

Occurrence and paleoecological significance of lyssacinoid sponges in the Upper Cretaceous deposits of southern Poland

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Abstract Cretaceous lyssacinoid sponges (Hexactinellida) are rare and poorly recognized. This is the first description of lyssacinoid sponges from the Cretaceous of Poland. The sponges (including six species and three types of root tufts) come from the Upper Turonian–Lower Coniacian of the Opole Trough, Upper Campanian of the Miechów synclinorium, and Upper Campanian of the SE part of the border synclinorium. All localities lie southwards of the previous reports, widening thus the paleogeographic distribution of the group within the North European Province. Cretaceous lyssacinoids seem to be a useful tool in paleoecological interpretations. The presence of thin-walled lyssacinoids with root tufts indicates a soft substrate, slow rate of sedimentation, and calm and deeper water conditions.

Keywords Sponges · Hexactinellida · Lyssacinoida · Paleocology · Upper Cretaceous · Southern Poland

Introduction

Sponges of the order Lyssacinoida Zittel, 1877 (subclass Hexasterophora Schulze, 1886) are a group of siliceous sponges of the class Hexactinellida Schmidt 1870, commonly referred to as “glass sponges”. Their oldest

representatives are known from the Upper Proterozoic (Gehling and Rigby 1996). Mesozoic lyssacinoids are rare and poorly recognized. Few assemblages of these sponges are known from the Triassic of Utah and Nevada (Rigby and Gosney 1983), China (Wendt et al. 1989; Wu 1989) and Poland (Pisera and Bodzioch 1991; Bodzioch 1993, 1994). Jurassic lyssacinoids were described from Germany (Zittel 1877; Schrammen 1937), Morocco (Dresnay et al. 1978) and Argentina (Beresi 2003). Their presence in Triassic and Jurassic reef biota in the Alpine Region is documented by loose spicules (Mostler 1989; Delecat and Reitner 2005; Delecat et al. 2011).

Occasionally, lyssacinoids appear in Upper Cretaceous sponge assemblages of the North European Province, which consists mainly of other hexactinellids (Hexactinosida and Lychniscosida) and lithistids. Best known are Coniacian lyssacinoids from Bornholm (Mehl 1992; Brückner and Janussen 2005; Brückner 2006). However, single species of Lyssacinoida were also identified in the Cenomanian of Normandy (Moret 1926), Lower Cenomanian and Campanian of northwest Germany (Schrammen 1912; Salomon 1990), and from the Chalk of England (Bowerbank 1869; Reid 1968). Lyssacinoida have never been documented from the Upper Cretaceous of Poland.

Because the skeleton of lyssacinoid sponges is composed of unfused, or only locally connected spicules, their fossilization potential is definitely lower than that of other siliceous sponges with a rigid skeleton (e.g., Krautter 2002). The poor preservational state of these sponges in the Upper Cretaceous is the reason for their poor taxonomic recognition. Root tufts of lyssacinoid sponges composed of long basal spicules, occurring in the Upper Cretaceous deposits of southern Poland, were mentioned in the literature as sea grasses (Rutkowski 1965) or plants (Roemer 1870, pl. 30, fig. 2; Kędzierski 1995).

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This paper aims to describe the lyssacinoid sponges from the Upper Turonian–Lower Coniacian of the Opole Trough, Upper Campanian of the Miechów synclinorium, and the SE part of the border synclinorium (Middle Vistula River section). In addition, their importance in paleoecological reconstructions is discussed.

Materials and methods

The studied collection of lyssacinoid sponges comprises 98 specimens. The material was collected from three sections in the Miechów synclinorium (Rzeżuśnia, Strzeżów Jędrzejów), a single section in the SE part of the border synclinorium (Piotrawin), and a single section in the Opole Trough (Folwark quarry) (Fig. 1a–c). Details of the skeleton were analyzed under a stereoscope microscope at the Institute of Geological Sciences of the Jagiellonian University, Krakow. Thin-sections and rock samples were also analyzed under an optical microscope.

The studied specimens are hosted at the Institute of Geological Sciences of the Jagiellonian University, Krakow, collection no UJ220P, and in the Laboratory of Geology of the University of Lodz (collection no. ULXXIII).

Localities

In the extra-Carpathian Poland, Upper Cretaceous rocks crop out in the Southern Polish Uplands, in the Opole Trough, and in the Sudety Mountains (Fig. 1a). The so-called mid-Cretaceous eustatic transgression started in the middle Albian, covering rapidly most of its territory (Pożaryski 1960; Marcinowski 1974; Marcinowski and Radwański 1983, 1989). The initial facies variability of the Albian and Cenomanian was quickly followed by a uniform facies during the Early Turonian. With the exception of the Sudetes, where siliciclastic sedimentation prevailed, the rest of the area is characterized by limestone-marly facies (Central Polish Uplands); limestones are restricted to the Krakow Swell area, while in other regions opoka (siliceous limestone)/marly facies dominate (Marcinowski 1970, 1974; Walaszczyk 1992; Voigt et al. 2008).

Opole Trough

The Cretaceous succession of the Opole Trough spans the Cenomanian to Middle Coniacian time interval (Walaszczyk 1992).

The Folwark section is an active quarry of the cement industry, located about 10 km SW from the city of Opole (Fig. 1a). The 54-m-thick succession (Fig. 1b) is composed

Fig. 1 a Tectonic sketch map of Poland without the Cenozoic cover (after Marcinowski and Radwański 1983, simplified), and location of the study area. b, c Geological columns of the studied sections; b inoceramid zonation based on Walaszczyk 1992; Walaszczyk and Wood 1998 and Walaszczyk and Cobban 2000; c inoceramid zonation based on Walaszczyk 2004; Walaszczyk et al. 2008 and Jagt et al. 2004

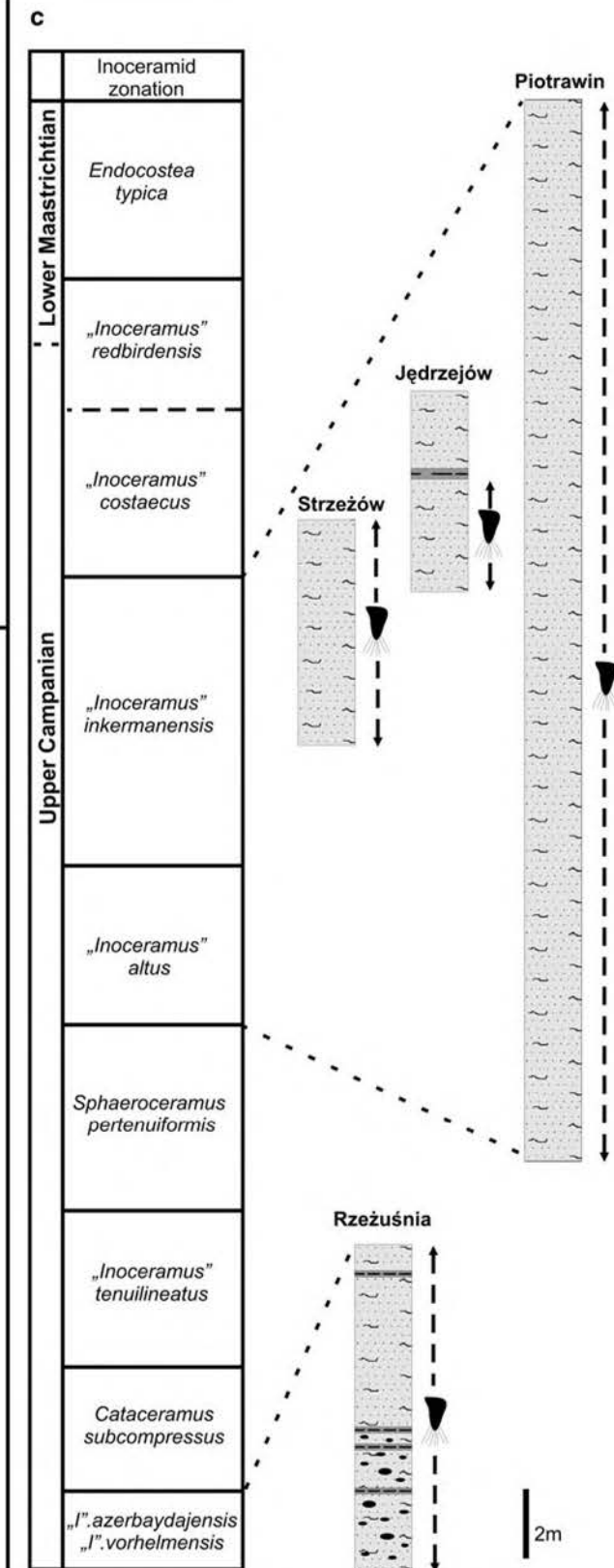
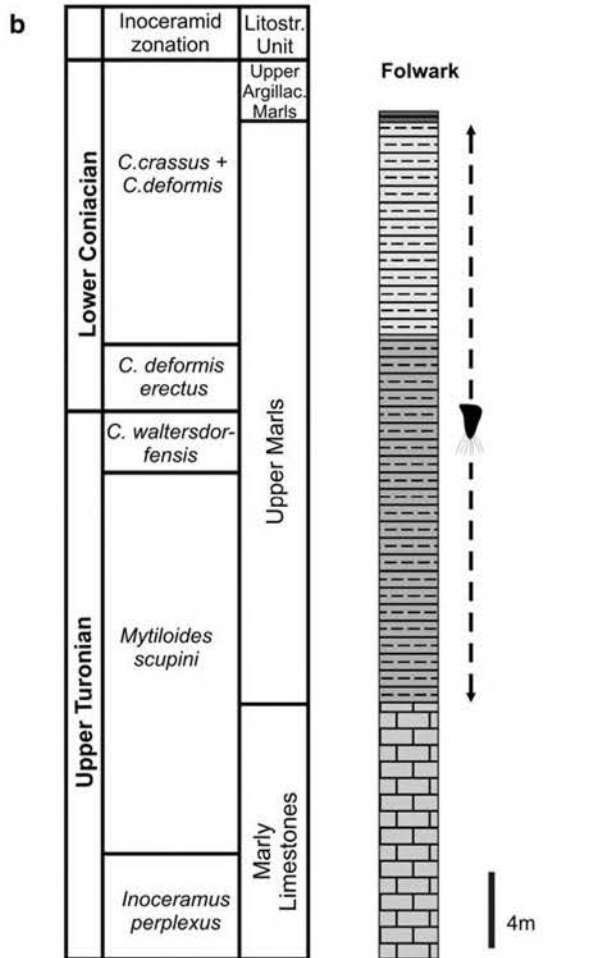
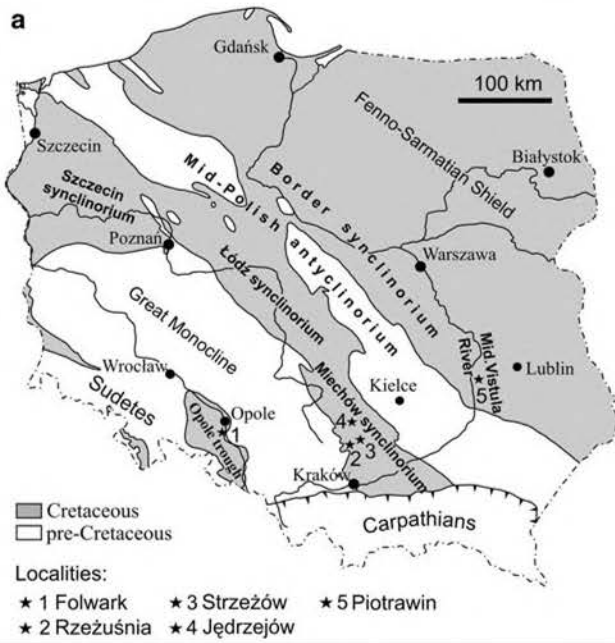
of Upper Turonian to Lower Coniacian deposits (Walaszczyk 1988, 1992; Tarkowski 1991; Kedzierski 2008). p. 4 line 92–97: The lower part of the succession (Marly Limestone Unit, after Alexandrowicz and Radwan 1973) is represented by marly limestone with very thin intercalations of dark-grey argillaceous marl belonging to the *Inoceramus perplexus* Zone (= *I. costellatus*, see Walaszczyk and Cobban 2000) and lower part of the *Mytiloides scupini* Zone (Walaszczyk 1992; Walaszczyk and Wood 1998). Overlying gray marl with intercalations of dark-grey argillaceous marl and light-grey siliceous marl (Upper Marl Unit after Alexandrowicz and Radwan 1973) belongs to zones of *Mytiloides scupini*, *Cremnoceramus waltersdorfensis waltersdorfensis*, *C. deformis erectus*, and of *C. crassus crassus* + *C. deformis deformis* (Walaszczyk 1992; Walaszczyk and Wood 1998). Microfacially, marls from the studied section represent wackestone with foraminifera and rare sponge spicules (Fig. 2a). Organic components also comprise fragments of bivalves and rare echinoids. Detritic material is insignificant. The highest part of the succession is represented by thin (0.5 m) soft, argillaceous marl (Upper Argillaceous Marl Unit after Alexandrowicz and Radwan 1973). The whole succession is relatively fossiliferous, with abundant inoceramids and ammonites (Walaszczyk 1988; Tarkowski 1991), echinoids (Olszewska-Nejbert 2007), and sponges (numerous hexactinoids and lychniscosids, rare lithistids) (Roemer 1870; Leonhard 1897; Tarkowski 1991). The whole succession has been intensively bioturbated (Kędzierski and Uchman 2001).

Rare lyssacinoid sponges occur in the Upper Marl Unit. All specimens are strongly pyritized with only single siliceous spicules preserved.

Miechów synclinorium

In the Miechów synclinorium, Cretaceous strata are represented by Upper Albian through to Lower Maastrichtian (Rutkowski 1965; Marcinowski 1974; Heller and Moryc 1984; Hakenberg 1986; Walaszczyk 1992; Świdrowska and Hakenberg 1999). The lyssacinoids were collected from three sections; two located in the southern part of the synclinorium (Rzeżuśnia and Strzeżów), and one in its northern region (Jędrzejów) (Fig. 1a, c).

The Rzeżuśnia section is an inactive quarry with exposed lower Upper Campanian [*Inoceramus azerbaijanensis*/



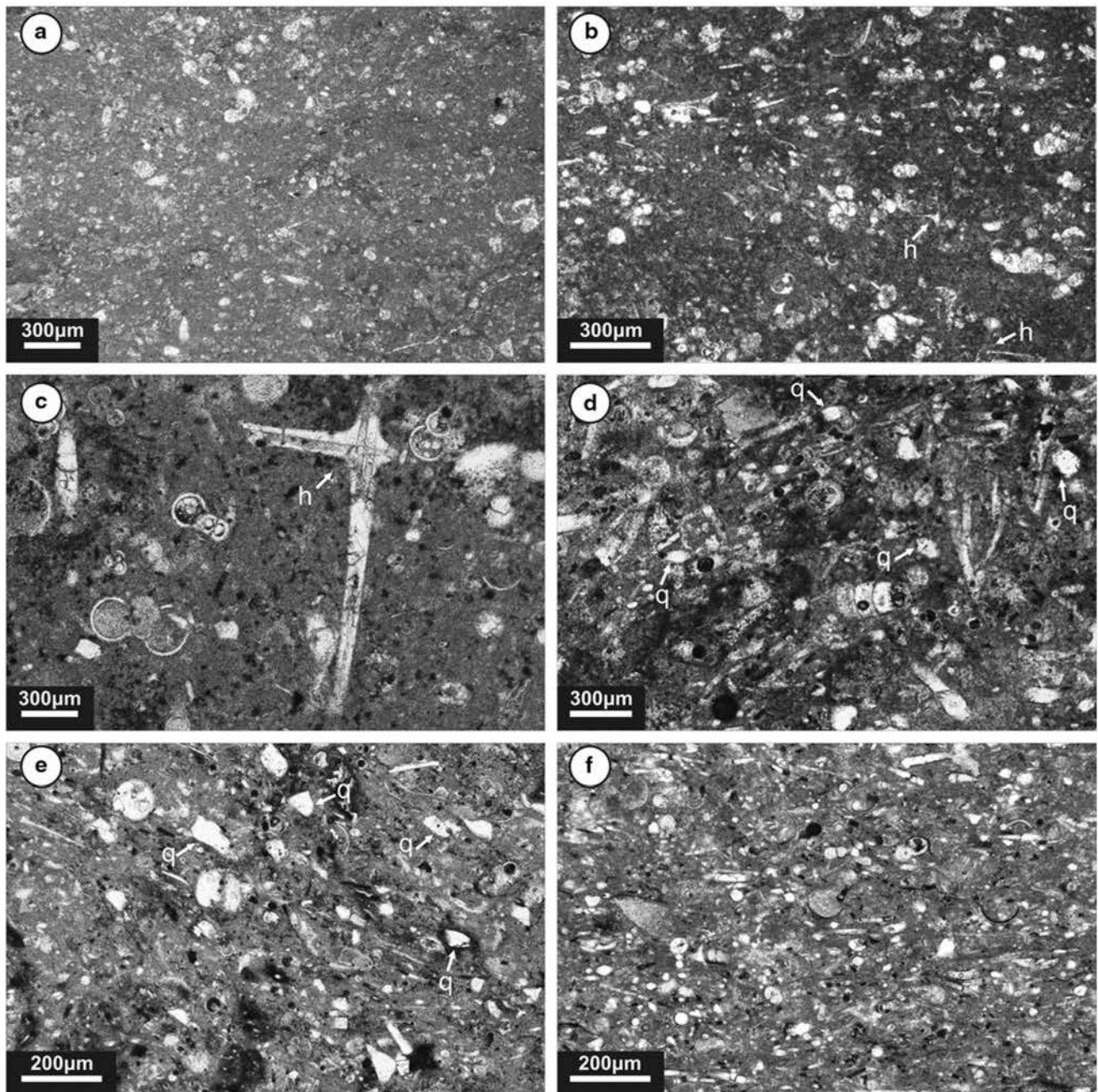


Fig. 2 Characteristic microfacies from the studied sections. **a** Foraminiferal wackestone from Folwark. **b, c** Packstone from Rzeżuśnia with foraminifers and sponge spicules, including loose hexactines (h). **d, e** Packstone with foraminifers and sponge spicules (mainly oxeas

of soft demosponges); quartz grains (q) are significant. **d** Packstone from Strzeżów; **e** packstone from Jędrzejów. **f** Packstone with foraminifers and sponge spicules (mainly oxeas of soft demosponges) from Piotrawin

Inoceramus vorhelmensis Interval Zone according to Jagt et al. (2004) and Walaszczyk et al. (2008)] opokas with cherts and marly intercalations. The relatively abundant fauna is dominated by inoceramids, gastropods, hexactinosid and lychniscosid sponges; less common are lithistid sponges and echinoids. Trace fossils are represented by *Thalassinoides* burrows. Lyssacosinids are very common, but only root tuft are preserved.

The Strzeżów section is an inactive quarry, with an Upper Campanian opoka succession, belonging to the “*Inoceramus*” *inkermanensis* and “*Inoceramus*” *costaeus* Zones (Jurkowska in prep.). The opokas are extremely fossiliferous, with abundant inoceramids, pectinids, gastropods, echinoids, and sponges (mainly hexactinosids and lychniscosids). Poorly preserved lyssacosinids appear throughout the succession.

The Jędrzejów section was a temporary road cut in the northern part of the city of Jędrzejów. The succession is composed of opokas and marls of the “*Inoceramus*” *inkermanensis* Zone to “*Inoceramus*” *costaecus*—“*Inoceramus*” *redbirdensis* Zone (Jurkowska, in prep.). The “*I.* *inkermanensis*” Zone is very fossiliferous, with abundant inoceramids, pectinids, belemnites, and echinoids. In the “*I.* *costaecus*” and “*I.* *redbirdensis*” Zones, echinoids and inoceramids become rare and big gastropods occur. Hexactinosid and lychniscosid sponges are numerous in the lower part of the succession but less common in the upper part where massive lithistids appear. Lyssacinosids are most numerous in the “*I.* *inkermanensis*” Zone, while in the “*I.* *redbirdensis*” Zone they are absent.

Microfacially, opokas from the studied sections represent packstone (Fig. 2b–e) with planktonic foraminifera and spicules of the siliceous sponges (mainly non-lithistid demosponges). In Rzeżuśnia, dispersed spicules of hexactinellid sponges also occur (Fig. 2c). In some thin-sections from Strzeżów, current alignment of spicules can be observed. Organic components also comprise fragments of bivalves and rare echinoids. An admixture of detritic material and glauconite was detected in Jędrzejów and Strzeżów; in Rzeżuśnia it is, however, insignificant.

All collected specimens of lyssacinosids are strongly limonitized. Rare, short fragments of siliceous or calcitized spicules have been found only in some specimens from Jędrzejów and Strzeżów. In all sections, root tufts type 1 are dominant. Large, fairly complete root tufts are preserved in life position while separated bundles of basal spicules lie horizontally.

SE part of the border synclinorium

In the SE part of the border synclinorium, the Upper Cretaceous succession is best exposed in the Middle Vistula River section (Pożaryski 1938; Marcinowski and Radwański 1983; Voigt et al. 2008) (Fig. 1a).

The Piotrawin section is an inactive quarry with a monotonous, poorly bedded succession of Upper Campanian opoka (Fig. 1c), which belongs to a local lithostratigraphic unit of Piotrawin Opoka (Walaszczyk 2004). Based on ammonites, Błaszkiwicz (1980) assigned the succession from this section to the *Nostoceras pozaryskii* Zone (= *Nostoceras hyatti* Zone according to Kennedy et al. 1992). Walaszczyk (2004) included its lower part into the “*Inoceramus*” *altus* Zone, whereas its middle and upper parts belong to the “*Inoceramus*” *inkermanensis* Zone.

The Piotrawin Opoka is extremely fossiliferous, with abundant siliceous sponges (Świerczewska-Gładysz 2006, 2012), ammonites (Błaszkiwicz 1980; Machalski 2012), belemnites (Kongiel 1962), inoceramids (Walaszczyk 2004) and non-ammonite molluscs (Abdel-Gawad 1986).

Microfacially, these opokas represent packstone (Fig. 2f) with foraminifera and spicules of siliceous sponges (mainly non-lithistid demosponges). Other bioclasts are fragments of bivalves, echinoderms, and rare bryozoans. Locally, in the upper part of the succession, current-aligned spicules are observed. Admixture of quartz and glauconitic grains is insignificant.

The lyssacinosid sponges are represented mainly by isolated root tufts. Bodily preserved sponges are much less numerous. Moreover, they are poorly preserved. All specimens are strongly limonitized and often only single spicules are visible. Fragments of siliceous spicules occur sporadically.

Lyssacinosid sponges from the studied sections

The studied material is dominated by isolated root tufts composed of basal spicules (spicules which protruded from the dermal surface and anchored sponges in the sediment).

Bodily preserved sponges are less numerous and, moreover, they are strongly deformed by compaction. They are usually incomplete, occasionally strongly fragmented with poorly visible single spicules. Better preserved specimens (described below) often possess only large spicules of the main (choanosomal) skeleton. Other taxonomically important spicules, such as autodermalia (megascleres supporting the dermal membrane directly), hypodermalia (megascleres lying under autodermalia), and supradermalia (megascleres protruding from the sponges surface), are rare. Microscleres, critical for the taxonomy of Recent taxa, have not been found. Due to their poor preservation, the taxonomic position of most of the sponges is uncertain.

Different types of spicules were recognized in studied specimens: monactines (one-rayed spicules), diactines (two-rayed spicules with rays aligned on the same axis), hexactines (spicules with six rays), and pentactines (hexactines with reduction of one ray) with four rays parallel to the body surface (tangential rays) intersecting at angles of 90° (ortotropal pentactines) or intersecting at angles other than 90° (paratropal pentactines).

Rossella rotunda Brückner, 2006

Figure 3a–c

Material

Three specimens from Folwark.

Description

The better preserved specimen is roundish, 35 mm in diameter (Fig. 3a). The round osculum on its top is 13 mm

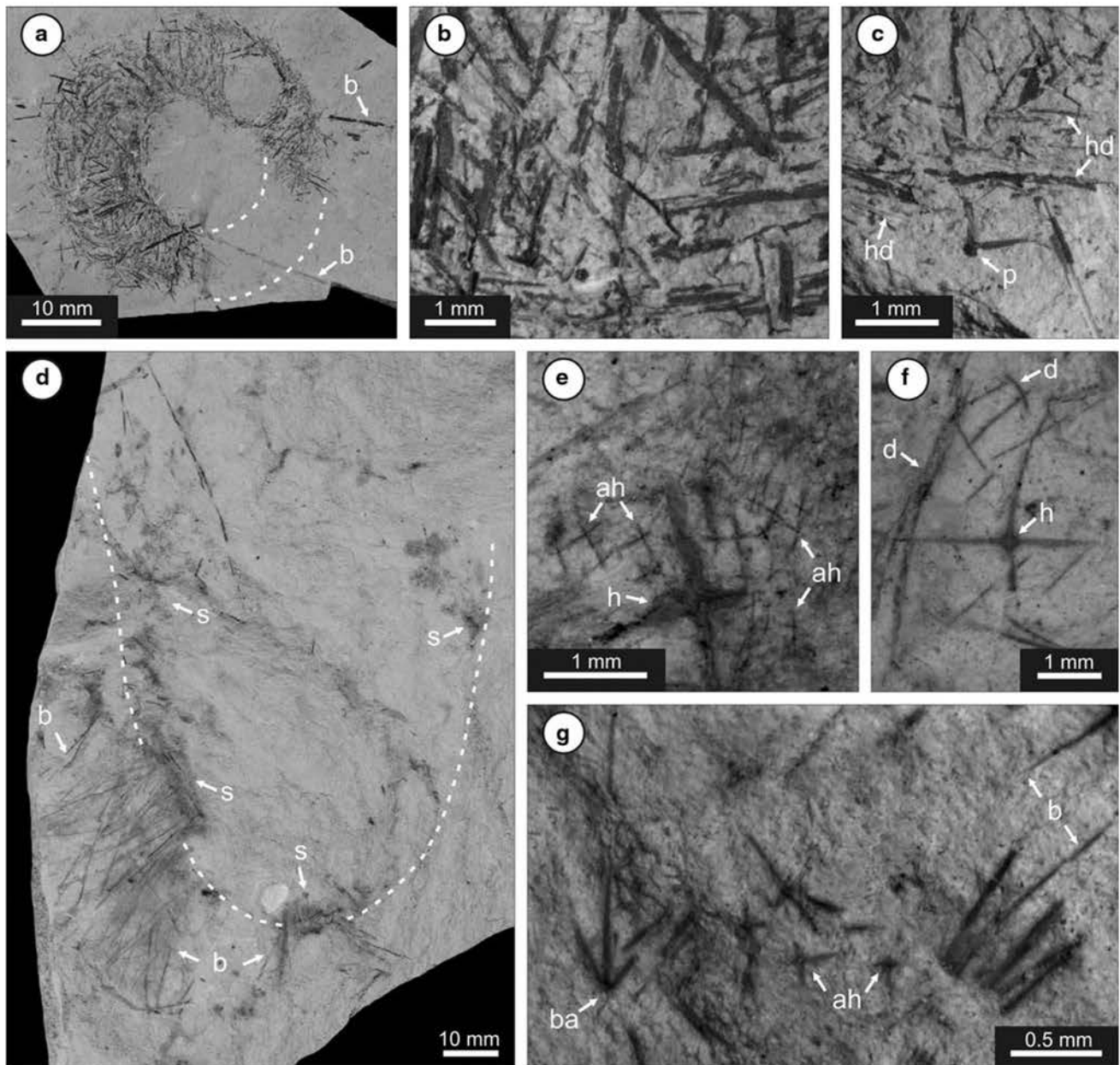


Fig. 3 a–c *Rossella rotunda* Brückner, 2006; Upper Turonian, Folwark, ULXXIII/F1. **a** Upper view of specimen; locally preserved are fragments of basal spicules (b). **b** Fragment of choanosomal skeleton with diactine bundles and isolated diactines. **c** Detail of skeleton with supradermal paratropical pentactine (p). **d–g** *Rossella cf. bromlei* Brückner and Janussen, 2005. **d** Fragments of destroyed sponge (s) and root tuft (b); Upper Campanian, Jędrzejów, ULXXIII/

J9. **e** Fragment of skeleton with auto dermal hexactines (ah) and choanosomal hexactine (h); Upper Campanian, Jędrzejów, ULXXIII/J9. **f** Detail of skeleton with choanosomal hexactine (h) and choanosomal diactines (d); Upper Campanian, Jędrzejów, ULXXIII/J7. **g** Fragments of broken basal pentactines (b), basal pentactine with preserved anchor (ba) and dispersed auto dermal hexactines (ah); Upper Campanian, Jędrzejów, ULXXIII/J7

in diameter. The height of the sponge is unknown, as the specimen was compressed almost parallel to its axis. The dense choanosomal skeleton is composed of variably oriented diactines and diactine bundles, up to 6–7 mm long (Fig. 3b). Small, 1–2-mm-long, hypodermal diactines are arranged parallel to the wall surface (Fig. 3c). Single auto dermal hexactines, supradermal orthotropical pentactines,

paratropical pentactines (Fig. 3c), and fragments of few basal spicules occur (Fig. 3a).

Remarks

The basal spicules are fragmentary, and the anchors typical of the genus *Rossella* Carter, 1872 (see Tabachnick 2002c)

are not preserved. The species has been so far reported from the Coniacian of Bornholm (Brückner 2006).

Rossella cf. *bromlei* Brückner and Janussen, 2005
Figure 3d–g

Material

Four specimens from Jędrzejów and 1 specimen from Strzeżów.

Description

The sponges are probably cup-like (Fig. 3d) and more than 80 mm in height. All skeletons are strongly disintegrated. The spicules are scattered and their primary arrangement is occasionally unclear. The choanosomal skeleton is composed of isolated diactines (3–4 mm in length), diactine bundles (4–5 mm in length), and large hexactines (4–10 mm in size) (Fig. 3f). Supradermal pentactines are rare. Small autodermal hexactines (0.5–0.9 mm in size), found in a well-preserved fragment, form a dense and quite regular lattice (Fig. 3e). Numerous autodermal hexactines and few choanosomal hexactines (probably derived from the lower part of the body) were also observed between basal spicules. Straight or wavy basal spicules are thin, with an average thickness of ca. 0.1 mm. They comprise a dense, broad root tuft (Fig. 3d). Some of the basal pentactines are preserved with toothed anchors (Fig. 3g).

Remarks

All specimens are very poorly preserved with most of the spicules lost. Composition and size of the preserved spicules corresponds well to the diagnosis of *R. bromlei* from the Coniacian of Bornholm (compare Brückner and Janussen 2005; Brückner 2006).

Chaunoplectella sp.
Figure 4a, b

Material

Three specimens from Strzeżów and 2 specimens from Jędrzejów.

Description

The fragments are derived from thin-walled, probably cup-like sponges. The largest fragment, with a partly damaged wall, measures 160 mm. These sponges are characterized by an irregular choanosomal skeleton (Fig. 4a, b) and are

composed mainly of giant hexactines, with thick rays (0.2–0.25 mm), and up to 16 mm long. The rays of some hexactines are curved (Fig. 4a). Variably orientated diactines, 0.1 mm thick and 4–8 mm long, are less common (Fig. 4b). Locally small autodermal hexactines, with rays up to 1 mm in length, are preserved (Fig. 4b).

Remarks

In contrast to Recent thick-walled representatives of the genus *Chaunoplectella* Ijima, 1896 (Tabachnick 2002b), the specimens are characterized by a thin wall, similar to *Chaunoplectella macrospiculata* Brückner, 2006, from the Coniacian of Bornholm. The choanosomal hexactines of the specimens are distinctly larger than hexactines in *Ch. macrospiculata* where rays are up to 8 mm long (Brückner 2006). Recent representatives of *Chaunoplectella* are basiphytous with a short stalk. Bases in the studied specimens were not preserved.

Indeterminate genus and species A
Figure 4c, d

Material

Five specimens from Jędrzejów and 1 specimen from Strzeżów.

Description

The fragments are derived from thin-walled (ca. 1 mm thick) tube- and cup-like sponges, up to 50–90 mm in diameter and over 150 mm in height. Occasionally they are preserved with broken single basal spicules or small fragments of dense root tuft. The characteristic feature of these sponges is their choanosomal skeleton, composed of diactine bundles and isolated diactines, which run parallel and diagonal in growth direction (Fig. 4c). The diactine bundles are large, 20–30 mm long. Isolated diactines are smaller, 10–15 mm long on average. The hexactines, also occurring in the choanosomal skeleton, are 2–8 mm in size (Fig. 4d). Dermal spicules are absent.

Remarks

A regular distribution of diactines and diactine bundles is known from the genus *Regadrella* Schmidt, 1880 from the Upper Cretaceous (Schrammen 1912; Brückner and Janussen 2005; Brückner 2006), as well as from several Recent genera of lyssacinoid sponges. Unfortunately, other features of the skeletons do not allow a precise taxonomic identification.

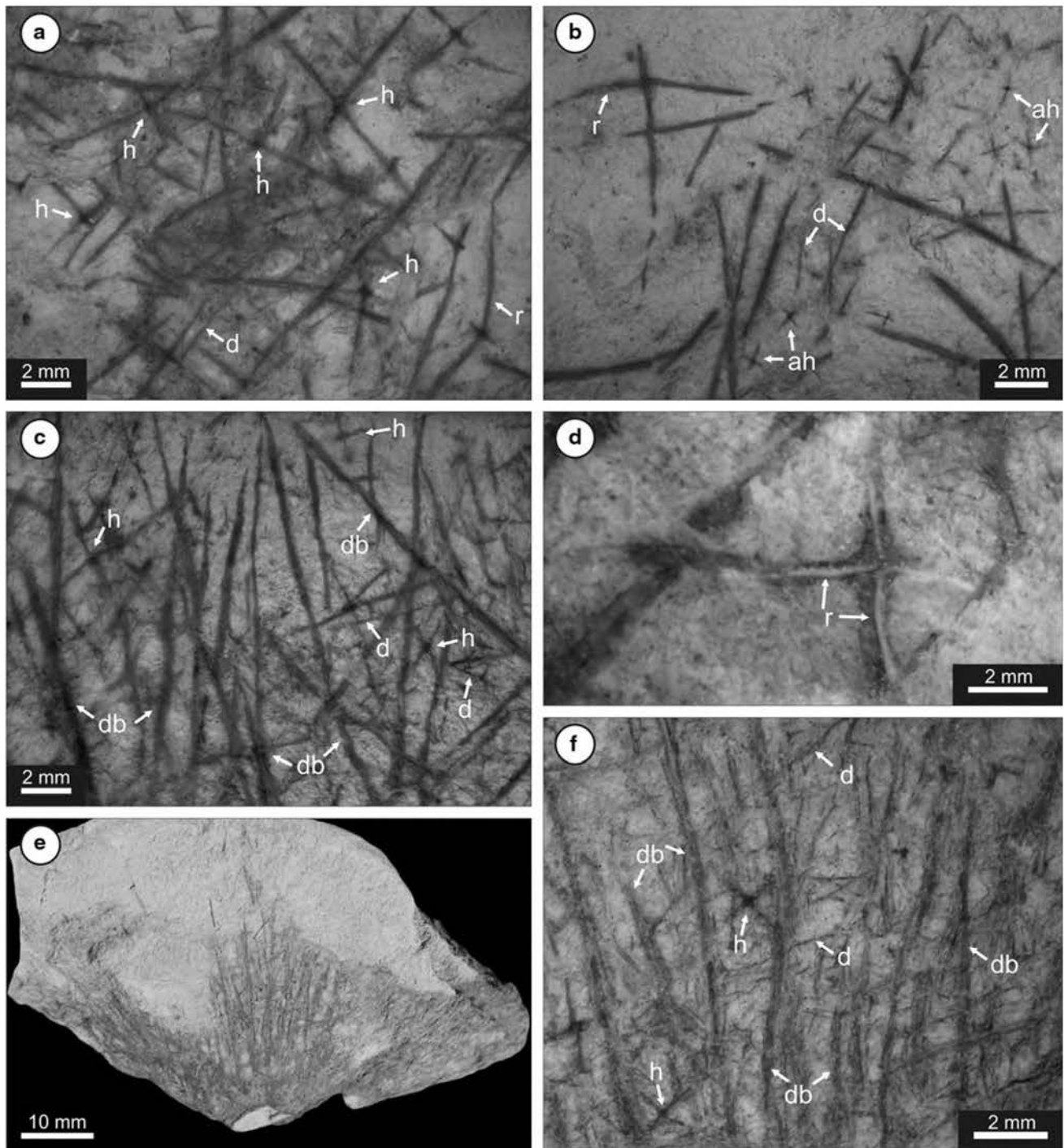


Fig. 4 a, b *Chaunoplectella* sp.; fragments of skeleton with large choanosomal hexactines (h), occasionally with curved rays (r), small choanosomal diactines (d), and autodermal hexactines (ah); Upper Campanian, Jędrzejów, UJ220P/38. c, d Indeterminate genus and species A; Upper Campanian, Jędrzejów, ULXXIII/J12. e Fragment of skeleton with oblique diactines bundles (db), isolated diactines

(d) and choanosomal hexactines (h). d Choanosomal hexactine with preserved fragments of siliceous rays (r). e, f Indeterminate genus and species B; Upper Campanian, Piotrawin ULXXIII/P6. e Lateral view of specimen. f Fragment of skeleton with thick diactines bundles (db), isolated diactines (d), and choanosomal hexactines (h)

Indeterminate genus and species B
Figure 4e, f

Material

One specimen from Piotrawin.

Description

This is a small, ca. 40-mm-high, thin-walled, cup-like sponge, with round to oval wall openings, 1–2 mm in diameter (Fig. 4e). The moderately dense skeletal lattice of this sponge is formed by long, thick (0.5–0.8 mm) diactine bundles, isolated diactines (0.1 mm thick and up to 3 mm in long) and rare hexactines, up to 2 mm in size (Fig. 4f). The diactine bundles run mostly in growth direction. Other spicules are not visible.

Remarks

The lack of dermal spicules does not allow a precise taxonomic identification.

Indeterminate genus and species C

Material

Three specimens from Folwark.

Description

These are wall fragments (up to 3 cm in size), derived from cup-like sponges. The wall is thin (up to 1 mm) with irregularly distributed rounded or oval wall openings, 0.8–2 mm in diameter. The dense choanosomal skeleton consists of diactines, pointing in all directions, and of single hexactines. These spicules are poorly visible in a pyritized mass. The fragment of broad root tuft, preserved in the lower part of one of the specimens, is composed of thin (ca. 0.1 mm), straight spicules with a broken terminal part. Others spicules were not observed.

Remarks

Because of their poor preservation, the specimens are left in open nomenclature.

Root tufts type 1
Figure 5a–d

Material

Nine specimens from Folwark, 35 from Rzeżuśnia, three from Strzeżów, five from Jędrzejów, and four from Piotrawin.

Description

The specimens are moderately dense, broad root tufts (Fig. 5a) composed of straight or slightly curved, thick (0.2–0.3 mm) spicules (Fig. 5d). The terminal parts of the spicules are not visible, but usually broken. The best-preserved specimens from Rzeżuśnia are very large, up to 250 mm long, and 160 mm wide (Fig. 5a). In the lower part of the root tufts, the spicules are loosely packed, the distance between them being up to 5–7 mm (Fig. 5b). A few specimens from Miechów synclinorium are represented by narrow (5–10 mm wide), separated bundles composed of few or several long spicules (Fig. 5c).

Remarks

Terminal parts of spicules forming these root tufts are not visible; thus a precise determination is impossible.

Root tufts type 2
Figure 5e, f

Material

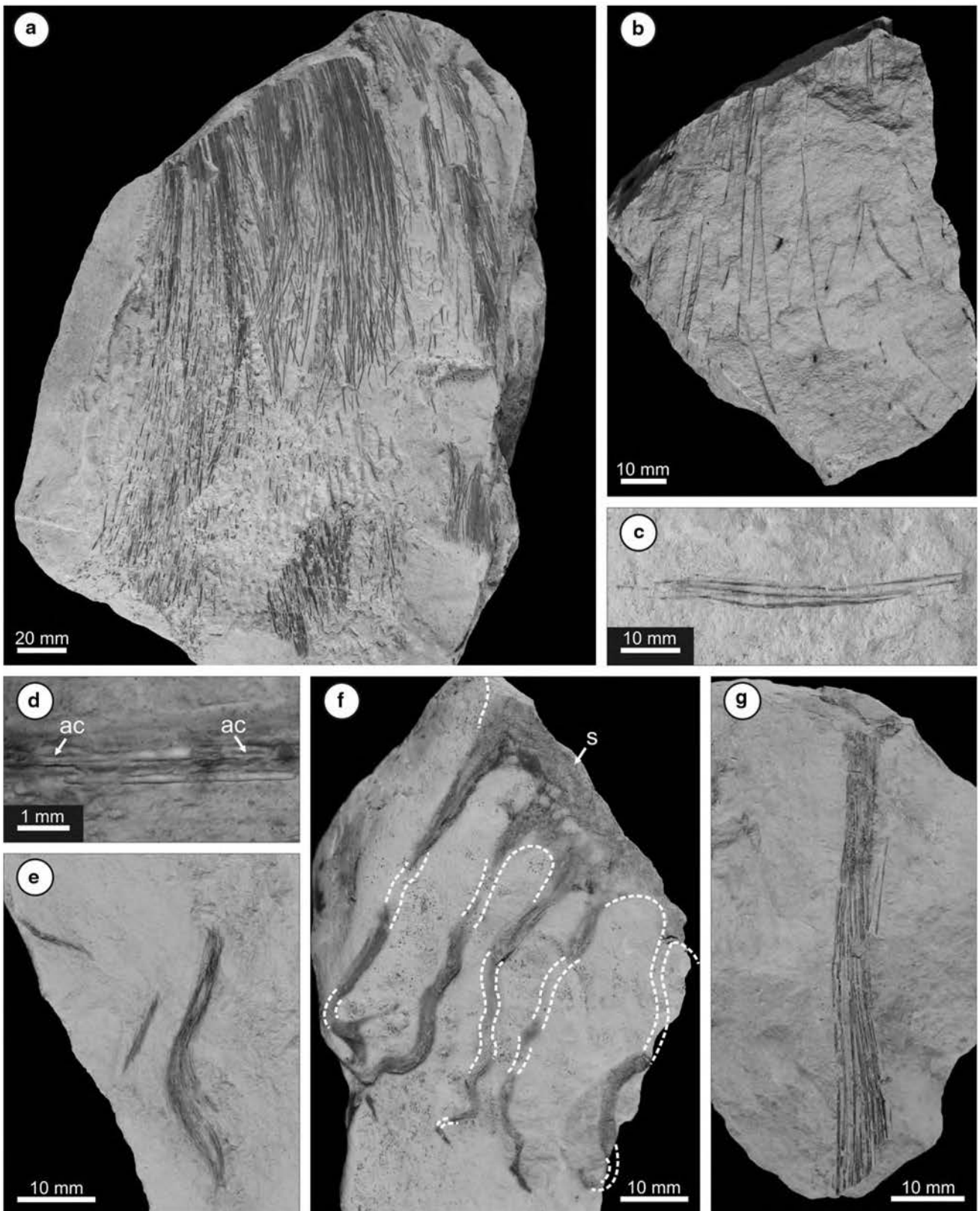
One specimen from Piotrawin and 2 specimens from Rzeżuśnia.

Description

The specimens are composed of thin (0.05 mm thick), non-anchorate basal spicules which form narrow, separate, wavy tufts. The specimen from Piotrawin is composed of a fragment of the body and five separate tufts (up to 55 mm long and 2.5–3.5 mm wide) (Fig. 5f). The root tufts from Rzeżuśnia are broken and dispersed (Fig. 5e).

Remarks

The basalia gathered in several tufts are characteristic of some Recent genera of lyssacinoids of the family Euplectellidae Gray, 1867 (e.g., genus *Chaunangium* Schulze, 1904) and Rossellidae Schulze, 1885 (e.g., *Lophocalyx* Schulze, 1887) (Tabachnick 2002a, c). Numerous separate tufts are also typical of the genus *Pheronema* Leidy, 1868 (subclass Amphidiscophora Schulze, 1886), but basal spicules of the specimen do not have anchors typical of *Pheronema* (compare Tabachnick and Menshenina 2002b). Moreover, in the strongly damaged body fragment preserved with root tuft from Piotrawin, single diactines were recognized. These spicules are uncommon in *Pheronema*.



◀ **Fig. 5 a–d** Root tufts type 1. **a** The largest specimen Upper Campanian, Rzeżuśnia, UJ220P/47/1. **b** Lower part of root tuft with loosely packed spicules; Upper Campanian, Strzeżów, UJ220P/34. **c** A few dispersed spicules, Upper Campanian, Rzeżuśnia, UJ 220P/26. **d** Preserved fragment of siliceous spicules with visible axial canal (ac); Upper Campanian, Piotrawin, ULXXIII/P10. **e, f** Root tufts type 2. **e** Three broken root tufts; Upper Campanian, Rzeżuśnia, UJ220P/12. **f** Specimen with five separated root tufts and body fragment (s); Upper Campanian, Piotrawin, ULXXIII/P11. **g** Root tuft type 3; Lower Coniacian, Folwark ULXXIII/F10

Root tufts type 3
Figure 5g

Material

One specimen from Folwark and two specimens from Piotrawin.

Description

Root tufts of type 3 are stalk-like with nearly parallel straight spicules (diactines?), 0.1–0.15 mm thick (Fig. 5g). In the lower part of root tufts, the spicules are slightly dispersed. The best-preserved root tuft from Folwark is over 65 mm long, 5 mm wide in the upper part, and ca. 8 mm wide in the lower part. Specimens from Piotrawin are large, over 90 mm in length and 15 mm wide. Terminal parts of all specimens are broken.

Remarks

Similar root tufts appear in several Recent lyssacinoids and in hyalonematid sponges (non-rigid hexactinellid sponges of the subclass Amphidiscophora Schulze, 1886). Sponges with stalk-like root tufts and some isolated stalk-like root tufts from the Upper Cretaceous of Germany were described as the sole fossil representatives of the genus *Hyalonema* Gray, 1835 (Mehl and Hauschke 1995). Basal spicules of living hyalonematid sponges usually have 4–8 teeth (Tabachnick and Menshenina 2002a). Due to the lack of the characteristic toothed anchors of basal spicules, the attribution of the specimen to *Hyalonema* is uncertain.

Paleoecological significance

Most of the Recent Lyssacinoida live in the bathyal or even abyssal zone (e.g., Koltun 1967; Janussen et al. 2004; McClintock et al. 2005; Van Soest et al. 2007; Janussen and Reisinger 2009). Shallow-water (below 100 m) lyssacinoids are known exclusively from circumpolar seas (e.g., Koltun 1970; McClintock et al. 2005), the fjords of British Columbia (e.g., Leys et al. 2004), submarine caves in the

western Mediterranean (Boury-Esnault and Vacelet 1994) and southern New Zealand (Leys et al. 2004). The occurrence of hexactinellid sponges in these places is possible only under special conditions such as: low temperatures, quiet waters, and low light levels (Leys et al. 2004; Whitney et al. 2005).

The distribution of ancient hexactinellids shows that they were more common in the neritic zone than their Recent counterparts. Development of hexactinellid sponges in the Late Cretaceous was correlated with high sea levels (Pisera 1999). It is also likely that the occurrence of lyssacinoids and other hexactinellids in Cretaceous European epicontinental seas, was related to the upwelling zones of the Tethys Ocean (see e.g., Mehl and Niebuhr 1995). The studied sections are located clearly southward of the formerly reported occurrences of lyssacinoids; the Tethyan influence could have been significantly higher.

The morphology and life function of lyssacinoids suggest that they were adapted to a low sedimentation rate and low turbulence, therefore they are located almost invariably in deeper shelf areas (e.g., Wendt et al. 1989; Pisera and Busquets 2002; Beresi 2003). Only some thick-walled sponges from the Triassic might have lived below the fair-weather wave-base but above the storm wave-base (Pisera and Bodzioch 1991; Bodzioch 1994). In all of the studied sections, lyssacinoids are represented by thin-walled forms, similar to deep-water forms known from the Coniacian of Bornholm (Brückner 2006). Recent thin-walled (<5 mm) lyssacinoid sponges occur at depth of ca. 100 m or deeper (up to 7,000 m) (Tabachnick 2002a, c).

Some modern lyssacinoid sponges live on a hard substrate, attached by a basal plate. Although basal plates occur in some fossil species (Pisera and Bodzioch 1991; Bodzioch 1994), they were not found in the studied sponges, suggesting their adaptation to soft-bottom conditions. Such adaptation is also suggested by the occurrence of lophophytal sponges (with root tufts) and numerous isolated long root tufts in the material studied (compare Brückner et al. 2003; Brückner 2006). The presence of lophophytal lyssacinoid sponges was used as an indicator of soft bottom conditions by Reid (1962) for the English Chalk Rock. Soft-bottom conditions in the studied successions is also suggested by the presence of rhizoidal lychniscoid and hexactinoid sponges (see also Tarkowski 1991; Świerczewska-Gładysz 2006), infaunal echinoids (Mączyńska 1968; Olszewska-Nejbert 2007), and some bivalves (Abdel-Gawad 1986).

The inferred life conditions of the studied sponges are also supported by other paleontological and sedimentological data. Packstone with foraminifera and spicules suggest calm water condition with periodic activity of weak currents. Weak currents favor the development of Recent hexactinellids (Leys et al. 2004; Whitney et al.

2005) and, consequently, are also inferred for the Cretaceous lyssacinosaurs.

Abundant lychniscosid and hexactinosid sponges, co-occurring with the studied lyssacinosaurs, indicate a deeper shelf environment (Świerczewska-Gładysz 2006). Moreover, some of these sponges [e.g., dish-shaped *Ventriculites chonoides* (Mantell, 1815) and *Leiostracosia punctata* (Schrammen, 1902)] indicate a very slow rate of sedimentation (Krautter 1997).

Thin-walled lyssacinosaur sponges can only be preserved intact when quickly buried (Brückner et al. 2003; Brückner 2006). Most of the specimens studied herein have been partly destroyed due to a prolonged residence time on the sea floor, suggesting a slow rate of sedimentation in all of the successions. Quite often, only the root tufts that were buried in the sediment during the sponges' lifetime have been preserved (Leys et al. 2007). The isolated root tufts of lyssacinosaurs and other non-rigid hexactinellid sponges were often described from other assemblages of fossil sponges, e.g., from Eocene of Catalonia (Pisera and Busquets 2002) or Permian of Texas (Rigby et al. 2007). The lack of well-preserved specimens and occurrence of dispersed spicules in the Campanian deposits result most likely from a slow rate of sedimentation and periodic weak bottom currents, which prevented the accumulation of the sediment and favored destruction of skeletons of dead sponges. Small specimens are more complete and may have been buried relatively quickly.

The significance of Lyssacinosa for bathymetric interpretation is confirmed by their distribution in the Cretaceous of the Opole Trough. Their occurrence in the Upper Marl Unit and absence from the underlying Marly Limestone Unit suggest deepening of the Opole Basin during the latest Turonian and Early Coniacian. This agrees well with the current bathymetric interpretation of the succession based on ichnofabrics (Kędzierski and Uchman 2001) and analysis of shark assemblages (Niedźwiedzki and Kalina 2003).

During the Campanian, the present-day Middle Vistula Valley area and Miechów area were situated in the Danish-Polish trough (Hakenberg and Świdrowska 1998). According to bathymetric interpretations based on non-cephalopoda molluscs from the Middle Vistula River section, Upper Campanian Piotrawin opokas were deposited in a mid to outer shelf setting (Abdel-Gawad 1986).

In the uppermost Campanian (“*T*”, *costaecus*—“*T*”, *redbirdensis* zones) of the Jędrzejów section (Miechów area) Lyssacinosa are not observed, suggesting shallower water conditions. This is confirmed by the replacement of hexactinellid sponges by lithistids in these zones (e.g., Reid 1968; Ulbrich 1974). In the stratigraphically equivalent deposits of the Middle Vistula River section, where lychniscosid and hexactinosid sponges are less common,

Lyssacinosa have not been noted (Świerczewska-Gładysz, 2012).

Conclusions

1. Although lyssacinosaurs have been rarely reported from benthic assemblages of European Late Cretaceous epicontinental seas, it seems that they were more abundant than suggested by previous studies. So far, Late Cretaceous lyssacinosaurs have been recorded from in England, France, Germany, and Denmark. Their presence in the Upper Cretaceous deposits of southern Poland indicates that during the Late Cretaceous they had a wide paleogeographic distribution in the North European province.
2. In the studied collection *Rossella rotunda* Brückner, 2006, *Rossella* cf. *bromlei* Brückner and Janussen, 2005, and *Chaunoplectella* sp were recognized. The taxonomic position of three other species is impossible to determine, because the specimens are poorly preserved without diagnostic spicules. Due to the lack of rigid skeletons, most of the specimens are strongly disintegrated, and occasionally only root tufts, composed of thick, long spicules, are preserved. In the studied section, three types of root tufts were recognized.
3. Cretaceous Lyssacinosa can be used as paleoenvironmental tools. The presence of thin-walled forms with root tufts indicates a soft bottom, slow rate of sedimentation, and calm and comparatively deep water conditions.

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