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The belemnite zonation of the uppermost Cretaceous in the Maastricht-Aachen-Liège, Brabant-Méhaigne and Mons areas (Belgium, southeast Netherlands)*

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Abstract

An overview is presented of belemnitellid faunas of Santonian to Maastrichtian (Late Cretaceous) age in the Mons Basin and in the Brabant-Méhaigne and Maastricht-Aachen-Liège areas (Belgium, southeast Netherlands). As many as twenty-two species of the genera *Actinocamax* Miller, 1823, *Gonioteuthis* Bayle, 1878, *Belemnitella* d'Orbigny, 1840 and *Belemnella* Nowak, 1913 have been recorded to date. On the basis of these, thirteen zones can be distinguished: three in the Santonian (*G. w. westfalica*, *G. westfalicagranulata* and *G. granulata*), six in the Campanian (*G. granulataquadrata*, *G. quadrata*, *Blt. mucronata*, *Blt. woodi*, *Blt. minor* I and *Blt. minor* II) and four in the Maastrichtian (*Bln. obtusa*, *Bln.* ex gr. *sumensis/cimbrica*, *Blt. junior* and *Bln. kazimiroviensis*). Correlative schemes between these zones and those proposed for Norfolk (southeast England) and for the combined Lägerdorf-Kronsmoor-Hemmoor section (northern Germany) are presented. The belemnitellid assemblage of the study area closely resembles that of Norfolk, but differs from the late Campanian faunas of northwest Germany.

Keywords: Belemnitellids, stratigraphy, *Actinocamax*, *Gonioteuthis*, *Belemnitella*, *Belemnella*, Upper Cretaceous, Belgium, the Netherlands

Introduction

During the last decades, belemnitellid cephalopods (Coleoidea) have been considered to be of fundamental importance for biostratigraphy and correlation of the Upper Cretaceous of Europe, particularly during the Santonian to Maastrichtian stages, because they are common and widely distributed and have a high fossilisation potential (Christensen, 1996, 1997). However, detailed studies carried out by Christensen (1995, 1999, 2000a, b) have shown a significant regional component within distributional patterns, in particular for the genus *Belemnitella*, during the late Campanian in northwest Europe. While in Norfolk (southeast England), the Maastricht-Aachen-Liège area (MAL; southeast Netherlands and adjacent areas) and the Mons Basin (southern Belgium), members of the lineage *Blt. mucronata / woodi / minor* I/ *minor* II predominate, *Blt. mucronata* persisted in northern Germany (Misburg-Höver area, east of Hannover) and Skåne, southern Sweden, (almost) to the top of the *Blt. woodi* Zone in the lower upper Campanian. In the upper upper Campanian, members of the *Blt. minor* group have not (yet) been identified in northern Germany (Kronsmoor, Lägerdorf), but there *Blt. langei* (sensu Schulz, 1978) and *Blt. schulzi* appear, two forms apparently restricted to that region and unknown from Norfolk, the Mons Basin and the MAL area. From the Vistula (Wisła) River valley in east-central Poland, another rich Belemnitella fauna has recently been noted in the upper Campanian, comprising additional regional elements such as *Blt. posterior* Kongiel, 1962 (Christensen, unpubl. data; Remin, 2007).

According to Christensen (2000b), his earlier suggestion (see Christensen, 1999) that the upper Campanian belemnite zonation of Norfolk could be used as a formal zonation throughout northwest Europe was no longer tenable. Hence, it is necessary first to establish regional belemnite zonations based on developmental lineages of the locally dominant species and, secondly, to note temporary invasions of additional species. These short-term invasions may be of great stratigraphic value as has been documented for instance for *Bln. praearkhangelskii* in the upper lower Maastrichtian of northwest Europe (Schulz, 1979; Keutgen, 1997). Alternatively, such temporary immigration events may reflect temporarily suitable environmental

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conditions for these belemnite species, which should then be considered more or less stenoecious.

The Upper Cretaceous deposits in the MAL, Brabant-Méhaigne and Mons areas (Fig. 1) have been subdivided into a large number of lithostratigraphic units; lithologies comprise chalks, calcarenites, calcirutites, sandstones, sands, silts and clays (Robaszynski et al., 2002). Differences in facies, and hence faunas, have hampered correlation of lithostratigraphic units. For example, the Benzenrade Member, considered the uppermost unit of the Vaals Formation, replaces (almost) the entire Gulpen Formation in the block-faulted region close to the Rur Valley Graben in the MAL area (Jagt, 1999; W.M. Felder & Bosch, 2000).

In addition, the exact stratigraphic age of the base and top of certain lithostratigraphic units is not well documented; in fact, it may even differ among localities. An example is the Vijlen Member, the oldest portions of which have been preserved solely within channel-like structures (P.J. Felder, 1997). Facies relationships in the MAL area have been discussed more fully by Bless et al. (1987) and P.J. Felder (2001), to whom reference is made.

The present study summarises available data on belemnitellid distribution during the Santonian, Campanian and Maastrichtian in the study area. None of these classic areas (separated by 125 km at most) offers a complete belemnite record for the latest 20 myr of the Cretaceous, but taken together, these regions provide an adequate overview of belemnite taxa populating these nearshore habitats, which were under tectonic control by the Ardennes and Brabant-London massifs and the Roer Valley Graben in the north.

Fig. 1. Map showing the location of the Mons Basin and the Brabant-Méhaigne and Maastricht-Aachen-Liège (MAL) areas.

Santonian-Maastrichtian belemnite zones; belemnites and stage boundaries

Coniacian/Santonian boundary

This boundary is defined by the first appearance datum (FAD) of the inoceramid bivalve *Cladoceramus undulatoplicatus* (Roemer, 1852), as discussed by Gale et al. (2007). The Santonian Stage is subdivided into a lower, middle and upper portion, but boundaries between these cannot be identified by belemnites. *Gonioteuthis westfalica praewestfalica* Ernst & Schulz, 1974 crosses the Coniacian/Santonian boundary, while *G. w. westfalica* (Schlüter, 1876) is known from the upper lower and lower middle Santonian (Christensen, 1997). Only the base of the upper Santonian can be identified by the FAD of *Gonioteuthis granulata* (De Blainville, 1827).

Santonian belemnite zones

Gonioteuthis westfalica westfalica *Zone*

Age
Late early-early middle Santonian.

Species recorded
Gonioteuthis w. westfalica and *Actinocamax verus* Miller, 1823.

Example
Lonzée Member ('Glauconie de Lonzée') near Gembloux, south-east Belgium.

Reference
Christensen (1994).

Remarks
Belemnitellids from the Lonzée Member represent a heterogeneous lot, comprising different species of *Gonioteuthis*. The majority of specimens can be assigned to *G. w. westfalica* and hence most belemnites in this unit, including *A. verus*, are assumed to originate from this zone. The Lonzée Member either represents a condensed deposit, with repeated winnowing having resulted in an admixture of belemnites from different zones, or, alternatively, is of late Santonian age (possibly even younger, i.e., earliest Campanian), and contains species reworked from the lower and middle Santonian. In Fig. 2, the first interpretation is favoured, in line with Robaszynski et al. (2002, fig. 1). The Lonzée Member in the Brabant-Méhaigne area is generally considered to be coeval with the Saint-Vaast Chalk Formation in the Mons Basin, for which Robaszynski et al. (2002) recorded *A. verus*. In England, this species ranges from the Coniacian to the lower lower Campanian *Offaster pilula* Zone *sensu germanico* (Christensen, 1991).

Gonioteuthis westfalicagranulata *Zone*

Age
Late middle Santonian.

Species recorded
Gonioteuthis westfalicagranulata (Schlüter, 1876) and *Actinocamax verus*(?).

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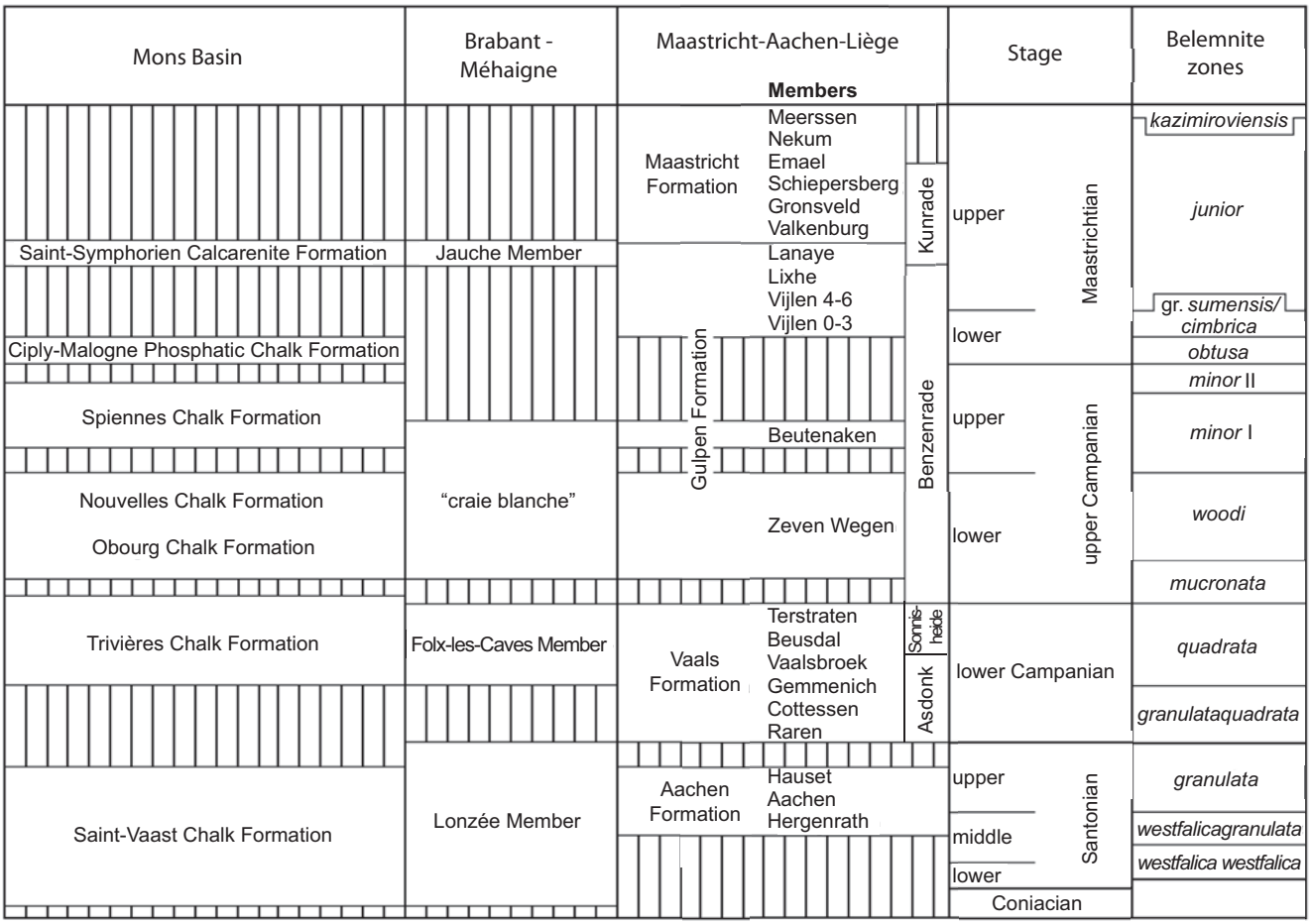

Fig. 2. Stratigraphic age and belemnite zones for the Upper Cretaceous (Santonian-Maastrichtian) of the Mons Basin and the Brabant-Méhaigne and Maastricht-Aachen-Liège areas.

Examples

Vaals Formation (Asdonk Member) in the Campine Basin, northeast Belgium; material collected during mine shaft construction (Houthalen and Zolder/Voort collieries); Lonzée Member near Gembloux, southeast Belgium.

References

Christensen (1994) and Jagt et al. (1995b).

Remarks

A small sample of Gonioteuthis from the Houthalen and Zolder/Voort collieries (MAL area) has been assigned to *G. westfalicagranulata* by Jagt et al. (1995b). In addition, a few specimens from Lonzée have been referred here (Christensen, 1994). In view of the fact that *A. verus* is unknown from the former Houthalen and Zolder/Voort collieries, but does occur at Lonzée, its presence in this zone cannot be ascertained (Fig. 3).

Slimani et al. (2011) proposed an early Campanian date for the levels penetrated in the Houthalen and Zolder/Voort mine shafts, which is at odds with the late middle Santonian date based on belemnites. Nannofossil assemblages indicate a late Santonian, possibly early Campanian, age (Jagt et al., 1995b), similar to what Slimani et al. (2011) suggest. Should future studies document an earliest Campanian date for these deposits, *G. westfalicagranulata* from the Houthalen and Zolder/Voort collieries may be considered to have been reworked.

Data from geophysical well logs, cores and boreholes in the Campine Basin favour a twofold subdivision of the Vaals Formation into an upper (Sonnisheide Member) and a lower (Asdonk Member) unit. The relationships to the classic six members of the Vaals Formation in the Aachen-Vaals area have not been firmly established yet. The base of the Sonnisheide Member corresponds to the base of Ecozone Ic of P.J. Felder (2001), which was tentatively correlated with the base of the Beusdal Member in the type area of the Vaals Formation (P.J. Felder, 2001).

Gonioteuthis granulata *Zone*

Age

Late Santonian.

Species recorded

Gonioteuthis granulata (De Blainville, 1827) and *Actinocamax verus*(?).

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Example
Lonzée Member near Gembloux, southeast Belgium.

Reference
Christensen (1994).

Remarks
Christensen (1994) assigned some guards from this unit to *G. granulata*.

Santonian/Campanian boundary

This boundary equates with the last appearance datum (LAD) of the crinoid *Marsupites testudinarius* (Von Schlotheim, 1820), as discussed by Gale et al. (2008), which coincides with the FAD of *Gonioteuthis granulataquadrata* (Stolley, 1897) in northwest Germany (Gale et al., 1995). The lower Campanian substage may be subdivided into a lower and an upper portion, the boundary being situated within the *Gonioteuthis q. quadrata* Zone (Fig. 3).

Lower Campanian belemnite zones

Gonioteuthis granulataquadrata *Zone*

Age
Earliest early Campanian.

Species recorded
Gonioteuthis granulataquadrata and *Belemnitella praecursor* Stolley, 1897.

Examples
Vaals Formation, uppermost Cottessen and Gemmenich members (c. 0.3 m below and c. 6.1 m above the Gemmenich Horizon) at Aachen-Lütticher Straße, Osterweg (western Germany).

Reference
Albers (1976).

Remarks
The identification of *G. granulataquadrata* near Aachen was based on five plus eight specimens (Albers, 1976), respectively, which may be regarded the critical number of specimens needed for a reliable assessment. One of the specimens from the Gemmenich Member had a deep pseudoalveolus and thus resembled *G. quadrata* (De Blainville, 1827). For this reason, the top of the *G. granulataquadrata* Zone is placed tentatively within the Gemmenich Member (Fig. 2).

A fragment of *Blt. praecursor* is known from the uppermost Cottessen Member (Albers, 1976). From the Lonzée Member, Christensen (1994) noted two specimens of *Gonioteuthis* with a comparatively deep pseudoalveolus; these represent either *G. granulata* or *G. granulataquadrata*.

		Biozones of Lägerdorf	Belemnite zones of Lägerdorf (northern Germany) and England	Belemnite zones of Mons basin and Maastricht-Aachen-Liège area
lower Campanian	upper	*gracilis/mucronata*	*G. q. gracilis/Blt. mucronata*	*G. quadrata*
		conica/gracilis	*G. quadrata gracilis*	
		papillosa	*G. quadrata quadrata*	
		senonensis		
		pilula/senonensis		
	lower	*pilula*		
		lingua/quadrata		
		granulataquadrata	*G. granulataquadrata*	*G. granulataquadrata*
Santonian	upper	*Marsupites/granulata*	*G. granulata*	*G. granulata*
		Uintacrinus/granulata		
	mid.	*rogalae/westfalicagranulata*	*G. westfalicagranulata*	*G. westfalicagranulata*
		rogalae/westfalica	*G. westfalica westfalica*	*G. westfalica westfalica*
	lower	*coranguinum/westfalica*		
		pachti/undulatoplicatus	*G. westfalica praewestfalica*	*Gonioteuthis* extremely rare in NW Europe

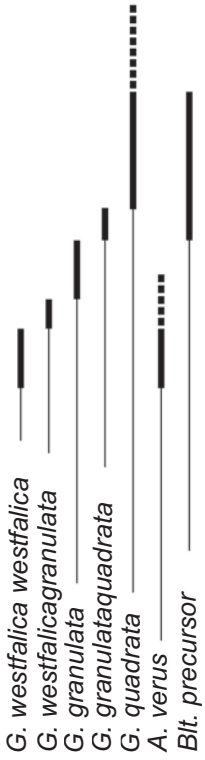

Fig. 3. Stratigraphical correlation diagram for the Santonian and lower Campanian (sources: Schulz et al., 1984; Christensen, 1997; Niebuhr, 2006). Abbreviations: A. = Actinocamax, *Blt.* = Belemnitella, *G.* = Gonioteuthis. *Dots indicate that the presence of a species at this level is uncertain. Vertical axis not to scale.*

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Gonioteuthis quadrata *Zone*

Age

Youngest portion of early early and late early Campanian.

Species recorded

Gonioteuthis quadrata and *Belemnitella praecursor*.

Examples

Vaals Formation, lowermost Beusdal Member, Hombourg, northeast Belgium; Vaals Formation, uppermost 3 m of smectite facies, former Ciments Portland Liégeois (CPL SA) quarry, Haccourt, northeast Belgium; Folx-les-Caves Member, Folx-les-Caves, Jauche (Orp-Jauche, eastern Brabant, Belgium).

References

Albers (1976), Christensen & Schmid (1987), Bless et al. (1991).

Remarks

According to Christensen & Schmid (1987), the belemnite assemblage of the uppermost portion of the smectite facies at Haccourt is typical of the upper *lingua/quadrata* Zone *sensu germanico*. A comparable age assignment (*lingua/quadrata* to *senonensis zones*) was proposed by Albers (1976) for a sample of *G. quadrata* from the Beusdal Member.

Robaszynski et al. (2002) noted *G. quadrata* from the Trivières Chalk Formation in the Mons Basin and from the Folx-les-Caves Member in the Brabant-Méhaigne region (Petite Gette valley). According to Christensen (1999), *Blt. praecursor* may occur in the Trivières Chalk Formation as well, but this is in need of confirmation.

Of *G. quadrata* three subspecies are distinguished, viz. *G. q. quadrata*, *G. q. gracilis* (Stolley, 1892) and *G. q. scaniensis* Christensen, 1975, the last-named representing a geographic subspecies from the uppermost lower Campanian of Skåne, southern Sweden. In the study area, only *G. q. quadrata* has been identified to date. For comparison, *G. q. gracilis* has also been recorded from Norfolk (Attlebridge and Ringland), but both specimens known were referred by Christensen (1991) to this subspecies with a query. Fletcher & Wood (1978, p. 95) noted *G. q. gracilis* from northern Ireland. For the time being, the latest early Campanian *G. q. gracilis* is not known from the MAL and Mons areas, which is why a *G. q. gracilis* subzone cannot be distinguished there.

Lower/upper Campanian boundary

The position of this boundary still is a matter of debate. The 'classic' zonation of the Campanian in the type area of Aquitaine (France) distinguishes, from base to top, a lower Campanian *Placenticeras bidorsatum* Zone overlain by the *Menabites delawarensis* Zone, and an upper Campanian *Hoplitoplacenticeras marroti* Zone, followed by the *Bostrychoceras polyplocum* Zone. In the MAL area, the base of the upper Campanian has therefore been placed at the FAD of *Hoplitoplacenticeras* (*H.*) *marroti* (Coquand, 1859) within the upper part of the Vaals Formation (Kennedy, 1986, 1987; Jagt et al., 1995a; Jagt, 1999). From an outcrop near Cottessen (Nieuwe Weg at the Zeven Wegen, between Epen and Vaals, southern Limburg, the Netherlands), Jagt et al. (1995a) recorded three specimens of *H. marroti*, in addition to five specimens from a field south of the so-called 'Koning van Spanje' near Gulpen, all from the Vaals Formation. At Cottessen, all belemnites collected from this formation are referred to as *Gonioteuthis* gr. *quadrata*, implying the co-occurrence of a late Campanian index ammonite and an early Campanian index belemnite species. This observation would be in line with the record by Kaever & Lommerzheim (1991) from the Münsterland area (northwest Germany), where *G. quadrata* gracilis was found c. 19 m above the FAD of *H. marroti*, indicating that this ammonite indeed predates the belemnite-defined lower/upper Campanian boundary.

In terms of belemnites, the lower/upper Campanian boundary has commonly been placed at the extinction level of *Gonioteuthis* (Jeletzky, 1958). The FAD of *Belemnitella mucronata* (Von Schlotheim, 1813) also predates the demise of *Gonioteuthis*. In northern Germany, *G. quadrata gracilis* and *Blt. mucronata* co-occur within the *gracilis/mucronata* Zone (Christensen, 2000b). Co-occurrences of *Gonioteuthis* and *Blt. mucronata* are also known from the Trivières Chalk Formation in the Mons Basin, c. 0.4 m below the Obourg Chalk Formation (CCC pit, Harmignies) as well as from the lowermost Zeven Wegen Member (former CPL SA quarry), but the *Gonioteuthis* material has been considered remanié (Jagt, 1984; Robaszynski & Christensen, 1989).

In summary, for the MAL, Brabant-Méhaigne and Mons areas, the LAD of *G. q. gracilis* cannot be used to define the top of the lower Campanian, because this subspecies has not yet been identified. Possible alternative candidates, i.e., the FADs of *H. marroti* or *Blt. mucronata*, predate the lower/upper Campanian boundary as defined in northwest Germany. The advantage of adopting *H. marroti* as the index taxon is its presence and use as a zonal index in the Aquitaine Basin of southwest France, in addition to its wide distribution with records from Germany, Portugal, Israel, central Asia, Madagascar and Texas (Jagt et al., 1995a). In contrast, *Blt. mucronata* is less widely distributed, being limited to the North European Province, but occurs more frequently in the corresponding deposits than does *H. marroti*. In the MAL area, it might occur slightly later than *H. marroti*, indicating that its FAD could be closer to the LAD *of G. q. gracilis*, which defines the lower/upper Campanian boundary in northwest Germany.

It is concluded here that for international correlation the FAD of *H. marroti* is more suitable to define the base of the upper Campanian substage in the study area. Nevertheless, the FAD of *Blt. mucronata* is accepted for the present study in order to facilitate correlation between the various ints in the study area.

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Lower upper Campanian belemnite zones

Belemnitella mucronata *Zone*

Age
Earliest late Campanian.

Species recorded
Belemnitella mucronata.

Examples
Vaals Formation, Benzenrade Member, de Dael (Ubachsberg), the Netherlands; Gulpen Formation, lowermost 5 m of Zeven Wegen Member, former CPL SA quarry, Haccourt, Belgium; Trivières Chalk Formation (uppermost 6 m), CCC pit, Harmignies, Belgium; Obourg Chalk Formation (lowermost 1.2 m), CCC pit, Harmignies, Belgium; 'conglomerate' at Folx-les-Caves, Jauche (Orp-Jauche, eastern Brabant, Belgium).

References
Jagt et al. (1987), Bless et al. (1991), Christensen (1999) and Keutgen & Jagt (1999).

Remarks
Belemnitella mucronata persisted in Lower Saxony (northern Germany) and in southern Sweden until the middle late Campanian (Christensen, 1986, 1993, 2000b), whereas it developed towards *Blt. woodi* Christensen, 1995 in southeast England, Belgium and the Netherlands during the early late Campanian (Christensen, 1995, 1999; Keutgen & Jagt, 1999).

Belemnitella woodi *Zone*

Age
Early late Campanian.

Species recorded
Belemnitella woodi and *Belemnitella* ex gr. *langei sensu* Christensen, 1995.

Examples
Nouvelles Chalk Formation (uppermost 4 m, with exception of hardground at top of unit), CCC pit, Harmignies, Belgium; Gulpen Formation, Zeven Wegen Member (10-28 m above base of unit), former CPL SA quarry, Haccourt, Belgium.

References
Christensen (1999) and Keutgen & Jagt (1999).

Remarks
Christensen (1995) distinguished early and late forms of *Blt. woodi*, the former being less slender than the latter. In the former CPL SA quarry, the section between 6 and 17 m above the base of the member yielded early forms, and that between 17 and 28 m, late forms of *Blt. woodi*.

Within the uppermost *Blt. woodi* Zone, *Belemnitella* ex gr. *langei* occurs in the Mons Basin, a form unknown from elsewhere in the study area (Fig. 4). According to Christensen (1999), it is characterised by a small and slender to very slender guard, which is slightly lanceolate in ventral view. Because the internal characters are known only from a single specimen, it is presumed that the Schatzky Distance is small and the fissure

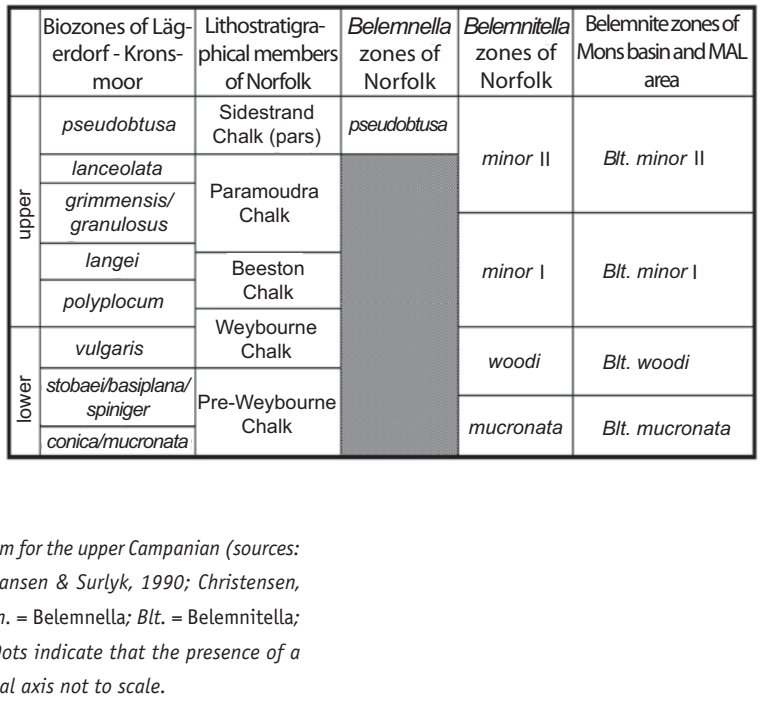

Fig. 4. Stratigraphical correlation diagram for the upper Campanian (sources: Schulz, 1979; Schulz et al., 1984; Johansen & Surlyk, 1990; Christensen, 1999; Niebuhr, 2006). Abbreviations: Bln. = Belemnella*; Blt.* = Belemnitella*; MAL = Maastricht-Aachen-Liège area. Dots indicate that the presence of a species at this level is uncertain. Vertical axis not to scale.*

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angle large. Due to the limited number of specimens, *Blt.* ex gr. *langei* cannot be assigned to any known species of the genus with certainty (Christensen, 1999).

Lower upper/upper upper Campanian boundary

The base of the upper upper Campanian is usually defined by the FAD of *Nostoceras* (*Bostrychoceras*) *polyplocum* (Roemer, 1841). In Norfolk, *Blt. minor* I Jeletzky, 1951 first appears in the Catton Sponge Bed, from which many specimens of *N.* (*B.*) *polyplocum* probably originated as well (Johansen & Surlyk, 1990). That particular bed forms the top of the Weybourne Chalk Member in Norfolk. The FAD of *Blt. minor* I represents an excellent approximation for the base of the upper upper Campanian (Figs 2, 4).

Upper upper Campanian belemnite zones

Belemnitella minor *I Zone*

Age
Late late Campanian.

Species recorded
Belemnitella minor I and *Belemnitella najdini* Kongiel, 1962.

Examples
Nouvelles Chalk Formation (hardground at top of unit), CCC pit, Harmignies, Belgium; Spiennes Chalk Formation (basal 10 m), CCC pit, Harmignies, Belgium; Gulpen Formation, Beutenaken Member at Slenaken and Bovenste Bos, the Netherlands.

References
Christensen (1999), Keutgen & Jagt (1999) and Keutgen et al. (2010).

Remarks
Apart from *Blt. minor* I, *Blt. najdini* occurs in this zone, but this has so far only been identified in the MAL area. The Limburg material of *Blt. najdini* corresponds well with specimens from the upper Beeston Chalk Member of Norfolk, as illustrated by Christensen (1995). With respect to its distribution in Norfolk, it is assumed that *Blt. najdini* appeared later than *Blt. minor* I (Fig. 4).

From c. 1.8 m above the base of the Spiennes Chalk Formation (CCC pit, Harmignies), Christensen (1999) recorded, under the name of *Belemnitella* sp., two specimens of the members of the *Belemnitella mucronata* group, characterised by their large and stout rostra (Birkelund indices of 2.9 and 3.2). He assumed these specimens to be related either to *Blt. mucronata* or to *Blt. woodi*, the small number of specimens on record precluding a more detailed identification.

Bless et al. (1991) noted, as *Blt.* gr. *mucronata*, a specimen from the uppermost portion of the 'Craie blanche' as exposed at Orp-le-Petit (eastern Brabant Massif, Belgium), seemingly resembling *Blt. minor* I. This specimen would favour a correlation of the uppermost portion of the 'Craie blanche' either with the hardground at the top of the Nouvelles Chalk Formation or with the Spiennes Chalk Formation in the Mons Basin or with the Beutenaken Member in the MAL area (Bless et al., 1991), a preliminary interpretation, here incorporated in Fig. 2.

Belemnitella minor *II Zone*

Age
Latest late Campanian.

Species recorded
Belemnitella minor II Christensen, 1995 and *Belemnella* (*Pachybelemnella*) *inflata* (Arkhangelsky, 1912).

Examples
Spiennes Chalk Formation (top 1 m), La Malogne-Cuesmes, Belgium; Spiennes Chalk Formation (topmost portion), André et Fils pit no. 6, Ciply, southern Belgium.

Reference
Christensen (1999).

Remarks
The present definition of the top of this zone differs significantly from that originally proposed by Christensen (1995, 1999) for the Norfolk area. While the *Blt. minor* II Zone of Christensen (1999, fig. 8) covered the upper portion of the Paramoudra Chalk Member and the *Bln. lanceolata*, *Bln. pseudobtusa* and most of the *Bln. obtusa* zones of the Sidestrand Chalk Member of Norfolk, the present interpretation defines the top of this zone by the FAD of *Belemnella obtusa* Schulz, 1979 (Figs 4, 5).

On the basis of members of *Belemnella* present in the *Blt. minor* II Zone in Norfolk, this zone may be subdivided informally in the study area into an upper portion with early representatives of that genus and a lower portion without. As formerly defined, the FAD of the genus *Belemnella* marks the base of the Maastrichtian Stage.

In the study area, the *Blt.* minor II Zone has so far been identified only in the topmost Spiennes Chalk Formation of the Mons Basin (Christensen, 1999). However, corresponding deposits must have been present locally during the early late Maastrichtian in the Beutenaken area (MAL area), because a remanié fauna with common *Blt. minor* II and rare *Bln. inflata* has recently been recorded from the base of the Vijlen Member in the Pesaken-Crapoel road section (Keutgen et al., 2010).

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Campanian/Maastrichtian boundary

At the Symposium on Cretaceous Stage Boundaries (Brussels, September 1995), the section at Tercis les Bains, near Dax (Landes, southwest France), was proposed as the Global Standard Stratotype Section and Point for this boundary; this was later ratified (Walaszczyk et al., 2002). However, correlation of this boundary with the belemnite zones established in northwest Europe was fraught with difficulties. On ammonite evidence, Niebuhr (2003, 2004) placed the Campanian/Maastrichtian boundary (as defined at Tercis) close to the top of the *Bln. pseudobtusa* Zone at Kronsmoor, which is well in line with earlier interpretations by Hancock et al. (1993) and Burnett et al. (1998). Ogg et al. (2004) dated the Campanian/Maastrichtian boundary at 70.6 Ma, close to the base of the *Bln. obtusa* Zone. This interpretation is followed herein.

Lower Maastrichtian belemnite zones

Belemnella obtusa Zone

Age
Early early Maastrichtian.

Species recorded
Belemnella (*Pachybelemnella*) *obtusa* Schulz, 1979, *Belemnitella minor* II and *Belemnitella pulchra* Schulz, 1982.

Examples
Ciply-Malogne Phosphatic Chalk Formation at La Malogne, André et Fils pits and Vienne pit near Ciply, southern Belgium.

Reference
Christensen (1999).

Remarks
Similar to the *Blt. minor* II Zone, in situ occurrences of the present zone are known exclusively from the Mons Basin, while in the MAL area this zone has been identified in remanié belemnite material (Keutgen et al., 2010). While *Bln. obtusa* and *Blt. minor* II have been documented from the base of the Vijlen Member at several outcrops in the Beutenaken area, *Blt. pulchra* appears confined to the *Bln. obtusa* Zone in the Mons Basin.

Four remanié specimens of *Belemnella* (*Bln.*) *lanceolata* (Von Schlotheim, 1813) have been collected from the basal Vijlen Member at the Bovenste Bos quarry (3) and near Beutenaken (1) in the MAL area, where they co-occur with *Bln. obtusa* (Keutgen & Van der Tuuk, 1991). They have been remeasured for the present study and the mean values of this small sample for Lsn (c. 74 mm) and AV (c. 21%) are more advanced than those of *Bln. lanceolata* from the *Bln. lanceolata* Zone at Balsvik (southern Sweden) and Kronsmoor (Schulz, 1979). They indicate either the *Bln. pseudobtusa* or the early *Bln. obtusa* zones sensu *germanico* and are tentatively considered to originate from the *Bln. obtusa* Zone.

Belemnella *ex gr.* sumensis/cimbrica *Zone*

Age
Late early Maastrichtian.

Species recorded
Belemnella (*Pachybelemnella*) ex gr. *sumensis* Jeletzky, 1949/*cimbrica* Birkelund, 1957 and *Belemnella* (*Belemnella*) *praearkhangelskii* Naidin, 1964.

Example
Gulpen Formation, Vijlen Member (unit 3), temporarily exposed sections at Aachen-Schurzelterstraße, Germany.

Reference
Keutgen et al. (2010).

Remarks
Belemnites which match the population concepts of both *Bln. sumensis* and *Bln. cimbrica* are common within the Vijlen Member. However, most of the samples recorded in the literature (Keutgen & Van der Tuuk, 1991; Keutgen, 1997) have recently been considered to consist of reworked material. Keutgen et al. (2010) mentioned but a single larger sample of *Belemnella* collected from a level within the Vijlen Member (unit 3) below the FAD of *Belemnitella junior*. This temporary section at Aachen-Schurzelterstraße yielded *Belemnella* ex gr. *sumensis/cimbrica* together with a well-preserved specimen of the typically early Maastrichtian index scaphitid ammonite *Acanthoscaphites tridens* (Kner, 1848). The mean values of characteristic parameters of the Schurzelterstraße sample indicate either a late form of *Bln. sumensis* or, alternatively, *Bln. cimbrica*; a more precise identification is impossible (Keutgen et al., 2010).

From unit 4 of the Vijlen Member at Altembroeck ('s-Gravenvoeren, Fouron-le-Comte), Keutgen (1997) noted early forms of *Bln. sumensis* (common) and of *Bln. praearkhangelskii* (very rare). These species co-occur with typically late Maastrichtian *Blt. junior* and *Blt. lwowensis*, which is why representatives of the genus *Belemnella* have been considered reworked (Keutgen et al., 2010). *Belemnella praearkhangelskii* is known in the Kronsmoor and Hemmoor sections from the middle *sumensis* Zone and has also been identified in Rügen (northern Germany). It is assumed that this species entered Germany and the study area during a short time interval, corresponding to the middle *sumensis* Zone *sensu germanico*.

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Lower/upper Maastrichtian boundary

At the Symposium on Cretaceous Stage Boundaries (Brussels, September 1995), a formal proposal for the definition of the base of the upper Maastrichtian could not be given (Odin et al., 1996). At the ENCI-Heidelberg Cement Group quarry (Maastricht, the Netherlands), the position of the lower/upper Maastrichtian boundary has been drawn, on benthic foraminiferal evidence, at the top of the interval with both *Bolivinoides draco draco* (Marsson, 1878) and *Stensioeina pommerana* Brotzen, 1936, i.e. within unit 6 of the Vijlen Member (Jagt, 2010). At Hemmoor (northwest Germany), Hofker (1961) found the highest occurrence of *Stensioeina* to equate with the lower/upper Maastrichtian boundary, at the base of marl bed T100, while Weiss (1999) pointed out that *S. pommerana* suddenly disappeared there near the top of the *Belemnella cimbrica* Zone, i.e., c. 10 m below marl bed T100. Strontium isotope data (Vonhof et al., 2011) corroborate the correlation of the lower/upper Maastrichtian boundary (as defined at Hemmoor) with a level either close to the base of or within unit 6 of the Vijlen Member.

Despite this, for over half a century, the base of the upper Maastrichtian in northwest Europe was defined by the FAD of *Belemnitella junior*. In the present study, this preliminary definition is accepted for the Mons, Brabant-Méhaigne and MAL areas. At Hemmoor, *Blt. junior* first appears about 4.9 m above marl bed T100 (Christensen et al., 2004), while in the MAL area the first representatives of *Blt. junior* appear close to the base of unit 4 of the Vijlen Member, about 20 m below the lower limit of unit 6 (Keutgen et al., 2010). Additional work is needed in order to explain the inconsistencies between belemnite stratigraphy on the one hand, foraminiferal zones and strontium isotope curves on the other.

Upper Maastrichtian belemnite zones

Belemnitella junior

Age

Early late to late late Maastrichtian.

Species recorded

Belemnitella junior and *Belemnitella lwowensis* Naidin, 1952.

Examples

Gulpen Formation, Vijlen Member (unit 4) at Altembroeck, 's-Gravenvoeren (Fouron-le-Comte, Belgium), Aachen-Hans-Böckler-Allee; Gulpen Formation, Vijlen (units 5-6), Lixhe and Lanaye members, former CPL SA quarry, Haccourt, Belgium; Maastricht Formation, Valkenburg, Gronsveld, Schiepersberg, Emael, Nekum members and lower portion of the Meerssen Member, ENCI-Heidelberg Cement Group quarry near Maastricht, the Netherlands.

References

Jagt (1999), Christensen et al. (2004) and Keutgen et al. (2010).

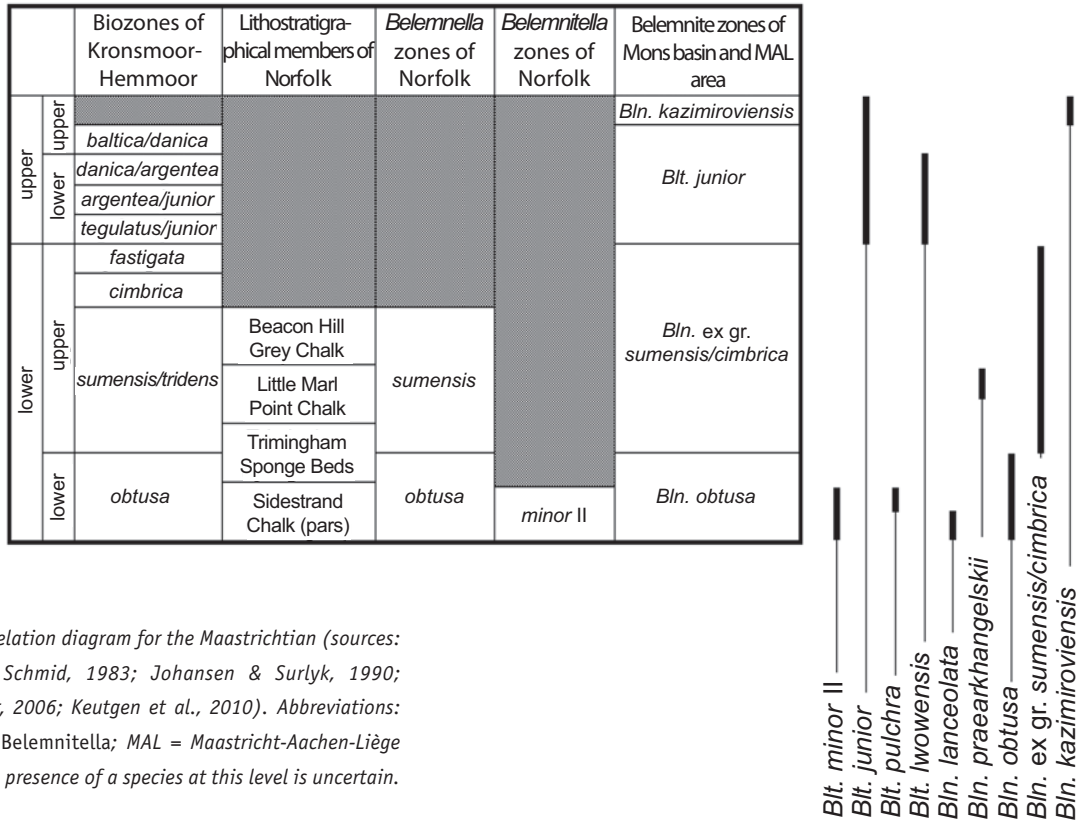

Fig. 5. Stratigraphical correlation diagram for the Maastrichtian (sources: Schulz, 1979; Schulz & Schmid, 1983; Johansen & Surlyk, 1990; Christensen, 1995; Niebuhr, 2006; Keutgen et al., 2010). Abbreviations: Bln. = Belemnella; Blt. = Belemnitella; MAL = Maastricht-Aachen-Liège area. Dots indicate that the presence of a species at this level is uncertain. Vertical axis not to scale.

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Remarks

The earliest representatives of *Blt. junior* and *Blt. lwowensis* are known from unit 4 of the Vijlen Member in the MAL area. In the Brabant-Méhaigne area and the Mons Basin, upper Maastrichtian deposits comprise only the Jauche Member (with *Blt. junior*) and the Saint-Symphorien Calcarenite Formation, which may correspond with portions of the Lanaye Member and lower Valkenburg Member in the MAL area (Bless et al., 1991).

While *Blt. junior* is known from the eponymous zone, the distribution of *Blt. lwowensis* is far less well documented. According to Christensen et al. (2004), that species ranges at least up to the middle portion of the Maastricht Formation (Emael Member).

Belemnella kazimiroviensis

Age

Latest late Maastrichtian.

Species recorded

Belemnella (*Neobelemnella*) *kazimiroviensis* (Skołozdrówna, 1932) and *Belemnitella junior*.

Example

Maastricht Formation, upper portion of Meerssen Member, former Ankerpoort-Curfs quarry, Geulhem, and ENCI-HeidelbergCement Group quarry, Maastricht, the Netherlands.

Reference

Jagt (1996, 1999).

Remarks

Belemnella kazimiroviensis first appears at the top of subunit IVf-3 or the base of subunit IVf-4 of the Meerssen Member and becomes extinct at the Cretaceous/Paleogene boundary, which equates with the lower limit of subunit IVf-7 (= Berg en Terblijt Horizon) within the highest Meerssen Member (Jagt, 1999). Belemnite guards accumulated on top of the Berg en Terblijt Horizon are mostly corroded and some of them are bored by other organisms, indicating condensation, if not reworking. Belemnites found above the Vroenhoven Horizon within the lowermost Geulhem Member (Houthem Formation; lowermost Paleocene, lower Danian) are frequently fragmentary and rounded and can obviously be considered reworked.

Christensen (1996, 1997) showed the distribution of *Bln. kazimiroviensis* between the eastern part of the Russian Platform and the Maastricht area to be highly diachronous. Consequently, this species should not be used as a zonal index for long-distance correlations. *Belemnitella junior* ranges throughout the *Bln. kazimiroviensis* Zone, but is never common.

Discussion

In the Santonian-Maastrichtian interval of the Mons Basin and the Brabant-Méhaigne and MAL areas, thirteen belemnite zones can be distinguished; three in the Santonian (*Gonioteuthis w. westfalica*, *G. westfalicagranulata* and *G. granulata*), six in the Campanian (*G. granulataquadrata*, *G. quadrata*, *Blt. mucronata*, *Blt. woodi*, *Blt. minor* I and *Blt. minor* II), and four in the Maastrichtian (*Bln. obtusa*, *Bln.* ex gr. *sumensis/cimbrica*, *Blt. junior* and *Bln. kazimiroviensis*). Within these, twenty-two species of belemnitellid have been documented, of the genera *Actinocamax*, *Gonioteuthis*, *Belemnitella* and *Belemnella*. Correlations of these zones with those established in Norfolk (southeast England; see Christensen, 1991, 1995) and northern Germany (see Schulz, 1979; Schulz et al., 1984; Niebuhr, 2006) is illustrated in Figs 3-5.

A comparison of the belemnite faunas of the study area has revealed that most of the belemnitellid species occur throughout this area, provided that the proper strata have been preserved. However, *A. verus*, *Belemnitella* sp., *Blt.* ex gr. *langei*, *Blt. najdini*, *Blt. pulchra*, *Blt. lwowensis* and *Bln. lanceolata* have a more restricted distribution in the study area, as follows:

Actinocamax verus has been recorded from the Mons Basin and the Brabant-Méhaigne area, but is unknown from the MAL area. This is, at least in part, due to the fact that the nearshore, sandy Aachen Formation, of Santonian age, has not yielded any belemnites to date. Santonian belemnitellids are known solely from levels penetrated in the former Houthalen and Zolder/Voort mine shafts, from where *G. westfalicagranulata* has been recorded. The Lonzée Member, in contrast, yields specimens from the stratigraphically older *G. w. westfalica* Zone. Hence, it cannot be ruled out that A. verus actually is restricted to that zone in the study area. Its absence from collections from the mine shafts would favour such an interpretation. Robaszynski et al. (2002) mentioned *A. verus* from the upper Coniacian-Santonian Saint-Vaast Chalk Formation in the Mons Basin, but no representatives of the genus *Gonioteuthis*. Additional studies of belemnites from the Saint-Vaast Chalk Formation are needed in order to determine if *Gonioteuthis* is really absent or not.

To date, *Belemnitella* ex gr. *langei* has only been recorded from the uppermost portion of the Nouvelles Chalk Formation in the Mons Basin. Thus, this species either is to be considered stenoecious or the corresponding deposits of the upper *Blt. woodi* Zone were eroded during the middle to late late Campanian regression in the MAL and Brabant-Méhaigne areas.

Belemnitella najdini is known exclusively from the Beutenaken Member in the MAL area, being absent from the Spiennes Chalk Formation in the Mons Basin. Christensen (1997) mentioned that small species of *Belemnitella*, i.e., *Blt. langei*, *Blt. najdini* and *Blt.* ex gr. *langei/najdini* (the latter also referred to *Blt. najdini* by Keutgen & Jagt, 1999) immigrated into the Norfolk area (England) three times during the late late Campanian, implying that *Blt. najdini* required special environmental conditions; seemingly such were not fulfilled in the Mons Basin at the time.

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Of *Belemnitella* sp. only two specimens have been recorded from the lower Spiennes Chalk Formation of the CCC pit (Harmignies, Mons Basin), showing this species to be very rare, which may explain the lack of records from the Brabant-Méhaigne and MAL areas. In addition, it is quite possible that deposition of the Beutenaken Member in the MAL area started later than that of the Spiennes Chalk Formation at Harmignies.

Belemnitella pulchra is a very rare latest Campanian-early Maastrichtian species, with records from Poland, Germany and Belgium. Its general rarity may explain the lack of records from the MAL area, where remanié early Maastrichtian belemnites are known from the Vijlen Member. Of note is that Keutgen et al. (2010) mentioned two specimens, referred to as *Blt.* ex gr. *pulchra/lwowensis*, from the Vijlen Member at Altembroeck, which could be interpreted as remanié *Blt. pulchra*.

At present, *Blt. lwowensis* is known exclusively from the MAL area. However, belemnites from the Jauche Member and Saint-Symphorien Calcarenite Formation should be studied in more detail in order to determine whether *Blt. lwowensis* is really absent there or not.

So far, of *Belemnella lanceolata* remanié specimens have been shown to co-occur with early forms of *Bln. obtusa* in the Vijlen Member near Beutenaken (MAL area). Schulz (1979) identified *Bln. lanceolata* from the base of the *Bln. lanceolata* Zone up to the lower *Bln. obtusa* Zone at Kronsmoor, which corresponds well with the co-occurrence of early forms of *Bln. obtusa* and *Bln. lanceolata* in the MAL area. The Ciply-Malogne Phosphatic Chalk Formation of the Mons Basin was dated as middle *Bln. obtusa* Zone (Christensen, 1999), which is younger than the documented range of *Bln. lanceolata*. In consequence, *Bln. lanceolata* may not be expected in these deposits.

In conclusion, the absence of some belemnite species in certain regions of the study area can in many cases be explained either by absence of the proper deposits (hiatuses), a general rarity of the species, or a poor knowledge of the belemnite assemblages in certain lithological units. For one or two species, *Blt. najdini* and possibly *Blt.* ex gr. *langei*, environmental aspects could have affected their distributional pattern. For *Blt. najdini* in particular, this conclusion may be of importance, because this species is considered an index belemnite of the latest Campanian.

The belemnitellid fauna of the study area closely resembles that of Norfolk (Christensen, 1991, 1995), but appears to have been less diverse. Only a single species, *Blt.* ex gr. *langei* (from the uppermost Nouvelles Chalk Formation) has not been recorded from Norfolk. For comparison, *Belemnellocamax* ex gr. *grossouvrei* (Janet, 1891), *Goniocamax lundgreni* (Stolley, 1897), *Belemnitella propinqua* (Moberg, 1885), *Belemnitella langei* Jeletzky, 1948, *Belemnitella pauli* Christensen, 1995 and *Belemnella* (*Pachybelemnella*) *pseudobtusa* Schulz, 1979, all documented for Norfolk, have not been recorded from the Mons Basin and the Brabant-Méhaigne and MAL areas. The absence of *Bx.* ex gr. *grossouvrei* may be explained by its overall rarity (compare Jagt et al., 2009), while *Gx. lundgreni* and *Blt. propinqua* occur mainly in the Central Russian Subprovince and southern Sweden. Their presence in southern England may be seen as an occasional immigration pulse from the north that did not reach the study area. The concept of *Blt. langei* has differed among authors, and, hence, reliable data on its distribution are not available. Preliminary data indicate that it occurs mainly in the Central Russian Subprovince and may have reached England from the north, similar to *Gx. lundgreni* and *Blt. propinqua*. In western Europe, it has so far been identified only in Norfolk. In addition, *Blt. pauli* appears to be confined to Norfolk, where it is rare in the Beeston and lowermost Paramoudra Chalk members. The absence of *Blt. pauli* in the study area may be related to its limited distribution, in addition to its primary rarity. The absence of *Bln. pseudobtusa* in the Mons Basin and in the MAL area is due to the rarity/absence of outcrops of latest Campanian deposits in these areas.

A comparison of the belemnitellid fauna of the MAL, Brabant-Méhaigne and Mons areas with that of northern Germany has revealed close similarities, but differences exist in particular during the late Campanian and early Maastrichtian. *Belemnitella woodi*, *Blt. minor* I, *Blt. minor* II and *Blt. najdini* are unknown from the Lägerdorf-Kronsmoor section, while *Blt. misburgensis*, *Blt. langei sensu* Schulz, 1978, *Blt. schulzi* Christensen, 2000a, a number of species of *Belemnella* and *Fusiteuthis polonica* Kongiel, 1962 (see Christensen, 2002) have never been recorded from the Mons Basin and the MAL area.

Belemnitellid cephalopods are reliable biostratigraphic tools, especially when developmental lineages within genera are considered. However, the present study has demonstrated that difficulties in correlation may occur when a zonal boundary is defined by the appearance or disappearance of a genus. For example, the FAD of *Bln. kazimiroviensis* is distinctly diachronous in the Central European Subprovince. It ranges through the entire upper Maastrichtian in eastern Europe (e.g. Poland), occurs in the upper upper Maastrichtian of Danemark, while in the type Maastricht area it is restricted to the uppermost portion of the upper upper Maastrichtian (Naidin, 1975; Christensen, 1996). The FAD of *Belemnella* within the uppermost Campanian is also slightly diachronous. While it defines the base of the *Bln. lanceolata* Zone at Kronsmoor (northwest Germany), contemporary deposits in Denmark have yielded exclusively *Blt. schulzi* (Christensen, 2000a). Whether this genus appeared later in Norfolk and the study area than in northwest Germany is open to discussion, because deposits of the critical interval are either not well exposed or have not been preserved.

The uncertainties related to the definition of the lower/upper Campanian boundary by belemnites in the study area have been discussed previously. This boundary is usually defined by the LAD of the genus Gonioteuthis (Jeletzky, 1958). However, it remains to be proved if the two regional subspecies of *G. quadrata*, viz. *G. quadrata gracilis* and *G. quadrata scaniensis*, did indeed disappear simultaneously.

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