# EXCURSIONS

A BRIEF INTRODUCTION INTO THE GEOLOGY OF THE HOLY CROSS MOUNTAINS, CENTRAL POLAND

Poland is the geological heart of Europe as it lies at the contact of the main tectonic units of Europe: East European Precambrian Platform, Palaeozoic foldbelt, and Alpine foldbelt of southern Poland. The East European Precambrian Platform and Palaeozoic foldbelt are mostly covered by thick cover of Permian–Mesozoic and Cainozoic deposits of the Southern Permian Basin of Europe.

The Holy Cross Mts. region, uplifted in Miocene times (Kutek & Głazek, 1972), contains Palaeozoic and late Neoproterozoic rocks outcropping beneath the thick Permian–Mesozoic cover. It includes two different tectonostratigraphic domains: Łysogóry to the north and Kielce to the south, separated by major Holy Cross Fault which represents a terrane boundary, between the Łysogóry and Małopolska Blocks (Kroner *et al.*, 2008, with references herein). In the Łysogóry domain, Early Devonian (Pragian) clastics were deposited conformably on late Silurian rocks (Mizerski, 1995, with references herein), and in the Kielce Domain, Early Devonian (Siegenian–Emsian) sediments unconformably overlie folded Lower Palaeozoic basement (including Silurian rocks – Szulczewski, 1995, with references herein). In both domains Emsian clastic sediments are followed by Eifelian shallow-marine sediments and the sedimentary facies became spatially diversified beginning in Givetian times, however, in both domains the sedimentary record indicates progressively deeper-marine conditions from the Late Devonian (when a carbonate platform was formed) to the Visean (when basinal
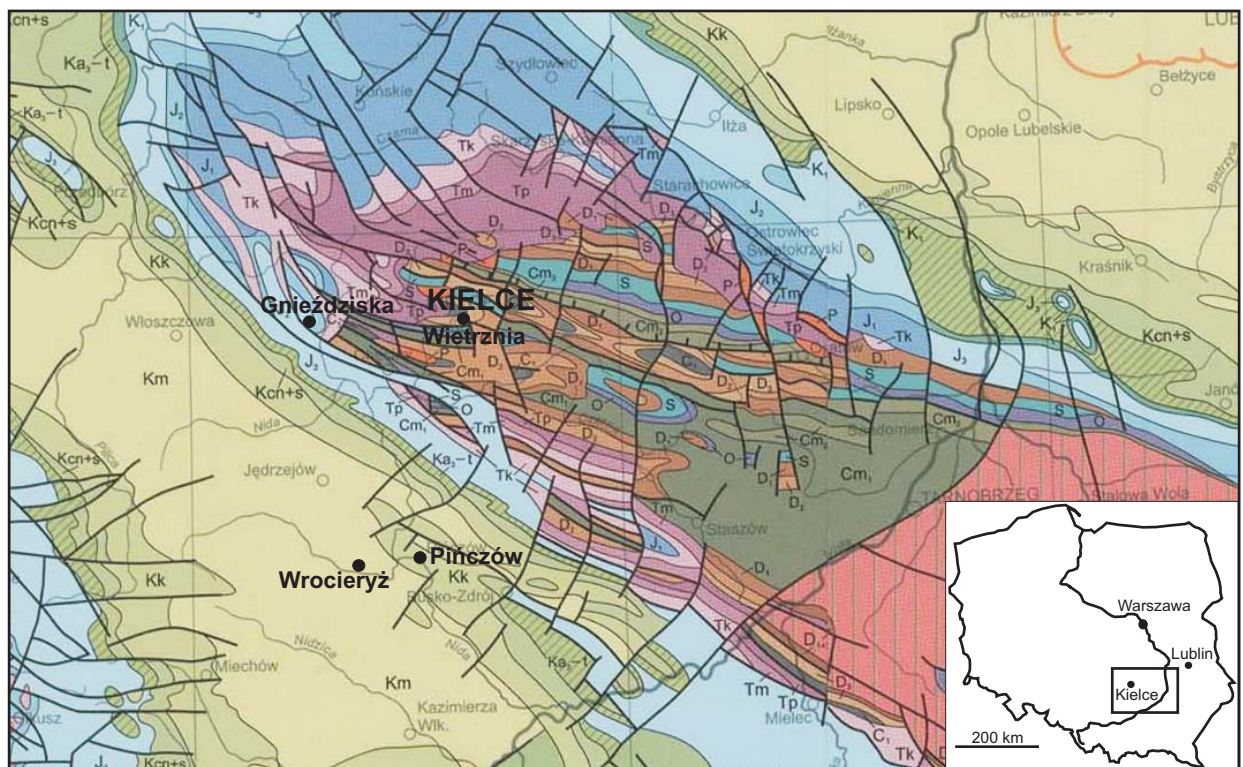
Location map of studied exposures. Geological map of the Holy Cross Mountains and adjacent areas without Cainozoic cover (after Dadlez *et al*., 2000)

and clastic deposits originated following the disintegration and submergence of the carbonate platform). The youngest rocks involved in the Variscan folding are of Visean age; the folding itself developed in a transpressional regime during the Late Carboniferous (Kroner *et al.*, 2008).

The Permian–Cretaceous tectonic evolution of the Holy Cross Mts. region was, as in the entire Central Europe, the transition from a period of thermally related subsidence to one of active rifting followed by compression (Scheck-Wenderoth *et al.*, 2008), and it was controlled by the Teisseyre–Tornquist Zone. During the Late Permian it was the marginal part of the basin, but already during the Early Triassic the depositional area was considerably widened. Intensive subsidence of the axial part of the Polish Basin lasted until the onset of inversion activity which may have commenced as early as the Late Turonian, although in the Nida Trough basement fault zones were first inverted in Early Palaeogene times (Scheck-Wenderoth *et al.*, 2008, p. 1024).

During the Middle Miocene, the region located south of the Holy Cross Mts. constituted a marginal part of the Carpathian Foredeep Basin, where mostly shallow-marine limestones and siliciclastic deposits of the Badenian and Sarmatian were formed, as well as characteristic evaporitic deposits (e.g. famous gypsum deposits of the Nida River Valley) (Peryt & Piwocki, 2004, with references herein).

The highest peak in the Holy Cross Mts. – Łysogóry (which rise up to 300 m above surrounding plains) – belongs to the large Variscan structure – Łysogóry Anticline – asymmetric fold striking WNW-ESE and overturned (overthrust) to the south. The Łysogóry Range is famous because of block fields composed of big angular blocks of quartzitic sandstones, which cover the slopes. They developed in periglacial environment of the Late Pleistocene glacials, mainly last one (Vistulian, Würm), due to mechanical weathering and subsequent solifluction and pluvial erosion.

<div style="text-align: right">Danuta Peryt</div>

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STOP 1

The Early/Middle Frasnian boundary interval and biogeochemical signals of the *punctata* Zone Isotopic Event at Wietrznia quarry (Holy Cross Mountains, Central Poland)

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The abandoned quarry Wietrznia-I situated three kilometers southeast of Kielce city centre, on the Wietrznia Hill, within the southern limb of the Kielce Syncline (see map of p. 85; Figs 1, 2).
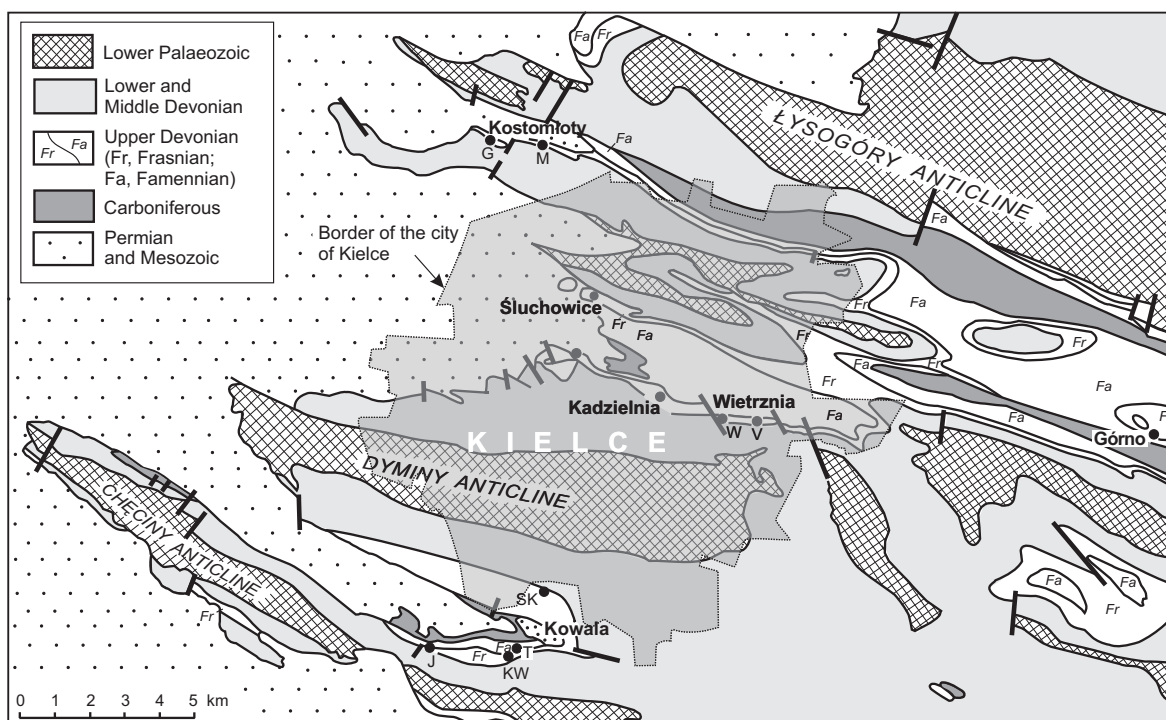

Fig. 1. Location map of studied Early to Middle Frasnian exposures in the Holy Cross Mountains (based on Szulczewski 1971: fig. 1; from Pisarzowska *et al.*, 2006).

Geological setting: The inactive Wietrznia quarry, preserved as the Zbigniew Rubinowski Reserve, is located in the eastern Kadzielnia Chain, in the southern part of Kielce (Fig. 2). The outcrop forms three quarries: Wietrznia (Wietrznia-I in Szulczewski, 1971), Międzygórz and Eastern Międzygórz (designated after Szulczewski, 1971 as Wietrznia-II).

Lithology: In exposed Frasnian limestones, Szulczewski (1971) distinguished five lithological units (A through E). Lithological unit A consists of thin-bedded detrital limestones intercalated with *Amphipora*-bearing marly intercalations (Racki & Bultynck, 1993) as well as thick-bedded to almost massive biorudites (set B) including tabular and rugose corals, stromatoporoids, brachiopods, and crinoid debris belonging to the lower Wietrznia Beds (Szulczewski, 1971; Racki *et al.*, 1993).

The middle to upper Wietrznia beds were studied in detail by Racki & Bultynck (1993), Racki *et al.* (1993), Pisarzowska *et al.* (2006) and Vierek (2007a, b). Lithological units C and D are very well exposed in sections WId-W and WIe (Fig. 3) located in the northern part of the Wietrznia-I quarry. Units C and D exhibit a distinct lateral variation traced over a distance of ca. 100 m. In the proximal WId-W section, Unit C comprises thin beds of knobby and/or wavy-bedded bituminous micrites intercalated with
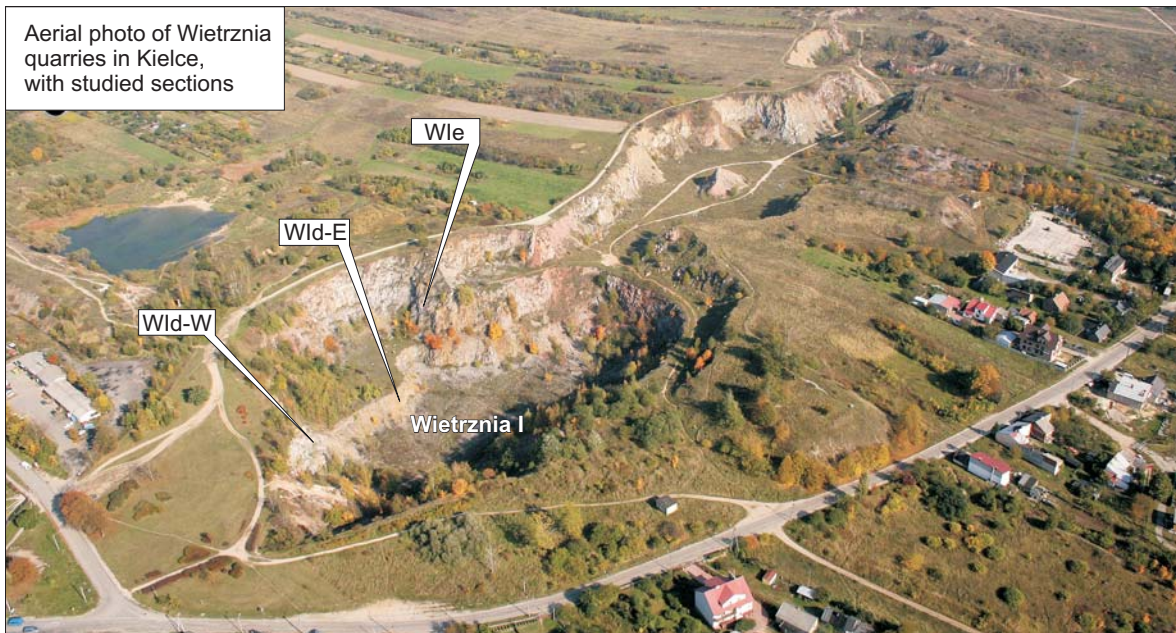
Fig. 2. Aerial photo of Wietrznia quarries in Kielce, with studied sections (from Baliński *et al.*, 2006).

marly shales. The second dominant lithology are thicker layers of biorudites with erosional bottom surfaces, including flat-pebble conglomerates. Successions of alternating fossil-impoverished very thin-bedded micrites and marly shales, form the uppermost part of Unit C (the Śluchowice Marly Level; *sensu* Pisarzowska *et al.*, 2006). At the distal WIe section, Unit C comprises rhythmically stratified, platy bituminous calcilutites and marly shale as well as thin layers of intraclastic biorudites.

At the WId-W section Unit D is distinguished by the appearance of thick-bedded calcirudites with redeposited reef-builders and renalcid-*Stachyodes* buildups. Alternating thin-bedded, poorly fossiliferous micrites and shales with styliolinids occur as subordinate partings. Unit D splits eastward into D_1 and D_2 subunits at the WIe section. The thin-bedded subunit D_1 is a transitional unit between Units C and D, as defined by Szulczewski (1971), while the thick layers of subunit D_2 corresponds well with Unit D of the WId-W section. The subunit D_1 is characterised by the absence of fossils except broken reef-builders and styliolinids in a few horizons. Unit D_2 comprises thick-bedded massive detrital limestones with many intraclasts and fragmented reef-builders, brachiopods, crinoids and also renalcid thrombolites.

The middle Wietrznia beds were episodically deposited on the northern, storm-affected flank of the Kielce carbonate platform. They comprise both coarse-grained, proximal tempestite layers (i.e., mostly episodic, storm-generated sediment-gravity flows from the Dyminy Reef margin) and micritic-marly (basinal) sediments (see the Transitional Facies of Szulczewski, 1971; Vierek, 2007a); the latter "background" lithofacies represents distal muddy tempestites (Vierek, 2007b). The region was affected by synsedimentary tectonic activity (Racki & Narkiewicz, 2000), recorded in a drastically different, locally somewhat condensed stratigraphic succession of the Early–Middle Frasnian (= *transitans–punctata* conodont Zones; E–MF; Ziegler & Sandberg, 2001) boundary beds in adjacent tectonic blocks recognised to the east, in the middle part of the Wierznia exposure (see Szulczewski, 1989; Lamarche *et al.*, 2003). Middle Frasnian deposition of the upper Wietrznia beds is marked by talus-like sediments in the upper foreslope setting, locally with a microbial and/or *Stachyodes*-dominated buildups.

Early–Middle Frasnian boundary

The Wietrznia sections are the most representative of the Early–Middle Frasnian interval in the Holy Cross Mountains. Due to the high-resolution conodont and isotopic study (inorganic and organic carbon isotope, Sr-isotope and O-isotope from biotic apatite; Fig. 4), supplemented by palaeontological, geochemical, sedimentological and magnetosusceptability works (Baliński, 2006; Głuchowski *et al.*, 2006; Pisarzowska *et al.*, 2006; Sobstel *et al.*, 2006; Vierek, 2007a; Nawrocki *et al.*, 2008) the Wietrznia Ie section was recommended as an Early–Middle Frasnian stratotype. The correlations of the Wietrznia sec-
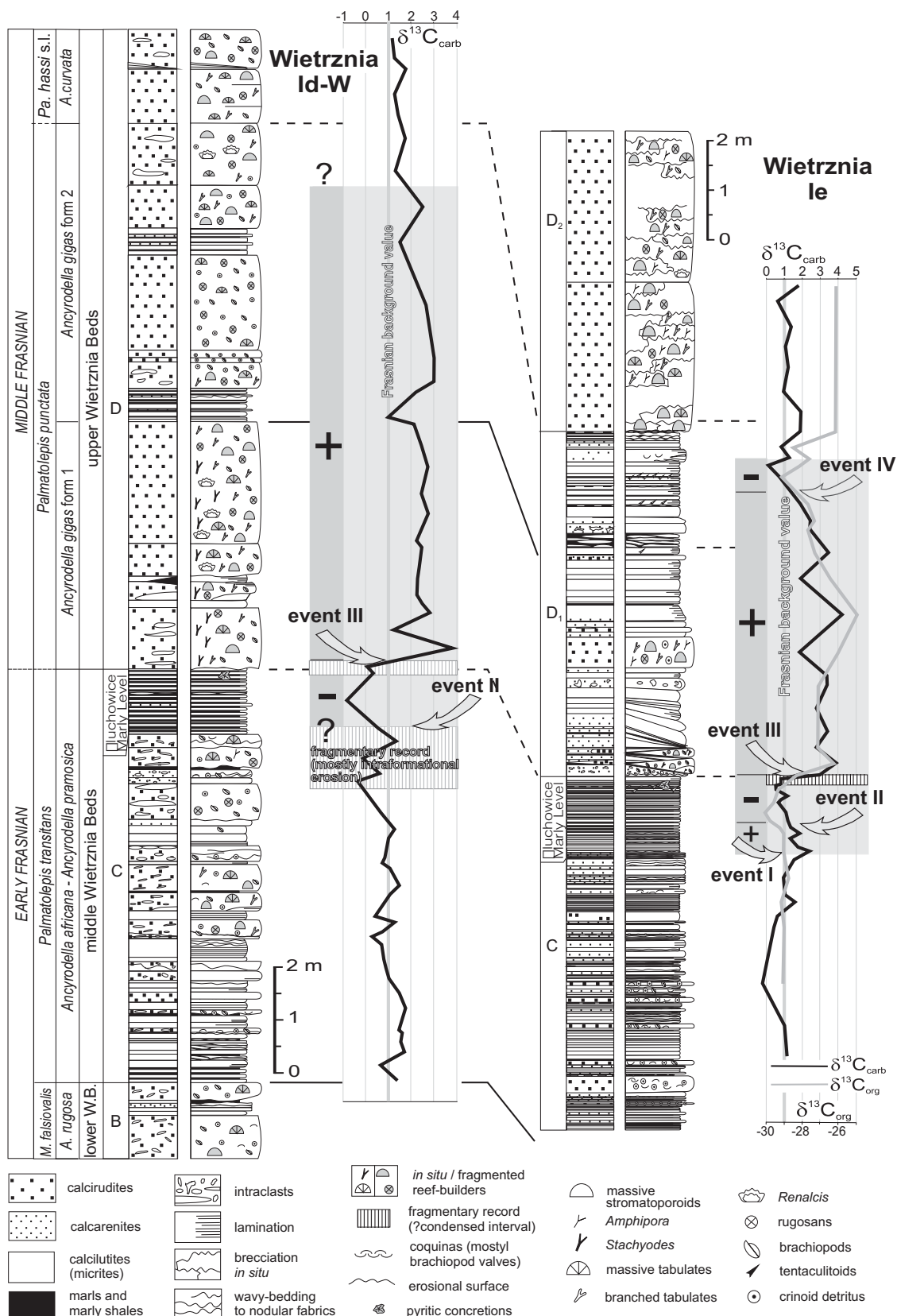
Fig. 3. Lithology, conodont biostratigraphy and stable carbon isotope geochemistry (both carbonates $\delta^{13}C_{carb}$ and organic matter $\delta^{13}C_{org}$; the results in per mil deviation from the Vienna Peedee belemnite standard, V-PDB) for the Lower to Middle Frasnian strata in the Wietrznia-Ie and Wietrznia-Id-W sections in Kielce. The geochemical anomaly interval is marked as grey interval, subdivided in positive (+) and negative (-) parts determined by four isotopic events I–IV (based on Pisarzowska *et al.*, 2006: figs 8–9). Abbreviations: *A.*, *Ancyrodella*; *M.*, *Mesotaxis*; *Pa.*, *Palmatolepis*; *Po.*, *Polygnathus*; W.B., Wietrznia Beds; s.l., *sensu lato*.
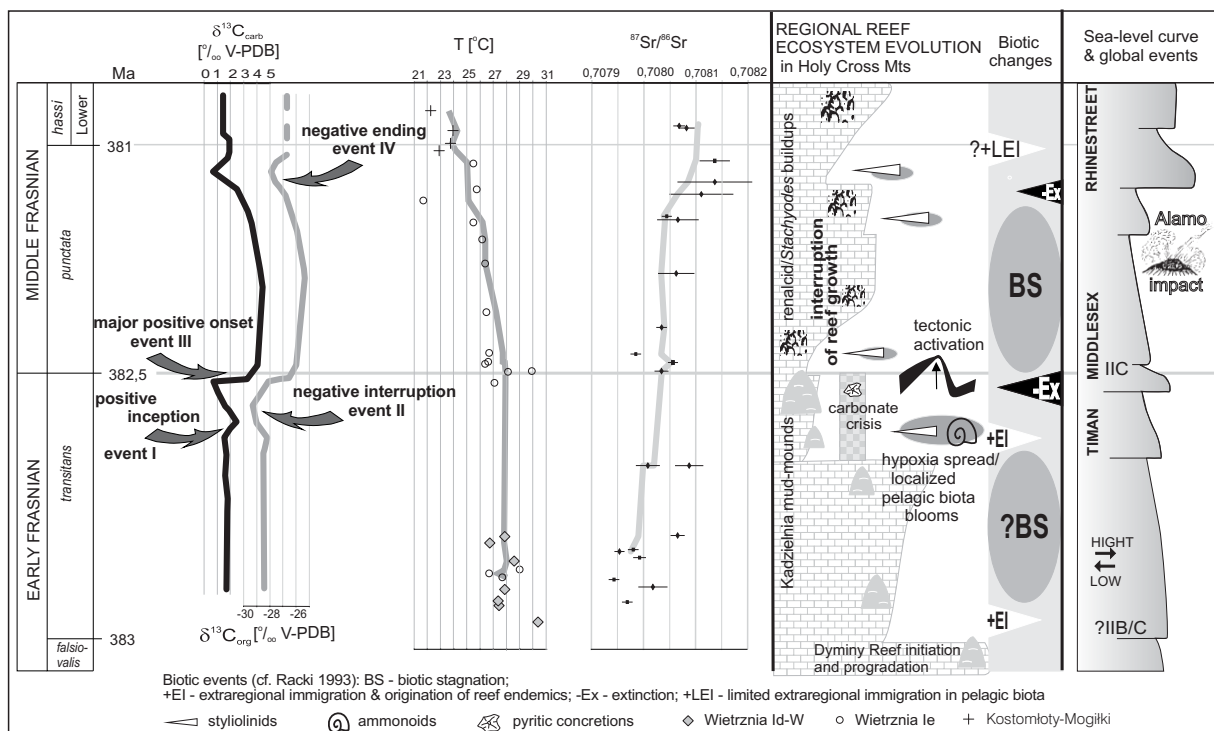
Fig. 4. Compilation of biogeochemical events, temperature and sea-level changes as well as conodont biostratigraphy of the Holy Cross Mountains across the Early–Middle Frasnian interval (based on Pisarzowska *et al.*, 2006: fig. 18). The regional geobiological history follows mainly conodont diversity dynamics and frequency patterns (Sobstel *et al.*, 2006); time after Kaufmann (2006).

tions with the standard conodont biozonation of Ziegler & Sandberg (1990) is difficult because of the absence or delay of index palmatolepid species, i.e. *Palmatolepis transitans*, *Pa. punctata* and *Pa. hassi* (Racki & Bultynck, 1993; Sobstel *et al.*, 2006). Polygnathid and polygnathid-ancyrodellid faunas represent typical conodont association from the Early–Middle Frasnian interval. Therefore, four ancyrodellid levels are distinguished across the *transitans–hassi* interval in the Holy Cross Mountains: *Ancyrodella africana–A. pramosica* belonging to the *transitans* biozone, *A. gigas* form 1 and *A. gigas* form 2 assigned to the *punctata* Zone and *A. curvata* (early form) in the earliest *hassi* Zone (Fig. 3). The base of the *punctata* Zone (Montagne Noire Zone 5; Klapper, 1988) determines the first appearance of *A. gigas*, whilst the position of the *punctata–hassi* zonal boundary is tied with the entry of *A. curvata* (for details see Pisarzowska *et al.*, 2006 and Sobstel *et al.*, 2006). The palynofacies study at the Wietrznia sections is impossible due to too high thermal maturation (Marynowski *et al.*, 2008).

Biogeochemical perturbation in the C-cycle across the E–MF transition

The high-resolution carbon isotope data of the Early to Middle Frasnian transition reveal the large scale perturbation in carbon cycling in the South Polish part of Laurussian shelf (Pisarzowska *et al.*, 2006; Yans *et al.*, 2006). This global *punctata* Zone Isotopic Event, lasting ca. 0.8 Ma (see Kauffman, 2006), is subdivided into two positive-to-negative excursions (Pisarzowska *et al.*, 2006), encompassing four isotopic events, perfectly recorded in the Wietrznia-Ie section (Figs 3–4). Comparison of biogeochemical signals and stratigraphical dates from Wietrznia as well as the sea-level fluctuations (Fig. 4) leads to the following conclusions:

The δ^{13}C values obtained through most of the *Pa. transitans* Zone show the Frasnian background values, which average ca. 1‰ (Yans *et al.*, 2006).

The δ^{13}C$_{carb}$ record indicates a slight positive peak about 2‰ visible across the *A. africana–A. pramosica* level (inception event I *sensu* Racki *et al.*, 2004 and Pisarzowska *et al.*, 2006) and coincides with the Timan Event of Becker & House (1997). This excursion correlates with the deepening and disappearance of shallow-water (Baliński, 2006; Głuchowski *et al.*, 2006) and reef-related (Sobstel *et al.*, 2006) faunal assemblages in aid of pelagic biota (Jagt-Yazykova *et al.*, 2006).

The both $\delta^{13}C_{carb}$ and $\delta^{13}C_{org}$ data suggest a negative excursions by ca. 2‰ (with $\delta^{13}C_{carb}$ as low as nearly -1‰ at Wietrznia-Id) primarily in the latest part of the *Pa. transitans* Zone (interruption event II). This shift noticeably coincides with the abrupt disappearance of the macrofauna and microfauna except of styliolinids and lingulid brachiopods (Baliński, 2006; Głuchowski *et al.*, 2006; Pisarzowska *et al.*, 2006) as well as with the crisis of shallow water carbonate production (Śluchowice Marly Level).

The overall pattern represented by $\delta^{13}C_{carb}$ and $\delta^{13}C_{org}$ values shows an abrupt, distinctive positive excursion (major onset event III) of about 4–5‰ through the *punctata* Zone. The positive shift in $\delta^{13}C$ linked with the rapid and extensive transgressive episode (Cycle IIc of Johnson *et al.*, 1985 and the Middlesex deepening in eastern North America; Ziegler & Sandberg, 2001) and coincides with the last appearance some reef-related brachiopod (Szulczewski & Racki, 1981; Baliński, 2006), gastropod (Krawczyński, 2002, 2006) and conodont (Sobstel *et al.*, 2006) species.

This isotopic "plateau" is followed in the latest part of the *Pa. punctata* Zone (*A. gigas* form 2 level) by a return to negative $\delta^{13}C$ values (the ending step IV), and then to background or even higher values in the *Pa. hassi* Zone. Two vast transgressions in the late *punctata* are recorded by styliolinid-rich marly litofacies (initiation of the multiphase Rhinestreet Event; House, 2002). The deepening pulses resulted in return to off-shore conditions and consequently to rebuilding and/or replacement of conodont assemblages (Sobstel *et al.*, 2006).

Block movements are recorded at the Wietrznia sections by rapid lateral thickness and fore-reef facies changes (Szulczewski, 1989; Dzik, 2002), as well as by an abrupt increase of carbonate mud and fine detritus depositional rates (Vierek, 2007a). In addition, wedge-shaped lithologies in the basal part of the *Pa. punctata* Zone are a signature of mass movements (?sliding) probably promoted by faulting and/or seismic shocks. The tectonic factors certainly modified benthic habitats in a local scale, influencing morphological differentiation and thus circulation patterns particularly over the northern slope of Dyminy Reef. More importantly, this activity was responsible for masking the IIc deepening pulse in most of the Holy Cross localities and for episodic development only of anoxia during the Middlesex sea-level rise.

The late *Pa. transitans* – early *Pa. punctata* time interval is not considered as a time of significant faunal turnover (see Baliński, 2006; Głuchowski *et al.*, 2006; Sobstel *et al.*, 2006; Yans *et al.*, 2006). Moreover, the *Pa. punctata* Zone is regarded as representing optimum environmental conditions for development of the marine biota, at least for conodonts and phytoplankton (Zhuravlev *et al.*, 2006; Marynowski *et al.*, 2008). However, only the stress-resistant conodonts, which went through the Early–Middle Frasnian perturbational interval, bloomed during the long-term stabilization phase in the early Middle Frasnian. The Early–Middle Frasnian conodont biodiversity crisis has definitely a stepwise nature, alongside with biogeochemical cycling changes, as refined by Sobstel *et al.* (2006), and may be partly correlated with the obviously more fragmentary recognized macrofaunal changes.

The long-lasting positive excursion in $\delta^{13}C$ is paired with enhanced bioproductivity and organic matter burial in anoxic conditions reaching the photic zone (Marynowski *et al.*, 2008), which suggests fluctuations of the chemocline during the early to middle Frasnian intermittently rising sea-level (basal IIc transgression; Timan and Middlesex global events). High rates of continental weathering around the *transitans–punctata* boundary have been confirmed by an increase in the $^{87}Sr/^{86}Sr$ isotopic ratio (John *et al.*, 2008; Fig. 4), an increase in detrital quartz content, and fluctuation of the magnetic susceptibility record (Nawrocki *et al.*, 2008). The oxygen isotope ratios based on analysis of conodont apatite from the coeval E–MF succession suggest a climatic cooling by 5°C over this time span (Fig. 4). Such a cooling trend may have been promoted by the accelerated burial of organic matter.

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STOP 2

Badenian (Middle Miocene) Foraminifera from organodetrital limestones of the Pińczów quarry (the southern part of the Holy Cross Mountains)

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The Pińczów quarry is located within the Wójcza and Pińczów Range (in the southern part of the Holy Cross Mountains) (see map of p. 85) and the Badenian organodetrital limestone deposits, called the Pińczów Limestone, are exposed there (Fig. 1).

The limestone deposit is at present exploited and it is formed by light cream bedded limestones 18 m thick (Bugajska-Pająk, 1974). Its bottom part, which lies upon the Cretaceous marls, is composed of fine-grained organodetrital limestone. Higher up in the section medium-grained deposits occur, and then coarse-grained deposits appear (Kozłowski, *et al*., 1971) (Fig. 1).

Fig. 1. The quarry in Pińczów with three Badenian organodetrital limestone types; from the bottom upwards: fine-grained, medium-grained, coarse-grained limestones (Photo by A. Chruszcz).

The organodetrital limestone consists of well-preserved fossils and limestone fragments cemented by calcareous material with argillaceous particles (Oterman, 1980). In the Pińczów quarry, a rich and diverse assemblage of fossil micro- and macrofauna is observed. Among the microfossils, Rhodophyta are well known (Studencki, 1988). Foraminifera have not been studied prior to the initial study by Chruszcz (2002). Vertebrates are represented by *Scorpoena ensiger* Jordan & Gilbert, the teleostean fish (Jerzmańska, 1958) and a cetacean species *Pinocetus polonicus* (Czyżewska & Ryziewicz, 1976). In addition, other groups became subject to study: brachiopods (Studencki, 1987), bivalves (Studencka & Studencki, 1988), and echinoids (Mączyńska, 1993).

Facies types of organodetrital limestone

In the area of the Wójcza and Pińczów Range, Studencki (1988) distinguished four facies types of the Pińczów Limestone: rhodolith pavement facies, branching algae facies, algal bryozoan facies and organodetrital facies, on the basis of different forms of red algae growth.

In Pińczów, which is located in the western part of the Wójcza and Pińczów Range (Fig. 2), Studencki (1988) distinguished two kinds of facies: an algal-bryozoan facies and an organodetrital facies.

In the algal-bryozoan facies, apart from the predominant rhodophyta and bryozoans, larger foraminifera, i.e., *Amphistegina mamilla* (Fichtel & Moll) and *Heterostegina costata* d'Orbigny ap-

pear. Those components of the facies occur in various proportions, they are most often mixed with one another, however, there are local tendencies of gathering only one of the components. Rhodophyta appear at all stages of growth: rhodoliths, crusts, branching thalli. They are represented by *Archaeolitamnium keenai* Howe, *"Lithothamnium" ramosissimum* (Gümbel), *Mesophyllum ingestum* Conti, *M. laffittei* Lemoine, *M. rigidum* Mastrorilli, *Litophyllum prelichenoides* Lemoine, *"Lithothamnium" praefruticulosum* Maslov and *Lithophyllum albaense* Lemoine.

According to Studencki (1988), "the typical features of the algal-bryozan facies are the lack of bioclasts sorting of, their chaotic arrangement and broken, non-rounded edges of fragmented grains. Locally observed horizontal textures result from the arrangement of flat heterosteginid tests and crustose algal thalli". The fauna in the facies is abundant and diversified; there occur corals, polichaetes, brachiopods, bivalves, gastropods, cirripedes, crustaceans, and echinoids.

In the organodetrital facies, Studencki (1988) and then Kuleta (2000) recorded fossils whose skeletons are preserved in fragments: rhodophyta, bryozoans, larger foraminifera, as well as other organisms, which occur in the algal-bryozoan facies. According to Kuleta (2000), the main components of the fine-grained organodetrital limestone are the fine bioclasts of foraminifera (from 0.1 mm to 0.3 mm across, either fragmented or complete tests) as well as small fragments of larger foraminifera (*Heterostegina*) and micritic irregular fragments of lithothamnia that are from 0.05 mm to 0.2 mm across. The main components constitute from 75% to 80%, and the secondary and accessory components (15%) are larger foraminifera (*Heterostegina*) – either complete or crushed tests (4–5 mm), fragments of bryozoans, tubes of Serpula and small lithothamnia. The grains of quartz, which are poorly rounded, isometric and slightly elongated form the terrigeneous admixture (from 2 to 3%).

Fig. 2. Geological column of the Pińczów limestone types: AB – algal-bryozoan facies, D – organodetrital facies (Studencki, 1988).

The cement (approximately 5%) of the contact and pore type is formed by carbonate micrite with an admixture of black organic matter. All components of the rock, i.e., allogenic – bioclasts and the terrigeneous – quartz are homogenously mixed and their arrangement is random, although rarely it follows the direction of the elongated components. The low porosity (from 2 to 5%) has an intragranular nature (Fig. 3A.I, A.II).

In the medium-grained type of limestone, the main components (75–80%) are larger foraminifera (*Heterostegina*) preserved as the complete forms or their final detritus as well as the fragments of oval and elongated rhodoliths (3 mm in size). The secondary and accessory components (approximately 15%) are small foraminifera, of various preservation, small fragments of large foraminifera, single specimens of *Amphistegina* and rare fragments of Serpula and possibly bryozoans. The cement (approximately 5%) is calcitic micrite of contact and pore types, with a small admixture of black organic matter. The porosity of the rock (2–3%) is mainly intragranular and occurs within both foraminifera and lithothamnia (Fig. 3B).

In the coarse-grained limestone, the main components (approximately 85%) are fragments of lithothamnian rhodoliths, which are most often irregular in shape, and bryozoans and larger foraminifer *Amphistegina*. The secondary and accessory components (approximately 5%) are fine detritus, fragments of larger foraminifera and bryozoans as well as the small foraminifera. The cement (approximately 5%) is calcitic, micritic. The porosity range is 10–15% (Fig. 3C).
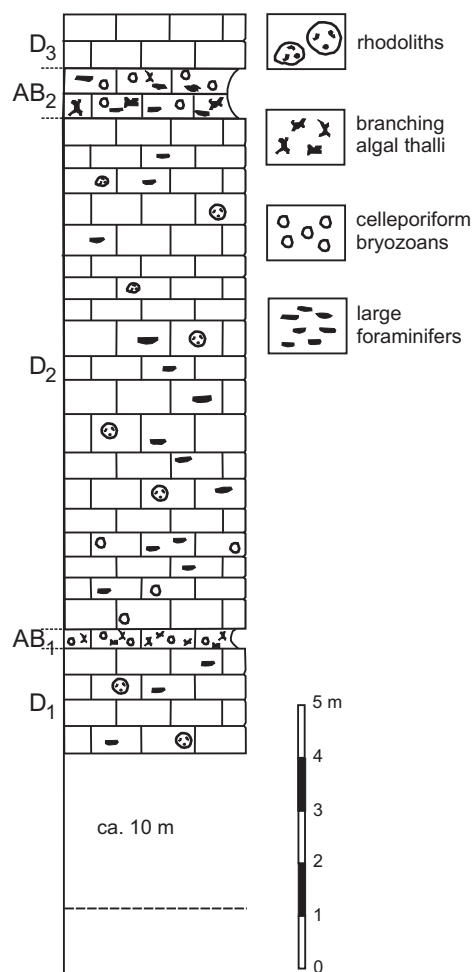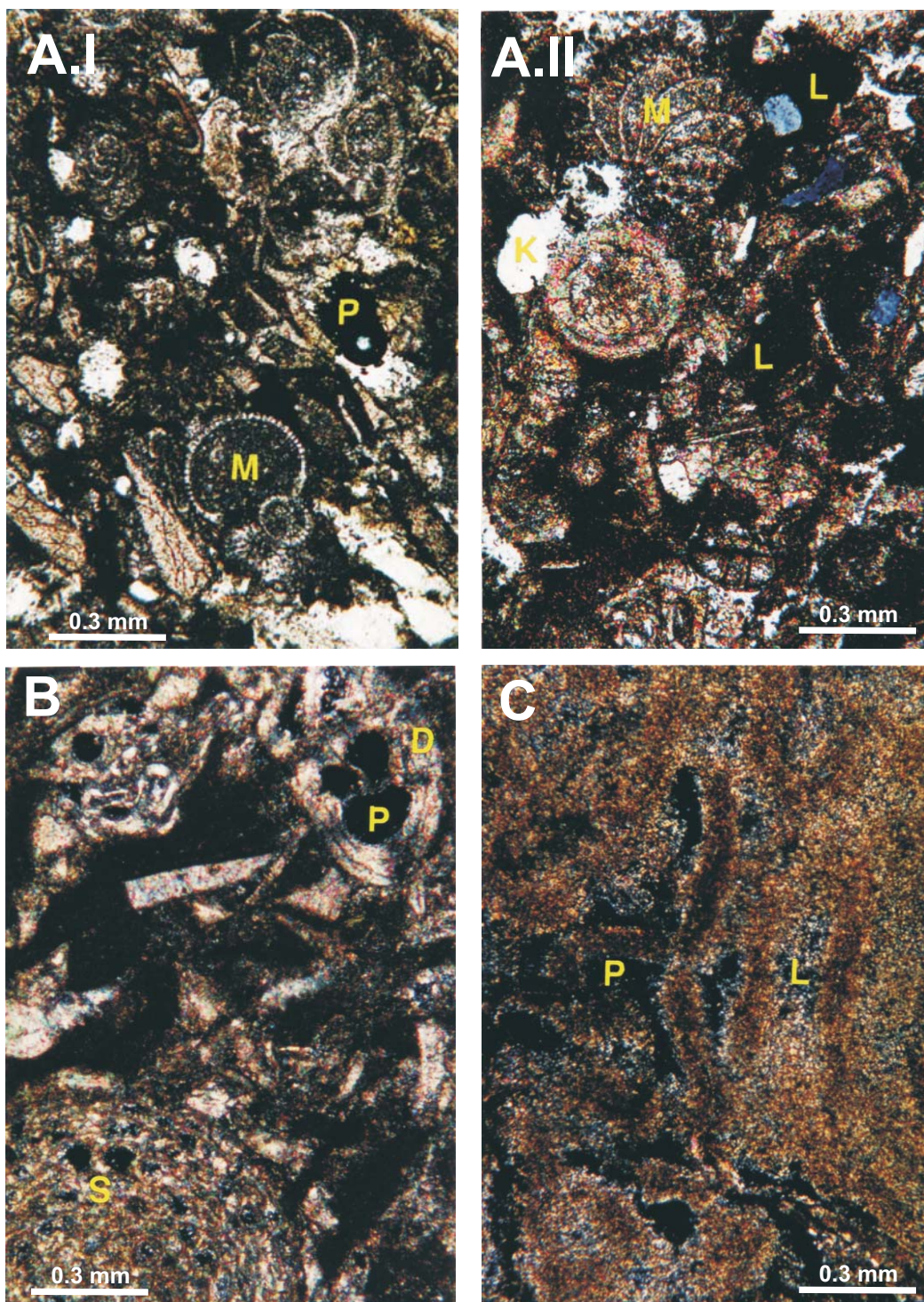
Fig. 3. The grain structure of organodetrital limestone types: fine-grained (A), medium-grained (B), and coarse-grained (C) occurring in the Pińczów quarry (Kuleta, 2000). A.I. Fine-grained organodetrital limestone: M – small foraminifera (*Globigerina*), P – intragranular pores. A.II. Fine-grained organodetrital limestone: M – foraminifera (*Elphidium*), P – intragranular pores, K – quartz, L – fragments of lithothamnia. B. Medium-grained organodetrital limestone: D – larger foraminifera, L – lithothamnia, S – bryozoa, P – pores. C. Coarse-grained organodetrital limestone: P – pores, L – lithothamnia.

Foraminifera of organodetrital limestone

The foraminiferal assemblage in the organodetrital limestone is very rich and shows significant taxonomical variation. The occurrence of 30 families represented by 84 species was recorded there (Table 1).

In the fine-grained limestone type, there are 66 species representing 20 families: *Cibicididae* (15%), *Elphidiidae* (14%), and *Nonionidae* (12%) are the most common (Fig. 4A). These families show the greatest variation in number of species and are characterised by the largest numbers of specimens. The greatest species diversity is observed in the youngest part of the succession (40 species); in the older part of the succession, the number is smaller (24–38 species). Species such as *Cibicides ungerianus*, *C. pseudoungerianus, Lobatula lobatula*, *Elphidium macellum*, *E. fichtelianum*, and *Nonion scaphum* appeared in the greatest number.

Table 1. Foraminiferal species occurring in fine-grained, medium-grained and coarse-grained organodetrital limestones in the Pińczów quarry (foraminiferal species were identified largely following Odrzywolska-Bieńkowa & Olszewska, 1996)

No.	Species	Fine-grained	Medium-grained	Coarse-grained
1	*Saccorhiza ramosa* Brady	–	R	R
2	*Spiroplectammina scaligera* Łuczkowska	–	R	R
3	*Quinqueloculina badenensis* d'Orbigny	–	R	R
4	*Borelis melo* Fichtel & Moll	–	–	R
5	*Spirolina pusilla* Schwager	R	–	R
6	*Amphicoryna scalaroides* ten Dam & Reinhold	R	R	R
7	*Lenticulina calcar* (Linne)	–	R	F
8	*Lenticulina echinata* (d'Orbigny)	–	–	R
9	*Globulina gibba* (d'Orbigny)	F	F	F
10	*Guttulina austriaca* d'Orbigny	–	–	R
11	*Glandulina laevigata* d'Orbigny	–	R	R
12	*Globorotalia pseudocontinuosa* Jenkins	–	–	R
13	*Paragloborotalia mayeri* (Cushman & Ellisar)	–	–	R
14	*Globigerina bulloides* d'Orbigny	R	R	R
15	*Globigerina dutertrei* d'Orbigny	R	R	R
16	*Globigerina* sp.	R	R	R
17	*Globigerinoides trilobus* (Reuss)	R	R	R
18	*Globigerinoides* sp.	–	R	R
19	*Candorbulina suturalis* (Brönnimann)	–	R	R
20	*Bolivina dilatata* Reuss	R	R	R
21	*Bolivina polonica* Bieda	R	R	R
22	*Bolivina* sp.	R	R	R
23	*Brizalina antiqua* (d'Orbigny)	R	R	R
24	*Brizalina hyalina* (Śmigielska)	R	R	R
25	*Cassidulina punctata* Reuss	R	R	R
26	*Bulimina gibba* Fornasini	R	R	R
27	*Bulimina buchiana* d'Orbigny	R	R	R
28	*Bulimina pupoides* d'Orbigny	R	R	R
29	*Bulimina* sp.	R	R	R
30	*Uvigerina tenuistriata* (Reuss)	R	R	R
31	*Uvigerina howei* Garret	R	R	R
32	*Uvigerina brunnesis* Karrer	R	R	R
33	*Uvigerina pygmoides* Papp & Turnovsky	R	R	R
34	*Uvigerina* sp.	R	R	R
35	*Reussella spinulosa* (Reuss)	–	R	R
36	*Coryphostoma sinuosa* (Cushman)	R	–	R
37	*Coryphostoma digitalis* (d'Orbigny)	R	–	R

38	*Valvulineria marmaroschensis* Pishvanowa	R	–	R
39	*Valvulineria complanata* (d'Orbigny)	–	–	R
40	*Eponides nanus* (Reuss)	R	R	R
41	*Eponides bradyi* (Trauth)	R	R	R
42	*Eponides praecinctus* (Karrer)	R	R	R
43	*Eponides* sp.	R	R	R
44	*Discorbis mira* (Cushman)	R	R	R
45	*Discorbis golbularis* (d'Orbigny)	R	R	R
46	*Discorbis* sp.	R	R	R
47	*Sphaeroidina bulloides* d'Orbigny	–	R	R
48	*Planulina ariminenzis* d'Orbigny	–	R	R
49	*Cibicides ungerianus* (d'Orbigny)	A	C	A
50	*Cibicides ungerianus* var. *ornatus* (Cushman)	C	F	R
51	*Cibicides ungerianus* var. *laevis* (Rzehak)	R	R	R
52	*Cibicides pseudoungerianus* (Cushman)	A	C	A
53	*Cibicides austriacus* (d'Orbigny)	R	R	R
54	*Cibicides boueanus* (d'Orbigny)	C	F	F
55	*Cibicides letkesiensis* (Franzenau)	R	R	R
56	*Cibicides* sp.	R	R	R
57	*Lobatula lobatula* (Walker & Jacob)	A	A	C
58	*Lobatula lobatula* var. *ornata* (Cushman)	R	R	R
59	*Sphaerogipsina globulus* (Reuss)	–	R	R
60	*Asterigerinata planorbis* (d'Orbigny)	F	F	F
61	*Amphistegina lessoni* (d'Orbigny)	C	C	A
62	*Amphistegina hauerina* (d'Orbigny)	R	F	A
63	*Amphistegina mamilla* (Fichtel & Moll)	F	C	A
64	*Nonion scapha* (Fichtel et Moll)	A	F	F
65	*Nonion elongatum* (d'Orbigny)	A	F	F
66	*Nonion boueanum* (d'Orbigny)	F	R	R
67	*Nonion depressulum* (Walker & Jacob)	F	R	R
68	*Nonion commune* (d'Orbigny)	C	F	R
69	*Nonion granosum* (d'Orbigny)	R	R	R
70	*Nonion* sp.	R	R	R
71	*Melonis pompilioides* (Fichtel & Moll)	R	R	R
72	*Heterolepa dutemplei* (d'Orbigny)	F	F	R
73	*Ammonia beccari* (Linne)	F	F	F
74	*Ammonia supera* Belford	–	R	R
75	*Elphidium crispum* (Linné)	C	A	A
76	*Elphidium macellum* (Fichtel & Moll)	A	C	A
77	*Elphidium fichtelianum* (d'Orbigny)	A	A	A
78	*Elphidium listeri* (d'Orbigny)	R	F	F
79	*Elphidium advenum* (Cushman)	R	R	F
80	*Elphidium antoninum* (d'Orbigny)	R	R	R
81	*Elphidium flexuosum* (d'Orbigny)	C	F	C
82	*Elphidium lessoni* (d'Orbigny)	R	F	R
83	*Elphidium* sp.	R	R	R
84	*Heterostegina costata* d'Orbigny	C	A	C

Other microfauna	Fine-grained	Medium-grained	Coarse-grained
Sponge spicules (*Porifera*)	R	R	R
Tubes of *Annelida*	F	F	F
Bryozoa	C	A	A
Amphineura	R	R	R
Bivalvia	F	F	F
Gastropoda	F	F	F
Ostracoda	C	C	C
Holothuria	R	R	R
Spines and fragments of plates of *Echinoidea*	R	R	R

Glossary: R – rare (1–5 specimens), F – few (6–10 specimens), C – common (10–15 specimens), A – abundant (more than 15 specimens).
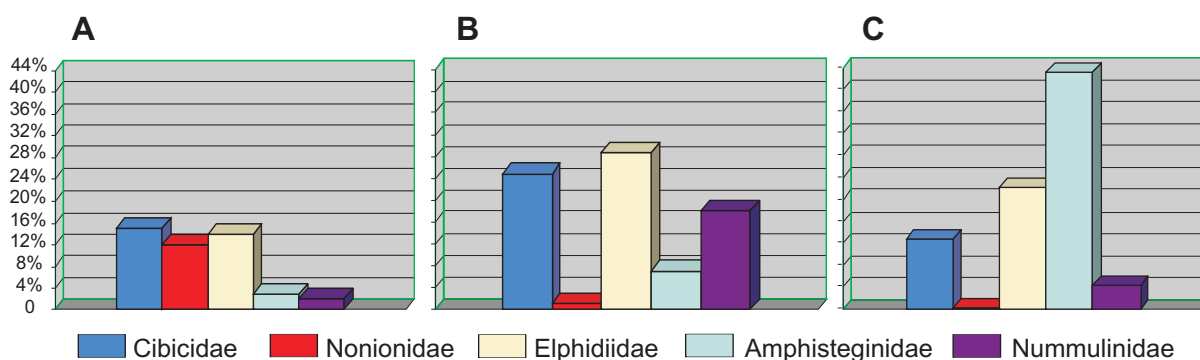
Fig. 4. The occurrence of the most common families of foraminifera in the the Badenian organodetrital limestone deposits in the Pińczów quarry: A – fine-grained limestone, B – medium-grained limestone, C – coarse-grained limestone.

The fine-grained limestone is characterised by *Cibicides–Elphidium–Nonionidae* assemblages and the species *Amphistegina lessoni* and *Heterostegina costata*. *Bolivina polonica* is the guide form of the oldest part of Badenian, i.e., the Moravian (Olszewska *et al.*, 1996).

The foraminiferal assemblage in the medium-grained limestone is more varied than in the fine-grained limestone. There were 74 species belonging to 25 families recorded in it. There occur all families found in the fine-grained limestone type except the *Peneroplidae*, *Fursenkoinidae*, and *Bagginidae* families, and additionally the following families occur: *Hippocrepinidae*, *Textularidae*, *Glandulinidae*, *Acervulinidae*, *Sphaeroidinidae*, *Hauerinidae*, *Planulinidae*, *Reussellidae*. The most common are *Elphidiidae* (28.7%), *Cibicididae* (24.9%), *Nummulitidae* (18%), *Amphisteginidae* (7.4%) (Fig. 4B). The species characterised by the greatest number of specimens were: *Elphidium crispum*, *Lobatula lobatula*, *Elphidium fichtelianum*. *Heterostegina costata*, *Amphistegina lessoni* and *Cibicides ungerianus* also occur quite common.

The medium-grained limestone type is characterised by the *Elphidium–Cibicides* assemblage and the species *Amphistegina lessoni* and *Heterostegina costata*. The species *Candorbulina suturalis* occurs, which is a guide form for the Moravian (Łuczkowska, 1974; Olszewska *et al.*, 1996).

In the coarse-grained limestone type, 84 species representing 30 families were found. In addition to the families that appeared in the fine-grained and medium-grained limestone types, the families *Alveolinidae* and *Globorotaliidae* occurred. The following families dominate: *Amphisteginidae* (43.4%), *Elphidiidae* (22.1%), *Cibicididae* (12.7%) (Fig. 4C). In the vertical section, the greatest species variety occurs in the oldest part of the section (63 species), in the younger parts of the section the number of species is lower (21 species). The species showing the greatest abundance are: *Amphistegina lessoni*, *Elphidium macellum*, *Elphidium fichtelianum*, *Elphidium crispum*, *Cibicides pseudoungerianus*.

The coarse-grained limestone is characterised by the *Amphistegina–Elphidium–Cibicides* assemblage. In addition, *Candorbulina suturalis* and *Lenticulina echinata* occur there; they are guide fossils for the Moravian (Olszewska *et al.*, 1996). In the vertical section of the deposit, the proportion of the most frequent families of foraminifera: *Cibicididae, Nonionidae, Elphidiidae, Amphisteginidae, Nummulinidae* is varying.

From the bottom towards the top of the organodetrital limestone deposit the share of Amphisteginidae increases and the share of Nonionidae decreases. The number of species increases up section: there are 66 species in the fine-grained limestone, 74 species in the medium-grained limestone, and 84 species in the coarse-grained limestone. In turn, the families *Cibicididae*, *Elphidiidae*, and *Nummulitidae* are the greatest in number in the medium-grained limestone located in the middle part of the limestone deposit (Fig. 4).

The foraminiferal assemblage in the organodetrital limestones of the Pińczów quarry is dominated by the benthic species (93%) with sparse plankton (7%). Foraminifera represent littoral zone (as indicated by a great proportion of taxa indicating the littoral zone, i.e., *Ammonia*, *Elphidium*). The water temperature is supposedly to be within the range of 18 to 23°C (as indicated by the genera: *Amphistegina* – 18–24°C, *Cibicides* – 18–23°C, *Elphidium* – 18–23°C, *Heterostegina* – 22–27°C; Gonera, 2001). The bottom surface was characterized by good oxygenation (as indicated by the proportion of the epifauna, i.e., *Eponides, Cibicides, Elphidium* – approximately 22%, and an insignificant proportion of *Bolivina* – 0.07%). The dynamics of the water appeared to be considerably high, which resulted in the damage and coating of the shells.

This estimation of the palaeoecological conditions agrees with the conclusions of Jerzmańska (1958), Pawłowska (1960) and Radwański (1965), who described fish fossils characteristic for subtropical climate.

Summarizing, the organodetrital limestones in the Pińczów quarry are characterised by the significant species diversity of foraminifera and the dominance of several genera in the assemblages: *Cibicides*, *Elphidium*, *Amphistegina*, *Heterostegina*. According to Murray (1991), this indicates an environment of considerable variability. Only some species were able to assimilate to it, and not having any competition then, they could develop intensively. In stable environments all species have similar possibilities.

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STOP 3

Palaeoenvironmental changes in the early Maastrichtian of the Nida Trough (Southern Poland): foraminiferal evidence

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Cretaceous deposits outcropping at the Wrocieryż quarry (southern Poland) occur within the Miechów (Nida) Trough which forms the southernmost part of the Szczecin–Łódź–Miechów synclinorium (see map of p. 85). Starting from the Early Permian, the area was located in the southern part of the Mid-Polish Trough developed at the boundary between the Precambrian and Palaeozoic platforms. The axial part of the Mid-Polish Trough underwent fast subsidence until the inversion commenced during late Turonian–Maastrichtian times (Walaszczyk in Voigt *et al.*, 2008, with references herein). In the Miechów Trough, the Cretaceous sequence (up to 600 m thick) is divided into two parts, a lower portion comprising Albian to Santonian strata, and an upper one comprising the

Fig. 1. Lithological column and location of samples in the Wrocieryż quarry section.
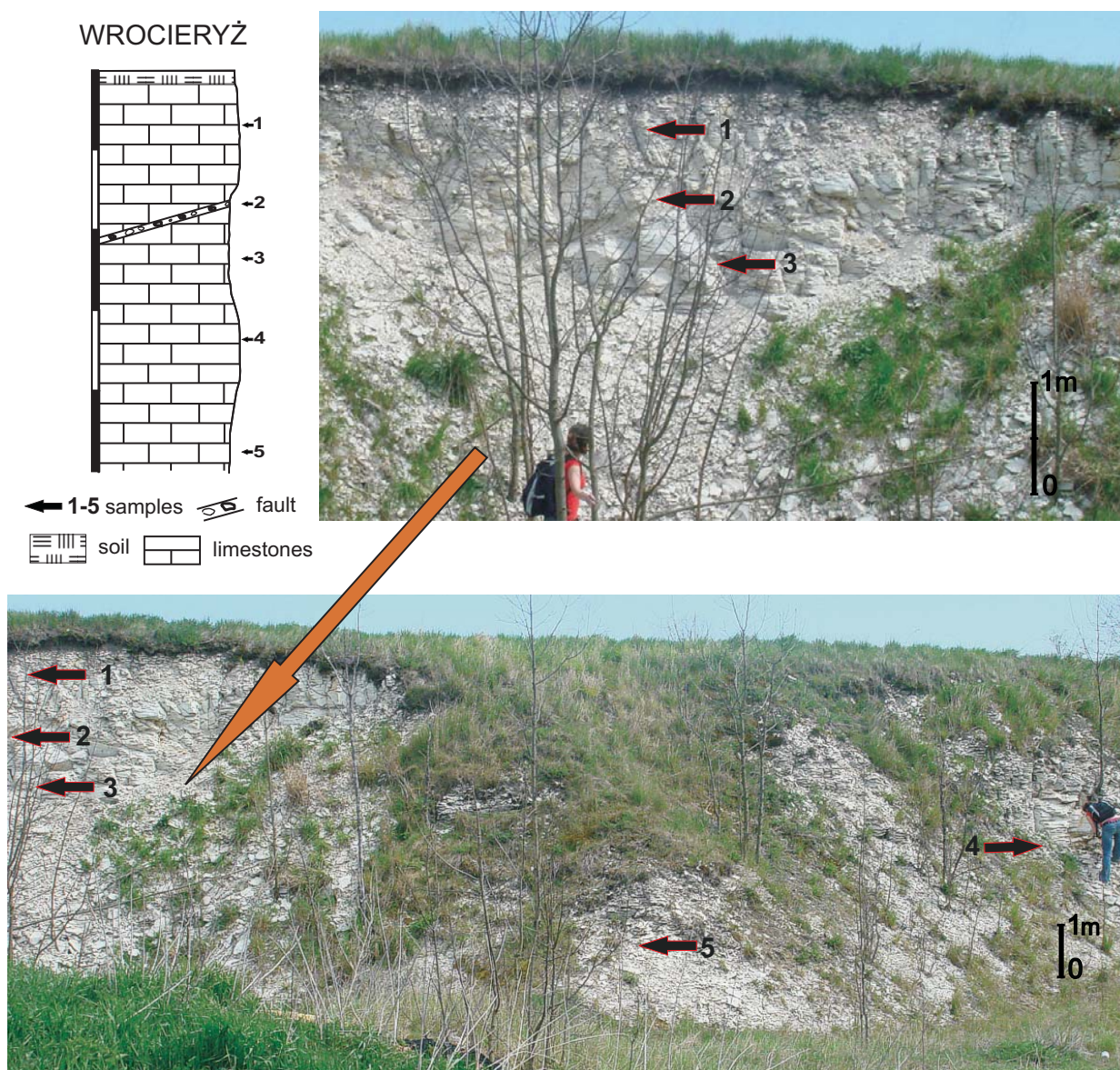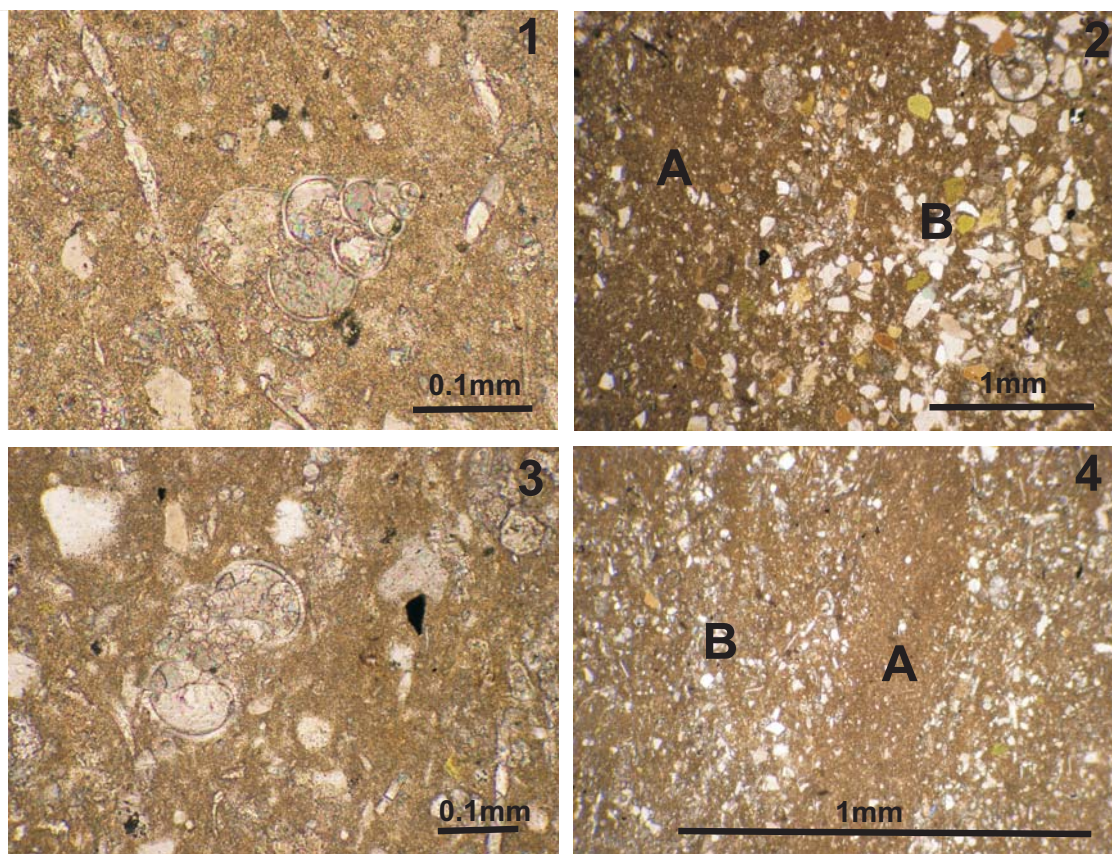
Fig. 2. Microfacies aspects of the Wrocieryż rocks. 1, 3 – bioclastic wackestone (the most common are planktonic foraminifers) containing quartz grains; 2, 4 – intercalations of laminae of carbonate mudstone and of granular deposit composed of quartz grains, glauconite, and bioclasts of foraminifers and sponges.

Campanian and lower Maastrichtian (Rutkowski, 1965; Cieśliński, 1973). Late Campanian through Maastrichtian is an interval characterized by three second-order marine regressions and several cooling events (Barrera & Savin, 1999; Friedrich *et al.*, 2005).

Geological setting and lithology

Wrocieryż is located about 20 km west of Busko Zdrój from where Machalski *et al.* (2004) described ammonites and assigned the ammonite-bearing deposits to lower part of the Upper Campanian *Neancyloceras phaleratum* Zone.

About 8 meters of sandy limestones outcrop in the old, non active quarry at Wrocieryż (Fig. 1). The rock is hard, gray in colour, massive, with no apparent bedding. In the upper part of the outcrop there is a fault and a 2-cm-thick marly layer on which a portion of Maastrichtian rock slided down.

Petrographically the sediment from the Wrocieryż section is a marly lithoclast mudstone (Fig. 2/2A, Fig. 2/4A) / wackestone (Fig. 2/2B, Fig. 2/4B). The rock is thus mud-supported with micritic cement. The grains include (mainly) fine-sand sized, angular quartz (white) and glauconite as well as some allochems (foraminifers and echinoid spines – Fig. 2/1, Fig. 2/3). The angular quartz grains are moderately sorted. Very thin dark and light laminae (Fig. 2/2, Fig. 2/4) lacking bioturbation and the low diversity (or lack) of benthic organisms altogether reflect poorly oxygenated bottom waters.

Foraminifera have not been studied in this area prior to this work. For the purpose of this study five samples were taken from the upper part of the Wrocieryż quarry (Fig. 3). 200–300 specimens from the >100 μm size fraction were picked up and all species in each sample were identified.

Results

Foraminifera are abundant and moderately well preserved. Both planktonic and benthic forms are present (Figs 3, 4, 5). Over 40 taxa were identified at the generic or specific level.
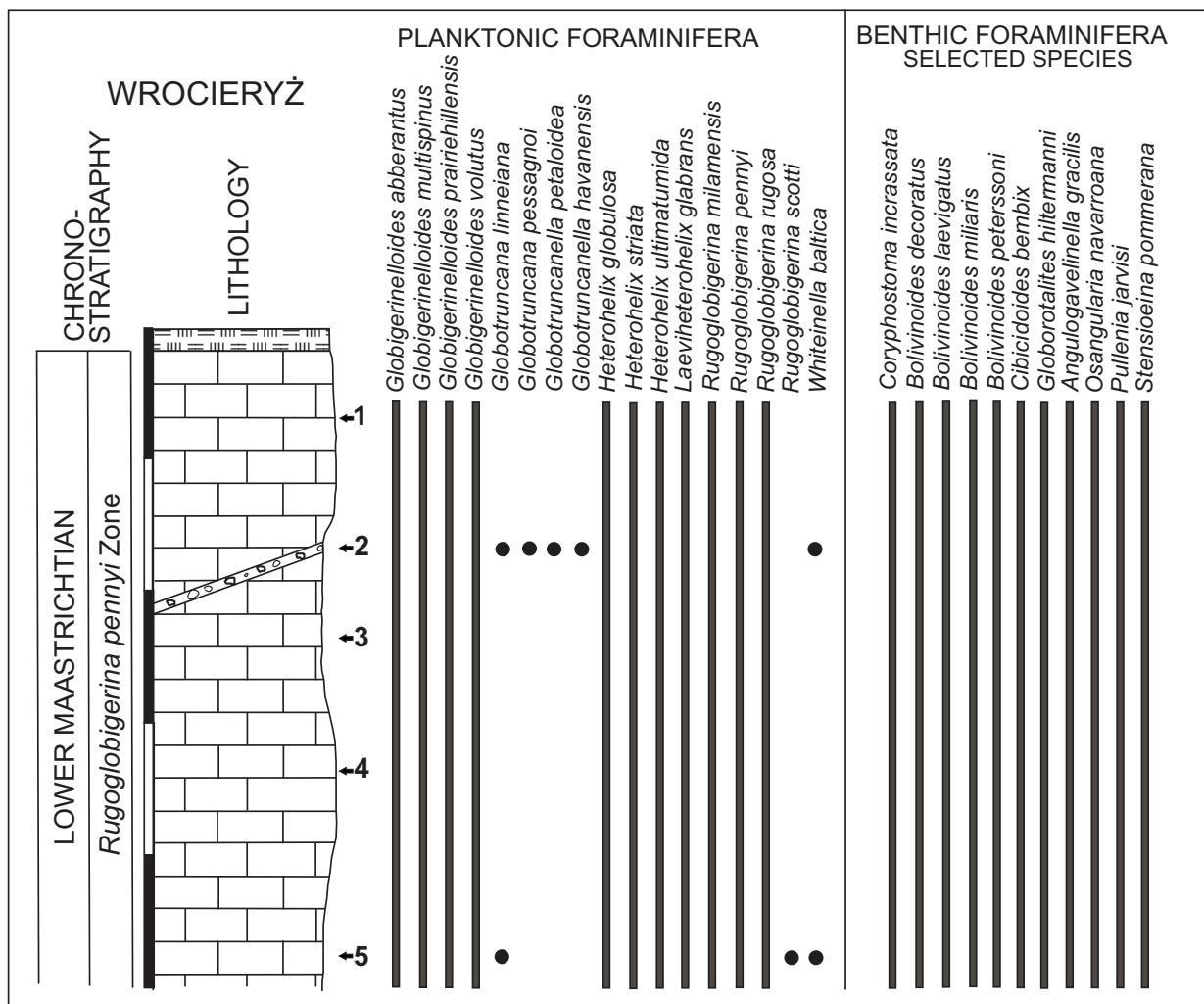
Fig. 3. Stratigraphy and distribution of foraminifers in the Wrocieryż profile. A – planktonic foraminifers, B – selected species of benthic foraminifers.

Contribution of planktonic foraminifera to the assemblages varies in the studied interval (Fig. 6A). They form from 25 to 70% of assemblages. Assemblages with low P/B ratio values (25 to 30%) alternate with the ones having high P/B ratio values (from 55 to 70%) (Fig. 6). 17 species of planktonic foraminifera are identified in the studied material (Fig. 3). *Heterohelix (H. globulosa, H. planata, H. punctulata, H. ultimatumida)* dominate planktonic foraminiferal assemblages. *Rugoglobigerina (R. pennyi, R. milamensis, R. rotundata, R. rugosa, R. scotti)* and *Globigerinelloides (G. prairiehillensis, G. multispinus, G. abberantus)* are common contributors of the assemblages. *Globotruncana (G. linneiana)*, *Globotruncanita* (*G. pessagnoi*), *Globotruncanella (G. havanensis, G. petaloidea)* and *Whiteinella (W. baltica)* represent rare species.

Over 20 genera of benthic foraminifers representing both calcareous and agglutinated forms are recorded in the studied section. Agglutinated foraminifers are very rare. Within benthic foraminiferal assemblages epifaunal morphogroups dominate. They form 55 to 75% of the assemblages (Fig. 6B). They are represented by *Stensioeina, Valvulineria, Angulogavelinella, Osangularia, Cibicidoides, Gavelinella, Gyroidinoides, Globorotalites, Lenticulina*.

Dentalina, Marginulina, Praebulimina, Coryphostoma, Bolivinoides, Neoflabellina, Nonion, Pullenia, Oolina, Glandulina, Guttulina, Marssonella, Gaudryina, Heterostomella and *Spiroplectammina* are interpreted as living dominantly infaunally. In the studied section infaunal morphogroups increase in abundance cyclically. Foraminiferal assemblages with higher share of infaunal morphogroups alternate with the ones where their contribution to the assemblages decreases (Fig. 6B).
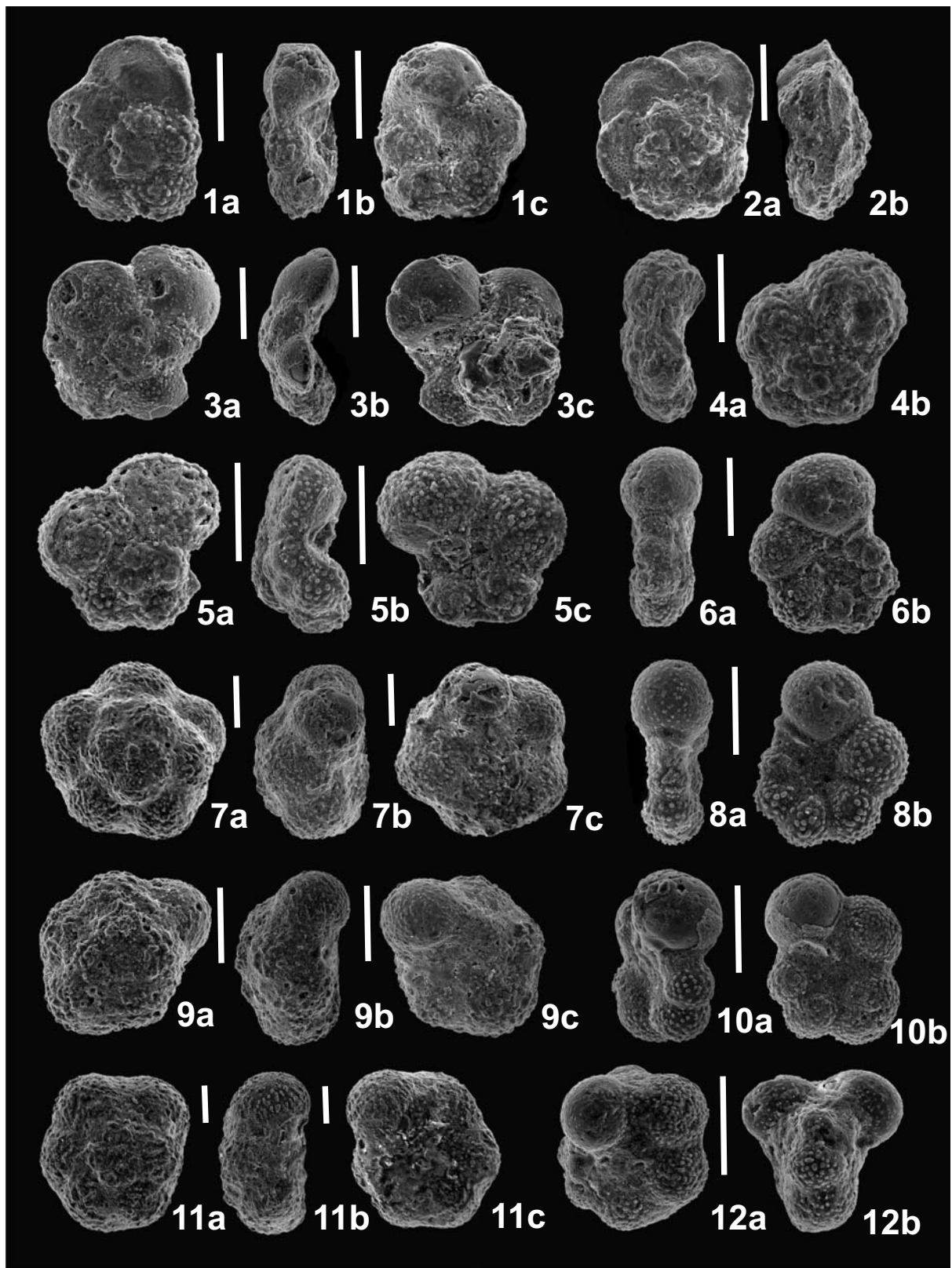
Fig. 4 Lower Maastrichtian planktonic foraminifers from the Wrocieryż quarry section. Scale bar – 100 µm. 1a–c. *Globotruncana linneiana* (d'Orbigny); 2 a–b. *Globotruncana pessagnoi* Longoria; 3a–c. *Globotruncanella havanensis* (Voorvijk); 4a–b. *Whiteinella baltica* Douglas & Rankin; 5a–c. *Globotruncanella petaloidea* (Gandolfi); 6a–b. *Globigerinelloides prairiehillensis* Pessagno; 7a–c. *Rugoglobigerina milamensis* Smith & Pessagno; 8a–b. *Globigerinelloides prairiehillensis* Pessagno; 8a–c. *Globigerinelloides prairiehillensis* Pessagno; 9a–c. *Rugoglobigerina milamensis* Smith & Pessagno; 10a–b. *Globigerinelloides abberantus* (Neckaja); 11a–c. *Rugoglobigerina pennyi* Bronnimann; 12a–b. *Globigerinelloides multispinus* (Lalicker).
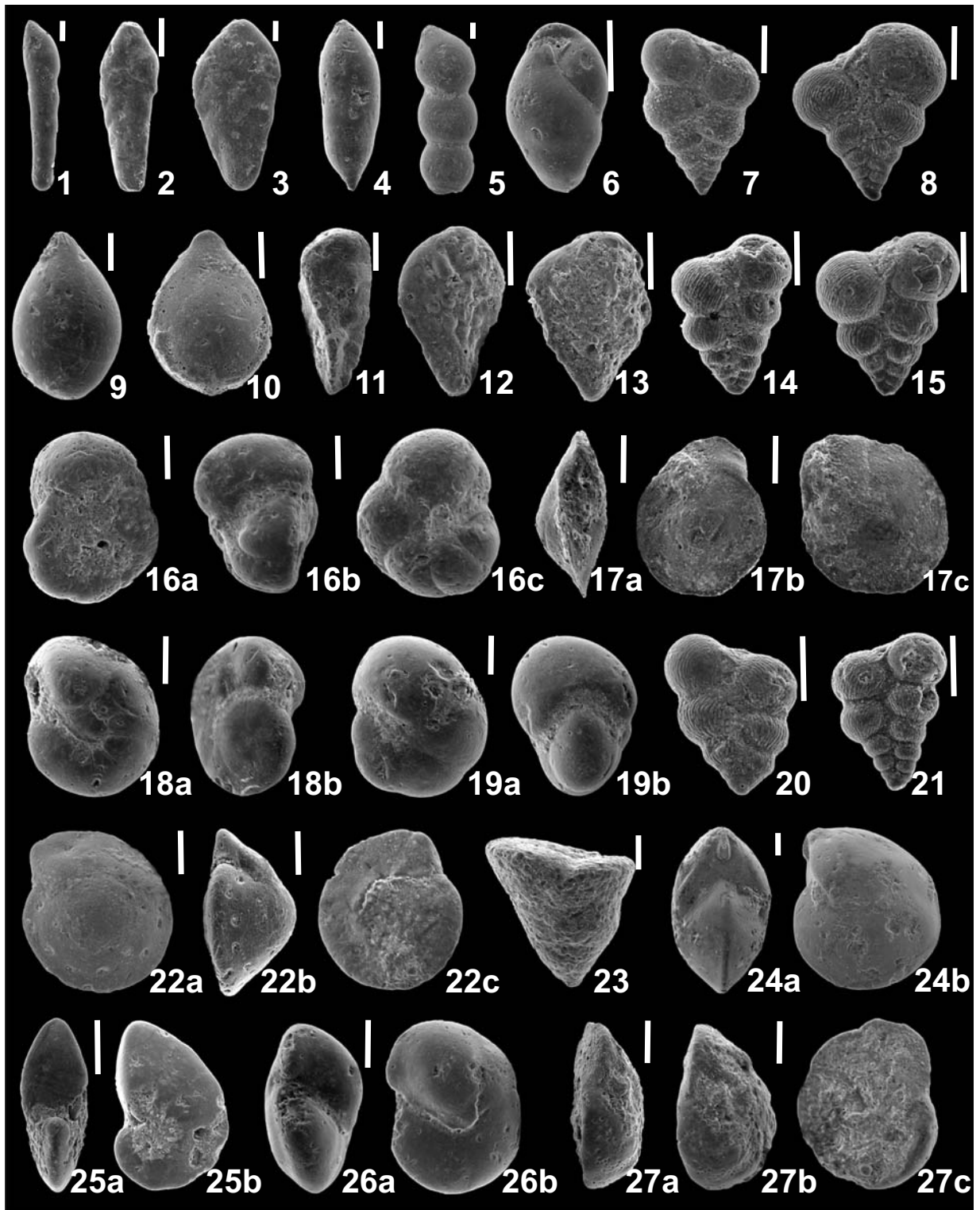
Fig. 5 Lower Maastrichtian foraminifers from the Wrocieryż quarry section. Scale bar – 100 µm. 1. *Laevidentalina nana* (Reuss); 2. *Coryphostoma incrassata* (Reuss); 3. *Coryphostoma crassa* (Vasilenko & Mjatliuk); 4. *Cribrebella ovata* Gawor-Biedowa; 5. *Laevidentalina catenula* (Reuss); 6. *Praebulimina carseyae* (Plummer); 7. *Heterohelix planata* (Cushman); 8. *Heterohelix ultimatumida* (White); 9. *Lagena globosa ovalis* Reuss; 10. *Fissurina marginata* (Walker & Boys); 11. *Heterostomella carinata* (Franke); 12. *Bolivinoides decoratus* (Jones); 13. *Bolivinoides miliaris* Hiltermann & Koch; 14. *Heterohelix globulosa* (Ehrenberg); 15. *Heterohelix globulosa* (Ehrenberg); 16a–c. *Cibicides excavatus* Brotzen; 17a–c. *Osangularia navarroana* (Cushman); 18a–b. *Valvalabamina* sp.; 19a–b. *Nonionella perdita* Haynes; 20. *Heterohelix punctulata* (Cushman); 21. *Heterohelix striata* (Ehrenberg); 22a–c. *Cibicidoides bembix* (Marsson); 23. *Marssonella oxycona* (Reuss); 24a–b. *Lenticulina* sp.; 25a–b. *Nonion troostae* Visser; 26a–b. *Valvalabamina lenticula* (Reuss); 27a–c. *Stensioeina pommerana* Brotzen.
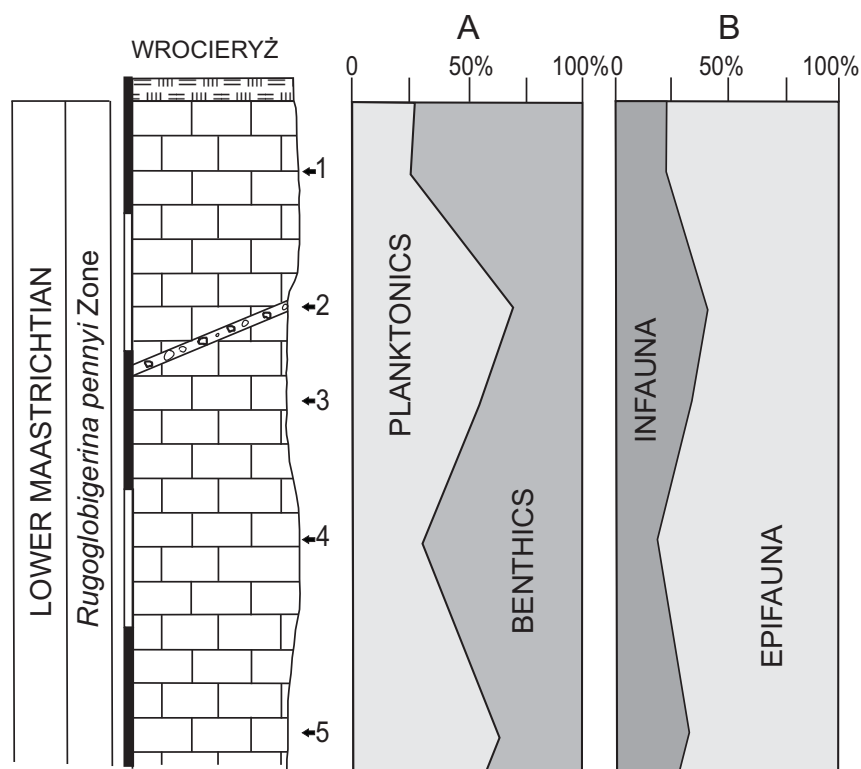
Fig. 6. Changes in foraminiferal assemblage composition in the Wrocieryż profile. A – relative abundances of planktonie and benthic foraminifers within assemblages. B – proportion of infaunal and epifaunal morphogroups within benthic foraminiferal assemblages.

There is a positive correlation between abundance fluctuations of planktonic foraminifers and infaunal morphogroups within benthic foraminiferal assemblages. Increasing abundance of planktonic forms is associated with increasing abundance of infaunal morphogroups. Higher values of both groups correspond with more muddy sediment.

Biostratigraphy

Planktonic foraminifera recorded in the studied material indicate that the sandy marls outcropping in the Wrocieryż section belong to the *Rugoglobigerina pennyi* Interval Zone established by Peryt (1980) in the lower Maastrichtian from the Middle Vistula River Valley. The lower boundary of the zone is defined by the FO of the index taxon, and the upper boundary by the FO of *Guembelitria cretacea* (Peryt, 1980). The continual presence of *Rugoglobigerina pennyi* accompanied by *Globigerinelloides multispinus* and lack of *Guembelitria cretacea* in the studied interval enable us to assign it to the lower part of the *R. pennyi* Zone. Peryt (1980) correlated the *R. pennyi* Zone in the Middle Vistula River Valley with the Lower Maastrichtian *Belemnella occidentalis* Zone (Błaszkiewicz, 1980). According to Peryt (2007) the FOs of *Rugoglobigerina pennyi* and *Rugoglobigerina milamensis* are a good proxy for the Campanian/Maastrichtian boundary, as defined in the Middle Vistula River section by Walaszczyk (2004).

Palaeoenvironment

The abundance of planktonic foraminifera is controlled by the occurrence and amount of the phytoplankton including bacteria and is believed to reflect primary productivity (Hemleben *et al*., 1989; Arnold & Parker, 2002). Planktonic forms are very important components of foraminiferal assemblages in the studied section. They are composed mainly by simple, small-sized, opportunistic, r-strategists taxa (*Heterohelix*) and by low to medium trochospiral morphotypes with subglobular chambers without keels, representatives of the more r-selected of the of r/k-intermediates: *Rugoglobigerina*, *Whiteinella* and planispiral *Globigerinelloides* (Caron & Homewood, 1983; Premoli Silva & Sliter, 1994; Petrizzo, 2002). In general opportunistic planktonic species are supposed to have

high reproductive potential and inhabit more nutrient-rich waters as well as can be considered indicators of cooler and/or unstable environments. The r/k intermediate morphotypes typify mesotrophic environments and the least complex (more r-selected r/k intermediates) closer to the eutrophic end of the spectrum (Petrizzo, 2002).

The depth in the sediment down to which foraminifers can live is determined by oxygen availability, and in the presence of oxygen, the vertical distribution of organisms is controlled by food availability (Jorissen *et al.*, 1995). A high flux of organic matter to the sea floor causes low oxygen concentrations within the sediment pore waters because oxygen is used in oxidation of the organic material. High abundance of infaunal forms in foraminiferal assemblages typifies aerobic/dysaerobic and mesotrophic/eutrophic environments (Corliss, 1985; Jorissen *et al.,* 1995; Murray, 2007).

Moderate to high P/B ratio, high percentage of epifaunal forms within benthic foraminiferal assemblages and dominance of *Heterohelix* along with *Rugoglobigerina* and *Globigerinelloides* within the planktonic foraminiferal assemblages indicate 100–150 m deep, cool, mesotrophic marine environment during the early Maastrichtian in the Nida Trough.

Parallel changes in abundance of planktonic foraminifera and infaunal morphogroups of benthic ones reflect probably short-term palaeoenvironmental changes resulting in changes in primary producitivity. High P/B ratio and higher percentage of infaunal forms within benthic foraminiferal assemblages are indicative of mesotrophic, close to eutrophic marine environment, higher organic matter flux and lower oxygenation at the seafloor. Intervals characterized by low P/B ratio values and low abundance of infaunal morphogroups reflect mesotrophic, close to oligotrophic surface waters, low organic matter flux and environment with well oxygenated bottom waters.

Several cooling events are described from the late Campanian through Maastrichtian (Barrera & Savin, 1999). We suppose that palaeoclimatic changes were responsible for cyclic changes in foraminiferal assemblages during early Maastrichtian in the Nida Trough. Cooling was accompanied by stronger wind stress, leading to enhanced surface-water mixing and increasing primary producitivity. This resulted in enhanced organic matter flux to the seafloor and low oxygen concentrations within the sediment pore waters because oxygen was used in oxidation of the organic material. Friedrich *et al.* (2005) applied similar explanation to Late Campanian–Early Maastrichtian changes in calcareous nannoplankton and foraminiferal assemblages and stable isotopes during formation of the homogeneous chalk sedimentation in epicontinental North German Basin. High P/B ratio values and increase in abundance of infaunal morphogroups reflect this situation. On the contrary, warming was responsible for decreasing of surface water mixing, low nutrient levels and low phytoplankton productivity. In highly oligotrophic regions all food particles are consumed or oxidised at the sediment surface.

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STOP 4

Callovian to Middle Oxfordian succession at Gnieździska quarry (Holy Cross Mountains, Central Poland)

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The Gnieździska quarry (40 km SW of Kielce) is situated at the Permo-Mesozoic margin of the Holy Cross Mountains (see map of p. 85). This area is a part of the Mid-Polish Anticlinorium, which stretches from NW to SE across the territory of Poland. The Anticlinorium is a Laramide structure, which exists since the late Cretaceous/Palaeogene.

The section exposes ca. 60 m thick Callovian to Middle Oxfordian siliceous and carbonate rock. Beds dip 130°/22°S to 160°/22°S and belong to the northern limb of the Mnin Syncline.

Callovian to Middle Oxfordian succession

The whole Callovian–Middle Oxfordian succession thickness exposed in Gnieździska quarry is nearly 60 m.

The E and NE side of the quarry exposes 25 m thick Callovian (Middle Jurassic) succession of siliceous gaizes. The lower part of the succession (2 m) consist of marls and marly gaizes of the Lower Callovian *Herveyi* Zone (Drewniak & Matyja, 1996). They are overlain by thickly bedded gaizes with cherts and in the uppermost part – by a layer of green claystone (0.35 m). Gaizes of this section are rich in detritic quartz. The latter constitutes ca. 20% of grains in the lower, and 5% in the upper part of the succession. Bioclasts are represented mainly by sponge spicules (up to 55%), less commonly by echinoderm plates (ca. 5%) and foraminifers.

Gaizes are strongly bioturbated. *Thalassinoides* burrows, which appear here in abundance (Pieńkowski *et al.*, 2008), were interpreted as privileged paths of migration of early diagenetic siliceous solutions (Drewniak, 1996). The *Thalassinoides* fill is silicified, which results in a certain nodular fabric of the rock.

Above the gaizes and green claystone there is a massive layer (0.8 m) (Figs 2–3) of two-part lithology: spiculite in the lower- and sponge-bearing limestone in the upper part. The layer contains some intraformational erosional surfaces.

The time of its forming spans from the late Middle or (?) early Late Callovian (ammonite of the genus *Hecticoceras* sp. occurs in the lower part of the layer, author's collection) to the earliest Oxfordian. The ammonites of the genus *Choffatia* sp. and early representative of *Cardioceras* (*Scarburgiceras*) sp. found in a single level (author's collection) indicates that the condensation and/or non-deposition across the Callovian/Oxfordian boundary comprises the *Lamberti* Zone and *Mariae* Zone respectively.

The limestones overlying the massive layer are Early to Middle Oxfordian in age (Fig. 1). They are sponge-bearing, bedded and attain a thickness of nearly 35 m in the Gnieździska quarry. The lithostratigraphical scheme used is that proposed for the Oxfordian of the Holy Cross Mountains by Matyja (1977) and characterised as follows:

Jasna Góra beds (Figs 1–3)

They represent an alternation of marly limestones and marls. They are mainly packstones or wackstones. They are rich in benthic and pelagic fauna (mainly sponges and ammonites). Microfossils consist of spongy spicules, echinoderm plates, foraminifers and mollusks. The thickness of this unit in Gnieździska is of ca. 5.5 m.

Grey limestones (Figs 1–3).

These are pelitic limestones impoverished of benthic macrofauna. Ammonites are very rare. The grey limestones contain dispersed ferrougineous sulphates which are responsible for its grey color. The
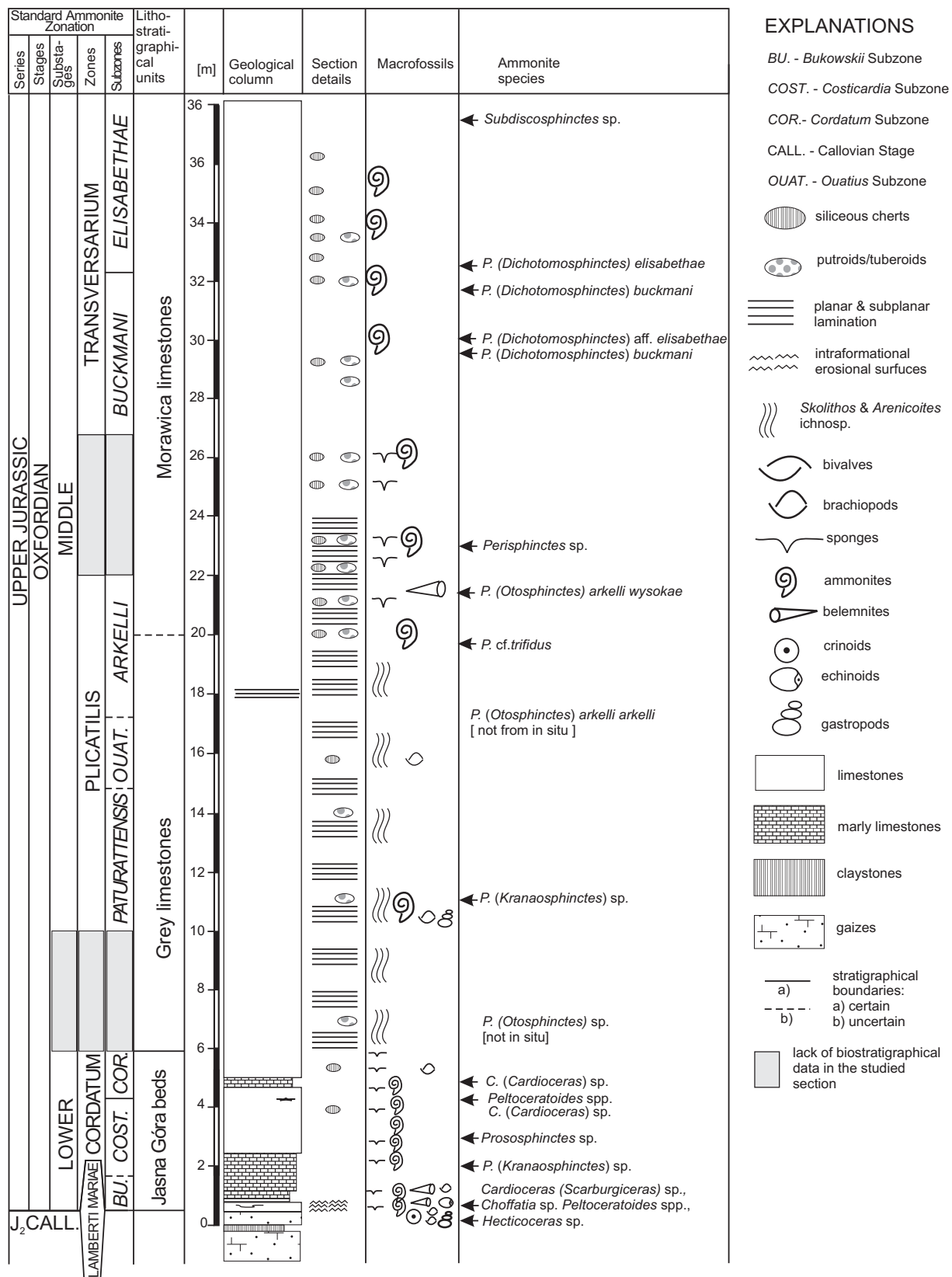
Fig. 1. Geological column of the Oxfordian limestones in the Gnieździska quarry.

thickness of this unit is ca. 14 m in Gnieździska quarry. The boundary with the overlying Morawica limestones is not clear.

In the grey limestones planar and low angle cross-lamination accompanied at the tops of beds by *Skolithos* and *Arenicolites* (characteristic members of *Skolithos* ichnofacies) appear (Pieńkowski *et*
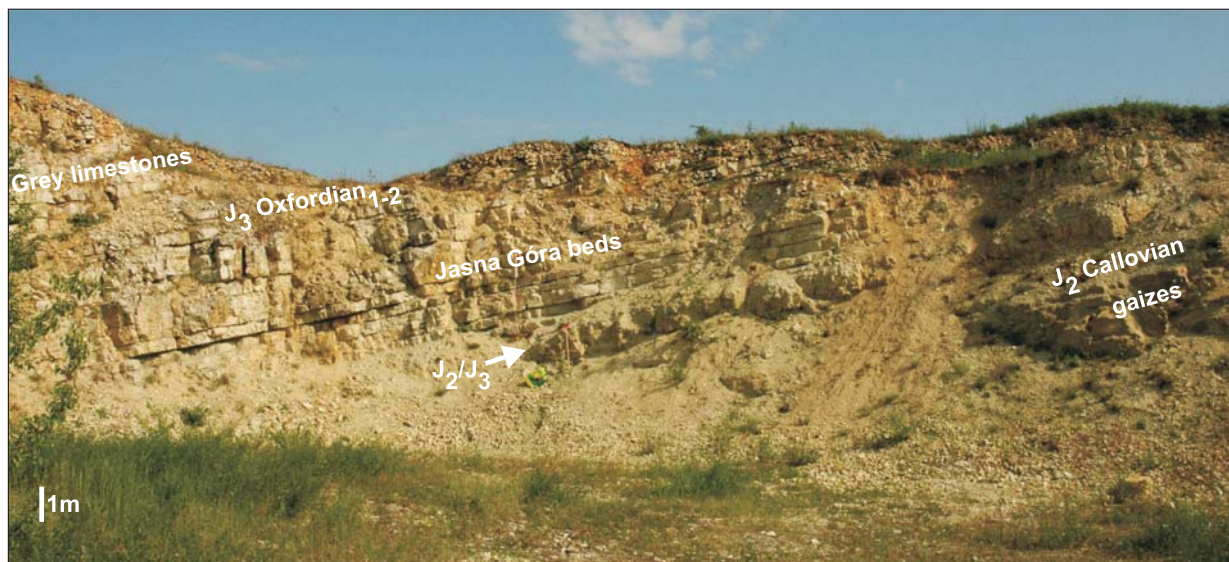
Fig. 2. General view on the Callovian–Oxfordian gaizes and limestone succession in the Gnieździska quarry (NW side). Arrow indicates a massive layer which contains the J2/J3 boundary.

al., 2008). The repetitive character of beds (erosional bottoms, subplanar lamination and bioturbated tops) conducted Pieńkowski *et al.* (2008) to the assumption of the tempestite origin of the grey limestones. This interpretation requires however some further studies as the environment of the latter unit has been commonly interpreted as a low energy open-shelf (e.g. Hoffmann & Uchman, 1992).

Morawica limestones (Fig. 1)

These are tuberolitic and putroidal bedded limestones with cherts. They contain abundant benthic and pelagic macro- and microfossils: ammonites, belemnites, foraminifers, brachipods, bivalvs, echinoderms, crustaceans, bryzoans and serpulids. Only the lower part of this unit, ca. 18 m thick, is exposed in the Gnieździska quarry.

The Oxfordian limestones in Gnieździska quarry range from the Lower Oxfordian *Cordatum* Zone through the Middle Oxfordian *Plicatilis* Zone and the *Transversarium* Zone (Głowniak, 2008) (Fig. 1). The standard perisphinctid Oxfordian zonation for the Submediterranean Province can be applied (Głowniak, 2002; 2006). Ammonites of the genera *Cardioceras* and *Peltoceratoides* appear in the *Jasna Góra* beds which thus assigned to the *Cordatum* Zone (Fig. 1) (for species register see Drewniak & Matyja, 1992; 1996). The boundary between the *Cordatum* Zone and the Middle Oxfordian *Plicatilis* Zone lies somewhere in the lower part of the overlying grey limestones. Its precise location has not been found because ammonites there are very rare (Fig. 1). Grey limestones belong mostly to the *Plicatilis* Zone as they yielded some undoubtful perisphinctid ammonites of the subgenera *Otosphinctes* and *Kranaosphinctes* accompanied by *Perisphinctes* cf. *trifidus* (Fig. 1). Lower part of the overlying Morawica limestones still belong to the *Plicatilis* Zone because of *Perisphinctes (Otosphinctes) arkelli wysokae* and *Perisphinctes* (*Otosphinctes*) *arkelli arkelli* occurrences (Fig. 1). The taxa are diagnostic for the *Arkelli* Subzone in the upper *Plicatilis* Zone. The upper part of the Morawica limestones in Gnieździska quarry belongs to the *Transversarium* Zone. They yielded *Perisphinctes* s. str. and of the subgenus *Dichotomosphinctes* (e.g. *P.* (*D.*) *buckmani* and *P.* (*D.*) *elisabethae*, Fig. 1) – ammonites diagnostic for the *Buckmani* and *Elisabethae* subzones of the *Transversarium* Zone.

Final remarks

In the Late Jurassic, the studied area was a part of the European epicontinental marine basins extended along the northern margin of the Tethys Ocean (e.g. Ziegler, 1990). The Holy Cross Mountains belonged to the southern margin of the Central European Basin located in the peri-Carpathian area (e.g. Kutek, 2001).
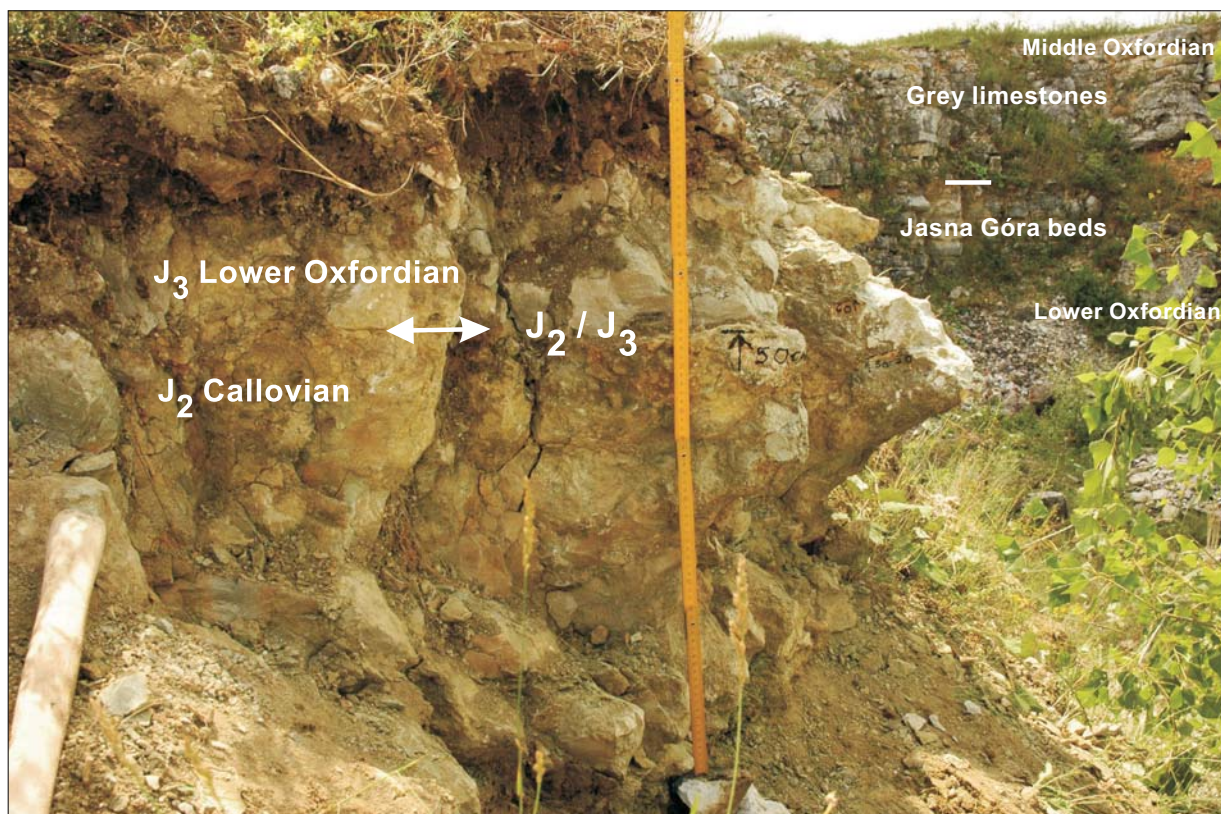
Fig. 3. The Callovian–Lower Oxfordian massive layer with the erosional surface (arrow) at the Middle/Upper Jurassic boundary. The overlying sponge-bearing limestones (Jasna Góra beds and grey limestones) are Early to Middle Oxfordian in age. Picture taken in the SE part of the Gnieździska quarry.

The Callovian sediments were accumulated during a period of sea-level rise (e.g. Hallam, 2001). The gaizes of Gnieździska originate from a highly porous spiculite, which was accumulated in low energy depressions. Basinal spiculites of Gnieździska underwent considerable compaction during diagenesis, the estimated original porosity having been 2–3 times bigger at the early stage of compaction (Drewniak, 1966). The early diagenetic processes led to appearance of cherts. *Thalassinoides* burrows were privileged paths of migration and precipitation of siliceous solutions.

The limit between the Callovian siliceous complex and the Oxfordian limestones in Gnieździska is discontinuous. The Callovian/Oxfordian discontinuity is a global phenomenon which occurred during the sea-level high stand conditions. This led to a widespread condensations and/or non deposition in the Middle/Upper Jurassic known e.g. from carbonate platforms of central and SW Europe.

During Oxfordian, an extensive development of the Late Jurassic sponge lithofacies took place in central and southern Poland, attaining a thickness of some hundred metres, documented as well in the SW margin of the Holy Cross Mountains (Matyja, 1977; Kutek, 2001). The lithofacies was dominated by siliceous sponges ("lithistida", *Hexactinosa* and *Lychniscosa*) and it was deposited in a neritic environment along the northern margins of the Tethys (Trammer, 1982, 1989). It extended from Lusitania through of central Europe, and further to the east as far as Tadzhikistan and the Pamirs. It also includes cyanobacteria-sponge bioherms and it was replaced in the deeper interbioherm depressions by layered limestones. Gnieździska quarry with its bedded limestones exposes just the deeper, interbiohermal facies.

The bathymetry of sponge megafacies has been estimated e.g. against the ecological limitations of siliceous sponges (according to Krautter, 1997) and independently calculated against the evaluation of the sea-bottom palaeorelief in the Late Oxfordian and Kimmeridgian by Matyja & Wierzbowski (1996, 2004). The latter authors (op. cit.) mention the depths of more than 100–300 m in the Early–Middle Oxfordian whereas over 400 m in the Late Oxfordian to Early Kimmeridgian.

The Oxfordian carbonate deposits of Poland became exceptionally useful for various stratigraphic research, due to its continuous sedimentation without gaps and condensations, homogeneous facies, and easy access to the outcrops. Being reach in ammonites, they have became well known for numerous relevant ammonite works (e.g. Bukowski, 1887; Głowniak & Wierzbowski, 2007; Kutek, 1968; Siemiątkowska-Giżejewska, 1974). Due to the convenient location at the cross roads of incursions of Boreal and Mediterranean ammonites, this region increased in significance in the last two decades as reference area for inter-regional biostratigraphic correlations (e.g. Głowniak, 2006; Matyja *et al.*, 2006) and also palaeomagnetic studies (e.g. Przybylski *et al.*, 2009).

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