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In commemoration of Helena Hurcewicz (1912-2007)

Porosphaera globularis (Phillips, 1829) (Porifera, Calcarea) in the Campanian (Upper Cretaceous) of extra-Carpathian Poland

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ABSTRACT:

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The stratigraphical distribution of *Porosphaera globularis*, a common calcareous sponge in the Upper Cretaceous (mostly Campanian and Maastrichtian) of Poland was studied. The presented material, both new and from museum collections, comes from the Campanian of the Miechów Synclinorium, in southern Poland, and from the Lower Campanian of Mielnik in the south-eastern part of the Mazury-Podlasie Homocline, in eastern Poland. The significance of the species in extra-regional correlation, its palaeobiogeography and stratigraphical potential is critically reviewed.

Key words: *Porosphaera globularis*; Calcareous sponges; Campanian; extra-Carpathian Poland.

INTRODUCTION

During stratigraphical studies of the Campanian–Maastrichtian succession of the Miechów Synclinorium the senior author (AJ) noticed that *Porosphaera globularis* occurs only in certain intervals, while absent in others. The aim of this paper is to document the detailed stratigraphical distribution of *P. globularis* and test its stratigraphical potential, based on extensive material (both historical and newly collected) from the Campanian of extra-Carpathian Poland.

In Poland, *P. globularis* is known so far from the uppermost Santonian through the Campanian. Its presence in the Campanian was first mentioned by Bieda (1933), based on specimens from the lower Campanian of Bonarka (now within the town limits of Kraków) (see also Barczyk 1956). Hurcewicz (1960) reported the species from various localities in the Kraków area. Later, Hurcewicz (1966) and Małecki (1989) reported it from the Lower Campanian of an area farther to the north. Apart from these localities, all within the Miechów Synclinorium, *P. globularis* was also noted from the white chalk of Mielnik and Kornica, two localities in east-central Poland (Olszewska 1987; Langner 1990; Olszewska-Nejbert and Świerczewska-Gładysz 2011).

Porosphaera globularis (Phillips, 1829) belongs to the small, calcareous sponges of the family Minchinellidae Dendy and Row, 1913 (order Lithonida Vacelet, 1981) possessing a skeleton consisting of linked and cemented spicules, which gives them an extremely high preservation potential. *P. globularis* is one of the most common members of the family, and it occurs abundantly in the Upper Cretaceous of Europe in both its western (Hinde 1904; Termier and Termier 1985a, 1985b; Wood 2002; Lepage and Lepage 2011) and central (e.g. Frič 1889; Wollemann 1901; Nestler 1961; Giers 1964) parts. It is also noted from the Peri-Caspian, Vol'sk and Khvalynsk Lowlands (Pervushov 1998) and from the Middle East (Wilmsen *et al.* 2012). *Porosphaera globularis* first appeared in the Early Cenomanian (Normandy, France after Termier and Termier 1985a) and ranged till the early Paleocene (Danian, Stevns Klint, Denmark, after Bjerager and Surlyk 2007). Its relative abundance in the basal Lower Maastrichtian white chalk '*Porosphaera* beds' in the glaciotectonic masses on the Norfolk coast in eastern England has long served as a good marker horizon, at least on a local scale (see Wood 1967; Johansen and Surlyk 1990; Mortimore *et al.* 2001).

MATERIALS AND METHODS

The studied material of *Porosphaera globularis* comes from fourteen sections in the Miechów Synclinorium (Kraków, Miechów and Szczekociny areas; the Bonarka, Pniaki, Iwanowice, Poskwitów, Wierzchowisko, Jeżówka 1, Jeżówka 2, Biała Wielka, Wola Więcławska, Falniów, Poradów, Bibice, Zbyczyce and Komorów sections) and from Mielnik and Kornica, two sections in east-central Poland. The chronostratigraphic position of particular sections studied is based primarily on inoceramid bivalves. Where inoceramids are absent, the stratigraphy is based on foraminifers. Dating of some of the historical outcrops (Bibice, Zbyczyce, Komorów) was possible based on associated museum inoceramid material or archival micropaleontological samples kept with the rest of the palaeontological material.

The studied specimens of *P. globularis* were collected bed by bed from each of the sections. Usually they occur in marls and opokas (siliceous limestones), and are common in specific intervals. These intervals with *P. globularis* were studied in detail.

In total, 161 specimens of *P. globularis* are available for palaeontological study; including both newly collected material and the museum collections of H. Hurcewicz and J. Małecki from the Kraków, Miechów and Szczekociny areas, housed in the University of Łódź. The new specimens are housed in the Laboratory of Geology of the same university (collection nos UL/I and UL/Ia).

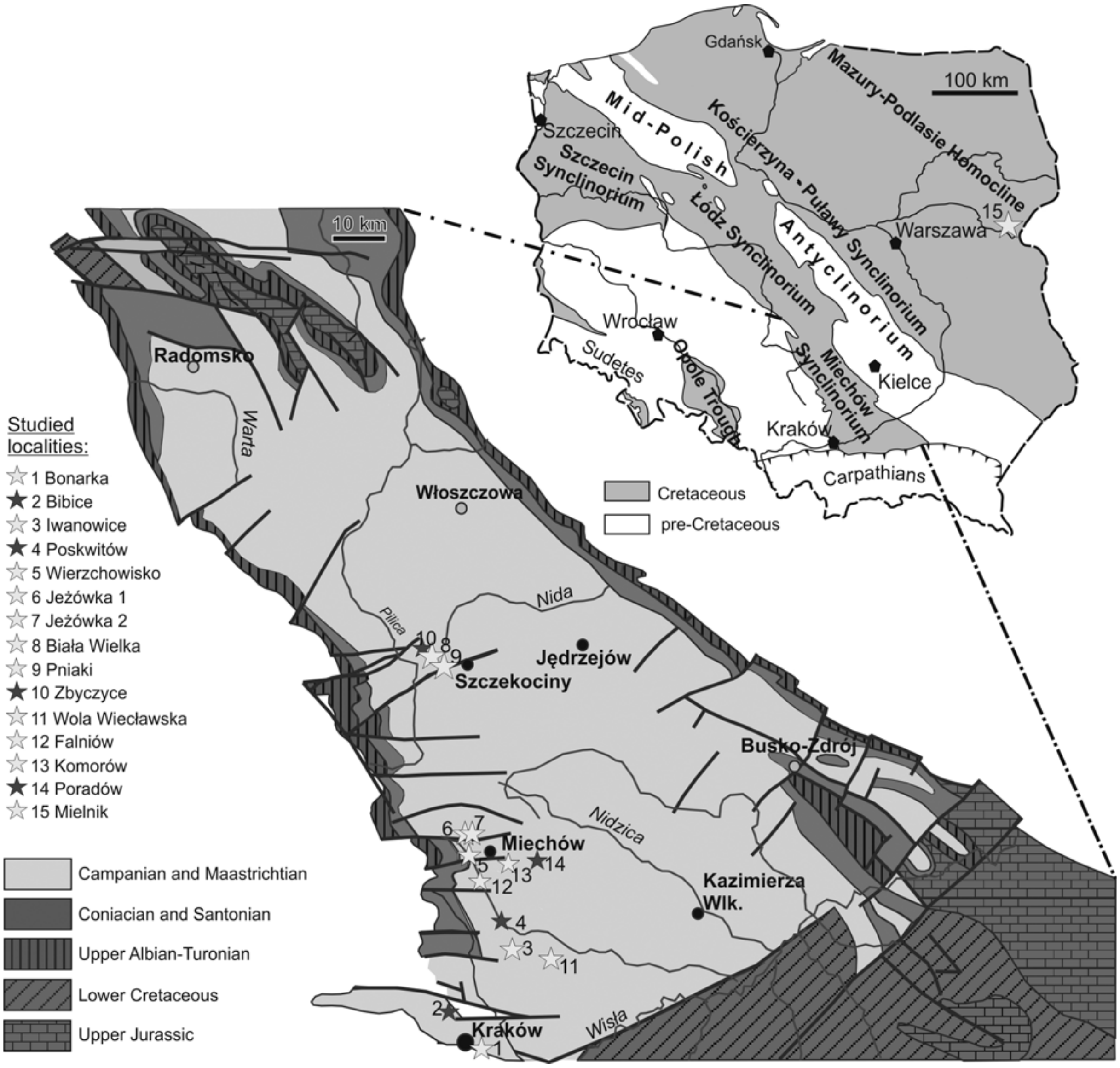
Thin sections, small skeleton samples, and photographic analyses were made in the Microscope Laboratory and Microanalysis Laboratory of the University of Warsaw using a Nicon SMZ 1000 stereoscope microscope, a Nicon ECLIPSE E600W POL optical microscope and a JEOL JSM-6380LA scanning electron microscope.

Following Ogg and Hinnov (2012), the tripartite subdivision of the Campanian Stage, is applied herein (see also Jurkowska 2014).

GEOLOGICAL SETTING AND PALAEOGEOGRAPHY

The Kraków, Miechów and Szczekociny areas are situated in the Miechów Synclinorium (Text-fig. 1), being a south-eastern segment of the Szczecin-Łódź-Miechów Synclinorium. The Mielnik area is located in the south-eastern part of the Mazury-Podlasie Homocline.

All source localities represent the record of the extensive epicontinental Late Cretaceous Sea of extra-Carpathian Poland (Pożaryski 1960; Leszczyński 1997, 2012), which was a part of the North European biogeographic province (Christensen 1976). The topmost Santonian and Campanian of the present-day Miechów Synclinorium (regions of Kraków, Miechów and Szczekociny) was dominated by monotonous carbonate sedimentation (opokas, marly limestones and marls) (Pożaryski 1960; Rutkowski 1965; Walaszczyk 1992, 2004). The Campanian of the Mielnik area is invariably in white chalk facies (Alexandrowicz and Radwan 1992).



Text-fig. 1. Tectonic sketch-maps of Poland (without the Cenozoic cover) (after Pożaryski 1974; Narkiewicz and Dadlez 2008; and Żelaźniewicz *et al.* 2011; simplified) and of the Miechów Synclinorium with source localities of *Porosphaera globularis* (Phillips); recent sites – light-grey stars; historical sites – dark-grey stars

Miechów Synclinorium

Over a dozen *P. globularis*-bearing localities, of the latest Santonian through Campanian, were recognized in the south-western limb of the Miechów Synclinorium (Text-fig. 1).

The Campanian of the area is composed of opoka with marly intercalations. The opoka is represented by wackestone (dominating the Lower Campanian) and packstone (dominating the Middle and Upper Campanian), with planktonic foraminifera and spicules of siliceous sponges. Organodetrital components also comprise fragments of bivalves and rare echinoderms. There is an insignificant admixture of detrital quartz and glauconite. The opoka is quite fossiliferous, with common sponges (lychniscosids, hexactinosids, lyssacinosids and lithistids), echinoids (*Echinocorys* and *Micraster* in opoka, and *Offaster* and rare *Micraster* in marl), bivalves and belemnites.

Some of the exposures (e.g. Narama, Miechów, Rudawa, Szczepanowice) listed by Hurcewicz (1960) and Małecki (1989) were impossible to locate. Moreover, in the case of Szczepanowice, it is difficult to state from which outcrop Hurcewicz's specimens of *P. globularis* were collected, as at least two distinct villages of Szczepanowice exist. The section of Wola Więcławska lies 2 km NE of the section of Michałowice described by Małecki (1989). Stratigraphically, the succession of the Michałowice section seems to be an equivalent of the Wola Więcławska section.

In the Miechów Synclinorium, *P. globularis* seems to be confined to the uppermost Santonian–lower Lower Campanian (*Sphenoceramus patootensiformis* through to *Sphaeroceramus sarumensis–Cataceramus dariensis* zones) the middle Campanian (‘*Inoceramus*’ *azerbaydjanensis*/‘*I.*’ *vorhelmensis* Zone to ‘*I.*’ *tenuilineatus* Zone) and the lowest part of the Upper Campanian (*Sphaeroceramus pertenuiformis* Zone). The species was found in all of the available sections of these stratigraphical intervals, where it occurs commonly in distinct layers.

All of the 14 localities with *P. globularis* are characterized briefly below (in alphabetical order) (Text-figs 1, 2):

Biała Wielka (N 50° 41′ 17.19″; E 19° 39′ 42.52″); working quarry in the Lower Campanian (*Cataceramus dariensis-Sphaeroceramus sarumensis*) opoka with marly intercalation.

Bibice; historical outcrop of Małecki (1989) and Zapałowicz-Bilan *et al.* (2009), c. 10 km north of Kraków. Based on archival collection of inoceramids, the deposit in the outcrop represented the Lower Campanian (*Cataceramus dariensis–Sphaeroceramus sarumensis* Zone) opoka with cherts.

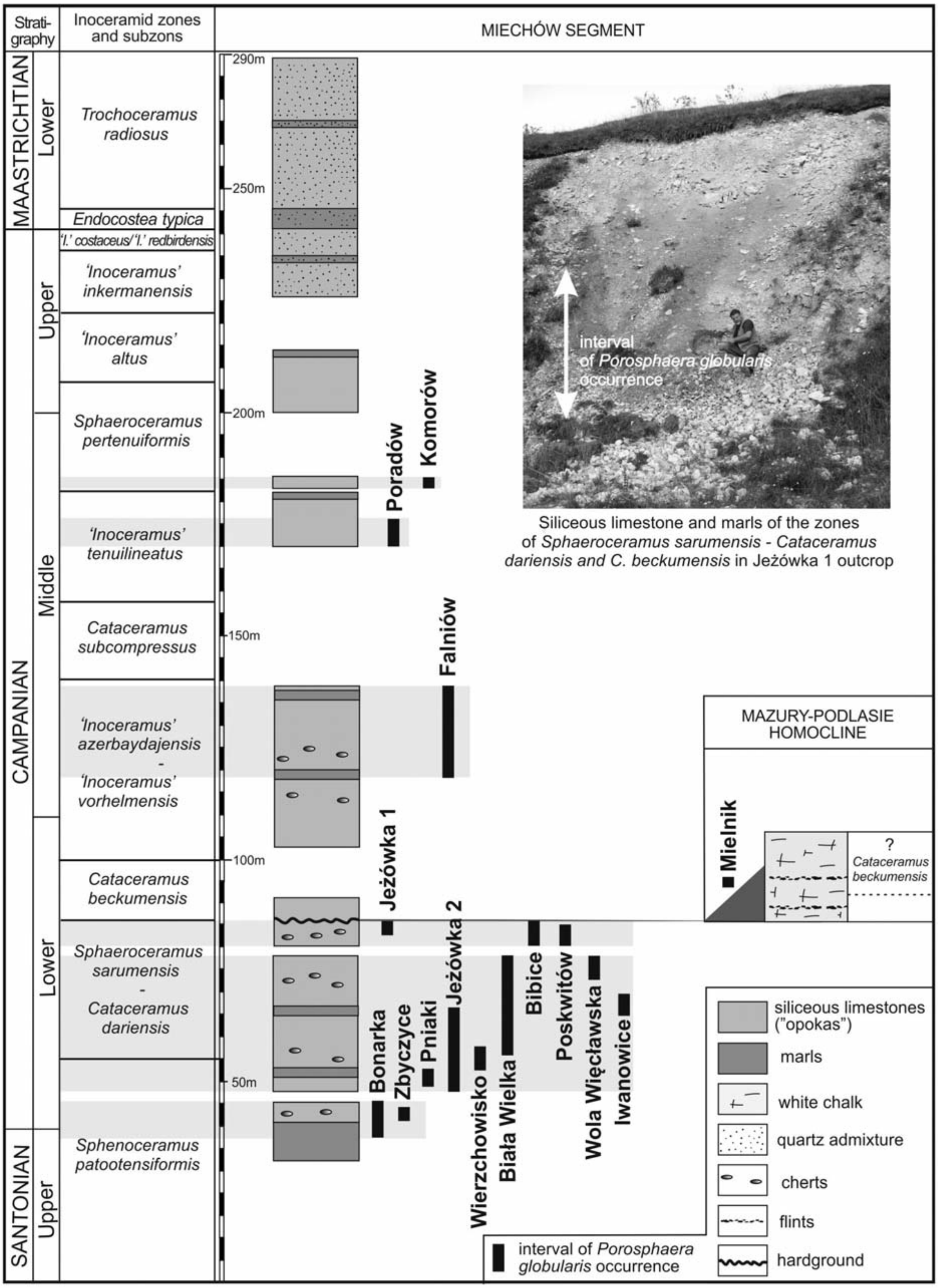
Bonarka (N 50°2′17. 39″; E19°57′15.44″); historical, abandoned quarry (nature reserve), now within the limits of the town of Kraków, in the uppermost Santonian and Lower Campanian (upper *Sphenoceramus patootensiformis* Zone) grey marl and opoka with marly intercalations (see e.g., Smoleński 1906; Panow 1934; Alexandrowicz 1954; Barczyk 1956; Gradziński 1960; Kudrewicz and Olszewska-Nejbert 1997). Apart from some specimens collected by the senior author, *P. globularis* is well represented in the collections of Hurcewicz (1960) and Małecki (1989). The species is abundant in the grey marl and less common in the overlying opoka. A sample from the marl yielded the foraminifera *Stensioeina gracilis* Brotzen, ‘early’ *Stensioeina pommerana* Brotzen and *Bolivinoides strigillatus* (Chapman), and the zonal index crinoid *Marsupites testudinarius*, proving its latest Santonian age. The overlying opoka lacks *M. testudinarius*, and is referred to the earliest Early Campanian.

Falniów (N 50°22′32.54″ E 19°57′56.35″); natural exposure in the Middle Campanian (*‘Inoceramus’ azerbaydjanensis / ‘Inoceramus’ vorhelmensis* Zone) opoka with marly intercalations. Macrofossils are relatively abundant, dominated by sponges and bivalves; *P. globularis* is recognized in the opokas and marls.

Iwanowice (N 50° 11′4. 74″; E 19°59′3.43″); natural exposure in eastern part of the village of Iwanowice (Słomniki area) in the Lower Campanian opoka with marly intercalations. Stratigraphical position of the section is documented by foraminifers studied herein. The co-occurrence of *Bolivinoides granulatus* Hofker, *Gavelinella clementiana* (d'Orbigny), *Stensioeina gracilis* Brotzen, *Gavelinella stelligera* (Marie) and the lack of *Cibicidoides voltzianus* (d'Orbigny) indicate its middle Early Campanian (an interval from the *Offaster pilula/Galeola senonensis* echinoid Zone to the *G. senonensis* Zone of Schulz *et al.* 1984) age. This interval corresponds to the *Cataceramus dariensis-Sphaeroceramus sarumensis* inoceramid Zone of Walaszczyk (1997). *P. globularis* is relatively abundant, mainly in the marls. Some specimens come from the Małecki collection.

Jeżówka 1 (N 50°24′41.37″; E 19°50′12.42″); abandoned quarry in the Lower Campanian opoka. The lower part of the section (below the hardground) represents the *Cataceramus dariensis–Sphaeroceramus sarumensis* Zone. The opoka above the hardground belongs to the upper part of the *Cataceramus beckumensis* Zone (see Jagt *et al.* 2004). Marly horizons with numerous *P. globularis* are 2 m below the hardground.

Jeżówka 2 (N 50°24′50.98″; E 19°49′4.43″); natural exposure in the Lower Campanian opoka with cherts and marly intercalations. The lower, 2 m thick part of the succession represents the upper part of the *Sphenoceramus patootensiformis* Zone. Two samples, collected 3 and 4 m above the base of the section respectively, yielded the biostratigraphically important foraminifers *Gavelinella clementiana*, *Gavelinella stelligera*, *Stensioeina gracilis* and *Bolivinoides granulatus*, dating this part of the succession as middle Early Campanian (*Offaster pilula/Galeola senonensis* echinoid Zone to the *G. senonensis* Zone). This interval corresponds to the inoceramid zone of *Cataceramus dariensis–Sphaeroceramus sarumensis* (Walaszczyk 1997). *P. globularis* was collected throughout the succession, mainly from the marly intercalations.



Text-fig. 2. Geological columns of the Upper Santonian – Lower Maastrichtian of the Miechów Synclinorium (stratigraphy after Jurkowska 2014), and of the Campanian in Mielnik, in the Mazury-Podlasie Homocline with ranges of *Porosphaera globularis* (Phillips, 1829). Outcrops location see Text-fig. 1

Komorów; locality of Hurcewicz (1960; and probably of Rutkowski 1965), near Miechów. Based on inoceramids the section represents the basal Upper Campanian *Sphaeroceramus pertenuiformis* inoceramid Zone.

Pniaki (N 50° 41′ 17.19″; E 19° 39' 42.52″); abandoned quarry in the Lower Campanian opoka with thin marly intercalations. Only the upper part of the section is currently available for research. The precise stratigraphical position of the section is based on newly studied foraminifera. The species present comprised *Bolivinoides granulatus*, *Gavelinella stelligera* and *Stensioeina gracilis*, an assemblage which indicates the middle Lower Campanian.

Poradów (N 50°20′5.12″; E 20°3′5.95″); natural exposure in the Middle Campanian marly opoka with marly intercalations. The following newly obtained foraminifers, *Globorotalites hiltermanni* Kaever, *Globorotalites michelinianus* (d'Orbigny), *Gavelinella monterelensis* (Marie) and *Coryphostoma incrassata* (Reuss), date the succession as belonging to the '*Inoceramus' tenuilineatus* Zone of the late Middle Campanian. *P. globularis* is common in the marly intercalations.

Poskwitów; outcrop of Mączyńska (1968; described also by Kudrewicz and Olszewska-Nejbert 1997) of Lower Campanian marl and marly opokas with cherts.

The newly studied foraminiferal samples from the Poskwitów section yielded: *Gavelinella stelligera*, *Stensioeina gracilis*; *S. pommerana* and *Bolivinoides decoratus* (Jones). These taxa indicate the *Bolivinoides decoratus decoratus* Zone *sensu* Koch, 1977 (the upper part of the Lower Campanian). This zone corresponds to the upper part of the *Sphaeroceramus sarumensis-Cataceramus dariensis* inoceramid Zone (Walaszczyk 1997). *P. globularis* is relatively common throughout the succession, particularly in the marls.

Wierzchowisko (N 50°22′9.35″; E 19°49′5.21″); abandoned quarry in the Lower Campanian (upper *Sphenoceramus patootensiformis* and lower *Cataceramus dariensis–Sphaeroceramus sarumensis* inoceramid Zones; see Jagt *et al.* 2004) opoka with cherts and marly intercalations.

Wola Więcławska (N 50°10′51.67″; E 20°0′58.61″); natural exposure in the Lower Campanian (*Cataceramus dariensis–Sphaeroceramus sarumensis* inoceramid Zone) opoka with marly intercalations, and common *P. globularis*, mainly in the marly intercalations.

Zbyczyce; outcrop of Lower Campanian opoka of Hurcewicz (1966). Newly studied foraminiferal sample yielded *Bolivinoides culverensis* Barr, *Stensioeina gracilis*, *Gavelinella stelligera* and *Globotruncana arca* (Cushman). This assemblage and the lack of *Gavelinella clementiana* indicate the lowermost Campanian *Gonioteuthis granulaquadrata* belemnite Zone (see Schönfeld 1990), which corresponds to the upper part of the *Sphenoceramus patootensiformis* inoceramid Zone (Walaszczyk 1997).

Mazury-Podlasie Homocline

Mielnik (N 52°19′47.49″; E 23°3′5.38″); large working quarry with an exposed succession of Campanian and Maastrichtian white chalk (Gaździcka 1981; Peryt 1981; Olszewska 1990; Olszewska-Nejbert and Świerczewska-Gładysz 2011). *P. globularis* was found in the middle part of the succession, 2–3 m below the upper of the two flints horizons (Text-fig. 2). According to Olszewska-Nejbert and Świerczewska-Gładysz (2011), this part of the succession represents the upper part of the Lower Campanian (undivided belemnite zones of *Goniotheutis gracilis* + *Belemnellocamax mammillatus*). The foraminiferal samples from this part of the succession yielded: *Cibicidoides voltzianus*, *Gavelinella* '*post*' *stelligera*, *Gavelinella clementiana*, *Gavelinella costulata* (Marie), *Bolivinoides decoratus*, and *Bolivinoides laevigatus*. This assemblage indicates the lower–upper Campanian boundary interval (Koch 1977; Hart *et al.* 1989; Schönfeld 1990), corresponding to the *Cataceramus beckumensis* inoceramid Zone (Walaszczyk 1997).

Porosphaera globularis was also noted in Kornica (historical outcrop located about c. 15 km south of Mielnik) by Langner (1990) probably in the same interval as Mielnik, but detailed stratigraphical data are not available.

SYSTEMATIC ACCOUNT

Class: Calcarea Bowerbank, 1864
Order: Lithonida Doederlein, 1892
Family: Minchinellidae Dendy and Row, 1913
Genus *Porosphaera* Steinmann, 1878

TYPE SPECIES: *Millepora globularis* Phillips, 1829, p. 186, pl. 1, fig. 12, by monotypy.

Porosphaera globularis (Phillips, 1829)
(Text-figs 3–6)

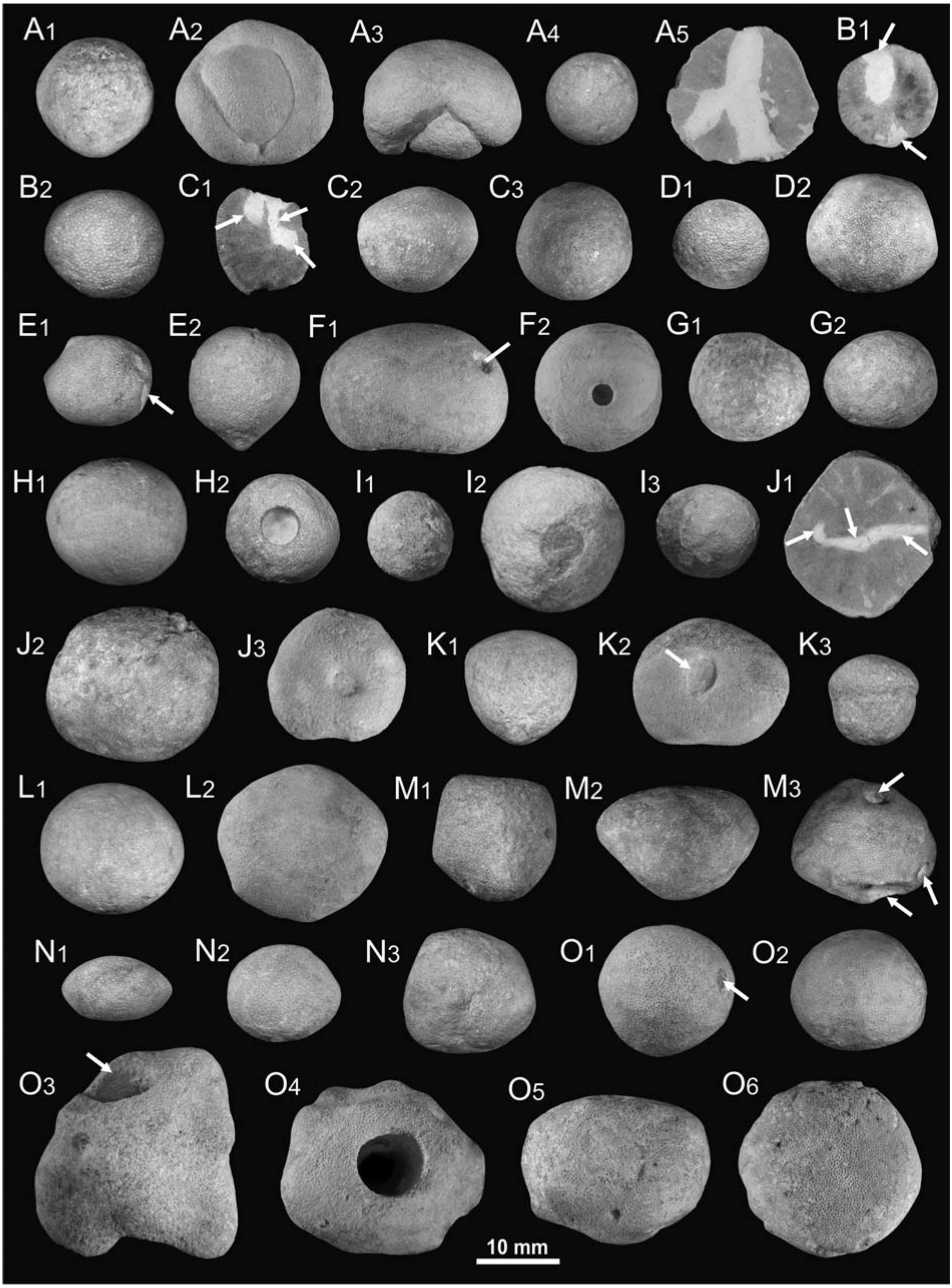
1829. *Millepora globularis*; J. Phillips, p. 186, pl. 1, fig. 12.
1878. *Porosphaera globularis* (Phillips); G. Steinmann, p. 102, pl. 13, figs 8–12.
1889. *Amorphospongia globosa* v. Hag. sp.; A. Frič, p. 108, fig. 52.
1901. *Porosphaera globularis* (Phillips); A. Wolleman, p. 10–11.
1903. *Porosphaera globularis* Reuss sp.; F. Počta, p. 8–10, pl. 1, figs 4–12; text-fig. 1.
1904. *Porosphaera globularis* (Phillips); G.J. Hinde, p. 18, pl. 1, figs 1–10, pl. 2, figs 1–3, 6–10.
1960. *Porosphaera globularis* (Phillips); H. Hurcewicz, pp. 438–444, text-fig. 1–3, pl. 1, fig. 1–29, pl. 2, figs 1–2 [with synonymy].
1961. *Porosphaera globularis* (Phillips); H. Nestler, p. 39, pl. 10, pl. 11, figs 1–8 [with additional synonymy].
1961. *Porosphaera nuciformis* (Hagenow); H. Nestler, pp. 43–44, pl. 11, fig. 10.
1964. *Porosphaera globularis* (Phillips); R. Giers, p. 223.
1974. *Porosphaera globularis* (Phillips); H. Ulbrich, p. 70.
1986. *Porosphaera globularis* (Phillips); H.H. Stühmer *et al.*, pl. 3, 4, 6.
1989. *Porosphaera globularis* (Phillips); H. Hurcewicz, p. 235, pl. 145, figs 8–10.
1989. *Porosphaera globularis* (Phillips); J. Małecki, p. 206, text-pl. 1, figs 1–5; pl. 2, figs 1–6; pl. 1, figs 2–17; pl. 2, figs 1–7; pl. 3, figs 1–6; pl. 4, figs 1–5. p. 206–215.
1989. *Porosphaera nuciformis* (Hagenow); J. Małecki, p. 216, pl. 1, fig. 1.
1990. *Porosphaera globularis* (Phillips); E. Langner, p. 39, pl. 4, figs 1–5.
2012. *Porosphaera globularis* (Phillips); M. Wilmsen *et al.*, pp. 92–94, figs 4, 5 [with additional synonymy].
2014. *Porosphaera globularis* (Phillips); T. Hansen and F. Surlyk, fig. 4.1.

TYPE: Phillips (1829) did not indicate the holotype of his new species *Millepora globularis*, however, the original of his illustrated specimen (Phillips 1829, pl. 1, fig. 12), from the topmost Santonian (see Wilmsen *et al.* 2012) of Dane's Dyke (Yorkshire Coast, eastern England), following Hinde (1904) should be housed in the York Museum. According to recent information from Sarah King, the curator of this Museum, their collections do indeed contain the specimen in question; the label accompanying it reads: *Millepora globularis* Phillips, Holotype: YM 26, Cretaceous, Chalk; Danes Dyke. Phillips 1829, pl. I, fig.12. Ed. 3 (1875) as *Coscinopora globularis*. According to Pyrah (1976), however, this specimen does not match the Phillips' illustrated specimen, and we fully agree with this statement, based on illustrations of it sent to us by Sarah King. It therefore appears that specimen YM 26 was never illustrated and/or described, although it most probably comes from Phillips' original collection. The present location of the Phillips' (1829) illustrated specimen is unknown.

MATERIAL: 38 specimens from Bonarka, 6 specimens from Bibice, 18 specimens from Iwanowice, 7 specimens from Poskwitów, 3 specimens from Wierzchowisko, 8 specimens from Jeżówka 1, 4 specimens from Jeżówka 2, 15 specimens from Biała Wielka, 24 specimens from Zbyczyce, 8 specimens from Wola Więcławska, 6 specimens from Falniów, 15 specimens from Komorów, 4 specimens from Poradów, 5 specimens from Mielnik.

DESCRIPTION: The specimens studied vary in shape (Text-fig. 3). These from the opoka of the Miechów Synclinorium are spherical, loaf-like or pearl-like, usually small, 10–15 mm in diameter. The larger specimens, up to 20–25 mm in diameter, are rare and usually less regular. In two atypical specimens from Bonarka (Text-fig. 3A2, A3) and one from Iwanowice, the outer (younger) layer of the skeleton is developed asymmetrically and the inner (older) part of a skeleton is visible on one side. Among the material from the marly facies of the Miechów Synclinorium, rhomboidal, triangular and flattened specimens, 9–15 mm in size, are frequent. Specimens from the white chalk of Mielnik are rounded, oval or very irregular (Text-fig. 3O1–O6), relatively large, up to 30 mm in diameter (Text-fig. 3O3). The outer surfaces of the specimens are covered by small pores, 0.15–0.3 mm in diameter. Shallow radial grooves, around the narrow site, were noted in only two pearl-like specimens.

All of the specimens are calcitized (Text-figs 4–6) and some of the specimens from Mielnik are partly silicified (Text-fig. 4 E, F). The best preserved is usually the outer layer of the basal skeleton, c.1 mm thick, especially in specimens from the white chalk of Mielnik (Text-figs 5A–D, 6B–D). This portion of the basal skeleton is composed of linked tetractines, the actines of which are up to 0.1 mm long and 0.04–0.05 mm wide. The free apical actines of teractines are damaged, without tips. The internal radial structure of the basal skeleton was observed in only a few specimens (Text-fig. 6A). In these specimens, mutually cemented tetractines forming radial skeletal fibres are partly masked by late sparry calcite, which fills the skeletal interspaces (Text-figs 4, 6A, E–F). Locally, the central part of the tetractines is discernible whereas the distal part of the actines and zygosis is not visible (Text-figs 4, 6A, E, F). In specimens from opoka, the late calcite infills almost the entire interspicular space of the skeleton and the spicules are completely unrecognizable (Text-fig. 4D).


A1
A2
A3
A4
A5
B1
B2
C1
C2
C3
D1
D2
E1
E2
F1
F2
G1
G2
H1
H2
I1
I2
I3
J1
J2
J3
K1
K2
K3
L1
L2
M1
M2
M3
N1
N2
N3
O1
O2
O3
O4
O5
O6
10 mm

REMARKS: *Porosphaera globularis* from the Kraków and Miechów areas was described by Hurcewicz (1960) and Małecki (1989), and those from the white chalk of Kornica by Langner (1990); specimens from Mielnik have not yet been studied.

The shape of specimens from the Campanian of Poland is very variable, but falls within the range of variability of *P. globularis* (e.g. Hinde 1904; Nestler 1961). Less regular specimens are more common in marl than in opoka (cf. Hurcewicz 1960), and are also common in white chalk. Rare, irregularly-shaped specimens, with the outer layer of the skeleton asymmetrical or incomplete, were noted earlier by Hurcewicz (1960, pl. 1 fig. 28) and Małecki (1989, pl. 2 fig. 6). The presence of such forms may be due to regeneration. Hurcewicz (1960, p. 441, pl. I, figs 25, 26) reported specimens with irregular grooves, often intersecting each other. In our experience, specimens with similar grooves or irregular pits were found only to occur in the talus and not in the fresh rock. This sculpure is thus not a characteristic feature of the sponges but results from damage due to weathering.

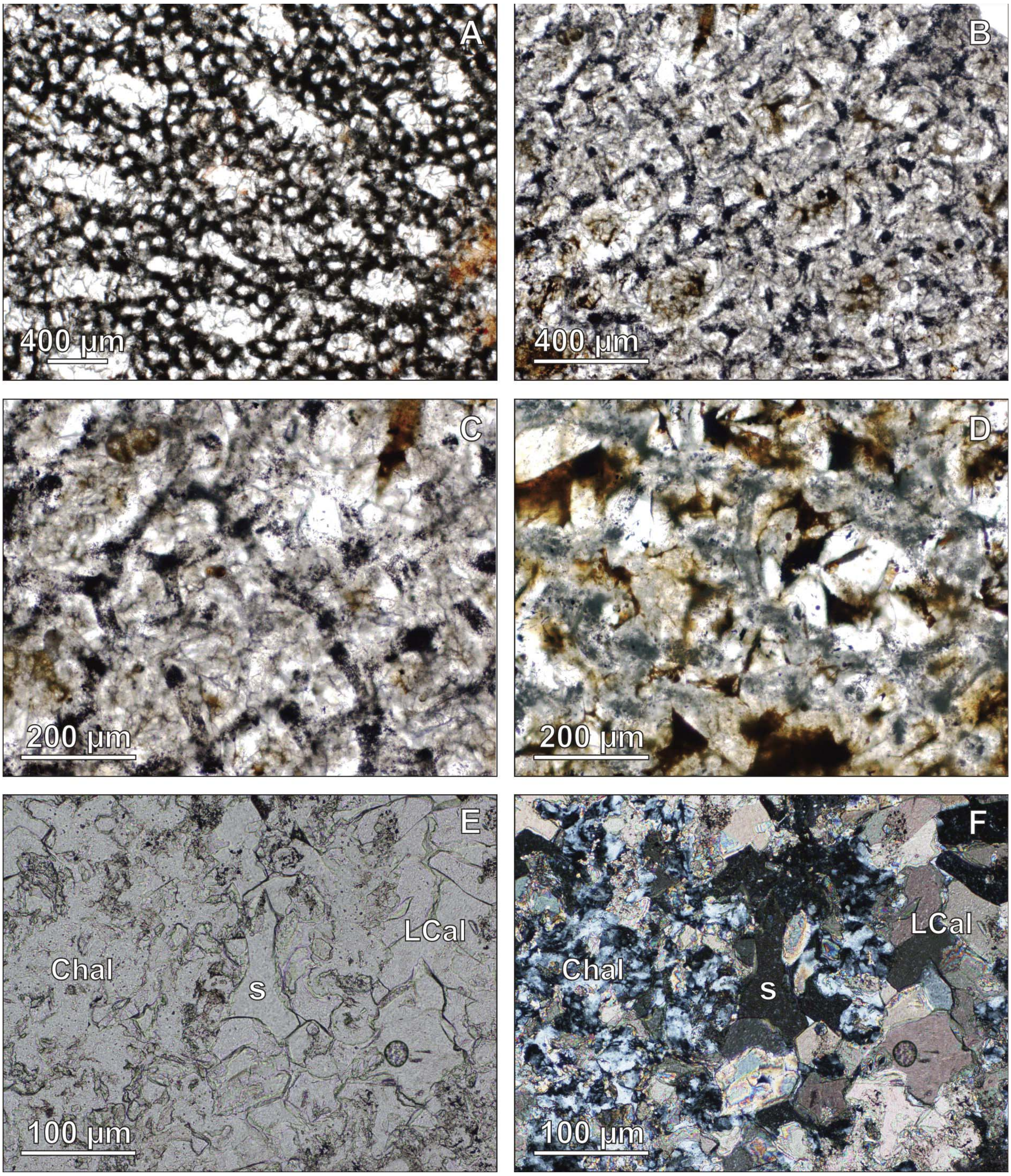
The arrangement of the skeletal fibres in the specimens studied is always radial, similar to that in specimens described elsewhere (e.g. Frič 1889; Hinde 1904; Nestler 1961; Wilmsen *et al.* 2012). However, Hurcewicz (1960), besides specimens with radial structures of the skeleton (her p. 441, pl. 2, fig. 1), also described specimens characterized by a large central core without radial structure (see Hurcewicz 1960, p. 441, pl. 2, fig. 2a, b). It seems that the presence of a central core could have been a result of improper orientation of the plane of the thin-section. In cross-sections which do not pass through the centre of the sponge, the radial skeletal fibres are perpendicular or nearly perpendicular to the plane of the sections and their radial arangament is not visible.

Małecki (1989, pl. 1, figs. 3, 4) illustrated tetractines from the inner part of the skeleton of *P. globularis* that were identical to spicules described by Hinde (1904). The distal parts of actines and the spines on the apical actines of tetractines illustrated by Małecki (1989, pl. 1, fig. 4a–c), were not observed in the material examined, including specimens from Małecki's own collection. Due to strong calcitization, the central part of tetractines is recognized only sporadically, similar to the spicules described by Hurcewicz (1960, fig. 1–3) and Wilmsen *et al.* (2012, fig. 5E–G).

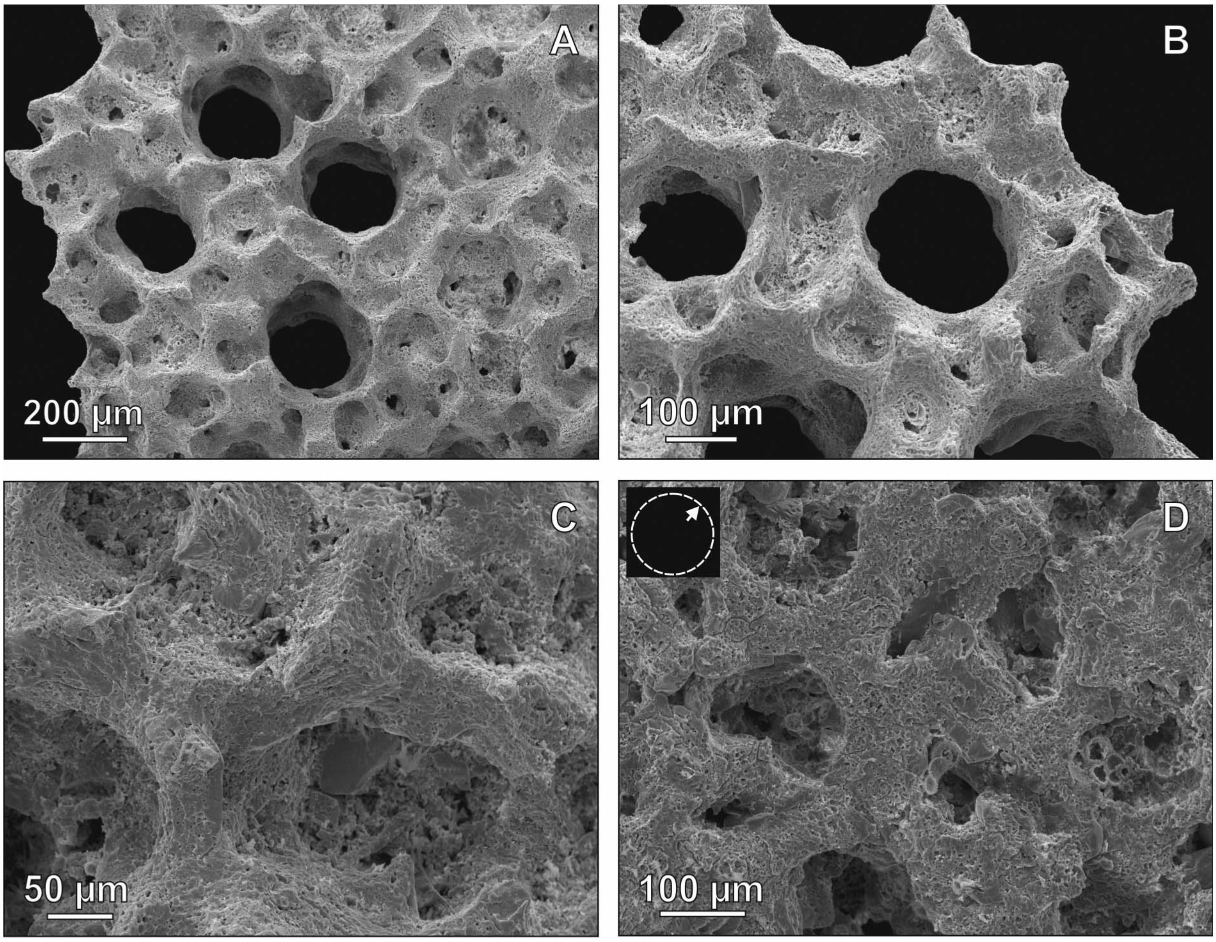
Hurcewicz (1960) and Wilmsen *et al.* (2012) included specimens with shallow radial furrows on the outer surface of the basal skeleton in *P. globularis*. On the other hand, Małecki (1989) and Nestler (1961) referred such specimens to *Porosphaera nuciformis* (Hagenow). The differences between *P. globularis* and *P. nuciformis* are not clear. According to Hinde (1904), the latter species is characterized by the presence of star-like furrows (see Hinde 1904, p. 20–21, pl. 1, figs 11–18, pl. 2, fig. 4), but shallow grooves may also occur in *P. globularis* (see Hinde 1904, pl. 1, figs 9–10). Other features unique to *P. nuciformis* are not known. Wilmsen *et al.* (2012) noted that *P. nuciformis* (Hagenow) was very rare and that it seemed to be identical in terms of stratigraphical and geographical ranges to *P. globularis*. Part of the specimens from the Campanian of Spain classified by Küchler (2000) as *P. nuciformis* are smooth, without grooves (Küchler 2000; and also his personal information and unpublished photographs), which correspond well to the diagnosis of *P. globularis.* The co-occurrence of both species in the same beds also suggests that *P. nuciformis* may be one of the numerous morphotype of *P. globularis*.

Among the numerous species of *Porosphaera* (e.g. Stolley 1892; Hinde 1904; Brünnich Nielsen 1929; Senowbari-Daryan *et al.* 2011) only some are well diagnosed. Most of them (e.g. *P. plana* (Stolley, 1892), *P. semiglobularis* (Stolley, 1892), *P. universa* Brünnich Nielsen, 1929 and *P. cerasi* Brünnich Nielsen, 1929) are rare Cretaceous species, based upon body form or size of pores. Both features are variable in *P. globularis* and it cannot be excluded that some of these specimens are its younger synonymus. However, their revision is hampered by the lack of data on their basal skeleton. *Porosphaera plana* (Stolley) was described by Małecki (1989, p. 216, pl. 1, fig. 18) from the Kraków area, but these specimens are missing and their skeleton cannot

Text-fig. 3. *Porosphaera globularis* (Phillips, 1829) from the Campanian of Poland. **A1-A5** – Bonarka. **A1** – ULIa/Bo1. **A2, A3** – view of the same specimen ULIa/Bo2; **A4** – ULIa/Bo3; **A5** – section trough specimen ULIa/Bo4 with two crossing borings. **B1-B2**, Bibice. **B1**, section trough specimen ULIa/Bi1with two borings. **B2** – ULIa/Bi2. **C1-C3** – specimens from Iwanowice; **C1** – section trough specimen ULIa/I1with three crossing borings. **C2** – ULIa/I2. **C3** – ULIa/I3. **D1-D2** – specimens from Poskwitów. **D1** – ULIa/Ps1. **D2** – ULIa/Ps2. **E1-E2** – specimens from Wierzchowisko. **E1** – ULIa/W1. **E2** – ULIa/W2. **F1-F2** – specimens from Jeżówka 1. **F1** – ULIa/J1. **F2** – ULIa/J2. **G1-G2** – specimens from Jeżówka 2. **G1** – ULIa/Je1. **G2** – ULIa/Je2. **H1-H2** – specimens from Pniaki. **H1** – ULIa/Pn1. **H2** – ULIa/Pn2. **I1-I3** – specimens from Biała Wielka. **I1** – ULIa/Bw1. **I2** – ULIa/Bw2 **J1-J3** – specimens from Zbyczyce; **J1** – section trough specimen ULIa/Z1with a three crossing borings. **J2** – ULIa/Z2. **J3** – ULIa/Z3. **K1-K3** – specimens from Wola Więcławska. **K1** – ULIa/Ww1. **K2** – ULIa/Ww2. **L1-L2** – specimens from Falniów. **L1** – ULIa/F1. **L2** – ULIa/F2. **M1-M3** – specimens from Komorów. **M1, M2** – ULIa/K1. **M3** – ULIa/K2. **N1-N3** – specimens from Poradów. **N1** – ULIa/Po1. **N2** – ULIa/Po2. **O1-O6** – specimens from Mielnik; **O1** – ULIa/M1. **O2** – ULIa/M2. **O3**, **O4** – view of the same specimen ULIa/M4. **O5**, **O6** – ULIa/M4. Some borings arrowed be examined. The loose ectosomal spicules, critical for the taxonomy of recent species of Minchinellidae (Vacelet 1981, 1991; Könnecker and Freiwald 2005), have usually not been found in fossil sponges. In our material these spicules are also missing. Tetractines described by Małecki (1989, pl. 1, fig. 2a, b) as ectosomal spicules are spicules from the outer layer of the basal skeleton.



Text-fig. 4. Skeleton of specimen ULI/256 Bonarka (A-D) and specimen ULI/M3 from Mielnik (E, F) observed in thin sections. A – internal structure of the skeleton shows the typical radiating canals. B, C – tetractines from external part of basal skeleton. D – poorly preserved tetractines masked by late calcite. E – internal structure of the poorly visible skeleton, strongly calcitized and silicified. F – the same, crossed nicols. Chal – chalcedone; LCal – late calcite; s – calcareous spicule (tetractine)



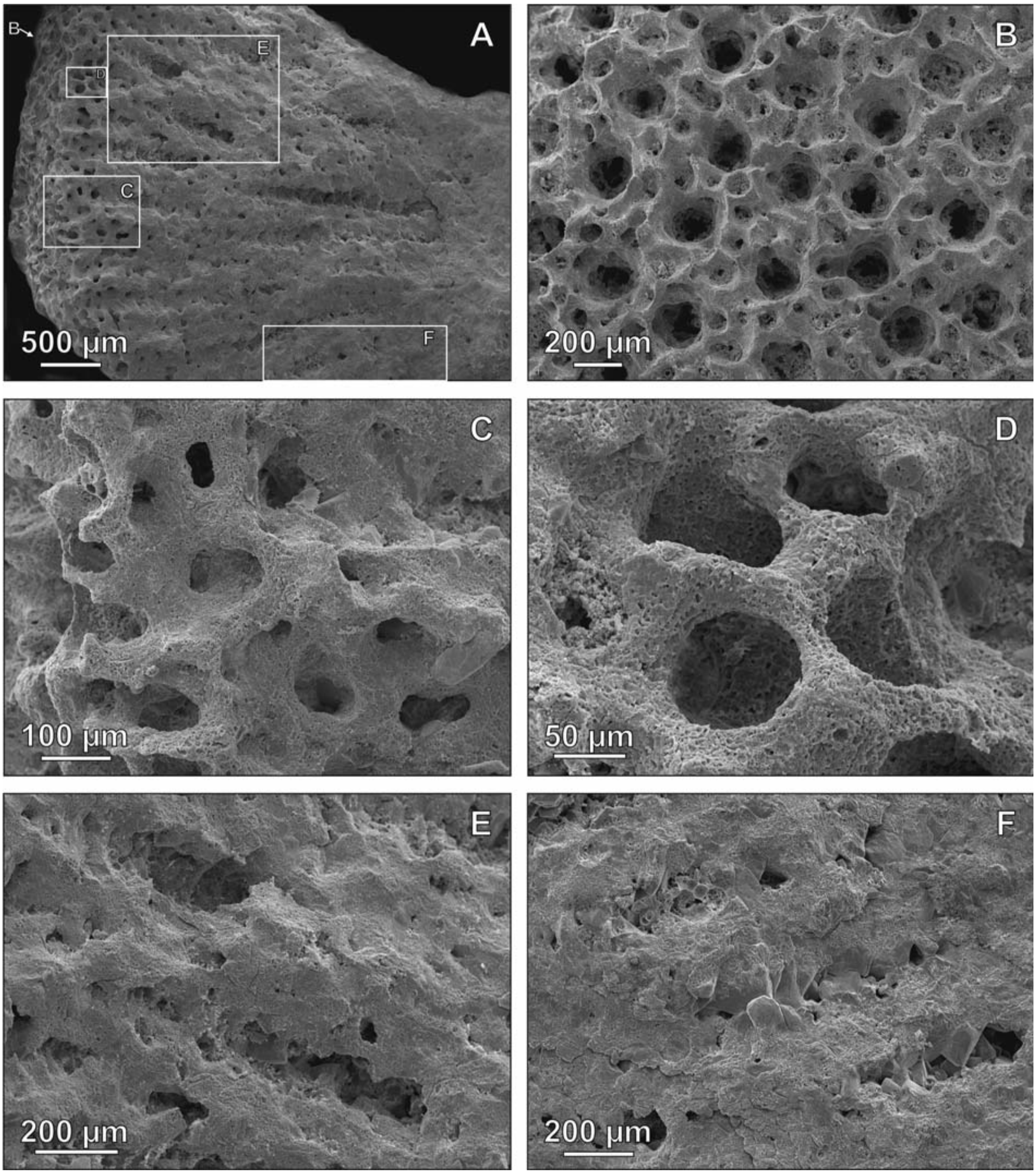
Text-fig. 5. SEM images showing the structure of outer layer of basal skeletal of *Porosphaera globularis* (Phillips, 1829) from Mielnik, ULIa/M5. A-C – external surface of outer layer of basal skeletal with fused tetractines; locally visible their free apical actines pointing outwards. D – inner surface (arrowed on scheme) of outer layer of basal skeleton; visible fused basal actines of tetractines; surface of tetractines less regular as on fig. A-C, due to the growth of late calcite

The ectosomal skeleton of *P. globularis* was described only by Hinde (1904, pl. 2, figs 2, 7, 10), which seems to be a unique phenomenon in the fossil representatives of Minchinellidae.

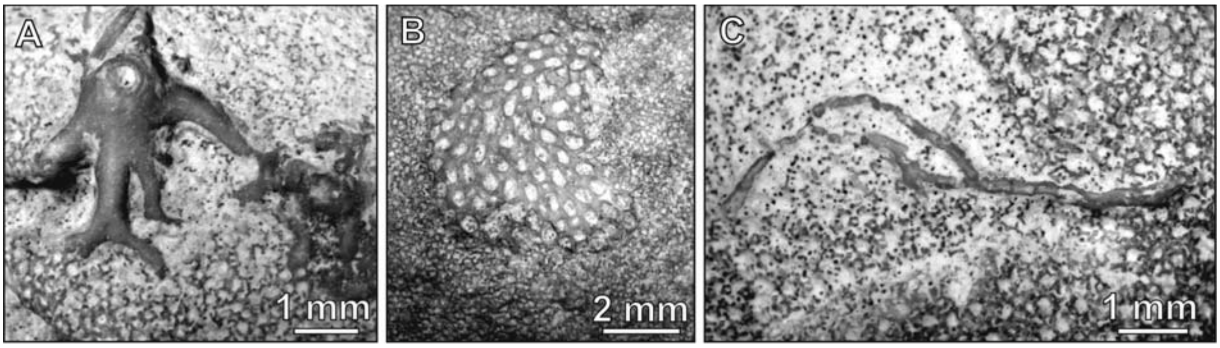
EPIFAUNA AND BORINGS: The epifauna, represented by bryozoans, octocorals (Text-fig. 7) and probably serpulids, is extremely rare; it was found only on six large specimens.

In the material studied ca. 17% of the sponges have cylindrical borings, with slightly rounded terminations (Text-fig. 3). Such borings are common in *P. globularis* from other localities (e.g. Nestler 1961; Wilmsen *et al.* 2012) and are interpreted as the mobile domicile of sipunculan worms (Neumann *et al.* 2008). Małecki (1989) described borings only in large specimens (more than 15 mm in diameter), while we noted them also on smaller ones, 8–10 mm in diameter. According to Hurcewicz (1960) and Małecki (1989), borings often pierce through the sponge's body. Our observations agree with Rigaud *et al.* (2009), that borings never go through the entire length of a specimen. Borings are often very deep which causes the remaining part of the sponge skeleton to be thinner (ca. 2 mm) so that it could be easily destroyed (Text-fig. 3A5). The wide conical shape of borings illustrated by Małecki (1989, pl. 2, fig. 4), is a result of damage of the sponge's skeleton around the terminal part of a boring. In some specimens 2–3, even 5 borings occur (Text-fig. 3B1, C1, J1, M3). Usually one boring is larger than the other or the others. Differently oriented borings inside the sponge skeleton may be connected and form an irregular system. Sometimes in transverse section only a small part of this system is visible, which seems to be one winding boring (Text-fig. 3A5, J1; see also Małecki 1989, pl. 2, fig. 5).

OCCURRENCE: Poland (Kraków, Miechów and Szczekociny area; uppermost Santonian, Lower and Middle Campanian; Mielnik, Lower Campanian; Kornica, ?Lower Campanian), England (southern England, Turonian–Campanian – after Hinde 1904 and Wood 2002; Norfolk, Lower Maastrichtian – after Peak and Hancock 1961, 1970 and Mortimore *et al.* 2001); Scotland (?Coniacian–?Campanian – after Mortimore *et al.* 2001), Northern Ireland (Santonian–Upper Campanian – after Fletcher and Wood 1978; Wilson and Robbie 1966); France (Normandy, Cenomanian – after Termier and Termier 1985a; northern France, Coniacian – after



Text-fig. 6. SEM images showing the skeletal of *Porosphaera globularis* (Phillips, 1829) from Mielnik, ULIa/M5. A – cross-section of basal skeleton; radiating structures are poorly visible; B – external surface of outer layer of basal skeletal. C – details of outer layer of skeleton ca. 400 µm thick, without late sparry calcite. D – enlarged fragment of skeleton from outer layer. E – inner layer of basal skeleton; single tetractines not visible, probably masked by filling of interspace by a late sparry calcite. F – close-up of the central part of the basal skeleton; visible radiating structures cemented by late sparry calcite, tetractines not visible



Text-fig. 7. Epifauna on the surface of *Porosphaera globularis* (Phillips, 1829). A – *Moltkia* sp., calcified attached base of octocoral comprising a root-like, multi-branching structure. B, C – bryozoans; B – sheet-like encrusting colony; C – poorly preserved runner-like encrusting form (? *Voigtopora* sp.); all specimens are from the Miechów Synclinorium

Lepage and Lepage 2011; Campanian – after Brünnich and Nielsen 1929, with additional comments by Gaspard 2002; south-western France, Santonian–Lower Campanian – after Termier and Termier 1985b), Spain (Lower, Middle and Upper Campanian – after Küchler, personal information); Netherlands (Upper Maastrichtian – after Neumann *et al.* 2008); Germany (Helgoland, Turonian – after Stühmer *et al.* 1986; Westphalia, Middle Campanian – after Giers 1964 with additional comments by Kaplan *et al.* 1996, Walaszczyk 1997 and Jagt *et al.* 2004; Stapelburg, Lower Campanian after Ulbrich 1974; Peine and Lehrte region near Hannover, Lower Saxony, Lower Campanian – after Niebuhr 1995; Misburg, Lower Saxony, Upper Campanian – after Neumann *et al.* 2008 and Niebuhr 1996; Rügen, Lower Maastrichtian – after Nestler 1961, Neumann *et al.* 2008, Reich and Frenzel 2002; Hemmoor, Schleswig-Holstein, Upper Maastrichtian – after Neumann *et al.* 2008); Denmark (Alaborg, Upper Maastrichtian – after Lauridsen and Surlyk 2008; Mons Klint, Upper Campanian and/or Maastrichtian – after Brünnich Nielsen 1929 with additional comments by Surlyk *et al.* 2013 and Ogg and Hinnov 2012; Stevns Klint, Upper Maastrichtian – after Hansen and Surlyk 2014; Lower Paleocene – after Bjerager and Surlyk 2007); Belgium (Upper Campanian – after Jagt and Michels 1986; Maastrichtian – after Jagt *et al.* 2009); Czech Republic (Upper Turonian and/or Lower Coniacian – after Frič 1889 with additional comments by Čech *et al.* 1980), Crimea (after Naidin, unpublished data); Russia (Vol'sk and Khvalynsk areas, Lower Maastrichtian – after Pervushov 1998 and Naidin, unpublished data); Khazakhstan (Embi and Kobda areas, Lower Maastrichtian - after Naidin, unpublished data); northern Causasus (Lower Campanian – after Naidin, unpublished data); Tajikistan (Lower Maastrichtian – after Naidin, unpublished data); Iran (Khur area, Central Iran, ?Lower Maastrichtian – after Wilmsen *et al.* 2012).

DISCUSSION

Porosphaera globularis ranges through most of the Upper Cretaceous of Europe, and usually occurs in distinct horizons of various thickness (e.g. Küchler 2000; Mortimore *et al.* 2001; Wilmsen *et al.* 2012). Hinde (1904) noted that the largest specimens of *Porosphaera globularis* occur in the Upper Santonian *Uintacrinus socialis* and *Marsupites testudinarius* zones in southern England, in which zones they are sufficiently common to serve as guide fossils.

Porosphaera globularis is also most common in the Campanian (e.g. Giers 1964; Küchler 2000; unpublished data of D.P. Naidin) and Maastrichtian (e.g. Nestler 1961; Pervushov 1998; Mortimore *et al.* 2001, Reich and Frenzel 2002; Wilmsen *et al.* 2012; unpublished data of D.P. Naidin) (Text-fig. 8).

Clearly, *P. globularis* is most common in the Lower Campanian. In Germany, it is known from the *Sphenoceramus patootensiformis–Cataceramus dariensis*/*Sphaeroceramus sarumensis* inoceramid zones of Lower Saxony (Niebuhr 1995; for details and correlation of inoceramid zonation see Walaszczyk 1997) and Sachsen-Anhalt (Ulbrich 1974). Küchler reported *P. globularis* from the *Scaphites hippocrepis III*/*Menabites* spp. ammonite Zone of Spain (personal information), which corresponds to the lower part of the *Cataceramus dariensis*/*Sphaeroceramus sarumensis* inoceramid Zone of Walaszczyk (1997). From the uppermost Lower Campanian, *P. globularis* is known from the *Cataceramus beckumensis* Zone (for stratigraphical details see Walaszczyk 1997; Jagt *et al.* 2004; Keutgen 2011) of the Zeven Vegen Member of the lower part of the Gulpen Formation in Belgium (Jagt and Michels 1986).

From the Middle Campanian, *P. globularis* is noted in Belgium, in the upper part of the *Belemnitella mucronata*/*Belemnitella woodi* belemnite Zone (Keutgen

2011) of the Zeven Vegen Member (Jagt and Michels 1986), which corresponds to the '*Inoceramus*' *azerbaydjanensis*/'*I.*' *vorhelmensis* inoceramid Zone (Walaszczyk 1997; Jagt *et al.* 2004). In the same interval *P. globularis* was recognized in Westphalia (Giers 1964; for stratigraphical details see Kaplan *et al.* 1996; Jagt *et al.* 2004). Küchler (pers. com) noted the species in the *Nostoceras* (*Bostrochyceras*) *polyplocum* ammonite Zone in Spain, which corresponds to the *Cataceramus subcompressus* inoceramid Zone of Walaszczyk (2004). Similarly *P. globularis* was noted in Lower Saxony (Nieburh 1996; Neumann *et al.* 2008) in the *Conulus vulgaris*/*Micraster stolleyi* echinoid Zone, which corresponds to the *C. subcompressus* inoceramid Zone of Walaszczyk *et al.* (2008). In the upper part of the Middle Campanian ('*Inoceramus*' *tenuilineatus* Zone), *P. globularis* is known so far only from the Miechów Synclinorium.

In the Upper Campanian *P. globularis* was recognized only in Spain (Küchler 2000) in the *Nostoceras* (*Nostoceras*) *hyatti* ammonite Zone, which corresponds to the '*Inoceramus*' *inkermanensis* Zone of Walaszczyk (2004).

P. globularis is also known from the Campanian of France (Termier and Termier 1985b; Brünnich and Nielsen 1929) but biostratigraphical details of the report are unknown.

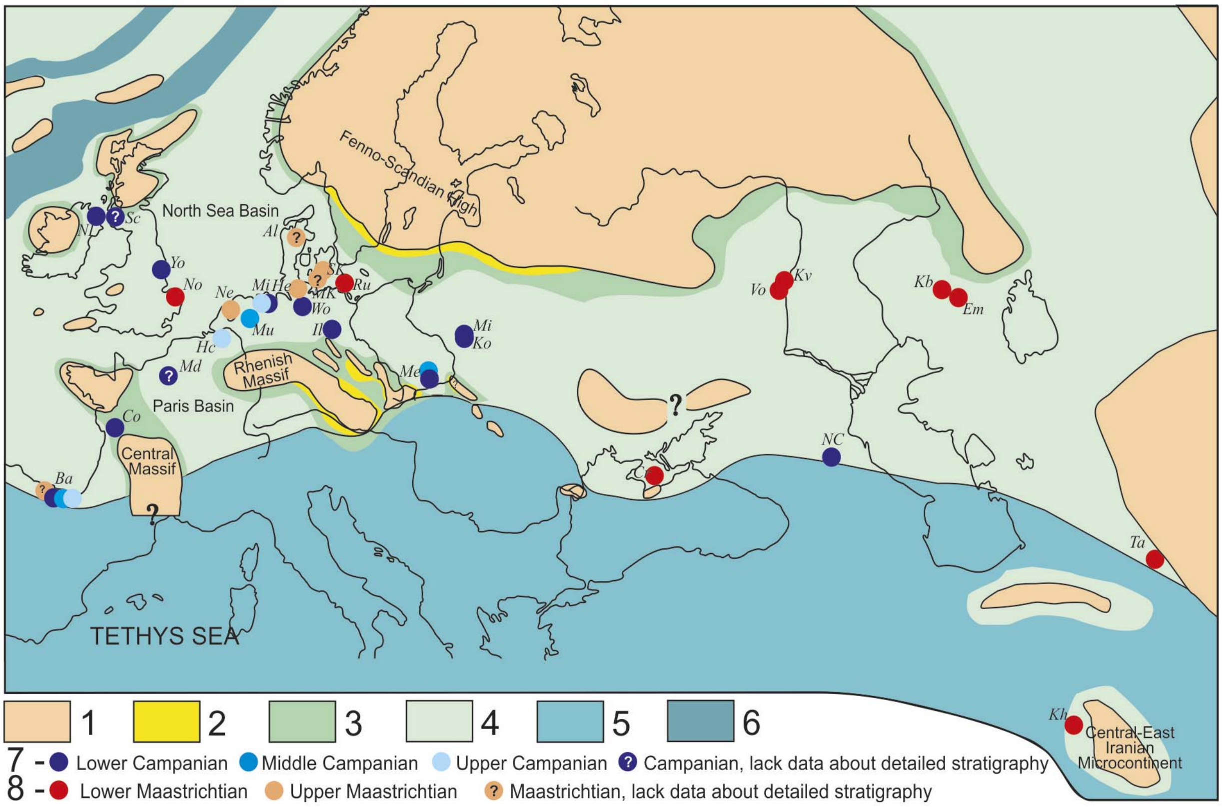
In the white chalk of the glaciotectonic masses on the Norfolk coast in eastern England an interval with relatively abundant *P. globularis* is called the '*Porosphaera* beds' and was used for local stratigraphical correlation of the various masses (Wood 1967; Johansen and Surlyk 1990; for detailed stratigraphy see Mortimore *et al.* 2001). According to Christensen *et al.* (2000) the *Porosphaera* Beds in England belong to the *Belemnella pseudobtusa* and *B. obtusa* belemnite Zones which correspond to the *Endocostea typica* inoceramid Zone (lower part of the Lower Maastrichtian) (see Keutgen *et al.* 2012). A mass-occurrence of *P. globularis* in the lower Maastrichtian white chalk was noted in Rügen Island, Germany (Nestler 1961; Reich and Frenzel 2002). Specimens illustrated by Reich and Frenzel (2002) derive from the V brachiopod Zone *sensu* Steinich (1965). Representatives of the foraminiferal genus *Stensioeina* were noted only in the lower part of this zone (Reich and Frenzel 2002). The last appearance of this genus is a good proxy of the lower/upper Maastrichtian boundary (Dubicka and Peryt 2012). These data suggest that the beds with *P. globularis* in Rügen are younger than the '*Porosphaera* beds' in England.

In the Santonian–Campanian Ulster White Limestone succession in Northern Ireland *P. globularis* is recorded from each of the members (see Fletcher and Wood 1978 for details); it has not been recorded from the overlying Lower Maastrichtian limestones but its apparent absence is almost certainly due to the difficulty of observing it in sections that are not air-weathered. There is therefore no evidence to show whether or not the *Porosphaera beds* abundance event is represented in Northern Ireland.

In Poland, the stratigraphically equivalent deposits of the white chalk facies *Porosphaera beds* in eastern England crop out near the town of Pińczów, in the Miechów Synclinorium (sandy marls of the *Endocostea typica* Zone), and near Kłudzie and Dziurków in the middle Vistula River valley (opoka of the *E. typica* Zone after Walaszczyk 2004; *Belemnella obtusa* Zone after Keutgen *et al.* 2012; Remin 2012). In spite of the rich literature devoted to these latter sections, *P. globularis* has never been noted from there and is unknown to the authors (observations of A.J and E.ŚG). Similarly, still higher Lower Maastrichtian deposits, which could be equivalent to the beds with *P. globularis* from Rügen, and which are known from the Miechów Synclinorium and from the middle Vistula River valley, have never yielded *P. globularis*.

P. globularis has not been noted in the Upper Maastrichtian of Poland whereas it is well known from this interval in north-western Europe. Neumann *et al.* (2008) have noted *P. globularis* in the *Belemnitella junior*–*Belemnitella kazimiroviensis* belemnite Zone (Keutgen 2011) of Maastricht (Netherlands). In the uppermost Maastrichtian, this sponge was found in Stevns Klint (Denmark) in the *Belemnitella junior*–*Belemnitella kazimiroviensis* Zone (Brünnich and Nielsen 1929; Hansen and Surlyk 2014). The species is also known from other Maastrichtian sections in this part of Europe, as e.g., Germany (Schleswig-Holstein region after Neumann *et al.* 2008), Belgium (Lixhe, province of Liege after Jagt *et al.* 2009) and Denmark (Alaborg, Mons Klint after Brünnich Nielsen 1929, for stratigraphical details see Surlyk *et al.* 2013), however, its precise stratigraphic locations from there are uncertain.

We also had the opportunity of studying the collection of *P. globularis* from various localities in Russia, Ukraine, Kazakhstan and Tajikistan, housed in the Museum of the University of Łódź, and given to the Museum by the late prof. Dimitr P. Naidin. Unfortunately, the specimens from those collections have only rough locality and stratigraphical data. However, on the basis of Naidin's unpublished notes it can be inferred that representatives of this species occur in northern Donbass (?Turonian), Crimea (Lower Maastrichtian), northern Caucasus (Upper Campanian), western Kazakhstan (Lower Maastrichtian of Emba and Khobda, Asia), and



Text-fig. 8. Localities with *Porosphaera globularis* (Phillips, 1829) on Campanian - Maastrichtian palaeogeography of the European area (paleogeography after Naidin 1959; Kauffman 1973; Ziegler 1990; Wilmsen et al. 2012). **North European Province:** 1 – Land areas; 2 – Deltaic, coastal and shallow-marine siliciclastic facies; 3 – Near-shore facies (sands, marls, carbonate marls, marly carbonates, carbonates); 4 – Shallow marine, dominantly carbonate marine facies (marly carbonates, carbonates, chalk, white chalk, carbonate shales); **Mediterranean Province:** 5 – area extent without facies characteristics; **Atlantic rift:** 6 – including future development; **Localities with *P. globularis:*** 7 – *Campanian localities:* Ko – Kornica, eastern Poland; Mi – Mielnik, eastern Poland, Me – Kraków–Miechów–Szczekociny area, southern Poland; Ba – Barranca, nothern Spain; Co – Cognac area, Charente, France; Md – Meudon, France; Hc – Haccourt, Belgium, Mi – Misburg, Lower Saxony, Germany, Mu – Münsterland, Westfalen, Germany; Wo – Wolfenbüttel, Lower Saxony, Germany; Il – Ilsenburg, Saxony-Anhalt, Germany; Yo – Yorkshire, England; Sc – Scotland, ?Coniacian - ?Campanian; NI – Northern Ireland; NC – northern Causasus; 8 – *Maastrichtian localities:* Al – Alaborg area, Denmark; MK – Mønt Klint, Denmark; SK – Stevns Klint, Denmark; Em – Embi, Khazakhstan; Kh - Khur area, Central Iran; Kb – Kobda, Kazkhstan; No – Norfolk, England; Ru – Rügen, Germany; Ne –Netherlands; He – Hemmor, Schelzwik-Holstein, Germany Kv – Khvalinsk, Russia; Vo – Vol'sk, Russia; Ta – Tajikistan

Tajikistan ('Senonian' Maastrichtian). With these occurrences included, the (probably) Early Maastrichtian finds of *P. globularis* from Iran (Wilmsen *et al.* 2012), although still far away to the south-east, are already much closer to other occurrences of this species in the eastern part of the boreal epicontinental sea of Europe (Text-fig. 8).

CONCLUSIONS

In the Campanian of extra-Carpathian Poland, the recognized representative of the genus *Porosphaera* Steinmann is *Porosphaera globularis*. The specimens from the Campanian of Poland are characterized by high intraspecific variability, similar to that of specimens from other parts of Europe.

In the Cretaceous of the Miechów Synclinorium, *Porosphaera globularis* occurs in the following stratigraphical intervals, defined by inoceramid bivalve zones: uppermost Santonian–basal Campanian (*Sphenoceramus patootensiformis* Zone to *Sphaeroceramus sarumensis–Cataceramus dariensis* Zone), parts of the Middle Campanian (upper *'Inoceramus' azerbaydjanensis/'I'. vorhelmensis* to *'I'. tenuilineatus* Zone), and lowermost Upper Campanian (*Sphaeroceramus pertenuiformis* Zone); being apparently absent from the intervals between.

In the *Cataceramus beckumensis* Zone *P. globularis* occurs in only one section (Mielnik). In the Miechów Synclinorium these interval is represented by hardgorund.

Intervals with *P. globularis* from the Campanian and Maastrichtian of Europe do not correlate with each other. The occurrence of *P. globularis* in the deposits of similar or the same age in different areas of Europe seems to be associated with similar environmental conditions prevailing in the various intervals of the Late Cretaceous. It suggests that the *Porosphaera*-rich intervals may have rather limited geographical extent and, consequently, do not represent events of high correlation potential. However, they may still be used successfully in local-scale correlations.

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