

REEF-MICROENCRASTERS ASSOCIATION *LITHOCODIUM AGGREGATUM*–*BACINELLA IRREGULARIS* FROM THE CIESZYN LIMESTONE (TITHONIAN–BERRIASIAN) OF THE OUTER WESTERN CARPATHIANS (POLAND)

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Abstract: Debris-flow sediments belonging to the Upper Cieszyn Limestone (Berriasian) are exposed near Żywiec (Polish part of the Outer Western Carpathians). The debris-flow sediments include clasts of bioclastic limestones (boundstones) derived from both microbial-sponge mud mounds and coral-algal reefs. The microencruster assemblage *Lithocodium aggregatum*–*Bacinella irregularis* has been found in clasts from coral-algal reefs. This assemblage unequivocally proves the presence of shallowing-upward reefal sequences on the Silesian Ridge. The development of the coral-algal reefs was probably a consequence of intense aggradational growth of microbolite-sponge mud mounds, accompanied by intense uplift movements of the neo-Cimmerian phase.

Key words: Outer Western Carpathians, Cieszyn Limestone, coral-algal reef, microbial-sponge facies, *Lithocodium aggregatum*, *Bacinella irregularis*.

Introduction

The Cieszyn Beds, present in the western part of the Polish Outer Western Carpathians, are divided into the Lower Cieszyn Shales, Lower Cieszyn Limestone, Upper Cieszyn Shales and Upper Cieszyn Limestone (Peszat 1967; Eliáš 1970; Malik 1986; Słomka 1986a,b, 2001). They are Kimmeridgian–Valanginian in age. Exotic clasts of the Cieszyn Beds have been deposited in the Silesian Basin, probably of pull-apart origin, bounded in the north by the Inwałd Elevation and in the south by the Silesian Elevation (cf. Peszat 1967; Słomka 1986a; Matyszkiewicz & Słomka 1994; Olszewska & Wieczorek 2001). Both elevations were probably broad ridges. Initially, in Kimmeridgian and Early Tithonian time, clastic material came to the basin mainly from the Baška-Inwałd Ridge. In the Late Tithonian, the importance of the Silesian Ridge began to increase in importance as the source area (Matyszkiewicz & Słomka 1994).

The Upper Cieszyn Limestone (Berriasian) in the area near Żywiec (Fig. 1) is represented by debris flows (Książkiewicz 1958; Słomka 1986b, 2001). The debris-flow deposits exposed in the bed of the Leśnianka stream at Leśna (Fig. 2) include clasts derived from erosion of microbial-sponge mud mounds and from coral-algal reefs. The latter have been found to include an association of microencrusters *Lithocodium aggregatum*–*Bacinella irregularis*, accompanied by a typical shallow-water assemblage of algae *Solenopora* sp., *Cayeuxia* sp. and microporellid *Koskinobullina socialis* Cherchi et Schroeder, 1979.

The taxonomic affinity of *Lithocodium aggregatum* Elliott, 1956 is unclear. Schmid & Leinfelder (1996) include it in the encrusting foraminifers of the family Loftusiaceae. According

to Moussavian (in Koch et al. 2002), these forms are akin to boring sponges. The assemblage with *Lithocodium aggregatum* also includes abundant *Bacinella irregularis* Radoičić, 1959, attributed to cyanobacteria (Schäfer & Senowbari-Daryan 1983; Schmid 1996), or regarded as one organism with *Lithocodium* (Segonzac & Marin 1972; Koch et al. 2002).

The assemblage *Lithocodium*–*Bacinella* in fossil sediments unequivocally identifies a shallow-water, reefal or lagoonal environment of normal salinity and moderate or elevated water energy (Schmid & Leinfelder 1996; Dupraz & Strasser 1999, 2002). The assemblage *Lithocodium*–*Bacinella* is sometimes accompanied by the boring foraminifer *Troglotella incrustans* Wernli et Fookes, 1992 (Schmid 1996; Schmid & Leinfelder 1996; Kołodziej 1997; Dupraz & Strasser 1999; Matyszkiewicz & Krajewski 2003), which proves a phase of bioerosion of the carbonate buildups. Neuweiler & Reitner (1992) — regarding *Lithocodium* and *Bacinella* as synonyms — relate the mass occurrence of *Lithocodium aggregatum* to eutrophication of the environment or increase in seawater alkalinity. Dupraz & Strasser (2002) propose the opposite interpretation of the *Lithocodium*–*Bacinella* association, which seems to prefer nutrient limited (oligotrophic) environments. This interpretation is not only based on microencruster association, but also on coral and other macrofauna species, bioerosion and sedimentation evidence. The presence of the microencruster assemblage *Lithocodium*–*Bacinella* is especially important in those sediments for which bathymetric interpretation is problematic (cf. Neuweiler & Reitner 1992; Matyszkiewicz & Krajewski 2003).

The *Lithocodium*–*Bacinella* association has been repeatedly described from Upper Jurassic platform deposits of the northern Tethys margin (Dragastan 1985; Leinfelder 1986; Golon-

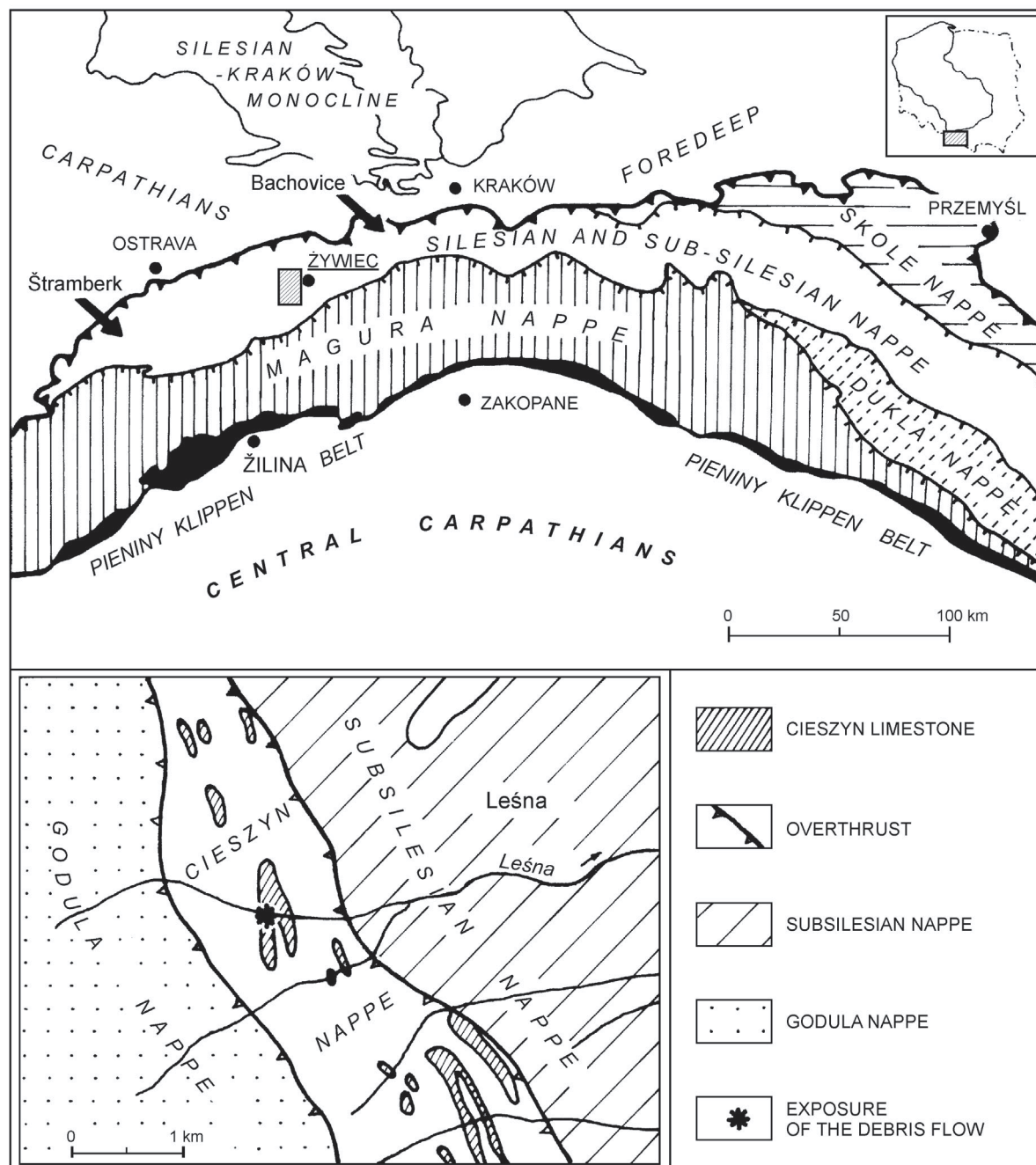


Fig. 1. Location of studied area (rectangled) with positions of Štramberk and Bachovice (black arrows).

ka 1970; cf. Barthel et al. 1971; Leinfelder et al. 1993, 1994; Schmid & Leinfelder 1995, 1996; Herrmann 1996; Schmid 1996; Hoffmann et al. 1997; Helm & Schülke 1998, 1999; Dupraz & Strasser 1999, 2002; Krajewski 2001; Matyszkiewicz & Krajewski 2003) and from the North Atlantic shelves (cf. Hüßner 1985; Leinfelder 1992; Leinfelder et al. 1993; Ourribane et al. 2000), where it is commonly encountered in coral-algal facies (Leinfelder et al. 1993; Dupraz & Strasser 1999, 2002; Ourribane et al. 2000). Recently, the same assemblage has been also found in deposits of the Upper Jurassic microbial megafacies of the northern Tethys margin (Matyszkiewicz & Krajewski 2003).

A shallow-water assemblage of reefal organisms from exotic limestones of the Silesian Unit of the Western Carpathians was mentioned by Mišík (1979), Eliášová (1981), Eliáš & Eliášová (1984), Hoffmann (1992), Kołodziej (1997), Soták & Mišík (1997) and Olszewska & Wiczeorek (2001). The *Lithocodium-Bacinella* association has been not hitherto reported from the Cieszyn Limestone exotics, though the presence of shallow-water, high-energy sedimentary environments has been proven (Matyszkiewicz & Słomka 1994). Olszewska & Wiczeorek (2001) have described exotics with the *Lithocodium-Bacinella* assemblage in the so called "Inwałd limestones". The Inwałd Elevation, which formed the northern

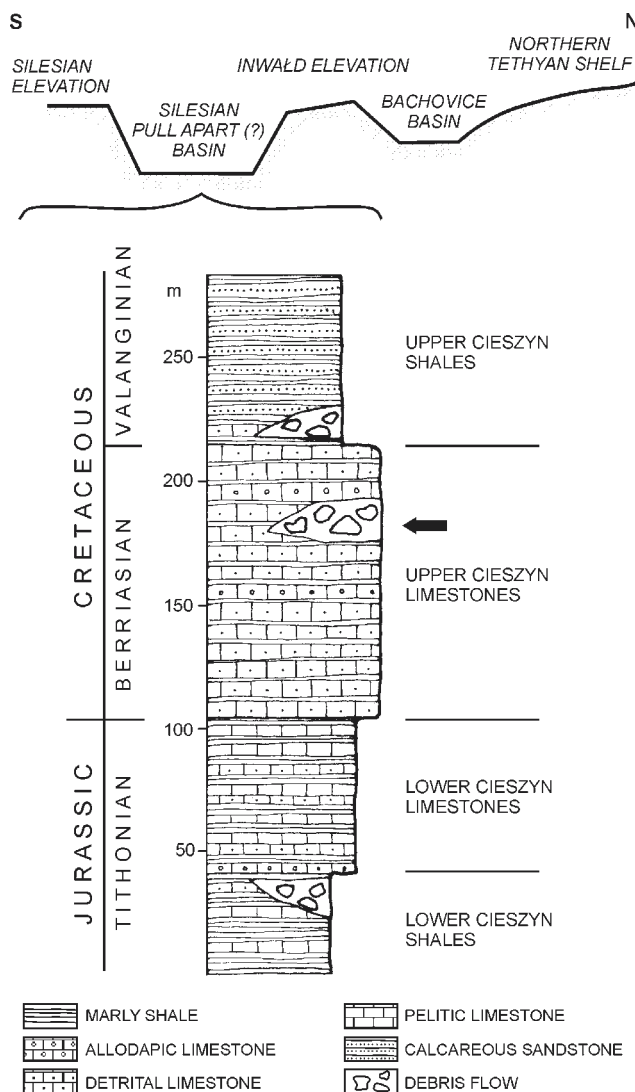


Fig. 2. Lithostratigraphic profile of the Cieszyn Beds in the Żywiec area and position of the Silesian pull-apart (?) Basin near the transition between the Jurassic and Cretaceous ages. Arrow indicates the position of the debris flow described in the text.

margin of the Silesian Basin, was proposed as the source of these exotics (Fig. 2).

Material and methods

The investigated exotic blocks in debris flow sediments have been found in one locality, in the bed of the Leśnianka stream at Leśna (Fig. 2). The debris flow layers vary in thickness from 30 to 100 cm. They include locally clasts of bioclastic limestones up to 0.5 m in size. About 40 samples have been taken in the layers.

The main method of the study was microfacies analysis, supplemented by mesoscopic observations of polished sections. In large samples, more than one thin section have been made to better control the variability. The microfacies analysis was performed on 46 thin sections of standard size.

Microfacies description

Limestone exotics from the Leśnianka stream section are rudstones with limestone intraclasts up to 1.5 cm in diameter embedded in blocky calcite cement (Fig. 3A). Also embedded in the cement are rare quartz grains up to 1 mm in diameter and echinoderm plates with syntaxial overgrowths. Two major facies types are present in intraclasts within one exotic block: the microbial-sponge facies and the coral-algal facies (Fig. 3A).

Microbial-sponge facies

The microbial-sponge facies is represented by intraclasts of microbolic-sponge boundstones, wackestones and packstones, embedded in blocky calcite cement. The shapes of some microclasts are highly irregular, with numerous processes and indentations (Fig. 3A).

Calcified skeletons of siliceous hexactinellid sponges (Fig. 4D,F), polychaetes *Terebella lapilloides* (Fig. 4D) and unidentified benthic foraminifers are clearly discernible in microbolic-sponge boundstones. Voids up to 1.5 mm in diameter, filled with dolomitic vadose crystal silt and cemented with Fe oxides are present at the grain boundaries (Fig. 4F). Some intraclasts consist of layered thrombolite (cf. Aitken 1967; Kennard & James 1986; Schmid 1996; Shapiro 2000), gradually passing to wackestone.

Wackestone intraclasts probably represent fragments of the sediment between the microbolite-sponge associations, which formed the rigid framework of the buildups. The wackestones include abundant dispersed fine (up to 0.2 mm in diameter) autigenic quartz grains and borings filled with dolomitic vadose crystal silt (Fig. 4E). Crystals of dedolomite calcite bound by Fe oxides are also locally present. The dolomite and dedolomite calcite crystals do not exceed 0.1 mm in diameter (Fig. 4E). Preserved boring organisms include the sponge *Aka* sp. (Fig. 4B; cf. Reitner & Keupp 1991). Irregular patches of epigenetic pyrite are also present locally.

Packstone intraclasts are a subordinate facies variety of the microbial-sponge facies. Its components include calcified spicules of siliceous sponges, small oncoids, indetermined benthic foraminifers and sporadic calcispheres.

Coral-algal facies

The coral-algal facies is represented by regularly shaped rounded intraclasts of coral-algal framestone (Fig. 3A). The main components are massive recrystallized scleractinian corals (Fig. 3B,C), accompanied by red algae *Solenopora* sp. (Fig. 4C), microproblematicum *Koskinobullina socialis* (Fig. 4A; cf. Cherchi & Schroeder 1979, 1985), *Cayeuxia* sp. and *Bacinella irregularis* (Figs. 3B, 4A,C) belonging to the Cyanophyceae and the microencruster assemblage *Lithocodium-Bacinella* (Fig. 3C).

Massive skeletons of scleractinian corals with strongly obliterated internal structure are commonly encrusted by microencruster assemblages. *Lithocodium* encrusts mainly outer surfaces of corallites (Fig. 3C) while *Bacinella* fills spaces between the septa and growth voids within the reef framework

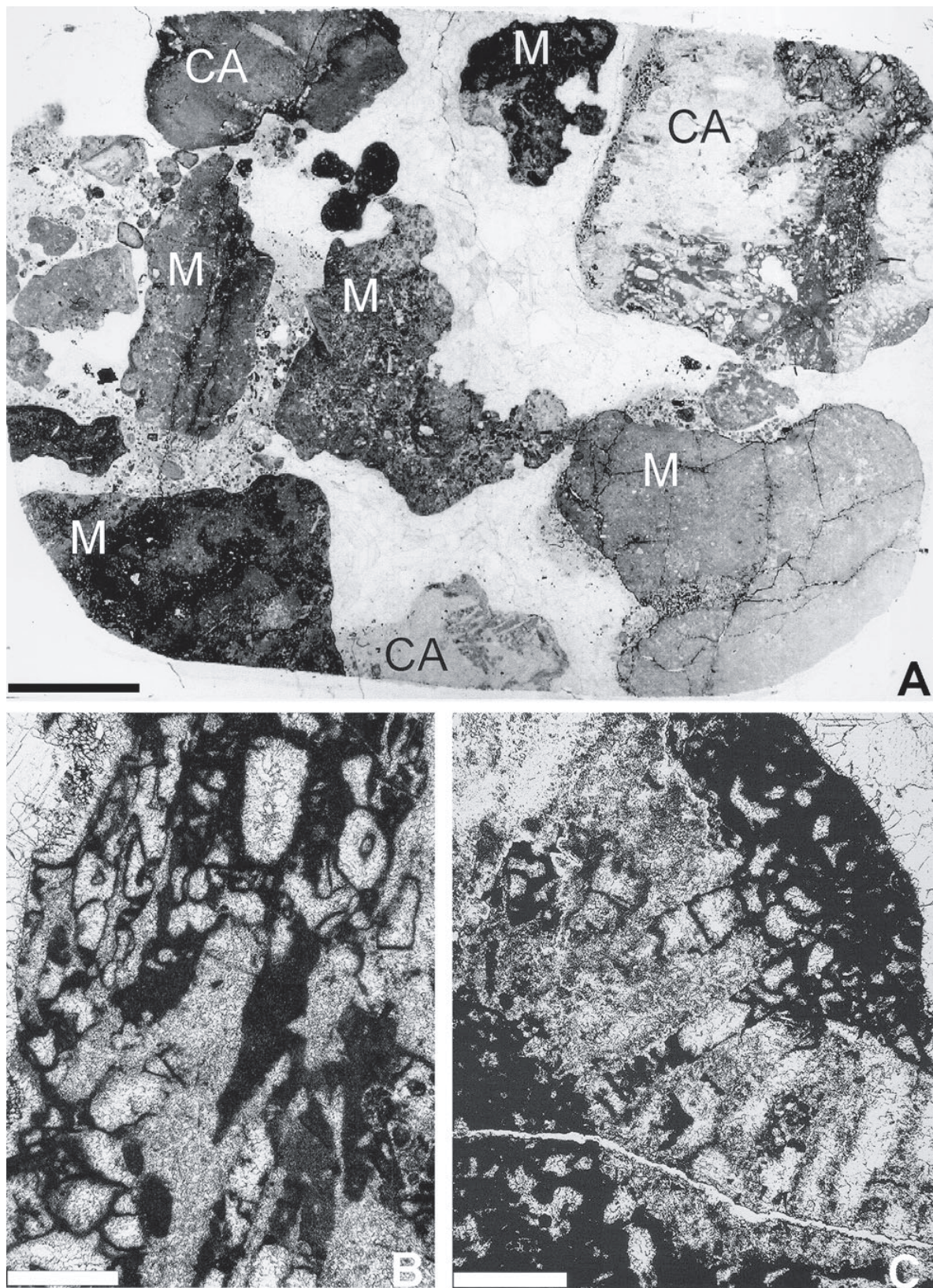


Fig. 3. Microfacies of exotic blocks from the Leśnianka stream section at Leśna. **A** — Rudstone with intraclasts of microbial-sponge (M) and coral-algal (CA) facies in blocky sparite calcite cement. Irregular shapes of some intraclasts are due to aggradational neomorphism. Scale bar is 5 mm long. **B** — *Bacinella irregularis* Radoičić, 1959, fills voids in a scleractinian coral. Coral-algal facies. Scale bar is 0.8 mm long. **C** — *Lithocodium aggregatum* assemblage (upper right corner)–*Bacinella irregularis*. *Bacinella* partly fills voids between the septa in a scleractinian coral. Coral-algal facies. Scale bar is 0.8 mm long.

(Fig. 3B,C; cf. Ourribane et al. 2000). *Lithocodium aggregatum* includes sporadic bubble-like structures, which may represent the commensalic foraminifers *Troglotella incrustans* (superfamily Hormosinacea). Juvenile forms of these foraminifers bored into the carbonate substrate and were commensal with *Lithocodium aggregatum* (Schmid & Leinfelder 1996; Dupraz & Strasser 1999). A part of the growth voids are settled by micropore-forming *Koskinobullina socialis* (Fig. 4A) and the cyanobacteria *Cayeuxia* sp. The coral-algal facies intraclasts also include large, up to ca. 1 cm in diameter, fragments of *Solenopora* sp., whose outer surfaces are encrusted by the *Bacinella irregularis* (Fig. 4C).

Discussion and conclusions

The concurrence in one exotic block of intraclasts of the microbial-sponge and coral-algal facies (Fig. 3A) indicates the presence of both typical microbolite-sponge buildups and coral-algal ones on the Silesian Ridge (cf. Matyszkiewicz & Słomka 1994). The lithology of the microbolite-sponge buildups is similar to their equivalents in platform sediments of the microbial megafacies (cf. Gwinner 1971; Matyszkiewicz 1997) of the Oxfordian-Kimmeridgian transition, known from the southern part of the Silesian-Kraków Monocline (cf. Matyszkiewicz 1997, 1999, 2001; Krajewski 2001; Matyszkiewicz & Krajewski 2003). This monocline is adjacent to the Carpathian Foredeep from the north (Fig. 1) and in Late Jurassic time it was part of the northern stable shelf of the Tethys. The age of the sediments from which the intraclasts were derived is difficult to establish because of the lack of index fossils. The presence of the microbial megafacies suggests that the clasts are not older than Late Jurassic and represent a higher, Kimmeridgian-Tithonian part of the Jurassic or earliest Cretaceous (cf. Darga & Schlagintweit 1991; Moshhammer & Schlagintweit 1999; Schlagintweit & Ebli 1999; Schlagintweit & Gawlik 2003).

Coral-algal reefs similar to those described from the exotic blocks in the Żywiec area do not occur in the nearby foreland of the Carpathians. However, quite numerous occurrences of debris of coral-algal limestones are known from the Upper Jurassic deposits in the southern part of the Silesian-Kraków Monocline (Matyszkiewicz 1993, 1997; Krajewski 2001; Matyszkiewicz & Krajewski 2003). Typical coral-algal reefs have been reported by Olszewska (2001) from boreholes reaching the basement of the Outer Carpathian flysch nappes. The exotic blocks from the Leśnianka stream section clearly differ from those found at Bachowice (Książkiewicz 1956), which were laid down in a basin situated north of the Inwałd Elevation (Fig. 2; cf. Olszewska & Wiczorek 2001).

According to Matyszkiewicz & Słomka (1994), two belts of carbonate buildups were present on the Silesian Ridge: a deeper belt of microbolite-sponge buildups and a shallower one, represented by coral-algal reefs. The new findings of exotics and results of microfacies studies on the Upper Jurassic deposits in the southern part of the Kraków-Wieluń Upland (Matyszkiewicz 1997; Krajewski 2001; Matyszkiewicz & Krajewski 2003) provide foundations for a new, alternative model of carbonate buildup distribution on the Silesian Eleva-

tion. This model accepts the presence of only one belt of the buildups, which underwent transformation from microbolite-sponge mud mounds to coral-algal reefs. Numerous examples of continuous transition from microbolite-sponge buildups to classical coral reefs have been described in literature (Steiger & Jansa 1984; Leinfelder et al. 1993; Leinfelder & Keupp 1995; Herrmann 1996; Ourribane et al. 2000; Schmid et al. 2001) and attributed to rapid aggradational growth not compensated by subsidence.

The rise of the microbolite-sponge buildups to the wave base depth, certainly within the euphotic zone, should be accompanied by a marked change in biocenoses, so that the next step in the ecological succession would be spectacular replacement of the microbolite-sponge buildups by coral-algal reefs (cf. Leinfelder 1993; Leinfelder & Keupp 1995; Leinfelder & Schmid 2000; Schmid et al. 2001). The intense water movement caused appearance of numerous encrusting organisms. The appearance of the *Lithocodium aggregatum*-*Bacinella irregularis* assemblage is an unequivocal indication of shallow oligotrophic environment (Dupraz & Strasser 2002). These could grow in shallow-water, highly energetic oligotrophic conditions due to their ability to penetrate the substrate.

Before the settlement of the coral-algal biocenoses, a phase of bioerosion occurred at the tops of the microbolite-sponge carbonate buildups (cf. Matyszkiewicz & Krajewski 2003), documented by numerous borings preserved in exotic blocks. Intense bioerosion combined with mechanical erosion above the wave base contributed to the destruction of the higher parts of the carbonate buildups. The presence of the *Aka* sp. sponges (Fig. 4B), adapted to boring exclusively in carbonate substrates, indicates that bioerosion occurred after the replacement of silica by calcite in the siliceous sponge skeletons, that is after early diagenesis (cf. Reitner & Keupp 1991; Matyszkiewicz 1997).

The microbial-sponge carbonate buildups were probably briefly emerged after the phase of intense bioerosion and before their colonization by coral-algal biocenoses. This is indicated by the presence of vadose crystal silt (cf. Aissaoui & Purser 1983) composed of dolomite and dedolomite calcite crystals, which fills borings only in the intraclasts of the microbial megafacies.

The presence of the dolomite crystals in the vadose silt is probably related to erosion of early diagenetic dolomites of unclear origin. It is possible that the dolomitization was taking place in the zone of mixing of fresh and saline waters (cf. Matyszkiewicz & Słomka 1994), or that it was caused by sediment interaction with migrating pore waters rich in magnesium. The migration could be due to differential compaction of carbonate buildups and the sediments filling the bottom lows between the buildups (cf. Reinhold 1998; Matyszkiewicz 1999).

The dedolomite calcite in the vadose crystal silt originated probably during short subaerial exposure of the higher parts of the carbonate buildups (Meder 1987; cf. Matyszkiewicz 1989; Matyszkiewicz & Słomka 1994). The emergence was probably caused by intense uplift within the Silesian Elevation during the neo-Cimmerian phase (Rakús 1996; Krobicki & Słomka 1999).

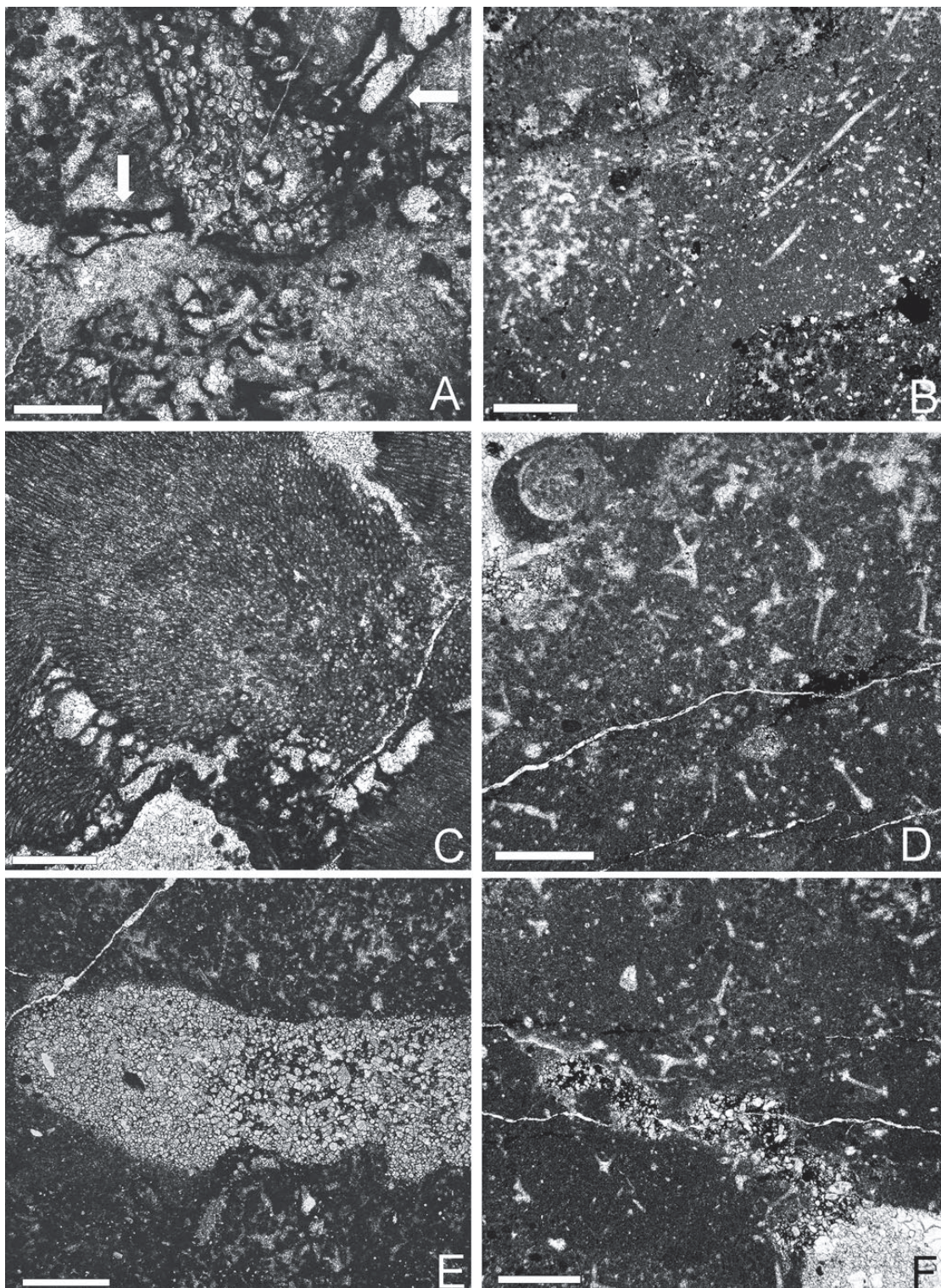


Fig. 4. Microfacies of exotic blocks from the Leśniana stream section at Leśna. Scale bar is 0.5 mm long. **A** — Growth void in coral-algal reef, filled by the microproblematicum *Koskinobullina socialis* Cherchi et Schroeder, 1979. The microbolite lamina on the wall of the growth void is a microbolite crust. Borings that reach the void (arrows) are filled by *Bacinella irregularis* Radoičić, 1959. Coral-algal facies. **B** — *Aka* sp. An excavating sponge within a calcified siliceous sponge. Microbial-sponge facies. **C** — Red algae *Solenopora* sp. with encrusting *Bacinella irregularis* Radoičić, 1959 (at bottom). Coral-algal facies. **D** — Intraclast of microbolitic-sponge boundstone. Preserved fragments of the calcified skeleton of a hexactinellid sponge are visible. *Terebella lapilloides* in the upper left corner. Microbial-sponge facies. **E** — Boring filled with dolomitic vadose crystal silt (in central part). The crystals of dolomite and dedolomite calcite are present in cement composed of Fe oxides. Microbial-sponge facies. **F** — Dolomitized vadose crystal silt fills fine borings in a calcified skeleton of a hexactinellid siliceous sponge. Microbial-sponge facies.

The growth of the coral-algal reefs did not occur before the brief exposure. Organic growth clearly predominated over bioerosion in the reefs, as is proven by the presence of only a few boring foraminifers *Troglotella incrustans* (cf. Schmid & Leinfelder 1996; Kołodziej 1997; Dupraz & Strasser 1999). The presence of numerous processes and indentations in the clasts of the microbial megafacies is the result of intense late diagenetic aggradational neomorphism during burial, resulting in transformation of the micritic matrix into blocky calcite cement. The intense aggradational neomorphism is also indicated by the presence of echinoderm debris encrusted with syntaxial cement. This debris forms the only bioclasts present in the blocky calcite cement, preserved due to their relatively high resistivity to recrystallization and neomorphism (cf. Huber 1987; Logan & Semeniuk 1976).

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