BOLIVINOIDES (BENTHIC FORAMINIFERA) FROM THE UPPER CRETACEOUS OF POLAND AND WESTERN UKRAINE: TAXONOMY, EVOLUTIONARY CHANGES AND STRATIGRAPHIC SIGNIFICANCE

ZOFIA DUBICKA¹ AND DANUTA PERYT²,³
BOLIVINOIDES (BENTHIC FORAMINIFERA) FROM THE UPPER CRETACEOUS OF POLAND AND WESTERN UKRAINE: TAXONOMY, EVOLUTIONARY CHANGES AND STRATIGRAPHIC SIGNIFICANCE

ZOFIA DUBICKA1 AND DANUTA PERYT2,3

ABSTRACT

The taxonomy of Late Cretaceous genus Bolivinoides is revised on the basis of rich, newly collected material from central and eastern Poland and western Ukraine. Twelve species are described of which one is new: Bolivinoides intermedius nov. sp. This species differs from the other bolivinoidid taxa in possessing two parallel medial rows of tubercles. The stratigraphic ranges of most of the taxa are compared with the macrofossil standard zonation, which allowed a correlation with the occurrence of bolivinoidids of distinct regions of Europe and other continents. The evolutionary trends of Bolivinoides are also discussed and two distinct lineages, Bolivinoides strigillatus and Bolivinoides laevigatus, are distinguished.

INTRODUCTION

The Late Cretaceous–Early Paleocene foraminiferal genus Bolivinoides Cushman is a unique group of benthic foraminifera. In contrast to most other benthic foraminiferans, it has a very broad, nearly global distribution in shelf sediments. Representatives of Bolivinoides have been reported from, for example, northwestern Europe (Hofker, 1962), England (Barr, 1966), Poland (Pozaryska, 1954; Bieda, 1958; Witwicka, 1958; Gawor-Biedowa, 1992), Belarus (Akimets, 1961), Ukraine (Kaptarenko-Chernousova et al., 1979), Kazakhstan (Vasilenko, 1961), Libya (Barr, 1970), Israel (Reiss, 1954), Egypt (Khalil, 1998), Texas (Frizzell, 1954), Mexico (Cushman, 1927), Trinidad (Beckmann & Koch, 1964), the Atlantic Coastal Plain (Petters, 1977), southern Chile (Martinez-Pardo, 1965), western Australia (Edgell, 1954; Belford, 1960) and New Zealand (Finlay, 1940).

The evolution and speciation of Bolivinoides was relatively rapid, and the stratigraphic ranges of many species seem to be very similar around the world. Accordingly they have been widely used as a biostratigraphic tool for almost worldwide correlation of Santonian–Maastrichtian strata. A series of important studies on Bolivinoides, presenting many aspects of its evolution and stratigraphic value, were published mainly between 1950 and 1980 (e.g., Hiltermann & Koch, 1955, 1960, 1962; Hiltermann, 1952, 1963; Pozaryska, 1954; Schmid, 1955; Hofker, 1958; Vasilenko, 1961; Beckmann & Koch, 1964; Barr, 1966, 1970; Petters, 1977). Many authors successfully correlated Bolivinoides species ranges with standard planktonic foraminiferal (Petters, 1977; El-Nady, 2006; Jaff et al., 2014) and macrofossil zonations (Hiltermann & Koch, 1950; Beckmann & Koch, 1964; Barr, 1966; Koch, 1977; Schönfeld, 1990). However, difficulties in correlating local stratigraphic schemes with standard zonations, poor definition of stage boundaries or generally poor stratigraphic data from the investigated regions, or different interpretations and nomenclature of particular bolivinoid taxa, has led to some differences and deficiencies in the Bolivinoides stratigraphy. Surprisingly, there is also a lack of discussion of bolivinoid stratigraphy in more recent comprehensive papers on Cretaceous biostratigraphy (e.g., Gradstein et al., 2012).

Our paper provides taxonomic descriptions, illustrations, evolutionary interpretations and stratigraphic range data for the Late Cretaceous genus Bolivinoides from the Polish Lowlands and western Ukraine. The analysis is based on newly collected material from an almost complete stratigraphic interval from the Upper Santonian to the end of the Maastrichtian, that is, the interval that corresponds with the total range of Cretaceous Bolivinoides. The studied successions are well documented stratigraphically, mainly by macrofossils, which allows for the estimation of the precise stratigraphic positions of evolutionary changes within Bolivinoides lineages and ranges of particular Bolivinoides species, as well as their correlation with those from remote regions of the world.

GEOLOGICAL SETTING

The material analyzed herein comes from 23 outcrops and 4 working quarries in southern, central and eastern Poland, and western Ukraine (Fig. 1). The successions represent the epicontinental Upper Cretaceous of central Europe. Palaeogeographically, the studied areas were situated at the the south-western part of the Mazury–Podlase homocline, the Kościerzyna–Pulawy synclinorium and the Strży–Lwów depression, which constitutes the extension of the southern part of the Kościerzyna–Pulawy synclinorium and at the southern part of the Szczeceń–Łódź–Miechów synclinorium during the Late Cretaceous (Pozaryski, 1960; Pasternak et al., 1987; Leszczyński, 1997, 2012; Świdrowska et al., 2008; Żelaźniewicz et al., 2011). Covered by European epicontinental sea, monotonous carbonate sedimentation dominated, including siliceous limestones (regionally called opokas), marly limestones and marls (Pozaryski, 1960; Rutkowski, 1965).

CENTRAL POLAND (MIDDLE VISTULA RIVER VALLEY AREA)

The composite section comprises a series of natural and artificial exposures in the banks of the middle Vistula river valley and at some distance from the river. The Cretaceous strata, represented by a nearly complete succession from middle Albian to the upper Maastrichtian, comprise alternating chalk, marls, marly chalk and opoka (Pozaryski, 1938; Pozaryska, 1954; Witwicka, 1977; Błaszkiewicz, 1980). The succession belongs to the southern Pulawy segment of the Kościerzyna–Pulawy synclinorium (Żelaźniewicz et al., 2011). The studied Campanian–Maastrichtian is exposed on the western bank of the river between the villages Dorotka and Nasiłów and on the eastern bank between Łopocznio and Kazimierz (Fig. 1). These strata...
are biostratigraphically well documented by more than 50 years of studies on macro- and microfossils: ammonites (Pożaryski, 1938; Błaszkiewicz, 1980; Machalski, 2005), belemnites (Kongiel, 1962; Błaszkiewicz, 1980; Remin, 2012), inoceramids (Walaszczyk, 1992, 2004; Walaszczyk & Peryt, 1998), foraminifera (Pożaryska, 1954; Peryt, 1980; Dubicka & Peryt, 2012a, b), and nannofossils (Gaździcka, 1978).

SOUTHERN POLAND (WOLBROM–MIECHÓW AREA)

The Upper Cretaceous sediments of the Wolbrom–Miechów area, exposed at Wierzchowisko, Rzęśnia and Jeżówka, belong to the southern part of the Szczecin–Łódź–Miechów synclinorium, named the Miechów synclinorium (Miechów Trough, Miechów segment; Pożaryski, 1974; Narkiewicz & Dadlez, 2008; Żelaźniewicz et al., 2011). In general, the Cretaceous succession is represented by Upper Albian–Lower Maastrichtian strata. The biostratigraphy of the studied successions was determined on the basis of macrofauna (ammonites, belemnites, inoceramids and echinoids) by Jagt et al. (2004) and foraminifera (Pożaryska, 1954; Peryt, 1980; Dubicka & Peryt, 2012a, b), and nannofossils (Gaździcka, 1978).

The lower part of the Jeżówka succession is correlated to the lower Campanian Sphaeroceramus sarumensis–Cataceramus dariensis inoceramid Zone (Jagt et al., 2004). In terms of echinoid zonations, the succession represents the conicalpapilosa and papilosa zones according to the German scheme. The upper part of the Jeżówka succession represents the upper part of the Cataceramus beckumensis inoceramid Zone (Jagt et al., 2004; Jurkowska et al., 2015). Based on the occurrence of inoceramid faunas, the Rzęśnia succession represents the upper Campanian “Inoceramus” azerbaydjanensis–“Inoceramus” vorhlemensis Zone (Jagt et al., 2004).

EASTERN POLAND

The upper Cretaceous strata examined in eastern Poland are exposed at Mielnik, Chelm, Rejowiec, Melgiew and Lechówka successions. The Mielnik succession belongs to the south-western part of the Mazury–Podlaskie homocline, the Perm–Mesozoic sedimentary cover of the East European Platform, whereas Chelm, Rejowiec, Melgiew and Lechówka successions represent the sediments of the southern part of the Kościerzyna–Pulawy synclinorium (Narkiewicz & Dadlez, 2008; Żelaźniewicz et al., 2011). The ~30 m thick white chalk exposed at Mielnik was interpreted by different authors to be early Campanian to early Maastrichtian in age (Bieda, 1958; Bittner & Pisera, 1979; Gaździcka, 1981; Peryt, 1981; Olszewska, 1990; Olszewska-Nejbert & Świerczewska-Gładysz, 2011).
On the basis of belemnites, the lower part of the Mielnik succession represents the upper part of the ‘boreal’ lower Campanian (undivided belemnite zones Gonioteuthis gracilis and Bellemnellopseudomax mammillatus) and the upper Campanian Belemnella mucronata Zone (Olszewska, 1990; Olszewska-Nejbert & Świerczewska-Głądzysz, 2011). The upper part of the Mielnik succession belongs to the lower Maastrichtian foraminiferal Rugoglobigerina pennyi Zone (Peryt, 1981), the IV or V Assemblage Zone (Dubicka & Peryt, 2012a) and the Belemnella inflata Zone (Olszewska, 1990). The Campanian and Maastrichtian strata are divided by discontinuities, expressed as hardgrounds, which represent large parts of the upper Campanian and lower Maastrichtian.

The Chent succession comprises ~40 m of chalk. It corresponds to the lower upper Maastrichtian, Spyridoceramus tegulatus–Belemnella junior junior Zone (Machalski, 2005; Machalski et al., 2008; Dubicka & Peryt, 2011), and to the foraminiferal VIII Interval and IX and X Assemblage Zones (Dubicka & Peryt, 2012a). The Melgiew and Lechówka successes belong to the ammonite Hoploscaphites constrictus johnjagti Zone (Machalski, 2005; Machalski et al., 2016) and the foraminiferal XIII Interval Zone (Dubicka & Peryt, 2012a; Machalski et al., 2016).

WESTERN UKRAINE

The studied sediments of the western Ukraine are exposed at Dubivtsi and Kamyanopil. The strata belong to the Lviv–Stryi depression (Swidrowska et al., 2008), which constitutes the extension of the southern part of the Kościerny–Pulawy synclinorium (Zelaźniwicz et al., 2011). The Dubivtsi succession, comprising ~60 m of marly limestones and marls, is exposed in a huge working quarry near the Dubivtsi village near Halych. The succession provides an almost complete record of the upper Turonian–Campanian interval (Dubicka & Peryt, 2012c, 2014). The Upper Santonian–Campanian part of the succession is exposed in the three highest (4, 5, and 6) exploitation levels (Dubicka & Peryt, 2014).

The Kamyanopil outcrop was exposed during the construction of a north-eastern ring road around Lviv in 2008. This outcrop revealed a few meters of lower Maastrichtian marls representing the foraminiferal V Assemblage Zone sensu Dubicka & Peryt (2012a).

MATERIAL AND METHODS

The 230 samples investigated in this study were collected from upper Santonian–uppermost Maastrichtian sediments from 17 natural outcrops and abandoned quarries in the Middle Vistula River Valley area, three outcrops in the Wolbrom–Miechów area, three working quarries and two outcrops in eastern Poland, and one outcrop and one working quarry in western Ukraine. Washed residues were obtained from chalk, marls and marly limestones by disaggregation using Na₂SO₄, and from siliceous limestones and limestones using liquid nitrogen (Remin et al., 2012), then sieving and examining the >63 μm size fraction. Minimum counts of 200 specimens of benthic foraminifera were taken from each sample. The specimens were studied under a standard optical binocular microscope and scanning electron microscope (SEM) Philips XL20 in the Institute of Paleobiology, Polish Academy of Sciences. The illustrated specimens are stored in the Institute of Paleobiology, Polish Academy of Sciences, Warszawa (Collection ZPAL F. 67).

SYSTEMATIC DESCRIPTIONS AND EVOLUTIONARY INTERPRETATION OF BOLIVINOIDES

The suprageneric classification outlined below is based on Loeblich & Tappan (1987). Species descriptions within lineages are introduced in stratigraphic order.

Order FORAMINIFERIDA Eichwald, 1830

Suborder ROTALIINIA Delage and Hérouard, 1896

Superfamily BOLIVINACEA Glaessner, 1937

Family BOLIVINOIDIDAE Loeblich and Tappan, 1984

Genus Bolivinoides Cushman, 1927

Type species: Bolivina draco Marsson, 1878

All representatives of the genus Bolivinoides are characterized by common features, which are as follows: test biserial, calcareous, rhomboidal or cudgel-shaped in outline, flaring, laterally slightly to strongly compressed, and oval or lenticular in cross section; the thickest portion of the test is near the aperture; chambers broad and low (much wider than high) increasing rapidly in size as added; aperture areal, elongate and narrow, with internal toothplate; test-wall perforated; pores circular or elongated to slit-like in shape, occasionally pores are located on incipient or well-developed pore mounds; chamber surface smooth or ornamented with tubercles and pore mounds.

Despite possessing many common characteristics, these particular taxa of Bolivinoides are also characterized by easily visible differences. Based on morphological differences as well as interpreted phylogeny, we include almost all representatives of Bolivinoides into two distinctive groups. The first includes B. strigillatus, B. culverensis, B. decoratus, B. miliaris, Bolivinoides intermedius nov. sp., B. draco, B. giganetus and B. sidestrandensis, which probably represent one evolutionary lineage, the Bolivinoides strigillatus lineage. The next group, named “tiny Bolivinoides”, includes B. granulatus, B. petersoni, B. paleoceniatus, and B. vistulae. Bolivinoides laevigatus, B. petersoni and B. vistulae probably also constitute one lineage - the Bolivinoides laevigatus lineage, whereas the phylogeny and origin of B. granulatus and B. paleoceniatus remain unclear.

THE BOLIVINOIDES STRIGILLATUS LINEAGE

Fig. 2

All representatives of this group are characterized by a relatively large, robust and thick test. Sutures are oblique and strongly depressed, resulting in clearly visible, distinct chambers. Moreover, they are partially covered by well-developed projections extending from basal margins of the succeeding chambers and merging into longitudinal costae, so-called ornamental lobes. Each chamber possesses two or more (up to 9) extensions. Projections are proximally directed that merge into longitudinal costae; they may bifurcate distally and compose some kind of optically radiate test-surface ornamentation. Backward chamber projections can be much shorter, resulting in tubercle ornamentation. The number of ornamental lobes changes with the succeeding forms, ranging from 2–9.

The phylogeny of large-sized Bolivinoides has been discussed in a number of papers (Edgell, 1954; Reiss, 1954; HoLker, 1958; Vasilenko, 1961; Hiltermann, 1963; Beckmann & Koch, 1964; Barr, 1966; Petters, 1977), and displays temporal distribution of all consecutive species with gradual morphological
transformations between the species. These morphological changes include an increase in size; gradual broadening of test from thin, carrot-shaped to the rhomboidal outline; the tendency towards an acute margin (Edgell, 1954); and an increase in the number of chamber extensions from 2–3 in *B. strigillatus* to 7–9 in the upper Maastrichtian *B. giganteus* (Hofker, 1958).

*Bolivinoides strigillatus* is commonly considered to be a basal form of the genus *Bolivinoides* (e.g., Edgell, 1954). During the latest Santonian–earliest Campanian, *B. strigillatus* likely evolved into *B. culverensis* and then into *B. decoratus* during the late early Campanian in the European sense (Ernst, 1963; Schulz et al., 1984). This morphological transition involved an increase in test size and thickness, as well as an increase in the number of ornamental lobes (Barr, 1966). The evolution of these species seems to occur by a successive speciation, within a single evolutionary line without branching.
A further morphological transformation within the *Bolivinoides strigillatus* lineage is recorded with the appearance of *B. miliaris*. The transition from *B. decoratus* to *B. miliaris* includes the development, during late Campanian, of numerous, disorderly distributed tubercles on the initial part of the test, which are diagnostic for *B. miliaris*. This irregular ornamentation becomes parallly arranged in *Bolivinoides intermedius* nov. sp., which is probably a descendant of *B. miliaris*. Finally, mesial tubercles seem to turn into parallel, well-developed medial, longitudinal ribs as observed in the study area.

Another form that is very common in the middle part of the Maastrichtian is *B. giganteus*. The species is characterized by having the largest number of indistinct lobes (6–8) and only a few, if any, irregularly spread tubercles on the initial part of the test. According to previous works (Hiltermann, 1963; Barr, 1966; Petters, 1977), *B. giganteus* evolved from *B. decoratus*. Our study suggests progressive diversification of *Bolivinoides intermedius* nov. sp. into two different species: *B. decoratus* and *B. giganteus*. *Bolivinoides giganteus* does not possess medial and longitudinal ribs or tubercles, which are diagnostic for the *Bolivinoides intermedius* nov. sp. – *B. decoratus* lineage and, therefore, do not belong to this lineage. Some rows of tubercles occur in the transitional forms between *B. giganteus* and its ancestor *Bolivinoides intermedius* nov. sp., from which *B. giganteus* possibly evolved during the late early Maastrichtian.

Hiltermann (1963) and Barr (1966) suggested that *B. australis* is an intermediary state between the ancestral *B. decoratus* and descendant *B. giganteus*. The description and the illustrations of *B. australis* by the author of the species (Edgell, 1954) indicate that *B. australis* is a synonym of *B. miliaris*. Thus, the interpretation of Hiltermann (1963) and Barr (1966) are in accordance with our observations.

*Bolivinoides sidestrandensis* seems to be a descendant of *B. decoratus*, from which it probably evolved during the *Bostrychoconus* polyplumum Zone (lower upper Campanian). Transitional forms between these two taxa are named (informally) *Bolivinoides* “prae”*sidestrandensis*. Morphological changes observed in the transformation from *B. decoratus* to *B. *“prae”sidestrandensis* involved a decrease in thickness of ornamental lobes and development of appendages in the initial part of the test. Moreover, morphological transformation from *Bolivinoides* “prae”*sidestrandensis* to *B. sidestrandensis* reflects an increase in the number of ornamental lobes (5–7), which is a general trend within the *Bolivinoides strigillatus* lineage.

*Bolivinoides strigillatus* (Chapman, 1892)
Figs. 3.1–3.3

*Bolivina strigillata* Chapman, 1892, p. 515, pl. 15, fig. 10; Goel, 1965, p. 79, pl. 7, figs. 6, 8.

*Bolivinoides strigillatus* (Chapman). Hiltermann & Koch, 1950, p. 614–617, fig. 5.6; Edgell, 1954, p. 70, 71, figs. 13.8, 14.8; Witwicki, 1958, p. 196–198, pl. 9, fig. 8; Vasištenko, 1961, p. 186, 187, pl. 39, pl. 39, fig. 7; Barr & Cordey, 1964, p. 308, pl. 49, figs. 1–3; Barr, 1966, p. 228, pl. 34, figs. 8–9, pl. 37, figs. 7–9; Barr, 1970, p. 651, 652, pl. 100, figs. 6–7; Helfer, 1975, pl. 4, fig. 11; Petters, 1977, p. 1035, pl. 1, fig. 9; Koch, 1977, pl. 12, figs. 7–8; Rozumio, 1978, p. 135–136, pl. 20, fig. 4; Kaptarenko-Chernousova et al., 1979, p. 147, pl. 55, fig. 8; Hart et al., 1989, p. 326, pl. 7.5, fig. 8; Schönfeld, 1990, p. 80, 81, pl. 3, figs. 12–13; El-Nady, 2006, p. 680, pl. 1, figs. 24–25.

*Bolivinoides strigillata strigillata* (Chapman). Belford, 1960, p. 61, pl. 15, figs. 14–18.


**Material.** More than 20 specimens.

**Description.** Test small, only slightly compressed, cudgel-shaped in outline, roundly oval in cross section; sides broad and rounded. Only two extensions on each chamber may bifurcate distally or merge into loosely connected, longitudinal, broad, irregular costae separated by a zigzag, longitudinal, median furrow (depression).

**Remarks.** *Bolivinoides strigillatus* is the most basal species of *Bolivinoides* and is commonly regarded as an ancestral species of all bolivinoidid lineages. *Bolivinoides strigillatus* evolved into the descendant species *B. culverensis*, from which it differs in possessing a smaller, less rhomboidal or kite-shaped test and characteristic pattern of chamber projections. Transitional forms between *B. strigillatus* and *B. culverensis* are illustrated in the Figures 3.4 and 3.5.

**Occurrence.** In the studied area, *B. strigillatus* occurs in the upper Santonian and lowermost Campanian of the Dubivtsi succession.

*Bolivinoides culverensis* Barr 1967
Figs. 3.6–3.8

*Bolivinoides hiltermanni* Barr, 1966, p. 229–231, pl. 36, figs. 7–8; pl. 37, figs. 1–3.

*Bolivinoides culverensis* Barr, 1967, p. 136; Petters, 1977, p. 1031, pl. 1, figs. 10–12; Pers, 1988, pl. 2, fig. 1; Hart et al., 1989, p. 322, pl. 7.4, figs. 10–11.

*Bolivinoides angulata* Reiss, 1954, p. 155, pl. 28, figs. 1–3, non fig. 4.


*Bolivinoides sp*. transitional form between *B. strigillata* (Chapman) and *B. decorata* (Jones). Hiltermann, 1963, p. 209, pl. 1, figs. 2–3, 7–9.

**Material.** More than 40 specimens.

**Description.** Test elongate, tapering, oval in cross section, 2–3 extensions on each chamber merging into loosely connected longitudinal, broad, irregular costae; periphery rounded to sub-acute.

**Remarks.** This species is a transitional form between *B. strigillatus* and *B. decoratus*. Accordingly, it is intermediate in test size and number of chamber extensions. It differs from *B. strigillatus* in possessing a larger, thicker and more broadened test that is broadly oval in cross-section; it differs from *B. decoratus* in having fewer ornamental lobes and a more cudgel-shaped test instead of kite-shaped one.

Barr (1966) indicated that *B. culverensis* is probably the ancestral species of the *B. postulata* Reiss (= *B. granulatus* Hofker) – *B. praelevigata* (Barr) – *B. laevigata* Marie-B. petrosvoni Brotzen lineage. However, our observations do not support this assumption.

*Bolivinoides decoratus* is likely a descendant of *B. culverensis*, from which it differs in possessing a less elongated and broader test, and by having 4–5 ornamental lobes

...
instead of 3. The initial part of the *B. decoratus* test is not ornamented. Transitional forms between *B. culverensis* and *B. decoratus*, characterized by a relatively narrow test and being smaller in size than true *B. decoratus* (Figs. 3.9–3.12), occur in the uppermost lower Campanian, within the belemnite *gracilis/mucronata* Zone.

**Occurrence.** In the studied area, *B. culverensis* is restricted to the lower Campanian.

*Bolivinoides decoratus* (Jones, 1886)
Figs. 4.1–4.4

*Bolivinida decorata* Jones in Wright, 1886, p. 330, pl. 27, figs. 7–8.

*Bolivinoides decoratus* (Jones). Akimets, 1961, p. 188, pl. 18, fig. 17; 18; Barr, 1966, p. 231–234, pl. 34, figs. 2–6, 12, pl. 35, figs. 6–9, pl. 36, figs. 1–5; Petters, 1977, p. 1032, pl. 1, fig. 2; Rozumeiko, 1978, p. 136, 137, pl. 20, fig. 6; Kaptarenko-Chernousova et al., 1979, p. 145, pl. 55, fig. 12; Peryt, 1988, pl. 2, figs. 2–4; Gawor-Biedowa, 1992, p. 99, 100, pl. 20, fig. 4; El-Nady, 2006, p. 674, 675, pl.1, figs. 5–7.

Material. More than 100 specimens.

Description. Test large, robust, rhomboidal in outline, compressed elliptical shape in cross section, periphery broad and rounded, 4–5 extensions on each chamber merging into loosely connected, longitudinal, broad, irregular costae, named as ornamental lobes.

Remarks. Bolivinoides decoratus probably gave rise to B. miliaris, which has more ornamental lobes (5–6) and characteristic tubercular ornamentation on the early part of the test. The species probably transitioned within the Bostrychoceras polyplocum Zone to B. sidestrandensis, from which it differs in possessing a thicker test and fewer ornamental lobes. Transitional forms between these taxa are illustrated in Figures 4.5 and 4.6.
**Occurrence.** In the studied area, common occurrence of *B. decoratus* is recorded from the uppermost lower Campanian (gracilisimid inocerata belemnite Zone) up to the "*Inoceramus* tenuilineatus" Zone (middle upper Campanian). Some morphological counterparts of *B. decoratus* sporadically appear in the uppermost Campanian and lower Maastrichtian.

**Bolivinoides sidestrandensis** Barr, 1966
Figs. 4.7–4.10
Bolivinoides delicatus Cushman. Akimets, 1961, p. 189, pl. 18, fig. 19; Vassilenko, 1961, p. 193, pl. 40, fig. 7; Rozuméiko, 1978, p. 139, pl. 20, fig. 8.

**Bolivinoides sidestrandensis** Barr, 1966, p. 239–241, pl. 34, figs. 10–11, pl. 36, figs. 6, 9, pl. 37, fig. 6; Petters, 1977, p. 1034, 1035, pl. 1, fig. 5; Hart et al., 1989, p. 326, pl. 7, fig. 7; Gawor-Biedowa, 1992, p. 107, 108, pl. 20, fig. 1.

**Bolivinoides decorata delicata** Cushman. Hiltmann & Koch, 1950, p. 614, 615, pl. 5, figs. 65–67; Pozaryská, 1954, p. 255, fig. 7; Witwicka, 1958, p. 199, pl. 9, fig. 10; Beckmann & Koch, 1964, pl. 5, fig. 22.

**Bolivinoides delicata** Cushman. Bieda, 1958, p. 38–39, fig. 10.


**Material.** More than 50 specimens.

**Description.** Test elongate, tapering, oval in cross section, periphery rounded to sub-acute; 7–8 pairs of biserial chambers, oblique and depressed sutures obscured by the well-developed thin, elongate lobes extending across older chambers and composed of some kind of optically delicate and open-work test-surface ornamentation. The initial part of the test possesses tubercles and spines.

**Remarks.** *Bolivinoides sidestrandensis* differs from all other large-sized *Bolivinoides* in having thinner lobes, which are located much closer to each other than in the other species.

**Occurrence.** In the studied area, *B. sidestrandensis* occurs from the "*Inoceramus* tenuilineatus" Zone (middle upper Campanian) up to the *Trochoceramus radius* inoceramid zones (lower Maastrichtian). Transitional forms between *B. decoratus* and true *B. sidestrandensis* occur in the ammonite *Bostrychoceras polylochum* Zone (lower upper Campanian).

**Bolivinoides miliaris** Hiltmann & Koch, 1950
Figs. 5.1–5.4
Bolivinoides decorata (Jones) australis Edgell. Edgell, 1965, p. 71–72, pl. 13, figs. 5–6, pl. 14, figs. 5, 6; Goel, 1965, p. 82, pl. 7, figs. 14, 15.

**Bolivinoides draco** (Marsson) intermedius Hiltmann & Koch, 1950, p. 604–606, text-fig. 5:9; Reiss, 1954, p. 155, pl. 28, figs. 9, 11–12, 14; Witwicka, 1958, p. 199, 200, pl. 9, fig. 11; Hiltmann 1963, p. 222, pl. 4, fig. 21; Beckmann & Koch, 1964, p. 44, 45, pl. 6, fig. 21; Koch, 1977, p. 56, 57, pl. 12, fig. 4; Schönhfeld, 1990, p. 84, 85, pl. 3, figs. 10–11; El-Nady, 2006, p. 678, 679, pl. 1, fig. 15.

**Bolivinoides miliaris** Hiltmann & Koch. Hoffr., 1957, p. 267, fig. 322 a, b; Vassilenko, 1961, p. 200, pl. 40, fig. 4; Barr, 1966, p. 234, 235, pl. 35, figs. 4–5.

**Material.** More than 20 specimens.

**Description.** Test large, robust, kite-shaped in outline, compressed to an elongated oval shape in cross section, periphery rounded to sub-acute, 5–6 ornamental lobes. Early part of the test is ornamented by numerous short tubercles and nodules.

**Remarks.** *Bolivinoides miliaris* probably evolved from *B. decoratus*, from which it differs in having tubercular ornamentation on the initial part of the test, and most likely gave rise to *Bolivinoides intermedius* nov. sp., which possesses parallel-arranged ornamentation.

**Occurrence.** In the studied area, the common occurrence of *B. miliaris* is noted from the inoceramid *Cataceramus subcompressus* (lower upper Campanian) up to the *Sphaeroeceramus pertenuiformis* zones (middle upper Campanian).

**Bolivinoides intermedius** nov. sp.
Figs. 5.5–5.9, Figs. 6.1–6.4
Bolivinoides miliaris Hiltmann & Koch. Barr, 1970, p. 650, pl. 99, figs. 1–2; Petters, 1977, pl. 1, fig. 3; Peryt, 1988, pl. 2, fig. 5; Hart et al., 1989, p. 75, fig. 3; Gawor-Biedowa, 1992, pl. 20, fig. 6.

**Bolivinoides draco** miliaris Hiltmann & Koch. Reiss, 1954, p. 155, pl. 28, fig. 10; Bieda, 1958, p. 44–45, fig. 14; Hiltmann, 1963, p. 222, pl. 4, fig. 22; Beckmann & Koch, 1964, p. 44, 45, pl. 6, figs. 22–23;

**Bolivinoides draco** miliaris-B. draco draco [transitional form between *Bolivinoides draco miliaris* and *B. draco draco*]. Hiltmann, 1963, p. 222, pl. 4, fig. 20.

**Bolivinoides draco** (Marsson). Kaptarenko-Chernousova et al., 1979, p. 144, 145, pl. 55, fig. 11; Jaff et al., 2014, pl. 2, fig. 6.

**Bolivinoides draco** draco (Marsson). Schönhfeld, 1990, p. 78–80, pl. 3, figs 1, 2.

**Holotype.** Fig. 5.5. Specimen deposited in the Institute of Paleobiology, Polish Academy of Sciences. ZPAL F 67/K 3/01

**Dimensions of the holotype.** Length of test [L]—480 μm, maximum width of test [W]—351 μm, maximum thickness of test [T]—230 μm.

**Type location.** Khudzie, Middle Vistula River Valley area, Central Poland.

**Type level.** Campanian–Maastrichtian boundary interval, "*Inoceramus* redhirdensis" Zone.

**Paratypes.** Five specimens deposited in Institute of Paleobiology, Polish Academy of Sciences.


**Material.** More than 50 specimens.

**Etymology.** Intermediate form between *Bolivinoides miliaris* and *B. draco*.

**Description.** A *Bolivinoides* species, with a large test, robust, kite-shaped in outline, compressed to an elongated oval shape in cross section, five ornamental lobes, two parallel medial rows of tubercles; periphery sub-acute to acute.

**Remarks.** Specimens that are now included in the species *Bolivinoides intermedius* nov. sp. have been commonly recorded from various parts of Europe. They have usually been considered to belong to either *B. miliaris* or *B. draco*, as this form is probably transitional (Fig. 6.5). *Bolivinoides intermedius* nov. sp. differs from the two taxa in possessing two parallel medial rows of tubercles instead of numerous short tubercles and nodules (*B. miliaris*) or two parallel medial ribs (*B. draco*). *Bolivinoides intermedius* nov. sp. probably...
gave rise to *B. giganteus* during early Maastrichtian by the development of additional lobes.

**Stratigraphic range:** In the studied area, the species occurs from the upper part of the upper Campanian (*Inoceramus* *altus* Zone) up to the upper part of the lower Maastrichtian–uppermost part of the *Belemnella occidentalis* Zone.

*Bolivinoides draco* (Marsson, 1878)
Figs. 6.6–6.10

*Bolivina draco* Marsson, 1878, p. 157, pl. 3, fig. 25.

*Bolivinoides draco* (Marsson), Hofker, 1957, p. 267, fig. 231b; Vasilenko, 1961, p. 201, pl. 34, fig. 2; Barr, 1970, p. 646, pl. 99, figs. 2–3; Petters, 1977, p. 1031, pl. 1, fig. 1; Peryt, 1988, pl. 2, fig. 6; Gawor-Biedowa, 1992, p. 101, pl. 20, fig. 8; Jaff et al., 2014, pl. 1, figs. 10–12, pl. 2, figs. 9–10.

*Bolivinoides draco draco* (Marsson). Hiltermann & Koch, 1950, p. 598–604, text-fig. 5:69, 1:72–73; Edgell, 1954, p. 73, pl. 13, figs. 1–3, pl.14, figs 1–3; Reiss, 1954, p. 155, pl. 29, fig. 1 3; Hiltermann, 1963, p. 222, pl. 4, figs. 16–19; Beckmann & Koch, 1964, p. 45, 46, pl. 6, fig. 24; Koch, 1977, p. 57, pl. 12, figs. 2–3; Hart et al., 1989, p. 322, pl. 7.4, fig. 13; El-Nady, 2006, p. 678, pl. 1, figs. 12–14.

*Bolivinoides miliaris* Hiltermann & Koch. Jaff et al. 2014, pl. 1, fig. 16.

**Material.** More than 30 specimens.

**Description.** Test large, robust, kite-shaped in outline, compressed to elongated lenticular shape in cross section, acute

**Figure 5.** Foraminifera of the *Bolivinoides strigillatus* lineage; scale bars = 100 μm. 1–4 *Bolivinoides miliaris* Hiltermann and Koch: 1, Cisyca Górska, sample 1, ZPAL F.67/CG/09; 2, Cisyca Górska, sample 1, ZPAL F.67/CG/10; 3, Cisyca Górska, sample 2, ZPAL F.67/CG/23; 4, Dorotka, sample 1, ZPAL F.67/D/06. 5–9 *Bolivinoides intermedius* nov. sp.: 5, Kludzie, sample 3, ZPAL F.67/K3/01; 6, Kludzie, sample 3, ZPAL F.67/KLD/08; 7, Kludzie, sample 3, ZPAL F.67/K3/09; 8, Pawłowie, sample 2, ZPAL F.67/9/3/9; 9, Kludzie, sample 1, ZPAL F.67/K3/07.
margin, 5–6 ornamental lobes. *Bolivinoides draco* has two very distinctive, well-developed, parallel medial ribs, which are produced by the fusing of the inner ornamental lobes.

**Remarks.** *Bolivinoides draco* is a descendant of *Bolivinoides intermedius* nov. sp. from which it differs in having an acute margin and two parallel, well-developed medial, longitudinal ribs instead of two parallel, medial rows of tubercles.

**Occurrence.** In the studied area, the first appearance of *B. draco* is noticed in the lower upper Maastrichtian (*ammonite Hoploscaphites constrictus Iwienis Zone*). The taxon occurs till the end of the Cretaceous.

*Bolivinoides giganteus* Hiltermann & Koch, 1950

Figs. 7.3–7.9
Description. Test large, robust, kite-shaped in outline, compressed to an elongated lenticular shape in cross section, periphery acute, 7–9 relatively continuous ornamental lobes, which are fairly uniform on the almost entire test. Some specimens possess short tubercles and nodules on the initial part of the test. According to Barr (1966), *Bolivinoides australis* Edgell (1954) may be considered as a subspecies of *B. giganteus* or even synonymous with this species.

Remarks. *Bolivinoides giganteus* Hiltermann and Koch probably evolved from *Bolivinoides intermedius* nov. sp., from which it differs in possessing larger numbers of ornamental lobes. A few single tubercles and nodules are only present on a very small portion of the initial part of the test, if any. Transitional forms between these taxa are illustrated in the Figures 7.1 and 7.2.

Occurrence. In the studied area, *B. giganteus* occurs in the upper part of *Belemnitella occidentalis* Zone and in the *Belemnitella junior* Zone.

“Tiny Bolivinoides”

Compared to the representatives of the *Bolivinoides strigillatus* lineage, all representatives of the “tiny Bolivinoides” are
characterized by comparatively small, thin, poorly ornamented tests, with a flatly elliptical cross section. They also possess fewer but more distinctive ornamental lobes. In contrast to large-sized members of the Bolivinoides striillatus lineage, their sutures are only slightly depressed and hardly visible. The ornamentation is also less distinct than in the other group and is mainly restricted to the central part of the test, while the marginal parts are smooth.

The phylogeny of the taxa included here as “tiny Bolivinoides” were discussed in a few papers (e.g., Edgell, 1954; Vasilenko, 1961; Hiltermann, 1963; Barr, 1966; Petters, 1977). Most of the authors suggested that B. striillatus is an ancestral form of all taxa classified herein as “tiny Bolivinoides” and that there exists the ancestor-descendant relationship between B. laevigatus and B. petterssoni.

According to Barr (1966), B. pustulatus (= B. granulatus), B. praelaevigata, B. laevigata and B. petterssoni constitute one evolutionary line, which evolved from B. hiltermanni (= B. culverensis), which is included herein as a member of the Bolivinoides striillatus lineage. Petters (1977) similarly suggested that the B. praelaevigata–B. laevigata lineage evolved from B. culverensis, which is also a representative of the Bolivinoides striillatus lineage. On the other hand, Vasilenko (1961) and Hiltermann (1963) interpreted that the B. laevigata–B. petterssoni lineage evolved from early and primitive forms of B. granulatus, and regarded B. granulatus as a descendant of B. striillatus. We have not recognized any transitional forms between representatives of the Bolivinoides striillatus lineage and “tiny Bolivinoides”, which could indicate that B. striillatus cannot be an ancestral form of “tiny Bolivinoides”. Rather, the latter could have evolved from different benthic foraminiferal genera instead from the Bolivinoides striillatus lineage. However, this problem requires further examination. In the studied material, we can distinguish one single evolutionary line: B. laevigata–B. petterssoni–B. vistulace (Fig. 8). The general trend in morphological modification of successive species concerns increase in emergence and projection above the test surface of ornamental lobes and broadening of the test (transition from B. petterssoni to B. vistulace). The phylogenetic relationships of other taxa of the “tiny Bolivinoides” group (i.e., B. granulatus and B. paleocenicus) remain unclear and require further studies.

**Bolivinoides granulatus** Hofker, 1957

Figs. 9.1–9.7

Bolivinoides granulatus Hofker, 1957. p. 250, 251, text-figs. 303, 310; Beckmann & Koch, 1964, p. 39, pl. 5, figs. 4–6; Hofker, 1957, p. 52, figs. 13.8, 13.9; Koch, 1977, p. 52, pl. 13, figs. 8–9; Schönfeld, 1990, p. 85, 86, pl. 3, fig. 9.

Bolivinoides decorata cf. delicatula Cushman. Edgell, 1954, p. 71, pl. 13, fig. 7, pl. 14, fig. 7.

Bolivinoides pustulatus Reiss, 1954, p. 156, pl. 29, figs. 9–10; Barr, 1966, p. 236, 237, fig. 37.4.

Bolivinoides pustulatus Reiss. Hart et al., 1989, p. 324, pl. 7.5, fig. 6.

Bolivinoides cyrenaicus Barr, 1970, p. 646, 647, pl. 99, figs. 2–3.


**Material.** More than 50 specimens.

**Description.** Test thin and elongate, with flat elliptical cross section, two elongate lobes extend from each chamber perpendicularly to the depressed sutures which are obscured by them; the initial part of the test surface is covered by dense pustules; periphery is sub-acute.

**Remarks.** *Bolivinoides granulatus* is commonly treated as a synonym of *B. pustulatus* in literature. Based on the characteristic elliptical and slit-like pores, Georgescu et al. (2011) identified a new genus *Elongateporeia*, which includes *E. culverensis* (Barr) and *E. elongatoporosa* Georgescu et al. is very similar to *B. granulatus* but commonly occurs in the upper Campanian and Maastrichtian. The elongate to slit-like pores, which can be located in the center of incipient pore mounds (Georgescu et al., 2011), are not only observed in *Elongateporeia*, but can occur sporadically in an almost all bolivinoidids taxa. The origin of the species is uncertain.

**Occurrence.** In the studied area, *B. granulatus* occurs in the upper lower Campanian to lower upper Campanian.

**Bolivinoides laevigatus** Marie, 1941

Figs. 9.8–9.11; 10.1

**Material.** More than 50 specimens.

**Description.** Test rhomboidal, elongate, 7–9 pairs of biseri ally arranged chambers, cross-section compressed, periphery sub-acute, sutures slightly depressed; test surface possessing weakly developed circular to elongate nodules (2–3 per chamber).

**Remarks.** The species differs from all other bolivinoidids by having only a very weakly ornamented test surface. It is an ancestral form of *B. petterssoni*, from which it differs in
possessing less distinctive ornamental lobes visible only in the younger part of the test.

**Occurrence.** In the studied area, *B. laevigatus* appears in the upper part of the lower Campanian (*gracilis/mucronata* belemnite Zone) and occurs up to the “*Inoceramus* teniilineatus” Zone (middle upper Campanian).

*Bolivinoides peterssoni* Brotzen, 1945

Figs. 10.2–10.5

*Bolivinoides peterssoni* Brotzen, 1945, p. 49, pl. 1, fig. 10; Hiltermann & Koch, 1955, p. 366, pl. 27, figs. 7–8; Pozaryska, 1954, p. 256, fig. 8; Barr, 1966, p. 238, 239, pl. 38, fig. 6; Barr, 1970, p. 650, pl. 99, fig. 6; Hart et al., 1989, p. 324, pl. 7.5, fig. 5; Schönfeld, 1990, p. 82, 83, pl. 3, figs. 3–4; Peryt, 2000, pl. 1, fig. 3; El-Nady, 2006, p. 679, 680, pl. 1, figs. 20–21; Kaptarenko-Chernousova et al., 1979, p. 146, pl. 55, fig. 16.

*Bolivinoides laevigatus* Marie. Koch, 1977, pl. 13, fig. 7.

**Material.** More than 50 specimens.

**Description.** Test biserial, elongate, 7–9 pairs of biserially arranged chambers, cross-section compressed, periphery sub-acute, sutures slightly depressed. On the central part of test, there are characteristic, well-developed, elongate lobes.
extending perpendicularly to the sutures. Apart from the lobes, the rest of the test surface is smooth.

Remarks. *Bolivinoides peterssoni* is likely a transitional form between *B. laevigatus* and *B. vistulae*. It differs from *B. vistulae* in having a less broad test and less distinctive ornamental lobes, and from its ancestor *B. laevigatus* in possessing much more distinctive ornamentation, which is restricted mostly to the central part of the test.

Occurrence. In the studied area, *B. peterssoni* appears in the middle upper Campanian ("Inoceramus altus" Zone) and occurs up to the upper part of the lower Maastrichtian.

*Bolivinoides vistulae* Pozarska, 1954

Figs. 10.6–10.10

*Bolivinoides vistulae* Pozarska, 1954, p. 253, fig. 2.

*Bolivinoides praecursor* Reiss. Kaptarenko-Chernousova et al., 1979, p. 146, pl. 55, fig. 10.

*Bolivinoides peterssoni* Brotzen. Vasilenko, 1961, p. 198, pl. 40, fig. 8; Gawor-Biedowa, 1992, p. 105, 106, pl. 19, fig. 9.

Material. More than 20 specimens.

Remarks. Test flaring, kite-shaped in outline, laterally strongly compressed, flat elliptical in cross section, periphery acute. Elongate, bluntly rounded, emerged and protruding
ornamental lobes are very distinctive features chiefly restricted to the central part of the test. Apart from the lobes, the rest of the test surface is smooth.

Remarks. Bolivinoides vistulae is a descendant of B. petersoni from which it differs in possessing a much wider test shape (kite-shaped), and much more distinctive and protruding ornamental lobes.

Occurrence. In the studied area, B. vistulae occurs in the Belemnella kazimiroviensis Zone, the upper upper Maastrichtian.

Bolivinoides paleocenica (Brotzen, 1948)
Fig. 10.11

Bolivina paleocenica Brotzen, 1948, p. 66, pl. 9, fig. 5;
Bolivina paleocenica Brotzen, Hiltermann & Koch, 1955, p. 370, pl. 27, figs. 3–6; Witwicka, 1958, p. 201, pl. 10, fig. 14.

Bolivinoides paleocenica (Brotzen). Barr, 1970, p. 650, pl. 99, fig. 7;
Koch, 1977, p. 60, pl. 13, figs. 1–3; Hart et al., 1989, p. 324, pl. 7.5, fig. 4; Schönfeld, 1990, p. 83, 84, pl. 3, figs. 7–8;
Gawor-Biedowa, 1992, p. 104, 105, pl. 20, fig. 3.

Material. 3 specimens.

Description. Test small, delicate, kite-shaped, compressed, periphery sub-acute and with deeply incised peripheral outline; 6–7 pairs of biserially arranged uninflated chambers, sutures distinct and depressed, obscured in the center of the test by raised, narrow, irregular and intersecting ridges.

Remarks. This taxon represents a quite different morphotype and possibly represents a distinct lineage from all other Bolivinoides.

Occurrence. In the studied area, B. paleocenica is very rare and was found in the lower Maastrichtian.

VERTICAL DISTRIBUTION AND STRATIGRAPHIC VALUE OF BOLIVINOIDES

THE BOLIVINOIDES STRIGILLATUS LINEAGE

Species of the genus Bolivinoides described herein occur during an interval from the latest Santonian to the latest Maastrichtian. The representatives of the B. strigillatus lineage appear in the late Santonian whereas “tiny bolivinoidids” appear in the early Campanian. Their contribution to the benthic foraminiferal assemblages seems to reflect sea-level changes (El-Nady, 2006) and their numbers are much higher in assemblages from deeper shelf environments. Accordingly, in the studied succession, representatives of Bolivinoides are very common throughout almost the entire Campanian, though much less frequent in the uppermost Campanian–lowermost Maastrichtian and most of the upper Maastrichtian strata. The intervals with low contributions of Bolivinoides to the benthic foraminiferal assemblages correlate with the intervals characterized by disappearances of deep-dwelling planktonic foraminifera (Dubicka & Peryt, 2012a), indicating sea-level drops (e.g., Caron & Homewood, 1983).

The first appearance of Bolivinoides in the studied succession (Fig. 11), represented by B. strigillatus, is recorded in the Dubivtsi 2 succession in the upper Santonian, within the Cordiceramus muelleri inoceramid Zone. Bolivinoides strigillatus is the oldest Bolivinoides, and the only member of this genus found in the upper Santonian strata. Its distribution is worldwide, including northwestern (Barr, 1966; Koch, 1977) and eastern Europe (Akimets, 1961), Kazakhstan (Vasilenko, 1961), North Africa (Barr, 1970; Khalil, 1998), North (Petters, 1977) and South America (Beckmann & Koch, 1964; Martinez-Pardo, 1965), and Australia (Edgell, 1954; Belford, 1960). Similar to our records, its first appearances in many other regions are usually described from the upper Santonian (e.g., Egypt (El-Nady, 2006), northwestern Australia (Edgell, 1954), Atlantic Coastal Plain of North America (Petters, 1977), and northern Europe (Hiltermann, 1963)]. Additionally, the first appearance datum of Bolivinoides strigillatus was recorded almost at the base of the Marsupites testudinarius echinoid Zone in northwestern Germany (Koch, 1977; Schönfeld, 1990), England (Barr, 1966; Hart et al., 1989; Hampton et al., 2007) and Libya (Barr, 1970). Accordingly, the event was discussed as a proxy for the Santonian/Campanian boundary (Birkelund et al., 1984). The first appearance of B. strigillatus has high stratigraphic and correlative importance, indicating a late late Santonian age in many distant regions of the world.

The highest occurrence of B. strigillatus is more problematic and has been differently recorded in the literature. Bolivinoides strigillatus gradually evolved into a younger form named B. culverensis. Since B. culverensis is a transitional form between B. strigillatus and B. decoratus (Barr, 1966), some authors do not distinguish this transitional taxon. The results are significant differences in the interpretation of the stratigraphical ranges of both taxa, especially between German (e.g., Hiltermann & Koch, 1950; Hiltermann, 1952; Koch, 1977; Schönfeld, 1990) and British authors (Barr, 1960; Hart et al., 1989; Hampton et al., 2007). Koch (1977) and Schönfeld (1990) do not distinguish B. culverensis and consequently the last occurrence of Bolivinoides strigillatus is the middle lower Campanian, basal senonensis echinoid Zone. In contrast, the occurrence of B. strigillatus in England is described only from the crinoid Marsupites testudinarius Zone (upper upper Santonian) and Ofaster pilula echinoid Zone (basal Campanian; Barr, 1966; Hart et al., 1989; Hampton et al., 2007). According to Hampton et al. (2007), the first appearance of B. culverensis and the last appearance of B. strigillatus, reflecting an evolutionary transition between these two taxa, are extremely important as these events can be found at the Seafood Head succession within the Uintacrinus anglicus crinoid Zone and therefore relatively close to what is currently accepted as the Santonian/Campanian boundary in southern England (Barr, 1966, 1967).

Bolivinoides culverensis is also found in the Atlantic Coastal Plain of North America (Petters, 1977), Israel (Reiss, 1954), and Egypt (El-Nady, 2006), and occurs there in a similar stratigraphic position as recorded in England and in the studied area. Consequently, the first appearance of B. culverensis seems to be a useful indicator for the basal Campanian in Europe, as well as in many other regions of the world. Bolivinoides culverensis, or some transitional forms between B. culverensis and B. decoratus, characterized by four lobes but a relatively narrow test and smaller size than true B. decoratus, occurs in the studied succession up to the upper part of the lower Campanian (lower part of Melnik succession), similar to what has been recorded in southern England (Hart et al., 1989).

The first common occurrence of true B. decoratus is recorded in the Melnik succession, within the gracilis/mucronata
Figure 11. Chronostratigraphy (1, 2), cephalopod (3) (after Błaszkiewicz, 1980), inoceramid (4) (after Walaszczyk, 2004; and Jurkowska et al., 2015) and ammonite (5) (Machalski, 2005) stratigraphy, lithological columns of the studied sections in central (outcrops located on the western (A) and eastern (B) banks of the middle Vistula river, and in the Wolbrom – Miechów area (C)), eastern Poland (D) and western Ukraine (E) and the ranges of Bolivinoides.
belemnite Zone. In the Cretaceous of southern England, the common occurrence of *B. decoratus* is also placed slightly below the boreal lower/upper Campanian, that is, in the uppermost part of the belemnite *Gonioteuthis quadrata* Zone (Hart et al., 1989). A slightly lower stratigraphic position of the event is recorded in the Cretaceous of Germany where the first appearance of the species is placed within the upper part of the lower Campanian, close to the base of the echinoid *senonensis* Zone (Hiltecrnann & Koch, 1950; Hiltecrnann, 1952; Koch, 1977; Schönfeld, 1990). This difference is very likely caused by the non-recognition of *B. culverensis* within the *Belemnella striligillatus*–*B. decoratus* lineage in the interpretation of German authors.

In general, the rough stratigraphic position of the first appearance of *B. decoratus* in many regions outside Europe is determined as middle Campanian: Israel (Reiss, 1954), Egypt (Khalil, 1998; El-Nady, 2006), the Atlantic Coastal Plain of North America (Petters, 1977), South America (Beckmann & Koch, 1964) and Libya (Barr, 1970). The continuous and abundant occurrence of *B. decoratus* in the studied area is recorded until the *Cataceramus subcompressus* Inoceramid Zone.

A slightly different stratigraphic position of the last occurrence of *B. decoratus* was noted in some areas of Europe. In northwestern Germany, the common occurrence of *B. decoratus* was recorded up to the lower boundary of the *Belemnella lanceolata* Zone and some sporadic appearances were recorded within the *Belemnella lanceolata* Zone (uppermost Campanian and lower Maastrichtian; Hiltecrnann, 1950; Koch, 1977). On the British Isles, the last appearance of the species was recorded in the lower part of the *Belemnella lanceolata* Zone (Barr, 1966). The slightly lower position of the disappearance of *B. decoratus* recorded in Poland compared to western Europe could be a result of infrequent occurrences in the uppermost Campanian of Poland, which corresponded to a significant regression observed in the area (Dubicka & Peryt, 2012a; Świerczewska-Ghadyz, 2012). In other places around the world, the last appearances of *B. decoratus* were roughly similar to those recorded in western Europe (uppermost Campanian), for example, Trinidad (Beckmann & Koch, 1964), Libya (Barr, 1970) and the Atlantic Coastal Plain of North America (Petters, 1977).

The first occurrence of *Bolivinoides miliaris* that we observed was in the Dorotka outcrop within the upper part of the *Cataceramus subcompressus* Zone. The event was described from the ammonite *Bostrychoceras polyplumca* Zone of northwestern Europe (Hiltecrnann, 1952; Barr, 1966; Koch, 1977; Hart et al., 1989; Schönfeld, 1990) and in the upper Campanian in North Africa (Reiss, 1954; Barr, 1966), the Atlantic Coastal Plain of North America (Petters, 1977), Trinidad (Beckmann & Koch, 1964), and Australia (Edgell, 1954). Accordingly, this foraminiferal event can serve as a potential marker for the end of the *Bostrychoceras polyplumca* ammonite Zone.

The stratigraphic position of the last occurrence of *Bolivinoides miliaris* is described in the literature much less precisely, probably caused by the occurrence of transitional forms between *B. miliaris* and *B. draco* in the uppermost Campanian and lower Maastrichtian. These transitional forms have been considered either as *B. miliaris* or *B. draco*. Only forms that have an irregularly ornamented initial part of the test are assigned to *B. miliaris* in this paper. All descendant forms possessing two parallel medial rows of tubercles are assigned to *Bolivinoides intermedius* nov. sp. The first appearance of this species is recorded in the “Sphaeroceramus pertenuiformis” inoceramid Zone. Consequently, the range of *B. miliaris* is restricted to the upper Campanian, *Cataceramus subcompressus*, “Inoceramus” *senonensis* and *Sphaeroceramus pertenuiformis* inoceramids zones.

The next event is the appearance of *Bolivinoides sidestrandensis* in the “Inoceramus” *senonensis* Zone. Its occurrence continues until the upper part of the lower Maastrichtian. A very similar stratigraphic position of the species range was presented by Koch (1977) from the Cretaceous of northwestern Germany, where the taxon appears in the *Belemnemita langei* Zone (upper Campanian) and occurs up to the *Belemnemita occidentalis* Zone (upper part of the lower Maastrichtian). Thus, *B. sidestrandensis* seems to be a stratigraphically important species for correlations of central European strata with those from western Europe. *Bolivinoides sidestrandensis* probably evolved from *B. decoratus* within the *Bostrychoceras polyplumca* ammonite Zone. Transitional forms between these two taxa occur in the uppermost *Bostrychoceras polyplumca* Zone.

*Bolivinoides giganteus* appears in the upper part of the lower Maastrichtian. The species occurs up to the upper part of the *Belemnemita junior* Zone. The stratigraphic range of *Bolivinoides giganteus* was roughly described from the Atlantic Coastal Plain as Maastrichtian (Peters, 1977). Similar to our data, the first appearance of *B. giganteus* was located close or slightly below the first occurrence of *B. draco* in many other regions, such as Australia (Edgell, 1954), Germany (Hiltecrnann & Koch, 1950), Atlantic Coastal plain of North America (Peters, 1977), and Libya (Barr, 1970). Koch (1977) recorded a stratigraphic range of *B. giganteus* in western Germany very similar to what we found in Poland. Its first appearance is located within the *Belemnemita occidentalis* Zone and its last appearance in the upper part of the *Belemnemita junior* Zone. Consequently, *B. giganteus* can be a useful stratigraphical marker for the upper lower and lower upper Maastrichtian.

The first record of *B. draco*, which is the youngest species of the *Bolivinoides strigillatus* lineage, is in the lower part of the *Belemnitella junior* Zone and within the ammonite *Hoploscaphites constrictus vivensis* Zone (Matyszki, 2005). The species likely evolved from *Bolivinoides intermedius* nov. sp. Transitional forms between these two taxa occur slightly lower, in the Boiska succession, which is placed close to the lower/upper Maastrichtian boundary (Blaszkiewicz, 1980; Dubicka & Peryt, 2012b). *Bolivinoides draco* occurs to the end of the Maastrichtian interval.

**“Tiny Bolivinoides”**

*Bolivinoides granulatus* is the oldest *Bolivinoides* species of “tiny *Bolivinoides*”. It appears in the Wierzchoslik succession, which according to Jagt et al. (2004) represents the middle part of the lower Campanian *pilula, pilulaisenonensis* and possibly *senonensis* echinoid zones (Schulz et al., 1984; Niebuhr et al., 1997). According to Dubicka (2015), the Wierzchoslik succession correlates to the echinoid *senonensis* Zone. The range of *B. granulatus* in Poland and western Ukraine corresponds to the
range in northern Germany (Koch, 1977; Schönfeld, 1990), where it appears within the echinoid *semonensis* Zone. The last occurrence of *B. granulatus* in the studied area is similar to that of Lägerdorf (Schönfeld, 1990). It is recorded in the higher part of the Miśn succession close to lower/upper Campanian boundary according to belemnites. In Germany, the event can be found at the base of the upper Campanian, in the middle part of the echinoid/belemnite *conica/senior* Zone. Accordingly, this species seems to be very useful for stratigraphic and correlation purposes across Europe.

The next important foraminiferal bioevent recorded in the studied successions is the first appearance of *B. laevigatus*. This event occurs slightly below the base of the upper Campanian in the lower part of the Miśn succession. However, the species is consistently present in the lowermost upper Campanian in the *Belemnitella mucronata* Zone (Olszewska Nejbert & Świerczewska-Gładysz, 2011). Similarly, in the Cretaceous of southern England, the first record of *B. laevigatus* was described from the topmost lower Campanian (uppermost part of the belemnite *Gonioteuthis quadra ta* Zone), whereas the common occurrence of *B. laevigatus* was recorded from the base of the *Belemnitella mucronata* Zone upward (Hart et al., 1989). Koch (1977) and Schönfeld (1990) described the first appearance of *B. laevigatus* from northwestern Germany, also from the lower part of the upper Campanian (i.e. from the lower part of the echinoid/belemnite *conica/senior* Zone). Therefore, the first appearances of *B. laevigatus* and its common occurrence seem to be in a similar stratigraphic position in western and central Europe.

Higher in the succession *B. laevigatus* gradually passes into *B. peterssoni*. Some transitional forms between these two taxa occur in the inoceramid *Cataceramus subcompressus* Zone. The fully developed *B. peterssoni* appears in the Piotrawin quarry, close to the base of the “*Inoceramus* altus” Zone. However, the positions of the last appearances of *B. laevigatus* and the first appearance of *B. peterssoni* are difficult to date precisely. For example, Koch (1977) described the last appearance of *B. laevigatus* and first appearance of *B. peterssoni* from the middle part of the *Belemnella lanceolata* Zone from Germany. According to Schönfeld (1990), the first appearance of *B. peterssoni* in the Lägerdorf succession is located below the *Belemnella lanceolata* Zone that is in the middle part of the echinoid *grimnensis/granulatus* Zone.

The last appearance of *B. peterssoni* in the studied area is recorded in the upper part of the Kamyanopol succession, which represents the lower part of the upper Maastrichtian. The same stratigraphic position of the event was recorded in the Lägerdorf succession by Schönfeld (1990).

In the lower part of the upper Maastrichtian, there are forms that possess tests much wider than seen in lower Maastrichtian *B. peterssoni*. These forms can be considered as transitional between *B. peterssoni* and *B. vistulae*. The typical morphotype of *B. vistulae* occurs in the upper part of the *Hoploscaphites constrictus crassus* and the *Hoploscaphites johnjagti* ammonite zones (Kazmierz, Naslowski Melgiew and Lechówka successions).

**SUMMARY**

The taxonomy, evolutionary changes and stratigraphic significance of the genus *Bolivinoides* (benthic foraminifera) from the Upper Cretaceous of central and eastern Poland and western Ukraine are discussed.

- Two evolutionary lineages are recognized: the *Bolivinoides strigillatus* lineage and the *B. laevigatus* lineage.
- The *Bolivinoides strigillatus* lineage comprises *B. strigillatus*, *B. culverensis*, *B. decoratus*, *B. miliaris*, *B. intermedius* nov. sp., *B. giganteus* and *B. draco*. Its main evolutionary changes are: increase in size and broadening of test from cudgel-shaped to rhomboidal outline, and a tendency towards an acute margin and increase in the number of lobes.
- *Bolivinoides decoratus* probably gave rise to *B. sidestrandensis* by decreasing the thickness of the ornamental lobes and developing appendages on the initial part of the test.
- The *Bolivinoides laevigatus* lineage comprises *B. laevigatus*, *B. peterssoni* and *B. vistulae*. Within this lineage the main morphological change are: decrease in test and increase in emergence of test surface projections.
- One new species, *Bolivinoides intermedius* nov. sp., is described. It is characterized by possessing two medial rows of tubercles parallel to growth direction, which distinguishes it from its ancestor *B. miliaris* and its descendant *B. draco*.
- The species ranges of *Bolivinoides* are presented in comparison to the macrofossil zonations and extra-regional stratigraphical value of first and last appearances of all species are discussed.

**ACKNOWLEDGMENTS**

This work was funded by a grant UMO-2013/09/D/ST10/ 04059 from the National Science Centre (NCN) and the statutory fund of the Institute of Paleobiology, Polish Academy of Sciences. Drawings of foraminifera on Figures 2 and 8 were made by Bogusław Waksmundzki (Faculty of Geology, University of Warsaw). This manuscript was greatly improved following comments from Holger Gebhardt, Haydon Bailey and editors Pamela Hallock and Maria Rose Petrizzo, to whom we are very grateful.

**REFERENCES**


Beckmann, J. P., and Koch, W., 1964, Vergleiche von *Bolivinoides*, *Aragonita* und *Tappanina* (Foraminifera) aus Trinidad (Westindien) – *Metallatera* (Foraminifera) aus Trinidad (Westindien) – *Metallatera* (Foraminifera) aus Trinidad (Westindien) – *Metallatera* (Foraminifera) aus Trinidad (Westindien) – *Metallatera* (Foraminifera) aus Trinidad (Westindien) – *Metallatera* (Foraminifera) aus Trinidad (Westindien) – *Metallatera* (Foraminifera) aus Trinidad (Westindien) – *Metallatera* (Foraminifera) aus Trinidad (Westindien) – *Metallatera* (Foraminifera) aus Trinidad (Westindien) – *Metallatera* (Foraminifera) aus Trinidad (Westindien) – *Metallatera* (Foraminifera) aus Trinidad (Westindien) – *Metallatera* (Foraminifera) aus Trinidad (Westindien) – *Metallatera* (Foraminifera) aus Trinidad (Westindien) – *Metallatera* (Foraminifera) aus Trinidad (Westindien) – *Metallatera* (Foraminifera) aus Trinidad (Westindien) – *Metallatera* (Foraminifera) aus Trinidad (Westindien) – *Metallatera* (Foraminifera) aus Trinidad (Westindien) – *Metallatera* (Foraminifera) aus Trinidad (Westindien) – *Metallatera* (Foraminifera) aus Trinidad (Westindien) – *Metallatera* (Foraminifera) aus Trinidad (Westindien) – *Metallatera* (Foraminifera) aus Trinidad (Westindien) – *Metallatera* (Foraminifera) aus Trinidad (Westindien)

Beld, E., 1958, Otwornice przewodnie i wiek kredy pisz cz [{index} foraminifery i the age of the Miśn chalk (Eastern Poland)]: Biuletyn Instytutu Geologicznego, v. 121, p. 17–89. (in ?)
El-Nady, H., 2006, Contributions to the stratigraphic significance of the Dubicka, Z., and Peryt, D., 2014, Classification and evolutionary inter-
Caron, M., and Homewood, P., 1983, Evolution of early planktonic for-
Chapman, F., 1892, Microzoa from the phosphatic chalk of Taplow:
Brotzen, F., 1948, The Swedish Paleocene and its foraminiferal fauna:
Bolivinoides
Cushman, J. A., 1927, Some characteristic Mexican fossil foraminifera:
Ernst, G., 1963, Stratigraphische und gesteinschemische Untersuchun-
Gałdzicka, E., 1981, Coccoliths and index foraminifera from the upper
Goel, R. K., 1965, Contribution à l’étude des Foraminifères du Crétacé
Hart, M. B., Bailey, H. W., Crittenden, S., Fletcher, B. N., Price, R. J.,
Hartmann, H., and Koch, W., 1955, Biostratigraphie der Grenzschich-
Hofker, J., 1958, Upper Cretaceous
Hofker, J., 1957, Foraminiferen der Oberkreide von Nordwestdeutsch-
Hofker, J., 1956, Die Pseudolitostrophia-Zone der Bohrung Massbüll I und ihre Foraminiferen Fauna: Paläontologische Zeitschrift,
Hoff, J., 1956, Die Pseudolitostrophia-Zone der Bohrung Massbüll I und ihre Foraminiferen Fauna: Paläontologische Zeitschrift,
Haff, R. B. N., Williams, M., Wilkinson, I. P., Lawa, F., Lee, S., and
Gałdzicka, E., 1981, Coccoliths and index foraminifera from the upper Cretaceous chalk of Mielnik region, Eastern Poland: Acta Palaeon-
tologicia Polonica, v. 26, p. 73–84.
Georgescu, M. D., Arzu, A. A., Macauley, R. V., Kukulski, R. A., Aren-
las, I., and Perez-Rodriguez, I. P., 2011, Late Cretaceous (Santo-
nian–Maastrichtian) serial foraminifera with pore mounds or pore
Hoff, J., 1956, Die Pseudolitostrophia-Zone der Bohrung Massbüll I und ihre Foraminiferen Fauna: Paläontologische Zeitschrift,
Haff, R. B. N., Williams, M., Wilkinson, I. P., Lawa, F., Lee, S., and
Zalasiewicz, J., 2014, A refined foraminiferal biostratigraphy for the Late Campanian–Early Maastrichtian succession of northeast
Linking southern Poland and northern Germany: Campanian cephalopods, inoceramid bivalves and echinoids: Acta Geologica Polonica, v. 54, p. 573–586.
Khallil, H., 1998, Late Cretaceous benthonic foraminiferal biostratigra-
phy, Sinai, Egypt, with special consideration to the genus Boliv-
inoides: Neues Jahrbuch für Geologie und Paläontologie, Monat-
Koch, W., 1977, Stratigraphie der Oberkreide in Nordwestdeutschland
(Pompejeckie Scholle). Teil 2. Biostratigraphie in der Oberkreide