

# Stratigraphy of the upper Vijlen Member (Gulpen Formation; Maastrichtian) in northeast Belgium, the southeast Netherlands and the Aachen area (Germany), with special reference to belemnitellid cephalopods

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## Abstract

Recent studies have demonstrated the complex depositional history of the Vijlen Member (Gulpen Formation) in the Maastricht-Aachen-Liège area, on which synsedimentary tectonics had a profound impact, in conjunction with regressive and transgressive episodes, the oldest portion of this member being preserved only locally, within channel-like structures. Our reinterpretation of the Vijlen Member, here presented, is at variance with current belemnite stratigraphy. To account for incongruities, reworking of belemnites is here proposed as a typical feature during Vijlen Member deposition. A renewed study of belemnites on the basis of these new data suggests that intervals 4-6 of the Vijlen Member are of late Maastrichtian age. With respect to the mean values of populations of *Belemnitella junior* Nowak and *Belemnitella lwowensis* Naidin, Vijlen Member intervals 4-5 are coeval with the *Spyridoceras tegulatus/Belemnitella junior* Zone (sensu germanico), whereas at least the upper portion of interval 6 is correlatable with the basal *Tenuipteria argentea/Belemnitella junior* Zone (sensu germanico). Although reworking of belemnites appears to have been a common feature, this cannot be properly substantiated without additional geochemical analyses of individual guards. For this reason, we refrain from proposing a biostratigraphic zonation of the Vijlen Member based on belemnites. Alternatively, scaphitid ammonites might be used to subdivide this member, because species such as *Acanthoscaphites (Acanthoscaphites) tridens* (Kner), *A. (Euroscaphites) varians blaszkiewiczzi* Jagt, Kennedy & Machalski, *Hoploscaphites constrictus* (J. Sowerby), *H. tenuistriatus* (Kner) and *Hoploscaphites* sp. have been recorded. The last-named taxon represents an interspecies hybrid between the North American *Jeletzkytes dorfi* Landman & Waage and an unidentified subspecies of the endemic European lineage of *H. constrictus*, allowing correlation of the lower portion of Vijlen Member interval 6 with the *Hoploscaphites birkelundae* Zone of the United States Western Interior.

**Keywords:** Coleoidea, Belemnitellidae, Vijlen Member, Maastrichtian type area, Netherlands, Belgium, Germany, correlation

## Introduction

As noted by Albers & Felder (1979), the Maastrichtian age of the Vijlen Member (Gulpen Formation; sensu Felder (1975a, 1975b) in the extended type area of the Maastrichtian Stage (Fig. 1) has never been in doubt. However, specific assignments and correlations between sections exposing portions of this unit have varied considerably. Using belemnites, Keutgen & Van der Tuuk (1991) identified relicts of the early Maastrichtian *Belemnella obtusa*, *sumensis* and *cimbrica* zones (sensu Schulz,

1979), in addition to the late Maastrichtian *Belemnitella junior* Zone. A more detailed biozonation was subsequently proposed by Keutgen (1996), who attempted to correlate these biozones with the seven intervals (0 to 6) distinguished by Felder & Bless (1994) in the combined type section of the Vijlen Member at Mamelis, just west of Vaals (Netherlands/Germany border). However, subsequent correlation of sections on the basis of bioclast (eco-)stratigraphy (Felder, 2001) proved to be in conflict with belemnite stratigraphy (Keutgen & Van der Tuuk, 1991; Keutgen, 1997) and with Keutgen's (1996) biozonation.

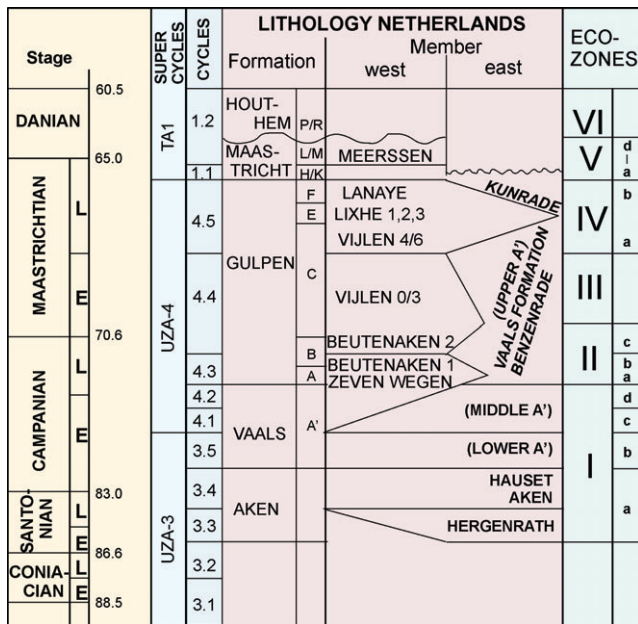


Fig. 1. Chrono- and lithostratigraphy of Upper Cretaceous and lower Paleocene strata exposed in the extended type area of the Maastrichtian Stage, correlated with sequence-stratigraphic units, and subdivided into foraminiferal zones (A'-R; see Hofker, 1966) and bioclast ecozones (I-VI) (modified after Felder, 2001).

For example, Felder (2001, fig. 38) identified relicts of intervals 0-5 within the lower c. 0.8 m of this member at the Bovenste Bos quarry (Netherlands) and correlated the overlying portion with interval 6, whereas Keutgen (1996) had equated the lower c. 2 m at that locality with interval 0, on account of the occurrence of early forms of *Belemnella* (*Pachybelemnella*) *sumensis* Jeletzky, 1949 (see Keutgen & Van der Tuuk, 1991). Similarly, Felder (2001, fig. 18) correlated the lower c. 5 m of the Vijlen Member at the CPL SA quarry (Haccourt, also referred to as Halembaye or Hallembaye), which are of late Maastrichtian age (Keutgen & Van der Tuuk, 1991), with interval 5 as documented at the Mamelis type section of this member, although that interval yielded the typically late early Maastrichtian *Belemnella* (*Pachybelemnella*) cf. *cimbrica* Birkelund, 1957 (Felder & Bless, 1994), which is also known from the Wilkensberg nearby (Keutgen & Van der Tuuk, 1991). The most notable difference in interpretation of the stratigraphy of Vijlen Member strata using either belemnites or bioclasts, however, was observed at Altembroeck (Voer, northeast Belgium). Keutgen (1997) proposed correlation of the entire Vijlen Member there with interval 0 (of the Mamelis section), on account of the occurrence of early forms of *Bln.* (*P.*) cf. *sumensis* and *Belemnella* (*Bln.*) cf. *praearkhangelskii* Naidin, 1964 at about 4.3-4.5 m below the top of the Vijlen Member exposed there. In contrast, Felder (2001, fig. 40) equated the entire Altembroeck section (c. 12 m thick) with intervals 2-4 of the Mamelis section. Most of the macrofossil taxa listed by Jagt et al. (1995), plus belemnites studied by

Keutgen (1997), come from interval 4 sensu Felder (2001) and some of these actually place in question the age assignment based on belemnites. For instance, the galeritid echinoid *Galerites stadensis* (Lambert, 1911) (sensu Schulz, 1985) was found to co-occur with early forms of *Bln.* (*P.*) cf. *sumensis* and *Bln.* (*Bln.*) cf. *praearkhangelskii*, indicative of the middle *Bln.* *sumensis* Zone, although in northern Germany the first appearance datum (FAD) of that echinoid is slightly later in the upper *Bln.* *sumensis* Zone; it ranges into the uppermost Maastrichtian (Schulz, 1985). From the same level at Altembroeck, Jäger (2004) recorded the serpulid *Conorca trochiformis* (Von Hagenow, 1840) which displayed morphological features favouring a *Bln.* *cimbrica* Zone dating.

The belemnite biostratigraphy of Keutgen & Van der Tuuk (1991) and Keutgen (1996, 1997) was based mainly on the succession, and disappearance, of species of the genus *Belemnella* Nowak, 1913. The genus *Belemnitella* d'Orbigny, 1840 received less attention, because at that time the late Maastrichtian *Belemnitella* fauna from northwest Europe was still poorly understood. Recently, Christensen et al. (2004) have re-evaluated *Belemnitella* from the upper Maastrichtian at Hemmoor (northern Germany) and this work now enables a reinterpretation of members of this genus in the Vijlen Member and a comparison of these results with current bioclast data.

**Abbreviations** — To denote the repositories of material illustrated and/or referred to in the text, the following abbreviations are used: NHM, The Natural History Museum, Department of Palaeontology, London (formerly British Museum of Natural History); NHMM, Natuurhistorisch Museum Maastricht, Maastricht. Schulz (1979) distinguished between early, typical and late forms of his species of *Belemnella* (*Pachybelemnella*). The following abbreviations were used: f.a., forma anterior; f.m., forma media; f.p., forma posterior.

### Current views on Vijlen Member stratigraphy

In the Netherlands/Belgium/Germany borderland, commonly referred to as the Maastricht-Aachen-Liège area, Vijlen Member strata are known from a relatively limited area between the Roer Valley Graben and the Brabant Massif (Felder, 1997; see Fig. 2 here). Amongst the most striking features of this unit are marked differences in thickness. In two narrow strips, more or less parallel to the Roer Valley Graben, this unit may reach thicknesses in excess of 70 metres, whereas beyond these strips, the magnitude generally varies between 0 and 30 m. These strips have been identified as part of a channel system (Fig. 2) running from Aachen to Gulpen and from Altembroeck to Lanaye ('Oost Maarland borehole'), possibly extending into the western Campine area, Belgium (Felder, 1997). This channel system developed during the late Campanian, early Maastrichtian or earliest late Maastrichtian, prior to the onset of sedimentation of the Vijlen Member and was eroded in an otherwise fairly flat, nearshore area.

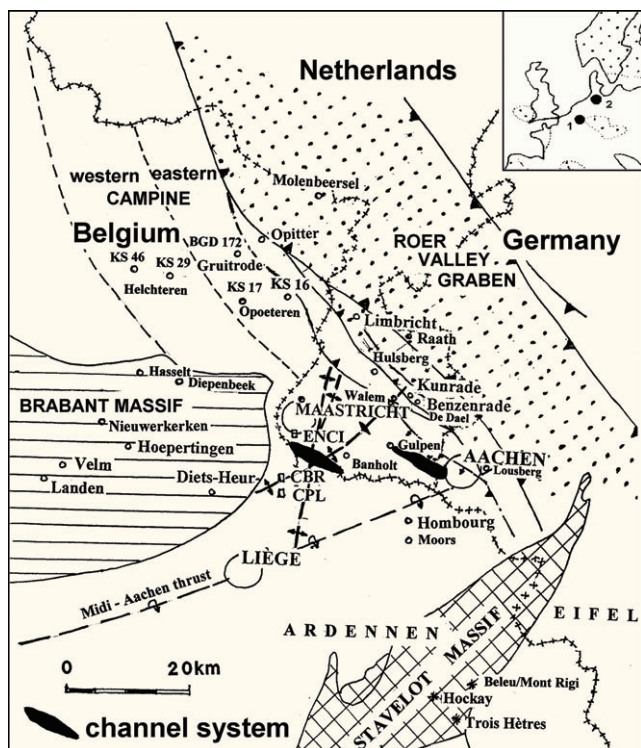


Fig. 2. The Maastricht-Aachen-Liège area and adjacent regions (1), compared (inset) to Krons Moor/Hemmoor, northern Germany (2). Channel systems, extending between Aachen and Gulpen and between Altembroeck and Lanaye, are indicated (after Felder, 1997).

The combined type section (Fig. 3) at Mamelis, where the Vijlen Member is completely developed, comprises the Mamelis sunken road section (locality 62D-79, co-ordinates 312.330/196.450) and the Mamelis borehole (locality 62D-68). At Mamelis, the Vijlen Member was subdivided by Felder & Bless (1994) into seven intervals, numbered 0-6, as based on bioclasts, benthic foraminifera and ostracods, as well as on lithological characteristics. Subsequent research on the bioclasts has revealed that especially benthic foraminifera in the 1-2.4 mm sieve fraction were suitable for further subdivision. At Mamelis, thirteen major foraminifer peaks, labelled A (base) to L (top) have been distinguished (Felder, 1997, 2001). Additional data derive from bivalve bioclasts; the boundaries between the seven intervals are defined either by peaks in foraminifer or bivalve distribution.

Interpretation of the oldest Vijlen Member deposits as channel infill has allowed the conclusion that at least part of the material filling up the channel system, namely glauconite and quartz grains, had been eroded from the channel margins. Glauconite, for example, may have originated from Vaals Formation strata (Felder & Bless, 1994), as may some of the reworked fossils (Keutgen, 1996). However, remanié fossils of late Campanian and early Maastrichtian age may also be expected within these channel deposits, having been derived from deposits that are no longer preserved. This represents a serious problem for belemnite stratigraphy, because belemnites

are considered to be comparatively resistant to reworking processes (Doyle & Macdonald, 1993).

For the present study, correlation of deposits with the Vijlen Member type section at Mamelis is based on results of bioclast stratigraphy (Felder, 1997, 2001). For localities from which bioclast samples have been studied, correlation with the seven lithological intervals exposed at the extended type section at Mamelis has proved possible, viz. for sections exposed at Altembroeck, Pesaken-Crapoel, Beutenaken, the Bovenste Bos quarry and the CPL SA quarry (Haccourt) (Fig. 4 here; see also Felder, 2001). For the localities Wilkensberg (Ebensberger, 1962) and Hans-Böckler-Allee (Felder & Bless, 1994), foraminiferal assemblages documented allow a rough match with the type section at Mamelis, while the locality Schurzelterstraße can be assigned to a level slightly below strata formerly exposed at the Hans-Böckler-Allee due to the proximity of both sections. Only the localities Lemierserberg and Vaalserstraße are difficult to date, but the documented faunal content allows at least a rough correlation with the type section of the Vijlen Member (Fig. 4).

Due to the inadequate exposure of Vijlen Member deposits at the type locality near Mamelis, a subdivision of this member is possible only by using foraminifera, ostracods, bioclasts and lithological characteristics. However, the lithology of the Vijlen Member can change considerably within a limited area so that beds extending over large distances were not encountered (Felder & Bless, 1994; Felder, 1997). Biostratigraphic subdivision of the Vijlen Member is still based mainly on foraminiferal and ostracod assemblages. Felder & Bless (1994) distinguished the foraminiferal assemblage zones C and D of Hofker (1966), with Zone D being restricted to the uppermost 7 m of the Vijlen Member. However, these authors also indicated that Zone C may be separated into a lower portion, where *Bolivinoidea draco miliaris* Hiltermann & Koch, 1950 and *Neoflabellina permutata* Koch, 1977 occur, and an upper portion with *Nonionella troostae* (Visser, 1951). At Mamelis, the boundary between subzones C<sub>upper</sub> and C<sub>lower</sub> corresponds roughly to the base of interval 4 of the Vijlen Member and this level is also characterised by a distinct change in macrofauna. While well-preserved specimens of *Acanthoscaphites* (*A.*) *tridens* (Kner, 1848) are known exclusively from deposits below the base of interval 4 (Jagt et al., 1999), *Diplodetus duponti* (Lambert, 1911) and *Hoploscaphites constrictus* (J. Sowerby, 1817) first occur frequently above this level (Van der Ham & Van Birgelen, 1992; Jagt et al., 1995; Keutgen, 1996). *Belemnitella junior* Nowak, 1913 and *Blt. lwowensis* Naidin, 1952 first appear close to the base of interval 4 as well (see hereafter). The FAD of *Acanthoscaphites* (*Euroscaphites*) *varians blaszkiewiczzi* Jagt, Kennedy & Machalski, 1999 is close to the base of interval 6 of the Vijlen Member (Jagt & Kennedy, 1989). In summary, a subdivision of the Vijlen Member into three portions appears possible, using either foraminifera or scaphitid ammonites.



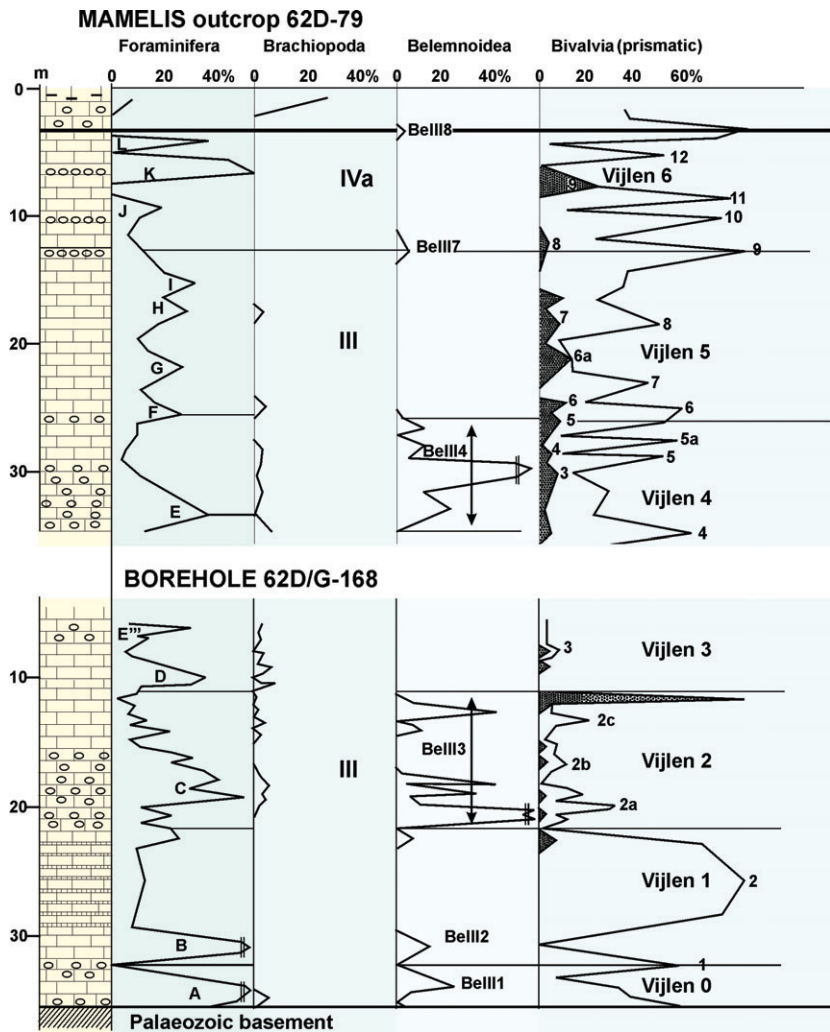


Fig. 3. Lithology and bioclast contents for the Vijlen Member in its type area near Mamelis (modified after Felder, 2001, fig. 22).

### Comments on previous identifications of material of *Belemnella*

The present study has made it clear that several so-called ‘populations’ of the genus *Belemnella* as described by Keutgen & Van der Tuuk (1991) and Keutgen (1997) actually consisted of reworked specimens. This conclusion was based on strictly biostratigraphical arguments, referring to anomalies in the expected biostratigraphic zonations of belemnites. Here, deposits have been dated with respect to the stratigraphically youngest belemnite species or stratigraphic forma(e); documenting evidence for reworking (e.g. sedimentological evidence for downslope transport or fossil preservational state) was beyond the scope of the investigation. In future studies, it would be worthwhile to document whether or not isotopic and elemental composition (Nieto et al., 2008) might be the key to distinguish between remanié and indigenous belemnite rostra in the study area. Seen in this light, the lack of isotopic continuity between belemnite rostra on the one hand and inoceramid shells and chalk matrix on the other (as documented for the Altembroeck section; see Elorza et al., 1997), might be re-interpreted in terms of belemnite reworking.

The realisation that strata assigned to the Vijlen Member contained remanié specimens of the genus *Belemnella*, posed the question of how to identify samples of reworked belemnites that may even have originated from different belemnite zones. The identification key provided by Schulz (1979) applies only to populations, while single specimens might easily fall into the range of variation of several populations, as described by Schulz (1979), and be referred to different species. In order to obtain a picture of the species of *Belemnella* that do occur, the range of variation of populations described by Schulz (1979) was taken as a basis. Schulz (1979) distinguished the subgenera *Belemnella* (*Belemnella*) Nowak (1913) and *Belemnella* (*Pachybelemnella*) Schulz (1979) on the Lsn value (see hereafter). Distinguishing between the subgenera did not present a problem for the belemnite material studied here, because only few specimens belong to the subgenus *Bln.* (*Belemnella*). For specific assignment within these subgenera, the AV value is of prime importance. A comparison of the standard deviations (S) and 95% confidence intervals of *Belemnella* (*Pachybelemnella*) *obtusa* Schulz (1979) and of *Bln.* (*P.*) *sumensis*, as recorded by Schulz (1979, tables 5, 6) with those of *Bln.* (*Pachybelemnella*) samples from the Vijlen Member (Keutgen & Van der Tuuk, 1991; Keutgen, 1997) has

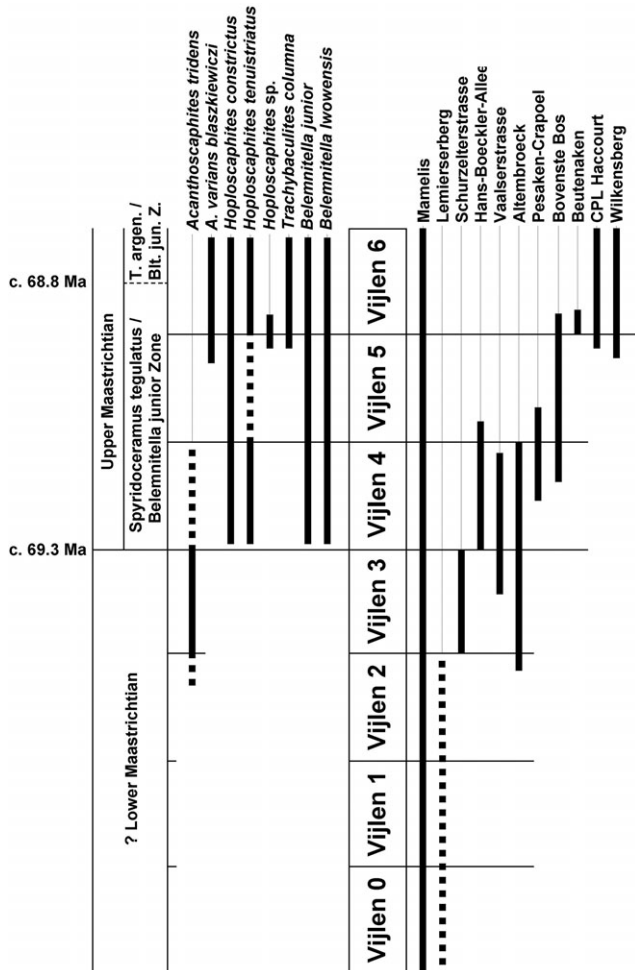


Fig. 4. Time scale for and correlation of Vijlen Member strata with biozones established at Hemmoor, northern Germany. The various localities studied are plotted on the right, and interpretation of strata exposed, as favoured herein, illustrated. In addition, ranges of index cephalopod taxa in the Maastricht-Aachen-Liège area are shown. Dots indicate uncertainty in ranges.

revealed that, firstly, in samples consisting of fewer than c. 20-40 specimens, a conclusion on the homogeneity could not be made using both the 95% confidence interval and S (Figs 5, 6) and, secondly, that in larger samples with  $S > 6$ , heterogeneity is probable (Fig. 6). Using these criteria, two heterogeneous samples could be identified, i.e. that of *Bln. (P.) sumensis* from the Bovenste Bos quarry ( $S = 7\%$ ; see Keutgen & Van der Tuuk, 1991) and that of the same species from level Bm 2 at Altembroeck ( $S = 7.3\%$ ; see Keutgen, 1997). The latter sample is of special interest. Although seemingly heterogeneous due to the large variation of AV and the presence of WQs values spanning the range of both *Bln. (P.) obtusa* and *Bln. (P.) sumensis* (Schulz, 1979, fig. 40; Keutgen, 1997, table 2), the means of AV and Lsn indicate the middle *Bln. sumensis* Zone, a correlation well in line with the occurrence of the probably eastern European species *Bln. (Bln.) cf. praearkhangelskii*, which invaded western Europe only during a brief interval in the middle *Bln. sumensis* Zone (Schulz, 1979) and which is limited to level Bm 2 at Altembroeck (Keutgen, 1997). In conclusion, the *Belemnella* sample of level

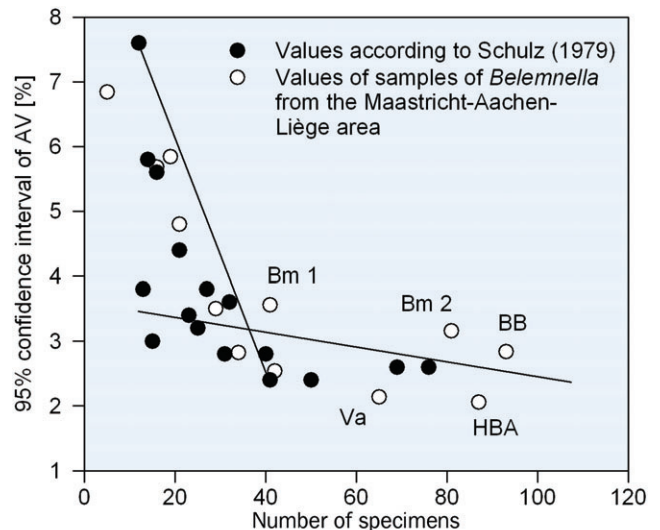


Fig. 5. Scatter plot of the 95% confidence interval of mean AV values of samples of *Belemnella* as influenced by sample size; ● = samples of *Bln. (P.) obtusa* and of *Bln. (P.) sumensis* (see Schulz, 1979, tables 5, 6); ○ = samples of the subgenus *Bln. (Pachybelemnella)* from the Vijlen Member (data from Keutgen & van der Tuuk, 1991; Keutgen, 1997). Localities and stratigraphic levels are as follows: Bm 1 and Bm 2 = belemnite levels Bm 1 and Bm 2 at Altembroeck section (interval 4); BB = Vijlen Member at Bovenste Bos quarry, with exclusion of burrow fills in the topmost Beutenaken Member (interval 5); HBA = upper glauconitic level of Vijlen Member at temporary Hans-Böckler-Allee I section (top of interval 4); Va = temporary section at Vaalserstraße (intervals 3-4).

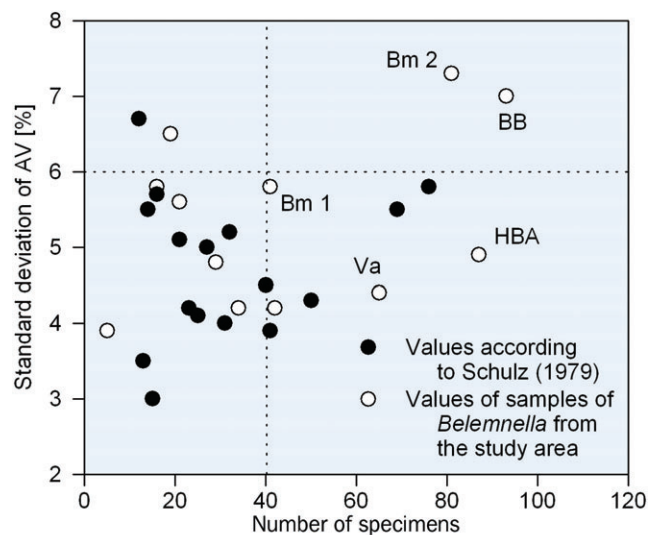


Fig. 6. Scatter plot of standard deviation of mean AV values of samples of *Belemnella* as influenced by sample size. Samples, localities and stratigraphic levels are as in Fig. 5.

Bm 2 consisted mainly of specimens from a comparatively narrow stratigraphic interval. Assuming that specimens in reworked samples of *Belemnella* generally are derived mainly from narrow stratigraphic intervals, the means of AV and Lsn, even of a heterogeneous sample, may yield data on the level from which most of the specimens originated (Fig. 7).

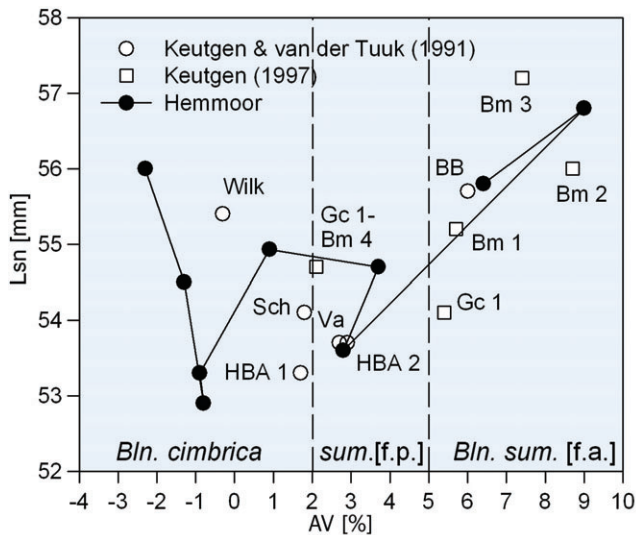


Fig. 7. Comparison of mean AV and Lsn values of samples of the subgenus *Bln.* (*Pachybelemnella*) (see Keutgen & Van der Tuuk, 1991; Keutgen, 1997) with late early Maastrichtian populations of the same subgenus as recorded from Krons Moor and Hemmoor, northwest Germany (see Schulz, 1979). Samples here considered possibly non-reworked are: Sch = Schurzelterstraße. Samples considered to comprise remanié specimens are: Bm 1, Bm 2, Bm 3, Gc 1, Gc 1-Bm 4 = levels at Altembroeck section, from which belemnites have been analysed; BB = Bovenste Bos quarry; Va = Vaalserstraße; HBA 1, HBA 2 = Hans-Böckler-Allee I, upper glauconitic layer and level above this layer, respectively; Wilk = Wilkensberg.

Taking into account the range of variation of AV, WQs and Lsn as reported by Schulz (1979) for populations from northern Germany, it is obvious that the range of variation is larger in some samples from the Maastricht-Aachen-Liège area. In the case of a higher variation in a sample it can be concluded that it is heterogeneous as well. Heterogeneity is regarded as a strong argument that a sample contains remanié specimens. The out-of-range specimens were identified by comparison with the previous or following populations as described by Schulz (1979), accepting that the stratigraphic interval of a sample of *Bln.* (*Pachybelemnella*) should be kept as small as possible. This concept resembles that used by Christensen (1994) for identification of specimens of the genus *Goniotenthis* Bayle, 1878 from the Glauconie de Loncée (Gembloux, province of Namur, Belgium), now the Loncée Member (Robaszynski et al., 2002). However, it is obvious that this kind of procedure is inaccurate and ignores the facts that with more specimens from a population available, the reported variation could be larger, that reworking itself may have modified single specimens, e.g. their shape, and that belemnite populations from the Maastricht-Aachen-Liège area could have differed slightly in their variation from coeval populations in northwest Germany. This uncertainty is here indicated by using 'cf.' for identification of specimens of *Belemnella* from a level which contains remanié belemnites.

## Localities

Localities exposing Vijlen Member strata in the Maastricht-Aachen-Liège area (Figs 4, 8) are discussed below, with outcrops exposing the oldest intervals (sensu Felder & Bless, 1994) first. Sections exposed at the localities studied are only briefly described when they have already been discussed at length in previous papers. The belemnite fauna of the outcrops is discussed more extensively.

### 1 – Mamelis

The Mamelis sunken road section (locality 62D-79, co-ordinates 312.330/196.450) and the Mamelis borehole section (locality 62D-68), municipality of Vaals (the Netherlands) are complementary without appreciable gap or overlap. Together these sections represent the combined type section of the Vijlen Member (Fig. 3). Felder & Bless (1994) distinguished seven intervals, in ascending order, Vijlen 0 (thickness 3.2 m), Vijlen 1 (10.5 m), Vijlen 2 (10 m), Vijlen 3 (estimated c. 14.3 m), Vijlen 4 (8.5 m), Vijlen 5 (12 m) and Vijlen 6 (11.5 m). Felder (1997, 2001) was able to identify twelve beds based on foraminiferal frequencies. Reference is made to those papers for detailed descriptions.

*Belemnitella junior* has been recorded from interval 6 and a reworked specimen of *Belemnella ex gr. sumensis/cimbrica* from interval 5 (Felder & Bless, 1994). Here, we add a specimen of *Belemnitella lwowensis*, which originates either from interval 5 or 6.

### 2 – Lemierserberg

Along the main road (N278) connecting Lemiers and Vaals (the Netherlands), at the corner of the 'Schuurmolenstraat', the base of the Vijlen Member was exposed in a temporary trench, overlying sands of the Vaals Formation. The Vijlen Member here comprised yellowish marls with glauconite and quartz grains, especially in the lowermost portion of the section. Belemnites were not found within the lowermost 0.5 m exposed, i.e. a belemnite graveyard was not present at that locality. Nevertheless, a few belemnite specimens were collected loose from the interval c. 1-5 m above the base in temporary trenches along the main road. A precise correlation with the Mamelis type section is not yet available. Nevertheless, the relative position of this section to other nearby, well-dated exposures of Vijlen Member deposits implies correlation with a level within intervals 0-2.

Although the sample of *Belemnella* from Lemierserberg is very small, the mean values of WQs ( $2.6 \pm 0.4$ ,  $N = 4$ , observed range 2.0-2.9) and Lsn ( $52.6 \pm 6.2$  mm,  $N = 5$ ) clearly indicate that the specimens belong either to *Bln. (P.) sumensis* or *Bln. (P.) cimbrica*. The shape of the guard can be used to distinguish these species. The 95%-confidence interval of the mean AV value





Fig. 8. Map of southern Limburg (the Netherlands), Voerstreek and Liège province (Belgium) and Aachen area (Germany), showing localities referred to in the text. The Aachen city area comprises the localities Schurzelterstraße, Vaalsstraße, Hans-Böckler-Allee and Wilkensberg.

( $4.3 \pm 3.9\%$ ,  $N = 5$ ) of specimens from Lemierserberg ranges from 0.9% to 7.8%, that of the mean AL value ( $-7.5 \pm 2.9\%$ ,  $N = 5$ ) from  $-10.1\%$  to  $-4.9\%$ , respectively. According to Schulz (1979), populations of *Bln. (P.) cimbrica* differ from those of *Bln. (P.) sumensis* in their smaller mean values for AV ( $<2\%$ ) and AL ( $<-10\%$ ). The specimens from Lemierserberg can thus be referred to as *Bln. (P.) cf. sumensis*. However, the sample is too small to distinguish between early and late forms of that species.

### 3 – Schurzelterstraße (Aachen)

The temporary section Schurzelterstraße at Aachen (Germany), as described by Keutgen & Van der Tuuk (1991), comprised several exposures, accessible between 1978 and 1981 during construction of houses at numbers 460-565, and exposed a yellow-grey, marly limestone. *Belemnella* collected from this locality are transitional between *Bln. (P.) sumensis* and *Bln. (P.) cimbrica* (Fig. 7), and are here referred to as *Bln. ex gr. sumensis/cimbrica*. In addition, *Belemnitella* sp. could be identified.

The localities Schurzelterstraße and Hans-Böckler-Allee (see below) are situated in close proximity and Keutgen (1996) therefore combined the two localities into a single section. However, the faunal contents of the two localities differ significantly (Keutgen, 1996), which enables correlation of the stratigraphically older deposits formerly exposed at Schurzelterstraße with interval 3 of the Mamelis stratotype section. However, it cannot be ruled out entirely that the base of interval 4 was actually exposed at single exposures listed under the designation 'Schurzelterstraße'. In the light of this, the record from Schurzelterstraße (interval 3) of *Belemnitella* sp. that resembles *Blt. junior* (known from intervals 4-6) has to be treated with caution.

### 4 – Hans-Böckler-Allee (HBA, Aachen)

This temporary section comprised two closely-spaced construction sites (HBA I = houses at numbers 40-42; HBA II = houses at numbers 50-68) at Aachen (Germany), close to the locality Schurzelterstraße. They were accessible in 1984 and 1991, respectively. Only section HBA I was described and illustrated in Keutgen & Van der Tuuk (1991, fig. 5). At that locality, 8.4 m of Vijlen Member were exposed. Within the lowermost 2.4 m, two c. 0.5 m thick glauconite-rich beds occurred (between c. 0.5-1 m and 1.9-2.4 m above the base of the section, respectively). The lower glauconite-rich bed was exposed only briefly in a corner of the temporary section, so belemnites could not be collected. Apart from the glauconite-rich beds, the Vijlen Member exposed at HBA I consisted of a marlstone or marly limestone with a low glauconite content. The upper glauconitic bed marked a distinct colour change in the Vijlen Member deposits, from yellow-grey below to yellow-white above this layer. Locally, changes into a yellowish brown colour appeared in the topmost portion of the section. It may be worth noting that the upper glauconitic layer was locally separated from the underlying yellow-grey marly limestone by a thin (a few millimetres) layer of brownish mud. The origin of the mud is not clear, but it may be due to groundwater percolating down through cracks in the overlying Vijlen Member. The comparatively sharp boundary between the yellow-grey limestone and the glauconitic bed marked by the mud layer attests to a short interruption of sedimentation.

At HBA II, about 10.2 metres of Vijlen Member were exposed. Three glauconite-rich beds were observed, at 0.4-1.4 m, 3.4-3.9 m and 7.2-7.5 m above the base of the section, respectively. Although HBA I and HBA II are closely spaced, it has so far been

impossible to correlate single glauconite-rich beds with certainty, because neither the thickness of beds nor that of the intercalated marlstones corresponded. This observation is in line with Felder & Bless (1994) and Felder (1997), who noted that beds within the Vijlen Member cannot be traced over larger distances.

Non-reworked belemnites collected from the upper glauconitic bed at HBA I and also from the interval 0-3 m above the higher glauconite-rich bed belong to *Blt. junior* and *Blt. lwowensis*. At HBA II, *Blt. junior* occurs at least in the upper two glauconite-rich beds, together with numerous remanié specimens assignable to *Bln. (Pachybelemnella)*. With respect to the means of AV and Lsn, remanié specimens of this subgenus from the upper glauconitic bed at HBA I may be compared to populations of *Bln. (P.) cf. cimbrica* or to *Bln. (P.) cf. sumensis*, while those from the interval 0-3 m above the higher glauconite-rich bed resemble more those of a late form of *Bln. cf. sumensis* (means of AV and Lsn; see Fig. 7). Because all of these samples of *Bln. (Pachybelemnella)* do not differ from those collected at Schurzelterstraße, they are considered transitional between these two species and are here also referred to as *Bln. ex gr. sumensis/cimbrica*.

Felder & Bless (1994) analysed a 3 kg sample from HBA II. The faunal assemblage of foraminifera and ostracods resembled that of interval 4 at the Mamelis stratotype section, which is why the deposits formerly exposed at Hans-Böckler-Allee were correlated with interval 4 of the Vijlen Member. Felder (1997, p. 133) assumed that the Böckler Horizon, marking the top of interval 4, might have been exposed at HBA I, indicating that this section could have extended into interval 5.

### 5 – Vaalserstraße (Aachen)

In 1985-1986, about 10 metres of Vijlen Member were exposed during roadworks along the Vaalserstraße, in the vicinity of the Westfriedhof cemetery at Aachen-Melaten (Germany). About 4 m above the base of the temporary section, a 0.3 m thick locally indurated, yellowish brown, marly limestone with very high glauconite content and some small quartz grains was exposed. The marly limestone intercalations below this indurated layer also contained glauconite. Up to 3.2 m above the 0.3 m-thick, locally indurated, marly limestone, the glauconite content remained high and glauconite concentrations occur. In the uppermost 2.5 m of the section, glauconite content was also high, but not concentrated at certain levels, indicating a trend towards lower contents, especially in the uppermost c. 1 m of the section exposed (Keutgen & Van der Tuuk, 1991).

Felder & Bless (1994) tentatively correlated the upper 6 m of the Westfriedhof temporary section with interval 2 of the Vijlen stratotype at Mamelis on the evidence of several glauconitic layers containing quartz grains, the frequency of belemnite guards, and the presumed lithostratigraphic position c. 9 m above the base of the Vijlen Member. However, the relative

position of the base of the Vijlen Member at that locality is doubtful at best, because Keutgen & Van der Tuuk (1991) estimated its position by comparing the Vaalserstraße section with that described by Breddin et al. (1963) from the borehole Vaalserstraße 242-246. Because it has recently been noted that the lithology of the Vijlen Member could change considerably within a limited area (Felder & Bless, 1994; Felder, 1997), the argumentation of Keutgen & Van der Tuuk (1991) and also the first and third argument of Felder & Bless (1994) must be treated with caution. The second argument of Felder & Bless (1994), in favour of correlation of the Vaalserstraße section with interval 2 of the Vijlen stratotype at Mamelis, the frequency of belemnite guards, has to be considered similarly. The detailed study of the Altembroeck section (Jagt et al., 1995) has shown that levels rich in belemnite guards do not necessarily coincide with belemnite bioclast peaks. The environmental conditions which were needed to fragment belemnite guards were probably different from those involved in the accumulation of rostra. In consequence, the evidence in favour of correlation with interval 2 is weak with respect to the variability of Vijlen Member lithology.

An alternative interpretation of the relative position of the Vijlen Member deposits exposed at the Vaalserstraße locality may be deduced from information given in Breddin et al. (1963, p. 292). At Königshügel, a hill north of the Vaalserstraße, the Vijlen Member reaches a thickness of c. 60 m. About 20-25 m below the top of the member there, at the level of the Bleyberger Straße, glauconitic layers were observed within a light-grey marlstone. Compared with the type locality of the Vijlen Member, the relative position of the glauconitic layers at Bleyberger Straße about 35-40 m above the basis of the Vijlen Member would imply correlation with interval 4. However, the Bleyberger Straße is a nearly horizontal road, which turns into the Vaalserstraße close to the locality mentioned here. Assuming no major fault, this would imply that the transition of intervals 3 to 4 was originally exposed at Vaalserstraße.

A few belemnites were collected up to 1 m below the locally indurated limestone, but most are derived from the interval immediately below to up to c. 1.5 m above this layer. A smaller number of specimens were collected from the upper c. 2 m of the section exposed. Specimens of *Belemnella* from the Vaalserstraße do not differ from those collected at Schurzelterstraße and Hans-Böckler-Allee. They are thus considered intermediate between *Bln. (P.) sumensis* and *Bln. (P.) cimbrica*; however, with respect to their mean AV and Lsn values, they are more typical of a late form of *Bln. (P.) sumensis* (Fig. 7). They are best referred to as *Bln. ex gr. sumensis/cimbrica*. Representatives of *Belemnitella* collected at Vaalserstraße are here referred to *Belemnitella* sp. (1 specimen) and *Belemnitella cf. lwowensis* (1 specimen). The latter specimen from the middle portion of the section would imply a correlation with interval 4 or younger deposits of the Vijlen Member.



Because neither bioclasts nor foraminiferal samples are available from the Vaalserstraße section, its position within the Vijlen Member must be estimated based on macrofaunal contents. The record of a well-preserved specimen of *Acanthoscaphites* (*A.*) *tridens* (see Jagt et al., 1999) collected in the lower portion of the section exposed (H. Knoll, letter of 17 April 2007) and the presence of large specimens of the holasteroid echinoid *Cardiaster granulatus* (Goldfuss, 1829) immediately below the indurated layer favour correlation of the lowermost 4 metres with interval 3, and possibly even older deposits. Index species such as *Diplodetus duponti* or *Hoploscaphites constrictus* have not been identified from levels above the indurated layer, but the record of *Blt.* cf. *lwovensis* from the Vaalserstraße section suggests the presence of interval 4 or even younger deposits of the Vijlen Member. In this context, the record of the isocrinid crinoids '*Isocrinus lanceolatus* (Roemer, 1840)? and *Nielsenicrinus agassizii* (Von Hagenow, 1840) from this locality (interval 4) may be of interest as well (Jagt, 1999b), because in the Maastricht-Aachen-Liège area these species are known exclusively from the upper portion of the Vijlen Member, i.e. from interval 4 or younger (e.g., at Mamelis, Altembroeck and Hans-Böckler-Allee). In summary, preliminary macrofossil evidence would suggest that the boundary level between intervals 3 and 4 of the Vijlen Member was exposed at Vaalserstraße, perhaps close to the base or top of the locally indurated, yellowish brown, glauconitic limestone c. 4 m above the base of the section.

## 6 – Altembroeck

The Altembroeck section (Voer, northeast Belgium) was described in detail by Jagt et al. (1995) and Felder (2001), including a stratigraphical interpretation based on bioclasts. The belemnite-bearing portion of the section (interval 4) was also discussed by Keutgen (1997). At Altembroeck, the first typically late Maastrichtian *Blt.* *junior* and *Blt.* *lwovensis* were collected from level Bm 1, about 1.2 m above the base of interval 4 (Felder, 2001, fig. 40). From layers below Bm1, no belemnites were available.

Keutgen (1997) described species of *Belemnella* from levels Bm 1, Bm 2, Bm 3, Gc 1, the interval between Gc 1 and Bm 4, as well as from level Bm 4, all of which are here considered to have been reworked. The records have now been reinterpreted based on the means of AV and Lsn (Fig. 7) and the range of variation documented in Keutgen (1997, table 2), yielding the following picture:

- Bm 1: the means of AV and Lsn indicate the presence of early forms of *Bln.* (*P.*) cf. *sumensis* (Fig. 7), but the observed range of variation of AV is larger than that documented for *Bln.* (*P.*) *sumensis* (f.a.) by Schulz (1979). AV values of up to 25% support the presence of *Bln.* (*P.*) cf. *obtusa* Schulz, 1979 within this sample.
- Bm 2: as mentioned above, the means of AV and Lsn of *Bln.* (*Pachybelemnella*) specimens (Fig. 7), in addition to the presence of *Bln.* (*Bln.*) cf. *praearkhangelskii* allow the

conclusion to be drawn that most of the specimens found at level Bm 2 were reworked from deposits that were first laid down during the middle *Bln.* *sumensis* Zone (sensu germanico). However, as at level Bm 1, the range of the AV value is larger than that recorded by Schulz (1979). It includes values typical of *Bln.* (*P.*) cf. *obtusa* and also of late forms of *Bln.* (*P.*) cf. *sumensis*. Keutgen (1997) reported a WQs value as low as 1.1 which, according to Schulz (1979, fig. 40), may be considered typical of *Bln.* (*P.*) *obtusa*.

- Bm 3: the means of AV and Lsn indicate a middle *Bln.* *sumensis* Zone provenance for the *Bln.* (*Pachybelemnella*) specimens, albeit *Bln.* cf. *praearkhangelskii* could not be identified at level Bm 3. This assignment corresponds to the documented range of variation.
- Gc 1: in the case of the *Bln.* (*Pachybelemnella*) specimens collected from this level, a comparison of the means of AV and Lsn with those of populations from northwest Germany proved unsuccessful (Fig. 7). Most specimens may be referred to *Bln.* (*P.*) cf. *sumensis*. The sample may contain both early and late forms of that species.
- Interval Gc 1 to Bm 4, Bm4: specimens in these samples are here lumped together. The means of both are virtually identical and plot close to those of populations of either *Bln.* (*P.*) *sumensis* 'Schichtgruppenfauna' SGF 47-54 m or *Bln.* (*P.*) *cimbrica* SGF 54-60 m at Hemmoor (Fig. 7). The documented range of variation also indicates the presence of early forms of *Bln.* (*P.*) cf. *sumensis*.

In summary, the occurrence of remanié belemnites of the early Maastrichtian *Bln.* *obtusa*, *sumensis* and *cimbrica* zones in interval 4 at Altembroeck is probable, with most of specimens having originated from the *Bln.* *sumensis* Zone.

## 7 – Pesaken-Crapoel

At the Pesaken-Crapoel road section, near Gulpen (the Netherlands), a few metres of white marl belonging to the Zeven Wegen Member are overlain by about 5 metres of almost exclusively greensand in its lower portion and a gradually increasing marl content towards its top (Hofker, 1966, figs 16, 17). The boundary between the Zeven Wegen Member and the glauconitic greensand is distinct. According to Hofker (1966), the lowermost c. 3.5 m of the glauconitic layer yielded species typical of his foraminiferal zone B. On this evidence, this portion of the layer was referred to the Beutenaken Member in some papers (Keutgen, 1996; Keutgen & Jagt, 1999). The upper c. 1.5 m of the glauconitic layer, which is characterised by a relatively higher marl content, has yielded foraminifera of Zone C and was considered to represent the Vijlen Member. The transition from the greensand to the overlying coarse-grained, glauconite-rich marl is more or less gradual. Hofker (1966) observed belemnite-enriched horizons within the glauconitic layer, for example one about 3.5 m above its base.

With respect to the belemnites collected, the glauconitic layer at Pesaken-Crapoel may be subdivided into three parts. The lower c. 2 m have yielded a belemnite fauna consisting of frequent *Belemnitella* cf. *minor* II Christensen, 1995 with a mean Birkelund Index of about 3.8. Were it not for a single specimen of *Blt. junior*, collected about 1.3-1.4 m above the base of the glauconitic layer, this fauna could have been regarded as typical of the upper upper Campanian, with respect to the Campanian/Maastrichtian boundary definition at Tercis les Bains (Landes, southwest France), ratified as the Global Standard Stratotype Section and Point (GSSP) for that boundary (Odin & Lamaurelle, 2001).

From the interval c. 2.0-3.5 m above the base of the glauconitic layer, *Blt.* cf. *minor* II with a mean Birkelund Index of about 3.6 has been collected. A non-reworked *Blt. junior* was found about 2.2-2.4 m above the base of the glauconitic layer and a single specimen (NHMM 2007 006) of *Bln. (P.)* cf. *inflata* (Arkhangelsky, 1912) (Fig. 11I-K) comes from c. 3.2-3.4 m above the base of the glauconitic layer, plus two additional specimens (NHMM 2007 005, NHMM 2007 007) whose exact provenance is unknown. Their critical characters are given in Table 1. The ratio Qp/Dp of these specimens is typical of the upper *Bln. pseudobtusa* Zone (Schulz, 1979, fig. 51).

Table 1. Measurements of critical characters of *Belemnella* (*Pachybelemnella*) cf. *inflata* (Arkhangelsky, 1912) (NHMM 2007 005 - 2007 007) from the basal Vijlen Member near Pesaken-Crapoel.

Character	NHMM 2007 006	NHMM 2007 005	NHMM 2007 007
Ls (mm)	57.5	58.0	estimated 60
Dp (mm)	6.7	9.3	9.0
Qp	0.96	0.98	0.96
Lsn (mm)	69.8	65.5	c. 68
AV (%)	27.6	30.7	c. 23
AL (%)	6.0	12.7	c. 15

The interval c. 3.5-5 m above the base of the glauconitic layer has yielded several *Bln. (P.)* cf. *obtusa* (f.m.) (mean values: WQs: 1.6±0.4, N = 9; Lsn: 49.9±3.8 mm, N = 15; AV: 7.4±4.9%, N = 14) and a single specimen each of *Blt.* cf. *minor* II and *Blt. lwowensis*.

In the Crapoel 62C-74 borehole, close to the road section, the c. 5 m thick glauconitic layer is also present. Felder (1997, fig. 5) proposed correlation of this layer with the upper portion of interval 4 and the lowermost portion of interval 5. Later, Felder (2001, fig. 14) provided a more detailed analysis of the bioclasts; however, this seemed to indicate ecozone IIB, which is typical of the Beutenaken Member. This identification of ecozone IIB in the glauconitic layer is probably due to the fact that the layer consisted mainly of reworked material from the upper Campanian Beutenaken Member (with respect to the Campanian/Maastrichtian boundary as defined at Tercis les

Bains; see Odin & Lamaurelle, 2001) that was redeposited during the late Maastrichtian. The belemnite fauna of the road section favours this interpretation. In the present paper, the glauconitic layer in the borehole Crapoel 62C-74 is correlated with the upper portion of interval 4 and the basal part of interval 5 of the Vijlen type section at Mamelis (Fig. 4), in line with Felder (1997).

## 8 – Bovenste Bos quarry

The Bovenste Bos quarry (locality 62D-27) is a small, disused and now largely overgrown quarry on the southern slope of the River Geul valley at Epen, the Netherlands. It was described in detail by, among others, Hofker (1966), Robaszynski et al. (1985), Keutgen & Van der Tuuk (1991), Felder & Bless (1994) and Felder (2001), the last-named paper including a stratigraphical interpretation based on bioclasts. At this quarry, the Vijlen Member starts with a glauconitic greensand-type of sediment that fills burrows piping down into the topmost Beutenaken Member and containing a multitude of belemnite guards ('belemnite graveyard'). The Bovenste Bos quarry is the type locality of the Bovenste Bos Horizon, which, by definition, represents the contact between the Beutenaken and Vijlen members. Subsequently, the interpretation of this horizon has been extended so as to characterise the base of the Vijlen Member at any locality where this member is exposed. It is worth noting here that the stratotypes of the Bovenste Bos Horizon and the Vijlen Member have been defined at different localities.

The Vijlen Member overlying the Beutenaken Member is characterised by an up to 5 cm thick 'conglomerate', which consists of belemnite guards and fragments, a few rounded quartz grains and quartzite pebbles. These components are embedded in a glauconitic, yellowish grey marlstone that differs from the material in the burrows. The boundary between the burrow infill and the yellowish grey marlstone is distinct and attests to a discontinuity surface (Jagt, 1999a).

The thin 'conglomerate' is overlain by 0.8-1 m of yellowish grey clayey and calcareous marlstones with a relatively high glauconite content. According to Felder & Bless (1994), this portion of the Vijlen Member consists of several glauconitic layers with glauconite-filled burrows and/or depressions. In this portion of the section, one of us (NK) has also observed a few partially indurated boulders of yellowish-grey, glauconitic and phosphatic marl, which otherwise do not differ from the surrounding softer marlstones. They might represent relicts of broken-down incipient hardground layers. In addition, phosphatic fossils (the heteromorph ammonite *Baculites* sp., bivalves and gastropods) have been collected from this level. The Vijlen Member above the basal c. 1 m contains less glauconite. Felder (2001, fig. 38) interpreted the lowermost c. 0.8 m of the Vijlen Member at the Bovenste Bos quarry as relicts of intervals 0-5 and referred the overlying portion to interval 6 of the Mamelis type section.

For the present study, belemnites occurring within the burrows of the topmost Beutenaken Member have been restudied in more detail. First of all, two groups of specimens could be distinguished: small, well-preserved ones (nine specimens of the subgenus *Bln.* (*Pachybelemnella*)) and larger ones showing clear signs of erosion. In a few of the specimens of the first group even the fragile anterior part of the alveolus has been preserved. Moreover, the colour of these guards is more honey-like and less grey or green-red than that of the other specimens. The *Belemnella* specimens of this small group could not be identified with certainty, because their small size did not allow splitting of the guards and measurement of WQs values. With respect to their means and range of variation (Lsn: 51.2±2.9 mm, N = 9, observed range 46.8-54.8 mm; AV: 9.5±7.4%, N = 9, observed range -3.7-20.9%), they resemble typical or late forms of *Bln.* (*P.*) *obtusa* or *Bln.* (*P.*) *sumensis*. Thus, these specimens are here referred to as *Bln.* ex gr. *obtusa/sumensis*.

The second group of specimens, which comprises both *Bln.* (*P.*) cf. *obtusa* and *Blt.* cf. *minor* II, shows clear signs of reworking. Analysis of this group has revealed that about 37% of specimens were complete or near-complete (specimens were considered complete when the AV value could be calculated). This percentage was larger for specimens originating from the interval 0-0.65 m than for those collected from 0.65-1 m below the top of the chalkstone (Table 2). About 33% of the *Belemnella* specimens were complete, compared to 53% of the *Belemnitella*. This distinct difference can be attributed to the more robust structure of the guard in *Blt.* cf. *minor* II, especially the rostrum cavum. Whereas the percentages of complete rostra of *Bln.* (*P.*) cf. *obtusa* in the upper (0-0.65 m) and lower part (0.65-1.00 m) of the burrows were similar, the corresponding percentages of *Blt.* cf. *minor* II differed considerably (Table 2). From the upper interval (0-0.65 m) four complete specimens were collected, whereas the lower part of the burrows (0.65-1 m) yielded only 36% near-complete specimens. Although this relationship might be biased, because indeterminate rostrum solidum fragments of *Belemnitella* might have been overlooked, the large number of fragments of *Blt.* cf. *minor* II in the lower section of the burrows is remarkable. Moreover, the percentage of *Blt.* cf. *minor* II in the belemnite fauna is twice as high in the

lower part of the burrows (17%) than in the upper portion (8%). These results are best interpreted by assuming that in the Bovenste Bos quarry some of the specimens referred to *Blt.* cf. *minor* II were washed down the burrows prior to the bulk of sediment with *Bln.* (*P.*) cf. *obtusa*.

With respect to their mean values (WQs: 1.8, N = 2; Lsn: 57.4±5.8 mm, N = 48; AV: 16.1±7.1%, N = 32), the less well-preserved specimens of *Bln.* (*Pachybelemnella*) from the 'belemnite graveyard' resemble *Bln.* (*P.*) *obtusa* (f.a.) at Krons Moor. A single specimen (Lsn = 68 mm, AV = 28%) plots well within the range of *Bln.* (*P.*) *inflata*, but could also be considered an extreme variant of *Bln.* (*P.*) *obtusa*. Schulz (1979) distinguished two 'Schichtgruppenfaunen' in the lower *Bln.* *obtusa* Zone at Krons Moor. The older one (SGF 15-18 m) contained several specimens with AV values >20%, the younger one (SGF 18-21 m) shorter specimens (Lsn <50 mm). Within the 'belemnite graveyard' at the Bovenste Bos quarry both 'extreme' forms are present in the lower (0.65-1.00 m) as well as in the upper portion (0.00-0.65 m) of the burrows. This may be interpreted as a sign of heterogeneity of the belemnite sample. Last, but not least, *Bln.* (*Bln.*) cf. *lanceolata* has been identified in the 'belemnite graveyard' of the Bovenste Bos quarry (Keutgen & Van der Tuuk, 1991), in addition to two specimens of *Belemnitella*, which according to Christensen (1995, p. 72) are out of the range of *Blt.* cf. *minor* II ('*Belemnitella* ex gr. *mucronata*' in Keutgen & Van der Tuuk, 1991). Both specimens of *Belemnitella* are here referred to *Blt.* *junior*, albeit with a query, probably indicating a late Maastrichtian age in terms of belemnite stratigraphy of the greensand that filled the burrows within the topmost Beutenaken Member.

In summary, belemnites were washed down the burrows penetrating the topmost Beutenaken Member during more than a single event and derived from different stratigraphical levels. The first set of belemnites that entered the burrows consisted mainly of *Blt.* cf. *minor* II, probably derived from Beutenaken Member deposits. Later, the burrows were filled mainly with *Bln.* (*P.*) cf. *obtusa* originating from different stratigraphical levels within the *Bln.* *obtusa* Zone. *Bln.* (*P.*) cf. *sumensis* is probably also present in the burrows.

The belemnite sequence within the burrows, *Blt.* cf. *minor* II below and *Bln.* (*P.*) cf. *obtusa* above, is reminiscent of the

Table 2. Distribution and frequency of belemnites with clear signs of erosion found in burrows within the chalkstone underlying the Vijlen Member at the Bovenste Bos quarry. Belemnites from intervals 0-0.65 m and 0.65-1 m below the top of the chalkstone were analysed separately (*Blt.* = *Belemnitella*; *Bln.* = *Belemnella*).

	All specimens	Specimens from 0-0.65 m	Specimens from 0.65-1 m	<i>Bln.</i> cf. <i>obtusa</i> all specimens	<i>Bln.</i> cf. <i>obtusa</i> from 0-0.65 m	<i>Bln.</i> cf. <i>obtusa</i> from 0.65-1 m	<i>Blt.</i> cf. <i>minor</i> II all specimens	<i>Blt.</i> cf. <i>minor</i> II from 0-0.65 m	<i>Blt.</i> cf. <i>minor</i> II from 0.65-1 m
Number	112	48	64	94	41	53	15	4	11
% of fauna				83.9	85.4	82.8	13.4	8.3	17.2
% of complete specimens	36.6	41.7	32.8	33.0	34.1	32.1	53.3	100	36.4



sequence within the 5 m thick glauconitic layer in the Pesaken-Crapoel road section, as is the glauconitic greensand-type of sediment. Because *Blt. junior* occurs in the glauconitic greensand at both localities, the glauconitic levels may be correlated. Consequently, at the Bovenste Bos quarry, deposition of Vijlen Member strata (greensand) started in the burrows of the topmost Beutenaken Member during the deposition of interval 4 or 5, i.e. during the *Blt. junior* Zone. The lower c. 0.8 m of the marlstone may be regarded as a condensed deposit, followed by interval 6 (Fig. 4).

The marlstones of the Vijlen Member at the Bovenste Bos quarry (interval 5-6) have yielded the typically late Maastrichtian *Blt. junior* and *Blt. lwowensis*. The means of AV and Lsn of remanié specimens of *Bln. (Pachybelemnella)* indicate the presence of early forms of *Bln. (P.) cf. sumensis* (Fig. 7), but the observed range of variation of AV is larger than that documented for *Bln. (P.) sumensis* (f.a.) by Schulz (1979). AV values of up to 29.3% and WQs values as low as 1.5 support the presence of *Bln. (P.) cf. obtusa*, while AV values as small as -6.4% that of late forms of *Bln. (P.) cf. sumensis*, and possibly also of *Bln. (P.) cf. cimbrica*.

## 9 – Beutenaken

The Habets quarry at Beutenaken (the Netherlands, locality 62C-22) is the stratotype of the Beutenaken Chalk Member and its succession is basically similar to that at Bovenste Bos quarry. From this quarry Keutgen & Van der Tuuk (1991) described a few belemnites, all collected loose and assumed to have come from the lowermost part of the Vijlen Member, at that locality considered to correspond to interval 6 (Felder, 2001, fig. 13). A re-investigation of the belemnite material from the Habets quarry has now revealed its heterogeneous character. Whereas the majority of specimens of *Bln. (Pachybelemnella)* resemble *Bln. (P.) cf. obtusa* (f.m.) on the means of WQs (1.4, N = 2), Lsn (53.3 mm, N = 11) and AV (11.8%, N = 8), a single specimen must be attributed either to *Bln. (P.) cf. obtusa* (f.a.) or to *Bln. (Bln.) cf. inflata*, due to its primitive shape (Lsn = 60.9 mm; AV = 29.8%). A fragment probably belonging to *Blt. cf. minor* II was also found.

Hofker (1966, fig. 14) mentioned a second locality near Beutenaken, the 'Road west of Beutenaken' on the opposite side of the River Gulp valley. From a nearby field, numerous belemnite guards were collected, which are assumed to stem from the lowermost Vijlen Member (interval 6). This fauna was also studied by Keutgen & Van der Tuuk (1991). It is basically identical to that from the Habets quarry, but single specimens each of *Belemnella (Belemnella) cf. lanceolata* (Von Schlotheim, 1813) and of *Blt. junior* or *Blt. lwowensis* were also identified. Of this latter comparatively large, strongly vascularised and pseudogranulate specimen (M.J. van Birgelen Collection), only a small part of the alveolus is preserved, so that the AV value could not be calculated. Its Birkelund Index was reported to be

5.4 (Keutgen & Van der Tuuk, 1991; specimen mentioned under '*Belemnitella ex gr. mucronata*'). The presence of this specimen indicates the *Blt. junior* Zone for the lowermost Vijlen Member near Beutenaken.

## 10 – The former Ciments Portland Liégeois (CPL) quarry, Haccourt

This quarry (locality 62H-9) is situated on the left bank of the River Maas, about 10 km south of Maastricht, in the Belgian province of Liège. The deposits exposed here have been described in several papers, e.g. Robaszynski et al. (1985), to which reference is made. Bioclast stratigraphy (Felder, 1997, 2001) correlated the Vijlen Member exposed here with the upper portion of interval 5 and interval 6. Belemnites described from these levels belong to the typically late Maastrichtian *Blt. junior* and *Blt. lwowensis* (Keutgen & Van der Tuuk, 1991; Christensen et al., 2004). Representatives of *Bln. (P.) ex gr. sumensis/cimbrica* are restricted to burrow fills in the chalkstone underlying the Froidment Horizon at the base of the Vijlen Member.

## 11 – Wilkensberg (Aachen)

At Wilkensberg (or 'Willkommberg' in older literature) near the Computer Museum of RWTH Aachen (Melatener Straße, Aachen, Germany), up to 15 m of Vijlen Member and the lowermost portion of the Lixhe (Orsbach) Member were exposed between 1983 and 1991. From the nearby locality Melaten, Ebensberger (1962) mentioned *Bolivinooides gr. draco* resembling *B. draco draco* (Marsson, 1878), which is why the deposits exposed at Wilkensberg are correlated with interval 6. Because this unit is characterised by a thickness of 11.5 m at the stratotype section near Mamelis, it is probable that the top of interval 5 was also exposed for a short period near Wilkensberg in 1991. However, most of the fossils collected at the latter locality derived from interval 6. Interval 6 at Wilkensberg yielded common *Blt. junior* and rare *Blt. lwowensis*. Specimens of *Belemnella* may be referred to *Bln. ex gr. sumensis/cimbrica*, although the means of AV and AL of the sample are more typical of *Bln. (P.) cimbrica* (see Keutgen & Van der Tuuk, 1991).

## Discussion

### General results

Most of the Vijlen Member sections studied in the Maastricht-Aachen-Liège area have yielded specimens of *Belemnitella* which resemble the late Maastrichtian *Blt. junior* or *Blt. lwowensis*. These specimens frequently co-occur with typically early Maastrichtian species of *Belemnella* such as *Bln. (P.) cf. obtusa*, *Bln. (P.) cf. sumensis*, *Bln. (Bln.) cf. praearkhangelskii* and *Bln. (P.) cf. cimbrica*. At Pesaken-Crapoel, they are also associated with latest Campanian taxa (with respect to the Campanian/

Maastrichtian boundary definition at Tercis les Bains), such as *Bln. (P.) cf. inflata* and *Blt. cf. minor* II. The frequency of late Maastrichtian representatives of *Belemnitella* at some of the localities studied is surprisingly low (Table 3). For example, at the Bovenste Bos quarry or at the Pesaken-Crapoel road section, species of *Belemnitella* typical of the *Blt. junior* Zone account for less than 5% of the belemnite assemblages.

Table 3. Approximate percentages of non-reworked *Belemnitella* within the late Maastrichtian belemnite samples from the Maastricht-Aachen-Liège area, in part after data supplied by Keutgen & van der Tuuk (1991); No. bel. = number of belemnites; nr = non-reworked; Blt. = *Belemnitella*; Bln. = *Belemnella*; A. = *Allee*.

Locality	Units	No. bel.	No. nr	% nr	Remarks
Pesaken-Crapoel	Vijlen 4	84	3	3.6	reworked <i>Bln.</i> and <i>Blt.</i>
Altembroeck	Vijlen 4	289	23	8.0	reworked <i>Bln.</i> and <i>Blt.</i>
Hans-Böckler-A.	Vijlen 4	100	10	10.0	reworked <i>Bln.</i>
Bovenste Bos	Vijlen 4-5	268	9	3.4	reworked <i>Bln.</i> and <i>Blt.</i>
CPL-Haccourt	Vijlen 5-6	21	21	100	
Wilkenberg	Vijlen 6	48	20	41.7	reworked <i>Bln.</i>

Based on the co-occurrence of *Blt. junior* and late early Maastrichtian species of *Belemnella*, Keutgen (1996) erroneously noted that *Blt. junior* first appeared in the Maastricht-Aachen-Liège area as early as in the late early Maastrichtian *Bln. sumensis* Zone. However, a re-evaluation of his material with respect to the recently established bioclast zonation of the Vijlen Member revealed that at least the sections exposing intervals 4-6 of this member contain identical populations of *Belemnitella* (*Blt. junior* and *Blt. lwowensis*), but different species of *Belemnella*. It is here concluded that these deposits are of late Maastrichtian age and that the early Maastrichtian and latest Campanian belemnite index taxa collected at these levels must be considered reworked. Due to the comparatively good preservation also of remanié material of *Belemnella*, Keutgen (1996, 1997) and, earlier Keutgen & Van der Tuuk (1991), were unable to distinguish between remanié and non-reworked samples of *Belemnella*, which resulted in the record of typical *Blt. junior* in the so-called 'early Maastrichtian'. Moreover, Keutgen & Van der Tuuk (1991) misinterpreted the concept of *Belemnitella pulchra* Schulz, 1982 and included the late Maastrichtian *Blt. lwowensis* in their '*Blt. pulchra*'.

Remanié belemnite rostra are frequently accumulated at certain levels within the Vijlen Member. Doyle & Macdonald (1993) proposed a model for the development of belemnite accumulations, which involved five possible pathways: post-spawning mortality, catastrophic mass mortality, predation concentration, stratigraphical condensation and resedimentation. To separate these pathways, palaeontological and sedimentological criteria have been introduced. According to scenarios

presented by those authors (p. 78), the belemnite accumulations at the base of the Vijlen Member in the region between Beutenaken, Pesaken-Crapoel, and Bovenste Bos, which represent intervals 4-6 of the Vijlen Member, reflect concentration by condensation, as this member is incompletely developed in this area. Belemnite rostra at these localities are eroded and associated with obvious omission surfaces. For the Altembroeck section (Vijlen Member interval 4), Keutgen (1997) proposed reworking of belemnite rostra from older layers and transport by currents. These belemnite accumulations may be interpreted as kinds of stratigraphical condensates (sensu Doyle & Macdonald, 1993). For the Vijlen Member, stratigraphic condensation represents the most probable origin for the belemnite accumulations, but resedimentation processes, e.g. of older belemnite accumulations, contributed to the accumulations as well. However, reworked rostra of *Belemnella* in this member are not limited to belemnite accumulations. The frequency of remanié belemnite rostra in the Vijlen Member can at least partly be explained by the deposition of a significant portion of this member in channel-like structures, which facilitated reworking of belemnites from older deposits, originally present at the channel margins, and their preservation within the channel deposits.

#### Intervals 4-6 of the Vijlen Member

The upper portion of the Vijlen Member (intervals 4-6) is well exposed, while its lower portion (intervals 0-3) is less accessible. Intervals 0-2 are known mainly from boreholes. Because more information on belemnites from intervals 4-6 is available, this portion of the Vijlen Member is discussed separately.

In the Vijlen Member of the Maastricht-Aachen-Liège area, the oldest unequivocal records of *Blt. junior* and *Blt. lwowensis* stem from interval 4, and material was collected at several localities. The base of the *Blt. junior* belemnite Zone is generally considered to correspond to the base of the upper Maastrichtian in terms of belemnite stratigraphy (Christensen, 1996). This interpretation is followed herein. The best exposed and most thoroughly studied section to date is that at Altembroeck, where intervals 2-4 were investigated (Jagt et al., 1995; Felder, 2001). In this section, the first representatives of both species have been collected from level Bm 1, about 1.2 m above the base of interval 4.

Although representatives of *Belemnitella* are comparatively rare within intervals 4-6 of the Vijlen Member, the tendency of *Blt. lwowensis* to constitute a smaller portion of the belemnitellid fauna towards the top of the Vijlen Member is clear. In strata referred to interval 4 and possibly the lower portion of interval 5, this species usually is as common as *Blt. junior*. In deposits referred to the upper portion of interval 5 and to interval 6, the percentage of *Blt. lwowensis* in the belemnitellid fauna is reduced to about 10% (Table 4). In comparison, Christensen et al. (2004) also noted that *Blt. lwowensis* constituted about 9% of the late Maastrichtian belemnitellid fauna in the Maastricht area (the Netherlands, Belgium).

Table 4. Approximate percentages of *Belemnitella lwowensis* Naidin, 1952 in the late Maastrichtian belemnitellid fauna of the Vijlen Member, in part after data supplied by Keutgen & Van der Tuuk (1991); No. Blt. jun. = number of specimens of *Belemnitella junior* Nowak, 1913; No. Blt. lw. = number of specimens of *Blt. lwowensis*; % Blt. lw. = percentage of *Blt. lwowensis*; HBA = Hans-Böckler-Allee.

Locality	Units	No. Blt. jun.	No. Blt lw.	% Blt. lw.
Pesaken-Crapoel	Vijlen 4	3	1	25
Altembroeck	Vijlen 4	11	12	52
HBA	Vijlen 4	7	6	46
Bovenste Bos	Vijlen 4-5	4	5	56
<b>Sum</b>	<b>Vijlen 4-5</b>	<b>25</b>	<b>24</b>	<b>49</b>
Mamelis	Vijlen 5-6	1	1	50
CPL-Haccourt	Vijlen 5-6	20	1	5
Wilkenberg	Vijlen 6	c. 18	c. 2	10
<b>Sum</b>	<b>Vijlen 5-6</b>	<b>c. 39</b>	<b>c. 4</b>	<b>c. 10</b>

The means of the investigated samples of *Blt. junior* from interval 4 of the Vijlen Member indicate the *Spyridoceras tegulatus/Belemnitella junior* Zone of the Hemmoor section in northern Germany (Fig. 2). With respect to *Blt. lwowensis* from interval 4 of the Vijlen Member, the slenderness and shape of the guards (BI = 5.6; AV = 12.9%) are more advanced than those of specimens of the ancestral species *Blt. pulchra* from the uppermost Campanian to middle lower Maastrichtian of the Kronsmoor quarry section, northern Germany (BI = 6.0; AV = 20.1%), but are slightly more primitive than those of *Blt. lwowensis* from the lower upper Maastrichtian of Hemmoor (BI = 5.4; AV = 10.0%). Because *Blt. lwowensis* first occurs 7.5 m above the base of the upper Maastrichtian at Hemmoor (Christensen et al., 2004), the more primitive means of the sample from interval 4 of the Vijlen Member might indicate a correlation of this unit with the lowermost c. 10-15 m of the *Spyridoceras tegulatus/Belemnitella junior* Zone at Hemmoor.

Since *Blt. lwowensis* disappears in the Hemmoor quarry one metre below the top of the *Spyridoceras tegulatus/Belemnitella junior* Zone (Christensen et al., 2004), the reduction in frequency of this species observed within interval 5 of the Vijlen Member may indicate correlation of this unit with the upper *Spyridoceras tegulatus/Belemnitella junior* Zone. It follows from this correlation that at least the upper portion of interval 6 of the Vijlen Member may correspond already to the basal *Tenuipteria argentea/Belemnitella junior* Zone of the Hemmoor quarry section in northern Germany (Figs 2, 4). This interpretation is in line with the small sample of *Blt. junior* from interval 6 of the Vijlen Member at Wilkenberg (compare Keutgen & Van der Tuuk, 1991), where most specimens are characterised by Birkelund Indices smaller than 4.0. With respect to BI and AV, these specimens resemble the sample of *Blt. junior* from the lower *Tenuipteria argentea/Belemnitella junior* Zone of Hemmoor described by Christensen et al. (2004).

### Intervals 0-3 of the Vijlen Member

Parts of the lower portion of the Vijlen Member were exposed at Lemierserberg and in the Aachen localities Schurzelterstraße and Vaalserstraße. The belemnite record of these sections is difficult to interpret and a reliable correlation either with the late Maastrichtian *Blt. junior* Zone or an early Maastrichtian *Belemnella* zone is impossible.

With respect to Lemierserberg, the number of available belemnites (N = 5) is too small to exclude the possibility that late Maastrichtian specimens of *Belemnitella* occur at that level, especially when keeping in mind that the frequency of non-reworked *Belemnitella* could become smaller than 5% in some localities.

At the Aachen locality Vaalserstraße, Vijlen Member intervals 3-4 were originally exposed. While the presence of *Blt. cf. lwowensis* implies a correlation at least of the upper portion of the section with interval 4 or younger deposits of the Vijlen Member, i.e. the late Maastrichtian *Blt. junior* Zone, the record from this section of *Belemnitella* sp. resembling *Blt. junior* is more difficult to interpret. The precise level from which the specimen originated is unknown. It is either from the upper portion of interval 3 or from the lowermost portion of interval 4.

Similarly, a rostrum solidum referred to *Belemnitella* sp. and resembling *Blt. junior* is recorded from the Aachen locality Schurzelterstraße. The deposits formerly exposed here are generally considered as part of Vijlen Member interval 3, but it cannot be excluded that the base of interval 4 was also temporarily exposed. The limited information available therefore cannot be used to prove or disprove the presence of *Blt. junior* in interval 3 (or older deposits) of the Vijlen Member. This portion of the Vijlen Member is either of earliest late or of late early Maastrichtian age.

The base of the upper Maastrichtian is here defined by the first appearance of unequivocal *Blt. junior* close to the base of Vijlen Member interval 4. This interpretation is also in line with the known stratigraphic range of scaphitid ammonites (see hereafter). In addition, a sequence-stratigraphical interpretation of Vijlen Member strata also appears to favour an early Maastrichtian date for intervals 0-3. Keutgen & Jagt (2009) identified a sea-level lowstand at the base of interval 4, which they interpreted as the sequence boundary dated at 69.4 Ma by Vandenberghe et al. (2004). Their interpretation would imply correlation of the base of interval 4 with the base of the Maastrichtian Ma 3 sequence sensu Ogg et al. (2008), which approximates to the base of the *Blt. junior* Zone, i.e. the base of the classic 'upper Maastrichtian' (Ogg, pers. commun.). It may be concluded that deposits of intervals 0-3 of the Vijlen Member are thus of early Maastrichtian age and belong to sequence Ma 2 (Vandenberghe et al., 2004), which probably is of *Bln. cimbrica* Zone age (J.G. Ogg, letter of 9 June 2009). However, an exact correlation of the FAD of *Blt. junior* and the Ma 3 sequence boundary has not yet been demonstrated, so that it is still



possible that Vijlen Member intervals 0-3 are of late Maastrichtian date, if comparatively rapid sedimentation rates are assumed.

It is worth noting that Vandenberghe et al. (2004) interpreted the belemnite lag deposits at the base of the Vijlen Member as part of sequence Ma 1. According to Ogg (pers. commun.), sequence Ma 1 would roughly correspond to the *Bln. obtusa* and *Bln. sumensis* zones (sensu germanico). However, the frequently cited belemnite accumulations in the Beutenaken area are now known to correspond to the base of intervals 4-6 of the Vijlen Member. Older strata of this member are missing in that area. As such, these belemnite accumulations must be part of sequence Ma 3. But, because most belemnite guards collected from those accumulations belong to *Bln. cf. obtusa* and *Bln. cf. sumensis*, index taxa of sequence Ma 1 of Ogg et al. (2008), belemnite accumulations in the Beutenaken area may be seen as reworked relicts of the latter sequence. They demonstrate that deposits of that age were indeed present along the channel margins during deposition of most of the Vijlen Member and served as a source of remanié rostra and possibly other index taxa of early Maastrichtian age, at least in the Gulpen-Aachen area. From the base of the channel system (interval 0), belemnites have not been recorded yet. Belemnite bioclasts are common (Felder & Bless, 1994), but, as noted above, peaks of such bioclasts do not necessarily coincide with levels rich in belemnite rostra.

In case an early Maastrichtian age of Vijlen Member interval 3 is accepted, on account of the presence of *Acanthoscaphites* (*A.*) *tridens* (see hereafter) and with respect to the sequence-stratigraphical interpretation of Keutgen & Jagt (2009), the *Belemnella* sample from the Aachen locality Schurzelterstraße may be used to determine the age of these deposits. It may be considered homogeneous with respect to standard deviation and range of variation of AV values, but reworking of part of the material cannot be ruled out entirely in view of deposition of interval 3 and older deposits of the Vijlen Member in a channel-like structure, while transport of remanié belemnites from the channel margins to its centre has been proved (see above).

Keutgen & Van der Tuuk (1991) referred *Bln. (Pachybelemnella)* specimens from the Schurzelterstraße exposures to late forms of *Bln. (P.) sumensis*. Indeed, the means of AV ( $1.8 \pm 4.2\%$ ,  $N = 34$ , observed range  $-8.7$  to  $9.2\%$ ) and Lsn ( $54.1 \pm 4.1$  mm,  $N = 20$ ) do not differ significantly at the 5% level from the population of *Bln. (P.) sumensis* (f.p.) SGF 38-47 m at Hemmoor (AV:  $t = 1.04$ ,  $0.5 > P > 0.2$  with 108 degrees of freedom; Lsn:  $t = 0.413$ ,  $P > 0.5$  with 94 degrees of freedom). The sample from Schurzelterstraße does not significantly differ from *Bln. (P.) sumensis* (f.p.) SGF 47-54 m at Hemmoor either (AV:  $t = 1.942$ ,  $0.1 \gg P > 0.05$  with 101 degrees of freedom; Lsn:  $t = 0.544$ ,  $P > 0.5$  with 87 degrees of freedom), although the probability for AV is very close to the 5% level. In addition, significant differences between the sample from the Schurzelterstraße and *Bln. (P.) cimbrica* from Hemmoor could not be detected (statistics not shown). Schulz (1979,

table 6) reported 95%-confidence intervals for the AV value of populations of the late form of *Bln. (P.) sumensis* ranging between 1.5 and 5%, but defined the threshold value separating this species from *Bln. (P.) cimbrica* at AV = 2% (Schulz, 1979, p. 124). Populations with a mean AV value between 1.5 and 2% as in the case of the sample from the Schurzelterstraße are, thus, difficult to refer to one of the two species with certainty.

Not only does the AV value of populations decrease steadily during the late early Maastrichtian in the subgenus *Bln. (Pachybelemnella)*, the AL value does as well (see Schulz, 1979, fig. 42) with the threshold value for AL separating *Bln. (P.) sumensis* from *Bln. (P.) cimbrica* being defined at AL = -10% (Schulz, 1979, p. 124). Therefore, the values for AV and AL of selected populations from the Maastricht-Aachen-Liège area (Keutgen & Van der Tuuk, 1991; Jagt et al., 1995) are plotted and compared with those of *Bln. (P.) sumensis* and *Bln. (P.) cimbrica* from Krons Moor and Hemmoor (Fig. 9). The means for AV and AL of the sample from the level Bm 2 at Altembroeck are typical of an early form of *Bln. (P.) sumensis*. In comparison, the AV value of the sample from the Bovenste Bos quarry is typical of an early form of *Bln. (P.) sumensis* as well, while the AL value is more advanced, pointing to a late form of this species. This discrepancy could at least partly be explained by the heterogeneity of this sample. The means of AV and AL of the

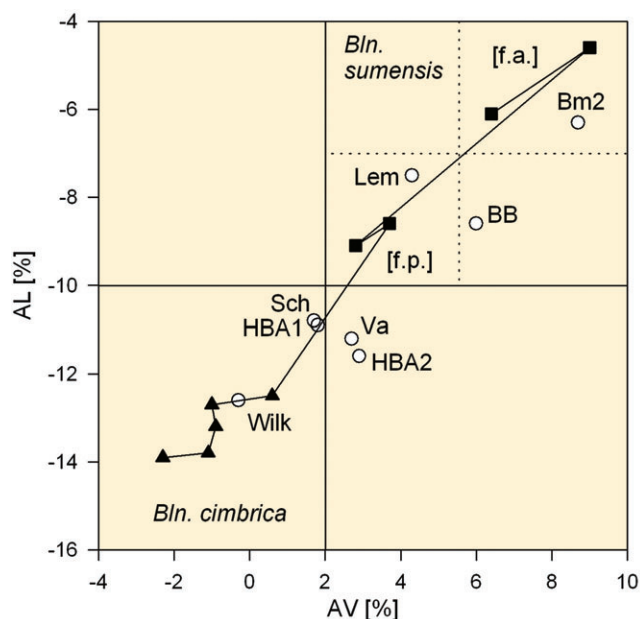


Fig. 9. Comparison of the mean AV and AL values of samples of the subgenus *Bln. (Pachybelemnella)* (Keutgen & Van der Tuuk, 1991; Jagt et al., 1995) with the late early Maastrichtian populations from Krons Moor and Hemmoor, northern Germany (Schulz, 1979). Localities: Lem = Lemierserberg; Sch = Schurzelterstraße; Va = Vaalersstraße; Bm 2 = belemnite level Bm 2 at Altembroeck; BB = Vijlen Member of the Bovenste Bos quarry, except the burrow fills in the topmost Beutenaken Member; HBA 1, HBA 2 = Hans-Böckler-Allee I, upper glauconitic layer and level above this; Wilk = Wilkensburg; ■ = *Bln. (P.) sumensis* Jeletzky, 1949; ▲ = *Bln. (P.) cimbrica* Birkelund, 1957.

small sample from the Lemierserberg are both typical of *Bln. (P.) sumensis*. The samples of *Bln. (Pachybelemnella)* from the Aachen localities Schurzelterstraße, Vaalserstraße and Hans-Böckler-Allee plot close to each other (Fig. 9). With respect to their positions, they can neither be referred to a population typical of a late form of *Bln. (P.) sumensis* nor to a population typical of *Bln. (P.) cimbrica*. These samples have reached a developmental stage with respect to the shape of the guards, which is transitional between both species. Finally, the sample of *Bln. (Pachybelemnella)* recorded by Keutgen & Van der Tuuk (1991) from the Aachen locality Wilkensberg plots close to populations typical of *Bln. (P.) cimbrica*, indicating the presence of this species in the Maastricht-Aachen-Liège area. However, the sample from Wilkensberg is obviously reworked, because contemporaneous deposits in the Haccourt area have not yielded specimens of the genus *Belemnella*.

The question is from which level of the Vijlen Member the sample from the Wilkensberg was reworked. Because interval 4 of the Vijlen Member must be attributed to the late Maastrichtian *Blt. junior* Zone, this would imply reworking from older deposits, perhaps from interval 3, of the Vijlen Member.

In summary, interval 3 of the Vijlen Member may be correlated either with the early Maastrichtian late *Bln. sumensis* Zone or with the *Bln. cimbrica* Zone (sensu germanico) based on the mean values of the *Belemnella* sample from the Aachen locality Schurzelterstraße. This result matches the sequence-stratigraphical interpretation, which would favour a *Bln. cimbrica* Zone age. However, an earliest late Maastrichtian date (lower *Spyridoceras tegulatus/Belemnitella junior* Zone (sensu germanico)) cannot be ruled out entirely for Vijlen Member interval 3.

### ***Scaphitid ammonite records from the Vijlen Member***

Scaphitids can be used to correlate Vijlen Member intervals 3-6 and successions in northern Germany and the United States. The early Maastrichtian age of interval 3 is corroborated by records of fairly well-preserved material of *Acanthoscaphites (A.) tridens* from the lower portion of the Vijlen Member as exposed at Vaalserstraße and Schurzelterstraße (Jagt et al., 1999), whereas specimens recorded from interval 4 (Altembroeck and Hans-Böckler-Allee) are fragmentary only (NK, unpubl. data) and may thus be considered reworked (Fig. 4). The documented range of *A. (A.) tridens* is *Bln. lanceolata* to *Bln. sumensis* zones (sensu germanico) (Niebuhr, 2003; Kin, 2010). However, for material from the Maastricht-Aachen-Liège area, a *Bln. cimbrica* Zone age has also been suggested (Jagt et al., 1992).

*Acanthoscaphites (A.) tridens* crosses the Campanian/Maastrichtian boundary (as defined at Tercis les Bains), the base of the Maastrichtian being near-contemporaneous with the lower limit of the *Endocostea typica* inoceramid Zone, which is situated either close to the base (Niebuhr, 2003) of or within the *Bln. obtusa* Zone (Machalski et al., 2007). The co-occurrence

of *A. (A.) tridens* and *Bln. ex gr. sumensis/cimbrica* within interval 3 of the Vijlen Member confirms the Maastrichtian age of this unit, most probably early Maastrichtian. Despite the presence of *A. (A.) tridens*, a late Maastrichtian age of Vijlen Member interval 3 cannot be ruled out entirely in view of the deposition of this and older intervals of this member in a channel-like structure, where transport of material from the channel margins into the centre may be considered to have been a significant factor, as demonstrated already for intervals 4-6. The short transport distance from the channel margins may explain the relatively good preservation of at least some of the *Acanthoscaphites* shells.

Equally important for supraregional correlations is *A. (Euroscaphites) varians blaszkiewiczii*, which is known from the uppermost portion of interval 5, plus interval 6. At Hemmoor (northern Germany), this taxon has been recorded from equivalents of the *Bln. cimbrica* Zone (i.e., upper lower Maastrichtian) to the *Tenuipteria argentea/Belemnitella junior* Zone (sensu germanico) (see Machalski, 2005). The commonest scaphitid in Vijlen Member intervals 4-6 is *Hoploscaphites constrictus*, which is long ranging (i.e., uppermost Campanian (*Bln. lanceolata* Zone) to lowermost Danian, sensu Machalski, 2005; Machalski et al., 2009). Two other species of stratigraphical value are *H. tenuistriatus* (Kner, 1848) and *Hoploscaphites* sp. (Fig. 4). The former is currently known from interval 6(?) at Mesch (southern Limburg, the Netherlands) and from interval 4 at Altembroeck. At Hemmoor, it occurs in the *Bln. sumensis* to *Spyridoceras tegulatus/Belemnitella junior* zones (sensu germanico) (Machalski, 2005). The presence of *Hoploscaphites* sp., interpreted as an interspecies hybrid (Machalski et al., 2007) between the North American *Jeletzkytes dorfi* Landman & Waage, 1993 and an unidentified subspecies of the endemic European lineage of *H. constrictus*, allows correlation of the lower portion of Vijlen Member interval 6 with the *Hoploscaphites birkelundae* Zone of the United States Western Interior. In this respect, the record of *Trachybaulites columna* (Morton, 1834) from interval 6 of the Vijlen Member is also important (Jagt, 2005). Records of this taxon from the Western Interior of the United States are from the zones of *Hoploscaphites nicolletii* and *Jeletzkytes nebrascensis* (Landman & Cobban, 2003; Jagt, 2005). A closely related form, referred to as *Trachybaulites* sp. cf. *T. columna*, has been recorded from the *Hoploscaphites birkelundae* Zone (Fox Hills Formation) in Larimer County, Colorado (Landman & Cobban, 2003).

### **Conclusions**

The present study has revealed that the typically late Maastrichtian belemnite taxa *Blt. junior* and *Blt. lwowensis* occur within intervals 4-6 of the Vijlen Member, while species of the genus *Belemnella* have locally been found up to the base of the Lixhe Member (Van der Ham & Van Birgelen, 1992; Felder, 1997). Nevertheless, the key sections Pesaken-Crapoel and

Haccourt indicate that specimens of *Belemnella* must be considered reworked into deposits belonging to Vijlen Member intervals 4-6, because at both localities, specimens which could be referred to *Bln.* ex gr. *sumensis/cimbrica* have not been found. The origin of remanié specimens of *Belemnella* is unknown, but preliminary data suggest they were derived from high-energy, nearshore marine settings along the margins of the channel system which extended from Aachen to Gulpen and from Altembroeck to Lanaye. Due to its sedimentation history, it may be speculated that reworked belemnite rostra can be expected to occur within the entire Vijlen Member. With reworking being a common feature of Vijlen Member belemnites, and in consideration of the fact that without additional geochemical analyses remanié material can barely be recognised (compare Nieto et al., 2008), we refrain from subdividing the Vijlen Member by belemnitellid cephalopods.

## Systematic palaeontology

### Terminology of the guard, measured characters and abbreviations

Terminology and methods to describe guards of the genus *Belemnitella* follow Christensen (1995) and Christensen (1999, figs 9, 14); the shape of guards is measured as suggested by Schulz (1979, 1982). Abbreviations, as indicated in Fig. 10, are as follows:

- Bs lateral diameter halfway between apex and protoconch (in mm).
- Bp lateral diameter at protoconch (in mm; corresponds to LDP of Christensen).
- Bc lateral diameter at rostrum cavum,  $\frac{1}{4}$  Ls from protoconch (in mm).
- Ds dorsoventral diameter halfway between apex and protoconch (in mm).
- Dp dorsoventral diameter at protoconch (in mm; corresponds to DVDP of Christensen).
- Dc dorsoventral diameter at rostrum cavum,  $\frac{1}{4}$  Ls from protoconch (in mm).
- Qp Bp/Dp.
- Ls length from apex to protoconch (in mm; corresponds to LAP of Christensen).
- BI Birkelund Index ( $BI = Ls/Dp$ ; corresponds to 'Elongation' of Schulz, 1982).
- AV ventral aspect ( $AV = (Bs-Bc) \times 100/Bp$  in %).
- AL lateral aspect ( $AL = (Ds-Dc) \times 100/Dp$  in %).
- AVs ventral aspect of rostrum solidum ( $AVs = (Bs-Bp) \times 100/Bp$  in %).
- ALs lateral aspect of rostrum solidum ( $ALs = (Ds-Dp) \times 100/Dp$  in %).
- SD Schatzky Distance, the distance (in mm) between the anterior part of the protoconch and the posterior end of the ventral fissure measured along the axis of the guard.

The SD has been measured in different ways by authors (compare Schulz, 1979, p. 26). It is worth noting that the present definition differs from that used by Schulz (1979) and Keutgen & Van der Tuuk (1991), who measured the Schatzky Distance as the distance between mid-protoconch and the posterior end of the ventral fissure. Their definition results in c. 0.5 mm larger values, which is the reason why some specimens of the genus *Belemnella* were incorrectly referred to *Belemnitella* ex gr. *junior* by Keutgen & Van der Tuuk (1991).

- AA alveolar angle, which is the dorsoventral angle (in degrees) between the walls of the alveolus measured in the median plane about 10-15 mm from the protoconch. It is worth noting that the alveolar angle changes during the ontogenetic development of the guard (Kongiel, 1962; Schulz, 1979). An inexact position of the measurement may thus result in significant differences, even within the same population (compare Schulz, 1979, p. 23).
- FA fissure angle, which is the angle (in degrees) between the wall of the alveolus and the straight line connecting the intersection points of the bottom of the ventral fissure on the wall of the alveolus and the outer margin of the guard. Note that this definition is different to that of Schulz (1979).

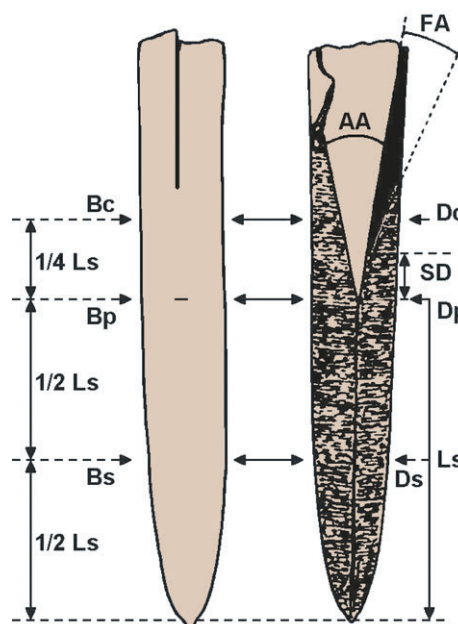


Fig. 10. Terminology of belemnite guard, ventral view and longitudinally split guard showing internal features (modified after Jagt et al., 1987); see text for abbreviations.

Linear measurements of Ls and SD were made with a ruler to an accuracy of 0.5 mm; those of Bs, Bp, Bc, Ds, Dp, and Dc with a vernier calliper to an accuracy of 0.1 mm. Angles were measured with a geometrical triangle to an accuracy of 1 degree.

The range of variation of the species studied was analysed using univariate and bivariate statistical methods, as described



in Keutgen & Jagt (1999). In the univariate analyses, estimates of the following statistics were calculated: arithmetical mean value (Mean), standard deviation (S) and coefficient of variation (CV). In addition, the observed range (OR) is recorded; N is the number of specimens. A linear regression analysis ( $D_p = a + b \times L_s$ ) was carried out in order to study the relative growth. The estimates of the following statistical parameters were calculated: the slope (b) and the standard deviation of the slope ( $S_b$ ), the intercept on the  $D_p$ -axis (a), the standard deviation of the intercept ( $S_a$ ), the standard deviation of the regression line ( $S_{yx}$ ), and the correlation coefficient (r).

The following categories have been defined by Christensen (1995) and Christensen et al. (2004) to characterise size, relative length and shape of species of *Belemnitella*:

Size:

- length from apex to protoconch <55 mm: small guard
- length between 55 and 65 mm: large guard
- length >65 mm: guard very large.

Birkelund Index:

- BI <4: stout guard
- BI between 4 and 5: slender guard
- BI >5: very slender guard.

Shape:

- AV and AL larger than 30%: lanceolate guard
- AV and AL between 10 and 30%: slightly lanceolate guard
- AV and AL between -10 and 10%: subcylindrical guard
- AV and AL between -30 and -10%: subconical guard
- AV and AL smaller than -30%: conical guard.

The following categories are proposed for the characterisation of SD and FA in the genus *Belemnitella*:

Schatzky Distance:

- distance <4 mm: very small
- distance between 4 and 7 mm: small
- distance between 7 and 11 mm: large
- distance >11 mm: very large.

Fissure angle:

- angle <25 degrees: small
- angle between 25 and 45 degrees: medium
- angle between 45 and 65 degrees: large
- angle >65 degrees: very large.

Order Belemnitida von Zittel, 1895

Suborder Belemnopseina Jeletzky, 1965

Family Belemnitellidae Pavlow, 1914

Genus *Belemnitella* d'Orbigny, 1840

#### Type species

*Belemnites mucronata* von Schlotheim, 1813; ICZN Opinion 1328 (1985); name no. 2979.

#### Emended diagnosis

See Christensen (1997).

## 1. *Belemnitella mucronata* group

This group includes species with small to very large, usually stout guards; fissure angle usually small to medium-sized, Schatzky Distance and alveolar angle variable.

*Belemnitella cf. minor* II Christensen, 1995

Fig. 11A, B.

compare

1991 *Belemnitella* ex gr. *mucronata* (Schlottheim); Keutgen & Van der Tuuk, p. 13 (partim), pl. 1, figs 1, 2.

1995 *Belemnitella minor* II Christensen, p. 64, pl. 7, figs 3-10; text-figs 20A-D.

1995 *Belemnitella minor* III Christensen, p. 69, pl. 8, figs 1-9.

1999 *Belemnitella minor* II Christensen, 1995; Christensen, p.114, pl. 3, figs 1-19; pl. 4, figs 1-7 (with additional synonymy).

#### Holotype

NHM C43553, the original of Christensen (1995, pl. 7, figs 3-6), from Whitlingham, near Norwich (England), Paramoudra1 Chalk, by original designation.

#### Material

Fifty-four specimens and larger fragments (NHMM 2007 002/1-54) from the lower 3.5 m of the glauconitic layer (Vijlen Member) at Pesaken-Crapoel.

#### Description

Guards of *Blt. cf. minor* II reach a large size ( $L_s$  slightly above 60 mm), are stout, but somewhat more slender than typical forms of that subspecies (mean BI c. 3.7). The relationship of  $L_s$  and  $D_p$  is isometric. Guards are cylindrical or slightly conical in ventral view and high conical in lateral view. Juvenile guards are more conical in ventral as well as in lateral aspect. The guards are slightly flattened over their entire length and the apex is acute or obtuse with a mucro. Vascular markings are well developed ventrally and laterally. The dorso-lateral depressions and dorso-lateral longitudinal double furrows are prominent. Some specimens are pseudogranulated ventrally and have longitudinal striae on the posterior dorsal side. For means and range of variation of internal characters (SD, AA, FA), as well as for AV, AL and BI, see Table 5 and Fig. 12.

#### Discussion

*Belemnitella minor* II differs from *Blt. minor* I Jeletzky, 1951a in being stouter and having a larger Schatzky Distance. Keutgen & Jagt (1999) referred specimens from the Beutenaken Member of Slenaken to *Blt. minor* II. However, since their study, more populations of *Blt. minor* I and *Blt. minor* II have been described from Norfolk and Mons (southern Belgium) (see Christensen,

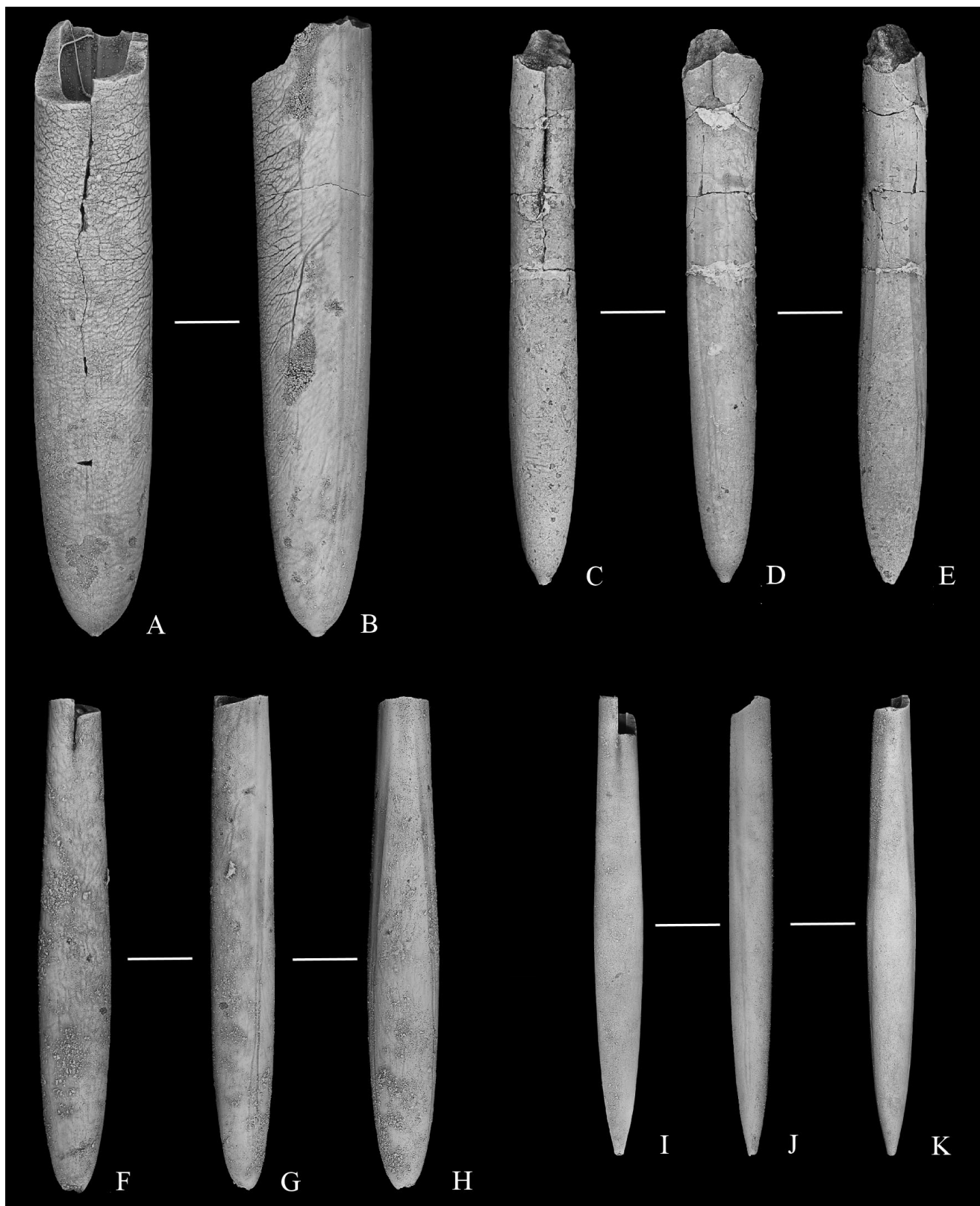


Fig. 11. Belemnitellid species from the Vijlen Member. A, B. *Belemnitella* cf. *minor* II Christensen, 1995 (NHMM 2007 002/1), Pesaken-Crapoel, lower 3.5 metres of glauconitic layer (ventral and lateral views, respectively); C-E. *Belemnitella* sp. (NHMM 2007 015), Vaalserstraße, interval 3 or 4 (ventral, dorsal and lateral views, respectively); F-H. *Belemnella* (*Pachybelemnella*) cf. *inflata* (Arkhangelsky, 1912) (NHMM 2007 005), Pesaken-Crapoel, glauconitic layer, exact level unknown (ventral, lateral and dorsal views, respectively); I-K. *Belemnella* (*P.*) cf. *inflata* (Arkhangelsky, 1912), NHMM 2007 006 (ex Bi 1), Pesaken-Crapoel, c. 3.2-3.4 metres above base of glauconitic layer (ventral, lateral and dorsal views, respectively). All specimens coated with ammonium chloride prior to photography; all figures are natural size.

Table 5. Univariate and bivariate analyses of *Belemnitella cf. minor II* Christensen, 1995 from the lower 3.5 metres of the glauconitic greensand at the Pesaken-Crapoel road section (see also Fig. 11).

Character	N	Mean	S	CV	OR
Ls (mm)	49	46.4	7.6	16.5	25-61
Dp (mm)	50	12.9	2.4	18.9	6.5-17.4
Qp	49	0.98	0.03	2.99	0.91-1.06
BI	49	3.7	0.3	7.1	3.1-4.3
SD (mm)	30	11.7	2.2	19.2	7.5- 17
FA (degrees)	28	23.4	15	63.9	8-70
AA (degrees)	29	19.3	1.3	6.7	17-22
AV (%)	44	-6.1	4.3	-	-14.4- 4.3
AL (%)	44	-19.4	3.6	-	-27.4-(-11.2)

$Dp = -0.6934 + 0.2906 Ls$ ;  $N = 49$ ;  $r = 0.92$ ;

$S_a = 0.8487$ ;  $S_b = 0.018$ ;  $S_{yx} = 0.9655$ ;

$t_a = 0.817$ ;  $0.5 > P > 0.4$  with 47 degrees of freedom.

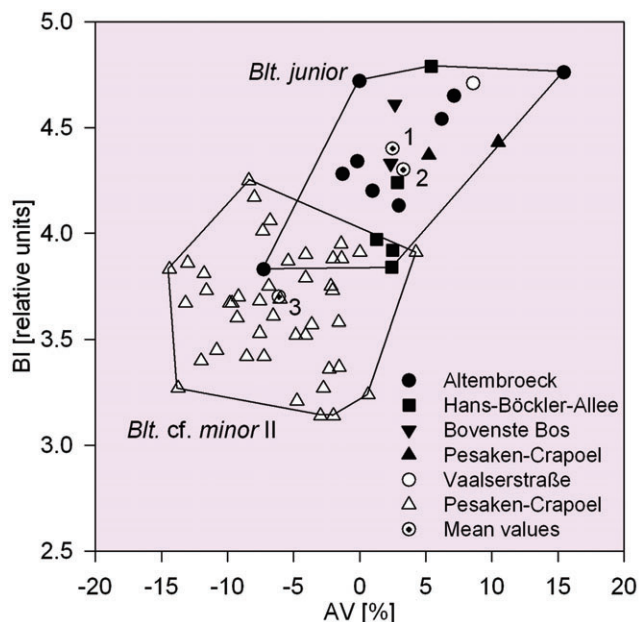


Fig. 12. Scatter plot of *Belemnitella junior* Nowak, 1913 (symbols ●, ■, ▼, ▲), *Belemnitella* sp. from Vaalserstraße (symbol ○), and remanié specimens of *Belemnitella cf. minor II* Christensen, 1995 from Pesaken-Crapoel (symbol △). The mean values correspond to: 1 – sample of *Blt. junior* from 0-36 m above the base of the upper Maastrichtian at Hemmoor (Christensen et al., 2004); 2 – sample of *Blt. junior* from the Vijlen Member; 3 – sample of *Blt. cf. minor II* from the Vijlen Member. AV = shape of guard in ventral view; BI = Birkelund Index.

1995, 1999), so that the range of variation of both subspecies is yet better known. In *Blt. minor I* the mean Birkelund Index (BI) varies between 3.7 and 4.2 and the mean Schatzky Distance (SD) between 8 and 10.5 mm, while in *Blt. minor II* the corresponding variation is 3.5 to 3.8 for the mean BI and 10.4 to 12.3 mm for the mean SD. The means of the sample from Slenaken (BI = 3.7; SD = 9.4 mm; see Keutgen & Jagt, 1999)

indicate that these specimens fall within the range of *Blt. minor I*. In conclusion, only *Blt. minor I* has yet been documented from the Beutenaken Member of the Beutenaken type area, but it cannot be excluded that the topmost Beutenaken Member locally contains *Blt. minor II*. In this context, the reworked belemnites of *Blt. cf. minor II* described here from interval 4 of the Vijlen Member at the Pesaken-Crapoel road section deserve special attention, because they co-occurred with bioclasts (Felder, 2001) and foraminifera (Hofker, 1966) typical of the Beutenaken Member. Presumably, specimens of *Blt. cf. minor II* were reworked from originally preserved, stratigraphically younger Beutenaken Member deposits.

Together with *Blt. cf. minor II*, two specimens of *Belemnitella* (NHMM 2007 034/1-2) have been collected, which could either represent extreme variants of *Blt. cf. minor II* or could be related to *Belemnitella najdini* Kongiel, 1962, a taxon known from the Beutenaken Member (Keutgen & Jagt, 1999). These specimens, which were found 10-30 cm and 130-140 cm above the base of the Vijlen Member respectively, are slender (BI = 3.9 and 4.3) and are characterised by large Schatzky distances (SD = 9 mm) as well as very large fissure angles (69 and 82 degrees). The large Schatzky distances favour an interpretation as *Blt. cf. minor II* rather than as *Blt. cf. najdini*.

#### Distribution

Christensen (1999) recorded *Blt. minor II* from Norfolk (Paramoudra and Sidstrand Chalk members), the Mons Basin, southern Belgium (top of the Spiennes Chalk Formation and Ciplu Malogne Phosphatic Chalk Formation), and from the study area. While the Paramoudra Chalk Member is of late Campanian age, the Sidstrand Chalk Member is more difficult to date. It comprises part of the *Bln. lanceolata* Zone, the *Bln. pseudobtusa* and part of the *Bln. obtusa* Zone (Christensen, 1995, text-fig. 3). Depending on whether the Campanian/Maastrichtian boundary as defined at Tercis les Bains is equated with the base of the *Bln. obtusa* Zone (Niebuhr, 2003) or with a level within this zone (Machalski et al., 2007), that boundary would have to be placed either within the upper portion of the Sidstrand Chalk Member or even at its top. As a consequence, *Blt. minor II* could represent an exclusively Campanian species, but at present it cannot be ruled out that the stratigraphical range of this species extended into the basal Maastrichtian. Specimens of *Blt. cf. minor II* collected from the basal Vijlen Member at Pesaken-Crapoel, the Bovenste Bos quarry and in the Beutenaken area may thus be of latest Campanian to earliest Maastrichtian age.



## Belemnitella junior Nowak, 1913

Fig. 13A-C, G, H, L, M.

- \*1913 *Belemnitella mucronata* Schlottheim sp. mut. *junior* Nowak, p. 398, pl. 42, figs 18, 21, 25 (non fig. 26).
- 1951b *Belemnitella junior* Nowak s. str.; Jeletzky, p. 99, pl. 2, figs 2, 6, 7; pl. 3, figs 1, 2.
- 1951b *Belemnitella junior* Nowak var. *nowaki* Jeletzky, p. 109, pl. 3, fig. 3; pl. 4, figs 1, 2.
- 1991 *Belemnitella* ex gr. *mucronata* (Schlottheim); Keutgen & Van der Tuuk, p. 13 (partim) (non pl. 1, figs 1, 2).
- 1991 *Belemnitella* ex gr. *junior* Nowak; Keutgen & Van der Tuuk, p. 15 (partim), pl. 2, fig. 4 (non pl. 1, fig. 3; pl. 2, fig. 3).
- 2004 *Belemnitella junior* Nowak; Christensen et al., p. 38, pl. 1, figs 1-13; pl. 2, figs 1-10 (with additional synonymy).

### Lectotype

The original of Nowak (1913, pl. 42, fig. 18), from Zaszkw near L'viv (western Ukraine), by subsequent designation of Jeletzky (1951b).

### Material

Eleven specimens (NHMM 1997 082, 1997 083/3, 2007 008/1-3, 2007 009/1-4 and 2007 010/1-2) from Altembroeck (levels Bm 1 (3 specimens), Bm 2 (4 specimens, plus a larger fragment), Bm 3 (1 specimen), interval Gc 1-Bm 4 (1 specimen)); seven specimens (NHMM 1997 073, 2007 020-022, 2007 031/1-2 and 2007 033) from Hans-Böckler-Allee (upper glauconitic layer (5 specimens) and overlying marlstone (2 fragments)); two specimens (NHMM 2007 003-004) from Pesaken-Crapoel (glauconitic layer, 1.3-1.4 m and 2.2-2.4 m above base of Vijlen Member, respectively); two specimens (NHMM 2007 012/1-2) from Bovenste Bos quarry, albeit with a query (glauconitic greensand filling topmost chalkstone of Beutenaken Member), plus one (NHMM 2007 013) from the same locality (overlying marlstone of Vijlen Member); one specimen (NHMM 2007 014) from Wilkensberg.

### Description

Guards large and, for representatives of the *mucronata* group, comparatively slender; generally subcylindrical in ventral and subconical in lateral view; slightly flattened over the entire length. Relationship between length from apex to protoconch and dorsoventral diameter at protoconch isometric (Fig. 14; Table 6). Apical end obtuse or acute with a distinct mucro; dorsolateral depressions, double furrows and vascular imprints usually well developed; guards pseudogranulated ventrally and showing longitudinal striae dorsally. For means and range of variation of internal characters (SD, AA, FA), as well as for AV, AL and BI, see Table 6.

### Discussion

Christensen et al. (2004) described *Blt. junior* from the upper Maastrichtian at Hemmoor and from the Maastricht-Aachen-Liège area, and were able to show that during the late Maastrichtian, guards of this species became stouter and more subconical. The means for AV and BI of material of *Blt. junior* from the Vijlen Member are closely similar to those of Hemmoor 0-36 m above the base of the upper Maastrichtian and these Vijlen Member specimens may therefore be referred to early forms of that species. It is worth noting that the earliest sample of *Blt. junior* from level Bm 1 at Altembroeck (interval 4) is characterised by means for AV and BI that are typical of this species (Table 7). The larger mean AV value of the Pesaken-Crapoel sample may be due to the fact that single more conical forms of *Blt. junior* could have been misinterpreted as *Blt. minor* II (Fig. 12).

### Distribution

*Belemnitella junior* is the index species of the upper Maastrichtian; earlier records from lower Maastrichtian strata in the Maastricht-Aachen-Liège area are here shown to be based on misinterpretations of the belemnite fauna. Kongiel (1962) recorded *Blt. junior* from the entire Maastrichtian in the Middle Vistula River valley section, central Poland; his early Maastrichtian records have to be checked carefully. *Belemnitella junior* is known from the upper Maastrichtian of the Netherlands, Belgium, Germany, Denmark, Poland, the Ukraine (including Crimea) and Azerbaijan.

### *Belemnitella* sp.

Fig. 11C-E.

- 1991 *Belemnitella* ex gr. *junior* Nowak; Keutgen & Van der Tuuk, p. 15 (partim), non pl. 1, fig. 3; pl. 2, figs 3, 4.

### Material

A single specimen (NHMM 2007 015) from Vaalserstraße, plus a fragment of a rostrum solidum (NHMM 2007 016) from Schurzelterstraße.

### Description

NHMM 2007 015 is slightly corroded. Dorsolateral depressions and double furrows are visible and are seemingly *Belemnitella*-like but only traces are left of the remaining surface sculpture. Apical end slightly obtuse, with a distinct mucro. Parameters describing size, shape and internal characters are summarised in Table 8.

NHMM 2007 016 is merely a rostrum solidum and, hence, critical internal characters are unknown. It is referred to the genus *Belemnitella* on account of its characteristic surface sculpture; dorsolateral double furrows straight and dorsolateral depressions fully developed; vascular imprints well developed



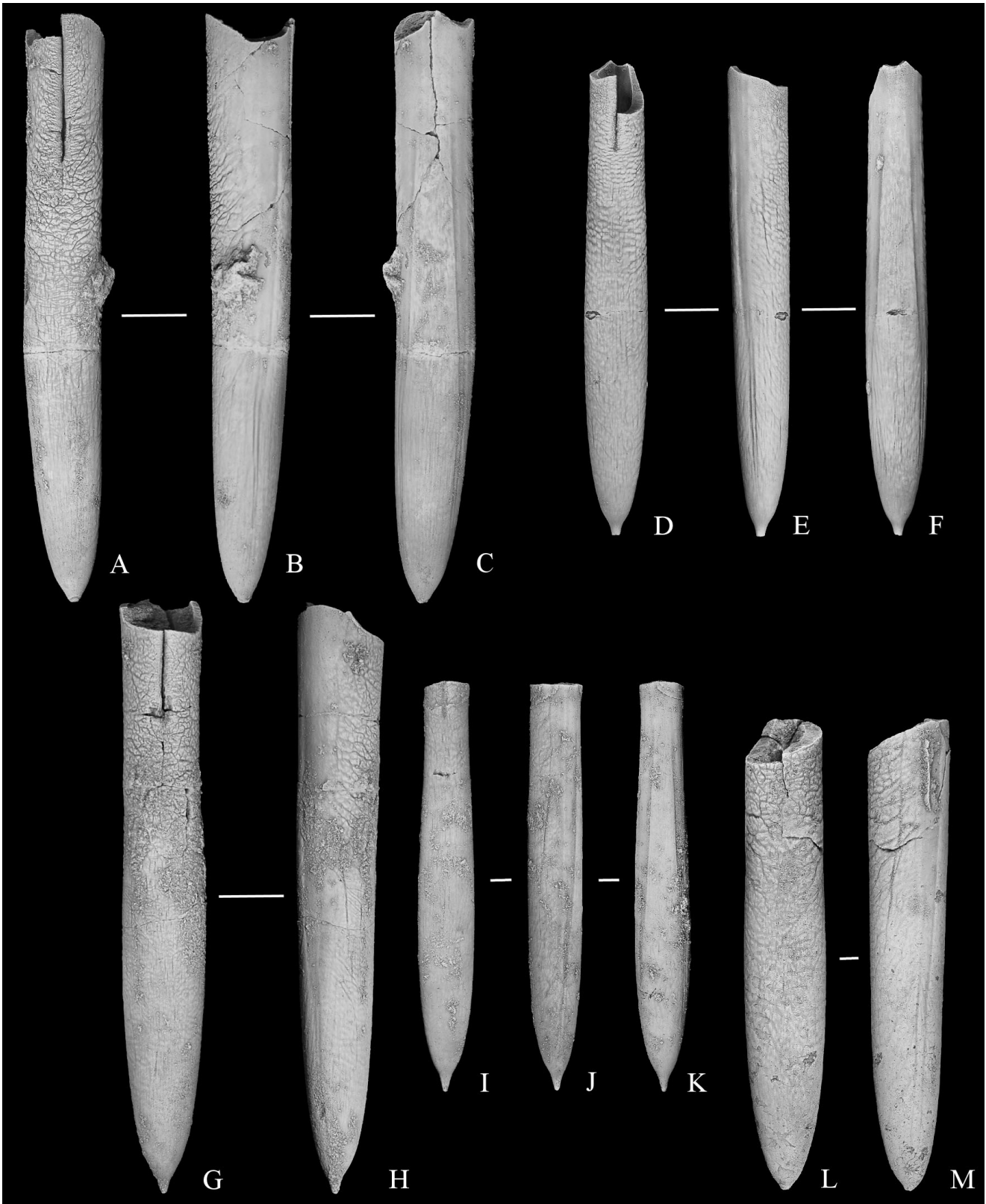


Fig. 13. Belemnitellid species from the Vijlen Member. A-C. *Belemnitella junior* Nowak, 1913 (NHMM 2007 009/1), Altembroeck, level Bm 2 (ventral, lateral and dorsal views, respectively); D-F. *Belemnitella lwowensis* Naidin, 1952 (NHMM 2007 026), CPL-Haccourt, Vijlen Member, interval 6 (ventral, lateral and dorsal views, respectively); G, H. *Belemnitella junior* Nowak, 1913 (NHMM 2007 008/2), Altembroeck, level Bm 1 (ventral and lateral views, respectively); I-K. *Belemnitella ex gr. pulchra/lwowensis* (NHMM 2007 011), Altembroeck, level Gc 1-Bm 4 (ventral, lateral and dorsal views, respectively); L, M. *Belemnitella junior* Nowak, 1913 (NHMM 2007 003), Pesaken-Crapoel, glauconitic layer, 1.3-1.4 metres above base of Vijlen Member (ventral and lateral views, respectively). All specimens coated with ammonium chloride prior to photography; all figures are natural size.

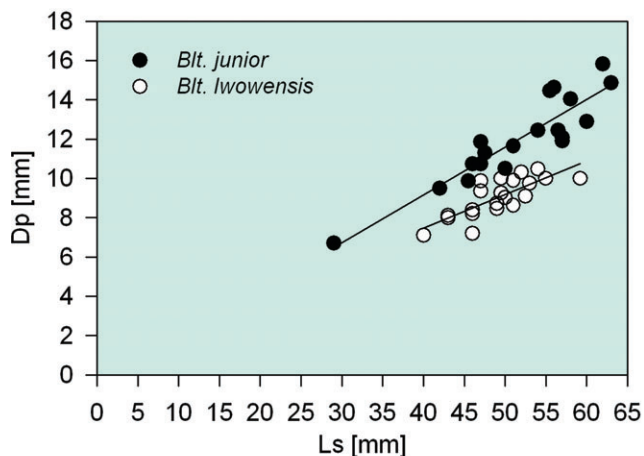


Fig. 14. Scatter plot and regression lines of *Belemnitella junior* Nowak, 1913 and *Belemnitella lwowensis* Naidin, 1952 from the Vijlen Member; Ls = length from apex to protoconch; Dp = dorsoventral diameter at protoconch.

Table 6. Univariate and bivariate analyses of *Belemnitella junior* Nowak, 1913 from the Vijlen Member.

Character	N	Mean	S	CV	OR
Ls (mm)	19	51.8	8.2	15.8	29-63
Dp (mm)	20	11.9	2.2	18.1	6.7-15.8
Qp	20	0.94	0.04	3.74	0.87-1.01
BI	19	4.3	0.3	7	3.8-4.8
SD (mm)	15	6.9	1.1	15.7	5-8.5
FA (degrees)	13	29.7	9.1	30.7	18-48
AA (degrees)	16	18.7	1.1	6.1	17-21
AV (%)	18	3.3	4.8	-	-7.3-15.5
AL (%)	18	-11.5	3.6	-	-18.2-(-2.3)

$$Dp = -0.5739 + 0.2432 Ls; N = 19; r = 0.9098;$$

$$S_a = 1.4100; S_b = 0.0269; S_{yx} = 0.9584;$$

$$t_a = -0.407; 0.7 > P > 0.60 \text{ with } 17 \text{ degrees of freedom.}$$

ventrally and laterally and extend almost to apex; longitudinal striae form distinct elements ventrally and dorsally, on ventral side forming pseudogranulate sculpture anteriorly.

## Discussion

NHMM 2007 015 resembles *Blt. junior* in its shape and Birkelund Index (Fig. 12), but differs from that species in having a larger Schatzky Distance (11 mm). In comparison, Christensen et al. (2004) reported the Schatzky Distance in *Blt. junior* to range between 5.2 and 9.7 mm at Hemmoor, based on as many as thirty-three specimens. In the present study, the SD is shown to vary between 5 and 8.5 mm (N = 15). Keutgen & Van der Tuuk (1991) measured Schatzky Distances for *Blt. junior* from Haccourt, and showed them to range between 5.5 and 10 mm (N = 8), while Keutgen (unpubl. data) measured values between 6 and 10 mm (N = 10) for a sample of *Blt. junior* from the Nekum Member (Maastricht Formation) at the Schiepersberg quarry,

Table 7. Means of AV, AL and BI for samples of *Belemnitella junior* Nowak, 1913 from the Vijlen Member, in part after data supplied by Keutgen & Van der Tuuk (1991).

Locality	Units	N	AV (%)	AL (%)	BI
Altembroeck Bm 1	Vijlen 4	3	3.4	-13.1	4.3
Bm 2	Vijlen 4	4	2.0	-10.9	4.4
Bm 3 - Bm 4	Vijlen 4	3	2.9	-12.9	4.4
Pesaken-Crapoel	Vijlen 4	2	7.9	-9.8	4.4
HBA I glauconitic layer	Vijlen 4	5	2.9	-12.0	4.2
Bovenste Bos	Vijlen 4-5	3	2.5	-9.2	4.3
CPL-Haccourt	upper Vijlen 5 - Vijlen 6	21	2.9	-12.6	4.5

Cadier en Keer (the Netherlands). The twelve SD measurements in *Blt. junior* recorded by Jeletzky (1951b, p. 103) may be added and those of eighteen specimens from the upper Maastrichtian of the Middle Vistula River Valley, central Poland (Kongiel, 1962, table 3) as well. These range between 6.5 and 8.5 mm and between 5 and 8.5 mm, respectively. Thus, as many as ninety-six measurements are available showing that SD does not exceed 10 mm in *Blt. junior*.

Christensen (1995, text-fig. 9) proposed a development from *Blt. minor* II to the late Maastrichtian *Blt. junior*. In view of the fact that *Blt. minor* II generally is characterised by large Schatzky Distances (mean SD > 11 mm; Christensen 1995, 1999), *Belemnitella* sp. from Vaalserstraße would fit into this developmental lineage. However, with respect to shape and Birkelund Index, the latter does not plot within the range of *Blt. minor* II, but rather within that of *Blt. junior* (Fig. 12).

*Belemnitella* sp. from Vaalserstraße also resembles stout specimens of the *Belemnitella pulchra-lwowensis* group in shape and slenderness but the Schatzky Distance within that group does not exceed 9 mm (Schulz, 1982; Christensen et al., 2004). In summary, were it not for the unusually large SD,

Table 8. Measurements of critical characters of *Belemnitella* sp. from the Vijlen Member (NHMM 2007 015).

Character	NHMM 2007 015	NHMM 2007 016
Ls (mm)	50.0	62.0
Dp (mm)	10.6	14.4
Bp (mm)	9.7	13.8
Qp	0.91	0.96
BI	4.7	4.3
SD (mm)	11.0	-
FA (°)	28	-
AA (°)	18	-
AV (%)	8.6	-
AL (%)	-5.2	-
AVs (%)	6.8	-3.6
ALs (%)	-6.5	-12.1

*Belemnitella* sp. from Vaalserstraße could be regarded as a typical representative of *Blt. junior*. In contrast, *Belemnitella* sp. from Schurzelterstraße (NHMM 2007 016) is well within the range of typical *Blt. junior*. However, definitive identification is impossible due to incomplete preservation.

Keutgen & Van der Tuuk (1991) referred to several specimens of *Blt. junior* from the lower Maastrichtian; most of these were misdated, because the age of the deposits which yielded them was based on samples of remanié material of *Belemnella*. However, those authors also recorded a few specimens of *Belemnitella* from presumably lower Maastrichtian strata from the localities Schurzelterstraße (interval 3) and Vaalserstraße (intervals 3-4). These specimens have been restudied, with the following results. One guard (NHMM 2007 016) from Schurzelterstraße is here referred to as *Belemnitella* sp., a second (NHMM 2007 017) may belong to the genus *Belemnella*, as the Schatzky Distance is slightly smaller than 5 mm. Of four specimens recorded from the middle portion of the Vaalserstraße section (Keutgen & Van der Tuuk, 1991, p. 15), three (NHMM 1997 069, 1997 075 and 2007 018) are referred to the genus *Belemnella*, the fourth (NHMM 2007 015) to *Belemnitella* sp. For example, NHMM 1997 075 illustrated by Keutgen & Van der Tuuk (1991, pl. 2, fig. 3) is characterised by a Schatzky Distance of 4.5 mm and an alveolar angle of 16°, which is typical of *Belemnella*. NHMM 1997 069, as illustrated by Keutgen & Van der Tuuk (1991, pl. 1, fig. 3), is more difficult to identify. Although the Schatzky Distance is in the range of 5.5 to 6.5 mm (i.e., typical of *Belemnitella*), the alveolar angle is as small as 16°. Ontogenetic growth stages visible in this specimen indicate allometric, rather than isometric, growth and the calculated late ontogenetic growth quotient (WQs) of 2.6 is typical of late early Maastrichtian species of the subgenus *Bln.* (*Pachybelemnella*). In addition, the weakly developed vascular imprints are more typical of *Belemnella* than of *Belemnitella*. Therefore, this specimen is best regarded as belonging to ?*Belemnella* sp., despite the unusually large Schatzky Distance.

### Distribution

At Vaalserstraße, *Belemnitella* sp. was collected from the 'middle portion' of the section exposed. It is either from interval 3 or interval 4, and thus of late early Maastrichtian or earliest late Maastrichtian age. The provenance of the specimen from Schurzelterstraße is not well documented. It is here assumed to have originated from interval 3, which would thus be early Maastrichtian. However, it should be noted that under the designation 'Schurzelterstraße' several small exposures (construction pits for house numbers 460-565, accessible between 1978 and 1981) have been lumped together. At that time, the subdivision of the Vijlen Member (Felder & Bless, 1994) was not available and hence it cannot be ruled out entirely that the base of interval 4 was actually exposed in any one of these exposures. Available data suggest that *Belemnitella* sp. from Schurzelterstraße and Vaalserstraße are best regarded as

doubtful specimens of the *Blt. junior* group that are probably of early late Maastrichtian age in terms of belemnite stratigraphy, while a latest early Maastrichtian age cannot be ruled out entirely.

## 2. *Belemnitella langei* group

This group comprises species with generally small, slender to very slender guards; Schatzky Distances are small and fissure angles large. Christensen et al. (2004) assigned four species to this group: *Blt. langei* Jeletzky, 1948, *Blt. najdini*, *Blt. pulchra* and *Blt. lwowensis*.

### *Belemnitella lwowensis* Naidin, 1952

Fig. 13D-F

- \*1952 *Belemnitella nowaki lwowensis* Naidin, p. 96, pl. 15, fig. 2.
- 1991 *Belemnitella* ex gr. *junior* Nowak; Keutgen & Van der Tuuk, p. 15 (partim).
- 1991 *Belemnitella pulchra* Schulz; Keutgen & Van der Tuuk, p. 14 (partim), pl. 2, fig. 2.
- 2004 *Belemnitella lwowensis* Naidin; Christensen et al., p. 46, pl. 3, figs 1-15 (with additional synonymy).

### Lectotype

The original of Naidin (1952, pl. 15, fig. 2) from Sawadow near L'viv (western Ukraine), by subsequent designation of Christensen et al. (2004).

### Material

Twelve specimens (NHMM 1997 083/12, 1997 083/4-8 and 2007 019/1-3) from Altembroeck (levels Bm 1 (2 specimens, plus one rostrum cavum fragment), Bm 2 (7 specimens, plus 2 fragments); six specimens (NHMM 2007 032/1-5, Sa1000 (ex J. Savelsberg Colln) from Hans-Böckler-Allee I (upper glauconitic layer (3 specimens, plus 2 rostrum cavum fragments); overlying marlstone (1 specimen)); one specimen (NHMM 2007 023) from Pesaken-Crapoel (glauconitic layer, 3.7-4 m above base of Vijlen Member (three specimens and two rostrum cavum fragments)); one specimen (NHMM 2007 024/1-4, ex Van der Tuuk Colln) from Bovenste Bos quarry (Vijlen Member marlstone); one specimen (NHMM 2007 025) from Mamelis (intervals 5-6); one specimen (NHMM 2007 029) from Wilkensberg; one specimen (NHMM 2007 026) from CPL-Haccourt. In addition, two ex situ specimens (NHMM 2007 030/1-2) from Aachen-Schneeberg have been included, both presumably from interval 4.

### Description

Guards large and very slender, slightly lanceolate to subcylindrical in ventral and subcylindrical in lateral view; flattened over their entire length. Relationship between



length from apex to protoconch and dorsoventral diameter at protoconch isometric (Fig. 14); apical end acute or slightly obtuse with a well-defined mucro; dorsolateral depressions, double furrows and vascular imprints usually well developed. Guards pseudogranulate ventrally and showing longitudinal striae ventrally and dorsally. For means and range of variation of internal characters (SD, AA, FA) as well as for those of AV, AL and BI see Table 9 and Fig. 15.

Table 9. Univariate and bivariate analyses of *Belemnitella lwowensis* Naidin, 1952 from the Vijlen Member.

Character	N	Mean	S	CV	OR
Ls (mm)	21	49.2	4.5	9.1	40-59.2
Dp (mm)	26	9	1.1	12.1	6.9-10.9
Qp	26	0.91	0.03	3.36	0.86-0.98
BI	21	5.5	0.4	7	4.8-6.4
SD (mm)	18	6.3	0.9	14.3	5-8
FA (degrees)	15	55.6	17	30.7	28-105
AA (degrees)	15	18.7	1.1	5.9	17-20
AV (%)	20	13.1	3.3	-	8-18.6
AL (%)	20	-4.2	4.4	-	-12.4-2.5

$$Dp = 0.6599 + 0.1704 Ls; N = 21; r = 0.7744;$$

$$S_a = 1.5769; S_b = 0.0319; S_{yx} = 0.6531;$$

$$t_a = 0.418; 0.7 > P > 0.6 \text{ with } 19 \text{ degrees of freedom.}$$

## Discussion

Keutgen & Van der Tuuk (1991) referred all small and slender specimens of *Belemnitella* from the Vijlen Member to *Blt. pulchra*, because they interpreted the range of variation of this species too widely. A thorough restudy of their, as well as of additional, material has now revealed that most specimens actually should be assigned to *Blt. lwowensis* instead. Most of them also plot close to *Blt. pulchra*, but isolated specimens from Altembroeck (level Bm 1), Hans-Böckler-Allee, Bovenste Bos and Pesaken-Crapoel are characterised by AV values smaller than 10% and thus are clearly out of the range of *Blt. pulchra*, but within that of *Blt. lwowensis* (Fig. 15). Still, samples of *Blt. lwowensis* from interval 4 comprise a high percentage of primitive, comparatively lanceolate forms. This may be due to the fact that these represent early representatives of *Blt. lwowensis*. The means of AV and Lsn of our samples plot more closely to those for *Blt. lwowensis* than to those for *Blt. pulchra* (Table 10; Fig. 15). For comparison, the means of a sample of *Blt. pulchra* from Kronsmeer are out of the observed range of specimens here assigned to *Blt. lwowensis* (Fig. 15).

In addition to the specimens from Altembroeck mentioned above, two specimens of *Belemnitella* from that locality cannot be assigned to *Blt. lwowensis* due to their distinctly lanceolate shape and AV values >25% (Fig. 13I-K; Table 11). In specimen NHMM 2007 019/4 from level Bm 1 (interval 4), the course of the ventral fissure on the guard surface is slightly deformed and this specimen might be considered pathological. The second

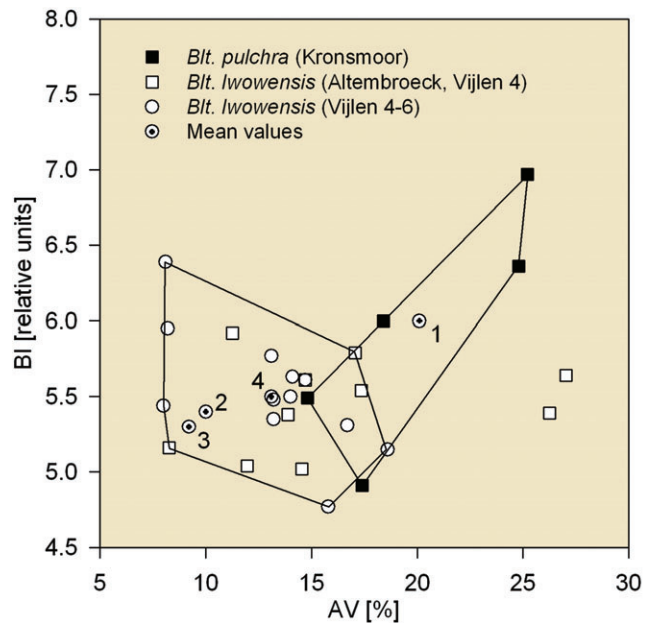


Fig. 15. Scatter plot of *Belemnitella pulchra* Schulz, 1982 and *Belemnitella lwowensis* Naidin, 1952. The specimens of the former, as described by Schulz (1982) from Kronsmeer (symbol ■), are compared with those of the latter from the Vijlen Member (symbols ○, □). Specimens of *Blt. lwowensis* from Altembroeck (symbol □) were separated from those collected at other localities (symbol ○). The mean values correspond to: 1 – *Blt. pulchra* from the lower Maastrichtian at Kronsmeer; 2 – *Blt. lwowensis* from the upper Maastrichtian at Hemmoor; 3 – *Blt. lwowensis* from the upper Maastrichtian of Belgium and the Netherlands (see Christensen et al., 2004) and 4 – *Blt. lwowensis* from the Vijlen Member. AV = shape of guard in ventral view; BI = Birkelund Index.

specimen NHMM 2007 011 from the level between Gc 1 and Bm 4 does not show any indication of deformation. These two specimens obviously are representatives of the *Blt. pulchra-lwowensis* group, but it is a matter of debate whether or not these should be regarded to represent remanié *Blt. pulchra*, or extremely lanceolate (i.e., primitive) variants of *Blt. lwowensis* (Fig. 15).

Keutgen and Van der Tuuk (1991) mentioned three specimens of *Blt. pulchra* from the locality Vaalserstraße. These specimens have been re-investigated with the following result. Two specimens (NHMM 2007 027/1-2, ex VA5 and VA6, respectively) are indeterminable and cannot be assigned to the genus *Belemnitella* with certainty. The third specimen (NHMM 2007 028, ex VA 200) from the middle portion of the section exposed represents a larger fragment of a rostrum cavum characterised

Table 10. Means of AV and BI for samples of *Belemnitella lwowensis* Naidin, 1952 from the Vijlen Member.

Locality	Units	N	AV (%)	BI
Altembroeck Bm 1	Vijlen 4	2	11.1	5.3
Bm 2	Vijlen 4	6	14.5	5.5
Hans-Böckler-Allee	Vijlen 4	4	12.0	5.7
Bovenste Bos	Vijlen 4-5	3	13.6	5.7



Table 11. Measurements of critical characters of *Belemnitella ex gr. pulchra/lwowensis* (NHMM 2007 019/4, NHMM 2007 011) and *Belemnitella cf. lwowensis* (NHMM 2007 028) from the Vijlen Member.

Character	NHMM 2007 028	NHMM 2007 019/4	NHMM2007 011
Ls (mm)	-	49	43.5
Dp (mm)	7.1	7.62	8.07
Bp (mm)	6.4	6.77	7.16
Qp	0.9	0.89	0.89
BI	-	5.6	5.4
SD (mm)	6	-	-
FA (°)	33	-	-
AA (°)	22	-	-
AV (%)	-	27	26.3
AL (%)	-	8.9	6.1
AVs (%)	-	18.8	17
ALs (%)	-	3.2	0

by a course of the ventral fissure that is typical of the *Blt. pulchra-lwowensis* group (Table 11). Nevertheless, the fissure angle is comparatively small, within the range of *Blt. lwowensis* and out of the range of variation of *Blt. pulchra* documented for the Krons Moor material (c. 40–125°; compare Schulz, 1982, fig. 5), but the four specimens studied by Schulz may not have been sufficient to cover the range of variation of this species. The estimated shape and Birkelund Index of NHMM 2007 028 are within the range of variation of both *Blt. pulchra* and *Blt. lwowensis*. The specimen is here referred to as *Belemnitella cf. lwowensis*, because belemnite specimens typical of the interval upper *Bln. lanceolata* to middle *Bln. sumensis* zones (topmost Campanian to middle lower Maastrichtian), which is the known stratigraphic range of *Blt. pulchra*, have not been identified at the locality Vaalserstraße.

### Distribution

To date, *Belemnitella lwowensis* is known from the upper Maastrichtian of Belgium, the Netherlands, Germany, Denmark(?), central Poland and the Ukraine. In interval 4 of the Vijlen Member of the Maastricht-Aachen-Liège area, *Blt. lwowensis* is almost as common as *Blt. junior*, whereas higher in the section, its frequency is reduced to about 10%.

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