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The Lower/Upper Maastrichtian boundary interval in the Lublin Syncline (SE Poland, Boreal realm): new insight into foraminiferal stratigraphy

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With 5 figures and 1 table

Abstract. A detailed micropaleontological study of the upper part of the Lower and Upper Maastrichtian strata of the Lublin Syncline (SE Poland) recorded several foraminiferal events and foraminiferal event stratigraphy turned out to be useful for interregional correlation. Main foraminiferal events recorded are: the temporary disappearance of *Rugoglobigerina* spp. coinciding with the last occurrence of *Angulogavelinella gracilis*; the reappearance of *Globotruncana* spp. after a longer absence in the area; the temporary disappearance of *Stensioeina* spp. and the last occurrence of *Gavelinella monterelensis*, as well as a short-lived bloom of *Globotruncanella petaloidea*. The reappearance of Globotruncanidae in SE Poland slightly above the base of the *Belemnitella junior* Zone probably reflects a global sea level rise recognised in north-western Europe and eastern North America. The temporary disappearance of the genus *Rugoglobigerina* at the base of the *Belemnitella junior* Zone may be used as a good marker for the Lower/Upper Maastrichtian substage boundary in the Boreal Province.

Key words. Lower/Upper Maastrichtian substage boundary, foraminiferal event stratigraphy, Lublin Syncline, SE Poland

1. Introduction

The Lower/Upper Maastrichtian substage boundary has not been ratified yet. As possible boundary criteria, the following events were recommended (Odin 1996): the extinction of rudist reefs; the extinction of the majority of the inoceramids; the lowest occurrence of a calcareous nannofossil species (*Lithraphidites quadratus*) and the lowest occurrence of the ammonite species *Pachydiscus fresvillensis*. However, two of them (rudist reefs and *Pachydiscus fresvillensis*) concern only to the Tethyan province. Moreover, the youngest "true" inoceramids were recently documented in the lower Upper Maastrichtian from the Vijlen Member in northern Belgium and in the Aachen area (Germany) (Walaszczyk et al. 2011). The correlation between mid-Maastrichtian strata of the Boreal Province and strata of the Tethyan Province is a significant problem because each of them is characterized by different fauna. For instance, the traditional zonation of the Boreal Province is based on belemnite fauna, which does not occur in the warm Tethyan Province. In the belemnite zonation the base of the Upper Maastrichtian is defined by the first appearance of *Belemnitella junior*. Standard planktonic foraminiferal zonations (Robaszynski and Caron 1995, Gradstein et al.

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2004, Ogg et al. 2008, Huber et al. 2008) were established for Globotruncanidae and Heterohelicidae based on observations from Cretaceous sections in the Mediterranean region. Due to planktonic foraminifer bioprovinciality these zonal schemes are well applicable only in tropical/subtropical regions.

The complete successions of the Boreal Lower/Upper Maastrichtian boundary interval are located only in a few areas. Today, natural exposures of this interval are accessible in two areas: in the Maastricht-Aachen-Liège area (the Netherlands, Germany and Belgium) and in the Lublin Upland (SE Poland).

Our study focuses on analysis of changes in planktonic and benthic foraminiferal assemblages of the Lublin Syncline in south-eastern Poland. The studied material yields abundant, well preserved planktonic foraminiferal fauna represented mainly by cosmopolitan, long-ranging species. *Gansserina gansseri* or *Abathomphalus mayaroensis* – index markers for the standard Maastrichtian planktonic biozones – are lacking in SE Poland.

To obtain a more refined subdivision of the Lower/Upper Maastrichtian boundary interval we used also LADs (last appearance datum) of three benthic foraminifera species, i.e. *Angulogavelinella gracilis*, *Stensioeina pommerana* and *Gavelinella monterelensis*. The combined use of both planktonic and benthic foraminifera resulted in a high resolution foraminiferal event stratigraphy of the Boreal Lower/Upper Maastrichtian boundary interval and appears to be an important additional tool in the correlation of the Maastrichtian throughout Europe.

2. Geological setting

Three sites in south-eastern Poland were investigated for the purpose of this work: the Middle Vistula River Valley section represented by a series of natural and artificial exposures (the most complete succession of the Mid-Polish Through); the section of the Puławy IG2 borehole; and the quarry sections at Chełm (Fig. 1).

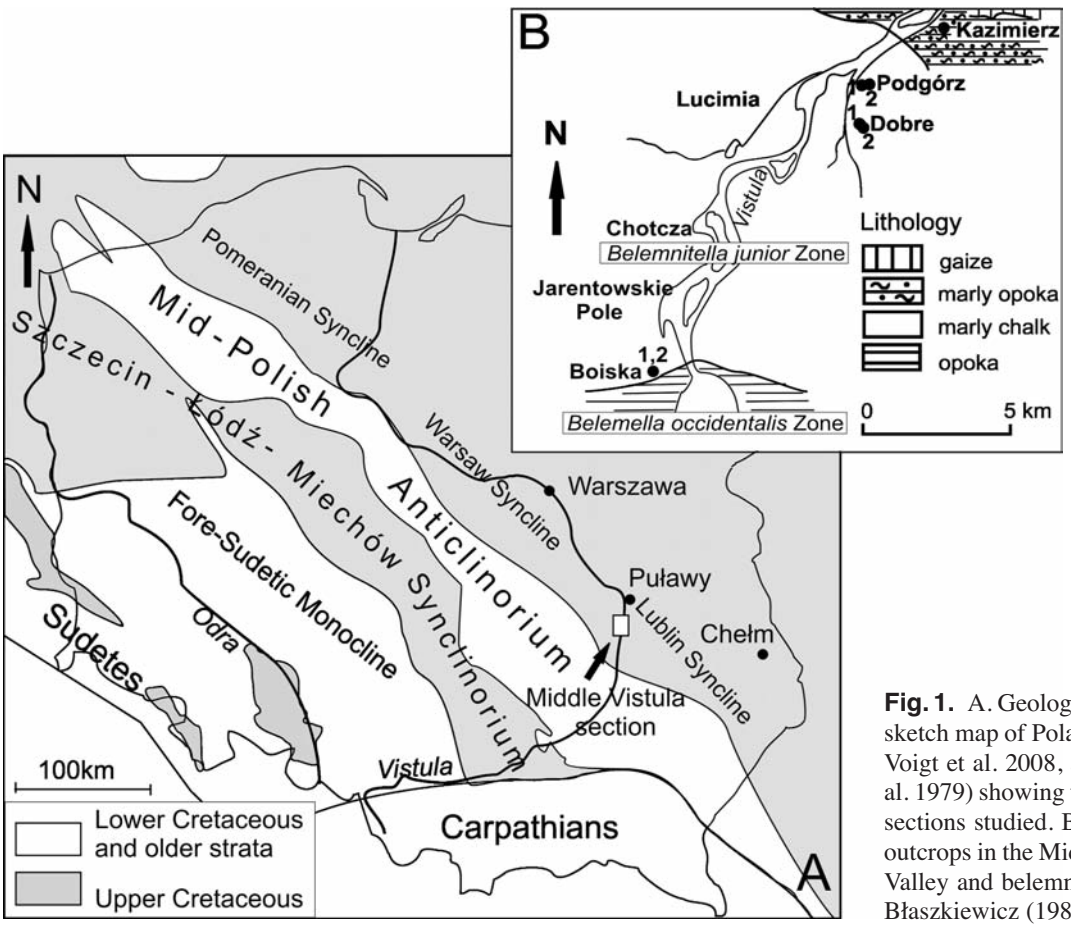

Fig. 1. A. Geological pre-Cenozoic sketch map of Poland (simplified by Voigt et al. 2008, after Pożaryski et al. 1979) showing the location of the sections studied. B. Location of the outcrops in the Middle Vistula River Valley and belemnite zonation after Błaszkiewicz (1980).

Table 1 Characteristics of the sections studied in the Middle Vistula River Valley.

Name	Exposure	Location	Exposed strata	Important fossils
Dobre 1, 2	Small natural exposures	The escarp at the path, north of the Dąbrówka – Dobre road	More than 10 meters thick succession of light yellow marls	*Hoploscaphites constrictus crassus*
Lucimia	The outcrop not currently available; in the 1980s there was an exploitation hole of chalk	1.5 km NE of the village in the slope of the Vistula River Valley, above the road to Baryczka	Marly chalk	*Belemnitella junior*
Podgórz 2	Small natural outcrop	An escarpment in the riverside between villages Podgórz and Dobre	5 m thick succession of marls	*Hoploscaphites constrictus crassus*
Podgórz 1	Small natural outcrop	The riverside		LAD of *Spyridoceramus tegulatus*
Chotcza	The outcrop not currently available; in the 1980s a few exploitation holes of chalk around the village		Marly chalk	*Belemnitella junior*
Jarentowskie Pole	No exposure at the present		Marly chalk	*Belemnitella junior*
Boiska 1, 2	Small natural exposures	The escarpment, east of the Boiska village, some hundred m east of the main cross-road in the village	A small portion of the succession composed of marly chalk	FAD of *Belemnitella junior*; FAD of *Lithraphidites quadratus*

The Middle Vistula River Valley section, located in the north-western part of the Lublin Syncline (south-eastern part of the Border Synclinorium) (Fig. 1A) (Pożaryski et al. 1979, Świdrowska 2007, Voigt et al. 2008), is the most complete, easily accessible, Maastrichtian succession of the Mid-Polish Through (e.g. Pożaryski 1938, Błaszkiewicz 1966, 1980, Gaździcka 1978, Peryt 1980, 1988a, Abdel-Gawad 1986, Walaszczyk 2004, Machalski 2005). The succession is composed of alternating grey marl, white siliceous limestone and marly siliceous limestone. It should be mentioned, however, that the interval investigated herein is partially covered. We have studied the following sites: Boiska 1, Boiska 2, Jarentowskie Pole, Chotcza, Lucimia, Podgórz 1, Podgórz 2, Dobre 2 (Fig. 1B; Table 1). The investigated interval comprises the upper part of the Lower Maastrichtian *Belemnella occidentalis* Zone and Upper Maastrichtian *Belemnitella junior* Zone (Błaszkiewicz 1966, 1980). The Lower/Upper Maastrichtian boundary, which in the Boreal belemnite zonation is placed at the base of *Belemnitella junior* Zone, is located in the Middle Vistula River Valley profile at Boiska (Błaszkiewicz 1966, 1980). At the same level, Gaździcka (1978) recorded the first occurrence of the calcareous nannofossil species *Lithraphidites quadratus* (Fig. 2).

The Puławy IG2 borehole is located in the north-western part of the Lublin Syncline, about 20 km northeast of Puławy. There the Maastrichtian succession is about 370 m thick and is represented by marl, chalk and marly siliceous limestone (Peryt and Wyrwicka 1993, Fig. 2) with a 180 m thick succession corresponding to the *Belemnella occidentalis* and *Belemnitella junior* Zones.

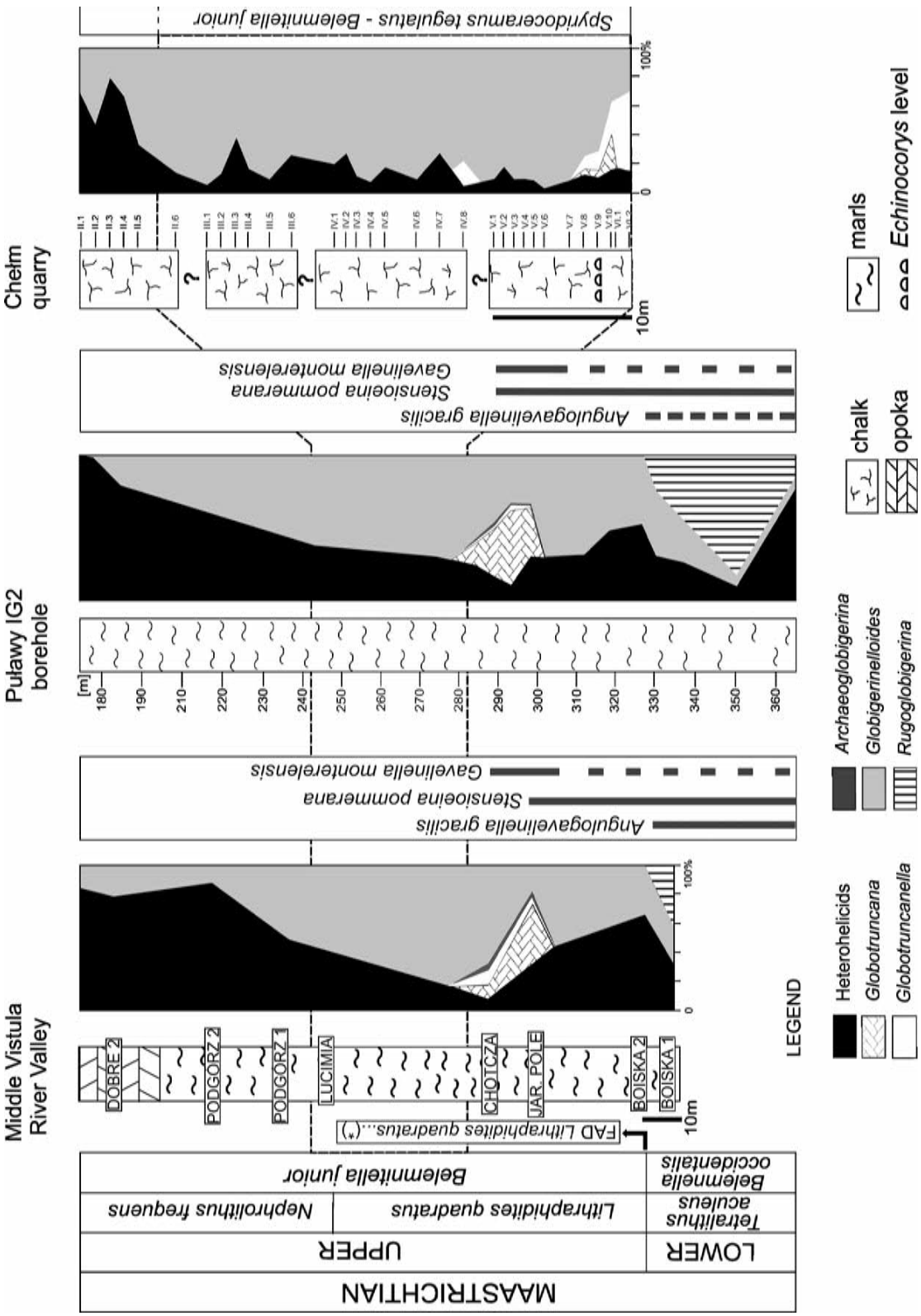

Fig. 2. Stratigraphy, lithological columns, changes in composition of planktonic foraminiferal assemblages and ranges of selected species of benthic foraminifera in the study sections. Ammonite/belemnite zonation of the Middle Vistula River Valley after Błaszkiewicz (1966, 1980); macrofaunal zonation of the Chełm section after Machalski (2005) and Machalski et al. (2008). Asterix indicates FAD (first appearance datum) of the nannofossil species *Lithraphidites quadratus* (after Gaździcka 1978).

The white chalk succession in the Chełm quarry, previously described by Wyrwicka (1977), Alexandrowicz (1977), Harasimiuk et al. (1984), Pióro (2007), Machalski et al. (2008) and Dubicka and Peryt (2011), is located in the south-eastern part of the Lublin Syncline. The approximately 40 metres thick interval is exposed along four exploitation levels, labelled as levels V to II, in an ascending order (level I has now been entirely excavated; Dubicka and Peryt 2011). Stratigraphically, it corresponds to the interval between the villages Chotcza and Lucimia in the Middle Vistula River Valley, i.e. to the middle part of the *Belemnitella junior* Zone (Dubicka and Peryt 2011).

3. Material and methods

A total of 52 samples were analyzed micropaleontologically. Samples were processed using Glauber's salt. An aliquot of about 300 specimens from the >63 μm size fraction was used for faunal analyses.

First we set ranges of three species of benthic foraminifera widely distributed in the Boreal Province i.e. *Angulogavelinella gracilis*, *Stensioeina pommerana* and *Gavelinella monterelensis*. Then we made a quantitative analysis of planktonic foraminiferal assemblages. Changes in planktonic foraminiferal assemblages enabled us to estimate precisely the stratigraphical positions of the sediments. The proportions of particular groups within the assemblages are very useful in stratigraphical investigations even if the taxonomic composition of the assemblages does not change at all. Rapid and short-lived blooms of some foraminiferal groups can be regarded as events, and thus can form the basis of event stratigraphy, which can define very precisely short stratigraphical intervals. The taxonomic composition of foraminiferal assemblages can be a good indicator for paleoenvironmental factors. For instance, planktonic foraminifera can be useful indicators of the ancient sea level changes because of their depth stratification. Keeled planktonic foraminifera and large biserial and multiserial heterohelicids are assumed to be deep-dwellers whereas simple serial, planispiral and trochospiral forms with globular chambers are considered to be more shallow-dwelling species, inhabiting the upper 100 m of the ocean water column. (e.g., Bé 1977, Hart and Bailey 1979, Caron and Homewood 1983, Hemleben et al. 1989, Premoli Silva and Sliter 1999, Petrizzo 2002, Gallala et al. 2009). Generally keeled morphotypes are not found in shallow shelf environments and their increase in number is observed with increasing water depth and distance from the shoreline (Leckie 1987).

Thus, it is possible to relate the sea level changes inferred from the taxonomic composition of planktonic foraminiferal assemblages with the changes deduced from sedimentological analysis such as trans-Atlantic correlations in the Campanian-Maastrichtian stages presented by Hancock (1993).

4. Results

The results of foraminiferal analysis are shown in Figs. 2 and 3.

At the top of the Lower Maastrichtian *Belemnella occidentalis* Zone, two important biotic events were observed: the temporary disappearance of *Rugoglobogigerina* spp. (*Rugoglobigerina hexacamerata*, *R. milamensis*, *R. pennyi*, *R. rugosa*) and the last occurrence of the benthic foraminifera species *Angulogavelinella gracilis*. These events are recorded at Boiska 1 (Middle Vistula River Valley) and at 330 m depth in the Puławy IG2 borehole (Fig. 2). It should be mentioned that these events are also recorded in some other boreholes of the Lublin Upland (Peryt 1988b, Gawor-Biedowa 1992). In the lowermost part of the Upper Maastrichtian *Belemnitella junior* Zone (Fig. 2) in the Lublin Syncline, two benthic foraminifers, *Stensioeina pommerana* and *Gavelinella monterelensis*, disappear within the same interval were globotruncanids occur. While *G. monterelensis* has its last occurrence at this interval, *Stensioeina pommerana* reappears in the uppermost Maastrichtian. Two very important events connected with a migration of a whole group of planktonic foraminifers are easy to identify in the investigated interval: the disappearance of the genus *Rugoglobigerina* in Boiska at the base of the *Belemnitella junior* Zone, which is very close to the first occurrence of the calcareous nannofossil species *Lithraphidites quadratus* (Fig. 2; Gaździcka 1978) and the reappearance of keeled planktonic foraminifers (*Globotruncana arca*, *G. bulloides*, *G. linneiana*, *Contusotruncana fornicata*, *C. patelliformis*) after a longer absence in the lower part of the *Belemnitella junior* Zone. At the same level, large biserial and multiserial heterohelicids (*Pseudotextularia deformis*, *Planoglobulina brazoensis* and *Racemiguembelina powelli*) appear, although in small numbers, for a short time. Upward in the *Belemnitella junior* Zone, the planktonic foraminiferal assemblages have a very low diversity, being characterized by the presence of only two mor-

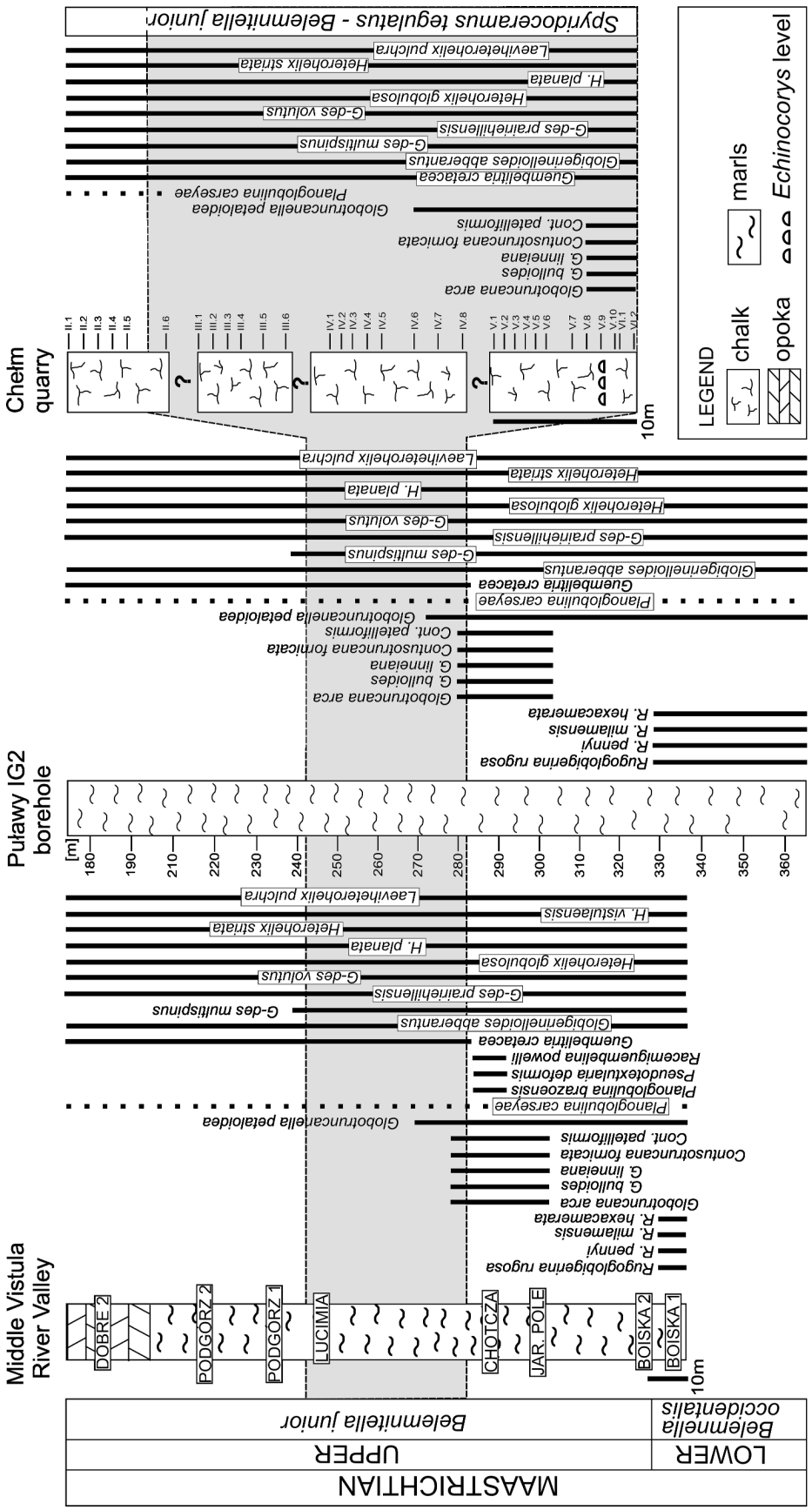

Fig. 3. Distribution of planktonic foraminifera in the sections studied.

phological groups: planispiral globigerinelloids (*Globigerinelloides abberantus*, *G. multispinus*, *G. prairiehillensis*, *G. volutus*) forming > 80 % of the assemblages and small, biserial heterohelicids (*Heterohelix globulosa*, *H. planata*, *H. striata*, *H. vistulaensis*, *Laeviheterohelix pulchra*) accounting for approximately 20 % of the assemblages. These assemblages characterize sediments exposed e. g. in the Chełm quarry (Fig. 2). This unusual biotic assemblage is distinct from any other stratigraphical interval of the study area and clearly places the interval in the upper part of the *Spyridoceramus tegulatus-Belemnitella junior* Zone sensu Schulz and Schmid (1983) (Dubicka and Peryt 2011).

In several samples from the lowest part of the Chełm quarry, *Globotruncanella petaloidea* Gandolfi forms 40 % of the total assemblage of planktonic foraminifers. This event coincides with the mass occurrence of the echinoderm *Echinocorys* (*Echinocorys* level).

5. Discussion

Three benthic species: *Angulogavelinella gracilis*, *Stensioeina pommerana* and *Gavelinella monterelensis*, disappear in south-eastern Poland in the lowermost part of the *Belemnitella junior* Zone.

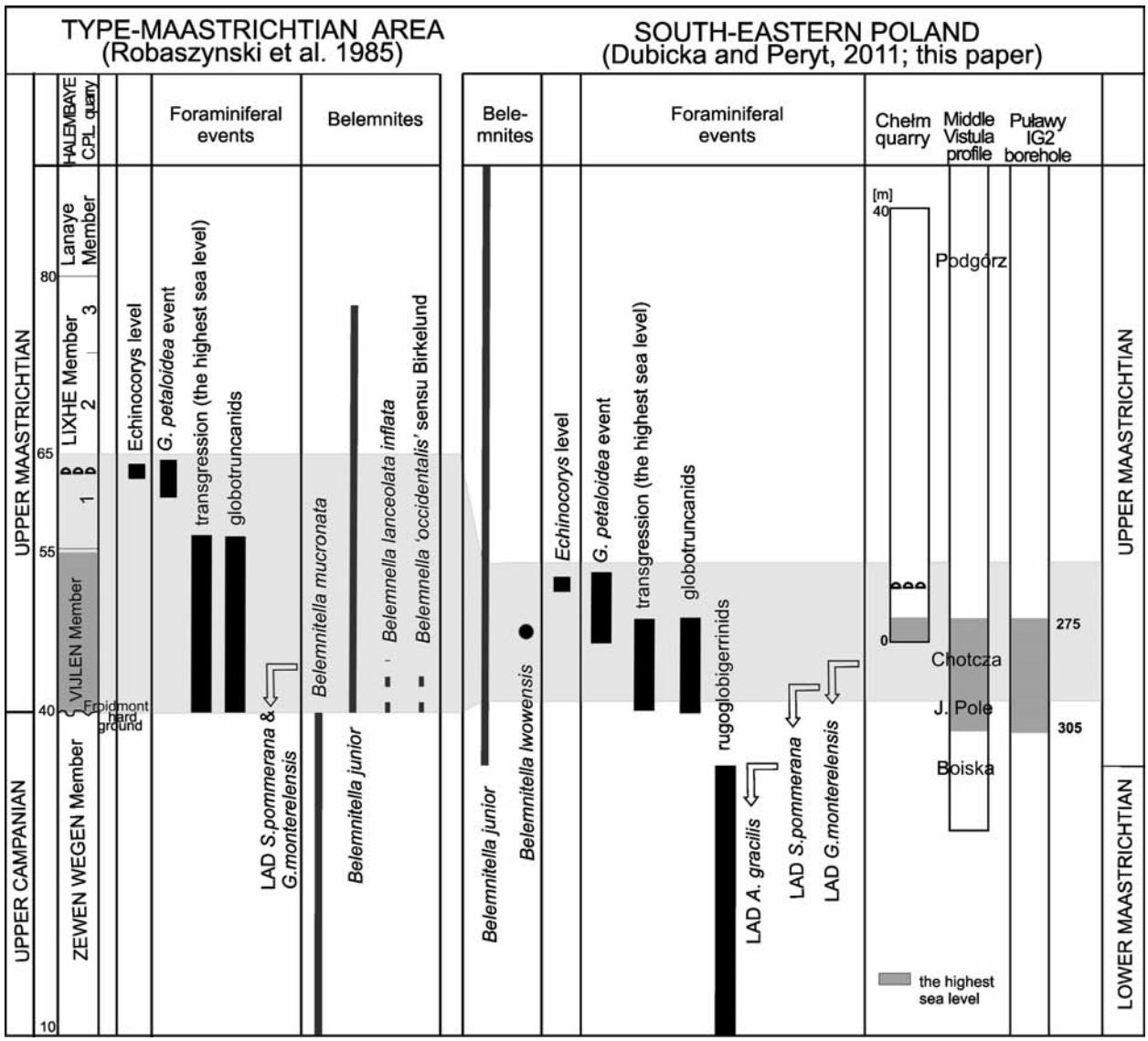

Fig. 4. Correlation of the mid-Maastrichtian events between Limburg area (Belgium) and SE Poland.

The last occurrence of *Angulogavelinella gracilis* coincides with a temporary disappearance of *Rugoglobogigerina* spp. in the uppermost part of the *Belemnella occidentalis* Zone. Pożaryska (1954) and Gawor-Biedowa (1992) also described the highest occurrence of this species from the Upper Lower Maastrichtian in eastern Poland. Brotzen (1945) recognized the lack of *A. gracilis* in the Upper Maastrichtian of southern Sweden and NW Germany. Weidich (1995, Fig. 4) showed that the range of *A. gracilis* includes almost the entire Maastrichian based on data given by Hofker (1957) who concluded that the species has a consistent occurrence in the Lower to middle Maastrichtian, and only a rare occurrence in the Upper Maastrichtian of NW Germany. However, he did not discuss the stratigraphy but rather followed general statements by Brotzen (1945) and Hofker (1957).

Stensioeina pommerana and *Gavelinella monterelensis* disappear within the interval of occurrence of globotruncanids in the lower part of the *Belemnitella junior* Zone. Exactly at the same stratigraphical position, the two events have been recorded in the Halembaye section (Belgium) (Robaszynski et al. 1985) (Fig. 3). The temporary disappearance of *Stensioeina pommerana* close to the Lower/Upper Maastrichtian boundary and its reappearance in the uppermost Maastrichtian was first recorded by Wicher (1953) from NW Germany. Similar distribution patterns of this species were later described from NW Germany (Koch 1977), NE Germany (Frenzel 2000, Reich and Frenzel 2002), SE Poland (Witwicka 1958, Gawor-Biedowa 1992) and Russia (Naidin et al. 1984). It seems that the disappearance of the genus *Stensioeina* (especially *Stensioeina pommerana*) in the lowermost Upper Maastrichtian is coeval throughout Europe and this event can serve as a good indicator for the lowermost Upper Maastrichtian.

Gavelinella monterelensis is a common species in the Upper Campanian of Europe (Hofker 1966); however, although much less common, it is also recorded in Lower Maastrichtian strata (Robaszynski et al. 1985, Gawor-Biedowa 1992). The LAD of *G. monterelensis* is shown as being synchronous with the Campanian/Maastrichtian boundary (Ogg and Ogg 2008). Records of *G. monterelensis* in the lowermost part of the Vijlen Member in Belgium (Robaszynski et al. 1985) and in the lowermost part of the *Belemnitella junior* Zone in SE Poland indicate that the highest occurrence of the species is in the mid-Maastrichtian.

The temporary disappearance of the genus *Rugoglobigerina* at the base of *Belemnitella junior* Zone (which occurs in the Tethys in the entire Maastrichtian) seems to be an event precisely defining the base of the Upper Maastrichtian substage in the Boreal Province. Thus, this event can serve as an indicator of the Lower/Upper Maastrichtian substage boundary in the Boreal Province. Keeled planktonic foraminifers reappear in the lower part of the *Belemnitella junior* Zone after a long absence encompassing the uppermost part of the Campanian and the entire Lower Maastrichtian of the Lublin Syncline. This very characteristic event coincides with the appearance of keeled planktonic foraminifers (*Globotruncana arca* group) in the same stratigraphic position in the Maastrichtian type area (Robaszynski et al. 1985). The lower part of the *Belemnitella junior* Zone is the only interval in the Boreal Maastrichtian where keeled planktonic foraminifers occur. This results in their significant stratigraphic correlation potential in the entire Boreal European Province.

In the upper part of the study interval, small heterohelicids start to prevail over globigerinelloids. These changes occur in the highest level of the Chełm quarry, between Podgórz 1 and Podgórz 2 in the Middle Vistula River Valley succession, and in the uppermost part of the section studied in the Puławy IG2 borehole (Fig. 2). In the upper part of the Chełm quarry (Machalski 2005, Dubicka and Peryt 2011) and in Podgórz (Abdel-Gawad 1986), the last occurrence of *Spyridoceramus tegulatus* was recorded. Thus, a very clear change in the proportion between heterohelicids and globigerinelloids in the planktonic foraminiferal assemblage is located close to the upper boundary of the *Spyridoceramus tegulatus-Belemnitella junior* Zone.

The occurrence of *Globotruncanella petaloidea* coinciding with the *Echinocorys* level as recorded in the Chełm quarry has been recognised earlier in the upper part of the Lixhe 1 Member of the Limburg Basin, representing the lower part of the *Belemnitella junior* Zone (Robaszynski et al. 1985). The occurrence of the *Echinocorys* event in the lower part of the *Belemnitella junior* Zone in both Belgium and SE Poland just above the "bloom" of *Globotruncanella petaloidea* strongly suggests that the *Echinocorys* level reflects an interregional event.

The re-appearance of Globotruncanidae in the analysed strata slightly above the base of the *Belemnitella junior* Zone, and the presence of complex heterohelicids probably relates to the global sea level rise corresponding to transgressive peak no. 4 recognised in north-western Europe (Hancock 1993). Han-

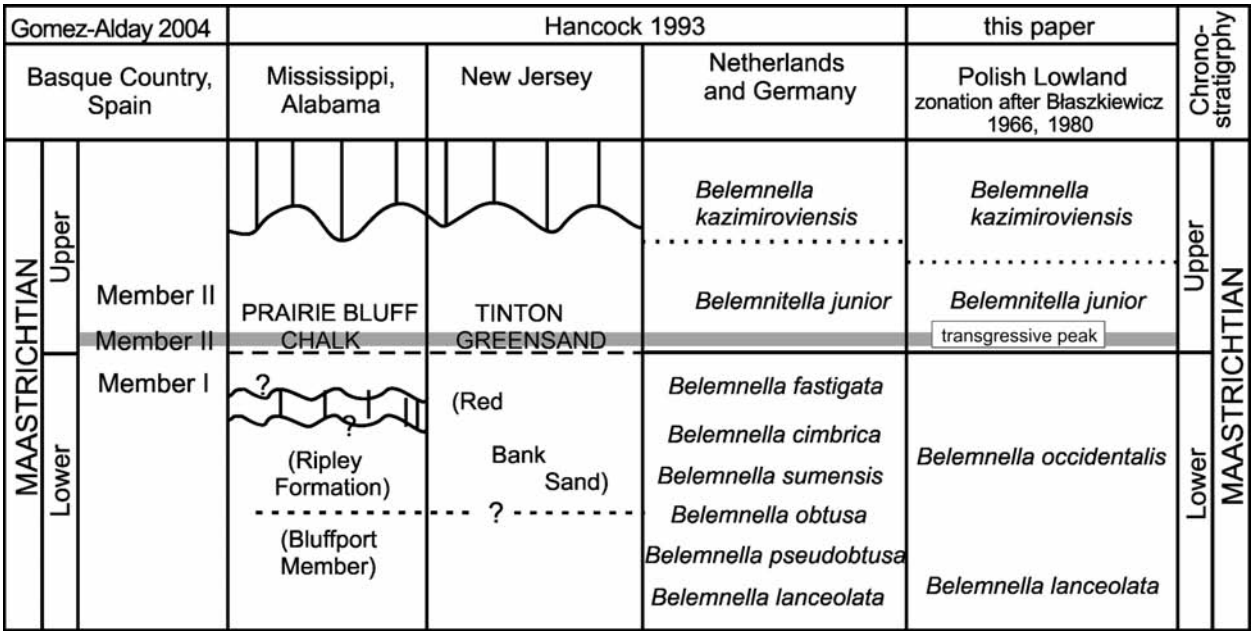

Fig. 5. Correlation of the early Late Maastrichtian transgressive peak recorded in Western Europe and eastern North America (Hancock 1993), Spain (Gomez-Alday et al. 2004) and SE Poland (this paper).

cock (1993) suggested that this transgressive peak may occur globally and correlated it with trangressive deposits of the Prairie Bluff Chalk on the northern margin of the Gulf of Mexico and with strata lieing slightly above the base of the Tinton Greensand of the Atlantic Coastal Plain. The transgressive peak in the earliest Late Maastrichtian was also documented in the Sopelana section of the Basque Arc Domain in Spain (Gómez-Alday et al. 2004). This event can be correlated with transgressive deposits in the Halembaye profile (Vijlen Member) (Fig. 5) where globotruncanids also commonly occur.

6. Conclusions

A detailed micropaleontological study allowed a precise definition of the Boreal Lower/Upper Mastrichtian transition in south-eastern Poland. Moreover, it enables to correlate the Maastrichtian strata of the study area with coeval strata in Western Europe and even with those from North America.

The following events characterize the interval comprising the uppermost Lower and Upper Maastrichtian strata in the Lublin Syncline (SE Poland):

1.) temporary disappearance of *Rugoglobigerina* spp. coinciding with the LAD of *Angulogavelinella gracilis*;
2.) dominance of heterohelicids and globigerinelloids in planktonic foraminiferal assemblages;
3.) reappearance of *Globotruncana* spp., after a longer absence in the area;
4.) LAD of *Stensioeina* spp. and *Gavelinella monterelensis*;
5.) a short-lived bloom of *Globotruncanella petaloidea*;
6.) a dominance of the planktonic foraminiferal assemblages by heterohelicids in the uppermost part of the study interval.

The disappearance of all representatives of the genus *Rugoglobigerina* at the base of the *Belemnitella junior* Zone and the reappearance of globotruncanids in the lowermost part of the *Belemnitella junior* Zone (the latter interpreted as due to a very significant sea level rise) are the indicators of the Lower/Upper Maastrichtian substage boundary in the Boreal Province.

The record of calcareous nannofossil species *Lithraphidites quadratus* at the base of the *Belemnitella junior* Zone in the Middle Vistula River Valley (Gaździcka 1978) strongly supports the possibility to use this event as an additional biomarker for the Lower/Upper Maastrichtian substage boundary.

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Appendix

Species recorded:

Contusotruncana fornicata (Plummer) = *Globotrunca fornicata* Plummer, 1931
Contusotruncana patelliformis Gandolfi = *Globotruncana patelliformis* Gandolfi, 1955
Globigerinelloides abberantus (Neckaja) = *Globigerinella abberanta* Neckaja, 1948
Globigerinelloides multispinus (Lalicker) = *Biglobigerinella multispina* Lalicker, 1948
Globigerinelloides prairiehillensis Pessagno, 1967
Globigerinelloides volutus (White) = *Globigerina voluta* White, 1929
Globotruncana arca (Cushman) = *Pulvinulina arca* Cushman, 1926
Globotruncana bulloides Vogler = *Globotruncana linnei* (d'Orbigny) subsp. *bulloides* Vogler, 1941
Globotruncana linneiana (d'Orbigny) = *Rosalina linneiana* d'Orbigny, 1839
Globotruncanella petaloidea (Gandolfi) = *Globotruncana* (*Rugoglobigerina*) *petaloidea* subsp. *petaloidea* Gandolfi, 1955
Heterohelix globulosa (Ehrenberg) = *Textularia globulosa* Ehrenberg, 1840
Heterohelix planata (Cushman) = *Guembelina planata* Cushman, 1938
Heterohelix striata (Ehrenberg) = *Textularia striata* Ehrenberg, 1840
Heterohelix vistulaensis Peryt, 1980
Laeviheterohelix pulchra (Brotzen) = *Guembelina pulchra* Brotzen, 1936
Planoglobulina carseyae (Plummer) = *Ventilabrella carseyae* Plummer, 1931
Planoglobulina brazoensis Martin, 1972
Pseudotextularia deformis (Kikoine) = *Guembelina deformis* Kikoine, 1948
Racemiguembelina powelli Smith and Pessagno, 1973
Rugoglobigerina hexacamerata Brönnimann, 1952
Rugoglobigerina milamensis Smith and Pessagno, 1973
Rugoglobigerina pennyi Brönnimann, 1952
Rugoglobigerina rugosa (Plummer) = *Globigerina rugosa* Plummer, 1926
Angulogavelinella gracilis (Marsson) = *Discorbina gracilis* Marsson, 1878
Gavelinella monterelensis Marie = *Anomalina monterelensis* Marie, 1941
Stensioeina pommerana Brotzen, 1936