INTRODUCTION

During the Late Cretaceous, the area of the present Miechów Synclinorium was a marginal part of the Polish-Danish Trough (Text-fig. 1). The area is critical for the interpretation of the evolution of extra-Carpathian Poland and first of all for deciphering the final stages (Campanian and Maastrichtian) of the inversion history of the Danish-Polish Trough (Marcinowski 1974; Walaszczyk 1992; Kutek 1996; Krzywiec 2006). This is because of its marginal position, which made the area sensitive to both regional (Subhercynian tectonics movements) and global events (eustatic changes). These events affected the sedimentary history of the area and are well recorded in available geological successions. Progress in the field was hindered so far by relatively...
rough chronostratigraphic recognition of the Campanian and Maastrichtian of the synclinorium, which is critical in the proper interpretation of the basin evolution. The existing studies are either too general (older publications, e.g., Sujkowski 1926, 1934; Paszewski 1927; Kowalski 1948), or are limited geographically (e.g. Rutkowski 1965; Łyczewska 1965). However, as demonstrated in some recent publications (Jagt et al. 2004; Machalski et al. 2004; Walaszczyk et al. 2008) the Campanian and Maastrichtian of the Miechów Synclinorium contain most of the stratigraphically important fossil groups that can serve for constructing a refined chronostratigraphy of the upper Upper Cretaceous of the area.

This paper presents the Campanian and Maastrichtian inoceramid-based chronostratigraphic framework of the Miechów Synclinorium, based on which the depositional architecture and sedimentary history of the area is discussed.

MATERIALS AND METHODS

Forty-one sections, mostly from the southern and central parts of the Miechów Synclinorium, were studied. Every section is documented with lithological and palaeontological samples. 220 specimens of inoceramid bivalves were collected and brought from the field. Three hundred and fifty thin sections were prepared in the AGH University of Science and Technology in Kraków and studied under the optical microscope at the Institute of Geological Sciences, Jagiellonian University in Kraków, and at the AGH University of Science and Technology in Kraków.

The palaeontological material is housed at the Institute of Geological Sciences of the Jagiellonian University in Kraków (collection No. U/220P/I). The bentonites were analysed by Jackson’s procedure (1969) at the Clay Minerals Laboratory of the Institute of Geological Sciences, Jagiellonian University in Kraków, and at the AGH University of Science and Technology in Kraków. Due to the lack of complete borehole cores, only the borehole cards hosted at the PIG-PIB were used.

PREVIOUS STUDIES

Stolley (1897), using belemnites, subdivided the Upper Santonian, Campanian and Maastrichtian (his Senonian) into the lower part, with *Actinocamax westfalicus* and *Actinocamax granulatus*, and the upper, with *Actinocamax quadratus* and *Belemnitella mucronata*. Already in 1906 Smolenśki recognised the lower unit with *Actinocamax quadratus* and the upper unit with *Belemnitella mucronata* from the Upper Cretaceous of Bonarka. In the NW part of the Miechów Synclinorium, Mazurek (1924, 1926, 1948) described beds with *A. granulatus*, *A. quadratus* and *B. mucronata*. Sujkowski (1926) distinguished zones with *Actinocamax verus* and *A. granulatus* and with *A. quadratus* and *B. mucronata* from the Wolbrom area. Kowalski (1948), Bukowy (1956), Senkowicz (1959), Rutkowski (1965), Pożaryski (1966) used a stratigraphical interpretation based on cephalopods and echinoids, proposed by Pożaryski (1938, 1948) and Kongiel (1962) (Text-fig. 2). The Santonian/Campanian boundary was defined with the last occurrence (LO) of the crinoid *Marsupites testudinarius* and the first occurrence (FO) of *Actinocamax quadratus*, and in the lower part, *Actinocamax quadratogranulatus* was documented (Pożaryski 1938). The Lower/Upper Campanian boundary was defined at the FO of *Belemnitella mucronata* (Kongiel 1962). The group of *B. langei*, composed of three species, *Belemnitella minor* and *Belemnitella najdini* and *Belemnitella langei* (Kongiel 1962), was significant in the Upper Campanian (Kongiel 1962). The *B. mucronata* Zone was divided using ammonites into the lower part, with *Acanthoscaphites spiniger*; middle part with *Hamites phaleratus*, and an upper part with *Bostrochyceras polyplocum*. The LO of the latter taxon defined the Campanian/Maastrichtian boundary (Pożaryski 1938). The Lower Maastrichtian was characterised by *Belemnitella lanceolata lanceolata* and
### CAMPAIGN AND MAASTRICHTIAN (CRETACEOUS) OF SOUTHERN POLAND

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<th>Inoceramid stratigraphy</th>
<th>Composite stratigraphical subdivision based on Northern Germany and Middle Vistula succession</th>
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**MAASTRICHTIAN**

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<th>Zone</th>
<th>Upper complex</th>
<th>Lower complex</th>
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<tr>
<td>Huáerceras sulcatus Acanthophactites tridens</td>
<td>Trochoderaeus radiosus</td>
<td>? Bn. sp. P</td>
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<tr>
<td>Acanthophactites tridens Huáerceras sulcatus Pachydiscus aff. neubergicus</td>
<td>Endocosta typica</td>
<td>Bn. sp. G</td>
</tr>
<tr>
<td>Belenmitella lanceolata lanceolata Belenmitella cf. lanceolata occidentalis</td>
<td>B. lanceolata lanceolata P. aff. neubergicus</td>
<td>Bn. inflata Bn. lanceolata</td>
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**CAMPANIAN**

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<tr>
<td>Belenmitella langei Belenmitella mcrconata minor</td>
<td>'Inoceramus' inkermanensis 'Inoceramus' altus</td>
<td>Nostoceras hyatti</td>
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<tr>
<td>Acanthophactites roemerli</td>
<td>S. pertenuiformis</td>
<td>Didymoceras donezianum</td>
</tr>
<tr>
<td>Bostrochoceras polyplocum Acanthophactites spiniger Pachydiscus cf. koeneni</td>
<td>Inoceramus tenuifineatus</td>
<td>Bn. langei</td>
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**SANCTOM**

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<th>Zone</th>
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<tr>
<td>Actinocamax quadratus</td>
<td>Sphaeroeramus sarumensis Cataceramus dariensis</td>
<td>Belemnitella gracilis /Belenmitella mcrconata senior</td>
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<tr>
<td>Belenmitella cf. precursor var. mcrconatiformis Actinocamax quadratus</td>
<td>Sphaeroeramus sarumensis Cataceramus dariensis</td>
<td>Echinocorys conica /Goniodothyris quadrata gracilis</td>
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<tr>
<td>Actinocamax quadratus</td>
<td>Sphaeroeramus sarumensis Cataceramus dariensis</td>
<td>Galeola papillosa</td>
</tr>
<tr>
<td>Actinocamax granulatus Marsupites testudinarius A. westfalicus granulatus</td>
<td>Sphaeroeramus sarumensis Cataceramus dariensis</td>
<td>Galeola senonensis</td>
</tr>
<tr>
<td>Actinocamax venus Actinocamax westfalicus</td>
<td>Sphaeroeramus sarumensis Cataceramus dariensis</td>
<td>Offaster pilula</td>
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</table>

Text-fig. 2. Correlation of inoceramid zonation applied herein (after Walaszczyk 1997, 2004; Walaszczyk et al. 2008), with zonations based on ammonites, echi-noids and belemnites for the Campanian and Lower Maastrichtian of Poland (Middle Vistula section; Blaszkiewicz 1980; Machalski 2012; Remin 2012, 2015) and Northern Germany (Schütz et al. 1984); and with faunal assemblages of Rutkowski (1965)
Belemnitella lanceolata occidentalis (Kongiel 1962), Acantoscaphites tridens, Haploscaphites constrictus vulgaris, Bostrochoceras schloenbachi and Pachydiscus aff. neubergicus were considered the characteristic forms of the Lower Maastrichtian (Pożaryski 1948). A foraminiferal scheme for the Campanian and Maastrichtian was proposed by Gawor-Biedowa and Wytywicka (1940) and was used by Rutkowski (1965). Senkowicz (1959) proposed a more detailed local stratigraphic scheme within the zones of Campanian and Maastrichtian of the NW part of the Miechów Synclinorium (earlier described by Mazurek 1924, 1926, 1948), based on lithology and echinoids. Senkowicz (1959) and Rutkowski (1976) reported the occurrence of sandy organodetrital limestones which were regarded to be either of Maastrichtian or Late Campanian age and were discussed by Machalski et al. (2004) who dated them as Miocene. An ammonite-bellemnite zonation proposed by Blaszkiewicz (1980), described from the Campanian and Maastrichtian of the Middle Vistula River, has never been used for the studied sequence. Recently, the inoceramid zonation of the Santonian and Campanian of the Miechów Synclinorium was published by Walaszczyk (1992), Jagt et al. (2004), Jurkowska et al. (2015), ammonite zonation by Machalski et al. (2004), and foraminiferal biostratigraphy by Dubicka (2015). The authors correlate the biostratigraphical zonations with the belemnites/echinoids zonation described from North Germany (Schulz et al. 1984) (Text-fig. 2). The inoceramid biostratigraphy of the Campanian and Lower Maastrichtian of the Miechów Synclinorium was presented by Jurkowska (2014; see also Jurkowska and Uchman 2013; Jurkowska et al. 2015).

GEOLOGICAL SETTING

The Miechów Synclinorium is the SE part of the Szczecin-Lódź-Miechów Synclinorium. To the SW the synclinorium passes gradually into the Silesian-Cracow Homocline, and to the NE into the Holy Cross segment of the Mid-Polish Anticlinorium (Text-fig. 1). The Cretaceous of the Miechów Synclinorium, represented by the Albian through the Lower Maastrichtian, overlies the Jurassic substrate unconformably and, in its central and southern parts, it is covered by the Miocene of the Carpathian Foredeep (Pożaryski 1977). The Cretaceous succession of the Miechów Synclinorium is distinctly two-fold (Text-fig. 3). Its lower, Albian through Santonian part, is composed of siliciclastic and carbonate units, relatively thin and stratigraphically largely incomplete (Sujkowski 1926, 1934; Różyczki 1937, 1938; Kowalski 1948; Marcinowski 1974; Walaszczyk 1992). At least the Upper Coniacian, Santonian and basal Campanian seems to be complete in the northern part of the Miechów Synclinorium (Walaszczyk 1992; Remin 2004, 2010). The upper part, the Campanian and Lower Maastrichtian, is composed of a monotonous succession of siliceous limestones (opokas) with marly horizons. The total thickness of the Campanian–Maastrichtian succession is about 300 m in the south-western part of the Miechów Synclinorium, and 500 m in its north-eastern part.

The so-called mid-Cretaceous transgression in extra-Carpathian Poland started in the Middle Albain, covering rapidly most of its territory (Pożaryski 1960, Marcinowski 1974). The initial facies variability of the Albian and Cenomanian was quickly followed by facies unification during the Early Turonian. With the exception of the Sudetes Mountains area, where siliciclastic sedimentation prevailed until the Santonian, the rest of the area is characterized by carbonate facies; limestones are restricted to the Kraków Swell area, while in other regions, opoka-marly facies dominate (Marcinowski 1974; Walaszczyk 1992).

STAGE AND SUBSTAGE SUBDIVISION

With the exception of the base of the Maastrichtian Stage, all other stage and substage definitions of the Campanian and Maastrichtian are still provisional. The current, widely followed recommendations (see Ogg and Hinnov 2012) were agreed mostly during the 1995 Brussels’ Symposium on Cretaceous Stage Boundaries (Rawson et al. 1996). As no formal requirements exist, however, definitions accepted in this paper, are shortly commented below.

The base of the Campanian was provisionally defined with the last occurrence of the stemless, pandemic crinoid species Marsupites testudinarius (Schlotheim, 1820) (Hancock and Gale 1996; see also Gale et al. 2008). As, however, this crinoid maybe limited to some environments, the base of the reversed polarity Chron C33r, which approximates the crinoid level, is evenly considered as the primary boundary marker (see comments in Ogg and Hinnov 2012).

According to the Brussels Symposium (e.g., Rawson et al. 1996), the tripartite subdivision of the Campanian stage is recommended. There are no formal definitions of particular substages, and the US Western Interior subdivision scheme (e.g., Cobban et al. 2006) is recommended (see Ogg and Hinnov 2012), and followed herein. The bases of the middle and upper Campanian substages in the US Western Interior ammonite
scheme are defined with the first appearances of ammonites, *Baculites obtusus* and *Didymoceras nebrascense*, respectively (e.g., Cobb 1994; Cobb et al. 2006; see also Ogg and Hinnov, 2012). Due to the endemic character of these ammonites, the biostratigraphic position of these boundaries in the European Campanian is interpreted with inoceramids (Walaszczyk et al. 2001, 2002a, b; Odin and Walaszczyk 2003; Walaszczyk 2004). Accordingly, the base of the middle Campanian lies within the ‘*I. azerbajdzjanensis* – *I. vorhelmensis* Zone, and the base of the upper Campanian within the ‘*I. tenuilineatus* Zone (see also Ogg and Hinnov 2012).

The Campanian/Maastrichtian boundary, one of the Cretaceous stage boundaries already approved by the International Commission on Stratigraphy (Ogg and Hinnov 2012), is defined as a statistical average of twelve bioevents recognized in the Campanian-Maastrichtian boundary interval in the Tercis les Bains (SW France) stratotypic section (Odin 1996, 2001; Odin and Lamaurelle 2001). In inoceramid terms this boundary correlates to the upper part of the ‘*Inoceramus* redbirdensis Zone, and approximates the FO of inoceramid species *Endocostea typica* (Walaszczyk et al. 2002; Odin and Walaszczyk 2003; see also Ogg and Hinnov 2012). This new definition places the base of the Maastrichtian in the lower part of the *B. obusta* Zone (e.g., Niebuhr et al. 2011; Keutgen et al. 2012), which is distinctly higher than

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**Text-fig. 3.** Geological map of the Miechów Synclinorium (Dadlez et al. 2000; modified) with studied localities
the FAD of Belemnella lanceolata (Schlotheim, 1813), the traditional marker of the Campanian–Maastrichtian boundary in the Boreal Realm (e.g., Birkelund 1957; Schulz et al. 1984).

The Maastrichtian Stage is commonly subdivided into two substages (Odin 1996; Ogg and Hinnov 2012). In the Boreal Europe, the base of the upper Maastrichtian is traditionally placed at the base of the belemnite zone of Belemnella junior (see e.g., Schulz et al. 1984), which is correlated to the base of the potential ammonite marker of this boundary, i.e., Menites fresvillensis (Suenes) (see e.g., Odin 1996; see also Walaszczyk et al. 2010). In inoceramid terms, this boundary corresponds to the top, or lies within the upper part of the Trochoceramus radiosus Zone (see Walaszczyk et al. 2009, 2010; Walaszczyk and Kennedy 2011).

LOCALITIES AND CAMPANIAN-MAASTRICTHIAN SUCCESSION

The Campanian-Lower Maastrichtian succession in the Miechów Synclinorium is accessible in a series of natural and artificial (abandoned quarries) exposures. The exposures are concentrated in the southern part of the area (Text-fig. 3). The tectonics of the Campanian and Maastrichtian of the study area is not well recognized. Previous authors (Sujkowski 1926, 1934; Rutkowski 1965; Jurkiewicz 1970; Łyczewska 1971, 1972; Kwapisz 1978; Szajn 1980; Walczowski 1984; Baran 1985; Bukowby 1968; Wiśniolski 1991; Boratyn and Brud 1993; Rutkowski and Mądry 1994) reported many uncertain faults; some of them were recognized during the fieldwork.

Lower Campanian

The Lower Campanian succession starts with grey marls, and overlies the Santonian glauconitic marls (Bonarka, Zabierzów) or, unconformably, the Upper Jurassic limestones (Rutkowski 1965). In the upper part, opokas with marly horizons and cherts dominate. Chert nodules are either chaotic (Bonarka, Biała Wielka, Iwanowice, Zabierzów) or occur in horizons (Wierzchowisko, Jeżówka 1 and Jeżówka 2). Two bentonite horizons are noticed (Wierzchowisko and Jeżówka 2) in the lower part of the Lower Campanian. The Sphaeroceramus sarumensis–Cataceramus dariensis inoceramid Zone was recognized by its index taxa; the level of the Sphaeroceramus patootensiformis Zone was documented by foraminifera (Jurkowska et al. 2015).

Microfacially the Lower Campanian opokas represent wackestone/packstone with foraminifera and spicules of siliceous sponges (Text-fig. 4a, b). There are also sponge fragments, echinoids and bivalves. An admixture of detrital quartz and glauconite is insignificant. The marls, which occur as interbeds in opokas, represent wackestone with foraminifera and spicules, and have a slightly higher content of detrital quartz and glauconite in comparison to opoka.

All Campanian–Lower Maastrichtian localities are briefly characterized below in alphabetical order. Their stratigraphic position is shown in Text-fig. 5 and their geographical location in Text-fig. 3.

Biała Wielka [N 50°41’ 17.19”; E 19°39’ 42.52”]; working quarry in the S. sarumensis-C. dariensis Zone opokas with marly intercalations (Jurkowska et al. 2015). Fossils are common, especially sponges and bivalves; inoceramid bivalves are rare.

Bibice; historical outcrop of Małecki (1989), Zapalówicz-Bilan et al. (2009), c. 10 km N of Kraków. Based on archival collection of rock samples and inoceramids, the outcrop represents opokas with cherts of the S. sarumensis-C. dariensis Zone.

Bonarka [N 50°2’17.39”; E 19°57’ 15.44”]; historical, abandoned quarry (currently nature reserve), now within the town of Kraków, in the uppermost Santonian–Lower Campanian S. patootensiformis Zone (Jurkowska et al. 2015), represented by grey marls and opokas with marly interlayers (see e.g., Smoleński 1906; Panow 1934; Alexandrowicz 1954; Barczyk 1956; Gradziński 1972; Kudrewicz and Olszewska-Nejbert 1997). The grey marls yielded abundant echinoids, belemnites and crinoids (Marsupites testudinarius in the lower part); the opokas contain common sponges and bivalves.

Iwanowice [N 50°11’ 74”; E 19°59’3.43”]; natural exposure in the eastern part of the village (Słomniki area) in the S. sarumensis-C. dariensis (Jurkowska et al. 2015) Zone opokas with marly interlayers. Rare fossils are dominated by sponges and bivalves with sporadic Cataceramus balticus.

Jeżówka 1 [N 50°24’ 41.37”; E 19°50’12.42”]; abandoned quarry. The lower part of the section, capped by glauconitic limestone, represents the S. sarumensis–C. dariensis Zone. The glauconitic limestone contains common sponges, echinoids (Galeola sp.), crinoids, crinoids and bivalves. The overlying opoka series belongs to the upper part of the Cataceramus beckumen-
CAMPANIAN AND MAASTRICHTIAN (CRETACEOUS) OF SOUTHERN POLAND

sis Zone (see Jagt et al. 2004; Dubicka 2015). It contains rare sponges, echinoids and inoceramids (C. dariensis), as well as ammonites and belemnites.

Jeżówka 2 [N 50°24′50.98″; E 19°49′4.43″]: natural exposure of opokas with cherts and marly horizons. The lower part, assigned to the S. patoootensiformis Zone and basal S. sarumensis-C. dariensis Zone (Jurkowska et al. 2015), contains a bentonite horizon. The fossils are quite abundant, mainly sponges echinoids, bivalves (inoceramids are rare, mainly imprints). The marly horizons yielded additionally echinoids, belemnites and solitary corals.

Pniaki [N 50° 41′ 17.19″; E 19° 39′ 42.52″]: abandoned quarry of the S. patoootensiformis Zone opoka with thin marly intercalations (Jurkowska et al. 2015). It provided relatively common sponges, bivalves and rare echinoids.

Poskwitów [N 50° 13′ 24.57″; E 20° 0′ 41.77″]: temporary road-cutting along the main street in the village (described by Mączyńska 1968, and Kudrewicz and Olszewska-Nejbart 1997). It is composed of marly opokas with cherts of the S. sarumensis-C. dariensis Zone. Opokas contain common echinoids and sponges; single specimens of C. dariensis were found.

Wierzchowisko [N 50°22′ 9.35″; E 19°49′5.21″]: abandoned quarry in the S. patoootensiformis and S. sarumensis-C. dariensis Zone (see Jagt et al. 2004; Jurkowska et al. 2015; Dubicka 2015). The exposed succession is represented by opokas with marly intercalations; a single chert horizon occurs in the middle of the succession. Rare sponges and echinoids were noticed.

Wola Więclawska [N 50°10′ 51.67″; E 20° 0′ 58.61″]: natural exposure in the S. sarumensis-C. dariensis Zone opoka with marly intercalations. In the middle of the succession, marly horizons with numerous inoceramids (C. ballicus) occur. Sponges, echinoids and large S. sarumensis inoceramids were noted in the opokas.

Zabierzów [N 50° 6′ 50.08″; E 19° 47′ 15.76″]: inactive reclaimed quarry. Glauconitic horizons documented in the lower part of the succession represent the Upper Santonian (Alexandrowicz 1956; Rutkowski 1965; Świerczewska-Gładysz 2010). The Santonian/Lower Campanian boundary runs in grey marls (Rutkowski 1965) overlying the glauconitic horizon. The next series of opokas with cherts represents probably the S. patoootensiformis Zone.


Middle Campanian

The Middle Campanian succession starts with opokas with marly interlayers (Rzeżuśnia, Falniów, Parkoszowice 1, 2 and Poradów). Cherts occur chaotically only in the lower part of the Rzeżuśnia succession. Two inoceramid zones were documented in the Middle Campanian: ‘I’. azerbaydjanensis-‘I’. vorhelmensis Zone (also documented near Busko Zdrój, in the NE part of the Miechów Synclinorium by Walaszczyk et al. 2008) and ‘I’. tenuilineatus Zone. The Cataceramus subcompressus Zone has not been documented by inoceramids, however an ammonite equivalent, Bastryhoceras polyplocum Zone, was reported by Rutkowski (1965).

Microfacially, opokas are represented by packstone with foraminfera and spicules (Text-fig. 4c, d). The other organic components comprise fragments of bivalves and echinoids. An admixture of detrital quartz (<0.1 mm) and glauconite (0.2 mm) grains is significant.

Falniów [N 50° 22′ 32.54′ E 19° 57′ 56.35″]: natural exposure at the NW end of the village on the fields behind the houses. The ‘I’. azerbaydjanensis-‘I’. vorhelmensis Zone opokas with marly horizons and rich sponges and echinoids, are exposed. The middle part of the succession contains horizons with abundant baculitid ammonites and inoceramids (‘I’. azerbaydjanensis and ‘I’. vorhelmensis) with glauconitic coatings.

Parkoszowice 1 [N 50° 18′ 59.39′; E 20° 3′ 36.86″]: abandoned quarry in the eastern bank of the Piotrówka stream in the village. The quarry exposes the ‘I’. tenuilineatus Zone opokas with marly interlayers. In the lower part of the section, horizons with baculitids occur. In the topmost part of the quarry, glauconitic marly opoka horizons with oysters, massive sponges, ichnofossils and gastropods were noticed. Fossils of sponges, ammonites, bivalves and gastropods are common throughout the section. ‘I’. tenuilineatus specimens are common, especially in the lower part of the succession. Cataceramus goldfussianus (d’Orbigny, 1847) and ‘Inoceramus’ nebrascensis Owen, 1852 were also found.

Parkoszowice 2 [N 50° 18′ 53.96′; E 20° 3′ 19.12″]: natural exposure on the eastern bank of the Piotrówka stream in the village of Parkoszowice in the ‘I’. tenuilin-
eatus opokas with marly horizons. Fossils are abundant, including mainly the inoceramids C. goldfussianus and ‘Inoceramus’ borilensis Jolckiev, 1962.

Rzeźuśnia [N 50° 20’ 9.98”; E 19° 58’ 15.53”]; abandoned quarry in the eastern end of the village represents I’. azerbaydjanensis- ‘I’. vorhelmensis opokas with marly interlayers (Jagt et al. 2004). In the lower part of the succession, opokas with cherts occur. Fossils are quite common: sponges, inoceramids (‘I’. vorhelmensis (Walaszczzyk, 1997), ‘I’. azerbaydjanensis Aliev, 1939 and C. balticus (Böhm, 1907)), echinoids, ammonites and belemnites. Two horizons with mass-occurrence of inoceramids and baculitids with glauconitic coatings were observed.

Poradów [N 50°20’5.12”; E 20°3’5.95”]; natural exposure in the ‘I’. tenulilinatus, (Jurkowska et al. 2015) Zone marly opoka with marly horizons. Fossils are common: sponges, echinoids, bivalves and belemnites. In the lower part of the succession there is a horizon with fragments of huge platyceramid inoceramids.

Upper Campanian

The Upper Campanian is represented by sandy opokas with grey marl horizons. Three inoceramid Zones are documented: Sphaeroceramus pertenuiformis, ‘Inoceramus’ inkermanensis and ‘Inoceramus’ costaceus – ‘Inoceramus’ redbirdensis. The ‘Inoceramus’ altus Zone has not been documented.

Upper Campanian opokas represent bioclastic wackestone (in the lower part of the succession) and packstone with spicules and foraminifera (in the upper part) (Text-fig. 4 e, f). They also contain sponges, bivalves, echinoids and high admixture of detrital quartz (0.1–0.3 mm) and glauconite grains (0.3 mm).

Głogowiany-Stara Wieś [N 50° 27’ 58.23”; E 20° 6’ 48.11”]; abandoned quarry in the eastern end of the village. A section of 4.5-m-thick highly bioturbated marly opokas was described. Fossils are common, but preserved fragmentarily (sponges, bivalves and ammonites). ‘Inoceramus’ alaeformis Zekeli, 1852, and huge representatives of Platyceramus sp. were found.

Jędrzejów [N 50° 31’ 5.05”; E 20° 17’ 4.76”]; temporary road-cutting in the northern part of the town of Jędrzejów. The succession is composed of sandy opokas and marls of the ‘I’. inkermanensis and ‘I’. costaceus-‘I’. redbirdensis zones (Świerczewska-Gładysz and Jurkowska 2013). The ‘I’. inkermanensis Zone is very fossiliferous with abundant sponges, inoceramids (‘I’. inkermanensis, ‘Inoceramus’ cobbani Walaszczzyk et al. 2002a, and ‘Inoceramus’ magniemonatus Douglas, 1942), echinoids, belemnites, large gastropods and plants (Debeya halodmania, Debey ex Saporta and Marion, 1873, and Debeya cf. paulinae sp. nov., Halamski 2013). In the upper part (‘I’. costaceus-‘I’. redbirdensis Zone) of the section, fossils become rare and there are only single representatives of inoceramids (‘I’. costaceus, E. aff. typica).

Komorów; historical locality of Hurcewicz (1960; and probably of Rutkowski 1965), near Miechów. Based on inoceramids (archival specimens), the section represents the Sphaeroceramus pertenuiformis Zone (Jurkowska et al. 2015).

Muniakowice [N 50° 17’ 7.99”; E 20° 7’ 10.85”]; seven abandoned quarries in the southern end of the village. Rocks are exposed in two of them only. Sandy opokas (‘I’. inkermanensis) with a marly horizon were described (from the topmost part of the succession). Fossils are abundant: mainly sponges, bivalves and ammonites. The inoceramid fauna is characterized by ‘I’. inkermanensis and ‘I’. magniemonatus (Douglas, 1942).

Nasiechowice [N 50° 18’ 30.09”; E 20° 8’ 2.28”]; abandoned quarry in the southern slope of the village of Nasiechowice. Only a 2-m-thick opoka bed with marl horizons in the lower part, and glauconitic marly opokas, highly bioturbated in the upper part, are available for observation. Specimens of ‘I’. redbirdensis were found in opokas below the glauconitic horizon.

Rakosyn [N 50° 38’ 40.64”; E 20° 5’ 50.78”]; temporary road-cutting along the main road from Rakosyn to Trzcinec, in Upper Campanian sandy opokas. A single specimen of ‘I’. nebrascensis and rare sponges and echinoids were only found.


Uniejów-Parcela [N 50° 25’ 41.9”; E 19° 56’ 51.13”]; outcrop of marly opokas in the lower part, and sandy opokas in the upper part. In the middle of the succession, there is a horizon with phosphorite concretions in the
lower part, and with glauconitic grains, quartz and phosphorite concretions in the upper part. All sponges, bivalves and belemnites detected in the horizon are preserved incomplete. The topmost part of the horizon is represented by highly bioturbated opokas with abundant inoceramids (*C. goldfussianus*) and pectenids. The ichnofoossils are filled with green, carbonate clasts. Above the horizon, 6-m-thick sandy opokas can be observed. Inoceramids are represented by *C. goldfussianus*, which are very common and probably indicate the *S. pertenuiformis* Zone (similar situations were described in the Middle Vistula Valley by Walaszczyk 2004).

**Wężerów** [N 50° 16ʹ 14.51ʺ; E 20° 3ʹ 5.49ʺ]; exposure behind the buildings in the eastern part of the village. It exposes a 3-m-thick succession of opokas with marly horizons, of the *S. pertenuiformis* Zone. Fossils are rich, including mainly bivalves, sponges, gastropods and echinoids. Inoceramids are represented by *S. pertenuiformis* and *Cataceramus ellipticus* (Giers, 1964).

**Lower Maastrichtian**

The Lower Maastrichtian is represented by sandy opokas (with a variable content of detrital quartz, generally increasing towards the top) with marly interlayers (sandy marly opokas were found only in the SE part of the study area). Two inoceramid zones were documented: *Endocostea typica* and *Trochoceramus radiosus*. The stratigraphic position of the sections of Antolka, Widnica, Tunel, Słaboszowice and Michałów is based on lithological correlation to the sections of Strzęźów 2 and Wola Chroberska, from which *Trochoceramus radiosus* (archival collections) was described (Walaszczyk et al.1996).

Microfacially, opokas from the lower part of the Lower Maastrichtian represent packstone with foraminifera and spicules (Text-fig. 4g, h), and high admixture of detrital quartz (0.1–0.2 mm). Opokas from the upper part of the succession represent wackestone with spicules and foraminifera. Detrital quartz in this part of the succession is abundant and the size of quartz grains increases upwards (Antolka and Tunel: <0.3 mm, and Strzęźów 2 and Widnica: 0.3–0.6 mm).

**Antolka** [N 50° 24ʹ 26.28ʺ; E 20° 5ʹ 28.66ʺ]; abandoned quarry near the road to Cisie. It exposes a 6-m-thick section of sandy and marly opokas with numerous inocerams, sponges, echinoids and belemnites was described. Inoceramids are very frequent and dominated by *C. subcircularis*, indicating the upper part of the *E. typica* Zone.

**Dzierżęcioły** [N 50°18ʹ 22.21ʺ; E 20°10ʹ 28.71ʺ]; abandoned quarry along the main road in the village. It exposes sandy opokas with frequent inoceramids and single ammonites. Horizons with mass-occurrence of inoceramids dominated by *C. subcircularis, Cataceramus barabini* (Morton, 1834), *Cataceramus glendivensis* Walaszczyk, Cobban and Harries, 2001 were described from the middle and the top parts of the succession. The opokas represent the upper part of the *E. typica* Zone.

**Jelcza Wielka** [N 50° 30ʹ 47ʺ; E 20° 24ʹ 52.24ʺ]; abandoned quarry in the village of Jelcza Wielka (in previous publications referred to as Wrocieryż). Foraminiferal stratigraphy of the exposed highly sandy opokas was provided by Dubicka and Peryt (2012), and it correlates with the *T. radiosus* Zone. Specimens of the scaphitid ammonite *Hoploscaphites constrictus* were also described from the section (Machalski, personal communication 2014).

**Kowala** [N 50° 28ʹ 46.03ʺ E 20° 32ʹ 50.53ʺ]; natural exposure on the left bank of the Nida River in the village of Kowala. It exposes sandy opokas of the *E. typica* Zone, with frequent *C. subcircularis* and single echinoids.

**Kozubów** [N 50° 26ʹ 15.3ʺ; E 20° 29ʹ 43.38ʺ]; natural exposure in the NW slope in the village of Kozubów. It reveals the upper part of *E. typica* Zone sandy opokas with highly bioturbated limestones and marl horizons. Abundant inoceramid fauna occurs in opokas, dominated by *C. subcircularis, C. barabini* and *Cataceramus balticus* (Böhm, 1907).

**Michałów** [N 50° 29ʹ 51.72ʺ; E 20° 27ʹ 51.23ʺ]; abandoned quarry in Lower Maastrichtian highly sandy opokas with marly horizons. Based on geological mapping data and a lithological comparison with Jelcza Wielka, the rocks probably represent the *T. radiosus* Zone.

**Pełczyska** [N 50° 21ʹ 34.58ʺ; E 20° 33ʹ 40.14ʺ]; natural outcrop in the *E. typica* Zone marly opokas. Rich fauna includes sponges, bivalves, belemnites and ichnofossils. Mass occurrence of small inoceramids of *En-
Pińczów [N 50° 32’ 13.41”; E 20° 32’ 16.69”]; natural exposure along the road from Pińczów to Kije. It exposes sandy opokas of the E. typica Zone. The opokas contain a rich inoceramid fauna dominated by C. subcircularis.

Rzędowice [N 50° 26’ 21.11”; 20° 5’ 22.64”]; natural outcrop in the southern bank of the village. Thick succession of highly sandy; yellow opokas of the T. radiosus Zone was described. Only rare specimens of T. radiosus were noticed.

Słaboszowice [N 50° 34’ 50.51”; E 20° 11’ 22.29”]; inactive quarry in the southern bank of the village. Yellow, highly sandy opokas were described. Only fragments of prismatic shells of inoceramids were found. Based on lithological similarities, the opoka probably represent the T. radiosus Zone.

Strzeżów Pierwszy 1 [N 50° 22’ 47.56”; E 20° 9’ 30.16”]; temporary road-cutting along the main road in the Strzeżów Pierwszy. The succession starts with glauconitic marls and marly opokas with phosphorite concretions and common fossils (Spondylus bivalves, belemnites, echinoids), but preserved incomplete. Marls are highly bioturbated. The marls are overlain by white sandy opokas with abundant inoceramids dominated by C. subcircularis and C. barabini, sponges, Spondylus bivalves and small echinoids. The overlying opoka contains only one specimen of Spiridoceramus tegulatus (Von Hagenov, 1842) form A and T. radiosus (archival collection of Warsaw University see Walaszczyk et al. 1996). White sandy opokas are separated from yellow highly sandy opokas by horizons with phosphorite concretions, detrital quartz and glauconitic grains. The collected and archival specimens indicate that the section represents the upper part of the E. typica Zone-T. radiosus Zone (yellow highly sandy opokas).

Strzeżów 2 [N 50° 22’ 56.6”; E 20° 25’ 7.34”]; three inactive quarries on the opposite side of the main road in Strzeżów Pierwszy yellow highly sandy opokas with marly horizons represent the T. radiosus Zone. Fossils are rare, only adapted for deep burrowing bivalves Lucina sp. and ichnofossils were noticed.

Tunel [N 50° 26’ 3.79”; E 19° 59’ 33.34”]; natural exposure near the railway station in Tunel. It exposes T. radiosus Zone sandy and highly sandy opokas with marly horizons. Only single fossils of bivalves (Lucina sp.) and ichnofossils can be found.

Widnica [N 50° 23’ 56.31”; E 20° 1’ 39.95”]; abandoned quarry. Highly sandy opokas with marly horizons were described from the T. radiosus Zone. Fossils are uncommon: only single bivalves and prisms of inoceramid shells were found.

Wola Chrobierska [N 50° 23’5 8.49”; E 20° 31’ 16.72”]; natural exposure along the road from Wola Chrobierska to Odrzywół, mentioned by Lyczewska (1965) and Mazurek (1924). It exposes the T. radiosus Zone highly sandy opokas. Fossils are relatively rare, only some fragments of inocerams were found. Archival specimens of T. radiosus from this section are stored at Warsaw University (Walaszczyk et al. 1996).

INOCERAMID BIOZONATION

Inoceramid biostratigraphy enables application of unified zonation recognized recently in the Western Interior (US) (Walaszczyk et al. 2001), Tercis (France) (Walaszczyk et al. 2002a), northern Germany (Walaszczyk 1997) and in the Middle Vistula River section (Walaszczyk 2004).

In inoceramid terms, the studied succession comprises an interval from the S. patootensiformis Zone up to the T. radiosus Zone. The Lower Campanian inoceramid succession can be compared with sections in northern Germany (Walaszczyk 1997). Inoceramids in this part of the succession are rare and the state of their recognition is poor. The inoceramid record of the Upper Campanian and Lower Maastrichtian of the study area can be directly compared to the succession known from the Middle Vistula River section (Walaszczyk 2004) and from Tercis (Walaszczyk et al. 2002a). Although it requires further studies, it seems that inoceramid diversity (actually richness) is lower than in the Middle Vistula area.

Sphenoceramus patootensiformis interval Zone. The base of the zone is defined by the FO of the index taxon, and the top by the FO of S. sarumensis and/or C. dariensis (see Walaszczyk 1997). This zone corresponds to the upper part of the Marsupites/granulata, granulataquadrautra, lingua-granulata and the lower part of the
Text-fig. 5. Lithology and inoceramid biostratigraphy of the studied sections.
pilula Zone (Walaszczyk 1997; Jagt et al. 2004). In the study area, this zone was recognized by micropalaeontological equivalents (Jurkowska et al. 2015).

Spaheroceramus sarumensis–Cataceramus dariensis interval Zone. The base of the zone is defined by the FO of the index taxa, and the top by the FO of C. becku-
C. balticus (Walaszczyk 1997). This zone corresponds to the upper part of the pilula, senonensis, papillosa, conica-gracilis and gracilis/senior zones (Walaszczyk 1997). In the study area, the zone was documented by C. dariensis (Text-fig. 6a) and micropalaeontological equivalents (Jurkowska et al. 2015). Horizons with mass occurrence of C. balticus and C. copetdagensis (Text-fig. 6f) were found in this zone.

Catacearmus beckumensis interval Zone. The base of the zone is defined by the FO of the index taxon, and the top by the FO of the ‘I.’ azerbaydjanensis-‘I.’ vorhelmensis assemblage (Walaszczyk 1997). The presence of this zone was suggested by Jagt et al. (2004) above the glauconitic horizon in the Jeżówka 1 section. This zone corresponds to the conica/micronata Zone.

‘Inoceramus’ azerbaydjanensis-vorhelmensis interval Zone. The base of the zone is defined by the FO of the index taxon, and the top by the FO of C. subcompressus (Walaszczyk 2004). This zone corresponds to the stobaei/bisiplana and vulgaris/bisiplana zones (Jagt et al. 2004). In the study area the zone was identified by the index taxon (Text-fig. 6b, d), which coincides with C. balticus and C. ellipticus.

‘Inoceramus’ tenuilineatus interval Zone. The base of the zone is defined by the FO of the index taxon (Text-fig. 6c), and the top by the FO of S. pertenuiformis (Walaszczyk 2004) (Text-fig. 7e). This zone was identified by the index taxon and correlated with the lower part of the Didymoceras donezianum ammonite Zone (Błaszkiewicz 1980; Walaszczyk 2004). I. borilensis (Text-fig. 6e), C. goldfussianus (Text-fig. 7a), ‘I.’ nebrascensis (Text-fig. 7b) and fragments of huge platyceramids were also found. Inoceramid fauna occurs in horizons. The lower part of the ‘I.’ tenuilineatus Zone has not been found in the study area and the uppermost part is absent due to a sedimentary gap (glauconitic horizon), thus the lowermost Upper Campanian was determined by the FO of S. pertenuiformis.

Sphaeroceramus pertenuiformis interval Zone. The base of the zone is defined by the FO of the index taxon (Text-fig. 7e), and the top by the FO of ‘I.’ altus (Walaszczyk 2004). This zone was identified by finds of the index taxon and correlated with the upper part of the D. donezianum Zone (Błaszkiewicz 1980; Walaszczyk 2004). C. ellipticus (Text-fig. 7f) and abundant C. goldfussianus were also found.

‘Inoceramus’ inkermanensis interval Zone. The zone ranges between the FO of the index taxon (Text-fig. 7c) and the FO of ‘I.’ costaeus (Walaszczyk 2004). This zone is documented by numerous inoceramids: ‘I.’ inkermanensis (Text-fig. 7c), I. balticus, ‘I.’ smirnovi (Text-fig. 8a) and ‘I.’ magniubonatus (Text-fig. 8b). The ‘I.’ inkermanensis Zone corresponds to the middle and upper parts of the Nostoceras hyatti ammonite Zone (Walaszczyk 2004).

‘Inoceramus’ costaeus and ‘Inoceramus’ redbirdensis Zones. This interval is between the FO of ‘I.’ costaeus (Text-fig. 9b) and the FO of E. typica (Walaszczyk 2004). The two index taxa occur in the succession; ‘I.’ costaeus appears first and is followed by ‘I.’ redbirdensis (Text-fig. 9t) appears after the FO of ‘I.’ costaeus. This zone corresponds to the interval from the Belemnella lanceolata up to middle part of the Belemnella vistulensis Zone (Remin 2012; compare also Keutgen et al. 2012 for zonation based on different methodology) and presumably to the basal part of the B. occidentalis Zone of Błaszkiewicz (1980) (see also: Walaszczyk 2004). The FO of E. typica was accepted as the beginning of the Lower Maastrichtian (Ogg and Hinnov 2012).

Endocostea typica interval Zone. The zone ranges between the FO of the index taxon (Text-fig. 7d) and the FO of T. radiosus (Walaszczyk 2004). Horizons with mass occurrence of small (< 4 cm) inoceramids are characteristic of this zone (Walaszczyk 2004). The lower part of the zone with E. typica (Text-fig. 7d) and C. subcircularis (Text-fig. 9d, e) was recognized in Pełczyska. In the remaining part of the study area only the upper part of the zone was identified. E. typica disappears in the upper part of the zone, but C. barabini, C. glendivensis (Text-fig. 9c) and C. balticus appear instead. The E. typica Zone corresponds to the Belemnella obtusa Zone of Remin (2012) without its basal part which is equal to the upper part of the Belemnella vistulensis B. sp. G and B. sp. F zones (compare, Remin 2012).

Trochoceramus radiosus interval Zone. This interval is between the FO of T. radiosus and the FO of ‘Inoceramus’ ianjonaensis Sornay, 1973 (Walaszczyk et al. 2002a, b, 2010). Two specimens from the archival collection of Alojzy Mazurek come from the Wola Chrobierska and Strzeżów sections (Walaszczyk et al. 1996). One specimen was collected by the author in the Rzędowice section. S. tegulatus forma A (Text-fig. 9a) were also noted in the T. radiosus Zone. This zone corresponds to at least to the upper part of the Belemnella obtusa Zone (Remin 2012).
EVOLUTION OF THE STUDY AREA DURING THE CAMPANIAN AND MAASTRICHTIAN

Global sea-level changes

Five unconformities represented by horizons of slower sedimentation rate, enriched with quartz, glauconitic grains and/or phosphorite concretions were recognized in the studied succession (Text-fig. 5). The contents of glauconitic grains, quartz and phosphorite concretions are different for each horizon. Four of them were recognized earlier, and used to subdivide the Campanian–Maastrichtian succession into three units (Rutkowski 1965, Table 1). Biostratigraphic analysis al-
lows determining the stratigraphic position of the horizons, to correlate them with eustatic sea-level trends.

**Marsupites transgression** (Text-fig. 5). The oldest glauconitic horizon was described from the western part of the Miechów Synclinorium: Zabierzów, Bonarka (Gradziński 1972), Korchkiew (Kurdzewicz and Olszewska-Nejburt 1997), Wielkanoc (Świerczewska-Gładysz and Olszewska-Nejburt 2009), Słomniki core (Rutkowski 1961), Potok Mały IG1 (Jurkiewicz 1980), Jędrzejów IG1 (Jurkiewicz 1999), Włoszczowa IG1 (Pożaryski 1966; Jurkiewicz 1990). The horizon is 0.5–1.0 m thick and is enriched with glauconitic grains and inoceramid prisms. Świerczewska-Gładysz and Olszewska-Nejburt (2009) described redeposited (Middle Coniacian and Middle Santonian) sponges in the glauconitic marls from the quarry of Wielkanoc. Bukowy (1956), Alexandrowicz (1960) and Rutkowski (1965) included the glauconitic marls into the Santonian (see Walaszczyk 1992 who included the glauconitic marls into the upper Santonian, *S. patootensiformis* Zone) based on finds of the crinoid *Marsupites testudinarius* in grey marls above the horizon. In the central and NE part of the synclinorium, the equivalent of the glauconitic marls is a sandy horizon, known from the Jaronowice IG1 (Jurkiewicz 1976) and Książ Wielki IG1 (Jurkiewicz 1991) borehole cores and from the Kije section (Walaszczyk 1992; Remin 2004).

This horizon could be interpreted as a record of the *Marsupites* transgression recognized in Europe (Niebuhr 1995; Ernst and Wood 2000). Based on carbon stable-isotope variations through the Campanian–Maastrichtian, Jarvis et al. (2002, 2006) recognized the *Marsupites* transgression in Tunisia, France and England. The transgression was also reported from Madagascar (Walaszczyk et al. 2014).

**Mucronata transgression** (Niebuhr 1995) (= Middle Campanian Event, Jarvis et al. 2002; 2006) (Text-fig. 5). The glauconitic horizon from Jezőwka 1 was also recognized from Grzegorzowice Wielkie, Lipna Wola (Rutkowski 1965), and Bibice (Panow 1934). It is also known from boreholes drilled in the SE part of the synclirnium (Heller and Moryc 1984). The horizon consists of limestone clasts with glauconitic coatings contained in marly deposits; the thickness of the horizon is about 40 cm. It is underlain by limestone with *Thalassinoideas* burrows. The horizon could have been produced by the *Mucronata* transgression, described from Germany (Niebuhr 1995), Tunisia, France, England (Jarvis et al. 2002; 2006), and Spain (Küchler 2000). The transgression started at the beginning of the *B. mucronata* Zone (the Early–Late Campanian boundary in traditional European subdivision).

**Late Campanian Event** (Voigt et al. 2012) (= Late Campanian Grobkreide Event; Niebuhr et al. 2011) (Text-fig. 5). The horizon from Parkoszowice 1 consists of 3-m-thick marly opokas with glauconitic grains. Common oysters (*Pycnodonte* sp.), gastropods and large sponges were reported. This horizon, which is an effect of slower or absence of sedimentation, could be connected with the Late Campanian Event (LCE) described by Voigt et al. (2012) from France, England, Italy and Germany (Niebuhr et al. 2011), which is manifested by a negative δ13C excursion. In Tercis (France), the LCE was recognized between the interval without any ammonite and inoceramid documentation and the ‘I.’ *altus* Zone (Odin and Lamurelle 2001; Walaszczyk et al. 2002a). The horizon from Parkoszowice 1 represents the ‘I.’ *tenuilineatus* Zone and is older than the LCE, although it could be produced by an event connected with LCE. Such is the case with the horizon identified in Uniejów-Parcela. This horizon starts with a boundary enriched with quartz grains, phosphorite concretions and glauconitic grains. The upper part is highly bioturbated and the bioturbation is infilled with glauconitic clasts and phosphorite concretions.

**Campanian–Maastrichtian Boundary Events** (≡CMBE) (Text-fig. 5). It was described by Jung et al. (2012) from the Pacific, France, England and Egypt (Jarvis et al. 2002), and is manifested by a strong negative δ13C excursion, which is an effect of supposed cooling. The horizon recognized in Nasiechowice and Strzęków Pierwszy 1 from the upper part of the ‘I.’ *redbirdensis* Zone and the lower part of the *E. typica* Zone could be associated with the CMBE. The correlation of these events on a global scale is controversial due to lack of precise stratigraphic data. Jarvis et al. (2002) determine the start of the negative δ13C excursion in the *Gansserina gansseri* foraminferal Zone, which correlates with the Belemnella lanceolata belemnite Zone and the ‘I.’ *redbirdensis* to *E. typica* Zones (Ogg and Hinovec 2012). Jung et al. (2012) show many small δ13C peaks during the CMBE and extended the CMBE to the *T. radiosa* Zone (see also Voigt et al. 2012). Voigt et al. (2012) connect the CMBE with global tectonic movements rather than climate cooling. In these terms, the upper horizon from Strzęków Pierwszy 1 could be a result of a short-term sea-level pulse.

The older horizon from Nasiechowice and Strzęków Pierwszy 1 comprises a 1.5-m-thick marly opoka enriched with glauconitic grains, quartz and fragmentarily preserved fossils (only *Spondylus* sp. are preserved whole). The horizon is strongly bioturbated and the sediment infilling ichnofossil burrows does not contain
glauconitic grains. The younger horizon from Strzeżów Pierwszy 1 is characterized by opokas with quartz, phosphorite concretions and rare glauconitic grains.

**Alloformations**

Inoceramid biostratigraphy is the most useful method for chronostratigraphic analysis of the Campanian and Maastrichtian of the Miechów Synclinorium. Its usefulness is limited to the exposed successions; inoceramids are rarely found in cores. For the reconstruction of the depositional architecture of the study area, a more precise chronostratigraphic analysis is needed.

The described horizons are useful for distinguishing alloformations in the Campanian and Maastrichtian of the Miechów Synclinorium. All of them are correlated with global eustatic sea-level changes, which makes them isochronous in the area studied.

Six alloformations have been distinguished in accordance with the Polish Rules of Stratigraphy (Racki and Narkiewicz 2006). Most of them represent third-order eustatic sea-level changes (Haq et al. 1987).

**Alloformation I**

The lower boundary is defined by Santonian glauconitic marls (or sandy marl horizon), and the upper one by the Lower Campanian horizon with limestone in glauconitic coatings. The lower horizon is well examined in the western part of the Miechów Synclinorium and in cores (see section: ‘Marsupites transgression’). In the NW part of the study area it correlates with the sandy marl horizon (Remin 2004). The glauconitic marls are overlain by grey marls and opokas with cherts. Locally, the grey marls lie on Jurassic limestones (Rutkowski 1965).

The thickness of alloformation I is variable: 2–10 m in the western part (Gradziński 1972, Świerczewska-Głądysz 2010, Jurkiewicz 1974), 40–45 m in the central (Rutkowski 1961, Jurkiewicz 1976, Jurkiewicz 1990) and eastern parts of the Miechów Synclinorium (Heller and Moryc 1984).

The opokas contain abundant fossils represented by epibenthos (sponges, bivalves) and endobenthos (echinoids); nektonic organisms (ammonites and belemnites) are rare.

Microfacially, the opokas represent packstone with foraminifers and spicules, the quartz content is insignificant.

**Alloformation II**

The limestone in glauconitic coatings recognized in the Jeżówka 1 section indicates the lower boundary of alloformation II, and the upper boundary is marked by the glauconitic horizon known from Parkoszowice I.

The horizon from the Jeżówka 1 section was also found in Lipna Wola, Grzegorzowice Wielkie (Rutkowski 1965) and Bībe (Panow 1934) and from cores in the SE part of the Miechów Synclinorium (Heller and Moryc 1984).

The thickness of alloformation II is about 100 m. Alloformation II is represented by marly opokas with cherts (in its lower part) and opokas with marly horizons (in its upper part). The fossils are abundant: sponges, inoceramids, baculitids. In the lower part of alloformation II, there are two horizons of abundant baculitids and inoceramids in glauconitic coatings (Rzeżuśnia section).

Microfacially, the opokas represent packstone with foraminifers and spicules, the quartz content is insignificant.

**Alloformation III**

The lower boundary of alloformation III is indicated by the glauconitic horizon from the Parkoszowice I section, and the upper boundary by the glauconitic-phosphorite horizon from the Uniejów-Parcela section. The glauconitic horizon from the Parkoszowice I section was also noticed in the Włoszczowa Trough by Pożaryski (1966).

The thickness of alloformation III is estimated in the southern part of the Miechów Synclinorium at 10 m, and in the northern part at 30–60 m.

Alloformation III consists of fossiliferous opokas with marly horizons. Microfacially, it is represented by bioclastic wackestone/packstone with quartz (0.1–0.2 mm) and glauconitic grains (0.1 mm).

Alloformation III spans the interval of the upper part of the ‘I. ’tenulineatus Zones.

**Alloformation IV**

Alloformation IV has been distinguished between the glauconitic-phosphorite horizon from the Uniejów-Parcela section and the glauconitic horizon from Strzeżów Pierwszy 1. The former was also described by Pożaryski (1966) from the northern part of the Miechów Synclinorium.
Alloformation IV is represented by fossiliferous, sandy opokas with marly horizons. Microfacially, the opokas represent bioclastic wackestone/packstone with abundant quartz grains (0.1–0.3 mm).

Alloformation IV spans between the S. pertenuiformis and E. typica zones (including a gap comprising the T. altus Zone).

Alloformation V

The lower boundary is indicated by the glauconitic horizon examined in the Strzeżów Pierwszy 1 section, and the upper boundary by the phosphorite horizon known from the Strzeżów Pierwszy 1 section.

Alloformation V consists of white sandy opokas with marly horizons. The lower part of the succession was recognized only in the Pełczyska section and is represented by fossiliferous marly opokas. Microfacially, the opokas are packstone with spicules and foraminifers; the admixture of quartz and glauconite grains is high.

The thickness of alloformation V is variable: about 60 m in the SW part of the Miechów Synclinorium, and about 130 m in the NE.

Alloformation V spans between the E. typica Zone to the lower part of the T. radiosus Zone.

Alloformation VI

The youngest alloformation was defined between the phosphorite horizon described from Strzeżów Pierwszy 1 and the youngest Maastrichtian deposits available in the Miechów Synclinorium.

Alloformation VI consists of sandy, yellow opokas with marly interlayers. Fossils are rare, represented by single inoceramids and other bivalves (Lucina sp.). Microfacially, the opokas represent packstone with spicules, foraminifers. The admixture of quartz grains (0.2–0.5 mm) is significant.

The thickness of alloformation VI is about 20–30 m in the SW part of the Miechów Synclinorium, and reach up about to 50 m in the NE part.

The alloformation is represented by the T. radiosus Zone.

Evolution of the study area

The chronostratigraphic and microfacies analyses provide a basis to analyze the thickness and facies changes in the Campanian and Maastrichtian in the study area. The thickness of particular chronostratigraphic units within the Campanian and Lower Maastrichtian increases progressively towards the axis of the Mid-Polish Anticlinorium, which suggests that the inversion of the Danish-Polish Trough could not have started before the Late Maastrichtian, which is in agreement with suggestions presented earlier by Kutek and Glazek (1972), and Świdrowska and Hakenberg (1999). It is significantly later than in the NE border of the Holy Cross Mountains, where the geophysical data show that the uplift movement started in the Late Turonian—Early Coniacian (Krzywiec 2002, 2006; Krzywiec et al. 2009; see also Dadlez et al. 1997; Leszczyński 2010). Signs of synsedimentary uplift tectonics during this time were not noted in the Miechów Synclinorium.

Five unconformity horizons, representing third-order eustatic sea-level changes (Haq et al. 1987), well recorded in European successions (Jarvis et al. 2006, Niebuhr et al. 2011), have been identified.

The lowest quartz content is found in opokas and marls of alloformations I and II, and it increases in alloformations III and IV; in opokas and marls of alloformation V and VI it is abundant. It is difficult to indicate the sediment provenance area; further investigations are necessary. Up-section, but not lateral, changes in the size of quartz grains in the Lower Maastrichtian sandy opokas described by Rutkowski (1960) were observed also by the present author. These could not be interpreted as an indicator of a sediment supply area. An area lying S/SW from the studied sections was indicated as a good provenance area for the S part of the Miechów Synclinorium (Kutek and Glazek 1972; Hakenberg and Świdrowska 1998; Świdrowska and Hakenberg 1999). Also the area lying N/NE from the Miechów Synclinorium, in the Holy Cross Mountains, was pointed out as a supplementary area (Małopolska Land; Jaskowiak-Schoeneichowa and Krassowska 1988). The data from leaf floras from the Miechów Synclinorium also suggest that, during the Campanian, there must have existed uplifted areas in the Holy Cross part of the Danish-Polish Trough (Halamski 2013). The leaf flora and a greater input of quartz were interpreted as a sign of the beginning of inversion of the Danish-Polish Trough. New data presented in this paper show that tectonic evolution of the study area could be more complicated. It is difficult to estimate whether the quartz content was an effect of eustatic sea-level changes or tectonic movements in the Danish-Polish Trough (Walaszczyk and Remin 2015).

CONCLUSIONS

1. In the Campanian–Lower Maastrichtian deposits of the Miechów Synclinorium, nine inoceramid zones, excluding C. beckamensis, C. subcompressus and T. albus, were identified by finds of the index taxa.

2. Five glauconitic horizons enriched with quartz and...
phosphorite nodules correlate with eustatic sea-level peaks well recognized in Europe.
3. Unconformity horizons allow the determination of six alloformations which are isochronous within the Miechów Synclinorium.
4. The thickness of particular alloformation units increases progressively toward the axis of the Danish-Polish Trough, which indicates that the inversion of the trough in the Miechów Synclinorium could not have started before the Late Maastrichtian.
5. The increasing quartz input in the Campanian–Lower Maastrichtian could be an effect of eustatic or tectonic movements in the Danish-Polish Trough.

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