' *garridoi* (Bataller, 1947) / '*I.*' *costaecus* Khalafova, 1966 lineage, which evolved in the latest Campanian;
2. the *Trochoceramus radiosus* (Quaas, 1902) lineage, which evolved in the mid-early Maastrichtian; and
3. the '*I.*' *ianjonaensis* Sornay, 1973 lineage, which first appeared slightly above the lower/upper Maastrichtian boundary, in terms of belemnite stratigraphy.

If this interpretation is correct, all members of the groups should no longer be referred to a single genus as the group is polyphyletic; only one of the lineages may be retained as *Trochoceramus*. Because the type species of the genus, i.e. '*Inoceramus*' *helveticus* Heinz represents the mid-early Maastrichtian lineage, only those forms (assuming that they do in fact represent a lineage) should be assigned to *Trochoceramus* from now on. Members of the two other lineages must be referred to other genus-level taxa, or retained in parental genera. For the time being, we leave the reference of the lineage comprising Sornay's species *ianjonaensis* open and consequently place it in '*Inoceramus*' (*sensu lato*).

Subspecific interpretation

In accordance with Walaszczyk et al. (2002, 2009) and López et al. (2004), we regard forms in Europe referred to '*I.*' *morgani* as conspecific with '*I.*' *ianjonaensis* Sornay. However, to indicate the differences in mean specimen size within populations of both taxa, as well some differences, e.g. in the dominance of particular morphotypes, we interpret '*I.*' *morgani* as a geographic subspecies of '*I.*' *ianjonaensis*.

'*Inoceramus*' *ianjonaensis* *morgani* Sornay, 1973

Fig. 7/1-13.

1973 *Inoceramus* (*Trochoceramus*) *morgani* Sornay, p. 91, pl. 3, figs 3, 4; pl. 4, figs 2, 3; text-fig. 5.

1987 *Inoceramus* sp. cf. *I. balticus* Böhm; Dhondt & Jagt, p. 82, fig. 3.4.

1994 *Inoceramus* (*Trochoceramus*) *morgani* Sornay; MacLeod, p. 1059, figs 10.3, 10.6-10.8.

1995 *Inoceramus* (*Selenoceramus*) *inaequabilis* Seitz; Keutgen, p. 303, pl. 7, fig. 3.

1995 *Inoceramus* (*Trochoceramus*) *nahorianensis* Kociubynskij; Keutgen, p. 305, pl. 7, fig. 4.

Type

Holotype, by original designation, is specimen no. M4, the original of Sornay (1973, pl. 4, fig. 6; text-fig. 5) from the Calcaire à *Baculites* of the Port-Filiolet near Picauville (Manche, France); Maastrichtian.

Material

Thirteen specimens: NHMM NK 7, NK 16, NK19 and NK 27a (all Wilkensberg, uppermost portion of interval 5, plus interval 6); NHMM JJ 2685b, JJ 2812, JJ 3090a/b, JJ 3893, JJ 3509, JJ 6447, JJ 6705, JJ 12204 and JJ 12266 (all Haccourt-Lixhe area, upper portion of interval 5, plus interval 6).

Description

This species is of small to moderate size, inequilateral, ?equivalved. The valves are distinctly geniculated. The juvenile stage, with H_{max} not exceeding 28 mm, is nearly flat, subrounded to subrectangular. The umbo is small, either projecting very slightly above the hinge line or not at all. The valves in this stage vary from almost upright to moderately oblique. The disc is not distinct. The juvenile ornament is composed of quite regularly spaced, concentric rugae that gradually increase in width towards the venter. Radial ornament is variably developed; best seen in a specimen with very weak obliquity (Fig. 7/4). The number of specimens is, however, too small to judge whether there is a positive relationship between the obliquity and radial ornament. The growth direction of the adult stage varies considerably and depends on the obliquity of the juvenile stage. It is ornamented either with regularly spaced rugae or is almost smooth. Numerous specimens bear a variously developed 'hohlkehle'.

Remarks

The description given fits particularly well the specimens from Wilkensberg (Fig. 7/1, 4, 8, 12). Some specimens from the Haccourt-Lixhe area, also referred herein to '*I.*' *ianjonaensis* *morgani*, differ slightly; they possess smaller juvenile stages and relatively larger and better-ornamented adult stages (Fig. 7/9, 13). On the one hand, as the source rocks of specimens from both localities are different (siliceous marls and chalk, respectively), this morphotypical variation may, to some extent, be due to facies and/or taphonomic controls. On the other hand, however, both morphotypes are also easily recognised in the material from Calcaire à *Baculites* (Walaszczyk, unpublished

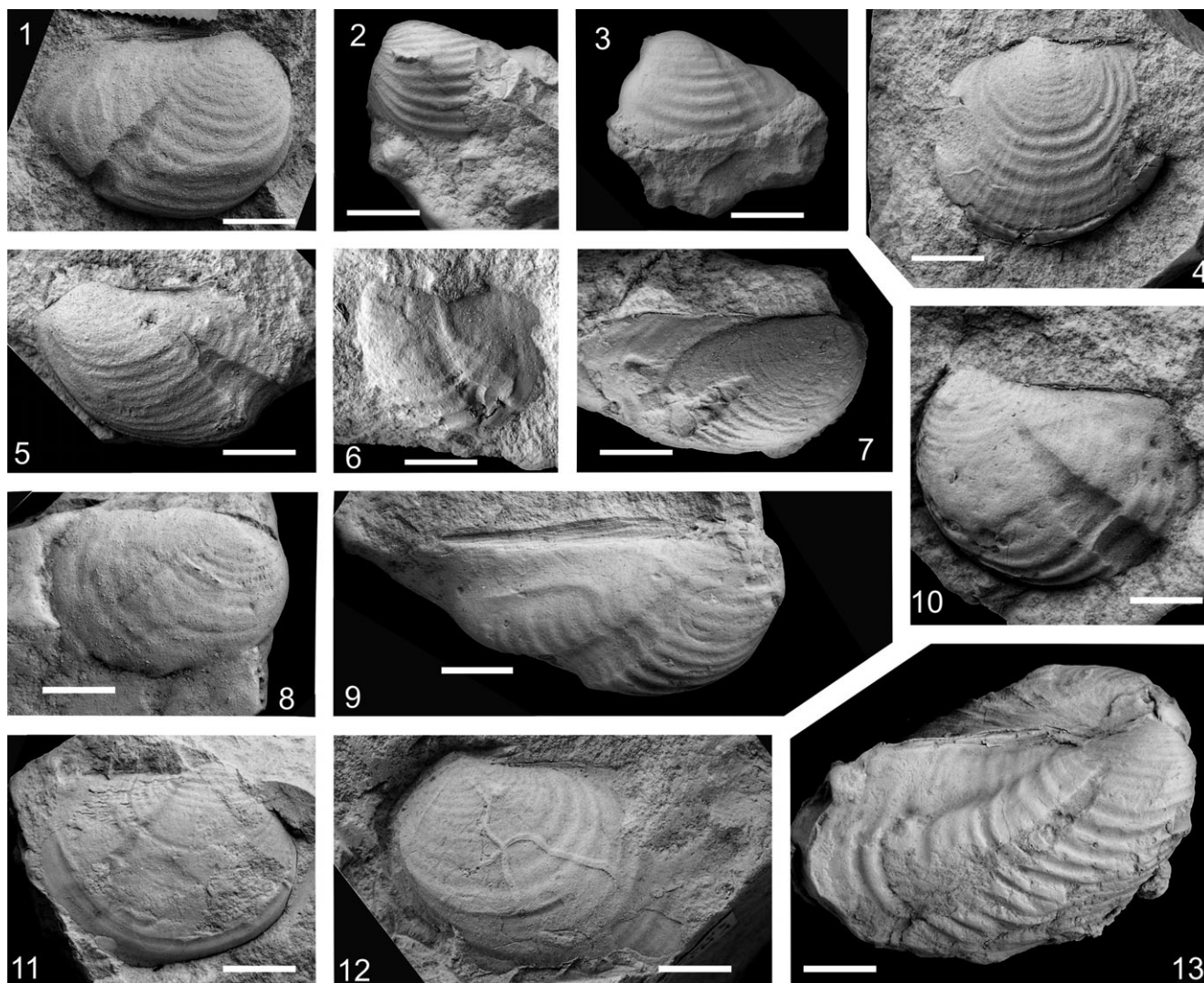


Fig. 7. *Inoceramids of the Vijlen Member*; 1-13. *Inoceramus* 'ianjonaensis' *morgani* (Sornay, 1973) (NHMM NK 7; Wilkensberg, interval 5; NHMM JJ 6705; CPL-Haccourt, interval 6; NHMM JJ 12266; CPL-Haccourt, interval 6; NHMM NK 16; Wilkensberg, interval 5; NHMM JJ 3090b; CPL-Haccourt, interval 6; NHMM JJ 12204; CPL-Haccourt, interval 6; NHMM JJ 3509; CPL-Haccourt, interval 6; NHMM NK 13; Wilkensberg, interval 5; NHMM JJ 2812; CPL-Haccourt, interval 6; NHMM JJ 2685b; CPL-Haccourt, interval 6; NHMM JJ 6447; CPL-Haccourt, interval 6; NHMM NK 19; Wilkensberg, interval 5; NHMM JJ 3893; CPL-Haccourt, interval 6, respectively. All scale bars represent 10 mm.

observations), where no facies dependence, based on lithology of rock fragments attached to the museum specimens, can be inferred. The studied material is not large enough to allow a final judgement, but it may appear reasonable to distinguish both morphotypes as separate taxa.

The material studied shows a wide range of morphological variation, mostly with respect to size of the juvenile stage, juvenile obliquity and the presence and strength of radial ornament. It matches well the variability of *I. ianjonaensis* as observed within the rich material from Libya (Tröger & Röhlich, 1991), Nigeria (López et al., 2004) and particularly from Zululand (Walaszczyk et al., 2009).

Occurrence

In the study area, *I. ianjonaensis morgani* occurs in the

uppermost portion of interval 5 and in interval 6, corresponding to the lower *Belemnitella junior* Zone. This level is roughly correlatable with the upper *Spyridoceramus tegulatus/Belemnitella junior* Zone in northern Germany. The subspecies *morgani* is also known from Calcaire à *Baculites*, Manche (France), from a level in the upper Maastrichtian (see Kennedy, 1986) and from the Bay of Biscay sections (southwest France, northern Spain), where it ranges throughout the lowermost part of the *Menuites fresvillensis* Zone (MacLeod, 1994, fig. 4). The species *I. ianjonaensis* is widely distributed in Africa (Libya, Nigeria, Zululand) and Madagascar.

Inoceramus 'sp.

Fig. 4/1.

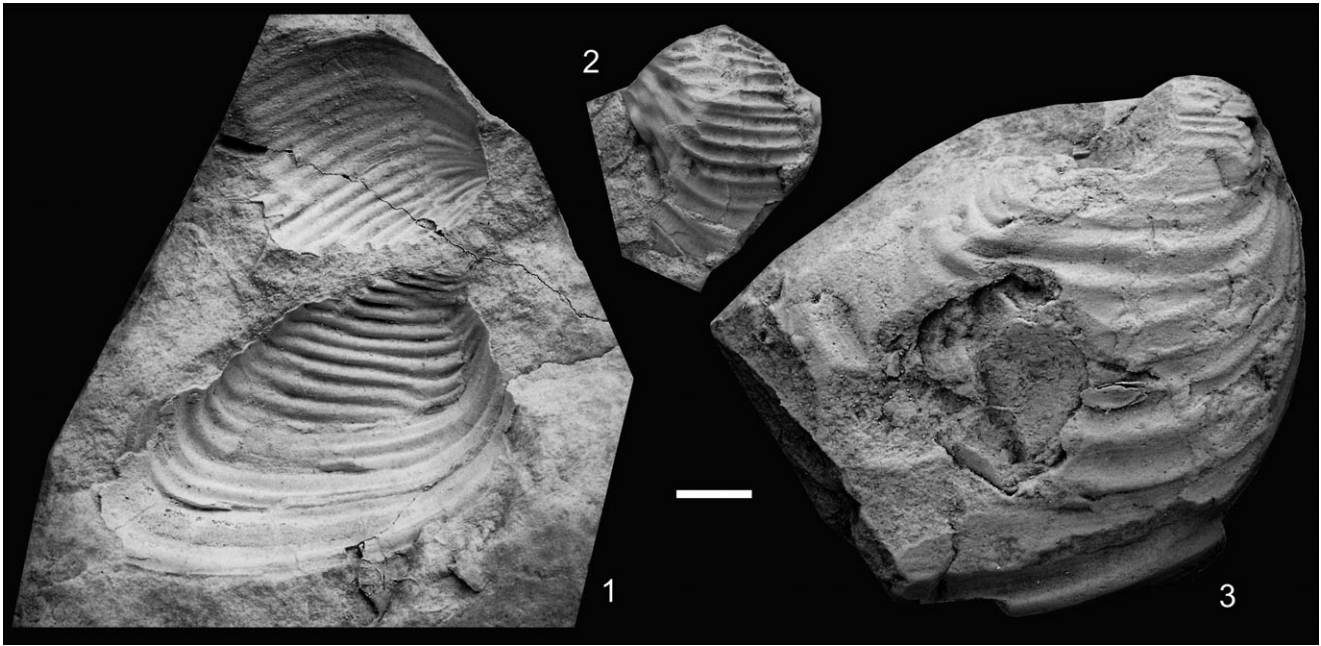


Fig. 8. *Inoceramids of the Vijlen Member*; 1-3. *Endocostea coxi* (Reyment, 1955) (NHMM NK 25; Hans-Böckler-Allee, interval 5; NHMM NK 27 and NHMM NK 6; both Wilkensberg, uppermost portion of interval 5, plus interval 6). All scale bars represent 10 mm.

Material

A single specimen: NHMM NK 35 (Lemiers-Schneeberg; exact provenance from within the Vijlen Member is unknown, but may have originated from interval 3).

Description and remarks

This is a single internal mould of a left valve; incomplete, with its dorsal and posterior parts missing. Despite this, the specimen clearly displays the anterior position of the beak and two growth stages; with the juvenile stage weakly inflated, quite large ($h_{\max} = 66$ mm) and the adult stage growing at a high angle in the anterior part and only weakly geniculated in the ventral and postero-ventral parts of the valve. The juvenile stage is covered with regularly spaced, sharp concentric rugae, with deep interspaces; the rugae are distinctly oblique in that portion of the valve anterior to the growth axis.

The type of ornament makes the specimen close to 'endocostean' inoceramids (see above, under *Endocostea* cf. *jolkicevi*). Rugae obliquity has been noted for numerous Late Cretaceous inoceramids, and in the Maastrichtian it is a feature found in trochoceramids and some *Cataceramus*-like forms.

Occurrence

Known only from ?interval 3, equating with the *Belemnella cimbrica* Zone.

Genus *Spyridoceramus* Heinz, 1932

Type species

Inoceramus tegulatus Von Hagenow, 1842 (non Ødum, 1922).

Spyridoceramus tegulatus (von Hagenow, 1842)

Fig. 9/1-8.

- 1842 *Inoceramus tegulatus* Von Hagenow, p. 559.
- 1932 *Inoceramus* (*Spyridoceramus*) *tegulatus* v. Hagenow; Wolansky, p. 28, pl. 4, fig. 5; pl. 5, figs 5, 6.
- non1959 *Inoceramus tegulatus* v. Hagenow; Dobrov & Pavlova, p. 150, pl. 23, figs 1-4 (= *Tenuipteria argentea*).
- 1986 *Spyridoceramus tegulatus* v. Hagenow; Abdel-Gawad, p. 146, pl. 31, figs 1, 2 (plus additional synonymy).
- 1995 *Spyridoceramus tegulatus* (von Hagenow); Keutgen, p. 311, pl. 8, fig. 4.
- 2001 *Spyridoceramus* cf. *tegulatus* (Hagenow); Tröger et al., p. 156, pl. 1, fig. 6; pl. 3, fig. 2; text-fig. 12.

Type

Lectotype, by subsequent designation of Speden (1970, p. 6), is the original of Wolansky (1932, pl. 5, fig. 6) from the lower Maastrichtian of Rügen (northeast Germany), a specimen from Von Hagenow's original collection.

Material

Sixteen specimens: NHMM NK 12 and NK 15A, B (both Schurzelterstraße, interval 3); NHMM NK 18 I, 22, 29 (external and internal moulds of the same specimen; Vaalserstraße, interval 4); NHMM NK 11A, B (two specimens; Hans-Böckler-Allee, interval 5); NHMM NK 32 and 20 (external and internal moulds of the same specimen) and NHMM NK 9 and 31 (internal and external mould of same specimen) (both Wilkensberg, uppermost portion of interval 5, plus interval unit 6); NHMM

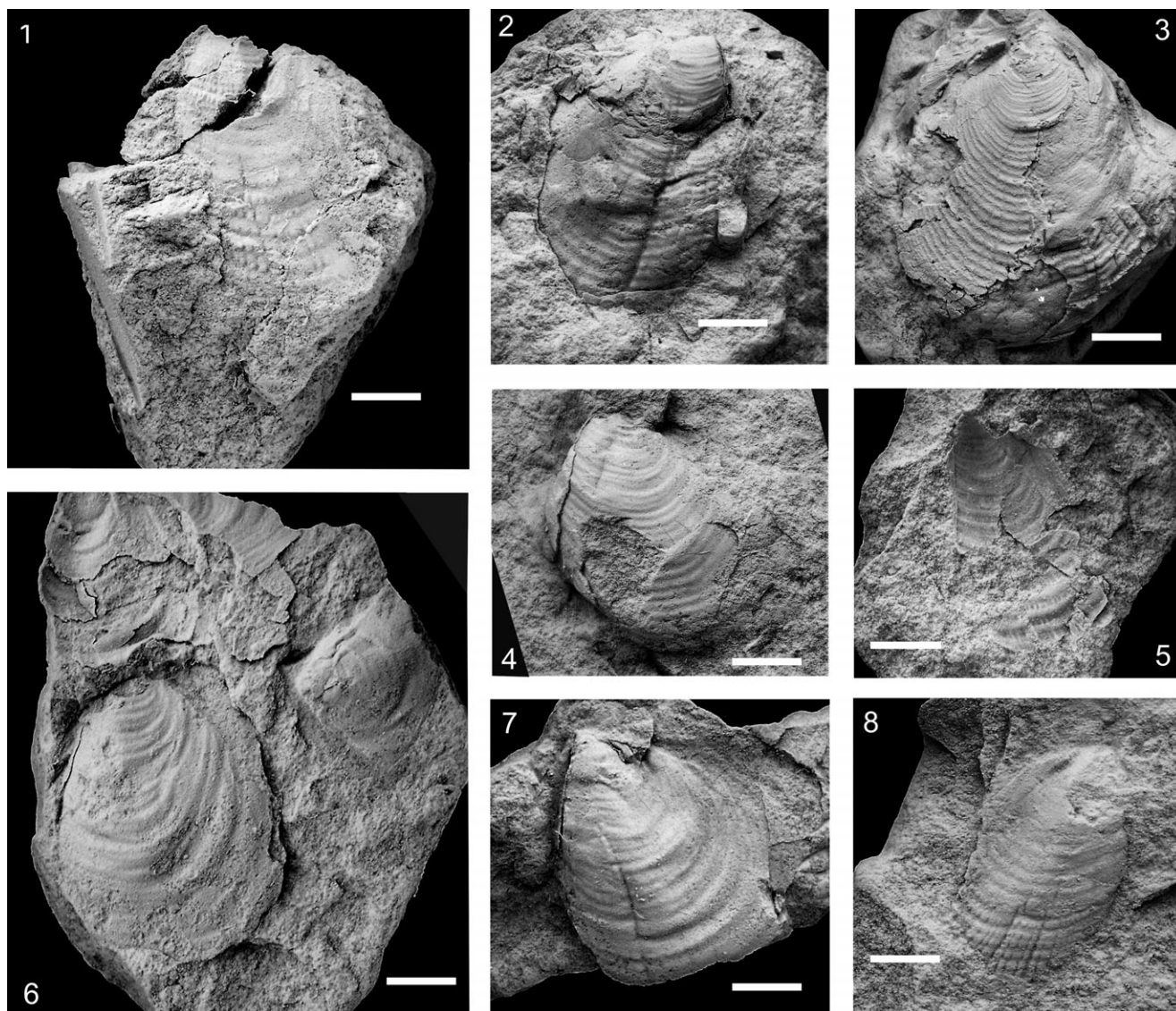


Fig. 9. *Inoceramids* of the Vijlen Member; 1, 5, 8. *Spyridoceramus tegulatus* (Von Hagenow, 1842) forma A (NHMM NK 18 I; Vaalserstraße, interval 4; NHMM NK 15A and NHMM NK 12; Schurzelterstraße, interval 3). 2-4, 6-7. *Spyridoceramus tegulatus* (von Hagenow, 1842), forma B (NHMM JJ 6375b; CPL-Haccourt, interval 6; NHMM JJ 3898; CPL-Haccourt, interval 6; NHMM NK 9; Wilkensberg, interval 5; NHMM NK 11B and NK 11A; Hans-Böckler-Allee, interval 5, respectively). All scale bars represent 10 mm.

NK 30A, B (strongly deformed; internal and external moulds of the same specimen), NHMM JJ 3898, JJ 4730, JJ 6375A-E, JJ 7011 and JJ 11853 (all CPL SA-Haccourt quarry, uppermost portion of interval 5, plus interval 6).

Description and remarks

Although the species is relatively common in the material studied, the actual number of specimens is rather low; altogether sixteen specimens, spanning intervals 3 to 6. At least three morphotypes can be distinguished in the material, which are here referred to as formae A, B and C.

Specimens from interval 3 belong to forma A; these are axially elongated, slender, with concentric rugae dominating the ornament pattern (NHMM NK 12, 15A, B, 18, 22, 29) (Fig. 9/1, 5, 8); radial elements are in the form of discontinuous ribs, forming

lines of nodes at the intersections with concentric rugae. This morphotype is the closest to illustrated specimens of *Tenuipteria fibrosa* (Meek & Hayden, 1860) (e.g., Speden, 1970, pl. 1, figs 1-6; Wright, 1981, pl. 2, figs 6-11, plus pl. 2, figs 1-5 referred to *Tenuipteria concentrica*). The type of *Spyridoceramus tegulatus* (illustrated by Wolansky, 1932, pl. 5, fig. 6), which, however, is incompletely preserved, belongs probably to the same variety.

A broader morphotype, forma B, with the ornament composed almost exclusively of concentric rugae (NHMM NK 11A, B, 9, 31) appears in interval 5 (Fig. 9/2-4, 6-7). The same morphotype appears to predominate in material from interval 6 (NHMM JJ 3898, 6375B-C, 6375A-E, 6375D; NHMM NK 30A, B). This wide morphotype resembles var. *ravni* of *Inoceramus caucasicus* of Dobrov (1951, p. 169, pl. 2, figs 9, 10). In the latter unit there are also two specimens (NHMM JJ 7011, JJ 11853) with very

strong radial ornament, forma C. This variety resembles closely var. *fistulata* of *Inoceramus caucasicus* described by Dobrov (1951, p. 169, pl. 2, fig. 8), as well as one of Von Hagenow's syntypes illustrated by Wolansky (1932, pl. 4, fig. 5).

The morphotypes recognised in our material potentially could have stratigraphic implications, but the low number of specimens precludes any definitive interpretation. The observed variability within *Spyridoceramus tegulatus* (see e.g. Dobrov, 1951) may appear to be a reflection of the evolutionary pattern within the *tegulatus* lineage, and consequently, could be used for taxonomic and stratigraphic purposes. The report by Kauffman et al. (1993) and the study by Wright (1981) suggest that there may be this potential; however, no precise stratophenetic analysis of the European material has been carried out yet.

Occurrence

In the United States Western Interior, the oldest representative of the *Tenuipteria-Spyridoceramus* group appears in the *Baculites baculus* Zone (Jeletzky, 1968), the base of which corresponds to the base of the *Endocostea typica* Zone. In the Wisła River sections, the oldest *Spyridoceramus* was reported from Dziurków quarry (Abdel-Gawad, 1986), within the *Endocostea typica* Zone, and corresponding, most probably, to the upper *Belemnella pseudobtusa* Zone. According to Dhondt (1982), *S. tegulatus* ranges up to the base of the *Belemnitella junior* Zone; reference is also made to Jagt (1999) for a brief discussion on the ranges of *S. tegulatus* and *T. argentea* in the type Maastrichtian.

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