

Integrated biostratigraphy of the Santonian through Maastrichtian (Upper Cretaceous) of extra-Carpathian Poland

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ABSTRACT:

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The biostratigraphic importance, current zonations, and potential for the recognition of the standard chronostratigraphic boundaries of five palaeontological groups (benthic foraminifers, ammonites, belemnites, inoceramid bivalves and echinoids), critical for the stratigraphy of the Santonian through Maastrichtian (Upper Cretaceous) of extra-Carpathian Poland, are presented and discussed. The summary is based on recent studies in selected sections of southern Poland (Nida Synclorium; Puławy Trough including the Middle Vistula River composite section; and Mielnik and Kornica sections of south-eastern Mazury-Podlasie Homocline) and of western Ukraine (Dubivtsi). The new zonation based on benthic forams is presented for the entire interval studied. Zonations for ammonites, belemnites and inoceramid bivalves are compiled. All stage boundaries, as currently defined or understood, may easily be constrained or precisely located with the groups discussed: the base of the Santonian with the First Occurrence (FO) of the inoceramid *Cladoceramus undulatoplicatus*; the base of the Campanian with the Last Occurrence (LO) of the crinoid *Marsupites testudinarius* and approximated by the range of the foraminifer *Stensioeina pommerana*; and the base of the Maastrichtian approximated by the FO of the inoceramid bivalve *Endocostea typica* and the FO of the belemnite *Belemnella vistulensis*. The positions of substage boundaries, as currently understood, are constrained in terms of the groups discussed.

Key words: Upper Cretaceous; Extra-Carpathian Poland; Biostratigraphy; Correlation; Chronostratigraphy.

INTRODUCTION

Much has changed in the stratigraphical understanding and resolution of Upper Cretaceous stratigraphy since the publication of the biostratigraphic summary on the Upper Cretaceous of extra-Carpathian Poland (Błaszkiwicz and Szymakowska 1984 in the Atlas of Cretaceous fossils by the Polish Geological Survey in

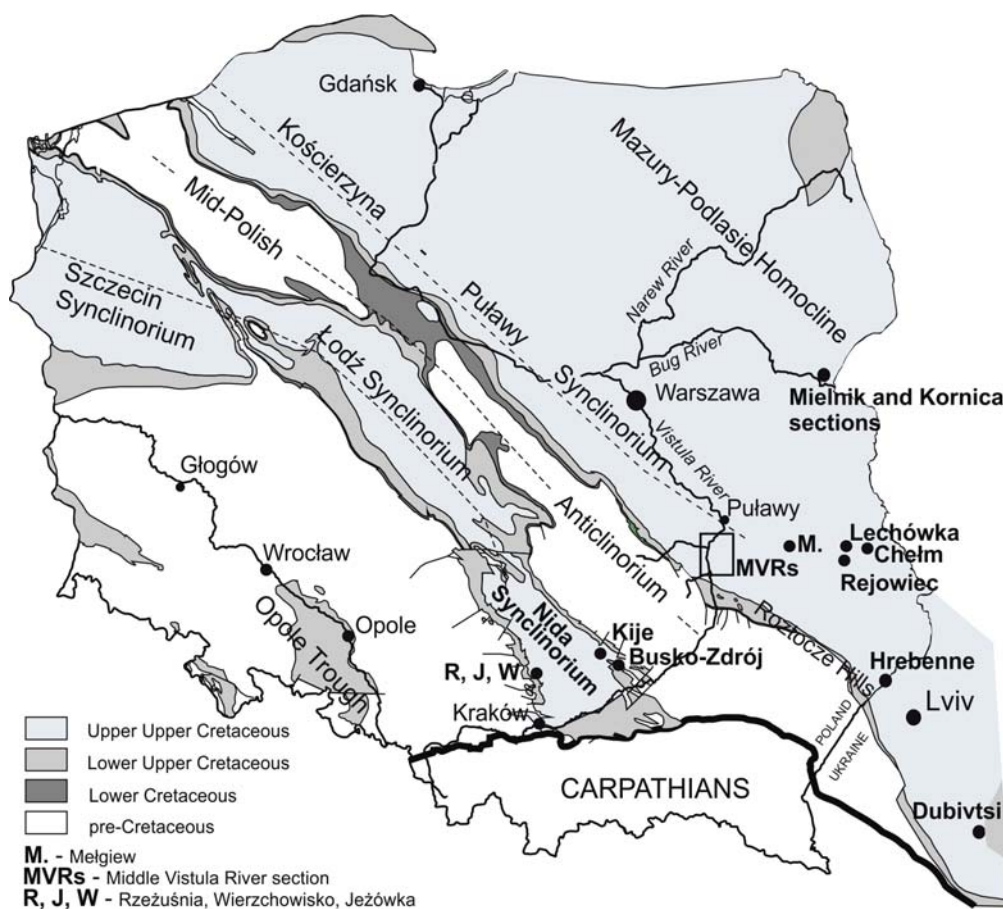
1984, with its English edition in 1989). The critical factor has been the change in approach; from the study of the stage and substage contents to the study of their boundaries, envisioned the best by the two symposia on Cretaceous Stage Boundaries, in Copenhagen in 1983 (Birkelund *et al.* 1984) and in Brussels in 1995 (Rawson *et al.* 1996). The symposia were followed by intensive studies by members, and associates, of the stratigraphical working groups, established and devoted to select the

most appropriate stratotype sections, and to recognize the stratigraphic successions and subdivisions of particular stages. As a result, most of the Upper Cretaceous stages already have formally designated stratotypes (Odin and Laumerelle 2001; Kennedy *et al.* 2004, 2005; Lamolda *et al.* 2014) and those which are left have been intensively studied (Gale *et al.* 2007; Walaszczyk *et al.* 2010, 2012). Much work has been done also on the substages (discussion in Ogg and Hinnov 2012).

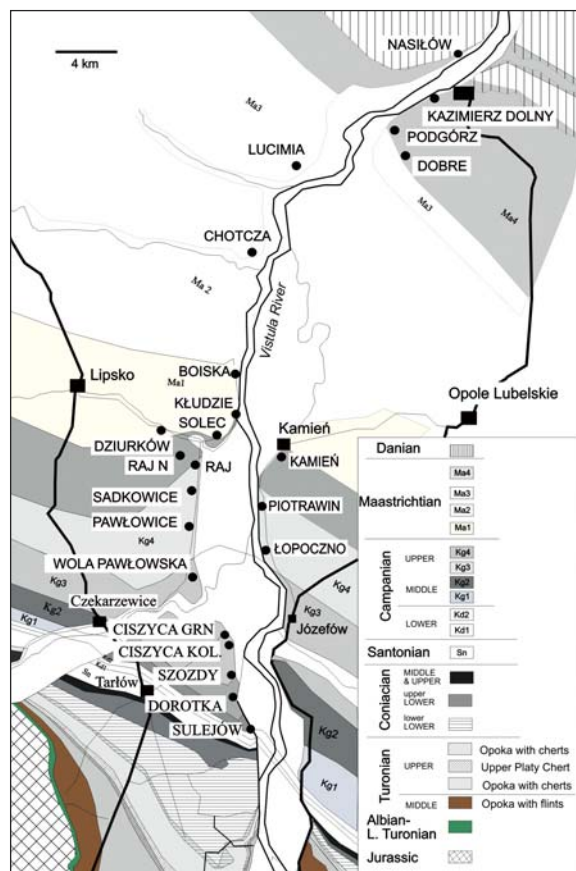
During these two decades, intensive works have been conducted on the biostratigraphy of the Upper Cretaceous of extra-Carpathian Poland. The selected best sections in the country were re-investigated with the aim of integrating the results based on critical macro- and microfossils. Although there are still biostratigraphic groups and other, non-biostratigraphic tools, which will contribute to the final scheme of the Upper Cretaceous subdivision of extra-Carpathian Poland, the results of recent studies have improved markedly the former biostratigraphic summary.

The present paper summarizes the current biostratigraphies and biostratigraphic recognition of the Santonian–Maastrichtian (Upper Cretaceous) chronostratigraphy of extra-Carpathian Poland. We have integrated the results inferred from benthic foraminifers, ammonites, belemnites, inoceramid bivalves, and echinoids. The results are based primarily on surficial sections, which provided parallel records of at least two groups included into the analysis. The critical sections studied are located in south-eastern Poland: the Lublin area, including the Middle Vistula River section, the Nida Synclinorium, and selected sections in the eastern part of the country (Text-figs 1, 2).

The main aim of the present account is to update and summarise the biostratigraphical subdivisions of the Santonian through Maastrichtian of extra-Carpathian Poland and to present the practically applicable biostratigraphic definitions of chronostratigraphic boundaries (at stage and substage levels), as currently understood. Nevertheless, the record of the palaeontological



Text-fig. 1. Geological sketch-map of extra-Carpathian Poland, without Cenozoic deposits; tectonic units after Żelaźniewicz *et al.* 2011. Localities studied are in bold; Middle Vistula River section is presented Text-fig. 2



Text-fig. 2. Geological sketch-map and main localities of the Middle Vistula River composite section; the homoclinical structure of the area gives consequently younger beds when moving northward

groups discussed herein is potentially also of key importance for constructing more reliable standard subdivisions of the interval. The middle Campanian through Maastrichtian of the Middle Vistula River section, as well as a number of sections in the marginal parts of the Nida Synclinorium, has long contributed to the general knowledge and understanding of Upper Cretaceous biostratigraphy. The only locations from outside Poland, which are included in the present discussion, are the Dubivtsi I and II quarry sections, situated close to the town of Halicz, in western Ukraine. The succession available in the quarries spans the entire Coniacian and Santonian, and the area is a direct extension of the Cretaceous of eastern extra-Carpathian Poland. Recent studies on the available succession have shown its extraordinary importance for the biostratigraphic and palaeogeographic interpretations of the entire central Europe area (Dubicka 2012; Dubicka *et al.* 2014; Remin *et al.* 2016).

The present summary provides for the first time, the complete zonation based on benthic foraminifera for the entire Santonian through Maastrichtian of extra-

Carpathian Poland. The zonation is accompanied by illustrations of all index taxa. Also illustrated are selected echinoid taxa, although this group is still in need of serious study before its reliable use may be proposed. The belemnites, ammonites and inoceramid bivalves from the area discussed herein, were recently published and extensively illustrated (see discussion below). Consequently, the reader is referred to these papers for their proper taxonomic and photographic presentation.

The material illustrated in the present paper is housed in the Geological Museum of the Faculty of Geology of the University of Warsaw.

REVIEW OF THE BIOSTRATIGRAPHICALLY CRITICAL GROUPS USED IN THE PRESENT SUMMARY

The present summary on the biostratigraphy of the Coniacian through Maastrichtian of extra-Carpathian Poland integrates the results based on benthic foraminifers, ammonites, belemnites, inoceramid bivalves and echinoids. Not every group allows for the subdivision of the entire succession, either because of their limited occurrence or because they are still insufficiently recognized. Inevitably, the groups with the most complete record are foraminifers, ammonites and inoceramid bivalves. The belemnites and echinoids, although spanning the entire interval studied, provide sufficiently good palaeontological documentation only in parts of their ranges.

Benthic foraminifers (Z. Dubicka)

Like today, Foraminifera were the most common and abundant calcareous shell marine microorganisms during the Late Cretaceous. Combined with their high fossilization potential, foraminifers provide the most complete and sufficiently good fossil record to trace the details of their evolutionary changes (e.g. Pearson and Ezard 2014).

Foraminifera occupied almost all marine environments from marginal marine to deep seas and from poles to the tropics, representing both the benthic and planktonic modes of life. Planktonic forms are commonly believed to be particularly effective for interregional bio-stratigraphic correlations, since their planktonic behavior affects their high dispersal potential. However, there are many factors which influence their distribution, including physical barriers, depth, salinity, and temperature of ambient waters, food availability

and related features such as primary production, upwelling and water currents (Hemleben *et al.* 1989; Sen Gupta 2002; Schiebel and Hemleben 2005). Recent planktonic foraminiferal communities are attributed to five major bioprovinces (tropical, subtropical, temperate, subpolar, and polar) which approximately follow the water temperature and salinity zonal pattern (Bé 1977; Boltovskoy and Wright 1979). The species diversity decreases generally pole-wards. At least four palaeobiogeographic provinces are distinguished among Late Cretaceous planktonic foraminifera (Hart 2000): Tropical (Tethyan), Transitional, Boreal (N) and Austral (S), of which the tropical is taxonomically the most diverse.

During the Late Cretaceous the area of extra-Carpathian Poland belonged to the Foraminiferal Transitional Province, located between the Tethyan and Boreal provinces (Pozaryska and Peryt 1979). Therefore, the foraminiferal assemblages of epicontinental Poland are taxonomically much more depleted than Tethyan–Central Atlantic assemblages, missing the most of the characteristic forms of the latter area. Consequently, the standard globotruncanid and heterohelicid zonations (i.a., Robaszynski and Caron 1979, 1995; Robaszynski *et al.* 1984; Huber *et al.* 2008; Pérez-Rodríguez *et al.* 2012; Ogg and Hinnov 2012), based mainly on Tethyan–Central Atlantic species, cannot be applied. Actually, this standard zonation works only, and to a limited extent, in the Cenomanian and Turonian (see Peryt 1980, 1983; Peryt and Wyrwicka 1991, 1993; Peryt *et al.* 1994; Dubicka and Machalski 2016), being almost totally useless in the later part of the epoch. In consequence, new local planktonic foraminiferal zonations were established (Peryt 1980; Gawor-Biedowa 1992; Dubicka and Peryt 2012a, b). Regrettably however, these zones, based on species with relatively long vertical ranges, have rather moderate chronostratigraphic potential. Nevertheless, some of the planktonic foraminiferal events can be used for local and even interregional correlations [e.g., the first occurrence of *Globotruncana linneaina* pill-box-like morphotypes close to the Coniacian–Santonian boundary and the extinction of marginotruncanids within the Santonian–Campanian boundary interval; their stratigraphic positions correspond to the coeval events recorded in the stratotypic Olazagutia section (Lamolda and Paul 2007; Lamolda *et al.* 1999, 2014) and in the Waxahachie Dam Spillway section, the GSSP candidate section for the base of the Campanian Stage (Gale *et al.* 2007)].

Instead, with the exception of very shallow coastal sediments, benthic foraminifera are common to abundant in almost all marine facies of the European epicontinen-

tal Cretaceous. They are mostly represented by calcareous forms of the Rotaliida, including buliminids (supraordinal classification follows Pawlowski *et al.* 2013) and the Lagenida, whereas representatives of the Miliolida are less frequent. Agglutinated taxa are in general rarer in more calcareous facies, however, their abundance and diversity increase significantly in oxygen-poor and organic-rich sediments (e.g. Bernhard 1986; Dubicka *et al.* 2014). They seem to be able to overcome the problems of carbonate undersaturation and the difficulty of secreting calcium carbonate in such environments (e.g. Bernhard 1986). Moreover, agglutinated forms dominate the foraminiferal assemblages of very shallow sandy facies (e.g., the Albian sands and marly sands of the Annapol succession – see Dubicka and Machalski 2016). In general, the taxonomic composition of Late Cretaceous benthic foraminifera is very similar across the entire epicontinental Europe, giving an opportunity of direct bio-correlations between regions. The available data suggest, moreover, that the majority of first appearances recognized in most of the taxa reflect actual evolutionary events. Several evolutionary lineages of arenobuliminids, bolivinoidids, gavelinellids, globorotalitids or stenioeinids have been recognized in these sediments (Vasilenko 1961; Carter and Hart 1977; Edwards 1981; Hart and Swiecicki 1988; Bailey *et al.* 2009; Dubicka and Peryt 2014, 2016; Dubicka 2015).

In view of the arguments provided, benthic foraminifera (mostly calcareous rotaliids) seem to have a much higher stratigraphic potential and applicability within the entire European epicontinental Upper Cretaceous, than planktonic ones (Reuss 1860; Marsson 1878; Brotzen 1936; Marie 1941; Hiltermann 1952; Hofker 1957, 1966; Vasilenko 1961; Hiltermann and Koch 1950, 1955, 1960, 1962; Goel 1965; Gawor-Biedowa 1972, 1992; Koch 1977; Bailey and Hart 1979; Edwards 1981; Akimetz *et al.* 1978; 1983; Bailey *et al.* 1983; Peryt 1983; Hart *et al.* 1989; King *et al.* 1989; Schönfeld 1990; Hradecká 1996; Walaszczyk *et al.* 2004; Hampton *et al.* 2007; Kopaevich *et al.* 2007; Olfieriev *et al.* 2007; Wilkinson 2011; Benyamovskiy *et al.* 2012).

Ammonites and belemnites (Z. Remin)

Ammonites and belemnites are critical groups for the biostratigraphy of the Upper Cretaceous of the entire North European Province. Both groups, because of their fast evolution, yielded several traditional zonal index fossils in the interval studied, however, the overall stratigraphic subdivision and resolution offered by ammonites and belemnites in the Cretaceous of extra-Carpathian Poland differ markedly in particular intervals.

The critical study on the Campanian–Maastrichtian ammonites of extra-Carpathian Poland is the monograph by Błaszkiwicz (1980), based on the fossiliferous and apparently continuous succession of the Middle Vistula River section (Text-figs 1, 2). Although his study was revised and amended in a series of subsequent papers (Burnet *et al.* 1992; Kennedy *et al.* 1992, Hancock and Kennedy 1993; Machalski 1996, 2005a, b; Machalski and Jagt 1998; Jagt *et al.* 1999; Landman *et al.* 2010; Machalski 2012a, b), the general succession recognized has been confirmed. The studies on the Campanian ammonites in the Miechów Trough (Jagt *et al.* 2004 and Machalski *et al.* 2004) and on the Campanian and Maastrichtian of the Roztocze region (SE Poland) (Machalski 2005a, b, 2012b; Kin 2010; Remin *et al.* 2015) supplemented and extended the stratigraphic knowledge of the Campanian–Maastrichtian ammonites in Poland. Topmost Coniacian and Santonian ammonites from Poland are known from the fossiliferous Lipnik–Kije section in the north-eastern Nida Synclinorium (Remin 2004, 2010; and also Remin *et al.* 2016); only a few reports from the Middle Vistula River section (Kurlenda 1966), North Sudetic Trough (Milewicz *et al.* 1968; Milewicz 1988) and from borehole material of the Polish Lowlands (Jaskowiak–Schoeneichowa 1979, 1981) are known outside this area.

In the case of the Santonian–Maastrichtian belemnites, the early recognition of their stratigraphic significance is best expressed in the old stratigraphic subdivision of Stolley (1897), into “granulaten-”, “quadraten-” and “mucronaten-Kreide”, based on the succession of the respective belemnite species groups. The belemnite subdivisions are, however, of geographically limited application. This is well exemplified by biostratigraphic schemes based on the genera *Belemnitella* and *Belemnella* as used in Western and Eastern Europe, which apply different zonal markers and/or present different understanding of apparently the same taxa. The Santonian through Maastrichtian belemnites of Poland (based on the material from the Middle Vistula River section) were monographed by Kongiel (1962). However, because of various reasons his taxonomic concepts have never gained wider acceptance. The revision of the rich Middle Vistula River material was recently accomplished by Remin (2007, 2008, 2012, 2015), who applied an artificial neural networks method, coupled with a unified biometric procedure. The direct comparison of Remin’s methodology with the classic Schulz 1979 procedure for the topmost Campanian–lower Maastrichtian *Belemnella* (see Keutgen *et al.* 2012) and for the topmost Maastrichtian *Bln. kazimiroviensis* (Skołodźdrówna, 1932) (Keutgen *et al.* 2016) showed quite divergent results, and the lack of

any possibility of a simple transformation between both schemes.

Inoceramid bivalves (I. Walaszczyk)

For decades, the upper–middle Coniacian and Santonian inoceramids of Europe have intensively been studied and their biogeographic and evolutionary patterns are well recognized (see e.g., Heinz 1928; Seitz 1935, 1961, 1965; Tröger 1974; Kauffman 1977; Tröger and Christensen 1991; Walaszczyk 1992). There is a distinct biogeographic pattern within the group in the late Coniacian and in the Santonian. The latest Coniacian and Santonian (up to early early Campanian) are characterised by *Sphenoceramus*, the genus typical of more boreal areas, whereas the southern areas are dominated by the genera *Platyceramus*, *Cladoceramus* and *Cordiceramus*. In central Europe the boundary between both biogeographic areas approximates to the palaeogeographic northern boundary of the Tethys. In the early and middle parts of the late Coniacian this biogeographic pattern is not as distinct, as, however, the genus *Magadiceramus*, the marker and dominant genus of this interval is rare or absent in more northerly parts of the European Biogeographic Province (see e.g., Tröger and Christensen 1991), where the genera *Volviceramus* and *Sphenoceramus* dominate.

Late Cretaceous inoceramid bivalves have long been recognized as a widely spread and fast evolving group with, consequently, very high stratigraphic potential (e.g., Tröger 1967; Kauffman 1977). As long as wide geographic distribution and fast evolution were recognized among lineages of the early Late Cretaceous (Cenomanian through Santonian), the late Late Cretaceous (Campanian–Maastrichtian) clades were regarded as characterized by higher provincialism and, first of all, much slower evolution (e.g., Dhondt 1983b, 1992; Voigt 1996). Nevertheless, the preliminary analysis of the diversity curves and of evolutionary rates among European inoceramids (Walaszczyk 1996), as well as stratigraphical summaries on inoceramids from the US Western Interior (Kauffman *et al.* 1994) and from Japan (Toshimitsu *et al.* 1995), suggested that the late Late Cretaceous inoceramids kept the same trend throughout the epoch, until their final extinction. Subsequent studies on the Western Interior material (Walaszczyk *et al.* 2001) and European faunas (from Tercis: Walaszczyk *et al.* 2002; Odin and Walaszczyk 2003; and from the Middle Vistula section: Walaszczyk 2004; as well as slightly earlier reports from various parts of Europe: Walaszczyk *et al.* 1996; Walaszczyk 1997) confirmed the preliminary results. Recently, the group was successfully applied to the biostratigraphic

study of the Campanian and Maastrichtian of the Nida Synclinorium (Jurkowska 2016; see also Jurkowska *et al.* 2015).

With a few exceptions, the Campanian and Maastrichtian inoceramids of Poland represent uniform faunas characteristic of the entire Euramerican Biogeographic Region. The final extinction of true inoceramids is dated as early late Maastrichtian (Walaszczyk *et al.* 2009, 2010; Walaszczyk and Kennedy 2011). The later part of the Maastrichtian is characterised by ‘teglated’ inoceramids, *Spyridoceramus tegulatus* (von Hagenow, 1842) and *Tenuipteria argentea* (Conrad, 1858) (see e.g., Speden 1970; Dhondt 1983a; Abdel-Gawad 1986). These forms, regarded as separate from ‘true’ Inoceramidae, based on the characteristics of their ligamental plate, seem, however, to be much closer to the latter than earlier assumed. The regularity of ligamental pits is lost in a number of late Campanian and early Maastrichtian inoceramid lineages and this feature should not be regarded as critical at the genus-level taxonomy.

Until the early late Maastrichtian, the time of the extinction of the ‘true’ inoceramids, the group was evolutionarily vigorous, with high taxonomic diversity and morphological disparity. Inoceramids, even in their present state of recognition, allow the subdivision of the entire Santonian–Maastrichtian interval with a resolution comparable to that of ammonites and benthic forams (as presented in this paper), with still a huge potential for further, more detailed subdivisions.

Echinoids (D. Olszewska-Nejbert)

Echinoids are common in the Upper Cretaceous successions of the North European Biogeographic Province. Although usually considered as of secondary stratigraphical importance, in some intervals the group is potentially of great stratigraphical value.

During the Late Cretaceous, most of the present area of Poland was located within the North European Province, stretching from the western tips of Central Asia (Kopet-Dagh and Mangyshlak Mts in Turkmenistan and Kazakhstan) to Ireland in the west (extra-Alpine area). In the Santonian–Maastrichtian the province was dominated by irregular echinoids, with regular forms rather rare (Ernst 1970b). The stratigraphically useful irregular echinoids are first of all holasteroids (*Offaster*, *Galeola*, *Echinocorys*), spatangoids (*Micraster*), and holectipoids (*Conulus* and *Galerites*).

Most of the published echinoid reports are accompanied by precise stratigraphies (e.g. Ernst 1970b, 1972, 1975; Smith and Wright 1999, 2003; Jagt 2000; Jagt *et*

al. 2004; Olszewska-Nejbert 2007; Schlüter and Wiese 2010). Consequently, it was possible to show that some genera, as e.g. *Micraster* (Ernst 1970c, 1972; Olszewska-Nejbert 2007) or *Offaster-Galeola* (Ernst 1971) are fast-evolving lineages, other are complex, and the rate of evolution of some others, is not clear at all. This is the case with e.g., *Echinocorys*, a key echinoid genus for the late Late Cretaceous biostratigraphy. This genus retained a very conservative architectural plan during its entire Late Cretaceous history, and displays a very weak morphological expression of its evolutionary changes. Consequently, the genus is understood by some researchers as a single large species complex (Wright 1864-1882; Willcox 1953; Smith and Wright 2003). Some other investigators do see phenotypic changes in its successive populations (e.g. Ernst 1970b, Jagt 2000, Smith and Wright 2003), arguing about stratigraphical value of the genus (Wright 1864-1882; Smith and Wright 2003). Ernst and Schulz (1974), Jagt *et al.* (2004) and Olszewska-Nejbert (2007) proposed the use of the concept of *Echinocorys* ‘species groups’, which would give a stratigraphically recognizable succession of morphotypes, and this concept is also adopted herein. A similar problem applies to some Campanian *Micraster*, where the ‘group’ concept, although informal, gives a preliminary solution to the taxonomy of these poorly understood clades (e.g. Jagt 2000; Jagt *et al.* 2004).

Echinoids are marine benthic fauna, with a strong dependence on the consistency and grain size of the substrate, as well as some other factors, such as water depth or temperature (e.g. Ernst 1970a, b; Smith 1984; Olszewska-Nejbert 2007). Numerous regular echinoids prefer nearshore settings, with a coarse-grained substrate or hard rocky bottom covered by algae mats. Irregular echinoids favor more distal and quieter environments in deeper parts of the basin. During the Late Cretaceous, with the CaCO₃ content increasing above 55–60%, holasteroids and spatangoids dominated the echinoid assemblages (Ernst 1970b). This type of substrate is found in most of the Santonian–Maastrichtian seas of extra-Carpathian Poland (Jaskowiak-Schoeneichowa and Krassowska 1988; Walaszczyk 1992; Leszczyński 1997, 2012). The echinoid faunas known from the Upper Cretaceous of extra-Carpathian Poland represent echinoids known from the entire North European Province (Stokes 1975; Jagt 2000; Jagt *et al.* 2004; Smith and Wright 1999, 2003, 2012; Olszewska-Nejbert 2007).

Although echinoids are known from various regions of extra-Carpathian Poland (Text-fig. 1), the most representative areas for the particular intervals, discussed in this paper, are: Santonian of the western flank of the

Nida Synclinorium (Hynda and Mączyńska 1979; Kudrewicz 1992); Campanian and Maastrichtian of the Nida Synclinorium (Mączyńska 1968, 1989; Jagt *et al.* 2004), Campanian and Maastrichtian of the Middle Vistula section (Mączyńska 1989), and the chalk succession of eastern Poland (Olszewska 1987; Langner 1990). The Coniacian-Maastrichtian echinoids from the Middle Vistula River and from the entire Lublin area have not received sufficient palaeontological documentation.

BIOZONATIONS

Among the groups discussed in this paper, the benthic foraminifers, inoceramid bivalves, ammonites and belemnites allow for a well-defined biozonation within the entire or in most of the Santonian through Maastrichtian interval of extra-Carpathian Poland. Besides benthic foraminifers, for which the original biozonation is presented in this paper, the schemes based on other groups are compiled from recent extensive studies and discussions (Peryt 1980, Błaszkiwicz 1980; Walaszczyk 2004; Remin 2004, 2010, 2012, 2015; Keutgen *et al.* 2012; Machalski 1996, 2005a, b; Jagt *et al.* 2004; Machalski *et al.* 2004; Machalski 2012a, b; Remin *et al.* 2015). The least known is the stratigraphic resolution of the echinoids; the vertical distribution of most of the taxa is only roughly recognized and, moreover, the taxonomic interpretation of a number of the lineages present in the studied interval remains far from well-established. This can hardly be because of the poor stratigraphic potential of the group, and reflects rather its poor recognition in Poland. This is well proved by a detailed biostratigraphic study on the strata at the lower–upper Campanian boundary (in the traditional two-fold subdivision of the stage) in the Nida Synclinorium, in which the refined North-German echinoid succession of Gundolf Ernst (see e.g., Ernst *et al.* 1979) is easily recognisable (Jagt *et al.* 2004). Further work is definitely needed.

The correlation of the particular zonations is shown in Text-figs 3 and 4.

Benthic foraminiferal biozonation (Z. Dubicka)

Twenty-eight benthic foraminiferal zones, corresponding to an interval from the middle Coniacian (*Volviceras involutus* Zone) up to the end of the Maastrichtian (*Hoploscaphites constrictus johnjagti* Zone *sensu* Machalski 2005a), are distinguished based on the material from more than 50 sections, published in Dubicka and Peryt 2011, 2014, 2016; Dubicka *et al.*

2014; Dubicka 2015; Jurkowska *et al.* 2015; Machalski *et al.* 2016; Peryt and Dubicka 2016 (see Text-figs 3, 4). The foraminiferal zones are correlated against the macrofossil zonations of Błaszkiwicz (1980), Walaszczyk (1997, 2004), Jagt *et al.* (2004), Remin (2012, 2015), and Jurkowska (2016), recognized in the same outcrops (Text-fig. 3).

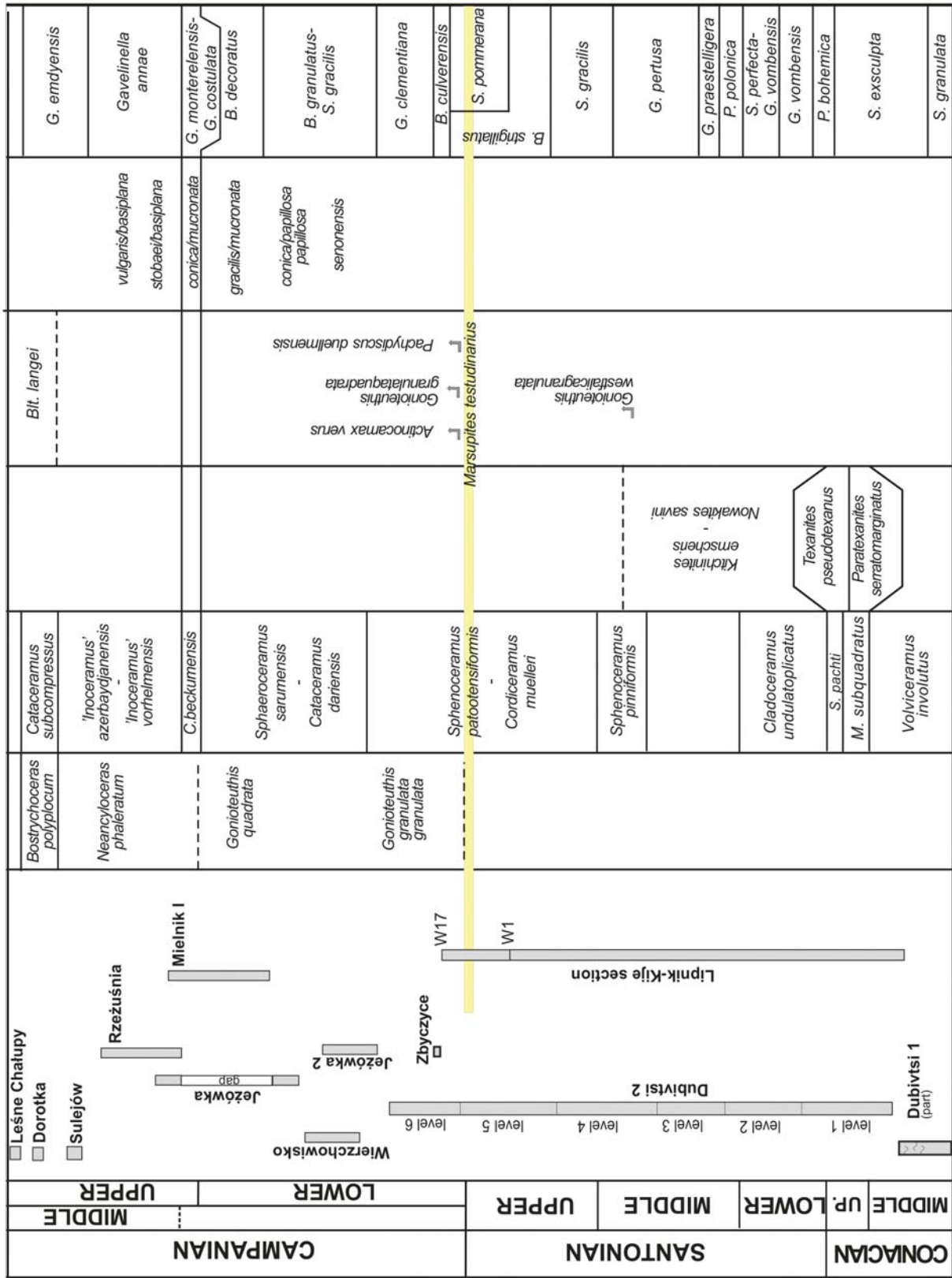
The first biostratigraphic study on the Late Cretaceous benthic foraminifera of extra-Carpathian Poland was published by Pożaryska (1954). Her study was based on the Middle Vistula River succession, and she was able to successfully correlate her foraminiferal ranges with Pożaryski's (1938) macrofossil zonation. Subsequent studies, published between 1950 and 1990, were mainly based on borehole material (Bieda 1958; Witwicka 1958; Gawor-Biedowa and Witwicka 1960; Gawor-Biedowa 1972, 1992; Pożaryska and Witwicka 1983; Gawor-Biedowa *et al.* 1984; Peryt 1988). Unfortunately, the zonation worked out on the borehole material was not directly correlated to the macrofossil standard zonation and consequently, its chronostratigraphic interpretation was difficult. The recent restudy of selected sections with well-constrained chronostratigraphy (Dubicka 2012, 2015; Dubicka and Peryt 2011, 2012a, b; 2014, 2016; Jurkowska *et al.* 2015; Peryt and Dubicka 2015; Machalski *et al.* 2016) allowed for the precise and rigorous correlations between micro- and macrofossil zonations. The summary on the recent development in the benthic foraminiferal zonation and its correlation to the chronostratigraphic standard is presented below.

The particular zones (Text-fig. 3), with their definitions, are discussed (in ascending order). The index taxa are illustrated in Text-figs 5–8.

Stensioeina exsculpta Partial-range Zone. The base of the zone is defined by the Last Occurrence (LO) of *Protostensioeina granulata* (Olbertz, 1942) and its top by the First Occurrence (FO) of *Protostensioeina polonica* (Witwicka, 1958). At the base of the zone *Gavelinella vombensis* (Brotzen, 1945), *Loxostomum eleyi* (Cushman, 1927), and the genus *Neoflabellina* appear. In the upper part of the zone appears *Protostensioeina* sp. E. The zone ranges from the upper part of the *V. involutus* Zone through to the upper part of the *Magadiceramus subquadratus* Zone. The zone is established based on the Ukrainian sections of the Dubivtsi I quarry (marls) and the Dubivtsi II quarry (lower half of the first exploitation level).

Protostensioeina bohémica Total-range Zone. This is the index taxon range zone. The top of the Zone is associated with the disappearance of all members of the

STAGES	MAASTRICHTIAN		CAMPIANIAN	
SUBSTAGES	UPPER		UPPER	
STAGES	LOWER		MID	
Stratigraphic ranges of sections studied				
Cephalopod zonation (Błaszczewicz 1980)	<i>Belemnella kazimirovicensis</i>		<i>Belemnella junior</i>	<i>Belemnella occidentalis</i> <i>Belemnella lanceolata</i>
Inoceramid zonation (Walaszczyk 2004), (Walaszczyk and Cobban 2006; Walaszczyk et al. 2010)	<i>Tenuipteria argentea</i>		<i>'Inoceramus' ianjonaiensis</i> <i>Trocho-ceramus radiosus</i> <i>Endocostea typica</i>	<i>'Inoceramus' redbirdensis</i> <i>'Inoceramus' costaceus</i> <i>'Inoceramus' inkermanensis</i> <i>'Inoceramus' altus</i> <i>Sphaeroceras pertenuiformis</i> <i>'Inoceramus' tenuilineatus</i>
Ammonite zonation (Machalski 2012b; Remin 2010)	<i>H.c. johniagti</i> <i>Merulites terminus</i> <i>Hoploscaphites constrictus crassus</i>		<i>Hoploscaphites constrictus livvensis</i> <i>Acanthoscaphites tridens</i> <i>Pachydiscus neubergicus</i>	<i>Nostoceras hyatti</i>
Belemnite zonation (Remin 2012, 2015)			<i>Bl.nadina</i> - <i>Bl.posterior</i> <i>Bl.minor II</i> <i>Bl.minor I</i> <i>Bl.oblusa</i> - <i>sp.F</i> <i>sp.G</i> <i>Bl.n.vist.</i> <i>Belemnella infolata</i> <i>Belemnella lanceolata</i>	<i>Belemnella langei</i>
Belemnite/echinoid zonation (Lagt et al. 2004)				
Benthic foraminiferal zonation (this paper)	<i>B. vistulae</i> <i>B. draco</i> <i>G. acuta</i> <i>B. giganteus</i> <i>A. gankinoensis</i> - <i>A. gracilis</i>		<i>N. reticulata</i> <i>O. navarrona</i> <i>B. decurrens</i> - <i>G. emdyensis</i> <i>B. intermedius</i> <i>A. gracilis</i> - <i>G. monterelensis</i> <i>B. miliaris</i> <i>B. incrassata</i> - <i>G. michelinianus</i>	



Text-fig. 3. Chronostratigraphy; ammonite, belemnite, echinoid, inoceramid bivalve, and benthic foraminifera zonations; and vertical ranges of critical sections for the Santonian through Maastrichtian of extra-Carpathian Poland

P. granulata group (see Dubicka and Peryt 2014). The zone corresponds to the upper part of the *Magadiceramus subquadratus* Zone and the lowermost part of the *Cladoceramus undulatoplicatus* Zone, thus coinciding with the Coniacian–Santonian boundary interval. The zone was recognized in the Ukrainian section of Dubivtsi II quarry (the middle and upper parts of the first exploitation level).

Gavelinella vombensis Partial-range Zone. The base of the zone is defined by the LO of *P. bohémica* (Jirova, 1958), and its top by the FO of *Stensioeina perfecta* Koch, 1977, the oldest member of the *Stensioeina perfecta* (“thick stensioeinids”) lineage (see Dubicka and Peryt 2014). The zone corresponds to the lower part of the *Cladoceramus undulatoplicatus* Zone. The zone was recognized in the Ukrainian section of Dubivtsi II quarry (uppermost part of the first exploitation level up to the lower part of the second level).

Stensioeina perfecta–*Gavelinella vombensis* Concurrent-range Zone. This is the interval between the FO of the index taxon and the LO of *G. vombensis*. The zone spans the upper part of the *Cladoceramus undulatoplicatus* Zone, and upper boundaries of both zones seem to be coeval; the LO of *G. vombensis* Zone is thus a good foraminiferal proxy for the lower/middle Santonian boundary. The zone is best represented in the Ukrainian section of Dubivtsi II quarry (middle and upper parts of the second exploitation level) (see Dubicka and Peryt 2014).

Protostensioeina polonica Interval Zone. The base of the zone is defined by the LO of *G. vombensis* and its top by the LO of its index taxon. The zone spans the lowermost middle Santonian. It was best studied in the Ukrainian section of Dubivtsi II quarry (uppermost second and lowermost third exploitations levels) (see Dubicka and Peryt 2014).

Gavelinella praestelligera Interval Zone. Its base is defined by the FO of the index taxon, the oldest member of the *Gavelinella stelligera* lineage, and its upper boundary by the FO of *Gavelinella pertusa* (Marsson, 1878). The zone spans the middle part of the middle Santonian. It was best studied in the Ukrainian section of Dubivtsi II quarry (lower part of the third exploitation level).

Gavelinella pertusa Interval Zone. The zone ranges between the FO of the index taxon (base) and the FO of *Stensioeina gracilis* Brotzen, 1945 (top). The zone spans

the upper middle Santonian, and corresponds to the *Sphenoceramus pinniformis* inoceramid Zone. It was best studied in the Ukrainian section of Dubivtsi II quarry (middle part of the third up to the middle part of the fourth exploitation levels) (see Dubicka and Peryt 2014).

Stensioeina gracilis Interval Zone. The zone ranges between the FO of the index taxon (base) and the FO of *Bolivinooides strigillatus* (Chapman, 1892) (top). The zone corresponds to the lower part of the *Cordiceramus muelleri* inoceramid Zone, which defines the lower upper Santonian. It is best accessible in the Ukrainian section of Dubivtsi II quarry (upper part of fourth exploitation level) (see Dubicka and Peryt 2014).

Bolivinooides strigillatus Lineage Zone. The base of the zone is defined by the FO of the index taxon and its top by the FO of its descendant, *Bolivinooides culverensis* Barr, 1967. The zone spans the upper upper Santonian and basal Campanian (upper part of the *Cordiceramus muelleri* and basal *Sphenoceramus patootensiformis* zones). The zone is well accessible in the Ukrainian section of Dubivtsi II quarry (fifth and basal sixth exploitation levels) (see Dubicka and Peryt 2016) and in the Lipnik–Kije section, in the NE Nida Synclinorium.

Stensioeina pommerana Subzone. This is the subzone of the *B. strigillatus* Zone. It ranges between the FO of true *Stensioeina pommerana* Brotzen, 1936 and the FO of *B. culverensis*. The subzone is best accessible in the Ukrainian section of Dubivtsi II quarry (see Dubicka and Peryt 2016) and in the Lipnik–Kije section, in the Nida Synclinorium.

Bolivinooides culverensis Interval Zone. The base of the zone is defined by the FO of the index taxon and its top by the FO of *Gavelinella clementiana* (d’Orbigny, 1840). The zone corresponds to the basal Campanian (middle part of the *Sphenoceramus patootensiformis* inoceramid Zone). The zone is accessible in the Ukrainian section of Dubivtsi II quarry, as well as in the Zbyczyce section (see Dubicka and Peryt 2014, 2016) and in the Lipnik–Kije section (both in the Nida Synclinorium).

Gavelinella clementiana Interval Zone. The base of the zone is defined by the FO of the index taxon and its top by the FO of *Bolivinooides granulatus* Hofker, 1957. The zone corresponds to a part of the lower lower Campanian (upper part of the *Sphenoceramus patootensiformis* inoceramid Zone). It is exposed in the uppermost strata of the Ukrainian section of Dubivtsi II quarry (see Dubicka and Peryt 2014, 2016).

Bolivinooides granulatus–*Stensioeina gracilis* Concurrent-range Zone. The zone is characterised by the co-occurrence of the index taxa. It spans the middle lower Campanian (uppermost part of the *S. patootensisformis* and a lower part of the *Sphaeroceramus sarumensis*–*Cataceramus dariensis* zones) (*senonensis*, *conica/papillosa papillosa* and the lower part of *gracilis/mucronata* zones in the belemnite/echinoid zonation). The zone is well exposed in the Wierzchowisko, Bonarka–Tesco and Jeżówka 1 sections of the Nida Synclinorium (see Dubicka 2015).

Bolivinooides decoratus Partial-range Zone. The base of the zone is defined by the LO of *Stensioeina gracilis* Brotzen, 1945 and its top by the FO of *Gavelinella monterelensis* (Marie, 1941) and of the plano-convex morphotype of *C. voltzianus* (d’Orbigny, 1840) (*C. voltzianus* morphotype B – see Dubicka 2015). The index taxon appears slightly above the base of the zone. The zone corresponds to the *gracilis/mucronata* belemnite Zone. The top of the zone approximates the lower/upper Campanian boundary in the two-fold subdivision. It is known from the Mielnik I section of the Mazury–Podlasie Homocline (see Dubicka 2015).

Gavelinella monterelensis–*Gavelinella costulata* Concurrent-range Zone. The zone is defined by the co-occurrence of the index taxa. Early in the zone, the *Gavelinella stelligera* (Marie, 1941) morphotype D (planispiral; see Dubicka 2015) disappears. The zone approximates the *C. becumensis* inoceramid Zone, and the *conica/mucronata* echinoid/belemnite Zone. It is best exposed in the middle part of the Mielnik I section (Mazury–Podlasie Homocline) and in the upper part (above the hardground) of the Jeżówka 1 section (Nida Synclinorium) (see Dubicka 2015).

Gavelinella annae Partial-range Zone. The base of the zone is defined by the LO of *Gavelinella costulata* (Marie, 1941) and its top by the FO of *Globorotalites emdyensis* Vasilenko, 1961. It corresponds to the ‘*Inoceramus*’ *azerbaydjanensis* – ‘*Inoceramus*’ *vorhelmensis* inoceramid Zone. It is best represented in the upper part of the Mielnik I section (Mazury–Podlasie Homocline) and in the Rzeżuśnia section (Nida Synclinorium) (see Dubicka 2015).

Globorotalites emdyensis Interval Zone. This is the interval between the FO of the index taxon and the FO of *Bolivina incrassata* Reuss, 1851. Higher in the zone *Bolivinooides miliaris* Hiltermann and Koch, 1950 appears. The zone begins in the upper part of the ‘*Inoceramus*’ *azerbaydjanensis* – ‘*Inoceramus*’ *vorhelmensis* Zone,

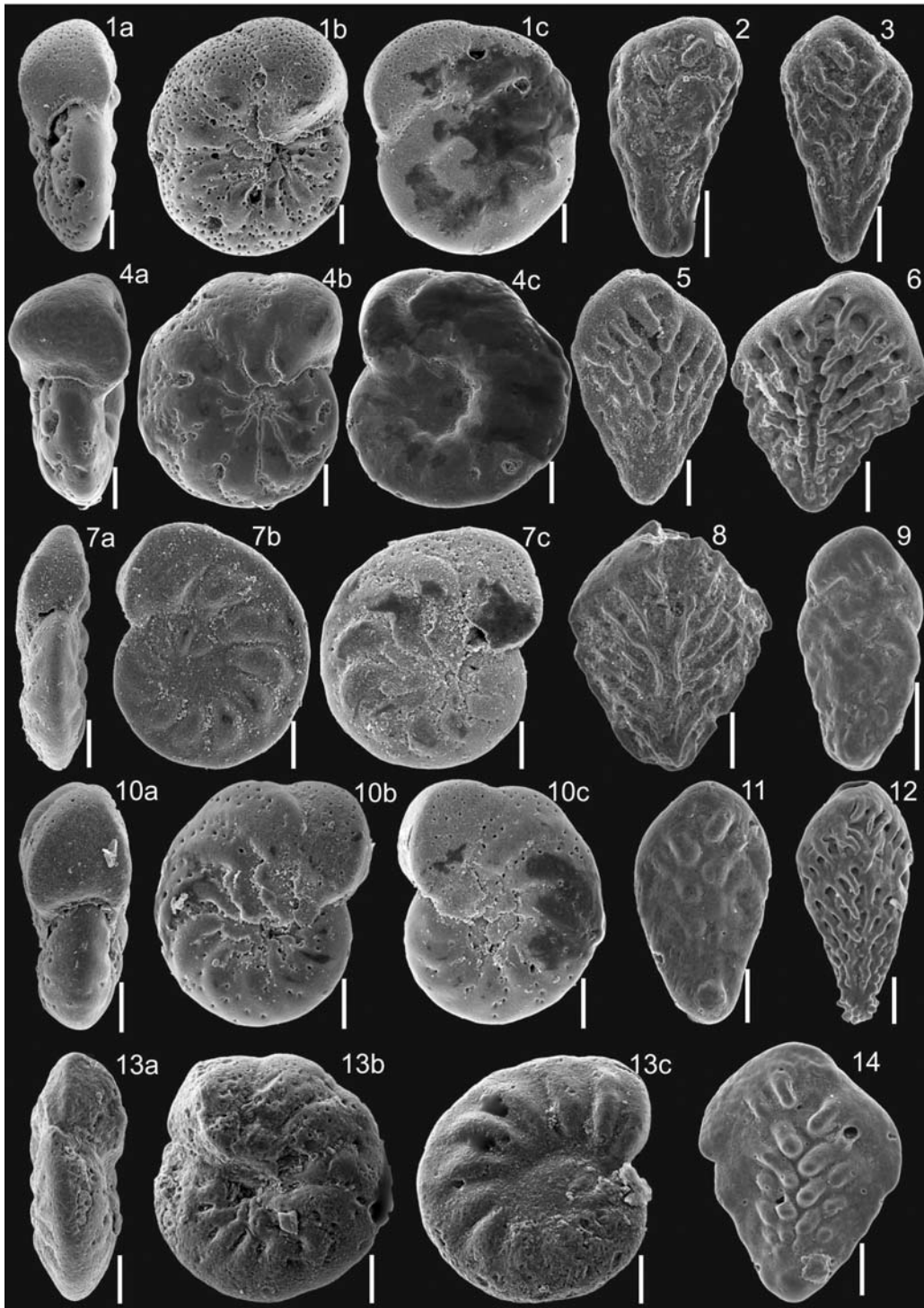
whereas its top coincides with the top of the *C. subcompressus* inoceramid Zone. This zone is exposed in the Sulejów and Dorotka section of the Middle Vistula River section.

Bolivina incrassata–*Globorotalites michelinianus* Concurrent-range Zone. The zone is defined by the co-occurrence of both index taxa. The lower part of the zone is additionally characterized by the occurrence of the relatively short-ranging taxon *Bolivinooides* sp. 1, followed by its successor *B. sidestradensis* in the middle part of the Zone. It corresponds to the ‘*Inoceramus*’ *tenuilineatus* inoceramid Zone and the lower part the *Didymoceras donezianum* ammonite Zone. It is best exposed in Leśne Chałupy, Ciszycza Kolonia and Ciszycza in the Middle Vistula River section (see Peryt and Dubicka 2015) and in the Szozdy section, Roztocze Hills.

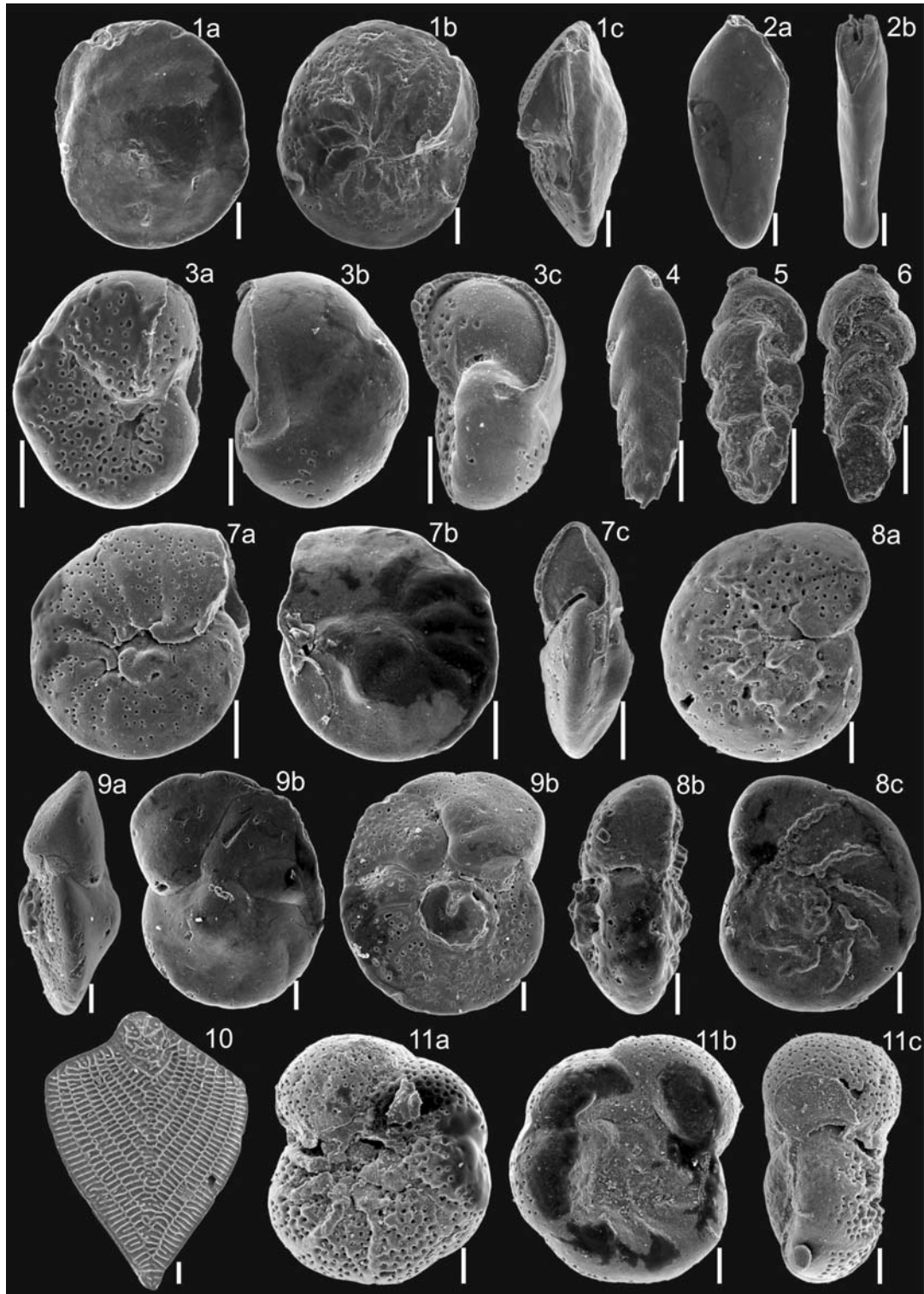
Bolivinooides miliaris Partial-range Zone. The base of the zone is defined by the LO of *Globorotalites michelinianus* (d’Orbigny, 1840) and its top by the FO of *Angulogavelinella gracilis* (Marsson, 1878). It corresponds to the lower part of the *Sphaeroceramus pertenuiformis* inoceramid Zone and the upper part of the *Didymoceras donezianum* ammonite Zone. The zone is known only from the Wola Pawłowska section of the Middle Vistula River section (see Peryt and Dubicka 2015).

Angulogavelinella gracilis–*Gavelinella monterelensis* Concurrent-range Zone. The zone is defined by the co-occurrence of both index taxa. *Bolivinooides intermedius* Dubicka and Peryt, 2016 appears in the zone. It corresponds to the lower part of the *Belemnitella najdini-Belemnitella posterior* belemnite Zone and to the upper part of the *Sphaeroceramus pertenuiformis* and the lowermost part of the ‘*Inoceramus*’ *altus* inoceramid zones. The zone is best exposed in the sections of Łopoczno and of the lowermost part of the Pawłowice Cementary of the Middle Vistula River section, as well as in the Gnatowice section of the Nida Synclinorium (see Peryt and Dubicka 2015).

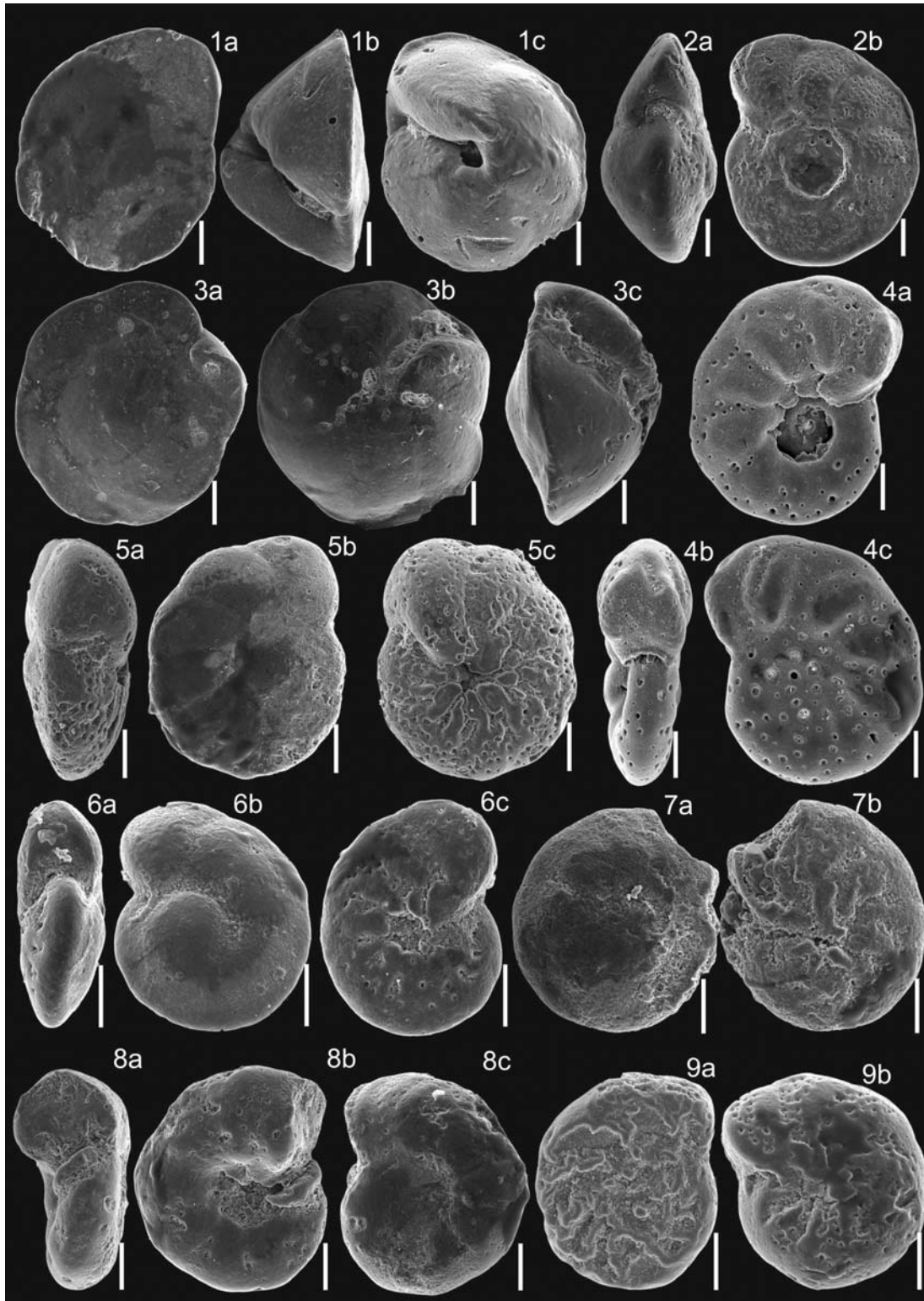
Bolivinooides intermedius Partial-range Zone. The base of the zone is defined by the LO of *Gavelinella monterelensis* (Marie, 1941), and its top by the FO of *Bolivina decurrens* (Ehrenberg, 1854). The zone spans the lower part of the *Nostoceras hyatti* ammonite Zone and most of the *Inoceramus altus* inoceramid Zone (except its basal part). It is best accessible in the lower third of Piotrawin Quarry and in the Pawłowice North section of the Middle Vistula River section (see Peryt and Dubicka 2015).



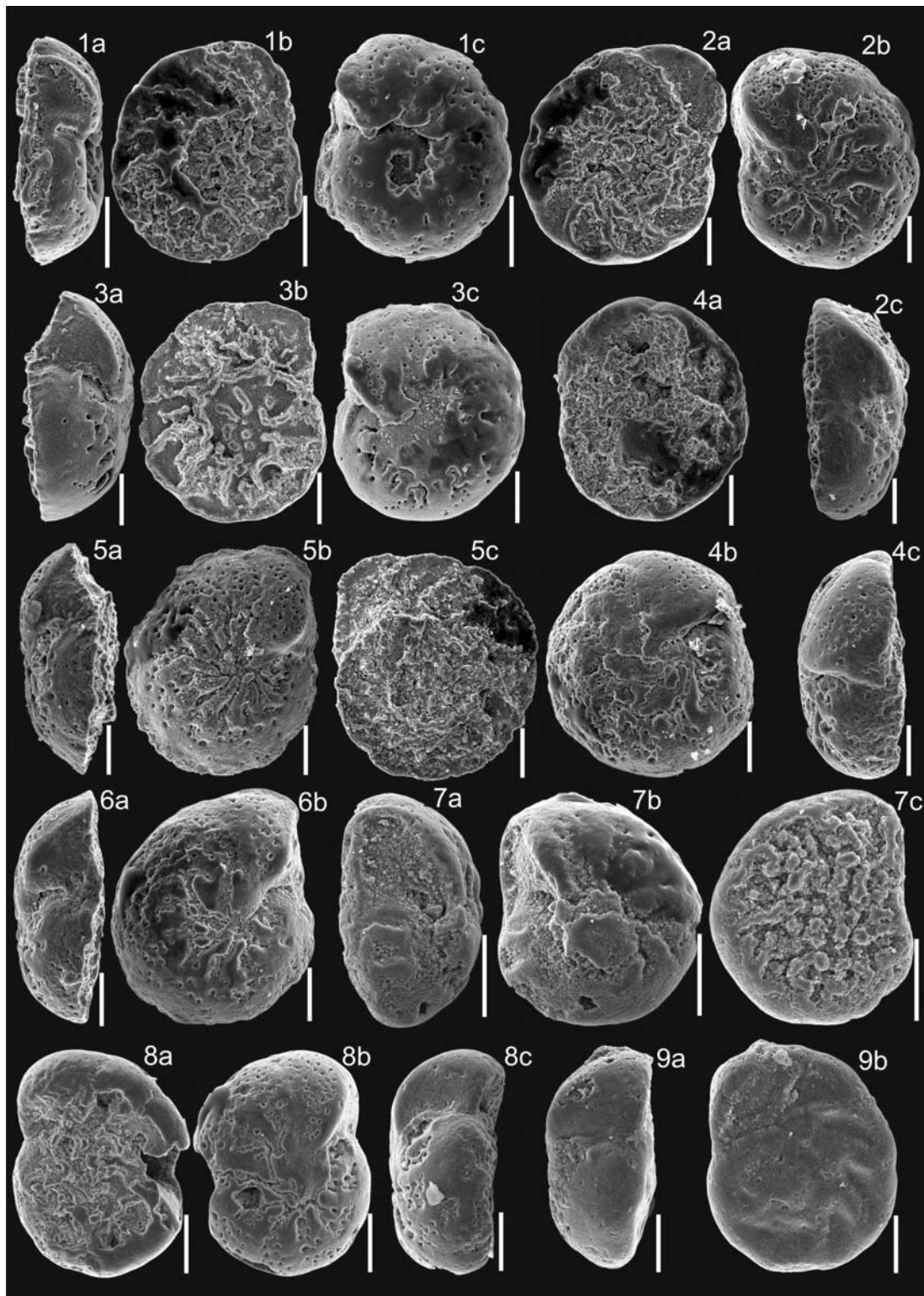
Text-fig. 5.1 – *Gavelinella costulata* (Marie, 1941), Mielnik, MWGUW ZI/67/36.32; 2 – *Bolivinoides strigillatus* (Chapman, 1892), Lipnik-Kije, MWGUW ZI/67/36.41; 3 – *Bolivinoides culverensis* Barr, 1967, Lipnik-Kije, MWGUW ZI/67/36.59; 4 – *Gavelinella lorneiiana* (d’Orbigny, 1840), Dubivtsi, MWGUW ZI/67/36.44; 5 – *Bolivinoides decoratus* (Jones, 1886), Mielnik, MWGUW ZI/67/36.30; 6 – *Bolivinoides intermedius* Dubicka and Peryt, 2016, Boiska, MWGUW ZI/67/36.07; 7 – *Gavelinella stelligera* (Marie, 1941) morphotype A, Mielnik, MWGUW ZI/67/36.31; 8 – *Bolivinoides draco* (Marsson, 1878), Kazimierz, MWGUW ZI/67/36.12; 9 – *Bolivinoides granulatus* Hofker, 1957, Wierchowisko, MWGUW ZI/67/36.33; 10 – *Gavelinella stelligera* (Marie, 1941) morphotype D, Mielnik, MWGUW ZI/67/36.13; 11 – *Bolivinoides laevigatus* Marie, 1941, Mielnik, MWGUW ZI/67/07.06; 12 – *Bolivinoides sidestrandensis* Barr, 1966, Mielnik, MWGUW ZI/67/24.16; 13 – *Gavelinella* sp. B (*praestelligera*) Dubicka and Peryt, 2014, Dubivtsi, MWGUW ZI/67/37.29; 14 – *Bolivinoides vistulae* Pożaryska, 1954 Lechówka, MWGUW ZI/67/36.10. Scale bars – 100 μ m



Text-fig. 6. 1 – *Angulogavelinella gracilis* (Marsson, 1878), Kłodzie, MWGUW ZI/67/36.02; 2 – *Bolivina incrassata* Reuss, 1851, Kłodzie, MWGUW ZI/67/36.04; 3 – *Anomalinooides gankinoensis* (Neckaja, 1948), Chełm, MWGUW ZI/67/36.35; 4 – *Bolivina decurrens* (Ehrenberg, 1854), Chełm, MWGUW ZI/67/36.56; 5 – *Eouvierina cretae* (Ehrenberg, 1854), Dubivtsi, ZPAL F63/32/38; 6 – *Eouvierina create* (Ehrenberg, 1854), Dubivtsi, ZPAL F63/29/48; 7 – *Gavelinella acuta* (Plummer, 1926), Chełm, MWGUW ZI/67/36.34; 8 – *Gavelinella clementiana* (d’Orbigny, 1840), Mielnik, MWGUW ZI/67/13.22; 9 – *Gavelinella monterelensis* (Marie, 1941), Dorotka, MWGUW ZI/67/36.01; 10 – *Neoflabellina reticulata* (Reuss, 1851), Chotcza, MWGUW ZI/67/36.18; 11 – *Gavelinella amae* (Pożaryska, 1954), Mielnik, MWGUW ZI/67/36.29. Scale bars – 100 μ m



Text-fig. 7. 1 – *Globorotalites michelinianus* (d'Orbigny, 1840) Dorotka, MWGUW ZI/67/36.08; 2 – *Cibicoides voltzianus* (d'Orbigny, 1840), Kłodzie, MWGUW ZI/67/36.03; 3 – *Globorotalites emdyensis* Vasilenko, 1961, Dorotka, MWGUW ZI/67/13.31; 4 – *Gavelinella pertusa* (Marsson, 1878), Mielnik, MWGUW ZI/67/36.28; 5 – *Gavelinella vombensis* (Brotzen, 1945), Dubivtsi, MWGUW ZI/67/36.14; 6 – *Gavelinella praeinfrasantonica* (Mjatluk), Dubivtsi, MWGUW ZI/67/36.52; 7 – *Gavelinella praeinfrasantonica* (Mjatluk, 1947), Dubivtsi, MWGUW ZI/67/36.53; 8 – *Gavelinella tumida* Brotzen, 1942 Dubovcy, MWGUW ZI/67/36.51; 9 – *Protostenioeina bohemica* (Jirová, 1958), Dubivtsi, MWGUW ZI/67/36.52 (a-b). Scale bars – 100 µm



Text-fig. 8. 1 – *Stensioeina exculpta* (Reuss, 1860), Dubivtsi, MWGUW ZI/67/36.27; 2 – *Stensioeina perfecta* Koch, 1977, Dubivtsi, MWGUW ZI/67/36.15; 3 – *Stensioeina pommerana* Brotzen, 1936, Boiska, MWGUW ZI/67/36.05; 4 – transitional form between *Stensioeina perfecta* Koch, 1977 and *Stensioeina pommerana* Brotzen, 1936, Dubivtsi, MWGUW ZI/67/36.22; 5 – *Stensioeina gracilis* Brotzen, 1945, Lipnik-Kije, MWGUW ZI/67/36.39; 6 – *Stensioeina* sp. A Dubicka and Peryt, 2014, Dubivtsi, MWGUW ZI/67/36.20; 7 – *Protostensioeina granulata* (Olbertz, 1942), Dubivtsi, MWGUW ZI/67/36.55; 8 – *Protostensioeina bohémica* (Jirová, 1958), Dubivtsi, MWGUW ZI/67/36.26; 9 – *Protostensioeina polonica* (Witwicka, 1958), Lipnik-Kije section, MWGUW ZI/67/38.02. Scale bars – 100 μ m

Bolivina decurrens–*Globorotalites emdyensis* Concurrent-range Zone. This zone is defined by the co-occurrence of both index species. It spans the middle part of the *Nostoceras hyatti* ammonite Zone and the lower part of the ‘*Inoceramus*’ *inkermanensis* inoceramid Zone. It is best exposed in the Sadkowice and Sadkowice North sections, as well as in the upper third of Piotrawin Quarry (all in the Middle Vistula River section) (see Peryt and Dubicka 2015).

Osangularia navarrona Partial-range Zone. This ranges between the LO of *G. emdyensis* and the FO of *Neoflabellina reticulata* (Reuss, 1851). The zone corresponds to the upper part of the ‘*Inoceramus*’ *inkermanensis* and ‘*Inoceramus*’ *costaecus* inoceramid zones. It spans the upper part of the *Nostoceras hyatti* ammonite Zone and the *Belemnella lanceolata* + *Belemnella inflata* belemnite zones. It is best accessible in the Raj, Raj North and Kamień sections and in the topmost part of the Piotrawin quarry of the Middle Vistula River composite section (see Peryt and Dubicka 2015).

Neoflabellina reticulata Interval Zone. The base of the zone is defined by the FO of the index taxon and its top by the FO of *Anomalinoidea gankinoensis* (Neckaja, 1948). In inoceramid terms, it ranges from the upper part of the ‘*Inoceramus*’ *redbirdensis* Zone to the lower part of the *Trochoceras radiusus* Zone. It is best exposed in the Kłudzie and Dziurków sections, of the Middle Vistula River section.

Anomalinoidea gankinoensis–*Angulogavelinella gracilis* Concurrent-range Zone. The zone is defined by the co-occurrence of both index species. It corresponds to the upper part of the *Belemnella occidentalis* Zone (sensu Błaszkiwicz 1980). It is known from the Ukrainian section of Kamyaniopil (‘Lvivskaya svita’ of Gavriliushin *et al.* 1991) and from the lower part of the Boiska section of the Middle Vistula River section (see Dubicka and Peryt 2012).

Bolivinoidea giganteus Interval Zone. The base of the zone is defined by the LO of *A. gracilis* and its top by a level of the temporal disappearance of *S. pommerana*. It corresponds to the basal part of the *Belemnella junior* belemnite Zone of the basal upper Maastrichtian. The zone was recorded in the Boiska and Jarentowskie Pole sections of the Middle Vistula River section (see Dubicka and Peryt 2012).

Gavelinella acuta Interval Zone. The base of the zone is defined by the temporal disappearance of *S. pommerana* whereas its top is marked by the FO of *Bolivi-*

noides draco (Marsson, 1878). It corresponds to the *Hoploscaphites constrictus lvivensis* ammonite Zone. The zone is known from the Chotcza and Lucimia sections of the Middle Vistula River section, as well as from the Chełm Quarry of the Lublin Upland (see Dubicka and Peryt 2011).

Bolivinoidea draco Interval Zone. The base of the zone is defined by the FO of the index taxon and its top by the FO of *Bolivinoidea vistulae* Pożaryska, 1954. It corresponds to the lower part of the *Hoploscaphites constrictus crassus* ammonite Zone. It is accessible in the Podgórz 1, Podgórz 2, and Dobre sections of the Middle Vistula River section.

Bolivinoidea vistulae Interval Zone. The base of the zone is defined by the FO of the index taxon and its top is marked by the disappearance of most of the Cretaceous planktonic foraminifers. The zone corresponds to the upper part of the *Hoploscaphites constrictus crassus* and *Hoploscaphites constrictus johnjagti* ammonite zones. It is exposed in the quarries of Kazimierz Dolny and Nasiłów in the Middle Vistula River section, and in the Mełgiew and Lechówka sections of the Lublin Upland (see Peryt and Dubicka 2012; Machalski *et al.* 2016).

Ammonite zonation (Z. Remin)

Paratexanites serratomarginatus Interval Zone. The base of the zone is defined by the FO of the index taxon. This taxon has not been found in Poland; however, the presence of the zone is confirmed by *Protexanites* (*Protexanites*) *bourgeoisianus* (d’Orbigny, 1850) accompanied by *Parapuzosia* (*Parapuzosia*) aff. *corbarica* (de Grossouvre, 1894). As indicated by Kennedy (1984) and Kennedy *et al.* (1995), the main occurrence of *P. (P.) bourgeoisianus* falls within the *P. serratomarginatus* Zone. Similarly, *P. (P.) corbarica* also first appears in this zone. The upper boundary of the zone is defined by the FO of *Texanites pseudotexanus* (de Grossouvre, 1894). This zone was best exposed in the temporary Lipnik–Kije section in the SW margin of the Holy Cross Mountains (Remin 2010).

Texanites pseudotexanus Interval Zone. The base of the zone is defined by the FO of its index taxon. In the Lipnik–Kije section the base of the zone is drawn at the FO of *T. cf. pseudotexanus*. This zone corresponds to the uppermost part of the *Magadiceramus subquadratus* and *Sphenoceras pachtii* inoceramid zones (Text-fig. 3). Its upper boundary is defined by the entry of *Kitchinites emscheris* Lommerzheim, 1995 and *Nowakites*

savini de Grossouvre, 1850, the event, which seems to coincide with the FO of *Cladoceramus undulatoplicatus* Roemer, 1852), the inoceramid marker of the base of the Santonian (Text-fig. 3). The *T. pseudotexanus* Zone was best exposed in the Lipnik–Kije section in the SW margin of the Holy Cross Mountains (Remin 2010); currently these ephemeral outcrops are no longer accessible.

Kitchinites emscheris–*Nowakites savini* Interval Zone. The base of the zone is defined by the FO of its index taxa. As its base correlates well with the FO of the inoceramid basal Santonian marker, *C. undulatoplicatus*, the base of the zone can be taken as the base of the Santonian Stage in ammonite terms. The zone corresponds to the lower and lower middle Santonian, the *Cl. undulatoplicatus* Zone and the lower part of the *Cordiceras* ssp. Zone, in inoceramid terms. It is an equivalent of the *K. emscheris* Zone of the Münsterland Cretaceous Basin, Germany (Kaplan and Kennedy 2000), and of the *Nowakites carezi* and *Texanites gallicus* sub-zones in Corbières, France (Kennedy *et al.* 1995).

Upper Santonian–*lower Campanian*. Because of the absence of stratigraphically important taxa no ammonite zones are distinguished in this interval.

Neancyloceras phaleratum Interval Zone. The base of the zone is defined by the FO of *Trachyscaphites spiniger spiniger* (Schlüter, 1872) and its top by the LO of the index taxon. Its upper boundary approximates the base of the succeeding *B. polyplacum* Zone. According to Błaszkiwicz (1980), the subspecies *posterior* (Błaszkiwicz, 1980) of *T. spiniger* ranges into *B. polyplacum* Zone. The *N. phaleratum* Zone corresponds to the lower part of the middle Campanian. In the Middle Vistula River section, it is accessible in the villages of Okół and Sulejów.

Bostrychoceras polyplacum Interval Zone. The base of the zone is defined by the FO of the index taxon, and its top by the FO of *Menuites portlocki posterior* (Błaszkiwicz, 1980). The index taxon ranges through the entire zone and, most probably, passes into the basal part of the *Didymoceras donezianum* Zone. The zone yielded also (according to Błaszkiwicz 1980): *Pachydiscus koeneni* de Grossouvre, 1894, *Menuites portlocki* (Sharpe, 1855), *Trachyscaphites pulcherrimus* (Roemer, 1841), *Hoploscaphites greenlandicus* (Donovan, 1953) and *Anapachydiscus wittekindi* (Schlüter, 1872). In the Middle Vistula River section, it is accessible between the villages of Sulejów and Dorotka. This zone is also accessible in some sections in the Roztocze Hills in SE Poland (Remin *et al.* 2015).

Didymoceras donezianum Interval Zone. The base of the zone is defined by the FO of *Menuites portlocki posterior* (Błaszkiwicz, 1980), and its top by the FO of *Jeletzkytes nodosus* (Owen) [= *Acanthoscaphites prequadriscopinosus* Błaszkiwicz, 1980 (see Kennedy *et al.* 1992)]. The index species dominates in the lower portion of the zone. The zone yielded also (according to Błaszkiwicz 1980): *Acanthoscaphites tuberculatus* (Giebel, 1849), *T. pulcherrimus*, *H. greenlandicus*, *Pachydiscus* cf. *oldhami* (Sharpe, 1855), and *A. wittekindi*. The zone is well exposed between the villages of Dorotka and Ciszycza in the Middle Vistula River section. The zone is also exposed in the Nida Synclinorium (Błaszkiwicz 1980; Jurkowska 2016) and in the Roztocze Hills (Remin *et al.* 2015).

Nostoceras hyatti [= *N. pozaryskii* of Błaszkiwicz, 1980] Interval Zone. The base of the zone is defined by the FO of *J. nodosus* and its top by the FO of *Pachydiscus neubergicus* (von Hauer, 1858). The index taxon first appears higher than *J. nodosus* and seems to range to the very top of the zone. In the Middle Vistula River section, it is accessible between the villages of Pawłowice and Raj, on the western bank and between Kamień and the Piotrawin Quarry, on the eastern bank of the river (Text-fig. 2). This zone is also accessible in selected locations in the Nida Synclinorium (Błaszkiwicz 1980; Jurkowska 2016) and in the Roztocze Hills in SE Poland (Remin, unpublished data).

Pachydiscus neubergicus Zone. The base of the zone is defined by the FO of the index species, and its top by the FO of *Acanthoscaphites tridens* (Kner, 1848) (compare Machalski 2012b). As noted by Machalski (2012a), the lowest well-localised specimen of *P. neubergicus* in the Middle Vistula River section comes from the bottom part of the Dziurków section, which corresponds to the lower part of the *Endocostea typica* inoceramid Zone (as recognized by Walaszczyk 2004). Loose specimens of *P. neubergicus* are known from Kłudzie and Kamień North, and come, most probably, from the upper part of the '*Inoceramus*' *redbirdensis* Zone (compare Machalski 2012b).

Acanthoscaphites tridens Zone. The base of this zone is defined by the FO of the index species sensu Kin (2010), i.e. comprising large representatives of *Acanthoscaphites* with siphonal tubercles, and excluding the stratigraphically older forms which lack siphonal tuberculation (compare Machalski 2012b). The top of the zone is marked by the FO of *Hoploscaphites constrictus lvivensis* Machalski, 2005. The zone was best exposed in Hrebenne, in the temporary excavations during

the constructions of the boundary post at the Polish-Ukrainian boundary. The part exposed belongs to the *Trochoceras radiosus* inoceramid Zone (Roztocze Hills, SE Poland) (Kin 2010). The zone is also available in the Bliżów section (Roztocze Hills area) in the upper part of the *E. typica* inoceramid Zone (Kin 2011). It is not exposed in the Middle Vistula River section (Machalski 2012b).

In the upper Maastrichtian, Machalski (2005b) recognized 13 scaphitid species/subspecies, with the newly named *H. constrictus lvivensis* and *H. c. johnjagti* Machalski, 2005. Machalski (2012b) used the chronosubspecies of *H. constrictus* to define three successive lineage zones. In ascending order, these are: *H. constrictus lvivensis* Zone, *H. c. crassus* Zone, and *H. c. johnjagti* Zone. As pointed out by Machalski (2005a, b; 2012b), the youngest member of the *H. constrictus* lineage, is expected to be the most important and useful ammonite proxy for the recognition of the topmost Maastrichtian. Other scaphitids of the interval, because of their limited occurrences and poor documentation, are of limited biostratigraphic use.

Hoploscaphites constrictus lvivensis Zone. The base of this zone is defined by the FO of the index subspecies and its top by the FO of *Hoploscaphites constrictus crassus* (Łopuski 1911) as defined by Błaszkiwicz (1980) and Machalski (2005b). It is documented in sections in eastern Poland (Chełm) and Ukraine (near Lviv) where it corresponds to the lower part of the *Belemnitella junior* Zone (*Spyridoceras tegulatus*–*Belemnitella junior* Zone *sensu germanico*; see Machalski 2005b; Dubicka and Peryt 2011). It seems that the base of the *lvivensis* Zone corresponds closely to the base of the upper Maastrichtian as understood herein (see discussion below).

Hoploscaphites constrictus crassus Zone. The base of this zone is defined by the FO of the index taxon and its top by the FO of *H. c. johnjagti*. The base of the zone is accessible in the locality Podgórz, in the Middle Vistula River section (Błaszkiwicz 1980; Machalski 2005b). It is widely distributed in central and eastern Poland (compare Machalski 2012b) and represents the highest ammonite zone recognized in the Middle Vistula River section (Machalski 2005a, b). The lower part of the zone is exposed in Kazimierz Dolny (Middle Vistula River section) and Rejowiec (eastern Poland), yielding *A. varians varians* (see Jagt *et al.* 1999; Machalski 2005b). The upper portion of the zone, as exposed in Nasiłów, was assigned to the *Menuites terminus* Taxon-range Zone (Machalski and Jagt 1998). In

belemnite terms it corresponds to the middle? and upper part of the *Belemnitella junior* Zone and to the almost whole *Belemnitella kazimiroviensis* Zone, albeit without the very last Maastrichtian levels. It is best exposed in the environs of Kazimierz Dolny, Bochońnica and Nasiłów, and Rejowiec in eastern Poland.

Hoploscaphites constrictus johnjagti Taxon-range Zone. This is the range zone of the index taxon. In Poland its top coincides with the top of the Maastrichtian stage (Machalski 2005b; 2012b). In Denmark and possibly in The Netherlands, this zone seems to extend into the basal Paleogene (compare Machalski 2012b). In Poland the zone is known from a single locality only, namely Mełgiew near Lublin (Machalski 2005b; 2012b). Machalski (2012b) suggested that *H. c. johnjagti* is of great potential for recognition of the terminal Maastrichtian in the Boreal Realm and possibly in Central Asia (Machalski 2005b; 2012b). In belemnite terms it corresponds to the very top of the *Belemnitella kazimiroviensis* Zone.

Menuites terminus Taxon-range Zone. This is the range zone of its index taxon. It is exposed in sections near Kazimierz Dolny and Nasiłów of the Middle Vistula River section (Machalski and Jagt 1998).

Belemnite zonation (Z. Remin)

The Santonian belemnite fauna is relatively rare. In the Vistula section belemnites are represented by the genera *Actinocamax* and *Goniotoothis*. *Actinocamax verus* seems to occur throughout the Santonian (Kongiel 1962; Błaszkiwicz 1980) and ranges into the lower Campanian (Błaszkiwicz 1980). Within the *G. granulata* lineage, Kongiel (1962) distinguished *G. westfalicagranulata* (Stolley, 1897), *G. pseudopropinqua* Kongiel, 1962, and *G. granulata* (Blainville, 1827), however he did not propose any formal zonation. Such a faunal composition supports the recognition of at least two standard zones, i.e. of *G. westfalicagranulata* and *G. granulata*, mainly in the middle and upper portions of the Santonian Stage (Kongiel 1962; Błaszkiwicz 1980).

Surprisingly, the Lipnik–Kije section, spanning the entire Santonian and basal Campanian, has not yielded any belemnite.

Lower Campanian. The Middle Vistula River section offers representatives of the genera *Actinocamax* and *Goniotoothis*. Błaszkiwicz (1980) distinguished the zones of *G. g. granulata* and of *G. quadrata* in this interval. According to the recent belemnite subdivision as

recognized in NW Europe (compare Christensen 1990, 1997a, b), the *G. g. granulata* Zone is late Santonian in age. The *G. quadrata* lineage may be subdivided into: *G. granulataquadrata* (Stolley, 1897), *G. quadrataquadrata* and *G. quadrata gracilis*. In a similar manner to the situation with the Santonian *G. granulata* lineage, Kongiel (1962) did not propose any subdivision based on the *quadrata* lineage. Both groups were, however, successfully applied to the biozonation of the Santonian and Campanian in NW Europe (see e.g., Christensen 1990, 1997a, b). *G. quadrata* sensu stricto is known from the lower Campanian of the Wierzchowisko section in the SW part of the Nida Synclorium (Jagt *et al.* 2004).

Belemnitella langei Interval Zone. The base of the zone is defined by the FO of the index taxon, and its top by the simultaneous FOs of *B. minor* I Jeletzky, 1951, *B. posterior* Kongiel, 1962, and *B. najdini* Kongiel, 1962. Only two *Belemnitella* species, i.e. *B. langei* and *B. mucronata* (Schlotheim, 1813) occur in this zone. In the Middle Vistula River section the lower boundary of the zone is not exposed. Its upper boundary is located between the Wola Pawłowska section and the base of the Pawłowice Cemetery section in the western bank of the river (see Text-fig. 3).

Belemnitella minor I Interval Zone. The base of the zone is defined by the FO of the index taxon or of *B. najdini* and *B. posterior*; its top is defined by the FO of *B. minor* II. Five *Belemnitella* species were recognized in this zone. In the Middle Vistula River section the lower boundary of the zone is not exposed, being located somewhere in an interval between the base of the succession exposed in the Pawłowice Cemetery section and the Wola Pawłowska section, in the western bank of the river. Its top is located between the Sadkowice N and Raj sections, and the entire succession exposed in the huge Piotrawin Quarry section belongs to this zone.

Belemnitella minor II Interval Zone. The base of the zone is defined by the FO of the index taxon; its top by LOs of *B. najdini* and *B. langei*. Five *Belemnitella* species have been recognized in this zone. In terms of the *Belemnella* zonation, the zone corresponds to the entire *Belemnella lanceolata* and *Belemnella inflata* zones. In the Middle Vistula River section the lower boundary is located in the Raj section, and its top is located at the “boundary marl”, well exposed in the sections of Podole, Kłudzie S and Kłudzie N, in the western bank of the river (Text-fig. 3).

Belemnitella najdini–*Belemnitella posterior* Concurrent

Range Zone. The base of the zone is defined by the FO of the index taxa or by the simultaneous entry of *B. minor* I; its top by the LO of *B. najdini* in addition to the LO of *B. langei*, which seem to disappear simultaneously. The upper part of this zone corresponds to the *Belemnella lanceolata* and *Belemnella inflata* zones.

Belemnella lanceolata Interval Zone. The base of the zone is defined by the FO of the index taxon; its top by the FO of *Belemnella inflata* (Arkhanelsky, 1912). In the Middle Vistula River section, the base of the zone is exposed at the top of the Raj section, and its upper boundary is located somewhere between the Raj and Raj N sections.

Belemnella inflata Interval Zone. Its base is defined by the FO of the index taxon; its top by the FO of *Belemnella obtusa* Schulz, 1979, or the entry of *B. vistulensis* (Kongiel, 1962). The zone is well documented in the Middle Vistula River section.

Belemnella obtusa Interval Zone. The FO of the index taxon or the entry of *B. vistulensis*, define the base of this zone. Its upper boundary is defined by the FO of *B. sumensis*. The zone is subdivided into the *Belemnella vistulensis*, *Belemnella* sp. G and *Belemnella* sp. F subzones defined as interval range subzones (see Remin 2012).

In the Middle Vistula River section, the base of the *B. obtusa* Zone is placed immediately above the “boundary marl”, well exposed at Podole, Kłudzie S and Kłudzie N, and the belemnite assemblages below and above this level differ significantly. Higher parts of the zone are exposed in the Dziurków and Przedmieście sections (Text-figs 1, 2). Its upper boundary is not exposed.

Upper lower Maastrichtian. The classic *Belemnella* zones distinguished in Germany by Schulz (1979), i.e., *Bln. sumensis* Jeletzky, 1949, *Bln. cimbrica* Birkelund, 1957, and *Bln. fastigata* Schulz, 1979, have not been recognized in the Polish sections yet, due to the lack of equivalent exposures. Provisionally, the *Bln. sumensis*/*Acanthoscaphites tridens* Zone was recognized in eastern Poland, i.e. in Hrebenne (Text-fig. 1), however, neither the upper nor the lower boundary of the zone could be studied.

Belemnitella junior Zone. The base of the zone is defined by the FO of its index taxon; its top by the FO of *Belemnella kazimiroviensis* (Skolozdrówna, 1932). In the Middle Vistula River section the base of the zone is exposed in the Boiska section, north of Solec. The top

is located in the environs of Męcimierz (Text-figs 1, 2). It is also available in few locations in the Lublin Uplands, i.e. at Pogórz and Chełm (compare Machalski 2005b).

Belemnella kazimiroviensis Zone. This is the youngest Maastrichtian belemnite zone. In the Vistula section, the base of the zone is exposed in the section of Męcimierz, south of Kazimierz Dolny, and its top is exposed further north in the Bochoznica and Nasilów sections (Text-fig. 2). Equivalent strata of the zone are also available further east in the Mełgiew and Rejowiec sections.

Inoceramid zonation (I. Walaszczyk)

The topmost Coniacian through Maastrichtian inoceramid biozonation, as applicable to the successions of extra-Carpathian Poland, is listed, defined and commented on shortly below. Most of the zones may be regarded as standard zones, applicable for the entire Euramerican biogeographic region. Others, however, are based on taxa with limited geographic distribution, or the understanding of the zones varies.

Magadiceramus subquadratus Interval Zone. The base of the zone is defined by the FO of the index taxon and its top by the FO of *Cl. undulatoplicatus*. The zone is potentially subdivided based on various morphotypes of Romer's species (treated usually as subspecies; the nominal one, *crenelatus* and *crenistriatus* – see e.g., Walaszczyk and Cobban 2006). This subzonal subdivision is not established in any section in Poland.

Cladoceramus undulatoplicatus Taxon-range Zone. This is the index taxon range zone. In Poland, the zone is poorly documented, however, it has been reported from the Lipnik-Kije section (Remin 2004) and from the North Sudetic Trough (Mitura *et al.* 1969; Milewicz *et al.* 1968; Milewicz 1988).

Cordiceramus cordiformis Partial-range Zone. The base of the zone is defined by the LO of *Cl. undulatoplicatus*, and its top by the FO of *Cordiceramus ex gr. muelleri*.

Cordiceramus muelleri Interval Zone. The base of the zone is defined by the FO of the zonal index species and its top by the FO of *Sphenoceramus patootensiformis* (Seitz, 1965) *lundbreckensis* (McLearn, 1929). The top of the zone should approximate to the base of the *Marsupites testudinarius* Zone, which is the crinoid-based topmost Santonian Zone. In extra-Carpathian Poland all inoceramid taxa are well documented.

Sphenoceramus patootensiformis Taxon-range Zone. This is the long-ranging zone of the index taxon, with a various sphenoceramids and *Cataceramus* species [*C. baltica* (Böhm, 1909) should start somewhere within the zone] present. The content and evolution of inoceramids within the zone is poorly understood.

Sphaeroceramus sarumensis-Cataceramus dariensis Interval Zone. The base of the zone is defined by the FO of any of the index taxa and its top by the FO of *Cataceramus beckumensis* (Giers, 1964). The zone was first documented in north German sections (Walaszczyk 1997) and recently in the Nida Synclinorium, in southern Poland (Jurkowska 2016).

Cataceramus beckumensis Interval Zone. The base of the zone is defined by the FO of the index species and its top by the FO of '*Inoceramus*' *azerbaydjanensis* (Aliev, 1939) and/or '*I.*' *vorhelmensis* Walaszczyk, 1997. The zone, well documented in the Westphalian sections (northern Germany) (Walaszczyk 1997), is poorly documented in Poland.

'Inoceramus' *azerbaydjanensis*–'*I.*' *vorhelmensis* Interval Zone. The base of the zone is defined by the FO of any of the index taxa and its top by the FO of *Cataceramus subcompressus* (Meek and Hayden, 1860) [= *C. haldemensis* (Giers, 1964)]. The zone is well documented in a number of sections in the Nida Synclinorium (Jagt *et al.* 2004; Walaszczyk *et al.* 2010; Jurkowska 2016).

Cataceramus subcompressus Partial-range Zone. The base of the zone is defined by the LO of members of the '*I.*' *azerbaydjanensis*–*vorhelmensis* group and its top by the FO of '*Inoceramus*' *tenuilineatus* Hall and Meek, 1856. The basal part of the zone is poorly documented; its upper part is best accessible at Dorotka in the Middle Vistula River section.

'Inoceramus' *tenuilineatus* Interval Zone. The base of the zone is defined by the FO of the index species and its top by the FO of *Sphaeroceramus pertenuiformis* Walaszczyk, Cobban and Harries, 2001. The zone is best exposed in the Kolonia Ciszycy and Ciszycy Górna parts of the Middle Vistula River section as well as in some sections of the Nida Synclinorium (see Jurkowska 2016).

Sphaeroceramus pertenuiformis Interval Zone. The zone begins at the FO of the index taxon and ranges to the FO of '*Inoceramus*' *altus* Meek, 1871.

'*Inoceramus*' *altus* Interval Zone. The base of the zone is defined by the FO of the index species and its top by the FO of '*Inoceramus*' *inkermanensis* Dobrov and Pavlova, 1959.

'*Inoceramus*' *inkermanensis* Interval Zone. The zone begins at the FOs of the species and its top is marked by the FO of '*Inoceramus*' *costaecus* Khalafova, 1966. The latter taxon was formerly referred to the genus *Trochoceramus* based on its radial ornament. It seems, however, that radial ornament appears independently in more than one lineage of the latest Campanian–early Maastrichtian inoceramids. Consequently, the species is left in open nomenclature.

'*Inoceramus*' *costaecus* Interval Zone. The zone begins at the FO of the index taxon and ranges till the FO of '*Inoceramus*' *redbirdensis* Walaszczyk, Cobban and Harries, 2001.

'*Inoceramus*' *redbirdensis* Interval Zone. This is the interval between the FOs of the index taxon and of *E. typica*. The Campanian–Maastrichtian boundary, as currently defined, is located in the upper part of this zone.

Endocostea typica Interval Zone. As defined herein, the zone may be treated as the range zone of its index taxon. *E. typica* is represented as the lower member of the *E. typica*–*E. barabini* lineage.

Cataceramus subcircularis Interval Zone. The base of the zone is defined by the LO of *E. typica*, and its top by the FO of *Trochoceramus radiosus* (Quaas, 1902). The zone is well represented in a number of sections of the Nida Synclinorium (see Jurkowska 2016) and in the Bliżów section, in eastern Poland.

Trochoceramus radiosus Taxon-range Zone. This is the range zone of the zonal index taxon. The zone was well documented in the village of Hrebenne, in eastern Poland (Kin 2010). The equivalent interval in the Middle Vistula River section is not exposed.

'*Inoceramus*' *ianjonensis* Taxon Range Zone. This is the taxon range zone of the index taxon. The zone has not been recognized in extra-Carpathian Poland yet.

Spyridoceramus tegulatus and *Tenuipteria argentea* zones. In Poland, the stratigraphy of tegulated inoceramids was intensively studied by Abdel-Gawad (1986). According to his data, correlated to the inoceramid zonation, as applied herein, *S. tegulatus* appears in the '*I.*' *redbirdensis* Zone, somewhere close to the

base of the Maastrichtian, as currently understood, and ranges high up into the *Belemnitella junior* Zone. The zone of *T. argentea* correlates approximately to the topmost Maastrichtian belemnite zone of *Bln. kazimiroviensis*, although the base of the inoceramid zone is not precisely indicated.

Echinoids (D. Olszewska-Nejbert)

The group may be used in the formal biozonation only for part of the succession discussed in the present paper. Consequently, instead of the consequent presentation of the biozonation, a discussion on critical taxa for the biostratigraphy of the Santonian through Maastrichtian of extra-Carpathian Poland is provided. The selected forms are illustrated (Text-figs 9–11).

Echinoids are useful biostratigraphically in the Campanian, mostly in its lower and middle substages. Their importance was documented, and the formal zonation based on selected lineages was worked out, in northern Germany (Ernst 1971; Ernst *et al.* 1979). The most important are holasteroids [*Offaster pilula* (Lamarck, 1816), *Galeola papillosa* (Leske, 1778), *Echinocorys* ex gr. *subglobosa/turrita*, *Echinocorys* ex gr. *conica* (Agassiz, 1847), *Echinocorys* ex gr. *gibba*], spatangoids [*Micraster* (*Gibbaster*) ex gr. *fastigatus/stolleyi*, *Micraster* (*Micraster*) ex gr. *schroederi/glyphus*] and rare echinoids of the genus *Galerites*.

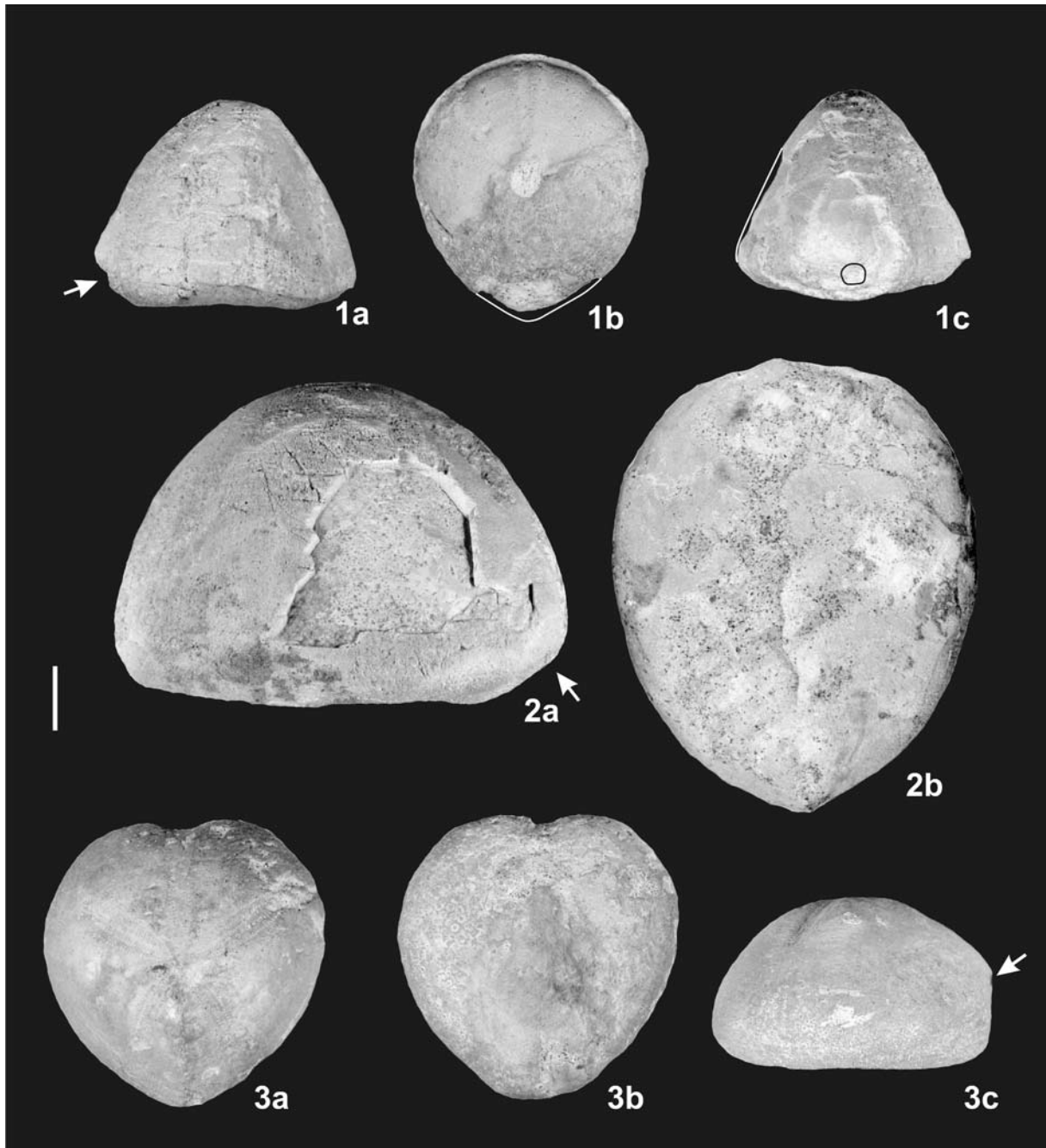
In the lower Campanian of Poland, *O. pilula* is best documented from the Nida Synclinorium (Text-fig. 10.2; Mączyńska 1989; Jagt *et al.* 2004), and reported also from the Middle Vistula section (Pożaryski 1938). This species is known in the western and central parts of the North European Province, and is restricted to the lower lower Campanian of Germany (Ernst 1971, 1975; Jagt *et al.* 2004; Schlüter and Wiese 2010), England and Northern Ireland (Smith and Wright 2003).

Also reported from the upper lower Campanian of the Nida Synclinorium are *G. papillosa* (see Mączyńska 1989; Jagt *et al.* 2004). A single specimen of this species was found also in the upper lower Campanian of Mielnik, eastern Poland (Text-fig. 10.3). This species represents the zonal form of the topmost lower Campanian of the North European Province (Ernst 1971; Jagt *et al.* 2004; Smith and Wright 2003; Schlüter and Wiese 2010).

Echinocorys ex gr. *conica* (L. Agassiz, 1847), which seems to represent the smallest specimens of the genus (Text-fig. 10.4–6), was recently reported from the Nida Synclinorium (Jagt *et al.* 2004), as well as from Mielnik (Olszewska 1987) and Kornica (Langner 1990) in eastern Poland. Synonymous with this species is *Echinoco-*

rys zejszneri Mączyńska, 1984, based on the material from the Nida Synclinorium (see remarks in Jagt *et al.* 2004). The *conica* group is biostratigraphically very useful for the lower–upper Campanian boundary interval (in the European two-fold subdivision) in the entire North European Province (Ernst 1972, 1975; Jagt 2000; Jagt *et al.* 2004; Smith and Wright 2003).

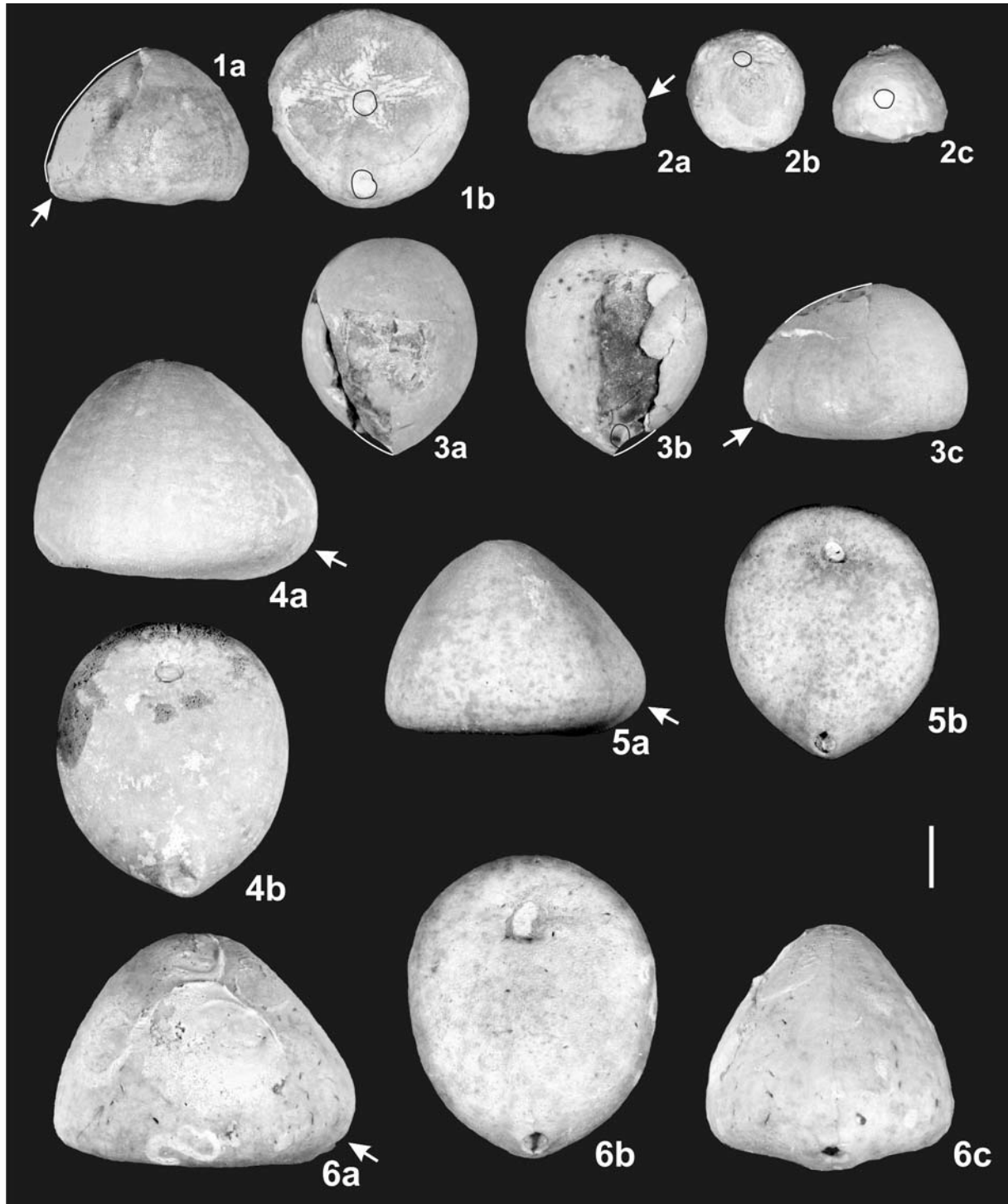
Another species, characteristic for the lower lower and lower middle Campanian is *Echinocorys* ex gr. *subglobosa* (Goldfuss, 1829) (Text-fig. 11.3). The group was reported from Rzeżuśnia in the Nida Synclinorium (Jagt *et al.* 2004), and dated for the '*Inoceramus*' *azerbaydjanensis* - '*I.*' *vorhelmensis* Zone (Jagt *et al.* 2004; see also Jurkowska 2016). The *Echinocorys turritus* of



Text-fig. 9. 1 – *Conulus albogalerus* (Leske, 1778), MWGUW ZI/77/001; base of (redeposited to) Upper Santonian, Korzkiew “Above the castle” outcrop, Nida Synclinorium; 2 – *Echinocorys* ex gr. *scutata* Leske, 1778, MWGUW ZI/77/018; “*vulgaris*” morphotype, base of (redeposited to) upper Santonian deposits, Korzkiew “U Krzywdy” outcrop, Nida Synclinorium; 3 – *Micraster (Micraster) malekii* (Hynda et Mączyńska, 1979) = *Micraster (Micraster) rogala* Nowak, 1909, MWGUW ZI/77/017; redeposited in the upper Santonian of the Wielkanoc section, Nida Synclinorium; scale bar is 1 cm

Mączyńska (1989), reported by her from the same area (see comments in Jagt *et al.* 2004), seems to be synonymous with this group. This group includes also the *E.*

pyramidatus of Mączyńska (1989), from the section of Chlina (a historical outcrop close to Jeżówka). Mączyńska's specimens differ clearly from the *E. pyra-*

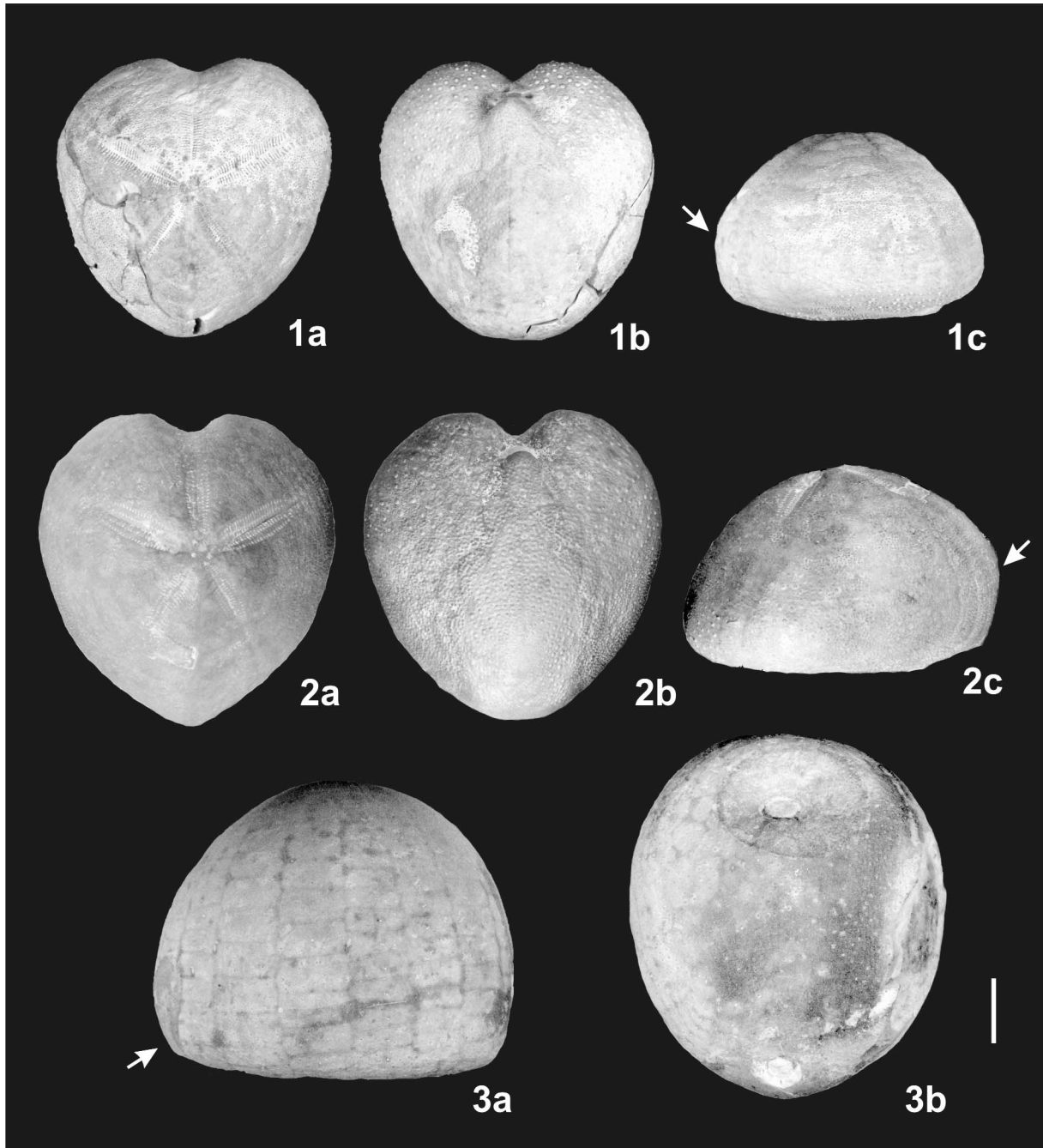


Text-fig. 10. 1 – *Galerites*, MWGUW ZI/77/020; lower lower Campanian, Poskwitów, Nida Synclinorium; 2 – *Offaster pilula* (Lamarck, 1816), MWGUW ZI/77/021; lower lower Campanian, Pychowice near Bonarka (Kraków), Nida Synclinorium; 3 – *Galeola papillosa* (Leske, 1778), MWGUW ZI/77/022; upper lower Campanian, Mielnik, Podlasie Homocline; 4–6 – *Echinocorys* ex gr. *conica* (AGASSIZ, 1847), 4 – MWGUW ZI/77/023, Mastomiąca, Nida Synclinorium, 5 – MWGUW ZI/77/034, Kornica, Podlasie Homocline; 6 – MWGUW ZI/77/039, Mielnik, Podlasie Homocline; scale bar is 1 cm

midata 'of authors' (Lambert 1903; Smiser 1935a,b; Jagt 2000; Jagt *et al.* 2004).

Micraster (Gibbaster) ex gr. *fastigatus/stolleyi* is another group, moderately well known, reported from the lower–lower middle Campanian of Poland (Text-fig. 11.1-2; see Jagt *et al.* 2004). Both *M. (Gibbaster)* *fasti-*

gatus and *M. (Isomicraster)* *stolleyi* were reported from a number of localities in the Nida Synclinorium (see Mączyńska 1968). This group, as understood herein, includes also *Micraster (Gibbaster)* *gibbus* of Mączyńska (1968), as well as her *Micraster (Isomicraster)* *dalloni* Lambert and *Micraster (Isomicraster)* *senonesis* Lambert.



Text-fig. 11. 1-2 – *Micraster (Gibbaster)* ex gr. *fastigatus/stolleyi*; 1 – MWG UW ZI/77/046, lower Campanian, Poskwitów, Nida Synclinorium, 2 – MWG UW ZI/77/047, lower upper (Middle) Campanian, Rzeżusnia, Nida Synclinorium; 3 – *Echinocorys* ex gr. *subglobosalturrita*; MWG UW ZI/77/045, lower upper (middle) Campanian, Rzeżusnia, Nida Synclinorium; scale bar is 1 cm

Another group of species, of more or less the same age, known from extra-Carpathian Poland, is the group of *Micraster* (*Micraster*) *schroederi/glyphus* (see Jagt *et al.* 2004). The following members of the group were described from various localities of the Nida Synclinorium by Mączyńska (1968, 1989): *Micraster* (*Micraster*) *schroederi schroederi*, *Micraster* (*Micraster*) *schroederi planus*, and *Micraster* (*Micraster*) *glyphus*. Moreover, her *Micraster* (*Micraster*) *brongiarti*, *M. (M.) bibicensis*, *M. (Paramicraster) cracoviensis*, *M. (P.) latior*, and *M. (P.)* sp. are regarded conspecific with *Micraster glyphus* (Stokes 1975; Jagt *et al.* 2004).

The echinoids in the Maastrichtian of extra-Carpathian Poland are still poorly documented, although known to occur continuously in all regions discussed herein. Rare hololectypoids, *Galerites vulgaris* (Leske) and *Galerites wollemanni* (Lambert), and a single specimen of *Echinocorys magnus* (Nietsch, 1921), are reported from the Nida Synclinorium (Mączyńska 1989) and from the Lublin area [Mączyńska's (1989) *E. magnus* may actually be *Echinocorys belgica* (Lambert, 1898), described originally from the lower Maastrichtian (Robaszyński *et al.* 2002) of Belgium and reported subsequently from the equivalent horizons of Norfolk (Peake and Hancock 1961, 1970)]. The two species described from the uppermost Maastrichtian of the Middle Vistula River section, i.e., *Echinogalerus bochotnicensis* Kongiel and *Hemicara pomeranum* Schlüter (see Mączyńska 1989), are poorly known indeed and require further study.

INTEGRATED BIO-CHRONOSTRATIGRAPHY

In the following, the discussion on the biostratigraphic constraints of stage and substage boundaries of the Santonian through Maastrichtian of extra-Carpathian Poland is provided. The discussion is not intended to be a general one on the stage boundaries and presents rather the state of bio-chronostratigraphic recognition of this interval in Poland.

Coniacian/ Santonian boundary

This boundary is formally defined with the FO of the inoceramid species *Cladoceramus* (or *Platyceramus* as interpreted by others) *undulatopticatus* (see Lamolda and Hancock 1996). Its stratotype section in the eastern border of the 'Cantera de Margas' quarry, Olazagutia, in northern Spain, was recently approved by the International Subcommission on Cretaceous

Stratigraphy and ratified by the International Union of Geological Sciences in January 2013 (Lamolda *et al.* 2014). The FO of *Cl. undulatopticatus* is widely recognized within the entire Euramerican biogeographic region (e.g., Seitz 1961; Gale *et al.* 2007; Lamolda *et al.* 2014), and was documented in the Lipnik–Kije section, southern Poland (Remin 2004), and in the Ukrainian section of Dubivtsi (e.g., Remin *et al.* 2016). *Sphenoceramus* ex gr. *pachti-cardissoides*, the traditional inoceramid marker of this boundary (see e.g., Błaszczewicz and Szymakowska 1984, 1989; Błaszczewicz 1997) appears first slightly lower, in the uppermost Coniacian *Magadiceramus subquadratus* Zone. With the exception of some sphenoceramids, which cross the boundary unchanged, there is an almost total taxonomic turnover in inoceramid faunas at the boundary level (see e.g., Tröger 1974; Walaszczyk and Cobban 2006, 2007).

In foraminiferal terms, the base of the Santonian lies within the zone of *Protostenioeina bohémica*. At the upper boundary of the *P. bohémica* Zone all other members of the *P. granulata* group disappear, including *Protostenioeina* sp. E. The same assemblage of *Protostenioeina* was also reported from the Coniacian–Santonian boundary of the Seaford Head section (Hampton *et al.* 2007; Howe *et al.* 2007) [although two of the species reported by Howe *et al.* (2007) were incorrectly determined: their *Stensioeina granulata granulata* (fig. 6, Y-AA) should be *Protostenioeina bohémica* whereas their *Stensioeina granulata inconstita* (fig. 6, BB-DD) is *Protostenioeina* sp. E.]

The FO of *Protostenioeina polonica*, the traditional marker of the base of the Santonian (see e.g., Witwicka 1958; Koch 1977, Pożaryska and Witwicka 1983, Gawor-Biedowa *et al.* 1984; Hart *et al.* 1989) is thus older and is actually latest Coniacian [as also documented in the Staffhorst Shaft section, northern Germany (Niebuhr *et al.* 1999), and in southern England (Bailey *et al.* 1983; Hampton *et al.* 2007; Howe *et al.* 2007)].

The ammonites at the Coniacian–Santonian transition are well documented from the Lipnik–Kije section, which yielded a diverse ammonite fauna, as well as inoceramids (Walaszczyk 1992; Remin 2004, 2010). The base of the Santonian corresponds to the boundary between the *Texanites pseudotexanus* Zone of the upper Coniacian and the *Kitchinites emscheris–Nowakites savini* Zone dated for the lower Santonian (Remin 2010).

In extra-Carpathian Poland, the Coniacian–Santonian boundary is directly available only in the Kije–Lipnik section (Remin 2004) and in the Ukrainian section of Dubivtsi (Dubicka 2012; Dubicka and Peryt 2014, 1016; Remin *et al.* 2016).

Santonian substages

There are no formally defined substages of the Santonian, however, a three-fold subdivision was recommended during the Brussels Symposium (see Lamolda and Hancock 1996). Among the biostratigraphic groups, discussed in Brussels as a potential Santonian substage marker, inoceramids are inevitably best represented in extra-Carpathian Poland. Consequently, and in accord with some previous proposals (see e.g., Niebuhr *et al.* 1999), the base of the middle and of the upper Santonian substages are defined here at a level of the LO of *Cl. undulatopectatus* and the FO of *Cordiceras muelleri* respectively. Both events are easily recognizable throughout at least the entire Euramerican Biogeographic Region (see e.g., Walaszczyk and Cobban 2006, 2007).

In foraminiferal terms, the base of the middle Santonian is close to the LO of *Gavelinella vombensis* (= *Gavelinella arnagerensis* Soliakius in the Anglo-Paris Basin). In equivalent stratigraphic positions, this event was also recognized in: (1) Lägerdorf, western Germany (Schönfeld 1990), at the boundary between the *coranguinum*/*westfalica* and *rogalae*/*westfalica* zones (see Schultz *et al.* 1984); and (2) Seaford Head of southern England (Hampton *et al.* 2007), c. 2 m above the LO of *Cl. undulatopectatus*. The base of the upper Santonian seems to be best defined by the FO of *Stensioeina gracilis* (see also the Staffhorst section, northern Germany, Niebuhr *et al.* 1999). The FO of *S. gracilis* at or close to the middle/upper Santonian boundary, as defined by the FO of the crinoid *Uintacrinus socialis* was also recorded in various West European localities (Koch 1977; Bailey *et al.* 1983; Schönfeld 1990; Hampton *et al.* 2007).

The belemnites of the *G. granulata* lineage [in ascending order: *G. praewestfalica* Ernst and Schulz, 1974, *G. westfalica westfalica* (Schlüter, 1876), *G. westfalica granulata* (Stolley, 1897) and *G. granulata* (Blainville, 1827)] are potentially of use in the Santonian subdivision (e.g., Christensen 1990, 1997a, b). The group is, however, poorly represented in the Santonian of extra-Carpathian Poland, with no reliable record available. Similarly, no ammonite proxies for the Santonian substages can be suggested.

The echinoids of the genera *Conulus*, *Echinocorys* and *Micraster* [e.g. *Conulus albogalerus*, *Echinocorys* ex gr. *scutata*, *Micraster maleckii* sensu Hynda and Mączyńska=*M. rogalae* in authors' concept] (Text-fig. 9) are potentially useful biostratigraphical proxies for the Santonian subdivision. The knowledge of their evolution and vertical ranges is, however, still insufficient to be practically applied.

In extra-Carpathian Poland, the Santonian succession is available in the railroad-cut section at Kije (see Walaszczyk 1992; Remin 2004). Other sections, with a rich and relatively complete palaeontological record of the stage, adding markedly to our data, are the Dubivtsi quarries in western Ukraine (SE of Lviv) (Dubicka 2012; Remin *et al.* 2016).

The Santonian–Campanian boundary

Although the Santonian–Campanian boundary has not been formally accepted yet, it is commonly defined by the extinction event of the crinoid *Marsupites testudinarius*. The boundary marker is well represented in numerous localities in Poland, mostly in the Nida Synclinorium (Roemer 1870; Smoleński 1906; Panow 1934; Kowalski 1948; Barczyk 1956; Walaszczyk 1992; Remin 2004).

The belemnite species *Goniotethis granulata quadrata*, which was shown to have its FO approximately coeval with the *Marsupites* datum (Ernst 1964), has not been studied in extra-Carpathian Poland, and there is no section that potentially could yield necessary material. Similarly, there is no good ammonite marker of this boundary (see discussion in Hancock and Gale 1996; see also comments in Walaszczyk 1992 about this boundary in southern Poland).

Inoceramids are very common in the boundary interval (see monographic description of the Santonian and lower Campanian inoceramids from northern Germany by Seitz 1961, 1965, 1967), however, none of the lineages give a firm biostratigraphic data. Walaszczyk (1992), based on the record from the Lipnik–Kije section, suggested that a morphotype that could be a good proxy of the base of the Campanian appears close to the boundary. He compared it to *Sphenoceras alexandrovi* (Bodylevski, 1959). This record from Lipnik–Kije has never been confirmed by finds from other sections.

In foraminiferal terms, this boundary is placed in the upper part of the *Bolivinoidea strigillatus* Zone, slightly above the FO of true *S. pommerana* (possessing an umbilicus completely covered by wide flaps or plug) and below the FO of *B. culverensis* followed by the consistent occurrence of *Gavelinella* ex. gr. *clementiana*. The FO of *S. pommerana* corresponds stratigraphically to the coeval event recorded in the Lägerdorf section (north-western Germany), where it is marked within the *testudinarius/granulata* Zone, c. 3 m below the base of the Campanian (Schönfeld 1990). The FO of *B. strigillatus*, the oldest species of the *Bolivinoidea* lineage, has been variably dated as late Santonian or earliest Campanian (White 1929; Cushman 1927; Edgell 1954; Reiss 1954; Koch 1977; Barr 1966,

1970; Akimetz *et al.* 1983; El-Nady 2006; Petters 1977; Dubicka and Peryt 2016). However, in stratigraphically well-labelled successions it is consistently dated as latest Santonian (Barr 1970; Koch 1977; Akimetz *et al.* 1983; Hart *et al.* 1989; Schönfeld 1990; Niebuhr *et al.* 1999; Hampton *et al.* 2007). Accordingly, this event can be regarded as a good proxy of the latest Santonian. Additionally, the geographic range of this event may appear extensive, as *Bolivinooides* is characterized by its worldwide distribution (Dubicka and Peryt 2015 and literature cited therein) [The reason for such a wide and rapid dispersion of these foraminifera could be either their planktonic larvae or propagules (Alve 1999; Alve and Goldstein 2003, 2010) or tychopelegic mode of life (Darling *et al.* 2009; Dubicka in preparation)].

The best accessible section of the Santonian–Campanian boundary is near the village of Kije, in the north-eastern part of the Nida Synclinorium (Walaszczyk 1992; Remin 2004). There are a number of sections in the south-western margin of the Nida Synclinorium, however, where these sections are strongly reduced/condensed (see summary in Walaszczyk 1992).

Campanian substages

In Europe, the Campanian stage was divided traditionally into two substages, with the boundary between them characterized by the significant change within the belemnite fauna, namely the extinction of the genus *Goniotoothis* and the appearance of the *Belemnitella mucronata* lineage, with a short-lived overlapping of their ranges. The boundary has been usually placed at the LO of *Goniotoothis* (e.g., Jeletzky 1958; Schultz 1978; Ernst *et al.* 1979; Schulz *et al.* 1984).

In foraminiferal terms, the base of the upper Campanian (in the traditional European two-fold subdivision) lies at the base of the *Angulogavelinella gracilis*–*Gavelinella monterelensis* Zone with an almost simultaneous appearances of *Gavelinella monterelensis* and *C. voltzianus* (plano-convex morphotype) (Dubicka 2015). In an equivalent stratigraphic position, these events were also recognized in southern England (Bailey *et al.* 1983).

Because of the significant longevity of the stage, following the discussion during the Brussels' 1995 Symposium, a three-fold subdivision, into the lower, middle and upper substages, was recommended (Hancock and Gale 1996). However, there are no formal proposals yet for substage definitions or their stratotypes (see Ogg and Hinnov 2012), and authors, if they wish to use the threefold subdivision in Europe, apply the US Western Interior ammonite-based subdivision of Cobban (1994; see also Cobban *et al.* 2006), with the mid-

dle and upper substages placed at the FO of *Baculites obtusus* Meek, 1876 and *Didymoceras nebrascense* (Meek and Hayden 1856) respectively. The lack of the North American ammonites in Europe precludes direct trans-Atlantic correlation. However, there are still some ammonites in common, and moreover, inoceramid bivalves appear very useful in such a correlation.

The base of the North American middle Campanian, in terms of inoceramids, is located within the lower part of the 'I.' *azerbaydjanensis*–*vorhelmensis* Zone. This inoceramid zone corresponds to the *stobaei/basiplana-vulgaris/basiplana* zone (see Jagt *et al.* 2004; Walaszczyk *et al.* 2008a). Consequently, it seems that the base of the *B. obtusus* Zone, marking the base of the middle Campanian in the US Western Interior, corresponds to the base of the *stobaei/basiplana* Zone in Europe, or slightly higher. It is slightly higher than the base of the European traditional upper Campanian. The base of the middle Campanian would correspond also to the base of the ammonite zone of *Trachyscaphtes spiniger*, which also appears in the *stobaei/basiplana* Zone (see e.g., Ernst *et al.* 1979; Schultz *et al.* 1984). There is no precise belemnite proxy. In benthic foraminiferal terms, this boundary is coeval with the base of the zone of *Gavelinella annae*. The base of the North American middle Campanian is thus clearly higher stratigraphically than the base of the European upper Campanian; actually both boundaries differ about the zone of *conica/mucronata*. The difference is bigger, when the base of the European upper Campanian is placed at the FO of *Belemnitella mucronata*, which appears one zone earlier, marking the base of the *gracilis/senior* [= *gracilis/mucronata*] Zone.

The position of the base of the North American upper Campanian within the European succession defined with the FO of *D. nebrascense*, can again be determined by inoceramids. In inoceramid terms, this boundary is located in the upper part of the 'I.' *tenuilineatus* Zone, which corresponds to a middle part of the *Didymoceras donezianum* ammonite Zone. This position is not well constrained at all and, if the position of this boundary is retained, further studies on this part of the succession are needed. In terms of benthic foraminifera, this boundary should be located roughly within the *B. incrassata*–*G. michelinianus* Zone. Of interest may be a number of appearance/disappearance events within this zone, with the FOs of *G. acuta* and *B. sidestrandensis*, and the LO of *Bolivinooides* sp. 1 ('*prae*' *sidestrandensis*). There is no good belemnite or echinoid proxy recognized in this interval.

The middle–upper Campanian succession is best exposed in the Middle Vistula River section (Błaszkiwicz 1980; Walaszczyk 2004; Remin 2012,

2015). It is also accessible and well exposed in the Nida Synclinorium (Jagt *et al.* 2004; Jurkowska 2016) and in the Mielnik section, in eastern Poland (Olszewska 1990).

The Campanian–Maastrichtian boundary

According to the formal definition, the base of the Maastrichtian stage is defined as an arithmetic mean of 12 bio-events (FOs and LOs of various micro- and macrofossils) and placed at level 115.2 m of the boundary stratotypic section at Tercis les Bains (near Dax, Landes) in SW France (Odin 2001; Odin and Laumurelle 2001). Its correlation to Poland is based on inoceramid bivalves and ammonites, and placed in the upper part of the inoceramid '*I.* *redbirdensis* Zone (Walaszczyk 2004) and in the basal part of the range of the ammonite *Pachydiscus* (*Pachydiscus*) *neubergericus* (see Machalski 2012). In belemnite terms the boundary approximates to the base of the zone of *Belemnella vistulensis* or *Belemnella obtusa* (see Remin 2012; Keutgen *et al.* 2012). This newly defined boundary is distinctly higher than the traditional European (=Boreal) definition of the base of the Maastrichtian Stage, located at the FO of the belemnite *Belemnella lanceolata* (e.g. Arkhangelsky 1912; Jeletzky 1951a,b).

There is no precise proxy of this boundary among benthic foraminifera. Nevertheless, the FO of *Neoflabellina reticulata* (Reuss, 1851) was recognised close to this boundary (see also Hart *et al.* 1989; Schönfeld 1990; Olferiev *et al.* 2007) and was even recommended as the secondary foraminiferal stage criterion for the base of the Maastrichtian during the Brussels' 1995 Symposium (Odin 1996). In the Campanian–Maastrichtian boundary succession of the Middle Vistula River section (Walaszczyk 2012), this event was recorded from the basal part of the Kłudzie section (Peryt and Dubicka 2015), dated to the *Belemnella inflata* Zone, which is the topmost Campanian belemnite zone in the present subdivision (see Remin 2012), and within the '*I.* *redbirdensis* inoceramid Zone which comprises the boundary (Walaszczyk 2004). The former report of *N. reticulata* from the Piotrawin succession (Peryt 2000), dated to a distinctly older level ('*I.* *inkermanensis* Zone), results from differences in the taxonomic concepts applied to this foraminifer; for, into the concept of *N. reticulata*, Peryt (2000) also included *N. praereticulata*, its evolutionary ancestor.

The Campanian–Maastrichtian boundary is well exposed in a series of sections around the town of Solec, in the Middle Vistula River section (Walaszczyk 2012).

The recent studies on the succession add much to the general knowledge of this interval (Remin 2012, 2015; Machalski 2012; Keutgen *et al.* 2012; Świerczewska-Gładysz 2012; Peryt and Dubicka 2015; Plasota *et al.* 2015). It is also easily accessible in the Nida Synclinorium (Jurkowska 2016).

Maastrichtian substages

In northern and central Europe, the base of the upper Maastrichtian is traditionally placed at the FO of *Belemnella junior* (Nowak, 1913) and the boundary is defined accordingly in extra-Carpathian Poland (Błaszkievicz 1980; Machalski 2005a, b). This level correlates closely to the base of the zone of *Anapachydiscus fresvillensis*, the commonly accepted ammonite marker of the upper Maastrichtian (see e.g., Ward and Kennedy 1993; Odin 1996). However, the extinction of 'true' inoceramids, quoted often as a good proxy of this boundary (Odin 1996) took place distinctly later (see e.g., Walaszczyk *et al.* 2009, 2010). This latter event, however, is well recorded in Europe, South Africa, and seemingly also in the North American Western Interior, being potentially a very good marker of the upper Maastrichtian (Walaszczyk *et al.* 2008b).

In foraminiferal terms, this boundary is located close to the LO of *Angulogavelinella gracilis*, the event which defines the boundary between the *A. gankinoensis*–*A. gracilis* and *B. giganteus* zones. The level is also slightly below the temporary disappearance of the genus *Stensioeina*. The lack of *A. gracilis* through almost the entire upper Maastrichtian of extra-Carpathian Poland was recognized by Pożaryska (1954) and Gawor-Biedowa (1992), and earlier it was reported from Sweden and north-western Germany (Brotzen 1945). Similarly, the temporary disappearance of stensioeoinids in the earliest late Maastrichtian of Poland was previously reported by Witwicka (1958) and Gawor-Biedowa (1992); this event was also recognized from western and eastern Germany (Koch 1977; Frenzel 2000; Reich and Frenzel 2002) and from Russia (Naidin *et al.* 1984).

In extra-Carpathian Poland, the lower–upper Maastrichtian boundary interval is poorly exposed.

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