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Integrated stratigraphy of the Campanian–Maastrichtian boundary succession of the Middle Vistula River (central Poland) section; introduction

IRENEUSZ WALASZCZYK

Faculty of Geology, University of Warsaw, Al. Żwirki i Wigury 93, PL-02-089 Warsaw, Poland.
E-mail: i.walaszczyk@uw.edu.pl

ABSTRACT:

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The Campanian–Maastrichtian boundary interval of the Middle Vistula River valley section (central Poland) represents a continuous, lithologically monotonous, fossiliferous succession, with a good stable isotope and palaeomagnetic signal. It yields all the biostratigraphically critical macro- and microfossil groups: ammonites, belemnites, inoceramid bivalves, foraminifera, nannofossils and dinoflagellates. Additionally, it is located in the transitional zone between the Boreal and Tethyan biogeographic provinces, as well as between the western and eastern biogeographic areas of Europe. The section supplements the data on the interval acquired recently from the basal Maastrichtian stratotypic section in Tercis, south-west France, and from the interval reference section in Kronsmoor, northern Germany.

Key words: Middle Vistula River section; Central Poland; Campanian–Maastrichtian boundary; Biostratigraphy; Correlation.

INTRODUCTION

Understanding of the Earth history relies heavily on accurate stratigraphic correlation at a global scale. That is why the efforts of stratigraphers world-wide, coordinated by the International Stratigraphic Commission through its various Subcommissions, have been to establish the most practical and most reliable chronostratigraphy, using any available tool. Fixing of the standard subdivision is realized through the selection of stratotypes, which are expected to represent the most complete sections, with possibly the richest choice of stratigraphic tools. Rarely, however, do any of the selected and accepted stratotypes contain all of the stratigraphic tools possible and the best record. Consequently, detailed studies of any available section that can supplement recognition of the stratigraphic interval represented by a stratotype are of extreme importance.

This volume of *Acta Geologica Polonica* presents the publication of the results of the studies of the Campanian–Maastrichtian boundary interval in the Middle

Vistula River valley section, in central Poland. Although the boundary stratotype at Tercis in south-west France was extensively studied (Odin 2001) and approved (Odin and Lamaurelle 2001), and much work was done on the Boreal reference section for the base of the stage in Kronsmoor in northern Germany (Niebuhr *et al.* 2011, and literature cited therein), the succession of the Vistula section still adds much to proper recognition of the Campanian–Maastrichtian record. The Campanian–Maastrichtian succession of the Middle Vistula River section represents an expanded, lithologically monotonous, complete and fossiliferous succession, with good palaeomagnetic and stable isotopic signals. Moreover, all the biostratigraphically important macrofossils (ammonites, belemnites, inoceramid bivalves) and microfossils (foraminifera, nannofossils, dinoflagellates) are well represented. Additionally, the section is located in the transitional zones between the Boreal and Tethyan provinces, and between the eastern and western areas of Europe, being a good tie point from a palaeobiogeographic point of view.

The studies of the topmost Campanian and basal Maastrichtian in the Vistula section started some years ago, and the first paper, providing the general stratigraphic interpretation of the succession and its inoceramid biozonation, was published by Walaszczyk in 2004. At the same time, restudies of the ammonite faunas were initiated, with the first results published by Machalski in 2012. The results of other studies are either ready to be published, and are contained in the present volume, or are in progress, and will appear in one of the next issues of *Acta Geologica Polonica* for 2013.

The main part of the present volume consists of two papers on belemnites, the critical group in the classic stratigraphic studies of the Campanian–Maastrichtian boundary interval in the Boreal province. The opening paper by Z. Remin, presents the results of a restudy of the Middle Vistula belemnites by means of Artificial Neural Networks (self-organizing Kohonen algorithm), an entirely new method in belemnite study. The accompanying paper by N. Keutgen, Z. Remin and I. Walaszczyk, compares the results of this new method with the classic belemnite study procedure of Schulz (1979) as applied to the Vistula material. The volume closes with the paper by E. Swierczewska-Gładysz on the sponges, which is the sequel paper to her 2006 publication on the Campanian and Maastrichtian sponges from the Vistula section. The rich, newly collected sponge material, precisely tied to the new stratigraphy in the Campanian–Maastrichtian boundary interval, provides valuable data that enable interpretation of the environmental changes in the succession.

The second set of papers will comprise the next part of the ammonite survey (by M. Machalski), reports on foraminifera (D. Peryt), nannofossils (J.A. Lees), magnetostratigraphy (J. Nawrocki, T. Plasota and I. Walaszczyk) and stable isotope stratigraphy (S. Voigt), as well as a synthesis of the results from the whole project.

Since its inception, the project has been continually supported by the Institute of Geology of the Geological Faculty of the Warsaw University.

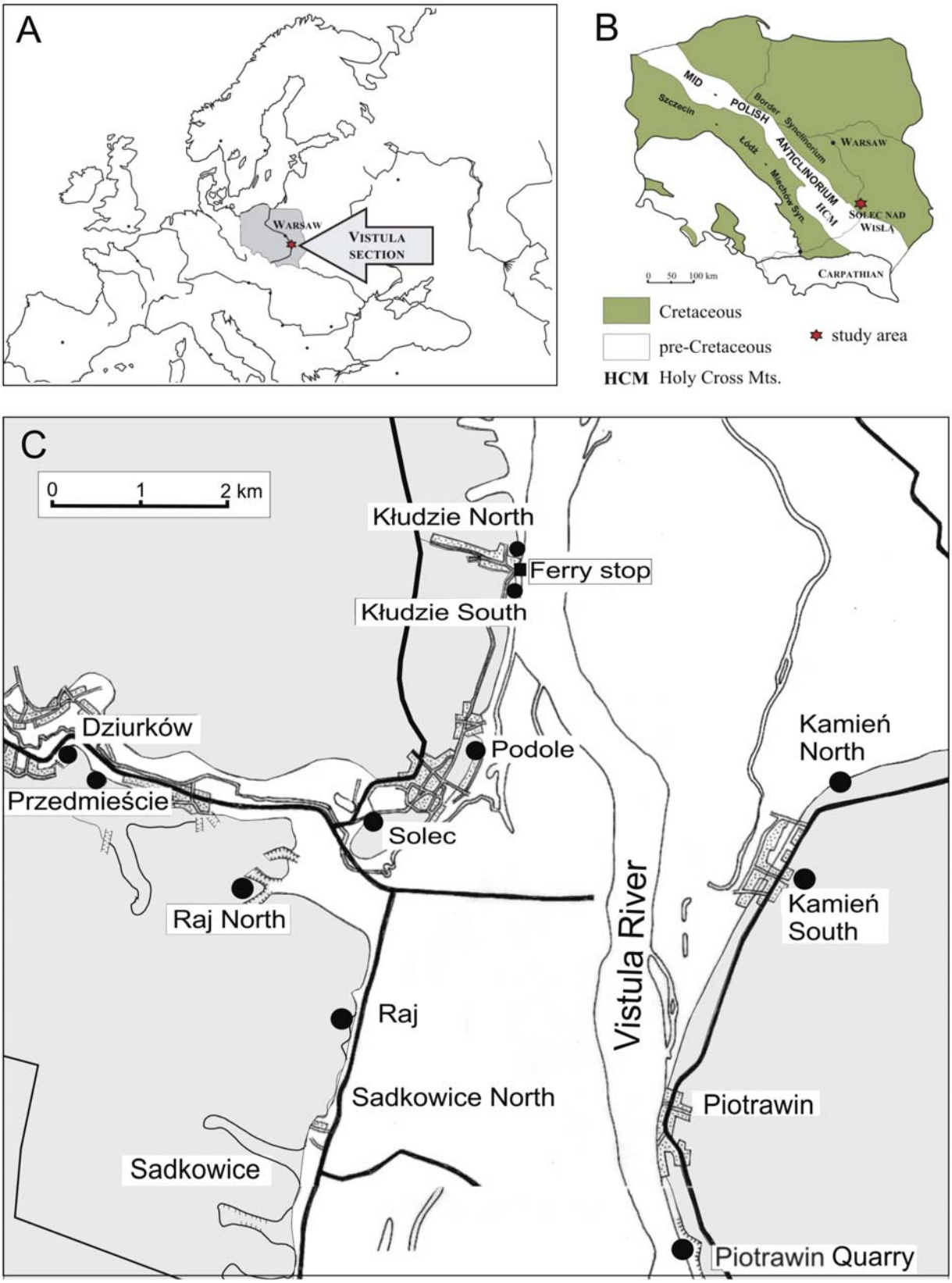
GEOLOGICAL SETTING

What is called the ‘Middle Vistula River valley section’ is a composite section, comprising a series of exposures in the banks of, or at some distance from, the Vistula river, between the towns of Zawichost in the south and Kazimierz Dolny in the north, with the latter town located slightly more than 120 km south of Warsaw (Text-fig. 1A) (see Marcinowski and Radwański 1983; Walaszczyk in Voigt *et al*. 2008). The river runs here more or less northward, cutting obliquely through the southern limb of the so-called border (or marginal) synclinorium, one of the main Permian–Mesozoic structures running NW-SE through the entire territory of Poland (Text-fig. 1). The Cretaceous succession starts here with the Middle Albian (Marcinowski 1980), exposed in the southern margin of the area, between Zawichost and Annopol, and the river exposes successively younger strata toward the north, with the Maastrichtian–Danian boundary directly accessible near the town of Kazimierz Dolny (Text-fig. 1).

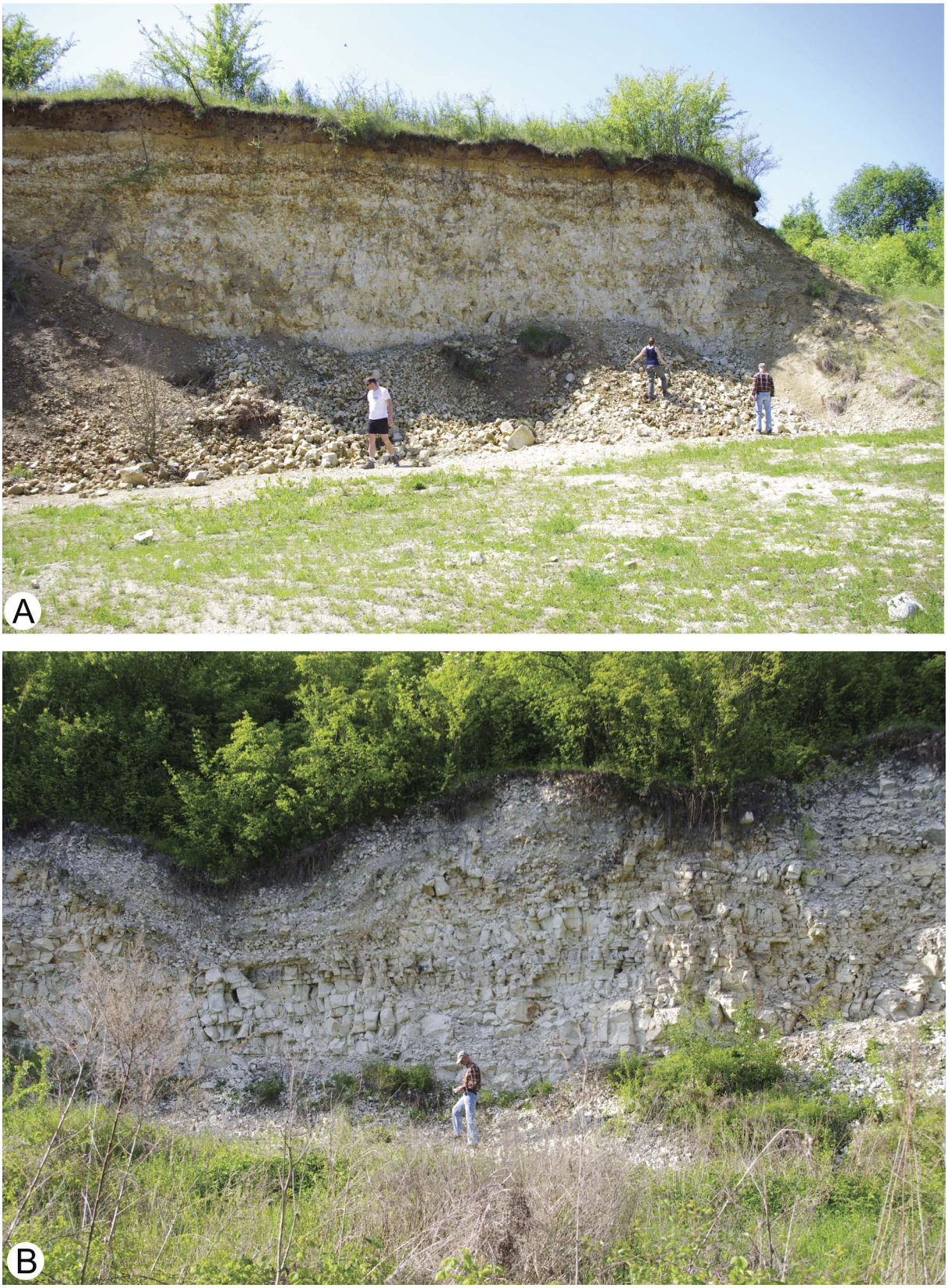
With small hiatuses, mostly in the lower part (Cieśliński 1976, Marcinowski 1980, Walaszczyk 1987), the Upper Cretaceous succession is quite complete, with monotonous siliceous marl (opoka) dominating in the Turonian through Maastrichtian part.

Most of the exposures are small to medium-sized quarries or artificial river-bank-cuttings along houses or roads, with the maximum thickness of the exposed succession rarely exceeding 30 m, and usually considerably less (Text-fig. 2). Natural good exposures are extremely rare. Cliffs along the Vistula banks, and along small gullies and creeks ending in the Vistula valley, are usually overgrown; this process seems to have been more intensive in recent years, most probably due to climate changes.

The Campanian–Maastrichtian boundary interval is probably the best exposed interval nowadays.



Text-fig. 1. A – Geological sketch-map of the territory of Poland with location of the study area; B – geological sketch-map of the upper Campanian and lowermost Maastrichtian part of the Middle Vistula River valley section, with location of the sections studied



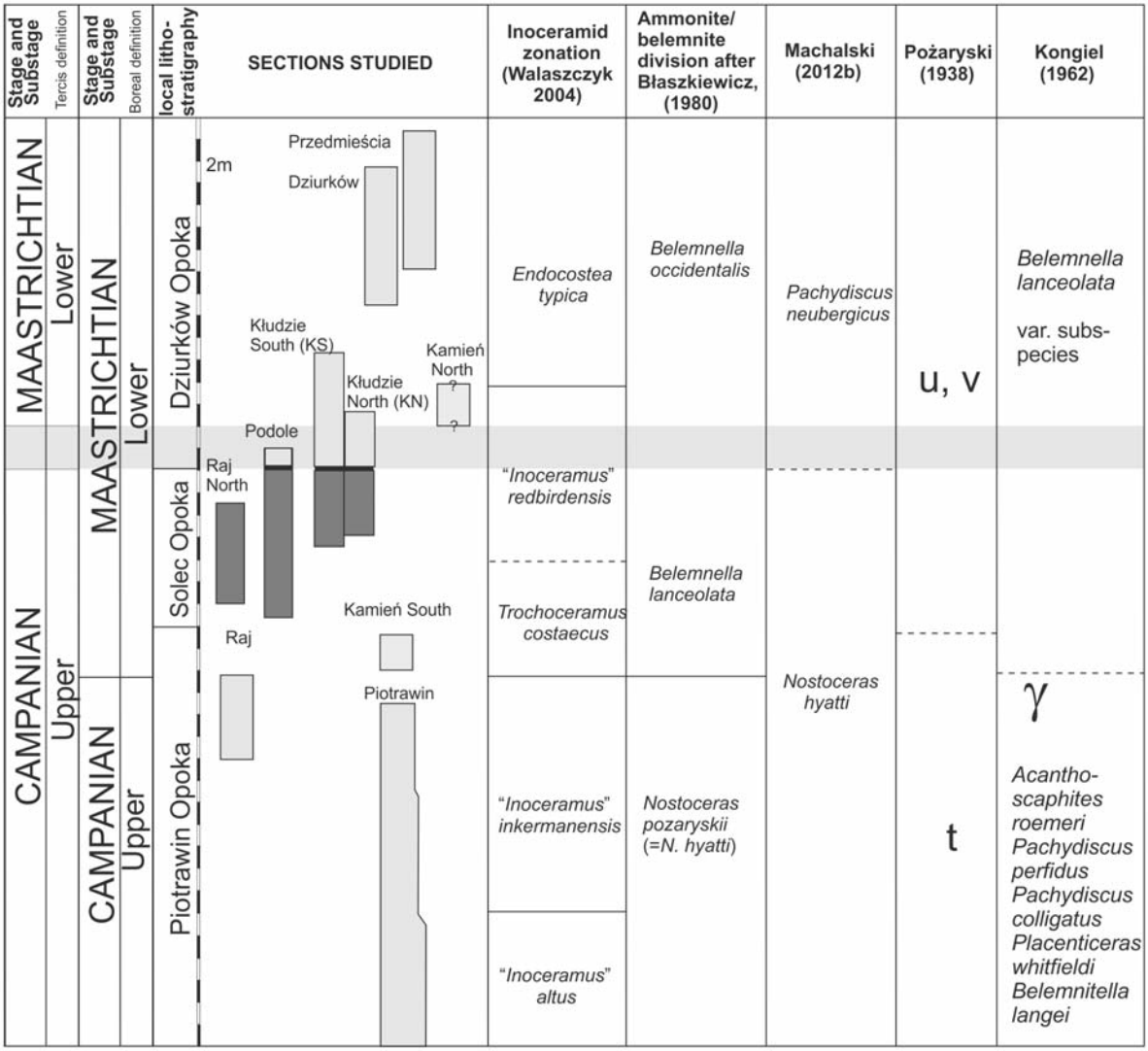
Text-fig. 2a. Photographic view of selected sections studied; A – Raj North section; view from the north; B – Raj section; view from the south

Text-fig. 2b. Photographic view of selected sections studied; C – Dziurków section, view from the west

HISTORICAL OVERVIEW

The simple, homoclinal structure of the Cretaceous deposits in the Vistula section, with gentle dip toward the NE, was first recognized by Krishtafovich (1899), and almost immediately accepted by subsequent students of the area. Pożaryski (1938) provided the first, modern subdivision of the 'Senonian' part of the succession, based on detailed petrographic and palaeontological studies. Because of the composite character of the Middle Vistula section, Pożaryski established a basic subdivision into a series of local units with mixed, petrographic/faunal definitions, designated alphabetically from a through to z. He interpreted the units biostratigraphically in terms of the then standard 'Senonian' zonal scheme. The part of the Campanian–Maastrichtian succession studied herein, belongs to his units t, u and v. All three units were distinguished on the basis of their faunal content; unit t being characterized by *Acanthoscaphites tridens* and *Hoploscaphites constrictus* var. *vulgaris*; and units u and v by the common occurrence of *Belemnella lanceolata*, with unit v being marked by a distinct drop in ammonite diversity. All three units were interpreted by Pożaryski (1938, 1948) as of Maastrichtian age. This chronostratigraphic interpretation was revised subsequently by Kongiel (1962), who, based on an extensive study of the belemnite faunas, demonstrated that the base of the Maastrichtian should be placed at the base of unit u, with the first appearance of *Belemnella lanceolata*. Additionally, based on their uniform belemnite faunas, units s and t of Pożaryski (1938), were referred by Kongiel (1962) to his new unit γ, representing the uppermost Campanian in the succession.

In the case of the Campanian–Maastrichtian boundary interval, the units of Pożaryski (1938), with their chronostatigraphic reinterpretation by Kongiel (1962), were generally applied and followed in subsequent papers (e.g., Gaździcka 1978; Peryt 1980), until the benchmark study by A. Błaszkiewicz (1980). Błaszkiewicz (1980) established an ammonite zonal scheme for the Upper Campanian, and placed the base of the Maastrichtian at the first appearance of *Belemnella lanceolata*. The Lower Maastrichtian he subdivided by means of belemnites, applying the successive zones of *Belemnella lanceolata* and *Belemnella occidentalis* of Jeletzky (1951) and Birkelund (1957).



Text-fig. 3. Chrono- and biostratigraphic correlations of the ammonite-bearing sections studied (after Walaszczyk 2004, modified); chronostratigraphy according to the "Tercis" and the traditional Boreal definitions of the base of the Maastrichtian Stage; inoceramid zonation after Walaszczyk 2004; ammonite zonations after Błaszkiewicz (1980) and Machalski (2012b)

The stratigraphy of the boundary succession, because of the composite nature of the Vistula section, was poorly recognized even after the publication of Błaszkiewicz (1980). Investigations to work out the exact succession were started by me in cooperation with Marcin Machalski, and published in 2004 (Walaszczyk 2004); the inoceramid bivalves then appeared to be critical in this study.

SOURCE LOCALITIES

Good exposures of the Campanian–Maastrichtian boundary succession are found close to the town of Solec nad Wisłą (Text-fig. 1), on both the eastern and western banks of the Vistula River; the succession close to the boundary is best exposed west of the river. The boundary interval, studied herein, spans the *Nostoceras hyatti* ammonite Zone of the mid-Upper Campanian through to the *Belemnella obtusa* belemnite Zone of the mid-Lower Maastrichtian; in inoceramid terms it corresponds to the interval spanning the "*Inoceramus*" *inkermanensis* through to the upper *Endocostea typica* Zone (Text-fig. 3).

In ascending stratigraphic order, the Campanian–Maastrichtian boundary succession is revealed in the following exposures (Text-figs 1–3): Piotrawin quarry; Raj quarry, Raj North quarry; the sections of Podole, Kłudzie South, and Kłudzie North, in the western bank of the Vistula Valley; and finally the Dziurków quarry, at the

eastern margin of the village of Dziurków, some kilometres west of Solec nad Wisłą. Apart from the Potrawin section, which is a large abandoned quarry, the rest of the sections are of small to medium size, exposing a few to a dozen metres of the succession. The correlation of particular sections is based primarily on biostratigraphy and cartographic interpretation; the three sections in the western bank of the Vistula (Podole, Kłudzie South and Kłudzie North) are easily correlated due to the presence of the 'boundary marl', a very good lithological marker. The section of Kamień (Text-fig. 3), an important source locality for both Pożaryski (1938) and Kongiel (1962) is no longer extant; however, some temporary excavations apparently close to the original section were available (studied in detail by M. Machalski) and provided important new ammonite, belemnite and inoceramid finds (see Machalski 2012a).

The upper Campanian–lowermost Maastrichtian succession of the Vistula section is represented by monotonous siliceous marl facies (opoka). Subtle lithological differences enabled three successive lithological units to be distinguished, which differ in clay content, colour and macrofaunal content (Walaszczyk 2004). In ascending stratigraphic order these are: Piotrawin Opoka; Solec Opoka; and Dziurków Opoka. The Piotrawin and Dziurków opokas are so similar that the latter was formerly interpreted as the direct continuation of the Piotrawin Opoka; the part of the succession referred now to the Solec Opoka was regarded as stratigraphically the youngest. Błaszkiewicz (1980) did not give explicit details of the succession in this interval. However, based on his locality map (his figure 1), it seems that he interpreted the sections of Kamień, Raj, Raj North, and Dziurków as representing his *Belemnella lanceolata lanceolata* Zone; and the sections of Podole and Kłudzie, along the Vistula river bank, he referred to his *Belemnella occidentalis* Zone (see also Text-fig. 3).

The sections used in the project are characterized briefly below. Their geographical locations are shown in Text-fig. 1 and their stratigraphic ranges in Text-fig. 3. Some are illustrated photographically (Text-fig. 2). Their ammonite content and ammonite stratigraphy, with reference to the inoceramid zonation, were recently discussed by Machalski (2012a).

Piotrawin: large quarry in the eastern bank of the Vistula River, c. 1 km south of the village of Piotrawin. The quarry was abandoned in the mid 1990s but the whole succession is still accessible for study. Slightly more than 30 m of the succession is exposed. The succession is composed of relatively soft, pale yellow opoka and is richly fossiliferous, particularly in the upper third. It is the type section of the Piotrawin Opoka. The section is known for its abundant ammonites (Błaszkiewicz 1980; Machalski 1996, 2012; see also Burnett *et al*. 1992), belemnites (Kongiel 1962; Remin 2007), inoceramids (Walaszczyk 2004), gastropods and bivalves (Abdel-Gawad 1986), sponges (Świerczewska-Gładysz 2006, 2012 this volume), foraminifera (Peryt 1980, 2000) and nannofossils (Gaździcka 1978, Burnett *et al.* 1992).

It is the type locality of the Zone of *Nostoceras pozaryskii* of Błaszkiewicz (1980); interpreted subsequently as a synonym of *Nostoceras* (*Nostoceras*) *hyatti* Stephenson, 1941 and *N.* (*N.*) *helicinum* (Shumard, 1861) (Kennedy *et al*. 1992; Burnett *et al*. 1992). A recent discussion of the ammonites from the section was provided by Machalski (2012).

In inoceramid terms, the section represents the '*Inoceramus*' *altus* and '*Inoceramus*' *inkermanensis* zones, with the boundary at approximately the base of the middle exploitation level. Based on belemnites, the succession was referred to the *Belemnitella langei* Zone (Burnett *et al*. 1992 and the late W.K. Christensen, unpublished report). Peryt (2000), based on benthic foraminifera, referred the upper half of the succession to the basal *Belemnella lanceolata* Zone.

Raj: small quarry in the northern wall of a creek entering the Vistula Valley from the west, c. 1 km south of the village of Raj (Text-figs 1, 3A). The 6 m thick succession is moderately well exposed but the highest part is clearly disturbed. Lithostratigraphically, the succession represents the topmost part of the Piotrawin Opoka and, based on the presence of *Belemnella lanceolata* Schlotheim (Remin 2007; 2012) (=*Belemnella* sp. in Keutgen *et al.* 2012 this issue) at its top, it corresponds to the topmost part of, or extends slightly higher than the succession in the Piotrawin quarry. Inoceramids are represented invariably by forms of the '*Inoceramus*' *inkermanensis* Zone

Raj North: small working quarry, south-east of the town of Solec, in the southern bank of the Krepianka River valley (Text-figs 1, 3B). It exposes an approximately 9 m thick succession of grey, brittle marly opoka, weathering pale grey, with white sponge detritus, representing the most typical Solec Opoka of the region. In comparison with the underlying Piotrawin Opoka, the ammonite and inoceramid diversity and abundance drops distinctly, with the exception of baculitid ammonites, which are common. The overall macrofaunal diversity seems, however, to be still high, albeit most of the specimens are poorly preserved. There is a level with belemnites in the middle part of the quarry wall. Numerous horizons with molluscan detritus characterize the upper half of the succession

In inoceramid terms the succession belongs to the zones of *Trochoceramus costaecus* and '*Inoceramus*' *redbirdensis*, as evidenced by the occurrence of their index taxa. Their precise vertical distribution is, however, unknown.

Solec: wall of a small, abandoned quarry at the main, entrance road at the western margin of the town of Solec nad Wisłą. Still exposed are a 3 m thick basal part and 3–4 m in the upper-middle part of the 14 m thick succession represented in the section. The strata exposed belong to the Solec Opoka, poorly fossiliferous, grey weathering to pale grey, with white spots around sponge fragments. In inoceramid terms, the succession belongs to the *Trochoceramus costaecus* and '*Inoceramus*' *redbirdensis* zones, with no precise location of the boundary between them.

Podole, Kłudzie South and **Kłudzie North**: these three sections are located in the high, western bank of the Vistula River, between the northern margin of the village of Podole and the ferry stop in the village of Kłudzie. The Podole section is an artificial cut in the valley bank, behind the two northernmost houses in Podole, c. 300 m south of the small creek that enters the Vistula valley from the west. The Kłudzie sections are located respectively c. 100 m south and 50 m north of the ferry port. All three sections span a similar stratigraphic interval and are easily correlated with each other due to the occurrence in each of the marly horizon referred to as the 'boundary marl' by Walaszczyk (2004). The 'boundary marl' is used to mark the boundary between the Solec Opoka and the overlying Dziurków Opoka; however, the change is rather transitional, and the typical Dziurków Opoka appears first some metres above the marly horizon (Walaszczyk 2004).

The succession below and some metres above the 'boundary marl' is composed of poorly fossiliferous, hard, grey-yellow opoka, with *Baculites* accumulations scattered throughout. In Podole, the boundary marl appears almost in the topmost part of the exposed succession; it is in the middle in the Kłudzie South section, and still lower in the Kłudzie North section. In inoceramid terms the succession belongs to the zones of '*Inoceramus*' *redbirdensis* and *Endocostea typica*. The latter forms were found in the Kłudzie North section, about 8 m above the 'boundary marl'

Dziurków: small working quarry at the eastern margin of the village of Dziurków, on the southern side of the road from Lipsko to Solec nad Wisłą (Text-figs 1, 3C). An almost 13 m thick succession of opoka, lying almost horizontally is exposed. It is the type locality of the Dziurków Opoka; a pale grey, fossiliferous siliceous chalk, weathering to yellow-grey, with brown spots around the margins of fossils. The section is rich in *Baculites*, sponges, and diverse bivalve and gastropod molluscs; *Baculites*-rich accumulations are noted in the basal part of the succession. This is the lowest, precisely located occurrence of *Pachydiscus* (*P.*) *neubergicus* in the Middle Vistula River section, although imprecisely located specimens are known from the underlying Kłudzie and Kamień North sections (Machalski 2012a). The Dziurków Opoka closely resembles the Piotrawin Opoka, both in lithological characteristics and faunal abundance.

In inoceramid terms the whole succession belongs to the *Endocostea typica* Zone.

Przedmieścia: small, abandoned quarry at the eastern margin of the village of Przedmieście, south of the road from Lipsko to Solec nad Wisłą, c. 1 km east of the Dziurków section. The lower half of the succession is represented by a typical Dziurków Opoka; in the upper half, the opoka becomes less fossiliferous and weathers pale grey, with white spots represented mostly by weathered sponge fragments. The succession extends 2–3 metres higher than the succession in the Dziurków section. In inoceramid terms, it belongs to the *Endocostea typica* Zone.

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