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The '*Inoceramus*' *azerbaydjanensis* fauna (Bivalvia) and its value for chronostratigraphic calibration of the European Campanian (Upper Cretaceous)

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Abstract

The '*Inoceramus*' *azerbaydjanensis* group which comprises the species '*I.*' *azerbaydjanensis* ALIEV, 1939 and '*I.*' *vorhelmensis* (WALASZCZYK, 1997), is widely distributed throughout the Euramerican biogeographic region. Its evolutionary history and, as a consequence, its taxonomic position remains unclear; morphological features which recall those of the genus *Cordiceramus* HEINZ, 1932, may easily have resulted from convergent evolution. Both species are found in the lowermost mid-Campanian *Baculites obtusus* and *Baculites maclearni* zones in the US Western Interior, and in the *Patagiosites stobaei/Galeola basiplana* and *Galerites vulgaris/Galeola basiplana* zones in northern Europe. Biostratigraphic correlation of the potential maximum range of their occurrences in both these regions enables geochronologic calibration of the lower part of the traditional European upper Campanian. The dating of the *Nostoceras polyplocum* ammonite Zone is critically reviewed in the light of this correlation.

Keywords: Bivalvia, Inoceramidae, Campanian, Europe, US Western Interior, trans-Atlantic correlation.

Résumé

Le groupe *'Inoceramus' azerbaydjanensis,* comprenant les espèces '*I.*' *azerbaydjanensis* ALIEV, 1939 et '*I.*' *vorhelmensis* (WALASZCZYK, 1997), est largement distribué dans la région biogéographique euraméricaine. Son histoire évolutive et, en conséquence, sa position taxinomique restent incertaines; ses caractères morphologiques, rappelant ceux du genre *Cordiceramus* HEINZ, 1932, peuvent très bien être le résultat d'une évolution convergente. Les deux espèces du groupe se retrouvent dans les zones à *Baculites obtusus* et *Baculites maclearni* de la partie inférieure du Campanien moyen du 'Western Interior' des États-Unis, et dans les zones à *Patagiosites stobaei/Galeola basiplana* et *Galerites vulgaris/Galeola basiplana* de l'Europe septentrionale. La corrélation biostratigraphique de leur extension maximale potentielle dans ces deux régions permet un calibrage géochronologique de la partie inférieure du Campanien supérieur, tel que défini traditionnellement en Europe. La datation de la zone à *Nostoceras polyplocum* (ammonites) est revue de manière critique à la lumière de cette corrélation.

Mots-clefs: Bivalvia, Inoceramidae, Campanien, Europe, Western Interior des États-Unis, corrélation trans-atlantique.

Introduction

Late early and early late Campanian inoceramid bivalve faunas of the Euramerican biogeographic region are dominated by 'cataceramids', for which the stratigraphic record is rather crude and whose evolutionary history is poorly understood. The associated 'platyceramids' and 'cordiceramids' are rare, and usually are assigned to long-ranging lineages, generally assumed to go mostly back well into the Santonian Hence, the apparently sudden appearance in the earliest late Campanian of forms referred herein to the group of '*Inoceramus*' *azerbaydjanensis* ALIEV, 1939, which comprises that species and '*I.*' *vorhelmensis* (WALASZCZYK, 1997), is of considerable biostratigraphic significance. Although the origin of this group and its stratigraphic range in other areas still raise a number of questions, the distinctive morphology, very narrow vertical range and occurrence throughout the entire Euramerican biogeographic region allow it to be used in trans-Atlantic correlations and, consequently, in the geochronologic calibration of the European Campanian, which remains highly controversial. The present paper summarises the main taxonomic and biogeographic views on '*I.*' *azerbaydjanensis* and '*I.*' *vorhelmensis* as currently recognised, and focuses on their geo-/chronostratigraphic importance and inferences for the European Campanian. North American records of this

group are well known and have been published in detail (COBBAN & SCOTT, 1964; COBBAN & KENNEDY, 1993; KAUFFMAN *et al.* 1994; WALASZCZYK *et al.*, 2001). European data are based on newly collected material from sections in southern Poland (Nida Trough), part of which has recently been published by JAGT *et al.* (2004).

Taxonomic and biogeographic remarks on the '*I.*' *azerbaydjanensis* fauna

What is referred to herein as the '*I.*' *azerbaydjanensis* group are *Cordiceramus*-like forms appearing in the early late (or early mid- in the US tripartite subdivision of the stage) Campanian of the Euramerican biogeographic region and possibly in the East African province (in KAUFFMAN's 1973 biogeographic subdivision). Two species are recognised within this group, namely '*I.*' *azerbaydjanensis* (see ALIEV, 1939, 1954; DOBROV & PAVLOVA, 1959; COBBAN & SCOTT, 1964; KOTSUBINSKY, 1974; MASSLENNIKOVA, 1982; COBBAN & KENNEDY, 1993; WALASZCZYK, 1997; WALASZCZYK *et al.*, 2001) and '*I.*' *vorhelmensis* (see WALASZCZYK, 1997; WALASZCZYK *et al.*, 2001). '*Inoceramus*' *tausiensis* ALIEV, 1954 shares all the characteristics of '*I.*' *azerbaydjanensis*, falls into its range of variation, and thus should be synonymised with it (COBBAN & KENNEDY, 1993; WALASZCZYK *et al.*, 2001). In the Euramerican region, both species are accompanied by *Cataceramus* ex gr. *balticus* (BÖHM, 1907), '*Inoceramus*' *ellipticus* GIERS, 1964 (Fig. 1I) and '*I.*' *agdjakendsis* ALIEV, 1954 (see *e.g.*, WALASZCZYK, 1997; WALASZCZYK *et al.*, 2001; JAGT *et al.*, 2004), typical early late Campanian inoceramids.

The distinction between '*I.*' *azerbaydjanensis* and '*I.*' *vorhelmensis* is purely typological and is based on the assumption of progressive development of their '*Cordiceramus*' characters. In contrast to '*I.*' *vorhelmensis* (see Fig. 1B, C, E-G), '*I.*' *azerbaydjanensis* (see Fig. 1A, D, H) possesses a more distinct and stronger axial sulcus (*i.e.*, the radial sulcus parallel to the growth axis), a more or less well-developed 'Schalenkante 1' (*sensu* SEITZ, 1961) along the anterior margin of the valve and an anterior sulcus. This might suggest a simple evolutionary lineage and ancestor/successor relationships between both species. In addition, transitional morphotypes between '*I.*' *vorhelmensis* and *Cataceramus beckumensis* (GIERS, 1964), the youngest member of the *Cataceramus copetdagensis-C. dariensis-C. beckumensis* lineage can be found, which may suggest evolutionary relationships between these two (WALASZCZYK, 1997). If this interpretation is correct, '*I.*' *azerbaydjanensis* and '*I.*' *vorhelmensis* would be descendants of the *Cataceramus* clade and their *Cordiceramus*-like architecture would result from convergent evolution. Taxonomically, both taxa could then be referred either to the genus *Cataceramus* or, alternatively, to a new genus. Another possibility is that both forms are descendants of a *Cordiceramus* clade, which is very poorly represented in the late early Campanian. The third possibility is that this fauna immigrated during the early late Campanian from another biogeographic region. A potential area could be *e.g.*, the East African province, where 'cordiceramids' predominate in the lower and lower upper Campanian (WALASZCZYK *et al.*, work in progress). In fact, a form which may belong to the '*I.*' *azerbaydjanensis* group is known to occur there (see WALASZCZYK *et al.*, 2001). In the two last-named options, both species would represent the genus *Cordiceramus*, as suggested by their morphological characteristics. Considering its uncertain evolutionary history, both species are herein referred to '*Inoceramus*' sensu lato.

Biostratigraphy of the '*I.*' *azerbaydjanensis* group

North America

In North America, the '*I.*' *azerbaydjanensis* group is known from Texas and the US Western Interior. In Texas, it occurs in the Wolfe City Sand, which is correlated with the *Baculites maclearni* Zone of the Western Interior (COBBAN & KENNEDY, 1993), the second oldest ammonite zone of the mid-Campanian, in the tripartite American sudivision of the stage (Fig. 2). Records from the US Western Interior are all dated as *Baculites obtusus* and *B. maclearni* zones (COBBAN & SCOTT, 1964; WALASZCZYK *et al.*, 2001), although the precise range of this species within the zones is unknown.

Europe and western Asia

In Europe and western Asia, the '*I.*' *azerbaydjanensis* group is widely known primarily from regions along the southern margin of the eastern European craton. '*Inoceramus*' *azerbaydjanensis* was first described by ALIEV (1939) from the Lesser Caucasus, originally from beds considered by him to be of Turonian age, but revised subsequently to Campanian (ALIEV, 1954). No type specimen was selected, but one of the original specimens illustrated was subsequently designated lectotype by ALIEV (1954). Specimens referred to this species recorded from the northern Great Caucasus

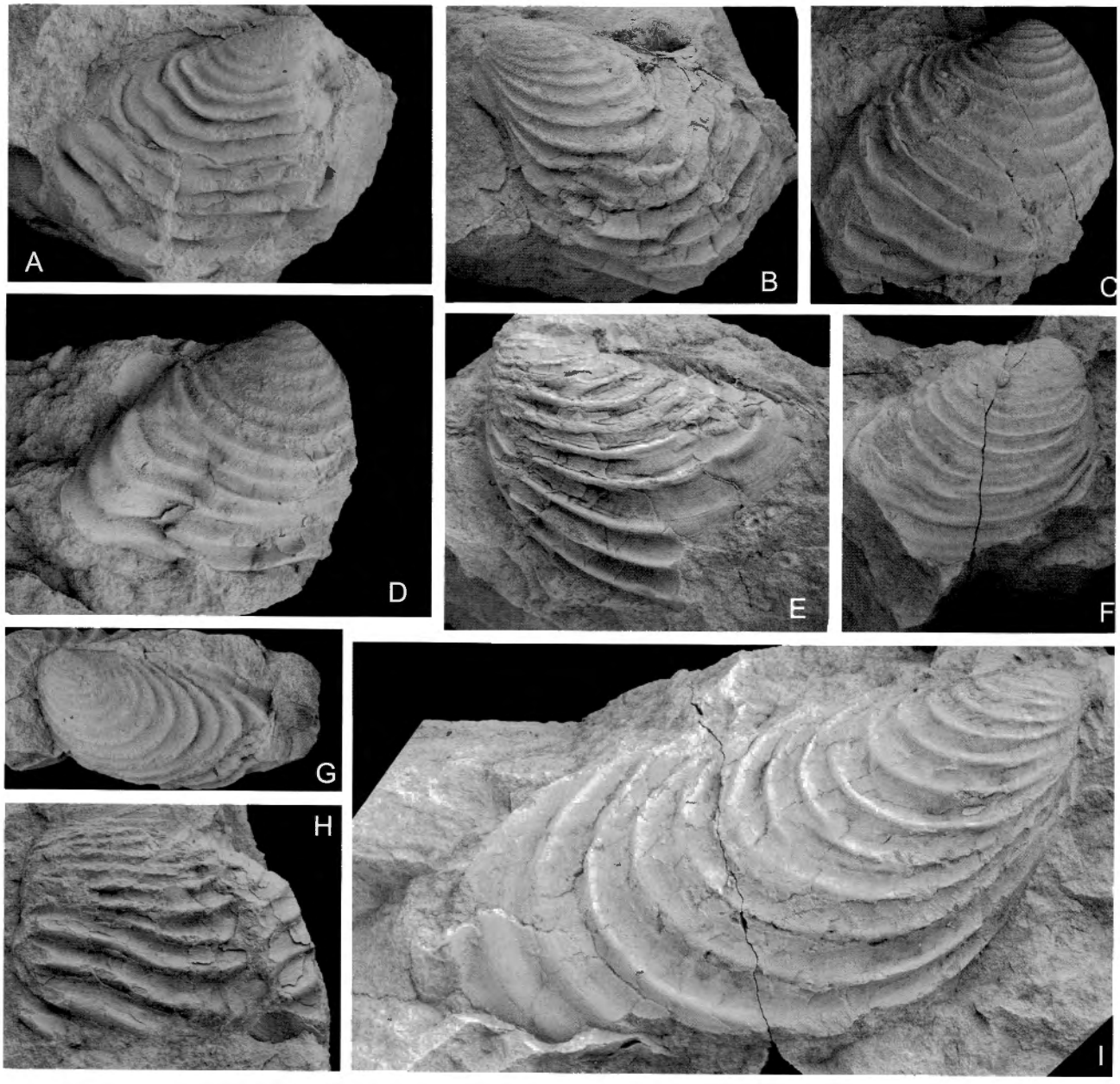

Fig. 1 – '*Inoceramus*' *azerbaydjanensis* fauna from Busko Zdrój, Nida Trough (southern Poland), lower upper Campanian. A, D, H. '*Inoceramus*' *azerbaydjanensis* ALIEV, 1939; A – FGUW ZI/35/148; D – FGUW ZI/35/151; H – FGUW ZI/35/155. B, C, E-G. '*Inoceramus*' *vorhelmensis* (WALASZCZYK, 1997); B – FGUW ZI/35/149; C – FGUW ZI/35/150; E – FGUW ZI/35/152; F – FGUW ZI/35/153; G – FGUW ZI/35/154. I. '*Inoceramus*' *ellipticus* (GIERS, 1964), FGUW ZI/35/156. With the exception of A and D, which are × 0.9, all other specimens are natural size. All material is housed in the Museum of the Faculty of Geology of the University of Warsaw (FGUW).

by DOBROV & PAVLOVA (1959) were dated as early Campanian. In more recent studies, the species is considered to be late early or early late Campanian in age, and records include the Crimea, Ukraine (ATABEKIAN, 1997), the Pericaspian Depression (MASSLENNIKOVA, 1982), Donbass (KOTSUBINSKY, 1974), the Great Caucasus (PERGAMENT & SMIRNOV, 1972) and other areas (ALIEV, 1979). KUZNETZOV (1968; see also ALIEV *et al.*, 1971) recorded the species from the upper upper Campanian of Tuarkyr, Russia. Based on dating of the North American and Central European (Westphalia, Germany; Nida Trough, southern Poland) material, the actual range of the species in regions south of the Russian Craton is here assumed to be early late Campanian. Differences between the various authors are here regarded to have resulted from variable bio-/

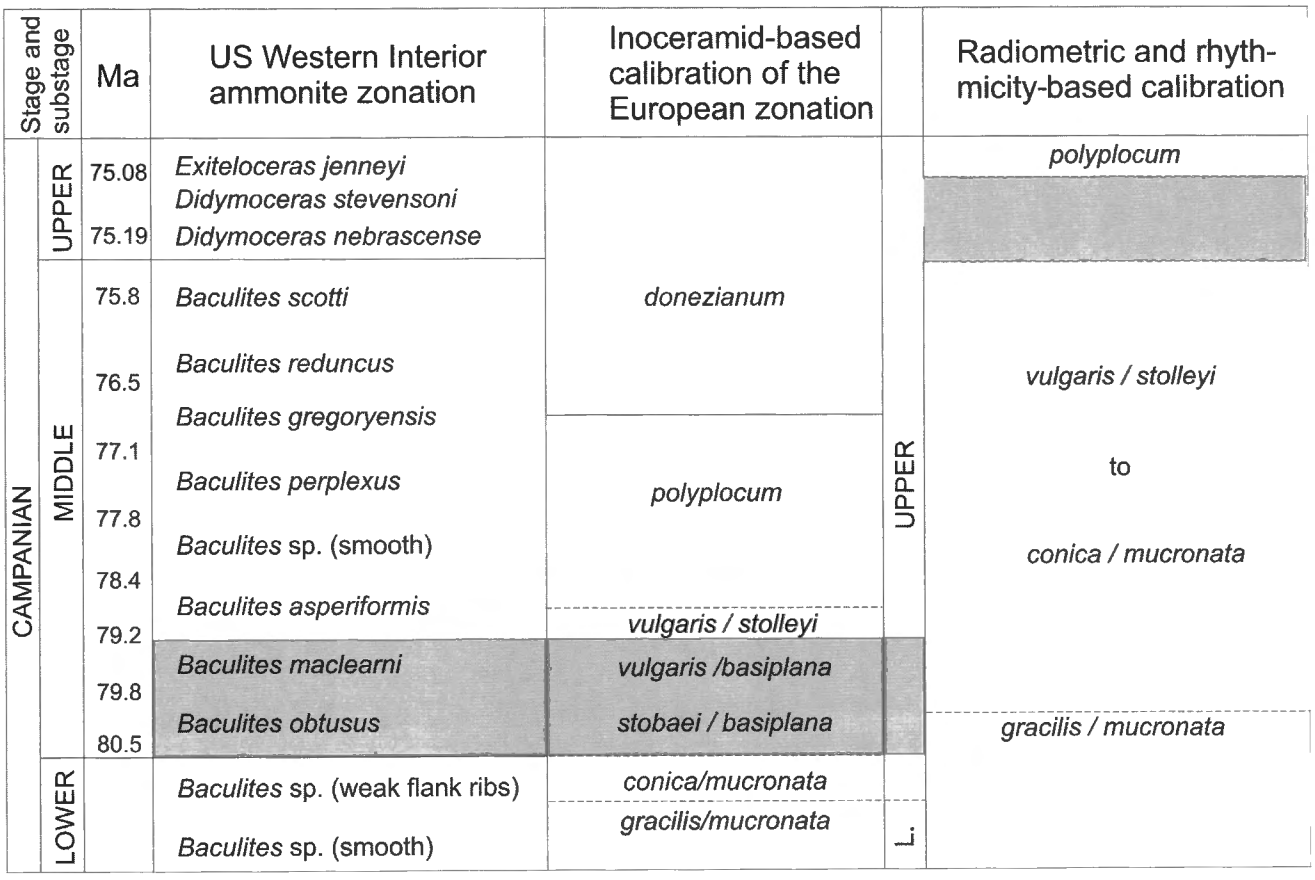

Fig. 2 – Intercorrelation of the US Western Interior ammonite zonation (after COBBAN, 1994) and the European ammonite/belemnite/echinoid zonation as based on inoceramids (in part after WALASZCZYK *et al.*, 2001; WALASZCZYK, 2004), and mixed rhythmicity and radiometric dates (after NIEBUHR, 2004, 2005); grey area in the left-hand and median columns shows the potential maximum range of the '*Inoceramus*' *azerbaydjanensis* group; the grey area in the right-hand column indicates the uncertainty interval in positioning of the base of the *Nostoceras polyplocum* Zone. The middle Campanian radiometric dates on the left-hand side are calculated dates. In the central column, the base of the European *N. polyplocum* Zone is indirectly correlated with the base of the *B. asperiformis* Zone.

chronostratigraphic concepts applied to the Campanian. This assumption is confirmed by early late Campanian records of '*I.*' *azerbaydjanensis* from Mangyshlak (western Kazakhstan), where Campanian zones were correlated with the German succession on the basis of belemnites (NAIDIN *et al.*, 1984). The species was found in the lower part of their lowermost upper Campanian zone characterised by the belemnite *Belemnitella mucronata mucronata* (VON SCHLOTHEIM, 1813) and the ammonites *Patagiosites* cf. *stobaei* (NILSSON, 1827), *Hoplitoplacenticeras coesfeldiense* (SCHLÜTER, 1867) and *Trachyscaphites spiniger* (SCHLÜTER, 1872). This biostratigraphically well-constrained record from Mangyshlak demonstrates clearly that the restricted early late Campanian date for occurrences of the '*I*'. *azerbaydjanensis* group in the Euramerican biogeographic region can be applied at least as far as western Asia. Nevertheless, as the possibility that the '*I.*' *azerbaydjanensis* group has a longer stratigraphic range in other parts of Asia cannot be completely excluded, the stratigraphic horizons of all the published records need to be investigated further.

In central and western Europe, '*I.*' *vorhelmensis* is quite well documented from Westphalia, Germany (WALASZCZYK, 1997), albeit its precise stratigraphic range is unknown, and it can only be broadly referred to the *Patagiosites stobaei/Galeola basiplana* and *Galerites vulgaris/Galeola basiplana* zones of the refined zonal scheme of the Campanian used in northern Germany (see WALASZCZYK, 1997). '*Inoceramus*' *azerbaydjanensis* in Germany is known only from a single ('aff.') record, also from Westphalia

(WALASZCZYK, 1997), referred to approximately the same interval. Two Campanian sections in the Nida Trough in southern Poland (see Fig. 3) are therefore of great importance, because there *'I.' azerbaydjanensis* is now on record from the Busko Zdrój composite section in the northeastern part of the trough (see MACHALSKI *et al.*, 2004) and from Rzeżuśnia in the southwest (JAGT *et al.*, 2004). The Nida (= Miechów) Trough is the southeasterly portion of the Szczecin-Łódź-Nida (= Miechów) Synclinorium, one of the major Alpine tectonic units in extra-Carpathian Poland (POŻARYSKI, 1977). The Busko Zdrój and Rzeżuśnia sections represent the northeasterly and southwesterly margins of this trough respectively.

1. Busko Zdrój section

This composite section comprises four temporary exposures in the town of Busko Zdrój, situated in the northern limb of the Nida Trough (Fig. 3; see also MACHALSKI *et al.*, 2004). The Campanian in the area is represented by a continuous succession of siliceous marls (opokas) and marls, apparently without stratigraphic gaps, and reaching a total estimated thickness of *c.* 300 m. The early late Campanian succession is quite fossiliferous, yielding heteromorph and non-heteromorph ammonites, belemnites, echinoids and inoceramid and non-inoceramid bivalves.

Based on ammonite evidence, the Busko Zdrój

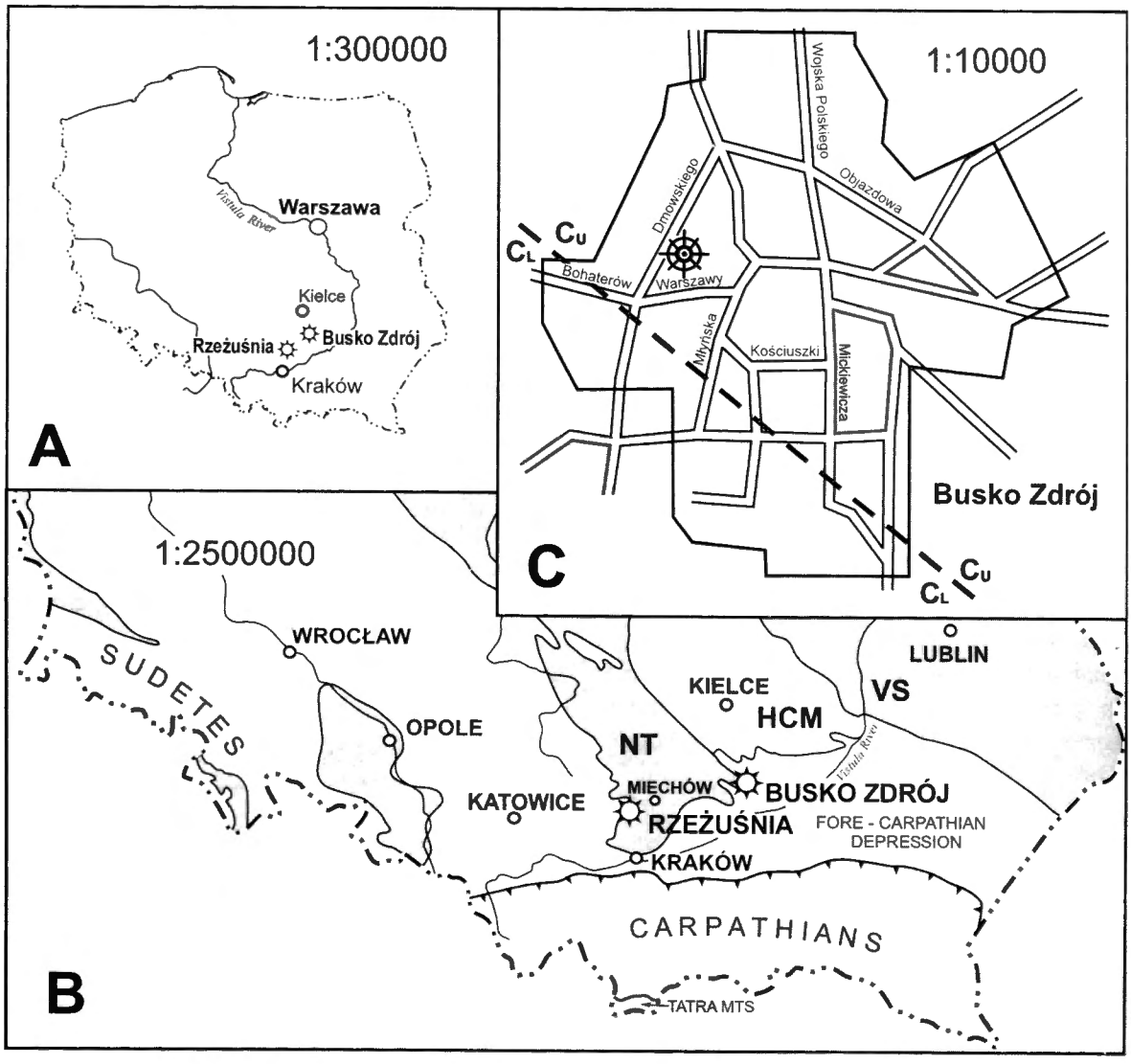

Fig. 3 – Location of the Busko Zdrój and Rzeżuśnia sections on a simplified regional geological map of southern Poland (B), its position in Poland (A) and provenance of inoceramid material from the Busko Zdrój area described herein (C) (modified after MACHALSKI *et al.*, 2004).

composite section was dated as *Galeola basiplana/ Trachyscaphites spiniger* and *Galerites roemeri* zones (as defined in the Lägerdorf-Kronsmoor area, northern Germany) and as *Patagiosites stobaei/Galeola basiplana*, *Galerites vulgaris/Galeola basiplana* and *Galerites vulgaris/Micraster stolleyi* zones (as defined in the Lehrte West Syncline, northern Germany; see MACHALSKI *et al.*, 2004, fig. 2).

2. Rzeżuśnia section

This is exposed at a working quarry near Rzeżuśnia, north of Kraków. The succession comprises *c.* 30 m of opokas with marly layers and siliceous concretions in the middle part (see JAGT *et al.*, 2004, fig. 2), correlated with the *Patagiosites stobaei/Galeola basiplana* and *Galerites vulgaris/Galeola basiplana* zones (JAGT *et al.*, 2004). Inoceramids of the *azerbaydjanensis* group occur in the middle part of the section, characterised by a series of siliceous concretions.

Correlations

Biostratigraphic correlation

Inoceramids from the Busko Zdrój composite section, recorded here for the first time, and those from Rzeżuśnia, enable dating of the '*I.*' *azerbaydjanensis* group with reference to the early late Campanian belemnite/echinoid/ammonite zonal scheme used in northern Germany. Although, on the basis of ammonites, the Busko Zdrój section was dated as equivalent to the *Patagiosites stobaei/Galeola basiplana* to *Galerites vulgaris/Micraster stolleyi* zones (MACHALSKI *et al.*, 2004), it is significant that, out of four exposures of this composite section, '*I.*' *azerbaydjanensis* is known from only one, namely from section 1 (see Fig. 3). The presence in section 1 of the ammonite *Pachydiscus* cf. *subrobustus* SEUNES, 1892 suggests correlation with the Vorhelmer Schichten of Westphalia, which are considered to equate with the *Galerites vulgaris/ Galeola basiplana* Zone (see KAPLAN *et al.*, 1996). Similarly, in the Rzeżuśnia section, dated as equivalent to the *Patagiosites stobaei/Galeola basiplana* and *Galerites vulgaris/Galeola basiplana* zones (JAGT *et al.*, 2004), the '*I.*' *azerbaydjanensis* group is known exclusively from the middle part of the succession. Based on sections in Texas (COBBAN & SCOTT, 1964; COBBAN & KENNEDY, 1993) and on the US Western Interior succession (COBBAN & SCOTT 1964; WALASZCZYK *et al.*, 2001), '*I.*' *azerbaydjanensis* is confined to the lowermost mid-Campanian (in the tripartite US subdivision of the stage) *Baculites obtusus* and *B. maclearni* zones (Fig. 2).

For the purpose of the correlation as proposed herein, the possible maximum range of the '*I.*' *azerbaydjanensis* group in the US (*B. obtusus-B. maclearni* zones) and in Europe (*Patagiosites stobaei/Galeola basiplana* and *Galerites vulgaris/Galeola basiplana* zones) is taken. It must be emphasised, however, that neither in the US Western Interior nor in the European sections is the actual range of the group known. Moreover, records from the Polish sections suggest that its stratigraphical range there may be extremely limited.

Implications for calibrating the European Campanian

Our '*I.*' *azerbaydjanensis*-based trans-Atlantic correlation has important implications for the intercorrelation of the European and the US Western Interior zonal schemes for the mid-Campanian. Correlations of this interval published so far differ quite considerably (compare *e.g.*, HARDENBOL *et al.*, 1998; OGG *et al.*, 2004) and, in the recent discussion on the base of the *Nostoceras polyplocum* Zone (and location of the mid-/upper Campanian boundary in Europe; see NIEBUHR, 2004), differences amount to 3-4 myr.

The base of the European upper Campanian

This is defined as the lower boundary of the *Echinocorys conica/Belemnitella mucronata* Zone, a level regarded to be coeval with the base of the *Baculites obtusus* Zone (see *e.g.*, MCARTHUR *et al.*, 1993; OGG *et al.*, 2004), which defines the base of the mid-Campanian in the US Western Interior ammonite succession (COBBAN, 1994). If we correlate the possible maximum range of '*I.*' *azerbaydjanensis* in North America and in Europe (*B. obtusus-B. mclearni* zones and *stobaei/basiplana-vulgaris/basiplana* zones, respectively), the base of the traditional European upper Campanian correlates with a level below the base of the *B. obtusus* Zone, somewhere within the upper lower Campanian of the US Western Interior succession (Fig. 2)

Campanian calibration and substage division

At the Second Symposium on the Cretaceous Stage Boundaries (Brussels, 1995), it was agreed that the Campanian should be divided into three substages, of approximately equal duration (see HANCOCK & GALE, 1996). A tripartite Campanian subdivision has long been used in the US Western Interior, with the FADs of *B. obtusus* and *Didymoceras nebrascense* defining the bases of the mid- and upper Campanian respectively (see COBBAN, 1994 and references therein), and

with a subequal duration of the substages. There are no good absolute dates available for the European Campanian, and the geochronologic calibration is usually based on biostratigraphic correlation to the North American succession. Ammonites, the key index group for the Upper Cretaceous, cannot be fully used in view of the highly endemic nature of the US Western Interior ammonite faunas. It has recently been demonstrated that inoceramids have a high trans-Atlantic correlation potential (WALASZCZYK *et al.*, 2001, 2002a; WALASZCZYK, 2004) but, until now, in the upper rather than the lower part of the stage (WALASZCZYK *et al.*, 2000b; ODIN & WALASZCZYK, 2003). The biostratigraphic correlation based on the '*I.*' *azerbaydjanensis* group as suggested herein is thus of considerable importance.

For the purpose of the present paper, the most recent radiometric dates by OBRADOVICH (in COBBAN *et al.*, 2006) for the US Western Interior succession are used. In the interval concerned, two direct dates are available: 80.58 ± 0.55 Ma for the lower part of the *B. obtusus* Zone and 75.84 ± 0.26 Ma for the *Baculites scotti* Zone (Fig. 2). The ages for the intermediate zones were obtained by an even subdivision of the resulting interval by the number of zones (albeit the actual durations of particular zones may differ quite considerably – see *e.g.*, MCARTHUR *et al.*, 1993). Accordingly, the calculated radiometric date for the base of the *B. maclearni* Zone is 79.8 Ma, and for the base of the *Baculites asperiformis* Zone, 79.2 Ma. Consequently, the lower and upper boundaries of the maximum potential range of the '*I.*' *azerbaydjanensis* group would be 80.5 and 79.2 Ma, respectively (Fig. 2). As the FAD of *Nostoceras polyplocum* in Texas is assumed to correlate with the *Baculites asperiformis* Zone in the US Western Interior (KENNEDY & COBBAN, 2001), it follows that the base of the *N. polyplocum* Zone in Europe could be as old as 79.2 Ma.

Correlation of the *N. polyplocum* Zone with the US Western Interior succession and its interpretation in terms of radiometric dates has lately led to very divergent views (see NIEBUHR, 2004). As stated above, based on direct correlation of the first occurrences of this ammonite species in Europe and North America (COBBAN in OGG *et al.*, 2004), the base of the European *N. polyplocum* Zone corresponds to the base of the Western Interior *Baculites asperiformis* Zone, *i.e.* quite low in the mid-Campanian (Fig. 2). Very different conclusions were reached, however, by NIEBUHR (2004, 2005), on the basis of analyses of Campanian marl-limestone rhythmites in the Lehrte West Syncline (northern Germany). Assuming the FAD of the belemnite *Belemnitella mucronata* to be at *c.* 80 Ma and calculating (by analysing rhythmicity) the duration of the interval between this level and the first occurrence of *N. polyplocum* (amounting to *c.* 5.3 myr), she dated the FAD of *N. polyplocum* at *c.* 75 Ma (Fig. 2). In radiometric ages, this level would thus correspond to the *Didymoceras nebrascense-Exiteloceras jenneyi* zones interval of the US Western Interior succession (see COBBAN *et al.*, 2006; Fig. 2 here), which represents the lowermost upper Campanian in the North American sense. Consequently, NIEBUHR proposed the FAD of *N. polyplocum* as a good potential marker for the base of the upper Campanian. The occurrences of *N. polyplocum* in Texas, in an interval equivalent to the Western Interior *Baculites asperiformis* Zone, she interpreted as a much earlier appearance of the species in North America. The difference in radiometric ages (79.2 and 75 Ma).between these two correlations is approximately 4 myr.

The correlation suggested herein, as based on records of '*I.*' *azerbaydjanensis*, corroborates previous inoceramid-based conclusions (*e.g.*, WALASZCZYK, 2004) and an isochronous FAD of *N. polyplocum* throughout the entire Euramerican biogeographic region. The *N. polyplocum* Zone would thus be entirely within the middle Campanian, and the mid-/upper Campanian boundary would be above it.

Discussion

The '*Inoceramus*' *azerbaydjanensis* group corroborates previous inoceramid-based correlations between the European and US Western Interior Campanian (WALASZCZYK *et al.*, 2001; WALASZCZYK, 2004), according to which the base of the European *Nostoceras polyplocum* Zone may equate with a level as low as the *Baculites asperiformis* Zone in the US Western Interior scheme. Also, it suggests that *N. polyplocum* appeared approximately synchronously all over the Euramerican biogeographic region. Such a correlation contradicts the rhythmicity-based dates (NIEBUHR, 2004, 2005), tied to the assumed radiometric age of *c.* 80 Ma for the lower/upper Campanian boundary, which suggest an interval of approximately 5 myr between the base of the European upper Campanian and the FAD of *N. polyplocum*. If the US radiometric dates are accepted there would simply be not enough time for that. Although every element of the correlation discussed (*e.g.*, US Western Interior radiometric dates; rhythmicity-based dates, and inoceramid and ammonite synchronous appearances) may be questioned and further work is needed, it

appears for now that the correlation based on the *'I.' azerbaydjanensis* group is the most parsimonious.

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