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Microbialites in the shallow-water marine environments of the Holy Cross Mountains (Poland) in the aftermath of the Frasnian–Famennian biotic crisis

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ABSTRACT

Microbial carbonates, consisting of abundant girvanellid oncoids, are described from cephalopod-crinoid and crinoid-brachiopod coquinas (rudstones) occurring in the lowermost Famennian of the Holy Cross Mountains, Poland. A Girvanella-bearing horizon (consist with numerous girvanellid oncoids) has been recognised at the Psie Górki section, and represents the northern slope succession of the drowned Dyminy Reef. This occurrence of microbialites in the aftermath of the Frasnian-Famennian event is interpreted as the result of opportunistic cyanobacteria blooms, which, as 'disaster forms', colonised empty shallow-water ecological niches during the survival phase following the Frasnian metazoan reef collapse, due to collapsed activity of epifaunal, grazing, and/or burrowing animals. The anachronistic lithofacies at Psie Górki is linked with catastrophic mass mortality of the cephalopod and crinoid-brachiopod communities during the heavy storm events. This mass occurrence of girvanellid oncoids, along with Frutexites-like microbial shrubs and, at least partly, common micritisation of some skeletal grains, records an overall increase in microbial activity in eutrophic normal marine environments. Microbial communities in the Holy Cross Mountains are not very diverse, being mainly represented by girvanellid oncoids, and stand in contrast to the very rich microbial communities known from the Guilin area (China), Canning Basin (Australia) and the Timan–northern Ural area (Russia). The association from Poland is similar to more diverse microbial communities represented by oncoids, trombolites and stromatolites, well known from the Canadian Alberta basin.

1. Introduction

Stromatolites and other microbial communities were abundant and occurred worldwide in many Precambrian normal marine environments, where they formed thick and extensive accumulations (e.g. Walter, 1983; Awramik, 1991, 1992; Grotzinger and James, 2000; Schopf, 2006). Following the Cambrian explosion (early Paleozoic diversification of metazoans) and the development of many grazing organisms, microbial structures declined significantly (e.g. Sheehan and Harris, 2004). Generally, in the Phanerozoic microbialites were mainly limited to more restricted and inhospitable (due to e.g. extreme changes of salinity), environments, such as the well-known modern Shark Bay in Australia (e.g. Schubert and Bottjer, 1992; Jahnert and Collins, 2011), as well as to alkaline lakes such as Lake Van in Turkey (e.g. López-García et al., 2005) or the caldera lakes of Niuafo'ou in Tonga (Kazmierczak and Kempe, 2006). However, the expansion of anachronistic facies (sensu Sepkoski et al., 1991), represented by microbial communities, has been documented in normal marine environments following mass extinctions (e.g. Schubert and Bottjer, 1992; Copper, 2002; Whalen et al., 2002; Pruss and Bottjer, 2004; Sheehan and Harris, 2004; Mary and Woods, 2008 and references therein; Forel et al., 2013; Woods, 2014; see also Table 1).

In this report, we present for the first time the results of a petrographic study conducted on post-extinction, lower Famennian (*triangularis* conodont Zone) microbialite limestone represented by the mass occurrence of oncoids with *Girvanella* from the shallow-water marine environment of the Holy Cross Mountains, Poland.

2. Geological setting

The Psie Górki hill section is located in the southern limb of the Kielce syncline, within the eastern part of the Kadzielnia Range (southern part of the Kielce city; see e.g. Szulczewski, 1971; Casier et al., 2002). Upper Devonian rocks on the Psie Górki hill, exposed in a few small abandoned quarries, are represented by diverse bioclastic pale grey

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Table 1
Examples of anachronistic lithofacies (=microbialites) after the Phanerozoic biodiversity crises.

Crisis	Locality	References
Late Ordovician	Nevada & Utah (USA)	Sheehan and Harries (2004)
Lau Event (Late Silurian)	Gotland (Sweden)	Calner (2005)
Frasnian/Famennian Event (Late Devonian)	Canning Basin (Australia)	Playford et al. (1984) Becker et al.(1991) Wood (2000) Webb (2001) Stephens and Summer (2003) Chow and George (2004) Shen et al. (2008)
	South China	Shen et al. (1997, 2008) Shen and Webb (2004a,b) Feng et al. (2010)
	Alberta Basin (Canada)	Mountjoy and Becker (2000) Whalen et al. (2002)
	Timan–northern Ural (Russia)	Antoshkina (1998, 2006, 2011) Copper (2002)
	Central–Southern Ural (Russia)	Chuvashov (1965)
	Kuznetsk Basin (Russia)	Ivanova (1983) Copper (2002)
	Prypiat High (Beloruss)	Makhnach et al. (1986) Copper (2002)
	Holy Cross Mountains (Poland)	Marynowski et al. (2011) Kazmierczak et al. (2012) (This study)
Permian/Triassic	South China	Kershaw et al. (1999, 2002, 2007) Lehrmann et al. (2003) Xie et al. (2005, 2007, 2010) Wang (2007) Chen et al. (2011) Yang et al. (2011) Yin et al. (2012)
	Turkey	Baud et al. (2005, 2007)
	Hungary	Hips and Haas (2006)
	California (western USA)	Mary and Woods (2008)
	Oman	Woods and Baud (2008)
	Nevada & Utah (western USA)	Schubert and Bottjer (1992) Pruss and Bottjer (2004)
	Poland	Peryt (1975)
Late Triassic	British Columbia (Canada)	Jiao et al. (2009) Kasprak et al. (2015)
End Cretaceous	Northern Italy Slovenia	Tewari et al. (2007)

limestones formed in the fore-reef environment (Racki, 1990; Casier et al., 2002; Bond et al., 2004). The sedimentary succession in the Psie Górki, encompassing the upper Frasnian (*hassi* conodont Zone) through the lower Famennian (*crepida* conodont Zone; see Szulczewski, 1971), was subdivided by Racki (1990) into seven lithological units (from C to I; see also Racki et al., 1993; Casier et al., 2002). However, lower Famennian marly shale set I (sensu Racki, 1990), described previously by Szulczewski (1971), is not accessible (see e.g. Gawlik, 1986). The Frasnian sediments (sets C to G) are represented mainly by thick-bedded grey detrital limestone with numerous stromatoporoids, as well as Rugosa and Tabulata corals. The total thickness of the Frasnian succession is approximately 36 m (Fig. 2A; Gawlik, 1986; Racki, 1990).

Racki (1990) stated that the contact between sets G and H corresponds to an erosional discontinuity surface close to the Frasnian/Famennian boundary (see also Casier et al., 2002). The Famennian succession accessible today is represented by set H (thickness over 4.5 m), subdivided into two subsets: H-1 and H-2 (see Racki, 1990; Racki et al., 1993). Set H-1 includes poorly-bedded, pale-grey, intraclast-rich, coarse-grained limestones with lateral variability, changing over to more fine-grained sediments containing crinoids and brachiopods, as well as a nautiloid coquina lenses (Racki, 1990). These sediments are covered by massive, non-skeletal calcarenites with local thick-grained partings, with very rare fossils represented by single crinoid columnals, brachiopod and mollusc shell debris, and corals (set H-2; see Racki, 1990). The sediments described in this report were found in local lenses of the nautiloid cephalopod coquina level (called PG-W), described for the first time by Racki (1990) in set H-1 in outcrop VII of the western part of the Psie Górki hill section (50°51,297′N 020°37,548E; Fig. 1; see also Fig. 2B in Racki, 1990). Racki (1990, Fig. 3 therein) mentioned, also for the first time, about the occurrence of microbial porostromate oncoids in this section. Microbial carbonates (grainstone-rudstone with a few oncoids and rare micritised ooids, thin stromatolitic mudstone laminae and microbreccia composed of algal mats) were also mentioned during a more detailed microfacies study of the Frasnian-Famennian boundary interval in the Psie Górki section by Casier et al. (2002, Fig. 3F).

The investigated sedimentary rocks are represented by pale grey, poorly sorted cephalopod-crinoid coquinas with numerous intraclasts and oncoids with *Girvanella*. This unit is approximately 1 m thick (Fig. 2B). These sediments overlie pale grey micritic limestones. The investigated sequences have been dated with the use of conodonts (Racki, 1990; Dzik, 2006) as the (?)lower *triangularis* conodont zone of the lowermost Famennian.

3. Material and methods

For palaeoenvironmental interpretation, five large-format thin sections were produced in the polishing laboratory at the Faculty of Earth Sciences of the University of Silesia, Sosnowiec, and three large-format thin sections were produced in the polishing laboratory at the Faculty of Geology University of Warsaw in Poland. The investigated thin sections were observed under a transmitted-light microscope in order to carry out detailed microfacies analysis, to which the limestone classification and nomenclature developed by Dunham (1962), and modified by Embry and Klovan (1971) and Wright (1992), was applied. The material examined in this study is housed at the Faculty of Earth Sciences, Sosnowiec, abbreviated GIUS 4-3656.

4. Results

4.1. Characteristics of the microbial carbonates

Girvanellid oncoids (=cyanoids sensu Riding, 1983), up to 11 mm in diameter, occur in medium-bedded, light grey cephalopod-crinoid and crinoid-brachiopod coquinas (see Figs. 2B–C and 3). Both types of the investigated rocks are very similar, with nautiloids less numerous in the lower part of the succession. Microscopically, the limestone consist of unsorted cephalopod-crinoid and crinoid-brachiopod rudstones (Fig. 3A–C). Skeletal grains include numerous orthoconic nautiloids (Fig. 2D) and crinoid ossicles, brachiopods, and girvanellid oncoids (Fig. 3A–C; Fig. 5). Cryptostomate bryozoans, gastropods, echinoid spines, calcispheres represented, among others, by volvocacean green algae (Fig. 4B,E; cf. Kaźmierczak, 1975, 1976; see also Racki and Soboń-Podgórska, 1993; Antoshkina et al., 2014) and parathuramminid foraminifera (Fig. 5H), mollusc and brachiopod shell debris, smooth-shelled ostracods, microconchids, and foraminifers (*Tikhinella*) are present as well (Fig. 4A,C–D). Additionally, some ferruginous encrustations (Fig. 6) very similar to *Frutexites* microbial shrubs (cf. Flügel, 2004 s. 409; see also Fig. 3G in Kazmierczak and Kempe, 2006; Mamet and Préat, 2006; Jakubowicz et al., 2014), are observable. However, due to