

# Stratigraphically important ammonites from the Campanian–Maastrichtian boundary interval of the Middle Vistula River section, central Poland

*In commemoration of Andrzej Błaszkiwicz, 1928–2008*

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## ABSTRACT:

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The formal definition of the Global Stratotype Section and Point (GSSP) for the base of the Maastrichtian Stage at Tercis, southwest France, is based on the first or last occurrences of twelve taxa, including three species of ammonites, *Pachydiscus* (*Pachydiscus*) *neubergicus*, *Diplomoceras cylindraceum*, and *Nostoceras* (*Nostoceras*) *hyatti*. The taxonomy and stratigraphical distribution of these, and allied forms, are studied, on the basis of material from the opoka succession across the upper Campanian–lowermost Maastrichtian boundary in the Middle Vistula River section, central Poland. In view of the imprecise location of two ammonite GSSP markers in that section, a direct ammonite-based correlation with the GSSP at Tercis is impossible. However, data available indicate that in the Middle Vistula River section the first occurrence of *Pachydiscus* (*P.*) *neubergicus* and the last occurrence of *Nostoceras* (*N.*) *hyatti* are situated significantly higher than the first occurrence of *Belemnella lanceolata*, the traditional belemnite marker for the base of the Maastrichtian Stage in the Boreal Realm, and that *Diplomoceras cylindraceum* appears significantly below this level. There are no unequivocal records of *Pachydiscus* (*P.*) *neubergicus* from the *Belemnella lanceolata* Zone s.l. in the Middle Vistula River section.

**Key words:** Ammonites; Campanian; Maastrichtian; Middle Vistula River section; Stratigraphy; Taxonomy; Correlation.

## INTRODUCTION

The Global Stratotype Section and Point (GSSP) for the base of the Maastrichtian Stage (Upper Cretaceous) is located at the 115.2 m level on platform IV of the disused limestone quarry at Tercis les Bains, Landes, southwest France (Odin and Lamaurelle 2001). The definition of the GSSP is based on the arithmetic mean of twelve biohorizons corresponding to the first or last occurrences of twelve stratigraphically important macro- and

microfossil taxa (Odin 2001a, b; Odin and Lamaurelle 2001).

Of four macrofossil markers used for the definition of the GSSP for the base of the Maastrichtian at Tercis, three are based on ammonites. These are: the FO (first occurrence) of *Pachydiscus* (*P.*) *neubergicus* (von Hauer, 1858), the FO of *Diplomoceras cylindraceum* (Defrance, 1816), and the LO (last occurrence) of *Nostoceras* (*N.*) *hyatti* Stephenson, 1941 (Odin 2001a, b; Odin and Lamaurelle 2001).

The aim of the present paper is twofold: to discuss the taxonomy and record of the stratigraphical ranges of *P. (P.) neubergicus*, *D. cylindraceum*, *N. (N.) hyatti* and allied species in the upper Campanian–lowermost Maastrichtian boundary interval of the Middle Vistula River section, central Poland, and to compare the stratigraphic distribution of these important taxa in the Middle Vistula River section with that from the GSSP interval at Tercis as documented by Odin *et al.* (2001) and in relation to the local FO of *Belemnella lanceolata* (von Schlotheim, 1813), which is the traditional belemnite marker for the base of the Maastrichtian Stage in the Boreal Realm, especially in Denmark, Poland and at Krons-moor, northern Germany (e.g., Schulz 1979; Błasz-kiewicz 1980; Christensen 1996; Niebuhr *et al.* 2011).

The present study is based on specimens collected mainly by the present author, but also by Ireneusz Walaszczyk, Zbigniew Remin, and Maciej Duda, and includes also material from museum collections. The material studied comprises 52 individuals, which belong to seven species. These are *Pachydiscus (P.) neubergicus* (von Hauer, 1858) *P. (P.) perfidus* de Grossouvre, 1894, *P. (P.) armenicus* Atabekian and Akopian, 1969, *Diplomoceras cylindraceum* (Defrance, 1816), *Nostoceras (N.) helicinum* (Shumard, 1861), *N. (N.) hyatti* (Stephenson, 1941), and *N. (N.) schloenbachi* (Favre, 1869). All specimens are preserved as composite or external moulds, which have usually suffered from *post-mortem* deformation.

#### STRATIGRAPHY, LOCALITIES AND AMMONITE SUCCESSION

The Campanian and Maastrichtian portion of the Middle Vistula River section has been widely known for its great stratigraphical and palaeontological potential (Pożaryski 1938; Kongiel 1962; Gaździcka 1978; Błaszkiwicz 1980; Peryt 1980; Abdel-Gawad 1986; Walaszczyk 2004; Machalski 2005; Świerczewska-Gładysz 2006). Of particular significance are papers of Błaszkiwicz (1980), who ‘produced the most significant account of uppermost Campanian and Maastrichtian ammonites from Europe’, according to Hancock and Kennedy (1993, p. 150), and of Walaszczyk (2004), who established an inoceramid zonation for the upper Campanian–lowermost Maastrichtian part of the Middle Vistula River section which allows for its interregional correlation with sections at Tercis (Walaszczyk *et al.* 2002a, b; Odin and Walaszczyk 2003) and in the US Western Interior (Walaszczyk *et al.* 2001, 2002a).

The ammonite material studied comes from nine outcrops of upper Campanian and lowermost Maastrichtian opoka (siliceous chalk), which are situated on both sides of the Middle Vistula River (Text-fig. 1). These localities are described below in alphabetic order. The lithostratigraphic position of these sections (Text-fig. 2) is based on Walaszczyk (2004). Their biostratigraphic position (Text-fig. 2) is presented in terms of the inoceramid zonation of Walaszczyk (2004) and the ammonite/belemnite stratigraphic scheme of Błaszkiwicz (1980). Occasionally, the local subdivision of Pożaryski (1938) is also referred to.

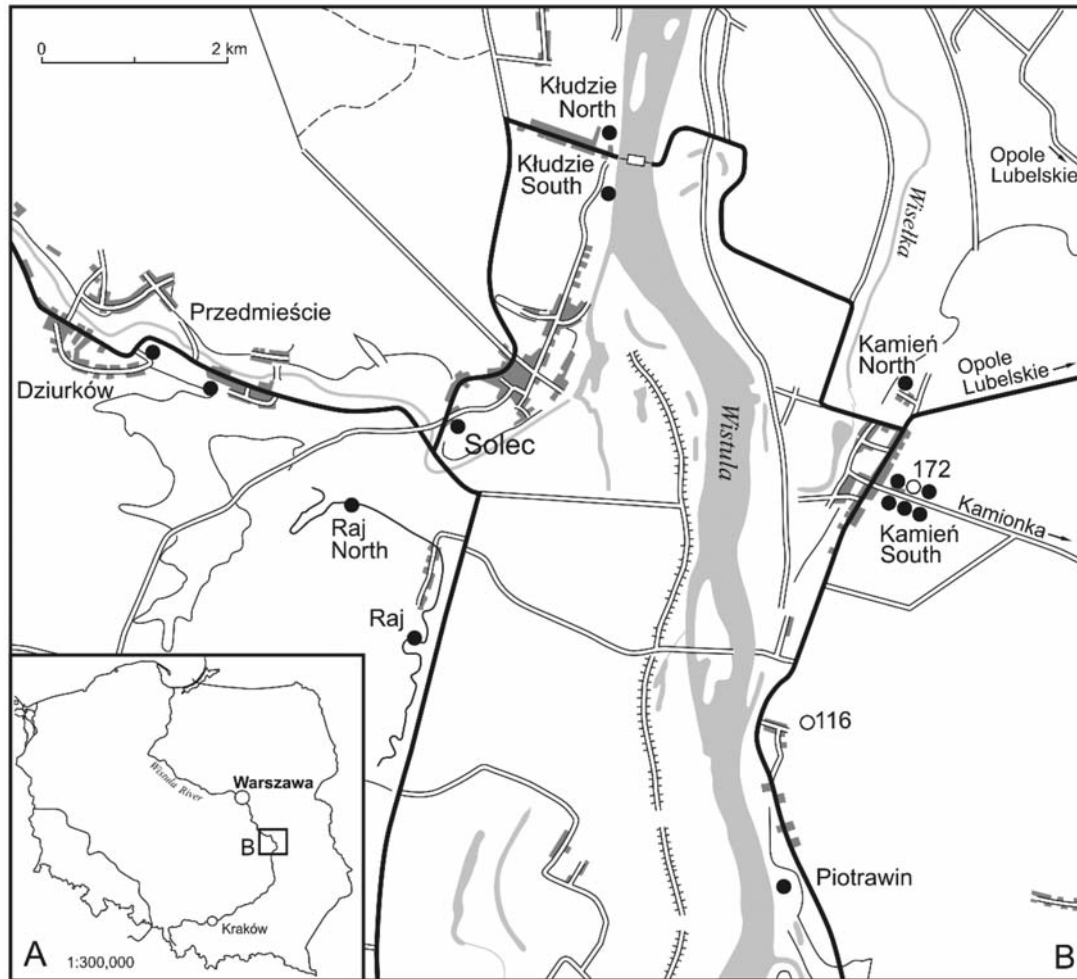
#### Dziurków

A working quarry at the eastern end of the village of Dziurków (Text-fig. 1). The quarry exposes over 12 m of Dziurków Opoka (*sensu* Walaszczyk 2004), belonging to the *Endocostea typica* Zone (Walaszczyk 2004). It was referred to the top of the *Belemnella lanceolata lanceolata* Zone by Błaszkiwicz (1980). The section is rich in fossils, dominated by sponges (Świerczewska-Gładysz 2006) and baculitids, the latter forming distinct layers in the lower part of the exposure. Belemnites, nautiloids and ammonites are relatively common.

Błaszkiwicz (1980) recorded *Pseudokosmaticeras galicianum* (Favre, 1869) and *P. (P.) neubergicus* from Dziurków. The available ammonite collection from Dziurków comprises *Neophylloceras* sp., *Hauericeras* sp., *Pachydiscus (P.) neubergicus*, *Nostoceras (N.) schloenbachi*, *Diplomoceras cylindraceum*, *Baculites* spp., *Hoploscaphites* sp. aff. *minimus* Błaszkiwicz, 1980, *Hoploscaphites quadrispinosus* (Geinitz, 1850), and *Acanthoscaphites tridens* (Kner, 1848) (*sensu* Kin 2010). Most of the specimens are not precisely located within the section, but one each of *Pachydiscus (P.) neubergicus*, and of *Nostoceras (N.) schloenbachi* were recovered from the opoka bed forming the bottom of the quarry. Specimen ZPAL Am. 12/891 constitutes the lowest, precisely located occurrence of *Pachydiscus (P.) neubergicus* in the Middle Vistula River section, although imprecisely located specimens from the underlying Kłudzie and Kamień North sections indicate that its FO is some distance below the Dziurków section (Text-fig. 2). Additionally, a specimen of nautiloid *Epicymatoceras vaelsense* (Binkhorst van den Binkhorst, 1861) was found in the lower part of the section.

#### Kamień

Several small quarries of opoka existed formerly in the village of Kamień (Pożaryski 1938; Błaszkiwicz 1980, fig. 1; see Text-fig. 1). According to Błaszkiwicz



Text-fig. 1. Location of the study area in the territory of Poland (A) and of the upper Campanian and lowermost Maastrichtian ammonite-bearing sections in the Middle Vistula River section which provided the material studied in the present paper (black circles) (B). Blank circles with numbers denote position of the former localities 166 and 172 of Błaszkiwicz (1980, fig. 1)

(1980) and Walaszczyk (2004), these outcrops yielded several stratigraphically important ammonite and inoceramid taxa, including *Pachydiscus (P.) neubergicus raricostatus* Błaszkiwicz, 1980 and *Trochoceras costaeus* (Khalafova, 1966), respectively. The southern outcrops, grouped along the road to the village of Kamionka (Text-fig. 1), represent the topmost part of the Piotrawin Opoka (Walaszczyk 2004) and belong to the *Belemnella lanceolata lanceolata* Zone of Błaszkiwicz (1980) and to the *Trochoceras costaeus* Zone of Walaszczyk (2004). The northern outcrops, grouped around the bend in the road to the town of Opole Lubelskie (Błaszkiwicz 1980, fig. 1; see Text-fig. 1), represent younger strata, assignable to the Solec Opoka of Walaszczyk (2004), the *Belemnella occidentalis* Zone of Błaszkiwicz (1980) and the inoceramid *Trochoceras costaeus* and “*Inoceramus*” *redbirdensis* zones of Walaszczyk (2004). Pożaryski

(1938) united the whole succession exposed at Kamień in his local zone u.

Błaszkiwicz (1980) illustrated and discussed the following ammonite taxa from Kamień: *Nostoceras* sp., *P. neubergicus raricostatus*, and *P. colligatus latumbilicatus* Błaszkiwicz, 1980. The record of *Nostoceras* sp. is based on specimen MUZ PIG 12 II 8, interpreted herein as *N. (N.) hyatti* (see further in the text). According to the original label, this specimen comes from the environs of the old mansion park at the northern end of the village, thus from the area where the upper part of the Solec Opoka crops out (Walaszczyk 2004, fig. 1), possibly not far from the locality of Kamień North (Text-fig. 1). Thus, it represents the highest, albeit imprecisely defined, occurrence of this stratigraphically important species in the Middle Vistula Valley section known to date. It is possible that this species may occur even up to 26 m above the FO of *Belemnella lanceolata*,

Stage	Substage	Stage	Substage	local litho-stratigraphy	SECTIONS STUDIED	Inoceramid zonation	Ammonite/belemnite division after Błaszkiwicz, (1980)	AMMONITE SPECIES
MAASTRICHTIAN	Lower	MAASTRICHTIAN	Lower	2 m	Dziurków	<i>Endocostea typica</i>	<i>Belemnella occidentalis</i>	<i>Pachydiscus (Pachydiscus) neubergicus</i> (von Hauer, 1858)
					Przedmieście			
CAMPANIAN	Upper	CAMPANIAN	Upper	Solec Opoka	Kłudzie South	<i>Trochoceras costaeus</i>	<i>Belemnella lanceolata lanceolata</i>	<i>Pachydiscus (Pachydiscus) cylindraceum</i> (Defrance, 1816)
					Raj North			
CAMPANIAN	Upper	CAMPANIAN	Upper	Piotrawin Opoka	Kłudzie North	<i>"Inoceramus" altus</i>	<i>Nostoceras (Nostoceras) schloenbachi</i> (Favre, 1869)	<i>Pachydiscus (Pachydiscus) perfidus</i> de Grossouvre, 1894
					Raj			
					Kamień North			
					Boundary Marl			
					Solec			
					Piotrawin			
					Kamień South			

Text-fig. 2. Stratigraphy and correlations of the ammonite-bearing sections studied (after Walaszczyk 2004, modified). The chronostratigraphic part of the scheme presents the subdivision of the section according to the new "Tercis definition" of the base of the Maastrichtian Stage (two left columns) and the traditional Boreal definition of this boundary (two columns to the right); dashed lines are maximum possible ranges

but probably much less than this figure (Text-fig. 2). In terms of inoceramid biostratigraphy, specimen MUZ PIG 12 II 8 is probably from the "I." *redibirdensis* Zone of Walaszczyk (2004). Specimen MUZ PIG 889 II 159, one of the topotypes of *P. n. raricostatus* (Błaszkiwicz 1980, pl. 35, figs 6–7), interpreted herein as a sparsicostate individual of *P. (P.) perfidus* de Grossouvre, 1894, and specimens of *Anapachydiscus colligatus latiumbilicatus* from the Błaszkiwicz collection, are labelled as coming from the outcrop 172. This outcrop was situated at the northern side of the road to Kamionka, c. 400 m from the northwestern end of this road (Błaszkiwicz 1980, fig. 1; see Text-fig. 1), thus in the area where the highest portion of the Piotrawin Opoka is exposed (Walaszczyk 2004, fig. 1). Other specimens from Kamień, including the holotype of *P. (P.) n. raricostatus*, are labelled as coming from local zone u of Pożaryski (1938), without further details. In belemnite terms, unit u of Pożaryski (1938) corresponds to the *Belemnella lanceolata lanceolata* and *Belem-*

*nella occidentalis* zones of Błaszkiwicz (1980). It is thus not clear why Błaszkiwicz (1980, p. 15) referred his *P. (P.) n. raricostatus* precisely to the upper part of the *Belemnella lanceolata lanceolata* Zone.

None of the outcrops at Kamień mentioned in the older literature is accessible nowadays. However, two temporary outcrops were studied by the present author in 2006 and 2007; these are referred to as Kamień South and Kamień North below.

### Kamień South

This outcrop was accessible in the summer of 2006, in two shallow trenches excavated on both sides of the road from Kamień to the village of Kamionka (Text-fig. 1). These trenches ranged from the northwestern end of the road to a deeper excavation near a drainage culvert crossing this road some 550 metres to the southeast. Several fossils were collected here from the white, pure and highly fossiliferous opoka, representing the topmost



part of the Piotrawin Opoka of Walaszczyk (2004). This fauna is dominated by sponges, fragments of large baculitids, and small bivalves and gastropods. Crushed tests of the echinoid *Echinocorys* sp. and nautiloid fragments are relatively common. Ammonites include *Baculites* spp., *P. (P.) armenicus*, *Diplomoceras cylindraceum*, *Hoploscaphites vistulensis* Błaszkiwicz 1980, fragments of large pachydiscids (possibly *Anapachydiscus colligatus latumbilicatus*), and fragments of a large, indeterminate scaphitid. Several fragments of belemnite rostra were also found, which belong to specifically indeterminate representatives of both *Belemnella* and *Belemnitella* (Z. Remin, pers. comm., 2008). Additionally, two small individuals of *Trochoceras costaeus* were found (identified by I. Walaszczyk). All these fossils were collected from loose slabs of opoka alongside the trenches, except for the specimen of *P. (P.) armenicus* which was found *in situ* at a depth of 1.5 m in the excavation near the drainage culvert.

Several fossils were collected from blocks of opoka originating from a demolished building at Kamień, situated at the northwestern end of the road to Kamionka. These blocks represent a lithology typical of the Piotrawin Opoka and yielded fragmentary sponges, baculitids, *D. cylindraceum* and *P. (P.) armenicus*, as well as three individuals of *Trochoceras costaeus*, identified by I. Walaszczyk. Additionally, a single specimen of the nautiloid *Cymatoceras* aff. *patens* (Kner, 1848) was found. According to information supplied by the local inhabitants, the opoka used for construction of the house originated from its immediate subsoil. In summary, one may safely assume that all fossils collected at Kamień South are from the top of the Piotrawin Opoka and from the *Trochoceras costaeus* Zone of Walaszczyk (2004) (see Text-fig. 2).

### Kamień North

During late spring of 2007, a deep excavation was dug for the base of a mobile telephone mast at the northern edge of the village of Kamień (Text-fig. 1), north of the old mansion park and south of the old distillery. Subsequently, the marly opoka from this excavation was accessible for study in several spoil heaps located around the base of the mast. It was whitish in colour and easily disintegrated when exposed to air. In terms of lithology, it resembles the opoka from the transitional zone between the Solec and Dziurków opokas as exposed on the left side of the Vistula River at the localities of Kłudzie South and Kłudzie North (Walaszczyk 2004; author's observations in 2007).

The fauna collected at Kamień North is dominated by sponges and fragments of *Baculites* sp. Other fossils are

rare. Non-baculitid ammonites include *Diplomoceras cylindraceum* and *P. (P.) neubergicus*, each represented by a single individual. The specimen of the latter species from Kamień North is virtually indistinguishable in respect of its preservation and morphology from the holotype of *P. (P.) n. raricostatus*. Nannofossil analysis of the opoka matrix of these individuals, kindly performed by M. Wagreich (pers. comm., 2009), indicates that they both belong to the standard calcareous nannofossil CC23a Zone of Sissingh (1977) and Perch-Nielsen (1985), and the UC 16 Zone of Burnett (1998). This is in accordance with nannofossil dating of the lowest records of *P. (P.) neubergicus* from the Tercis section by Wagreich *et al.* (2003). According to Niebuhr *et al.* (2011), however, the lowest records of this ammonite at Tercis and Kronsmoor correspond to the UC 15 nannofossil zone.

No inoceramids have been found at Kamień North, despite extensive search for these fossils; a few belemnite rostra belong to *Belemnitella* sp. (Z. Remin, pers. comm., 2008). Lithological correlation with outcrops on the left side of the river suggests this fauna to have come from the “*Inoceramus*” *redbirdensis* Zone of Walaszczyk (2004) (see Text-fig. 2).

### Kłudzie

There are two exposures along the banks of the Vistula River in the village of Kłudzie (Text-fig. 1), designated Kłudzie South and Kłudzie North, respectively, by Walaszczyk (2004). Both sections expose upper part of the Solec Opoka and lower part of the Dziurków Opoka with the “boundary marl” horizon sandwiched between these units (Text-fig. 2). The sections at Kłudzie represent mostly the “*Inoceramus*” *redbirdensis* Zone, although that at Kłudzie South ranges into the lower part of the overlying *Endocostea typica* Zone (Walaszczyk 2004; Text-fig. 2). In terms of belemnite zonation, the sections at Kłudzie belong to the *Belemnella lanceolata lanceolata* and *Belemnella occidentalis* zones of Błaszkiwicz (1980).

A single ammonite specimen from Kłudzie, identified as *N. (N.) schloenbachi*, was available for the present study. Błaszkiwicz (1980) reported from Kłudzie: *P. (P.) neubergicus* and *P. gollevillensis nowaki* Mikhailov, 1951 [= *P. (P.) neubergicus*]. The precise location of these specimens in the Kłudzie sections cannot be determined. They may have come either from the “*Inoceramus*” *redbirdensis* Zone or from the bottom of the *Endocostea typica* Zone of Walaszczyk (2004). Together with a single record from the locality Kamień North (see above), they indicate an approximate position of the FO of *P. (P.) neubergicus* in the Middle Vistula River section.

## Piotrawin

A large, abandoned quarry situated on the left bank of the Vistula River, south of the village of Piotrawin (Text-fig. 1). The quarry face, along three exploitation levels, exposes c. 30 m of brittle, white-yellow, highly fossiliferous marly opoka with characteristic brown, limonitic spots. This is the Piotrawin Opoka of Walaszczyk (2004) (see Text-fig. 2). The quarry section was assigned by Walaszczyk (2004) to the inoceramid zones “*Inoceramus*” *altus* (lower third of the quarry face) and “*Inoceramus*” *inkermanensis* (the remaining part of the succession; see Text-fig. 2). In ammonite terms, the whole succession was assigned to the *Nostoceras pozaryskii* Zone by Błaszkiwicz (1980) (= *Nostoceras hyatti* Zone, according to Burnett *et al.* 1992; Kennedy *et al.* 1992; Hancock and Kennedy 1993; Kennedy and Cobban 1993). In terms of the standard belemnite zonation, the whole section at Piotrawin was assigned to the *Belemnella langei* Zone by Burnett *et al.* (1992) and by the late W.K. Christensen (unpubl. data).

The large Piotrawin quarry represents one of the most important fossil localities in the Middle Vistula River section (Pożaryski 1938; Kongiel 1962; Błaszkiwicz 1980; Walaszczyk *et al.* 2002a; Walaszczyk 2004). The fauna is dominated by sponges (Świerczewska-Gładysz 2006), baculitid ammonites, small bivalves and gastropods. Large echinoid tests (*Echinocorys* sp.) are relatively common. Non-baculitid cephalopods are quite numerous, represented by ammonites, belemnites and nautiloids.

Błaszkiwicz (1980) recorded from this locality the following non-baculitid ammonite taxa: *Nostoceras pozaryskii* Błaszkiwicz, 1980, *Hoploscaphites vistulensis*, *H. angulatus* (Łopuski, 1911), *H. minimus* Błaszkiwicz, 1980, *Acanthoscaphites praequadriscopinosus* Błaszkiwicz, 1980, *Pachydiscus* (*P.*) *perfidus*, *P.* cf. *colligatus latiumbolicatus*, *Pseudokossmaticeras galicianum* (Favre, 1869), *Pseudophyllites indra* (Forbes, 1846), *Placenticeras meeki* Böhm, 1898, and *Hauericeras* sp. [= *Hauericeras* aff. *sulcatum* (Kner, 1848) in Hancock and Kennedy 1993]. None of the specimens from Piotrawin reported by Błaszkiwicz (1980) was precisely located within the quarry section.

The holotypes of two stratigraphically important ammonite species, namely *N. pozaryskii* [reillustrated as *N. (N.) helicinum* (Shumard, 1861) by Hancock and Kennedy 1993, pl. 16, figs 7–9], and *Acanthoscaphites praequadriscopinosus* (refigured e.g., in Landman *et al.* 2010, fig. 10), come from Piotrawin. According to Hancock and Kennedy (1993) and Kennedy and Cobban (1993), *N. pozaryskii* is based on material of *N. (N.) hyatti* and *N. (N.) helicinum*. As far as *A. praequadriscopinosus*

is concerned, it was regarded as a synonym of *Jeletzkytes nodosus* (Owen, 1852) by Kennedy and Cobban (1992). However, Landman *et al.* (2010) considered “*Acanthoscaphites*” *praequadriscopinosus* to be a distinct species. In view of the absence of siphonal tubercles it is better assigned to the genus *Hoploscaphites* Nowak, 1911.

Nine non-baculitid ammonite taxa from Piotrawin quarry are available for the present study. These are *N. (N.) hyatti*, *N. (N.) helicinum*, *D. cylindraceum*, *H. vistulensis*, *H. minimus*, *H. praequadriscopinosus* (represented by macro- and microconchs), *P. (P.) perfidus*, *Patagiosites* sp., and *Pl. meeki*. Available data indicate that *N. (N.) hyatti*, *N. (N.) helicinum*, *D. cylindraceum*, *H. vistulensis*, *H. minimus*, *H. praequadriscopinosus*, and *Pl. meeki* range to the very top of the succession. The precisely located records of *D. cylindraceum* are restricted to the upper third of the quarry face with the lowermost specimen (ZPAL Am. 12/1123) found *in situ* at the bottom of the upper third of the section. The only exception is specimen MUZ PIG 12.II.38 with no precise location in the section. One may safely assume, however, that the level with ZPAL Am. 12/1123 marks the FO of *D. cylindraceum* in the Middle Vistula River section. According to Burnett *et al.* (1992), *N. (N.) hyatti* and *N. (N.) helicinum* are present between 12 and 30 m from the base of the Piotrawin sequence. The present author confirmed (pers. comm. in Walaszczyk 2004, p. 100) the occurrence of a specimen of the former taxon as low as 3 m from the base of the Piotrawin succession (the specimen was owned by a private collector and must be considered lost). *Patagiosites* sp. is represented by a single specimen from the upper third of the section, while there are no data on the provenance of specimens of *P. (P.) perfidus*, which were all obtained from quarries with no information on their location within the section. Additionally, a well-preserved specimen of the nautiloid *Cymatoceras patens* comes from the upper third of the Piotrawin section.

In the past, small opoka outcrops were available for study and fossil collecting in the village of Piotrawin (Pożaryski 1938; Błaszkiwicz 1980). One of these outcrops (outcrop 166 of Błaszkiwicz 1980, fig. 1; see Text-fig. 1) yielded the lowest record of *Belemnella lanceolata*, the traditional belemnite marker for the base of the Maastrichtian in the Boreal Realm, on the right side of the Middle Vistula River section (as can be judged from fig. 1 in Błaszkiwicz 1980). The section formerly exposed in outcrop 166 probably corresponded to an interval of opoka, a few metres thick, between the large Piotrawin quarry section in the south and the Kamień South section in the north (compare Walaszczyk 2004, fig. 1; see Text-fig. 1).

### Przedmieście

A large disused quarry at the eastern margin of the village of Przedmieście, south of the Lipsko-Solec road (Text-fig. 1). The quarry exposes c. 10 m of yellow opoka (Dziurków Opoka of Walaszczyk 2004), roughly correlatable with the succession exposed at Dziurków (Text-fig. 2). A specimen of *P. (P.) neubergicus* from Przedmieście (ex M. Duda collection) was available for the present study.

### Raj

An abandoned opoka quarry located along the northern bank of a small valley, about 100 m of the southern end of the village of Raj (Text-fig. 1). The quarry wall is c. 100 m long and exposes up to 7 m of light-yellow, fossiliferous opoka (Piotrawin Opoka of Walaszczyk 2004; see Text-fig. 2). The fauna is dominated by sponges, baculitid ammonites and small bivalves. The available non-baculitid ammonite collection from Raj comprises *H. vistulensis*, *H. praequadriscopinosus*, *D. cylindraceum*, *P. (P.) perfidus*, and *Pl. meeki*. The commonest taxon is *H. vistulensis*, represented by seven specimens, coming mostly from the upper part of the succession. The Raj section was assigned by Walaszczyk (2004) to the “*Inoceramus*” *inkermanensis* Zone. It seems to correspond to the upper part of the opoka exposed at the Piotrawin quarry, possibly also to a level slightly higher than that.

### Raj North

A small working quarry along the northern bank of the Krępianka River, southwest of the town of Solec (Text-fig. 1). The quarry face exposes c. 9 m of brittle, grey marly opoka (Solec Opoka of Walaszczyk 2004; see Text-fig. 2). Fossils are rare, with sponge fragments, baculitids, belemnites and small bivalves being the commonest elements. The available non-baculitid ammonite collection from Kamień North comprises *Gaudryceras* sp., *Hauericeras* sp., *Hoploscaphites* sp., *H. quadriscopinosus*, and *D. cylindraceum*, plus isolated aptychi of the scaphitid type. According to Walaszczyk (2004, p. 105), this exposure yielded the stratigraphically lowest record of *Belemnella lanceolata* on the left bank of the Vistula River section. In terms of inoceramid biozonation, the section corresponds to the upper part of the *Trochoceras* *costaecus* and lower part of the “*Inoceramus*” *redbirdensis* zones (Walaszczyk 2004, fig. 3; Text-fig. 2).

### Solec

An old quarry face, partially overgrown and covered by scree, in the western part of the town of Solec, east of the cross-road in the village (Text-fig. 1). The exposure shows a c. 14 m thick succession of marly opoka (Solec Opoka of Walaszczyk 2004; Text-fig. 2) with rare fossils. The available ammonite collection comprises baculitids, plus *D. cylindraceum* and *N. (N.) schloenbachi*, both found in the upper part of the succession. The Solec section represents a transitional zone between the inoceramid *Trochoceras* *costaecus* and “*Inoceramus*” *redbirdensis* zones of Walaszczyk (2004), the above-mentioned ammonite records coming from the latter zone (see Text-fig. 2).

## SYSTEMATIC PALAEOLOGY

The following abbreviations are used to indicate the repositories of specimens mentioned in the text: GBA, Geologische Bundesanstalt, Vienna; GIUW, Geologisches Institut, Universität Wien; GSO, G.S. Odin Collection, Université Pierre et Marie Curie, Paris; IRScNB, Institut Royal des Sciences Naturelles de Belgique, Brussels; OGM, Orton Geological Museum, Ohio State University, Columbus; MUZ PIG, Muzeum Państwowego Instytutu Geologicznego, Warszawa; MZ, Muzeum Ziemi PAN, Warszawa; NHMW, Naturhistorisches Museum Wien, Vienna; SLJ, Steiermärkisches Landesmuseum Joanneum, Graz; UPMC, Université Pierre et Marie Curie, Paris; USNM, United States National Museum, Washington DC; ZPAL, Instytut Paleobiologii PAN, Warszawa.

Order Ammonoidea von Zittel, 1884

Suborder Ammonitina Hyatt, 1889

Superfamily Desmoceratoidea von Zittel, 1895

Family Pachydiscidae Spath, 1922

Genus *Pachydiscus* von Zittel, 1884

TYPE SPECIES: *Ammonites neubergicus* von Hauer, 1858, p. 12, pl. 2, figs 1–3, non pl. 3, figs 1–2, by the subsequent designation of de Grossouvre (1894, p. 177).

Subgenus *Pachydiscus* von Zittel, 1884

*Pachydiscus (Pachydiscus) perfidus* de Grossouvre, 1894

(Pl. 1, Figs 1–2; Pl. 2, Fig. 4)

1894. *Pachydiscus perfidus* de Grossouvre, p. 213, pl. 34, fig. 1.
1894. *Pachydiscus neubergicus* F. von Hauer, sp. emend.; de Grossouvre, p. 207, pl. 38, fig. 3.
1980. *Pachydiscus perfidus* Grossouvre; Błaszkiwicz, p. 43, pl. 29, figs 1–4; pl. 30, figs 1, 3, 4; pl. 31, figs 1–3; pl. 32, figs 1–3; pl. 33, figs 3, 4; pl. 37, figs 1, 2.
1984. *Pachydiscus (Pachydiscus) perfidus* de Grossouvre; Kennedy and Summesberger, p. 160, pl. 3; pl. 6, fig. 6.
1993. *Pachydiscus (Pachydiscus) perfidus* de Grossouvre, 1894; Hancock and Kennedy, p. 161, pl. 9, figs 9, 10; pl. 10, figs 1, 2, 4, 5; pl. 11, figs 5, 6; pl. 12, figs 1–4, 6; pl. 13, figs 3, 4.
2001. *Pachydiscus perfidus* de Grossouvre 1893; Courville and Odin, p. 533, pl. 5, figs 37, 39.
2001. *Pachydiscus perfidus*; Odin *et al.*, pl. 2 (bottom figure).

TYPE: Lectotype, designated by Kennedy and Summesberger (1984), is the original of de Grossouvre (1894, pl. 34, fig. 1) from Tercis, southwest France, an unregistered specimen in the UPMC collections, reillustrated by Hancock and Kennedy (1993, pl. 13, figs 3, 4) and Odin *et al.* (2001, pl. 2, bottom figure).

MATERIAL: Seven specimens: five from Piotrawin (ZPAL Am. 12/1284, 1286, 1287, 1289, and 1298), one from locality 172, Kamień (MUZ PIG 889 II 159) and one from Raj (ZPAL Am. 12/1285, *ex* Remin collection). None of these specimens can be precisely located within the quarry sections.

DISCUSSION: The lectotype and topotypic material of *Pachydiscus (P.) perfidus* from Tercis were described by Hancock and Kennedy (1993), their photographs showing 14–17 umbilical and 32–40 ventral ribs. At a maximum preserved diameter of 120 mm, the lectotype has 14 umbilical and 34 ventral ribs. The rib density decreases as size increases. The ornament of the largest specimen from Tercis (diameter 160 mm) is dominated by distant, strong primary ribs with pronounced umbilical and ventrolateral bullae (Hancock and Kennedy 1993, pl. 11, figs 5, 6).

The present material matches that from Tercis well. The smallest specimens is a nucleus, ZPAL Am. 12/1287, 112 mm in diameter, with 14 feebly bullate primary ribs and 42 ventral ribs on the last whorl, i.e., slightly more than Tercis specimens of comparable size. A later growth stage is represented by ZPAL Am. 12/1289, which is a septate mould of half a whorl, 155 mm in diameter, with 8 umbilical and 16 ventral ribs (Pl. 2, Fig. 4). The primaries are distant, continue across the flanks, and have strong umbilical and ventrolateral bullae. An intermediate growth stage is represented by ZPAL Am.

12/1284 (Pl. 1, Fig 1) with 14 umbilical ribs on the ultimate whorl and 21 ventral ribs on the first half of that.

Specimen MUZ PIG 889 II 159, labelled ‘locality 172 Kamień’, is one of the topotypes of *Pachydiscus neubergicus raricostatus* (Błaszkiwicz 1980, pl. 35, figs 6, 7). It is a crushed composite mould of a septate individual, 96 mm in diameter. It has 11 umbilical and 30 ventral ribs; the main ribs are straight and strong, and continue across flanks without effacing. The specimen is interpreted herein as a sparsicostate specimen of *P. (P.) perfidus*.

A specimen from Tercis, identified as *Pachydiscus neubergicus* F. von Hauer, sp. emend. by de Grossouvre (1894, p. 207, pl. 38, fig. 3), is 150 mm in diameter (de Grossouvre 1894). Judging from the figure, it has 14 umbilical bullae on the last whorl and 17 ventral ribs on the second half of that. Strongly bullate primary ribs continue across the flanks and are associated with intercalatory ribs which insert either singly or in pairs between the primaries. Thus, de Grossouvre’s specimen falls into the range of variation of topotypical material of *P. (P.) perfidus*. It is closely similar to individuals of comparable diameter studied here (e.g., compare de Grossouvre 1984, pl. 38, fig. 3 with Pl. 1, Figs 1–2 here).

In general, *P. (P.) perfidus* has fewer ventral ribs than the closely allied *P. (P.) neubergicus* in early to mid-growth stages: 32–40 in topotypical material from Tercis (Hancock and Kennedy 1993) vs 48–60 in topotypes of *P. (P.) neubergicus* from Neuberg, Austria (Kennedy and Summesberger 1986). However, there is some overlap in number of ventral ribs between these two species, as exemplified by specimens of the ‘*raricostatus* type’ occasionally occurring at various levels within the European Maastrichtian (Błaszkiwicz 1980; Birkelund 1993; Ivanov 1995; Niebuhr 2003). Another difference concerns the development of primary ribs, which are usually stronger and continue unchanged across the flanks in *P. (P.) perfidus* but typically weaken or even efface at mid-flank in *P. (P.) neubergicus*. At larger growth stages, ribs become weaker and more distant in both species, but are still stronger across the venter in *P. (P.) perfidus* than in *P. (P.) neubergicus*.

Recently, Kin and Niedźwiedzki (2012) discussed some large pachydiscids from Poland, noting that, ‘Examples include Łuniewski (1936, p. 121) and Pożaryski (1948, p. 68), who recorded from the Lower Maastrichtian (*sensu* Walszczyk, 2004) in the vicinity of Antoniów near Annopol, a specimen referred to as *Pachydiscus egertoni* (Forbes, 1846) (possibly conspecific with *Pachydiscus perfidus* de Grossouvre, 1894), c. 500 mm in diameter’ (Kin and Niedźwiedzki 2012, p. 16). This is a misleading statement for the following reasons: 1) Antoniów is located not “near



Annopol” but c. 40 km northwest of Annopol; 2) neither Łuniewski (1936) nor Pożaryski (1948) provided data which allow the succession near Antoniów to be assigned to the lower Maastrichtian *sensu* Walaszczyk (2004); 3) not “a specimen”, but specimens – Pożaryski (1948) quoted Łuniewski (1936), who reported on the occurrence near Antoniów of “large pachydiscids (50 cm in diameter)”; 4) neither Łuniewski (1936) nor Pożaryski (1948) assigned these specimens to *Pachydiscus egertoni*; 5) based on the paper by Pożaryski (1938), one may assume that what he meant in his 1948 paper was his *Pachydiscus* aff. *colligatus*. Thus, the records of Łuniewski and Pożaryski have nothing to do with *Pachydiscus perfidus* de Grossouvre, 1894.

STRATIGRAPHIC AND GEOGRAPHIC RANGE: Upper Campanian of Landes, France; Middle Vistula Valley, Poland; Gschlieflgraben and Grünbach, Austria.

*Pachydiscus (Pachydiscus) neubergicus* (von Hauer, 1858)  
(Pl. 2, Figs 1–3; Pl. 3; Pl. 4; Pl. 5, Fig. 2; Text-figs 3A–C, 4, 5A)

- pars 1858. *Ammonites Neubergicus* v. Hauer, p. 12, pl. 2, figs 1–3.  
1872. *Ammonites neubergicus*, v. Hauer; Schlüter, p. 59, pl. 18, figs 1–3.  
non 1894. *Pachydiscus neubergicus* F. von Hauer, sp. emend.; de Grossouvre, p. 207, pl. 38, fig. 3.  
1980. *Pachydiscus neubergicus neubergicus* (Hauer, 1858); Błaszczkiewicz, p. 44, pl. 35, figs 4, 5; pl. 36, figs 5, 6.  
pars 1980. *Pachydiscus neubergicus raricostatus* Błaszczkiewicz; p. 43, pl. 35, fig. 8; pl. 36, figs 1–4, 7–10.  
1980. *Pachydiscus gollevillensis nowaki* Mikhailov, 1951; Błaszczkiewicz 1980, pl. 35, figs 2, 3.  
1986. *Pachydiscus (Pachydiscus) neubergicus* (von Hauer, 1858); Kennedy and Summesberger, p. 189, pl. 2, figs 1–2; pl. 3, figs 1–3; pl. 4, figs 1–5; pl. 5, figs 1, 4, 5; pl. 6, figs 1, 2, 5; pl. 15, figs 7, 8; text-fig. 5A, B.  
1993. *Pachydiscus (Pachydiscus) neubergicus neubergicus* (von Hauer, 1858); Hancock and Kennedy, p. 158, pl. 3, figs 6, 7; pl. 9, figs 5–8; pl. 12, figs 7–9; pl. 13, figs 5–7.  
1993. *Pachydiscus (Pachydiscus) neubergicus* (von Hauer, 1858); Birkelund, p. 47, figs 1, 2; pl. 8, fig. 1; pl. 10, fig. 1.  
1995. *Pachydiscus neubergicus neubergicus* (Hauer, 1858); Ivanov, p. 66, pl. 2, fig. 5; pl. 3, fig. 4; pl. 5, figs 1–3.

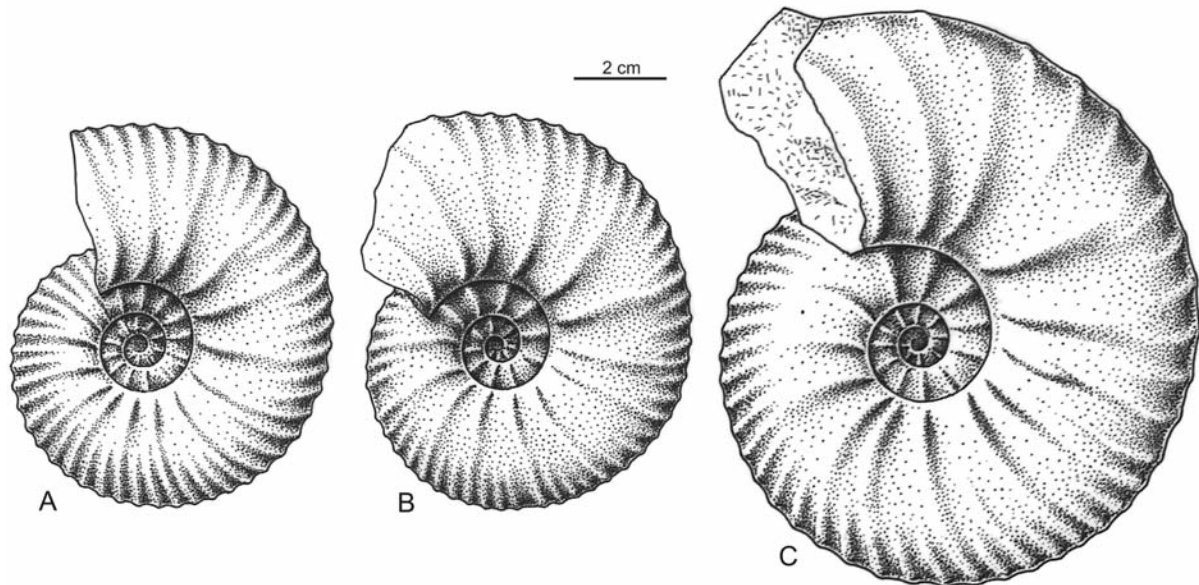
1995. *Pachydiscus neubergicus rarecostatus* [sic] Błaszczkiewicz [sic], 1980; Ivanov, p. 67, pl. 1, figs 6, 7.  
2001. *Pachydiscus neubergicus* (von Hauer, 1858); Courville and Odin, p. 533, pl. 6, figs 48–50.  
2001. *P. perfidus/neubergicus*; Courville and Odin, p. 534, pl. 5, fig. 36; pl. 6, fig. 46.  
2001. *Pachydiscus neubergicus*; Odin *et al.*, pl. 2, top figure.  
2003. *Pachydiscus (Pachydiscus) neubergicus* (von Hauer, 1858); Niebuhr, p. 263, pl. 1, figs 6, 7.  
2010. *Pachydiscus* cf. *neubergicus* (Hauer) subsp. indet.; Seltser and Ivanov, p. 63, pl. 32, fig. 1

TYPES: Lectotype is GBA 1858.1.6, the original of von Hauer (1858, p. 12, pl. 2, figs 1, 2), from Neuberg (Steiermark, Austria), as designated by de Grossouvre (1894, p. 209), and reillustrated by e.g., Kennedy and Summesberger (1986, pl. 3, figs 1–3) and Hancock (2000, figs a–e).

MATERIAL: Fifteen specimens: MZ VIII Mc 501 from Kamień, the holotype of *Pachydiscus neubergicus raricostatus* Błaszczkiewicz, 1980; topotypes of *P. neubergicus raricostatus* Błaszczkiewicz, 1980 from Kamień: MUZ PIG 889 II 159, outcrop 172 of Błaszczkiewicz (1980, fig. 1), MZ VIII Mc 500, 501, MUZ PIG 1, 3010 II, 421–423, all labelled as coming from horizon u of Pożaryski (1938); ZPAL Am. 12/1293 from Kamień North; ZPAL Am. 12/891, 897, 1294, 1295 from Dziurków; MZ VIII Mc 492 and Mc 491 (= *Pachydiscus gollevillensis nowaki* Mikhailov, 1951 of Błaszczkiewicz 1980, pl. 36, figs 2, 3) from Kłudzie, and an unregistered specimen from Przedmieście (M. Duda Collection). Only three specimens from Dziurków have precise provenance data: ZPAL Am. 12/891 is from the bottom, ZPAL Am. 12/897 and 12/1294 from the lower part of the section.

COMPARATIVE MATERIAL: Plaster casts of the lectotype and two topotypes from Neuberg (GIUW 1875.XXX 1 and SLJ 6109); specimen GSO 210 from the P 115,2 m level at Tercis.

DISCUSSION: Kennedy and Summesberger (1986) described and illustrated the lectotype and topotypes from Neuberg, Austria. The Neuberg material comprises specimens with 14–17 umbilical bullae and 48 to almost 60 ventral ribs. The lectotype, reconstructed here in Text-fig. 3A, is ‘absolutely typical of the smallest individuals’ (Kennedy and Summesberger 1986, p. 189) in having 50 ventral ribs and 16 umbilical bullae at the largest preserved diameter of 93 mm. As size increases, the bullae become elon-



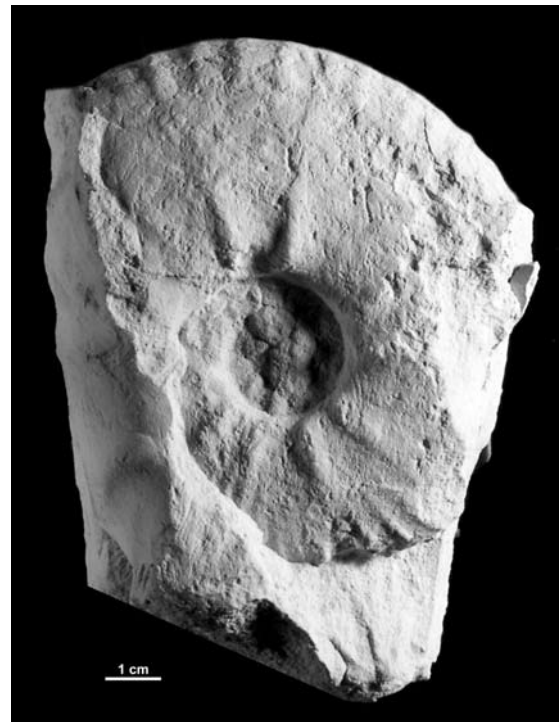
Text-fig. 3. Reconstructions of the original, undeformed appearance of the specimens of *Pachydiscus (Pachydiscus) neubergicus* (von Hauer, 1858) from Neuberg, Steiermark, Austria; A – Lectotype GBA 1858.1.6; B – PIUW unregistered; C – GIUW 1875.XXX.1

gate and ribs weaken and become more distant at mid- and outer flanks, but, contrary to what Kennedy and Summesberger (1986, p. 189) indicated, are still relatively narrow and distinct latero-ventrally (see Text-fig. 3B, C). Specimen GIUW 1875.XXX.1 from Neuberg, reconstructed in Text-fig. 3C, of which a plaster cast was studied, has 14 umbilical bullae and c. 38 ventral ribs at a diameter of 120 mm. Of special note is a rapid change in density of ventral ribbing clearly visible at a diameter of 100 mm (see reconstruction in Text-fig. 3C; compare Kennedy and Summesberger 1986, pl. 5, figs 4, 5).

There is a good match between the smallest specimens studied and Neuberg individuals of comparable size. Thus, ZPAL Am 12/897, an external cast of a nucleus 75 mm in diameter (Pl. 2, Fig. 1), has 7 umbilical bullae and 25 ventral ribs on the second half of the last whorl. Another specimen, ZPAL Am 12/1294, a wholly septate mould 70 mm in diameter, has 8 umbilical bullae and 24 ventral ribs on the second half of the last whorl. Specimen ZPAL Am. 12/891 is a nucleus (D=98), with a crushed portion of the body chamber (Text-fig. 4). There are 12 umbilical bullae and an estimated 48 ventral ribs (12 counted on one quarter of whorl) in this specimen, thus two umbilical bullae less than in Neuberg material of comparable size, which seems to be an insignificant difference.

Specimen MZ VIII Mc 501 from Kamień is the holotype of *Pachydiscus neubergicus raricostatus* Błaszkiwicz, 1980 (pl. 36, figs 3, 4, 8; reillustrated herein in Pl. 3, Figs 1–3 and Pl. 4, Fig. 2). It is still sep-

tate at its maximum preserved diameter of 140 mm, and relatively involute with the umbilicus comprising c. 28% of the diameter. The youngest part of the last whorl is badly damaged from one side (Pl. 3, Fig. 1) and strongly worn from the other (Pl. 3, Fig. 2; Pl. 4, Fig. 2;



Text-fig. 4. *Pachydiscus (Pachydiscus) neubergicus* (von Hauer, 1858), specimen ZPAL Am. 12/891 from the bottom of the Dziurków section, the lowest precisely located specimen of this species in the Middle Vistula River section

see also Błaszkiwicz 1980, pl. 36, fig. 8). However, 8 umbilical and 23 ventral ribs may be recognised on the first half of the last preserved whorl. Błaszkiwicz (1980, table 36) wrote that there were 14? umbilical vs 38 ventral ribs at a diameter of 141.5 mm on the final, preserved whorl in this specimen, but these data are unreliable in view of the poor preservation of the relevant sector of the shell. In contrast, earlier whorls are better preserved (Pl. 3; Błaszkiwicz, pl. 36, fig 3) and, according to Błaszkiwicz (1980), there are 13 umbilical bullae and 39 ventral ribs on the nucleus of this specimen (at a diameter of 112 mm).

Distant ribbing of the outer whorl of MZ VIII Mc 501 is in accordance with the general trend noted for larger specimens from Neuberg (see Text-fig. 3), but its sparsicostate nucleus deviates significantly from the densely ribbed individuals of comparable size in the Neuberg material. However, sparsicostate specimens assigned to early and mid-growth stages of *P. neubergicus* are known from various levels within the European Maastrichtian (as defined on the basis of traditional belemnite zones). These include records from the upper lower to lower upper Maastrichtian of Denmark (Birkelund 1993), the middle lower Maastrichtian at Krons Moor (Niebuhr 2003), the upper lower to lower upper Maastrichtian of the historical type area of the Maastrichtian Stage (Jagt 2002; Jagt and Felder 2003), and from the upper Maastrichtian of Bulgaria (Ivanov 1995). For example, an *ex situ* specimen from the interval between the *Micraster grimmensis*/*Cardiaster granulatus* to *Belemnella pseudobtusa* zones at Krons Moor (Niebuhr 2003, pl. 1, fig. 6a, b), has 12 umbilical bullae and c. 36 ventral ribs at a maximum preserved diameter of 76 mm, as based on the illustration. Another example is NHMM GK 9356 from the Vijlen Member (Gulpen Formation, lower *sumensis* Zone) of southern Limburg, the Netherlands, which has 6 umbilical bullae vs c. 27 ventral ribs per half whorl at a preserved diameter of 72 mm (Jagt and Felder 2003). It appears that the Danish and Dutch material is dominated by such sparsicostate forms (see Birkelund 1993; Jagt and Felder 2003). In view of the discrepancies in dating of the Neuberg material (upper Maastrichtian nanofossil standard zone CC 25b according to Wagreich *et al.* 2003 vs lower Maastrichtian *Belemnella sumensis* Zone according to Kennedy and Summesberger 1986) one cannot decide whether these differences are of a geographic or temporal nature.

Specimen ZPAL Am. 12/1293 (Pl. 4, Fig. 4) from Kamień North represents the same growth stage as the holotype of *P. n. raricostatus*, also measuring 140 mm in maximum diameter. In details preserved, both specimens are closely comparable in terms of proportions

and ornament (compare Pl. 4, Figs 1, 2). There are 9 umbilical bullae and 25 ventral ribs on the first half of the last preserved whorl in ZPAL Am. 12/1293 (at a diameter of 104 mm), thus one umbilical bulla and two ventral ribs more than in the corresponding part of the holotype, which is deemed an insignificant difference.

Individual MUZ PIG 889 II 159, labelled ‘locality 172 Kamień’, one of the topotypes of *P. n. raricostatus* (Błaszkiwicz 1980, pl. 35, figs 6, 7), is a crushed composite mould of a septate individual, 96 mm in diameter, with 11 strong umbilical and 30 ventral ribs; primary ribs are straight and continue across the flanks without effacing. It is thus interpreted herein as sparsicostate specimen of *P. (P.) perfidus*. Other topotypes of *P. n. raricostatus* from the Middle Vistula River section, MZ VIII Mc 500 and 501, clearly belong to *P. (P.) armenicus* Atabekian and Akopian, 1969, as the one in Pl. 5, Fig. 1 shows.

According to the diagnosis given by Błaszkiwicz (1980, pp. 43, 44), ‘earlier stages [of *P. n. raricostatus*] display a similarity in ornamentation to septate stages of *Pachydiscus perfidus*. In later stages ornamentation disappears, at first on a wide area on the sides and later, on the remaining parts of the whorl’. Błaszkiwicz (1980, p. 44) also stated that, ‘In its septate stages, the new species displays a lower number of both internal and external ribs as compared with the nominate one (13 to 15 and 33–40 as compared with 16 to 17 and 49–50)’ and that, ‘It is interpreted as stratigraphically lower situated’.

Błaszkiwicz (1980) clearly regarded *P. n. raricostatus* as a temporal subspecies, intermediate in terms of morphology and stratigraphic position between late Campanian *P. (P.) perfidus* and late early Maastrichtian *P. (P.) n. neubergicus*. However, the validity of Błaszkiwicz’s subspecies is questioned herein, based on the following summary of the above-mentioned data and observations:

- ribs effacing in the later ontogenetic stage of the holotype of *P. (P.) n. raricostatus*, regarded by Błaszkiwicz to be a diagnostic feature, is a preservational artefact;

- all topotypes of the subspecies from the Middle Vistula River section belong to species other than *P. neubergicus*;

- contrary to Błaszkiwicz’s claims, neither the holotype nor the topotypes are precisely located within his *Belemnella lanceolata lanceolata* Zone, i.e., lower lower Maastrichtian in traditional belemnite zonal terms;
- the distant ribbing on the outer whorl of the holotype matches the trend (rib density decreases as size increases) present in type material of *P. neubergicus*;

- the nucleus of the holotype shows much more distant ribs than specimens from Neuberg of comparable size; however, similar sparsicostate specimens of com-



parable size do occur sporadically at various levels within the European Maastrichtian.

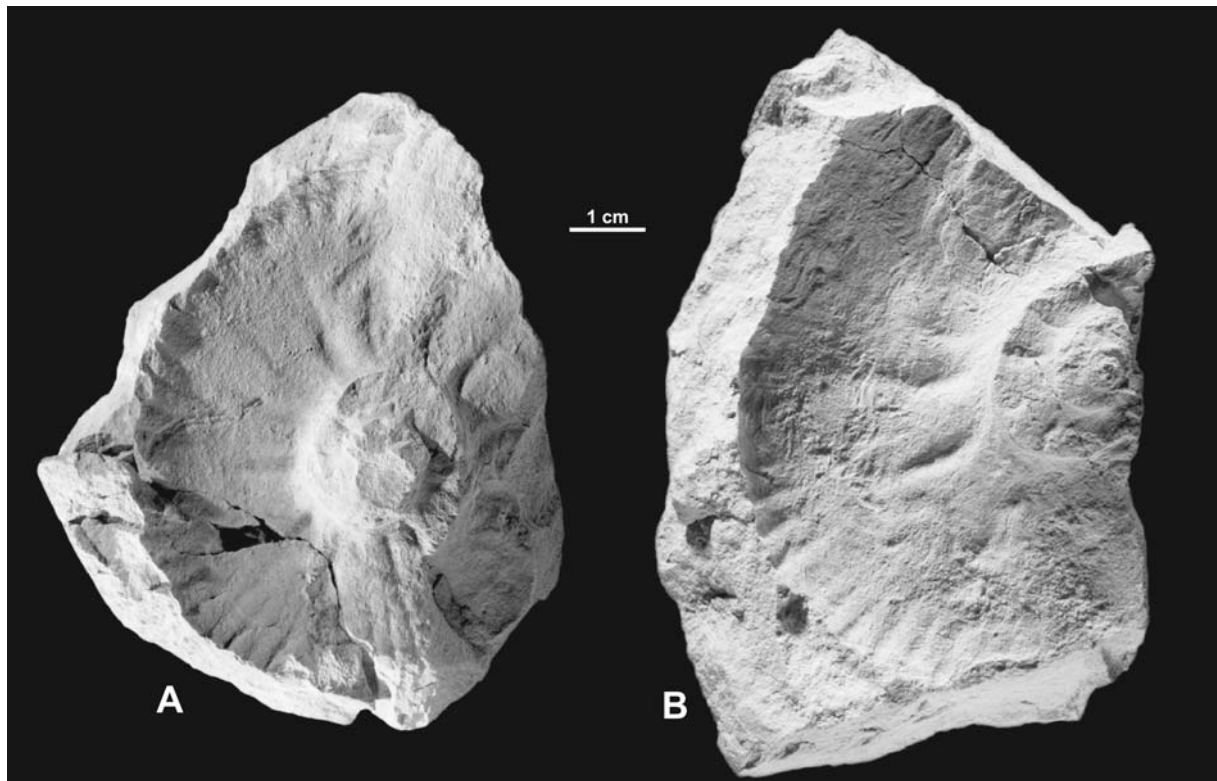
*Pachydiscus (P.) neubergicus* is closely related to *P. (P.) perfidus*, possibly representing its descendant (Błaszkiwicz 1980; Kennedy and Summesberger 1986). However, specimens from Tercis, claimed to be transitional between *P. perfidus* and *P. neubergicus* by Courville and Odin (2001, p. 534, pl. 5, fig. 36; pl. 6, figs 45, 46), have in fact no transitional morphology between these species. In fact, 'intermediate' specimens occurring below that boundary are either *P. perfidus* or *P. armenicus*, and these occurring at or above that level match *P. n. neubergicus s.s.* Amongst the latter is specimen GSO 210 from the 115.2 m level at Tercis. The internal mould of this specimen (Courville and Odin 2001, pl. 5, fig. 36) is poorly preserved and barely identifiable, but the external cast (Text-fig. 5A) displays 8 umbilical bullae plus 28–30 ventral ribs on the second part of the last whorl (at a diameter of 78 mm) and matches the densely ribbed specimens from Neuberg. Specimen GSO 210 is the lowest record of *P. n. neubergicus* at Tercis.

STRATIGRAPHIC AND GEOGRAPHIC RANGE:  
Lower Maastrichtian of Europe (including Russia),

Africa, and India, with some records ranging into lower upper and upper upper Maastrichtian (e.g., Denmark and Bulgaria).

*Pachydiscus (Pachydiscus) armenicus* Atabekian and Akopian, 1969  
(Pl. 5, Figs 1, 3–4; Text-Fig. 5B)

1969. *Pachydiscus gollevillensis armenicus* Atabekian and Akopian, p. 8, pl. 1, fig. 2; pl. 3, figs 1, 2.  
1969. *Pachydiscus gollevillensis gollevillensis* (d'Orbigny); Atabekian and Akopian, p. 4; pl. 1, fig. 4.  
1993. *Pachydiscus (Pachydiscus) armenicus* Atabekian and Akopian, 1969; Hancock and Kennedy, p. 159, pl. 13, figs 1, 2.  
1993. *Pachydiscus (Pachydiscus) armenicus* Atabekian and Akopian, 1969; Ward and Kennedy p. 34, figs 27.1, 27.2, 27.8–27.10, 29.5, 34.1–34.6.  
pars 1993. *Pachydiscus (Pachydiscus) armenicus* Atabekian and Akopian, 1969; Hancock and Kennedy, p. 584, pl. 2, fig. 1 (non pl. 2, figs 4, 5).  
?1994. *Pachydiscus (Pachydiscus) gollevillensis* (d'Orbigny, 1850); Yazikova (*recte* Yazykova), p. 297, pl. 11, fig. 2.



Text-fig. 5. External casts of the pachydiscid ammonites from the Tercis section, Landes, southwest France. A – *Pachydiscus (Pachydiscus) neubergicus* (von Hauer, 1858), specimen GSO 210 from the 115.2 m level, thus from the level of GSSP for the Campanian-Maastrichtian boundary; B – *Pachydiscus (Pachydiscus) armenicus* Atabekian and Akopian, 1969, specimen GSO 238 from the 98.2 m level, upper Campanian



1995. *Pachydiscus gollevillensis armenicus* Atabekian and Akopian, 1969; Ivanov, p. 70, pl. 2, fig. 4; pl. 4, figs 1, 4.
2001. *Pachydiscus armenicus* Atabekian and Akopian, 1969; Courville and Odin, p. 533, pl. 4, fig. 32.
2001. *P. perfidus/neubergicus*; Courville and Odin, p. 534, pl. 6, fig. 45.
- ?2002. *Pachydiscus (P.) cf. armenicus* Atabekian and Akopian, 1969; Jagt, text-fig. 6D.

**TYPES:** Holotype is specimen 3/101 of Atabekian and Akopian (1969, pl. 3, fig. 1) from the upper Maastrichtian of the Azizbek region, Armenia, reillustrated by Ward and Kennedy (1993, figs 29.4–29.6).

**MATERIAL:** Seven specimens: MZ VIII Mc 499, 500, MUZ PIG 1, 3010 II.421–423, all labelled as coming from horizon u of Pożaryski (1938) at Kamień, and ZPAL Am. 12/1290 and 12/1292, both from Kamień South.

**COMPARATIVE MATERIAL:** A plaster cast of the holotype, specimen 3/101 of Atabekian and Akopian (1969), a plaster cast of the external mould of specimen GSO 238 (illustrated by Courville and Odin 2001, pl. 6, fig. 45 as *P. perfidus/neubergicus*) from the 98.2 m level at Tercis.

**DISCUSSION:** The type material of the species, described originally by Atabekian and Akopian (1969) as *Pachydiscus gollevillensis armenicus*, is from upper Maastrichtian marls as exposed 1.5 km west of the village of Barcruni, in the Azizbek region of Armenia. It comprises the holotype 3/101 and a smaller topotype 2/101, both preserved as composite moulds. The former is a moderately involute specimen, consisting of a phragmocone and part of the body chamber, with 20 umbilical bullae and c. 73 ventral ribs at a maximum diameter of 129 mm. There is a distinct zone where ribs efface at mid-flank of the last preserved whorl. Specimen 2/101 is phragmocone with a small portion of the body chamber and has 19 umbilical bullae and c. 62 ventral ribs at a maximum diameter of 98 mm.

Specimen 1/101 of Atabekian and Akopian (1969, pl. 1, fig. 4), referred by them to *P. g. gollevillensis* (d'Orbigny, 1850), is a wholly septate composite mould, 100 mm in diameter. It comes from the same locality and stratum as both individuals of *P. g. armenicus*. It has the same proportions and style of ornament, but only 14 umbilical bullae in addition to 65 ventral ribs. In spite of the smaller number of umbilical bullae it is interpreted herein as a sparsicostate representative of *P. (P.) armenicus* (compare Błaszczewicz 1980, p. 45). Taking

into account the inclusion of the latter specimen, *P. (P.) armenicus* combines numerous umbilical bullae (14–20 per whorl) with 62–73 ventral ribs per whorl. A lectotype and topotypes of similarly ornamented *P. (P.) gollevillensis* from the Maastrichtian Calcaire à *Baculites* of the Cotentin Peninsula, Manche, France have only 9–11 umbilical bullae and up to 80 ventral ribs (Kennedy 1986), thus much fewer umbilical bullae and more ventral ribs than *P. (P.) armenicus*; moreover, the umbilical bullae are much weaker in the former than in the latter species.

All specimens from the Middle Vistula River section assigned here are fragmentary, but display numerous ventral ribs and numerous and strong umbilical bullae. The proportions of the whorls and ribs effacing at mid-flank are also typical of the species.

The external mould of specimen GSO 238 from the upper Campanian IV 98.2 m level at Tercis (see Text-fig. 5B; the corresponding internal mould was illustrated by Courville and Odin 2001, pl. 6, fig. 45 as *P. perfidus/neubergicus*) displays features typical of *P. (P.) armenicus*, e.g., numerous ventral ribs plus ribs effacing at mid-flank.

*Pachydiscus (P.) cf. armenicus* from near the base of Vijlen Member interval 6, at the CPL SA quarry, Haccourt, Liège, Belgium (Jagt 2002, text-fig. 6D) may either belong to the eponymous taxon or to *P. (P.) gollevillensis*. Both species are characterised by a large number of ventral ribs and by ribs effacing at mid-flank, but differ in the development of umbilical ribbing (see above) which is not preserved in that specimen.

**STRATIGRAPHIC AND GEOGRAPHIC RANGE:** The species is known from the lower and upper Maastrichtian of Armenia, the Bay of Biscay sections, Tercis, Landes, ?northeast Belgium, Bulgaria, Pyrénées-Atlantiques, possibly also western Sakhalin, Far East Russia. In the Middle Vistula River section and in Tercis the species enters in upper Campanian strata, which constitutes the stratigraphically lowermost occurrence known to date.

Suborder Ancyloceratina Wiedmann, 1966  
 Superfamily Turrilitoidea Gill, 1871  
 Family Diplomoceratidae Spath, 1926  
 Genus *Diplomoceras* Hyatt, 1900

**TYPE SPECIES:** *Baculites cylindracea* Defrance, 1816, p. 160, by original designation.

*Diplomoceras cylindraceum* (Defrance, 1816) *sensu* Kennedy, 1987  
 (Pl. 6; Pl. 7, Figs 1–5; Pl. 8, Figs 9, 11)

- ?non 1816. *Baculites cylindracea* Defrance, p. 160.  
 ?non 1817. *Baculites gigantea* Desmarest, p. 47, pl. 1, figs 1, 2  
 ?non 1825. *Hamites cylindricus*; de Blainville, p. 382, pl. 13, fig. 1.  
 1858. *Hamites cylindraceus*, Defr., sp.; von Hauer, p. 8, pl. 1, figs 3–6.  
 1861. *Hamites cylindraceus*, Defr.; Binkhorst van den Binkhorst, p. 36, pl. 5b, figs 5–7.  
 1869. *Hamites cylindraceus*, Defrance, sp.; Favre, p. 26, pl. 7, fig. 1.  
 1953. *Diplomoceras lambi* Spath, p. 17, pl. 2, figs 1-3; pl. 3, fig. 1.  
 1980. *Diplomoceras cylindraceum lvoventse* Mikhailov, 1951; Błaszkiwicz, p. 30, pl. 54, fig. 4.  
 non 1980. *Diplomoceras cylindraceum cylindraceum* (Defrance, 1916) [*sic*]; Błaszkiwicz, p. 30, pl. 54, fig. 2; ?pl. 55, figs 6, 7.  
 1986. *Diplomoceras cylindraceum* (Defrance, 1816); Kennedy, p. 51, pl. 4, figs 1, 2; pl. 9, figs 8–10, pl. 10; text-figs 3i–l, 6, 7g–m.  
 1986. *Diplomoceras cylindraceum* (Defrance, 1816); Kennedy and Summesberger, p. 194, pl. 15, figs 1, 2, 5; pl. 16, figs 14, 15; text-fig. 6.  
 1987. *Diplomoceras cylindraceum* (Defrance, 1816); Kennedy, p. 181, pl. 17, fig. 3; pl. 18, fig. 5; pl. 21, figs 2, 3, 5, 6; pl. 22, fig. 6; pl. 23, figs 1, 2; pl. 24, figs 1-3; pl. 25, figs 1–8; pl. 26, fig. 18; pl. 33, fig. 16; pl. 36, fig. 6; Text-figs 9, 10.  
 1989. *Diplomoceras lambi* Spath, 1953; Olivero and Zinsmeister, p. 627, figs 2.1–2.4.  
 ?non 1995. *Diplomoceras cylindraceum* (Defrance, 1816); Jagt, p. 28, figs 1, 2, 7–9.  
 1996a. *Diplomoceras cylindraceum* (Defrance, 1816); Machalski, p. 953, fig. 2.  
 2001. *Diplomoceras cylindraceum* (Defrance, 1816); K uchler and Odin, p. 521, pl. 6, figs 12–13.  
 2003a. *Diplomoceras cylindraceum* (Defrance, 1816); Klinger and Kennedy, figs 1–7.  
 2003b. *Diplomoceras cylindraceum* (Defrance, 1816); Klinger and Kennedy, p. 303, figs 53–55.  
 2003. *Diplomoceras cylindraceum* (Defrance, 1816); Niebuhr, p. 268, pl. 1, fig. 8, pl. 4, fig. 1.  
 2007. *Diplomoceras cylindraceum* (Defrance, 1816); Klinger and Kennedy, p. 119, fig. 1A.

TYPE: Specimen IRScNB 10293 was designated neotype by Kennedy (1987, pl. 24, figs 1–3), not IRScNB 10511 as mentioned in the text (op. cit., p. 183). According to Kennedy (1987, p. 183), the neotype is ‘from the upper Maastrichtian Nekum or Meerssen Chalk of St. Pietersberg, Maastricht, the Netherlands’. However, the neotype designated by Kennedy is actually from the

Kunrade Limestone facies (Maastricht Formation) of the environs of Kunrade, in the eastern part of southern Limburg (J.W.M. Jagt, pers. comm., 2010).

MATERIAL: Ten specimens: ZPAL Am. 12/1122, 12/1123 and 12/1280, from the upper third of the Piotrawin section (ZPAL Am. 12/1123 having been collected from the base of this portion of the section), MUZ PIG 12.II.38 from Piotrawin with no precise location, ZPAL Am. 12/1283 (*ex Remin* Collection) from Raj, ZPAL Am. 12/1103 from Raj North, ZPAL Am. 12/1282 from Kamie n South (*ex situ*), ZPAL Am. 12/1281 from Kamie n North, ZPAL Am. 12/1120 from Solec (middle part of the section), and ZPAL Am. 12/898 from Dziurk w.

DISCUSSION: *Diplomoceras* is distinctive amongst heteromorphs by its paper clip-like coiling with several shafts connected by U-shaped curved parts, dense transverse ribbing of the shell with no tubercles, and, in some instances, gigantic size; no apical and apertural parts are known as yet (Kennedy 1987; Olivero and Zinsmeister 1989; Klinger and Kennedy 2003a). The collection studied is typical with respect to preservation, consisting exclusively of fragmentary composite moulds of shafts, most of them representing body chambers.

Whorl section and rib density have been treated by students of *Diplomoceras* as characters of taxonomic value (e.g., Mikhailov 1951; Kennedy 1987; Olivero and Zinsmeister 1989; Klinger and Kennedy 2003 a, b). The latter feature is typically expressed by the rib index (Ri), denoting the number of ribs in a distance equal to the whorl height (Wh) at the mid-point of the interval counted (e.g., Kennedy 1987; Olivero and Zinsmeister 1989). However, in view of the strong *post-mortem* crushing of the present specimens, their whorl section cannot be established and their rib density can be compared with three-dimensionally preserved materials only in a qualitative rather than quantitative way.

In view of the actual provenance of the neotype, the material studied should be first of all compared with that from the Kunrade limestone facies, which is early late Maastrichtian in age (*Belemnitella junior* Zone, see Kennedy 1987; Jagt 2002). However, the Kunrade material is not fully adequate for a complete characterisation of the species – most of the specimens from that unit described and illustrated by Kennedy (1987), including the neotype, are internal moulds with no, or only faint, traces of ribbing. The rib index can be counted only in IRScNB 10290 (Kennedy 1987, pl. 21, figs 5, 6; pl. 22, fig. 6, the latter view erroneously assigned to IRScNB 10291 in the figure caption) with re-

tained silicified shell. It has a rib index of 15 at a whorl height of 55 mm. The other specimen with distinct ribbing amongst the suite studied by Kennedy (1987) is incomplete; IRScNB 10294 has a minimum of 20 ribs at a whorl height of a minimum of 88 mm (Kennedy 1987, pl. 26, fig. 18). In addition, the rib index vs whorl height may be established from the illustrations of two moulds from Kunrade presented by Binkhorst van den Binkhorst (1861). These are 11 vs 34 for the specimen in his pl. Vb, fig. 5 and 20 vs 60 for the specimen in his pl. Vb., fig. 6. There is thus a distinct tendency in the Kunrade material for Ri to increase as Wh increases (cf. Kennedy 1987, p. 184). It should be also noted that the interspaces between ribs are more or less equal throughout the preserved fragments from Kunrade, except for occasional crowding at the bends, and the observed increase of Ri results only from increase of Wh (Text-fig. 6).

More representative biometric data concerning the variability of *Diplomoceras*, including those concerning the ontogenetically young portions of the shell, are provided by the material from the Campanian and Maastrichtian of the Antarctic Peninsula (Olivero and Zinsmeister 1989). These authors distinguished two species of *Diplomoceras*: the older *Diplomoceras lambi* Spath, 1953 and the younger *Diplomoceras maximum* Olivero and Zinsmeister, 1989. There are no differences in Ri between these species up to whorl heights of c. 55 mm, but later growth stages differ significantly in rib pattern and density (Olivero and Zinsmeister 1989, fig. 3, redrawn here as Text-fig. 6). *Diplomoceras lambi* occurs in the lower part of the Lopez de Bertodano Formation in Seymour Island and adjacent islands, which is late Campanian-?early Maastrichtian in age. It is characterised by Ri from 13 to 20; more important is that the distance between ribs does not change throughout ontogeny but Ri increases due to increase of Wh, just like in the Kunrade material (Text-fig. 6). The younger species, *D. maximum*, occurs in the upper part of the Lopez de Bertodano Formation in Seymour Island, which is of late Maastrichtian age (Olivero and Zinsmeister 1989). It is characterised by Ri ranging from 9 to 13 with distinct increase of distance between ribs as the size increases; Ri is, however, stable throughout ontogeny due to compensation of the increasing distance between ribs by an increase of Wh (Text-fig. 6). Contrary to Kennedy and Henderson (1992) and Henderson *et al.* (1992), *D. maximum* is here regarded as a valid species by virtue of the distinctive ribbing pattern of its growth stages with whorl height equalling or exceeding 55 mm (Olivero and Zinsmeister 1989, Text-fig. 6).

*Diplomoceras lambi* matches *D. cylindraceum* as defined by the neotype and topotypes from Kunrade

(Text-fig. 6) and it may safely be regarded a synonym of the latter, although specimens of *D. lambi* usually are more depressed than those from Kunrade (Kennedy 1987, fig. 10). In turn, the present material from the Middle Vistula River section matches the Kunrade and Seymour materials of *D. cylindraceum*, showing dense ribbing with no obvious changes throughout the preserved fragments. This concerns specimens of which whorl height can be estimated as exceeding the critical value of 55 mm. Especially impressive in this respect are densely ribbed specimens figured in Pl. 7, Fig. 1 and in Pl. 6, both from Piotrawin. All the material studied from the Middle Vistula River section can thus be safely assigned to *Diplomoceras cylindraceum*.

A revision of the global temporal patterns within the genus *Diplomoceras* is beyond the scope of the present paper (this results in a rather limited synonymy above). One may note, however, that *D. maximum* probably extends outside Antarctica as Błaszkiwicz (1980) recorded a large fragment of *Diplomoceras* with distant ribbing (Ri = 9 at Wh = 84) from the upper part of local horizon x of Pożaryski (1938), thus from the upper upper Maastrichtian *Belemnella kazimiroviensis* Zone of Middle Vistula River section (specimen MZ VIII Mc 530), assigned by him to *D. c. cylindraceum* (Defrance, 1916) [*sic*]. This fragment (Błaszkiwicz 1980, pl. 54, fig. 2) falls well within the variability of *D. maximum* (Text-fig. 6) and is probably conspecific with the Antarctic populations. It should be noted that Błaszkiwicz (1980) separated his *D. c. cylindraceum* from a densely ribbed specimen from the 'lower Maastrichtian' of Solec, referred by him to as *D. c. Iovovense* Mikhailov, 1951. Another suspected European record of *D. maximum* is a rarely ribbed fragment of a rather large shaft, referred to as *D. cylindraceum* by Birkelund (1993, pl. 11, fig. 1). It comes from the Maastrichtian part of the white chalk succession at Bjerre in Denmark, thus from the top of the upper upper Maastrichtian brachiopod zone 10 of Surlyk (1984), which is equivalent of the *Belemnella kazimiroviensis* Zone.

The youngest well-dated and well-preserved specimens attributable to *D. cylindraceum* in Europe are those from Kunrade limestone facies, which is of early late Maastrichtian in age (*Belemnitella junior* Zone, see above). As far as the non-European records are concerned, there is a well preserved, huge fragment of *D. cylindraceum* reported by Klinger and Kennedy (2007) from Richards Bay, Kwa Zulu-Natal, South Africa. It is circular in whorl section and reveals Ri = 25 at the whorl diameter of 125 mm; the interspaces are as wide as the ribs themselves (Klinger and Kennedy 2007, p. 119). The deposits which yielded this fragment, claimed by Klinger and Kennedy (2007)





to be the largest specimen of *D. cylindraceum* ever known, are also dated for early late Maastrichtian (see Klinger *et al.* 2001). Data from Kunrade and Richards Bay thus confirm that *D. cylindraceum* reached at least as high as into the lower upper Maastrichtian. The suspected European records of *D. maximum* are younger, coming from the upper upper Maastrichtian *Belemnella kazimiroviensis* Zone or its equivalents (see above). It is thus reasonable to assign all pre-late late European Maastrichtian records of *Diplomoceras* to *D. cylindraceum*, even if they are partly based on specimens of smaller whorl height than the critical value of 55 mm. This holds true especially for the stratigraphically low-positioned specimens from the Campanian-Maastrichtian interval of Tercis (Küchler and Odin 2001), and from the white chalk section at Kronsmoor (Niebuhr 2003; Niebuhr *et al.* 2011). As far as the material of *D. cylindraceum* from Maastrichtian Calcaire à *Baculites*, Manche, France (Kennedy 1986) is concerned, it must be noted that this unit, assigned by Machalski (1996b) to the upper upper Maastrichtian, was subsequently dated as early late Maastrichtian on inoceramid evidence (Walaszczyk *et al.* 2009).

Finally, it is worth commenting on records of *Diplomoceras* from the Maastrichtian type area which are younger than those from the Kunrade Limestone facies. Surprisingly, the published record of these specimens is very sparse. According to Jagt (2002, 2005), the highest occurrences of *Diplomoceras* in the Maastrichtian type area are those from the lowermost Meerssen Member (Maastricht Formation). The best documented are specimens of *D. cylindraceum* in flint preservation, which come from a flint layer in the upper part of the Nekum Member in northeast Belgium (Jagt 1995). Surprisingly, the published record of these specimens is very sparse. The specimens illustrated by this author in pl. 6, figs 1, 2, and pl., 6 figs 7, 8 have  $R_i = 11$  and  $R_i = 9$ , respectively at  $Wh = 25$  (counts from photographs). At this growth stage both temporal species of *Diplomoceras* are indistinguishable (Text-fig. 6). However, a large specimen in flint preservation, apparently from the same or closely related horizon, illustrated as *Baculites giganteus* by Desmarest (1817, pl. 1, figs 1, 2), resembles strongly specimens of *D. maximum* of comparable size. The possible occurrence of this species in the Nekum or lower Meerssen members in the Maastricht-

ian type area should be checked on a basis of new materials. Paradoxically, the original material of *Baculites cylindracea* Defrance, 1816 from ‘Maëstricht’, now considered to be lost (Kennedy 1987), must also have come from these or similar levels as the older parts of the local Maastrichtian succession were inaccessible at that time (J.W.M. Jagt, pers. comm., 2010). Unfortunately, the figure of *Hamites cylindricus* in the volume of plates to the Defrance’s work (de Blainville 1825, pl. 13, fig. 1) is far too idealised for any reliable comparison with the Antarctic material.

STRATIGRAPHIC AND GEOGRAPHIC RANGE: Lower(?)–upper Campanian, and lower to lower upper Maastrichtian worldwide; the upper upper Maastrichtian records may represent *D. maximum* (see discussion above).

Family Nostoceratidae Hyatt, 1894  
Genus and subgenus *Nostoceras* Hyatt, 1894

TYPE SPECIES: *Nostoceras stantoni* Hyatt, 1894, p. 569, by original designation.

*Nostoceras* (*Nostoceras*) *helicinum* (Shumard, 1861)  
(Pl. 8, Figs 1–3)

1861. *Turrilites helicinum* Shumard, p. 191.  
1941. *Nostoceras helicinum* (Shumard); Stephenson, p. 410, pl. 80, figs 11, 12.  
1974. *Nostoceras helicinum* (Shumard); Cobban, p. 8, pl. 4, figs 1–21; text-fig. 6.  
1980. *Nostoceras pozaryskii* Błaszkiwicz, p. 26 (pars), pl. 10, figs 1–7, 11, 13, 15.  
1993. *Nostoceras* (*Nostoceras*) *helicinum* (Shumard, 1861); Kennedy and Cobban, p. 414, figs 8.6–8.12, 9.1, 10.1–10.23.  
1993. *Nostoceras* (*Nostoceras*) *helicinum* (Shumard, 1861); Hancock and Kennedy, p. 163, pl. 16, figs 1, 4–9; pl. 17, figs 5–8; pl. 18, figs 1, 6; pl. 19, figs 5–7.  
1997. *Nostoceras helicinum*; Ward and Orr, fig. 6/1, 2, 4–6.  
2001. *Nostoceras* (*Nostoceras*) *helicinum* (Shumard, 1861); Küchler and Odin, p. 514, pl. 4, figs 1–2, 6, 8, 12; pl. 5, figs 18–20.

Text-fig. 6. Morphology and biometry of *Diplomoceras*. A – reconstruction of fragmentary specimen OGM 40477 of *D. cylindraceum* (Defrance, 1816) (= *D. lambi* Spath, 1953) from the upper Campanian-lower Maastrichtian of Cockburn Island, Antarctica; B – reconstruction of fragmentary specimen OGM 40484 of *D. maximum* (Olivero and Zinsmeister 1989) from the upper Maastrichtian of Seymour Island, Antarctica (based on photographs of the original specimens; see Olivero and Zinsmeister 1989, figs 2-1 and 5-2, respectively); C – graph of the rib index vs whorl height in *D. maximum* (blank squares – specimens from upper Maastrichtian of Antarctica, blank circle – specimen from the upper upper Maastrichtian of Middle Vistula River section), *D. cylindraceum* (= *D. lambi*) (black squares – specimens from the upper Campanian-lower Maastrichtian of Antarctica, blank circles – specimens from the lower upper Maastrichtian Kunrade limestone facies).

Data from Antarctica from Olivero and Zinsmeister (1989, fig. 3), for further details see text

2001. *Nostoceras (Nostoceras) helicinum* (Shumard, 1861); K uchler *et al.*, pl. 5, figs 2, 8–9, 11, 13–16; pl. 6, figs 6–9.  
 2012. *Nostoceras (Nostoceras) helicinum* (Shumard, 1861); Larson, p. 21, pl. 7, fig. 10; pl. 8, figs 1–6.

TYPE: As Shumard’s type material is lost, Stephenson designated specimen USNM 21103a neotype of the species; it is a spire from the Nacatoch Sand near Chatfield, Navarro County, Texas (Stephenson 1941, p. 411, pl. 80, figs 11, 12).

MATERIAL: Eight specimens: seven from Piotrawin (ZPAL Am. 12/1137, 1158 – 1161, 1168 with no precise location, plus ZPAL Am. 12/1167 from the top of the quarry section), and specimen MZ VIII Mc 494 from Kamie n South (the specimen is labelled as coming from horizon u from Kamie n, but is tentatively assigned to the Kamie n South locality basing on lithology of its matrix which is identical to that of the topmost part of the Piotrawin Opoka as exposed at the southern end of the village of Kamie n).

DISCUSSION: Shells of *N. (N.) helicinum*, and of the closely allied *N. (N.) hyatti*, consist of a tightly coiled spire, either dextral or sinistral, followed by a free, U-shaped body chamber directed first down off the spire and then retroversal, bringing the aperture back to a position close to the base of the last whorl of the spire (Reeside 1962; Cobban 1974).

No spires are present in the material from Piotrawin which mainly consists of fragmentary body chambers, some of them with preserved adjoining parts of the septate whorl. A fragmentary specimen, MZ VIII Mc 494, from Kamie n South, comprises the last part of the phragmocone and the lowermost portion of the body chamber. In size and ornament, MZ VIII Mc 494 closely resembles a corresponding fragment of *N. helicinum* from the basal part of the Navesink Formation (Cobban 1974, pl. 4, figs 8–10).

According to Hancock and Kennedy (1993) and Kennedy and Cobban (1993), *Nostoceras (N.) pozaryskii* Błaszkiwicz, 1980 is in part based on *N. (N.) helicinum* [including the holotype of *N. (N.) pozaryskii*] and in part on *N. (N.) hyatti*. Body chambers of *N. (N.) helicinum* differ from those of *N. (N.) hyatti* ‘by their much finer ribbing, bullae on the flanks, and complex pattern of looped and intercalated ribs as opposed to the very coarse simple ribbing of *N. (N.) hyatti*’ (Hancock and Kennedy 1993, p. 163).

It should also be noted that K uchler and Odin (2001) assigned to *N. (N.) approximans* (Conrad, 1855) many specimens from Tercis, referred to as *N. (N.) helicinum* by Hancock and Kennedy (1993).

STRATIGRAPHIC AND GEOGRAPHIC RANGE: Upper Campanian of Arkansas, Texas, Tennessee and New Jersey; Israel, Tercis (Landes, France), Barranca (Navarra, northern Spain), and Middle Vistula River section, Poland.

*Nostoceras (Nostoceras) hyatti* Stephenson, 1941  
(Pl. 8, Figs 4–5)

1941. *Nostoceras hyatti* Stephenson, p. 410, pl. 81, figs 9–12.  
 1974. *Nostoceras hyatti* Stephenson; Cobban, p. 10, pl. 5, figs 1–21; pl. 6, figs 1–12; pl. 7, figs 1–10; pl. 8, figs 1–30, text-fig. 12 (with synonymy).  
 pars 1980. *Nostoceras pozaryskii* Błaszkiwicz, p. 26, pl. 10, figs 8, 9, 12.  
 1980. *Nostoceras* sp.; Błaszkiwicz, p. 27, pl. 2, figs 7, 8.  
 ?1980. *Nostoceras* sp.; Błaszkiwicz, p. 27, pl. 5, fig. 3.  
 pars 1993. *Nostoceras (Nostoceras) hyatti* Stephenson, 1941; Hancock and Kennedy, p. 162, pl. 9, figs 1, 4; pl. 14, figs 2–4; pl. 16, figs 2, 3; pl. 17, figs 10, 11; pl. 18, figs 4, 5, 7, 8; pl. 19, figs 1–4, 8–10 (with synonymy).  
 1993. *Nostoceras (Nostoceras) hyatti* Stephenson, 1941; Kennedy and Cobban, p. 417, figs 9.2, 11.1–11.27.  
 2000. *Nostoceras (Nostoceras) hyatti* Stephenson; K uchler, p. 480, pl. 17, figs 2–6.  
 2001. *Nostoceras (N.) hyatti* Stephenson, 1941 I subsp. nov.; K uchler and Odin, p. 516, pl. 3, fig. 4; pl. 4, figs 11, 13 (with synonymy).  
 2001. *Nostoceras (N.) hyatti* Stephenson, 1941 II; K uchler and Odin, p. 517, pl. 3, figs 1–3, 6, 7, 10–13; pl. 4, figs 3–5.  
 2001. *Nostoceras (N.) hyatti*; K uchler *et al.*, p. 739, pl. 5, figs 3, 6, 7; pl. 6, fig. 1.  
 2007. *Nostoceras (Nostoceras) hyatti*; Summesberger *et al.*, p. 446, fig. 3.  
 2012. *Nostoceras (Nostoceras) hyatti* (Shumard, 1861); Larson, p. 22, pl. 7, figs 8, 9; pl. 9, figs 1–7.

TYPE: Holotype, by original designation, is USNM 77258, the original of Stephenson (1941, p. 410, pl. 81, fig. 9) from the upper Campanian Nacatoch Sand on Postoak Creek on the north edge of Corsicana, Navarro County, Texas.

MATERIAL: Two specimens: ZPAL Am. 12/1169 from the middle part of the Piotrawin section, and MUZ PIG 12 II 8 (*Nostoceras* sp. of Błaszkiwicz 1980, pl. 2, figs 7, 8) from the northern part of Kamie n (found ‘at the distance of 200 metres from the park’, according to the original label).

DISCUSSION: Both specimens at hand are fragments of body chamber and match well the corresponding parts of the North American materials of the species.

Küchler and Odin (2001) proposed that *Nostoceras* (*N.*) *hyatti* occurs at Tercis as two temporal subspecies, which they numbered I and II. The earlier subspecies differs from the younger one by its larger size and more distant, single ribs. It remains to be tested if the chronological subdivision of *N. (N.) hyatti* as proposed by Küchler and Odin (2001) is valid elsewhere, in particular in the North American successions, and the species is left undivided at the subspecific level herein. It should be noted that at Tercis the earlier form enters at the 66.5 m level, which corresponds to the *Sphaeroceramus pertenuiformis* Zone in terms of the inoceramid biostratigraphy (Walaszczyk *et al.* 2002b). In the Middle Vistula River section this zone is documented for Wola Pawłowska and Łopoczno (Walaszczyk 2004). Unfortunately, no nostoceratids are known from these sections to date.

According to Küchler and Odin (2001, p. 527), the specimen from Tercis illustrated in Hancock and Kennedy (1993 pl. 18, figs 2, 3) as *N. (N.) hyatti* actually belongs to another species from the *Nostoceras* (*Didymoceras*) *archiacum-donezianum* group.

STRATIGRAPHIC AND GEOGRAPHIC RANGE. Upper Campanian of New Jersey, Texas, Tennessee and Arkansas; Angola, Israel, France, Poland, Austria.

*Nostoceras* (*Nostoceras*) *schloenbachi* (Favre, 1869)  
(Pl. 8, Figs 6–8, 10)

1848. *Crioceras plicatilis* Kner, p. 9, pl. 2, fig. 3.  
1869. *Helicoceras schloenbachi* Favre, p. 30, pl. 7, fig. 5.  
1913. *Heteroceras polyplocum* Roemer var. *Schlönbachi* Favre sp.; Nowak, p. 385, pl. 41, fig. 14; pl. 44, fig. 42.  
?1974. *Nostoceras mendryki* Cobban, 1974, p. 13, pl. 10, figs 1–17; text-fig. 11.  
1980. *Nostoceras* (?) *schloenbachi* (Favre, 1869); Błaskiewicz, p. 27, pl. 10, figs 6, 7, 10.  
1987. *Nostoceras* (*Nostoceras*) *schloenbachi* (Favre, 1869); Kennedy and Summesberger, p. 30, pl. 2, figs 1–5.

TYPE: Holotype, by monotypy, is NHMW 1862.V.49. from Nagoryany (Nagórzany of Polish authors) near Lviv (Lwów), Ukraine.

MATERIAL: Three specimens: ZPAL Am. 12/879 from the bottom of the Dziurków section; ZPAL Am. 12/1116 from the middle part of the Solec section and ZPAL Am. 12/1109 from Kłudzie, from above the boundary marl.

DISCUSSION: The holotype of the species is part of a body chamber with no spire preserved (Favre 1869; Kennedy and Summesberger 1987). The fragmentary topotypes described and illustrated by Kner (1848) and Nowak (1913) represent fragments of spires with the same style of ribbing and tuberculation as the holotype.

Based on the material from Nagoryany it can be concluded that the shell of *N. (N.) schloenbachi* was composed of a relatively low, tightly coiled spire and a free, curved body chamber. The direction of the body chamber in relation to the spire cannot be established on the Nagoryany material. However, specimens of the closely allied *N. (N.) mendryki* Cobban, 1974 from the Navesink Formation, New Jersey (e.g., Cobban 1974, pl. 10, figs 15–17) suggest that the body chamber of *N. (N.) schloenbachi* curved away the spire in a direction roughly perpendicular to the axis of the spire, with only a minor downward inclination.

The whorls of the spire and body chamber in *N. (N.) schloenbachi* are oval in cross section and show the same pattern of ornament: paired ribs on the upper flank of the whorl link to an upper row of tubercles, and mostly single ribs on a lower flank link to the lower row of tubercles; a mid-flank zone between both rows of tubercles is weakly ornamented.

Specimen ZPAL Am. 12/879 from Dziurków is a fragmentary spire; ZPAL Am. 12/1116 from Solec seems to represent part of the body chamber of the individual larger than the largest known specimen from Nagoryany; and ZPAL Am. 12/1109 from Kłudzie (not figured herein) is a fragment of mid-flank portion of the whorl with two rows of tubercles and a near-smooth zone between them. All these specimens show the same character and density of ornament as the material from Nagoryany. The only significant difference is that the whorls in ZPAL Am. 12/879 are compressed in cross section, but this may result from the *post-mortem* deformation of this specimen.

*Nostoceras* (*N.*) *mendryki* is a very close ally of *N. (N.) schloenbachi*; it is probable that the two forms are conspecific in spite of some differences in ornament and size (Kennedy and Summesberger 1987; Küchler and Odin 2001), but the scarcity of material on both sides of the Atlantic prevents any firm conclusions in this respect.

*Nostoceras* (?*Didymoceras*) *obtusum* Howarth, 1965 from Tercis (Küchler and Odin 2001, p. 507, pl. 4, fig. 7; pl. 5, figs 21–25) has a similar style of ornament. However, there are significant differences in density of ribs and tubercles: *N. (?D.) obtusum* possesses much more numerous ribs and much finer tubercles at corresponding diameters than *Nostoceras* (*N.*) *schloenbachi* (Küchler and Odin 2001).

STRATIGRAPHIC AND GEOGRAPHIC RANGE: Lower Maastrichtian of Ukraine; upper Campanian and lower Maastrichtian of Poland, Bulgaria, and possibly New Jersey, USA.

## DISCUSSION

Amongst twelve biohorizons used for definition of the GSSP for the base of the Maastrichtian Stage at Tercis, three are based on ammonites: the FO of *Pachydiscus* (*P.*) *neubergicus*, the FO of *Diplomoceras cylindraceum* and the LO of *Nostoceras* (*N.*) *hyatti* (see Odin 2001a, b; Odin and Lamaurelle 2001). The most important of these taxa is *Pachydiscus* (*P.*) *neubergicus* which formerly was recommended as a sole biostratigraphic marker for the definition of the Campanian-Maastrichtian boundary (Odin 1996) and subsequently was treated as an important 'guide-event' for its definition (Odin and Lamaurelle 2001).

According to Courville and Odin (2001), the lowest specimen of *P. (P.) Neubergicus* at the Tercis section is GSO 252, which comes from the 116,1 m level, thus 0.9 m above the GSSP (see also Odin 2001a, b; Odin and Lamaurelle 2001). A reinterpretation of specimen GSO 210 from the 115.2 m level as *P. (P.) Neubergicus* (see above) indicates that the FO of *P. (P.) Neubergicus* at Tercis coincides precisely with the GSSP. In terms of inoceramid biozones, the FO of *P. (P.) Neubergicus* at Tercis lies within the top of the "Inoceramus" *redbirdensis* Zone (Walaszczyk *et al.* 2002a, b). In the Middle Vistula River section, the lowest well-localised specimen of this species is ZPAL Am. 12/891, which comes from the bottom of the Dziurków succession, representing the inoceramid *Endocostea typica* Zone (Text-fig. 2; Walaszczyk 2004). However, imprecisely located specimens from the underlying Kłudzie and Kamień North sections clearly indicate that the FO of *P. (P.) Neubergicus* occurs some distance below the Dziurków section (Text-fig. 2), thus, possibly in the upper part of the "Inoceramus" *redbirdensis* Zone of Walaszczyk (2004).

The FO of *Diplomoceras cylindraceum* at Tercis is at the 111 +/-3 m level (Küchler and Odin 2001; Odin 2001a, b; Odin and Lamaurelle 2001), i.e., within the "Inoceramus" *redbirdensis* Zone in the inoceramid zonation of Walaszczyk *et al.* (2002a, b). In the Middle Vistula River section, the lowest precisely located record of *D. cylindraceum* is specimen ZPAL Am. 12/1123 found *in situ* at the bottom of the upper third of the Piotrawin section. This level probably marks the FO of *D. cylindraceum* in the Middle Vistula River section (Text-fig. 2), which lies within the "Inoceramus" *inkerma-*

*nensis* Zone of Walaszczyk (2004). Consequently, in terms of inoceramid biozones the local FO of *D. cylindraceum* is located considerably lower than that at Tercis. Both in the Tercis section and in Krons Moor, the standard reference section for the base of the Maastrichtian in the Boreal realm (northern Germany), the FO of *D. cylindraceum* is situated below that of *P. Neubergicus* (see Niebuhr 2003 and Niebuhr *et al.* 2011 for precise data concerning the Krons Moor section).

The LO of *Nostoceras* (*N.*) *hyatti* is at the 114.1 m level at Tercis (Küchler and Odin 2001; Odin 2001a, b; Odin and Lamaurelle 2001). This corresponds to the uppermost part of the "Inoceramus" *redbirdensis* Zone (Walaszczyk *et al.* 2002a, b). In the Middle Vistula River section, the LO of *N. (N.) hyatti* is based on specimen MUZ PIG 12 II 8 from the northern end of the village of Kamień, thus probably from the "I." *redbirdensis* Zone of Walaszczyk (2004), which is in good agreement with the situation at Tercis. It cannot be excluded that the vertical range of this species overlapped shortly with that of *P. Neubergicus* (see Text-fig. 2), like in northern Spain (Kühler 2000, fig 13).

In view of the imprecise location of two ammonite markers for the GSSP, the direct location of the Campanian-Maastrichtian boundary in the Middle Vistula River section, as a mathematic means of three ammonite-based biomarkers (compare Odin and Lamaurelle 2001), is impossible. However, some conclusions can be drawn on the relationship of the vertical ranges of the above-mentioned ammonite taxa with respect to the FO of *Belemnella lanceolata* (von Schlotheim, 1813), which is the traditional belemnite marker for the base of the Maastrichtian Stage in the Boreal Realm (e.g., Schulz 1979; Christensen 1996; Niebuhr *et al.* 2011). According to Walaszczyk (2004, p. 105), the stratigraphically lowest record of *B. lanceolata* on the left bank of the Vistula River section is in the Raj North section. On the opposite bank of the river, the lowest occurrence of this species was recorded from outcrop 166 in Piotrawin, north of the large Piotrawin quarry (Błaszkiwicz 1980, fig. 1). The section formerly exposed in the outcrop 166 belongs to the upper part of the Piotrawin Opoka, corresponding to the interval between the topmost part of the large Piotrawin quarry succession and the Kamień South succession (compare Walaszczyk 2004, fig. 1; Text-fig. 2 here), which represents the *Trochoceras costaeus* Zone of Walaszczyk (2004). Thus, the above-mentioned Piotrawin record forms the FO of *Belemnella lanceolata* in the Middle Vistula River section. Based on the correlative scheme of Walaszczyk (2004, fig. 3; see also Text-fig. 2 herein), it is clear that the FO of *P. (P.) Neubergicus* is located



significantly higher than that level (at least 12 m, but possibly much more). This is in agreement with Hancock *et al.* (1993) and Christensen *et al.* (2000), who correlated the FO of *P. neubergicus* at Tercis with the *Belemnella obtusa* Zone or with the top of *Belemnella lanceolata* Zone s.s. Assuming that the net sedimentation rate for opoka in the Campanian-Maastrichtian boundary interval of the Middle Vistula River section is c. 50 kyr for 1 metre (I. Walaszczyk, pers. comm., 2011), its 12 m-thick interval may correspond to c. 600 kyr, but this is a highly speculative value. As far as the LO of *Nostoceras (N.) hyatti* is concerned, an imprecisely located record of this species from Kamień North suggests that it may occur even up to 26 m above the FO of *Belemnella lanceolata*, but most probably this figure is much exaggerated. The FO of *Diplomoceras cylindraceum* is located significantly below (at least 10 m) that of *Belemnella lanceolata*. In contrast, it is situated significantly above the FO of *Belemnella lanceolata* at Krons Moor, northern Germany (Niebuhr 2003; Niebuhr *et al.* 2011). A small number of specimens available from the Krons Moor section (only three, see Niebuhr 2003) precludes any reliable explanation of this fact.

## SUMMARY

Three ammonite taxa were used in 2001 for the formal definition of the Global Stratotype Section and Point (GSSP) for the base of the Maastrichtian Stage at Tercis, southwest France. These are *Pachydiscus (P.) neubergicus*, *Diplomoceras cylindraceum*, and *Nostoceras (N.) hyatti*. The taxonomy and stratigraphical ranges of these and allied species [*Pachydiscus (P.) perfidus*, *P. (P.) armenicus*, *N. (N.) helicinum*, and *N. (N.) schloenbachi*] in the upper Campanian-lowermost Maastrichtian boundary interval of the Middle Vistula River section, central Poland, are discussed and presented against inoceramid and ammonite/belemnite zonations.

The lowest well-localised specimen of *Pachydiscus (P.) neubergicus* in the Middle Vistula River section is that from the bottom of the Dziurków succession (*Endocostea typica* Zone). However, imprecisely located specimens from the underlying Kłudzie and Kamień North sections indicate that the FO of this species occurs some distance below, possibly in the upper part of “*Inoceramus*” *redbirdensis* Zone. This is in agreement with Tercis, where the first specimens of *Pachydiscus (P.) neubergicus* occur in the uppermost part of the “*Inoceramus*” *redbirdensis* Zone.

Contrary to claims of previous authors, no un-

equivocal specimens of *Pachydiscus (P.) neubergicus* are known to date from the *Belemnella lanceolata* Zone s.l. in the Middle Vistula River section. The holotype of *Pachydiscus n. raricostatus* is imprecisely located in the interval near the village of Kamień, which straddles the *B. lanceolata* and *B. occidentalis* zones; whereas all topotypes from the same area belong to other pachydiscid species.

The FO of *Diplomoceras cylindraceum* in the Middle Vistula River section falls at the bottom of the upper third of the Piotrawin section (in the “*Inoceramus*” *inkermanensis* Zone). In terms of inoceramid biozones, the local FO of *D. cylindraceum* is located considerably lower than that at Tercis, which lies in the “*Inoceramus*” *redbirdensis* Zone.

Both in Tercis and in the Middle Vistula River section, *D. cylindraceum* enters below the FO of *P. neubergicus*. It seems also to appear below the FO of *P. neubergicus* in the standard Boreal reference section at Krons Moor, northern Germany, although the precise FAD of the latter species at Krons Moor cannot be established.

Upper Campanian and lowermost Maastrichtian specimens of *Diplomoceras cylindraceum* from the Middle Vistula River section reveal significant differences in ribbing pattern from the upper upper Maastrichtian specimens described earlier from this area and from the white chalk succession in Denmark. The latter specimens probably represent *Diplomoceras maximum*, a species previously known exclusively from the Antarctic Peninsula.

The LO of *Nostoceras (N.) hyatti* in the Middle Vistula River section is based on an imprecisely located specimen found at the northern end of the village of Kamień, thus probably in the “*P. redbirdensis* Zone. This is in agreement with the LO of this species at Tercis which also falls within the eponymous inoceramid zone.

In view of the imprecise location of two ammonite GSSP markers, the direct location of the Campanian-Maastrichtian boundary in the Middle Vistula River section is impossible.

Conclusions are possible, however, on the relation of the vertical ranges of *Pachydiscus (P.) neubergicus*, *Diplomoceras cylindraceum*, and *Nostoceras (N.) hyatti* in respect to the FO of *Belemnella lanceolata*, which for a long time has been regarded as a belemnite marker for the base of the Maastrichtian Stage in the Boreal Realm.

The FO of *Pachydiscus (P.) neubergicus* in the Middle Vistula River section is located significantly higher than the FO of *Belemnella lanceolata* (at least 12 m, but possibly much more). This is in agreement with conclusions of those researchers who correlated the FO of

*P. neubergicus* at Tercis with the *Belemnella obtusa* Zone or with the top of the *Belemnella lanceolata* Zone *s. s.* (see discussion above).

An imprecisely located record of *Nostoceras (N.) hyatti* from the northern end of the village of Kamień suggests that that this species may occur even up to 26 m above the FO of *Belemnella lanceolata*, but probably much less than this figure.

The FO of *Diplomoceras cylindraceum* is located significantly below (at least 10 m) the FO of *Belemnella lanceolata*. In contrast, it is markedly higher than the latter level at Krons Moor.

The records of *Pachydiscus (P.) armenicus* from the Middle Vistula River section and from Tercis, as documented in the present paper, are anomalous in terms of their stratigraphic position, coming from the upper Campanian *Trochoceramus costaeus* Zone. Earlier, this species was reported from the upper and upper lower parts of the Maastrichtian.

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