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MIDDLE JURASSIC AMMONITICO ROSSO DEPOSITS IN THE NORTHWESTERN PART OF THE PIENINY KLIPPEN BELT IN POLAND AND THEIR PALAEOGEOGRAPHIC IMPORTANCE; A CASE STUDY FROM STANKOWA SKAŁA AND "WAPIENNIK" QUARRY IN SZAFLARY

Magdalena SIDORCZUK

Institute of Geology, University of Warsaw, Al. Żwirki i Wigury 93, 02-089 Warszawa, Poland; e-mail: sima@uw.edu.pl

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Abstract: Carbonate deposits of the ammonitico rosso-type developed in the Czorsztyn Succession represent the shallowest northern facies zone of the Pieniny Klippen Basin, formed on the southern slope of a submarine ridge named the Czorsztyn Ridge. The lithology of the Middle Jurassic ammonitico rosso-type deposits in the Czorsztyn Succession of the north-westernmost part of the Pieniny Klippen Belt in Poland appears highly diversified and includes: shell coquinas and distinctly laminated limestones consisting of micritic and organodetrital, mostly crinoidal laminae. The microfacies vary from pure micrite to packstones rich in filaments, and packstones-grainstones rich in various bioclasts and peloids. Neptunian dyke infillings are of similar lithological and microfacies types. The history of deposition of the oldest ammonitico rosso-type and associated deposits was different in the north-westernmost part of the Polish section of the Pieniny Klippen Basin, compared to its central and eastern parts. A distinct differentiation of the basin is thus proposed along the Czorsztyn Ridge: from a shallower, north-westernmost part to deeper parts, with the boundary-zone in the present Szaflary area, which is characterised by scarp breccias and neptunian dykes cutting through the basement composed of crinoidal limestones. This indicates that the Czorsztyn Ridge was laterally differentiated into subordinate highs and lows that were formed in a tectonically active environment.

Key words: Western Carpathians, Pieniny Klippen Belt, Czorsztyn Ridge, Middle Jurassic, palaeogeography, ammonitico rosso, microfacies, neptunian dykes.

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INTRODUCTION

The Pieniny Klippen Belt is a narrow structure that separates the Carpathians into the Outer and Inner domains (Fig. 1A). Stretching for a distance of ca. 600 from Vienna to Maramures (East Carpathians, Romania), it is built of mainly pelagic carbonates aging from Jurassic to Cretaceous time. However, an existence of the shallower zone of the northern ridge, namely the Czorsztyn Ridge, during the mid-Jurassic to Cretaceous was proposed by Birkenmajer (1963, 1977, 1986). The aim of this study is to shed more light on the lateral variations of depositional environments within the Czorsztyn Ridge, constrained to the westernmost part of the Polish sector of the Pieniny Klippen Belt. Outcrops are located at Stankowa Skała to the west (close to Zaskale village), and in the "Wapiennik" Quarry close to Szaflary town to the east (Fig. 1B).

GEOLOGICAL CONTEXT

Most of the ammonitico rosso-type deposits of the lower part of the Czorsztyn Limestone Formation in the Czorsztyn Succession, particularly in the central and the eastern parts of the Pieniny Klippen Belt in Poland, are developed as nodular red limestones. Rocks under study are correlated with the lower part of the Czorsztyn Limestone Formation (Birkenmajer, 1977) (Fig. 2). However, they include well-bedded, non-nodular ammonitico rosso-type limestones, thus differing from typical limestones representing the Czorsztyn Limestone Formation in other parts of the Pieniny Klippen Belt, which consist of nodular limestones (Kutek & Wierzbowski, 1986).

Specific deposits associated with the rocks in question are neptunian dyke infillings and breccias (Wapiennik Breccia Member; see Birkenmajer, 1977), which can be recog-

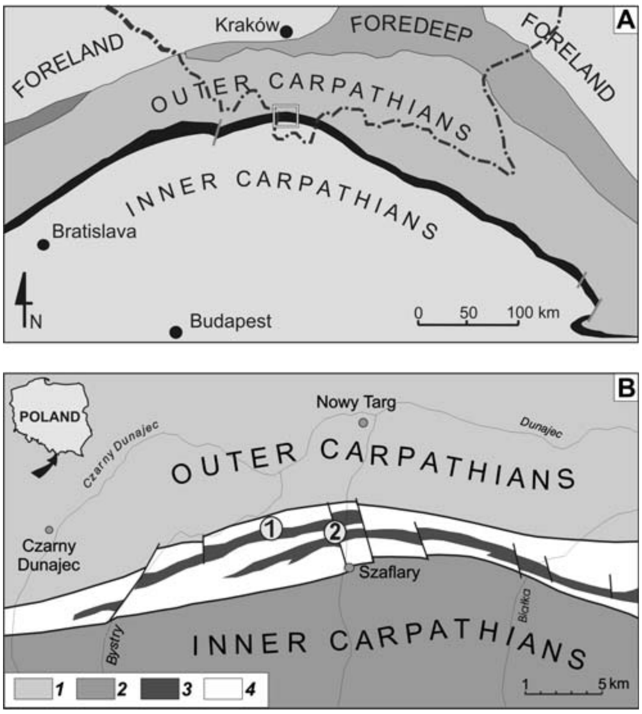

Fig. 1. **A.** Location of the Pieniny Klippen Belt (in black) within the Carpathians. **B**. Location of the studied sections of the Pieniny Klippen Belt in Poland (base map simplified from Birkenmajer, 1963, 1977). *1* – Magura Palaeogene flysch (Magura Nappe); *2* – Podhale Palaeogene flysch (autochthonous); Pieniny Klippen Belt successions: *3* – Czorsztyn Succession: 1 – Stankowa Skała, 2 – "Wapiennik" Quarry in Szaflary; *4* – other successions

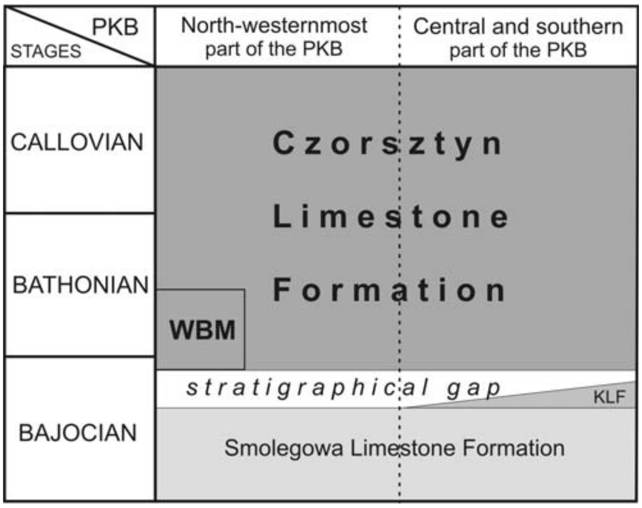

Fig. 2. Schematic lithostratigraphic units referred in the text. PKB – Pieniny Klippen Belt, WBM – Wapiennik Breccia Member, KLF – Krupianka Limestone Formation

nised in the "Wapiennik" Quarry. Despite lithological differences, a general microfacies sequence recognised in the studied deposits is compatible with the oldest ammonitico rosso of the Czorsztyn Succession identified in the central and eastern parts of the Pieniny Klippen Belt in Poland (Wierzbowski *et al.*, 1999), where crinoid microfacies are succeeded by limestones rich in thin-shelled pelecypods of the genus *Bositra*, the so-called filament microfacies. The filament microfacies are replaced by younger deposits of the ammonitico-rosso developed as the *Globuligerina* ("*Protoglobigerina*") microfacies.

Ammonitico rosso deposits similar to those of Stankowa Skała and Szaflary were earlier described by Slovak workers (Mišík *et al.*, 1994a, b; Aubrecht *et al.*, 1997), who noticed that many sections in the Slovak segment of the Pieniny Klippen Belt display depositional features which differ from classic lithostratigraphic divisions introduced by Andrusov (1945) and Birkenmajer (1963, 1977). Consequently, new lithostratigraphic units have been distinguished within the Czorsztyn Succession, namely the Krasin Breccia Member (Mišík *et al.*, 1994b; Mišík *et al.*, 1996), for the Upper Bajocian–Bathonian breccia composed of crinoidal limestones, and the Bohunice Limestone Formation (Aubrecht, 1992; Mišík *et al.*, 1994a, Mišík *et al.*, 1996, Aubrecht *et al.*, 1997), for the Oxfordian–Lower Tithonian biomicritic limestones. The present work provides new data on lithological variability within the Pieniny Klippen Belt in Poland, which are then utilized for a syntethic, though spatially limited, model of the Mid- to Late Jurassic evolution of the sedimentary basin related to the Czorsztyn Ridge.

SECTIONS DESCRIPTION

Stankowa Skała

The section is situated near the top and in the south-westernmost part of Stankowa Skała (49°26'4.1''N, 19°59'23.6''E; Fig. 3). It begins with crinoidal limestones of the Smolegowa Limestone Formation. The latter are overlain by limestones representing the Czorsztyn Limestone Formation (according to Birkenmajer 1977), the lowest part of which has been studied here in detail for the first time. Still younger are limestones representing the Dursztyn Limestone Formation (Birkenmajer, 1977) cropping out above the Czorsztyn Limestone Formation.

Crinoidal limestones (of the Smolegowa Limestone Formation). These are light-grey crinoidal limestones. Their top surface is uneven and covered by a thin stromatolitic layer. The deposits represent the *crinoidal microfacies*. These are mainly grainstones rich in fine-graded echinoderm skeletal elements (40–45%), most commonly crinoids, which are accompanied by extraclasts: rounded limestone clasts, scarce detrital quartz grains, fragments of fine-grained quartz sandstones, and single solitary corals and fragmented brachiopod shells. The thickness of crinoidal limestone is about 1.5 m. Their base is not exposed.

Ammonitico rosso deposits (traditionally included into the Czorsztyn Limestone Formation). The studied lower part of the formation is about 0.9 m thick and is composed of red-grey and red-brown, hard, non-nodular limestones forming five distinct beds (beds:1a, 1b, 2a, 2b, 2c; see Fig. 3), attaining the thickness of few, up to a dozen or so centimetres.

Two beds representing the lowermost and middle parts of the studied section (beds 1a and 2b) are developed as limestones with bioclasts, mainly shell coquinas and thin subordinate micritic laminae. Among the grain particles, fragments of thin-shelled *Bositra* bivalves, accompanied by crinoid fragments are predominant. In bed 1a, also intraclasts of light-grey limestones occur. Bed 2b contains small Fe-Mn nodules and sporadic fragments of yellow dedolomites (Zydorowicz & Wierzbowski, 1986). The limestones of this part of the section represent two types of microfacies: *filament microfacies* (Fig. 4A) and *filament-peloid with echinoderms microfacies* (Fig. 4B).

Filament microfacies (Fig. 4A). These are mainly grainstones, sometimes packstones. The deposits are rich in filaments, which are thin-shell bivalve shells of genus *Bositra* (5–40%). There also occur skeletal echinoderm elements (5%), and rarely ostracods, *Globochaete* spores, fragments of bryozoan colonies, and benthic foraminifers (*Marsonella* sp., *Spirillina* sp., *Lenticulina* sp., *Ophthalmidium* sp.). Detrital quartz grains do not exceed 2%. Limestone intraclasts, as well as small (2–3 mm) Fe-Mn nodules are also sporadically met.

Filament-peloid microfacies with echinoderms (Fig. 4B). These are grainstones, sometimes packstones, rich in filaments (25–30%), peloids (15%) and echinoderm fragments (10%). Ostracods, benthic foraminifers (*Lenticulina* sp., *Spirillina* sp., *Marsonella* sp.), fragments of wackestone and dedolomites, and also detrital quarz are less common.

The remaining part of the section studied (beds 1b, 2a and 2c) is composed of distinctly laminated limestones (Fig. 5A). The thickness of laminae ranges between 2 and 25 mm. The laminae boundaries are sharp. Thinner laminae are usually composed of micrite, while the thicker ones show a fine-grained texture and contain crinoid fragments, sometimes accompanied also by calyxes, shell fragments and detrital quartz grains, and also rare, well-rounded limestone intraclasts. Graded bedding is visible in some laminae. In some places, cross-bedding commonly occurs (Fig. 5B). The laminated limestones of this part of the studied section represent the following microfacies types: *echinoderm-shell microfacies*, *peloid microfacies*, *peloid-echinoderm microfacies*, *filament-crinoid microfacies*, *microfacies with crinoids*, and *micritic microfacies* (Fig. 4C–F).

Echinoderm-shell microfacies (Fig. 4C). These are packstones and grainstones. Corroded echinoderm fragments (up to 30%), mainly crinoid ossicles, predominate among detrital elements; they are abundantly accompanied by fragments of shells, mainly of brachiopods (up to 15%) and filaments (up to 20%). Present are also: detrital quartz grains (up to 5%), fragmented shells of ostracods and benthic foraminifers (*Patellina* sp., *Spirillina* sp., *Lenticulina* sp., *Ophthalmidium* sp.), gastropod shells and intraclasts of wackestone with filaments.

Peloid microfacies. These are grainstones with abundant peloid accumulations (60–70%) and scarce fine admixture of organogenic material.

Peloid-echinoderm microfacies (Fig. 4D). These are packstones and grainstones, in which echinoderm fragments (7–15%), corroded crinoids and peloids, are important components (15–30%). Fragments of juvenile ammonite shells, sharp-edged corroded grains of detrital quartz (up to 5%), filaments, ostracods and benthic foraminifers of genera *Lenticulina, Trocholina, Nodosaria* and *Ophthalmidium* are less common.

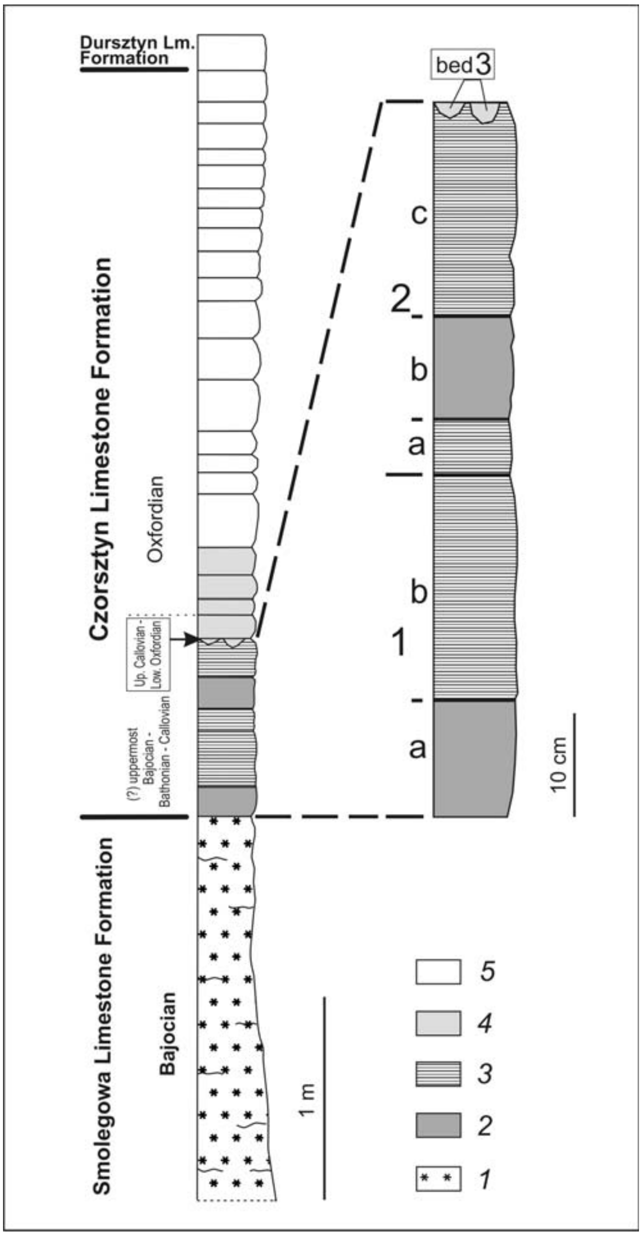

Fig. 3. Stankowa Skała section. *1* – crinoidal limestones, *2* – limestones with filaments, *3* – laminated limestones, *4* – limestones with *Globuligerina*, *5* – limestones with *Saccocoma* (after Kutek & Wierzbowski, 1986; Jaworska, 2000)

Filament-crinoid microfacies (Fig. 4E). These are packstones and grainstones, rarely wackestones, rich in filaments (15%) and crinoid skeletal elements (10%), commonly corroded. In small quantities, grains of detrital quartz and peloids are present as well. Limestone intraclasts with single filaments occur, as well as rare intraclasts with cyanobacterial coatings impregnated by Fe-Mn oxides.

Microfacies with crinoids (Fig. 4F). These are wackestones with crinoid fragments (up to 12%). Less common are: grains of detrital quartz (1–2%), fragmented brachiopod shells, filaments and ostracode shells. A shell of ostracode *Pokornyopsis* (see Aubrecht & Kozur, 1995) has been iden-

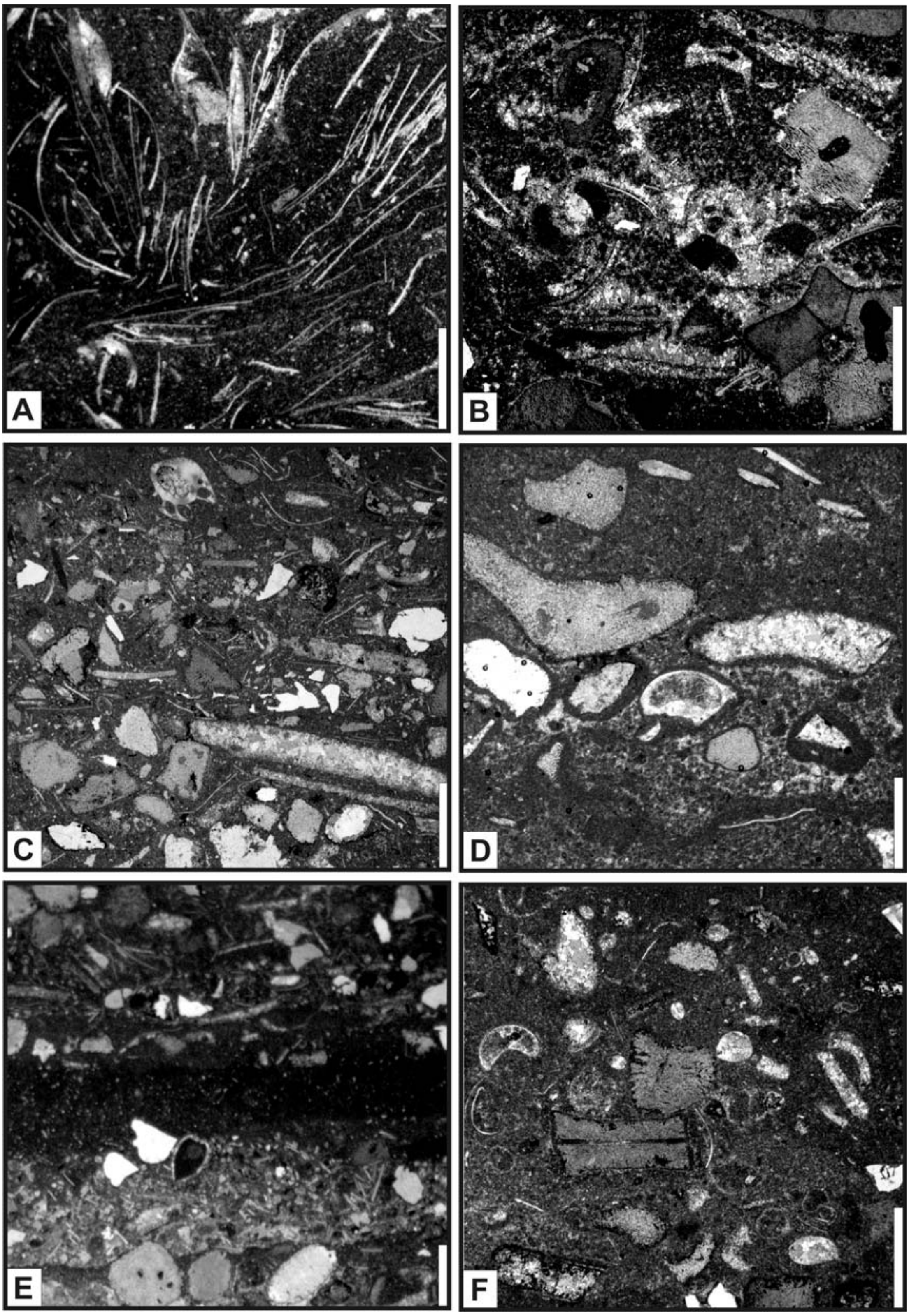

Fig. 4. Microfacies of the lower part of the Czorsztyn Limestone Formation from Stankowa Skała. Scale bar 1 mm. **A** – filament microfacies (bed 1a); **B** – filament-peloid microfacies with echinoderms (bed 2b); **C** – echinoderm-shell microfacies (bed 2c); **D** – peloid-echinoderm microfacies (bed 1b); **E** – filament-crinoid microfacies and micritic microfacies (bed 2c); **F** – microfacies with crinoids (bed 1b)

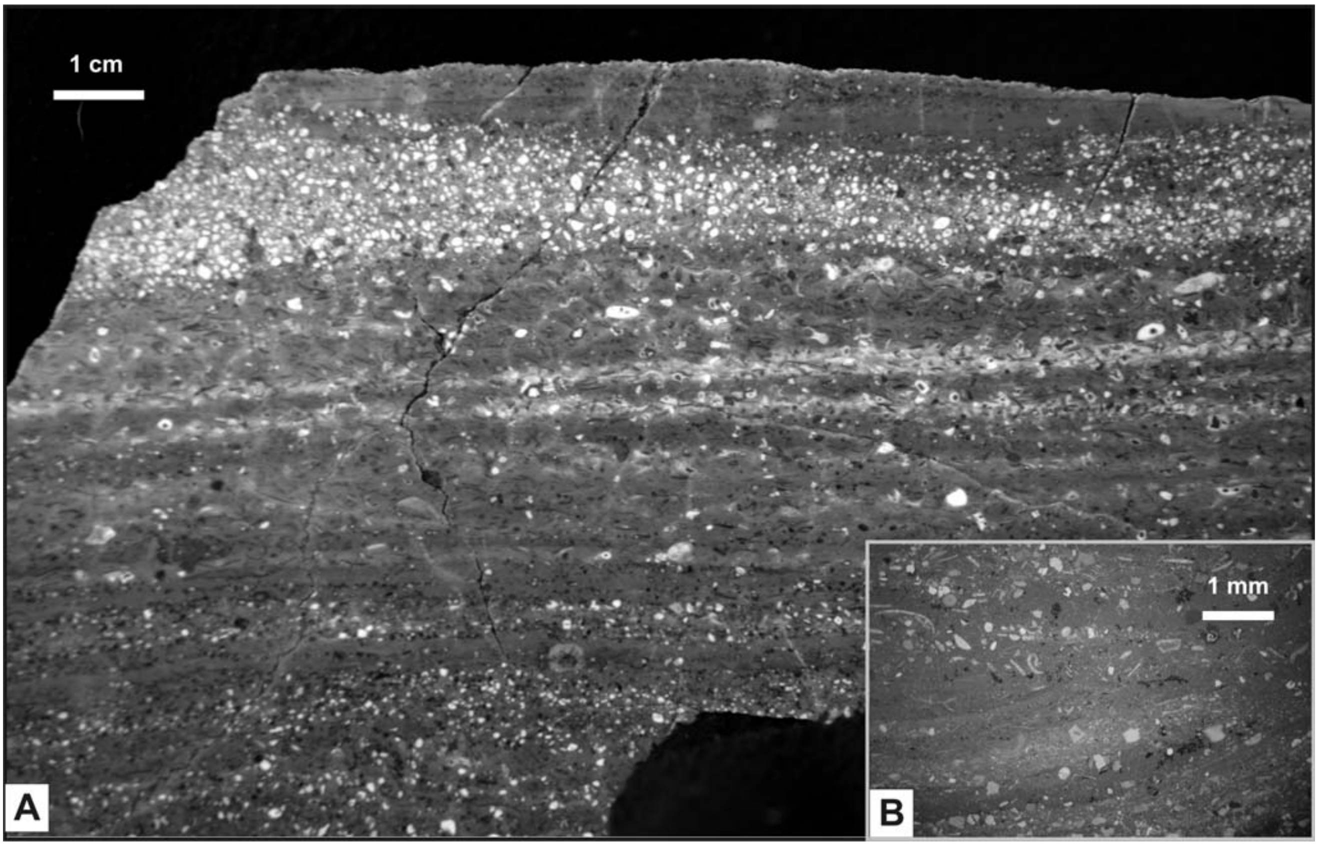

Fig. 5. **A** – laminated limestone from bed 1b of Stankowa Skała; **B** – laminated limestone with cross-bedding from bed 2a of Stankowa Skała

tified. Grains are mostly enveloped by thin micritic coatings.

Micritic microfacies (Fig. 4E). These are mudstones, less commonly wackestones, with small amounts of fine bioclasts, difficult to identify.

The top of bed 2c of the studied interval of the Czorsztyn Limestone Formation is uneven and covered by dark Fe-Mn oxides; it constitutes a hard ground surface. Bed 2 is capped by hard, non-nodular, micritic detrital limestones which infill the surface depressions (bed 3). Bed 3 yielded Fe-Mn nodules and a lot of organogenic remains – mainly fragmented ammonite and brachiopod shells. These limestones represent already the *Globuligerina microfacies*.

"Wapiennik" Quarry in Szaflary

The white and light-grey crinoidal limestones belonging to the Smolegowa Limestone Formation, cut by neptunian dykes filled with the limestones of the Czorsztyn Limestone Formation, crop out in western part of the "Wapiennik" Quarry (49°26'16.2N, 20°0'52.4''E; Fig. 6). The crinoidal limestones are directly overlain by well-bedded limestones of the Czorsztyn Limestone Formation.

Crinoidal limestones (of the Smolegowa Limestone Formation). In the "Wapiennik" Quarry at Szaflary, the deposits of the Smolegowa Limestone Formation are developed as light grey, indistinctly bedded crinoidal limestones. The section is 12 m thick and locally strongly tectonized. The sediments represent the *crinoidal microfacies*; mainly

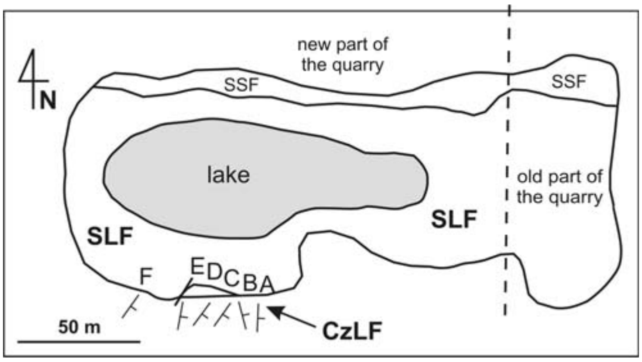

Fig. 6. Schematic map of "Wapiennik" Quarry in Szaflary: CzLF – Czorsztyn Limestone Formation; SLF – Smolegowa Limestone Formation; A–F – neptunian dykes and their orientation; lithostratigraphic unit not distinguished in the text: SSF – Skrzypny Shale Formation

grainstones. Crinoid fragments are dominant (40–60%), and are accompanied by detrital quartz (2–5%). Fragments of fine-grained quarzitic sandstones and dedolomites are sporadically observed, as well as single foraminifers and shell fragments.

Neptunian dykes (traditionally included into the Czorsztyn Limestone Formation) (Figs 7 and 8). The crinoidal limestones exposed in the southern wall of the quarry are cut by neptunian dykes, filled with red and violet-brown limestones. Six neptunian dykes (A–F) can be observed in

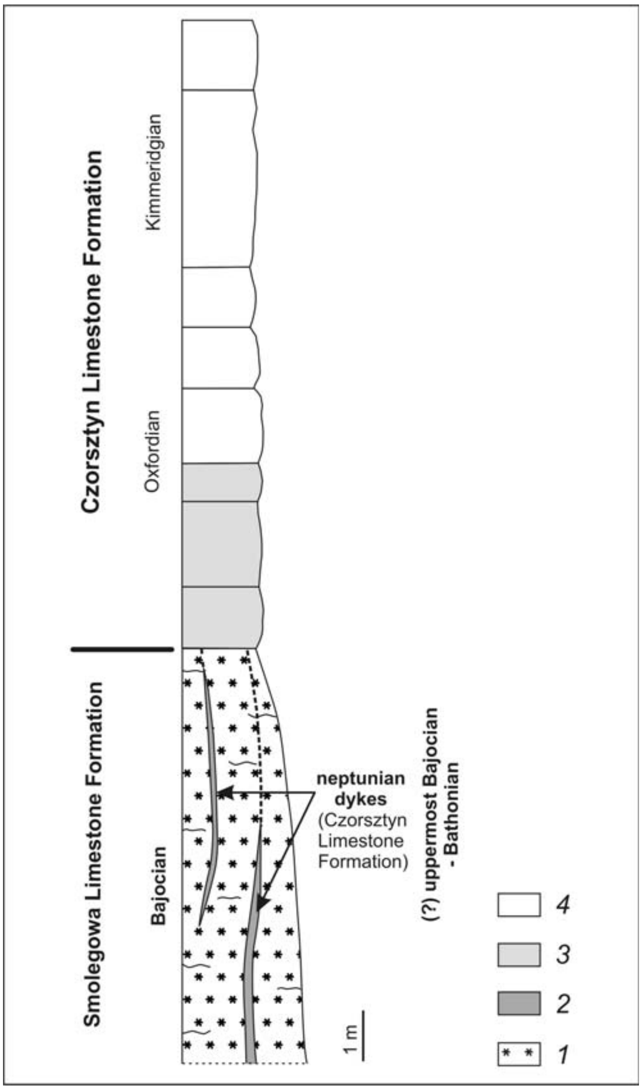

Fig. 7. Szaflary section. *1* – crinoidal limestones, *2* – laminated limestones, *3* – limestones with *Globuligerina*, *4* – limestones with *Saccocoma* (Jaworska, 2000)

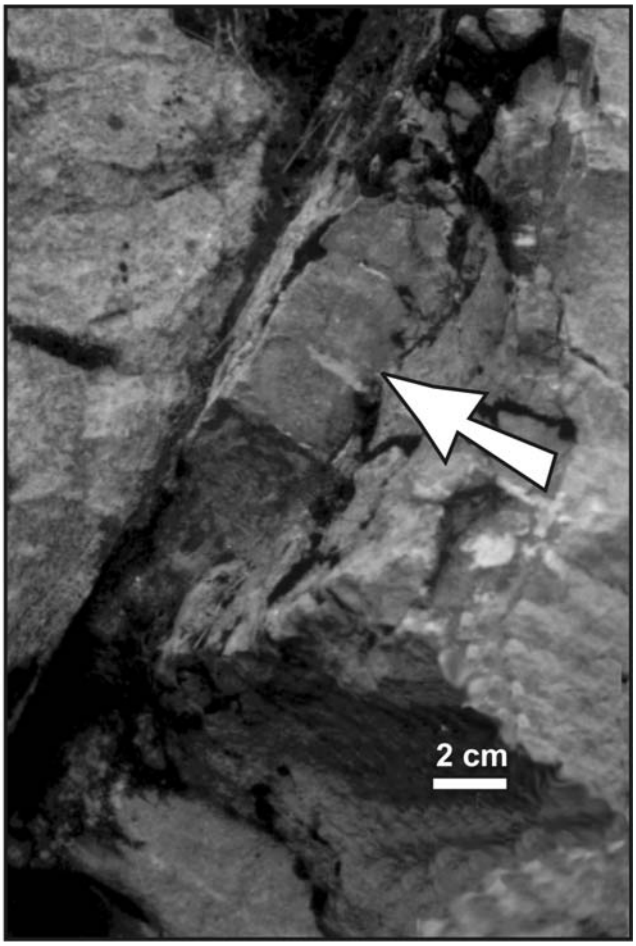

Fig. 8. Neptunian dyke from "Wapiennik" Quarry in Szaflary – dyke A

the quarry. Their thickness usually ranges between 0.5 and 7 cm, and reaches the maximum of 25 cm. Their visible length ranges between 80 to 350 cm. Dykes are developed along two fracture systems: 28°–43°/58°–76°S and 165°–190°/57°–70°S (before rotating the overlying strata into horizontal). The measurements of the orientation of neptunian dykes revealed a possible existence of two fracture systems: (1) neptunian dykes C, D and F – mean orientation: 174°/45°N, and (2) neptunian dykes A, B and E – mean orientation: 151°/73°N (after rotating the overlying strata into horizontal, but without correction for palaeomagnetic declination).

Dyke boundaries with the host rock are sharp. The limestones in dykes are often bedded parallel to the walls' outline. The boundaries between particular deposits are sharp and irregular. The most common dyke infillings are micritic or bioclast-bearing limestones. Sharp-edged fragments of white crinoidal limestones and admixtures of detrital quartz are also present. Limestones with small (up to 2 mm in diameter) oncoids (dykes C, E) are less common.

Deposits of the Czorsztyn Limestone Formation in the neptunian dykes represent several microfacies types: *echinoderm-filament microfacies* (dykes: C, D, E, F), *echinoderm-shell microfacies* (dyke B), *peloid microfacies* (dykes: C, E), *peloid-filament microfacies* (dykes: C, E), *filament microfacies* (dykes: A, C, E, F), *micritic microfacies* (dykes: A, D, E), and *grains with microbial coatings and peloid microfacies* (dykes: C, E) (Fig. 9). Many detrital elements in the infillings of neptunian dykes are covered by brown Fe-Mn coatings.

Echinoderm-filament microfacies (Fig. 9A). These are packstones and grainstones. Scattered echinoderm fragments (15–40%) – mainly crinoids, and filaments (5–30%), are the main detrital components. Grains of detrital quartz and limestone intraclasts (up to 2%) are less common. Benthic foraminifers *Marsonella* sp., *Lenticulina* sp. and *Ophthalmidium* sp., and fragments of solitary corals occur also sporadically.

Echinoderm-shell microfacies (Fig. 9B). These are packstones and grainstones. The dominating detrital components are represented by corroded echinoderm fragments (up to 50%) – mainly crinoids, but sometimes also echinoid spines. They are abundantly accompanied by recrystallized shell fragments (up to 20%) of brachiopods and filaments.

Peloid microfacies (Fig. 9C). These are laminated packstones with rich peloid accumulations (up to 40%).

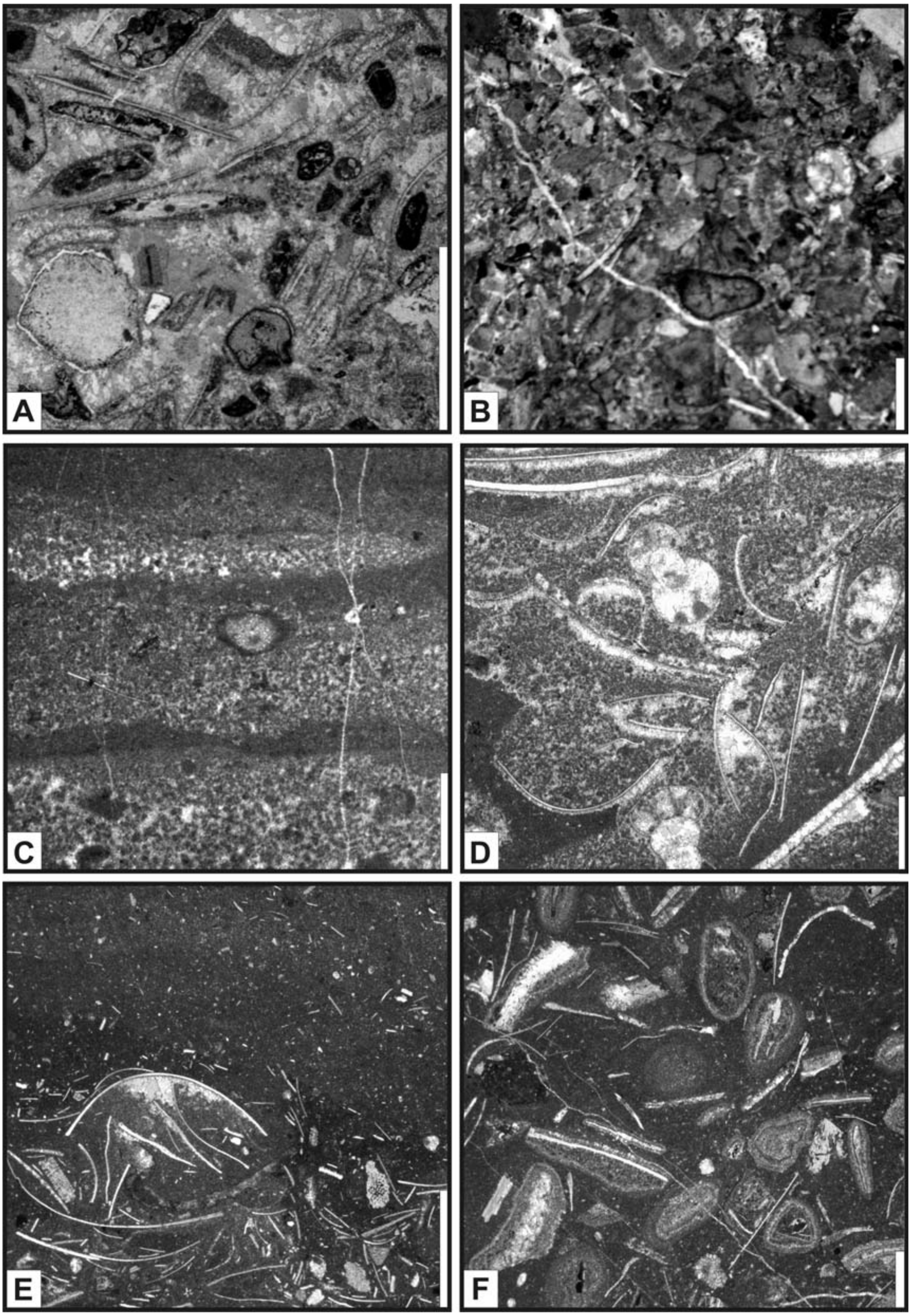

Fig. 9. Microfacies of the Czorsztyn Limestone Formation forming neptunian dykes in the "Wapiennik" Quarry in Szaflary. Scale bar 1 mm. **A** – echinoderm-filament microfacies (dyke C); **B** – echinoderm-shell microfacies (dyke B); **C** – peloid microfacies (dyke C); **D** – peloid-filament microfacies (dyke C); **E** – filament microfacies and micritic microfacies (dyke A); **F** – grains with microbial coatings and peloid microfacies (dyke E)

Echinoderm fragments (up to 7%) are also observed, as well as filaments and grains of detrital quartz.

Peloid-filament microfacies (Fig. 9D). These are laminated grainstones and packstones. The deposits are characterised by the occurrence of filaments (10%) and numerous peloids (30–50%). Shells of juvenile ammonites also sporadically occur.

Filament microfacies (Fig. 9E). These are packstones with various amounts of filaments (15–40%), which are accompanied by scarce echinoderm skeletal elements, *Globochaete* spores, brachiopod shell fragments, ostracods, benthic foraminifers *Ophthalmidium* sp., fragments of juvenile ammonites, juvenile gastropods, grains of detrital quartz, peloids, and intraclasts of mudstone and wackestone with filaments and *Globochaete* spores.

Micritic microfacies (Fig. 9E). These are laminated mudstones, less commonly wackestones, with a minor admixture of very small bioclasts, which are difficult for closer identification. Small broken filaments, crinoid fragments and *Globochaete* spores are also sporadically observed.

Grains with microbial coatings and peloid microfacies (Fig. 9F). These are packstones and grainstones composed of two kinds of grains: the ones are oncoids (up to 50%) and others devoid of microbial coatings. The nuclei of grains covered by microbial coatings are composed mainly of shell fragments – filaments and brachiopods, intraclasts of laminated limestones, and less commonly of echinoderm fragments. Grains devoid of microbial coatings are mainly peloids (20%), grains of detrital quartz, and various biogenic elements such as filaments, echinoderm plates, foraminifers of genus *Lenticulina*, and gastropod shells.

Czorsztyn Limestone Formation overlying the deposits of the Smolegowa Limestone Formation. These are 13-m-thick non-nodular, hard, red-brown pelitic limestones locally enriched in bioclasts. The limestones contain belemnite rostra and single crinoid ossicles. The lowest layer is enriched in Fe-Mn oxides and represents already the *Globuligerina microfacies*.

Breccia of the Wapiennik Breccia Member. In the eastern, older part of the "Wapiennik" Quarry, breccias of the Wapiennik Breccia Member were exposed (Birkenmajer, 1977). The rock attributed to the Wapiennik Breccia Member was discovered and described by Birkenmajer (1952, 1958, 1963, 1977) at the base of the Czorsztyn Limestone Formation. This is a breccia composed of angular fragments of white and red crinoidal limestones (from the Smolegowa Limestone and the Krupianka Limestone formations – see Fig. 2), 1–5 cm in diameter, cemented by red or pink matrix with sparse crinoidal fragments and filaments (Zydorowicz, 1991), which crops out in the old part of the "Wapiennik" Quarry in Szaflary (Fig. 6). The described thickness is 0.5 m.

STRATIGRAPHY

The crinoidal limestones of the Smolegowa Limestone Formation are mostly barren in fossils that would allow for their precise dating. Only recently, the Early Bajocian age of the lower part of the crinoidal limestone has been well documented by ammonite faunas (Krobicki & Wierzbowski, 2004; Wierzbowski *et al.*, 2004a). The upper part of this formation can be attributed to the Bajocian, since the overlying deposits are of latest Bajocian age (see Myczyński, 1973; Wierzbowski *et al.*, 1999).

Limestones representing the lowermost part of the Czorsztyn Limestone Formation in Stankowa Skała and neptunian dyke infillings in the "Wapiennik" Quarry at Szaflary yielded no fauna of stratigraphic importance. However, still younger deposits developed as the *Globuligerina microfacies* yielded few ammonites, found directly above the surface at the top of the studied deposits (e.g. bed 3 on Fig. 3). These include: *Euaspidoceras* sp., and fragmentary perisphinctids, some of them possibly representing specimens of Peltoceratinae (after determination of A. Wierzbowski). The data suggest an Oxfordian age of these deposits, so the lowermost part the Czorsztyn Limestone Formation in Stankowa Skała should be considered not younger than the Oxfordian. The neighbouring section in Babiarzowa Skała, a lithologic and microfacies analog to the Stankowa Skała, yielded ammonites of Callovian age, such as *Hecticoceras* and *Grossouvria*, which were described by Uhlig (1881; see also Birkenmajer, 1963). The recently discovered fauna in the Babiarzowa Skała section (Wierzbowski *et al.*, 2004b, 2005), possibly corresponding to that of Uhlig's, occurs within laminated limestones of the *filament microfacies*. Hence, the oldest deposits of the ammonitico rosso-type, occurring below the deposits of the *Globuligerina microfacies* in the Stankowa Skała section, could be ascribed to a stratigraphic interval from the (?)uppermost Bajocian to Callovian. Moreover, taking into account the overall microfacies development, it can be assumed that limestones occurring in the neptunian dykes in the "Wapiennik" Quarry at Szaflary represent the same discussed stratigraphic interval.

ENVIRONMENT PRECEDING AMMONITICO ROSSO SEDIMENTATION

Vertical movements in the Pieniny Klippen Basin and emergence of the Czorsztyn Ridge during the Bajocian resulted in a marked change of sedimentary conditions from oxygen-reduced dark terrigenous deposits (fleckenkalk/fleckenmergel facies) to appearance crinoidal limestones in the study area (Birkenmajer, 1963; see also Krobicki & Wierzbowski, 2004; Golonka & Krobicki, 2004). The occurrence of crinoid limestones was a result of development of crinoid communities on the southern, submerged slope of the Czorsztyn Ridge (Wierzbowski *et al.*, 1999). The studied localities represent sedimentary conditions nearest to the zone of crinoid habitats occupied by original crinoid populations, the "crinoid gardens", where the most typical locality of the zone close to the habitats is the "Wapiennik" Quarry at Szaflary (Głuchowski, 1986, 1987).

Rock fragments, which are often found in the crinoidal limestones of the Pieniny Klippen Belt, are a testimony of emergence of the northern part of the Czorsztyn Ridge (the so-called "external continental Czorsztyn Ridge" of Mišík

& Aubrecht, 1994). Quartz grains and dolomite fragments of the Middle Triassic age are most abundant. Fragments of the Lower and the Upper Triassic, and probably also the Lower Jurassic clastic rocks, as well as spongiolite, probably of Early Jurassic age, and fragments of magmatic rocks are less common (Aubrecht, 1993; Mišík & Aubrecht, 1994).

The deposition of crinoidal limestones was often related to the existence of sea bottom elevations, being a consequence of tectonic differentiation of the sedimentary basin into swells and deeper basins (Fig. 10A; e.g., Jenkyns, 1986; Winterer *et al.*, 1991; Wendt & Aigner, 1985). In the studied part of the Pieniny Klippen Basin, the sedimentation of crinoid calcarenites of the Smolegowa Limestone Formation corresponded to a single shallower-water episode that took place after the Czorsztyn Ridge was formed. The crinoidal limestones are interpreted as deposits building a temporary carbonate platform-like depositional form (Wierzbowski *et al.*, 1999).

The Czorsztyn Succession described in this study is represented only by white and grey crinoidal limestone, belonging to the Smolegowa Limestone Formation. Importantly, there are no red crinoidal limestones that could be ascribed to the Krupianka Limestone Formation (see Fig. 2), which are common at localites in the central and eastern parts of the Polish section of the belt. This may point to an existence of a major stratigraphic gap, embracing at least a part of the Upper Bajocian (uppermost part of the Garantiana Zone and the lowermost part of the Parkinsoni Zone; see Wierzbowski *et al.*, 1999). Only in the "Wapiennik" Quarry, in the Wapiennik Breccia Member, fragments of crinoidal limestones of the Smolegowa Limestone and also the Krupianka Limestone formations do occur, which may be treated as an evidence of local erosion that took place after the deposition of crinoidal limestones (Birkenmajer, 1958, 1963, 1977).

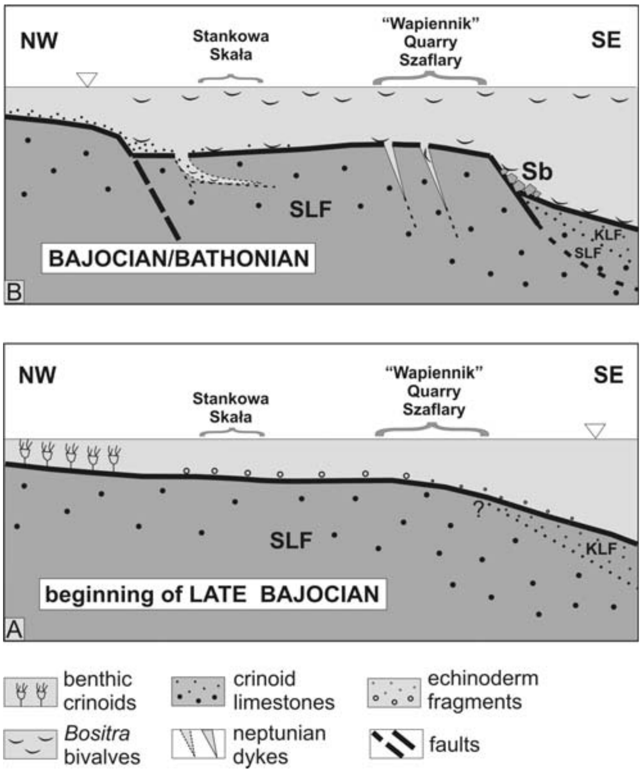

Fig. 10. Suggested geological evolution of the north-western-most part of the Pieniny Klippen Basin with the southern part of the Czorsztyn Ridge. SLF – Smolegowa Limestone Formation; KLF – Krupianka Limestone Formation; Sb – scarp breccias (Wapiennik Breccia Member)

AMMONITICO ROSSO SEDIMENTARY ENVIRONMENT

In contrast to the central and eastern part of the Pieniny Klippen Belt, where ammonitico rosso-type deposits have been preserved in a more complete sequence (see Wierzbowski *et al.*, 1999), in the Szaflary area these deposits can be found within the neptunian dykes only (Fig. 10B).

The trends of dykes observed in the "Wapiennik" Quarry at Szaflary show directional preference in line with orientation of tectonically induced fractures, being particularly abundant in the vicinity of normal faults. A system of normal faults, probably dipping eastwards, could form a submarine scarp, below which the detrital material derived from the erosion of the hanging wall built of crinoidal limestones was accumulated.

The neptunian dykes may develop in peripheral parts of elevated blocks during periods of active extensional tectonics (Blendinger, 1986). The tectonic origin of neptunian dykes is also indicated by the fact of their co-occurrence with crinoidal limestones in the palaeogeographic development of marine basins, and precisely in the early stage of disintegration of carbonate platforms (cf. Jenkyns, 1970, 1971). Some workers stress the correlation between the appearance of the neptunian dykes and the periods of basin deepening (Füchtbauer & Richter, 1983; Lehner, 1991: Winterer *et al.*, 1991).

In some places, the dykes contain sharp-edged fragments of crinoidal limestones of the Smolegowa Limestone Formation, detached from the fracture walls and incorporated into the infilling deposits. This proves that the period between the void opening and its infilling was relatively short. Detailed analyses of the surfaces of fractures cutting the crinoidal limestones in the "Wapiennik" Quarry at Szaflary revealed no features, which are characteristic for the surfaces subjected to a long non-deposition period, such as, for instance: covering by speleothems, cements and ferruginous encrustations (Schöll & Wendt, 1971; Wendt, 1971; Braithwaite & Heath, 1992). The surfaces of the studied fractures are usually sharp and smooth, and the shapes of the dykes are relatively simple. The depth of penetration into the underlying deposits is difficult to estimate and ranges between few and a dozen or so metres (in the available part it is up to 3.5 m).

The neptunian dykes are often filled with a characteristic sediment, i.e. red laminated pelite, the so-called "rot Pelit" (Wendt, 1971; Schlager, 1974). According to Wendt (1965; 1969; 1971), sedimentation of this type takes place in a calm environment of horizontal dykes ("S-fissures"), while the vertical dykes ("Q-fissures") are filled faster and in a higher energy environment by the sediments actually deposited on the sea bottom. Similar deposits, described here as the *micritic microfacies,* are observed in four of the dykes studied at Szaflary: A, B, D and E. These infillings show either distinct or faint lamination parallel to the walls limiting the dykes, and usually occur in the central parts of neptunian dykes (e.g. dykes A and B). The measurements of dip and strike do not, however, point to horizontal position of the dykes.

Numerous dykes of such a type have also been described from the Slovak part of the Pieniny Klippen Belt (Mišík, 1979; 1993; Mišík & Sýkora, 1993; Mišík *et al.*, 1994b; Aubrecht, 1997; Aubrecht *et al.*, 1997; Aubrecht & Túnyi, 2001). In this context, it should be noted that a characteristic feature of the lowermost part of the Czorsztyn Limestone Formation in Stankowa Skała and in a number of neighbouring klippes is the lack of nodularity, which is so characteristic of the ammonitico rosso-type deposits (see Kutek & Wierzbowski, 1986). Similar deposits were described as the Bohunice Limestone Formation from the Slovak part of the Pieniny Klippen Belt (Mišík *et al.*, 1994a; Mišík *et al.*, 1996). The lowermost part of this section in Stankowa Skała (beds 1a and 2b) is developed as reddish limestones with bioclasts, mainly shell coquinas, with subordinate micritic laminae. These deposits are rich in filaments, peloids and skeletal echinoderm elements, mainly crinoids. Moreover, a part of the deposits in Stankowa Skała (beds 1b, 2a and 2c) is developed as laminated limestones (Fig. 5A). Their special character is indicated by the following features: horizontal lamination, small-scale cross bedding (Fig. 5B), indistinct graded bedding of some portions of the sediment, erosive boundaries of some layers, and their alternation with limestones containing a large number of filaments. Graded bedding and cross bedding of the carbonate material and detrital admixtures, mainly quartz, point to redeposition of the material.

It is, therefore, plausible that these laminated limestones and limestones with filaments are infillings of horizontal neptunian sills. In such a case, the detrital material and, at least partly, the crinoid fragments may have originated due to erosion of older limestones of the Smolegowa Limestone Formation. It is likely that the crinoidal part of the covered sill was eroded before sedimentation of the *Globuligerina*-bearing limestones (see Fig. 3).

Another argument in favour of the hypothesis of sill deposits at Stankowa Skała is the presence of *Pokornyopsis* ostracods, since they are seldom found in open marine environments, being rather associated with horizontal fissures or submarine caves (Aubrecht & Kozur, 1995).

It is worth mentioning that the recently discovered contact with the overlying limestones can indicate that the rock in question really forms a sedimentary dyke (Andrzej Wierzbowski, *pers. comm.*). Also recently rediscovered red laminated limestones of the filament microfacies in the adjacent Babiarzowa Klippe, forming the subhorizontal neptunian dykes of Callovian age, can confirm this statement (Wierzbowski *et al.*, 2005).

Deposits rich in filaments from the studied part of the Czorsztyn Limestone Formation in the Stankowa Skała section are similar to those observed in the neptunian dykes in the "Wapiennik" Quarry at Szaflary.

Some features of the Stankowa Skała section differ from neptunian dykes from "Wapiennik" Quarry at Szaflary: larger quantities of detrital quartz in the Stankowa Skała section, even up to 5% in particular laminae, appear to indicate a smaller distance of this locality from the source area compared to the Szaflary outcrop, where the amount of detrital quartz does not exceed 1%. Other specific deposits exposed at Szaflary are limestones from neptunian dykes consisting of the *grains with microbial coatings and peloid microfacies*, which can be found in the neptunian dykes C and E. These limestones are one of the youngest dyke fillings, and can serve as indicators of slow deposition prevailing in the final phases of dyke infilling. Deposits partly resembling the *grains with microbial coatings and peloid microfacies* from neptunian dykes – the *filament-crinoid microfacies*, have been found only in Stankowa Skała, where apart from filaments and peloids, clasts covered by cyanobacterial coatings occur as well. The deposits resembling the *grains with microbial coatings and peloid microfacies,* namely limestones built of ooids and microoncoids, have also been described from neptunian dykes from the Czorsztyn Succession of the western part of the Pieniny Klippen Belt in Slovakia (Aubrecht *et al.*, 1997). There is, however, a possibility that the aforementioned ooids can be interpreted as recrystallised microoncoids with a radial structure (Aubrecht *et al.*, 1998).

In general, the development of the dyke infillings may be connected with the onset of deposition of the ammonitico rosso-type limestones, which took place at the fall of the Bajocian and in the Bathonian. This was genetically connected with the Meso-Cimmerian tectonic movements leading to a tectonic break-up and submergence of some parts of the Czorsztyn Ridge.

Associated with neptunian dykes are breccias forming at the foot of submarine scarps, the so-called "scarp breccias", which are similar to that from the "Wapiennik" Quarry in Szaflary described by Birkenmajer (1952, 1958, 1963, 1977). They have also been observed in the Slovak segment of the Pieniny Klippen Belt, mainly in its western part (Mišík, 1993; Mišík *et al.*, 1994b; Mišík *et al.*, 1996; Aubrecht, 1997; Aubrecht *et al.*, 1997), but locally also from the eastern part (Mišík & Sýkora, 1993). This type of breccias, composed of fragments of crinodal limestones similar to the basement rocks (Smolegowa Limestone Formation) from the western part of the Pieniny Klippen Belt in Slovakia, has been described as the Krasin Breccia. Its formation was partly coeval with the deposition of the crinoidal limestones, and partly also with the younger limestones represented by the *filament microfacies* (Mišík *et al.*, 1994b), and therefore must have taken place close to the Bajocian/Bathonian boundary due to syndepositional tectonics.

The Meso-Cimmerian activity resulted in transversal topographic differentation of the Czorsztyn Ridge and, in cosequence, an abrupt turnover in sedimentary development, which is expressed by the appearence of ammonitico rosso-type limestones (e.g. Wierzbowski *et al.*, 1999; see also Jenkyns & Torrens, 1971; Dewey *et al.*, 1973). Tectonic activity may be related to the Meso-Cimmerian extensional movements, which dismembered the Czorsztyn Ridge into a set of submerged blocks (Birkenmajer, 1963, 1977, 1986; see also Wierzbowski, 1994; Golonka *et al.*, 2003; Golonka & Krobicki, 2004; Krobicki & Wierzbowski, 2004). The fault-induced break-up caused not only great topographical differences in the submarine part of the Czorsztyn Ridge, but also led to submergence of some parts of the elevated Czorsztyn Ridge, resulting in interruption of sedimentation, and ceased the delivery of clastic material to the ammonitico rosso-type deposits in the Czorsztyn Succession, which now crop out in the central and eastern parts of the Polish segment of the Pieniny Klippen Belt (Wierzbowski *et al.*, 1999).

CONCLUSIONS

There are major differences in the development of the oldest ammonitico rosso-type deposits between the northwesternmost and central/eastern parts of the Pieniny Klippen Belt in Poland. While in the central and eastern parts limestones of Middle Jurassic age are represented by typical red nodular limestones with a minor admixture of crinoidal material and fragments of older rocks, the so-called "extraclasts" (cf. Wierzbowski *et al.*, 1999), the deposits attributed to the Czorsztyn Limestone Formation in the northwesternmost part are mostly non-nodular shell coquinas, represented by the *filament microfacies* rich in various bioclasts, numerous peloids, as well as laminated limestones composed of crinoidal fragments and "extraclasts", which show cross stratification and graded bedding represented by neptunian dykes. A peculiar rock type corresponding to the lower part of the Czorsztyn Limestone Formation in the study area is the breccia formed at the base of submarine scarps. All these facts indicate that the central and eastern parts of the Pieniny Klippen Belt in Poland and northwesternmost part represent different sedimentary zones which existed at that time in the Pieniny Klippen Basin (Sidorczuk, 2003), with "transitional area" in the present Szaflary region.

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Streszczenie

ŚRODKOWOJURAJSKIE OSADY AMMONITICO ROSSO W PÓŁNOCNO-ZACHODNIEJ CZĘŚCI PIENIŃSKIEGO PASA SKAŁKOWEGO POLSKI I ICH ZNACZENIE PALEOGEOGRAFICZNE NA PRZYKŁADZIE STANKOWEJ SKAŁY I KAMIENIOLOMU "WAPIENNIK" W SZAFLARACH

Magdalena Sidorczuk

Środkowojurajskie osady typu ammonitico rosso, będące przedmiotem badań, znajdują się w dwóch odsłonięciach północno-zachodniej części polskiego odcinka pienińskiego pasa skałkowego. Wybrane odsłonięcia – Stankowa Skała koło Zaskala i kamieniołom "Wapiennik" w Szaflarach należą do czorsztyńskiej sukcesji skałkowej (Fig. 1). Profil Stankowej Skały rozpoczyna się wapieniami krynoidowymi zaliczanymi do formacji wapienia ze Smolegowej. Powyżej występują wapienie reprezentujące formację wapienia czorsztyńskiego (Fig. 2), z których została szczegółowo opisana najniższa cześć (warstwy 1 i 2 – Fig. 3). W kamieniołomie "Wapiennik" występują wapienie krynoidowe zaliczane do formacji wapienia ze Smolegowej, które są pocięte opisanymi w pracy żyłami neptunicznymi formacji wapienia czorsztyńskiego (Fig. 7). Bezpośrednio nad wapieniami krynoidowymi znajdują się uławicone wapienie formacji wapienia czorsztyńskiego. Ze wschodniej, starej części kamieniołomu pochodzi brekcja zbudowana z okruchów wapieni krynoidowych i czerwonego matryksu zaliczana do ogniwa brekcji z Wapiennika, najniższej części formacji wapienia czorsztyńskiego, opisywana przez Birkenmajera (1952; 1958; 1963; 1977) (Fig. 6).

Osady w wymienionych odsłonięciach, mimo, że tradycyjnie zaliczane do osadów typu ammonitico rosso, znacznie różnią się pod względem wykształcenia od osadów formacji wapienia czorsztyńskiego z centralnej i wschodniej części pienińskiego pasa skałkowego. Profil Stankowej Skały charakteryzuje się występowaniem uławiconych, twardych, niezbulonych wapieni, które często wykazują laminację (warstwa 1b, 2a i 2c; Fig. 5). Wapienie laminowane reprezentują następujące mikrofacje: *szkarłupniowo-muszlową*, *peloidową*, *peloidowo-szkarłupniową*, *filamentowo-krynoidową*, *mikrytową* oraz *"z krynoidami"* (Fig. 4). Wapienie pozostałej części badanego odcinka formacji wapienia czorsztyńskiego (warstwa 1a i 2b) reprezentują dwa rodzaje mikrofacji: *filamentową* i *filamentowo-peloidową ze szkarłupniami* (Fig. 4). W kamieniołomie "Wapiennik" w obrębie wapieni krynoidowych występują skośne żyły neptuniczne, głównie z wapieniami mikrytowymi i wapieniami ziarnistymi (Fig. 8). Osady tworzące żyły neptuniczne reprezentują następujące mikrofacje: *szkarłupniowo-filamentową*, *szkarłupniowo-muszlową*, *peloidową*, *peloidowo-filamentową*, *filamentową*, *mikrytową* oraz mikrofację *ziarn z powłokami mikrobialnymi i peloidami* (Fig. 9).

Wapienie dolnej części formacji wapienia czorsztyńskiego z odsłonięcia Stankowa Skała i wypełnienia żył neptunicznych z kamieniołomu "Wapiennik" k/Szaflar można zaliczyć do przedziału najwyższy(?) bajos – kelowej.

Istnieją znaczne różnice w wykształceniu najstarszych osadów typu ammonitico rosso występujących we wschodniej i środkowej części pienińskiego pasa skałkowego w Polsce oraz tych obserwowanych w opisanych odsłonięciach z części północo-zachodniej. W profilach wschodniej i środkowej części pienińskiego pasa skałkowego, poniżej wapieni ammonitico rosso, występują czerwone wapienie krynoidowe zaliczane do formacji wapienia z Krupianki, których nie stwierdzono w badanej północno-zachodniej części, co może wskazywać na istnienie znacznej luki stratygraficznej w tym rejonie (Fig. 10A; patrz także Fig. 2). Natomiast w środkowej i wschodniej części pienińskiego pasa skałkowego występują wapienie bulaste, charakteryzujące się obecnością mikrofacji *filamentowej* i mikrofacji *filamentowej ze ślimakami juwenilnymi* z niewielkim udziałem innych bioklastów oraz okruchów skał starszych – "ekstraklastów". W części północno-zachodniej wapienie ammonitico rosso nie są zbulone, często wykazują laminację nawet z warstwowaniem skośnym i uziarnieniem frakcjonalnym, a mikrofacje reprezentują znacznie szersze spectrum: od mikrofacji *filamentowych* poprzez *szkarłupniowe* i *szkarłupniowo-muszlowe* aż do *peloidowych* i *mikrytowych,* są także bogatsze w "ekstraklasty". Zespół wymienionych cech wskazuje na redepozycję materiału, a sedymentacja tego osadu mogła zachodzić w połogich spękaniach dna tworząc poziome żyły neptuniczne (sille), które na skutek późniejszej erozji zostały pozbawione osadu przykrywającego.

Ponadto z rejonu Szaflar opisano liczne żyły neptuniczne i brekcje wapienne (Birkenmajer, 1952, 1958, 1963, 1977) interpretowane jako brekcje przyskarpowe, związane z synsedymentacyjnymi procesami tektonicznymi zachodzącymi na obszarze grzbietu czorsztyńskiego, które miały miejsce na przełomie bajosu i batonu w czasie mezokimeryjskich ruchów ekstensyjnych (Fig. 10B).

Powyższe obserwacje wskazują, że wschodnia i środkowa część pienińskiego pasa skałkowego Polski oraz jego północno-zachodni obszar reprezentują odmienne strefy sedymentacji w basenie skałkowym, ze strefą "graniczną" w rejonie dzisiejszych Szaflar.