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Equatorial Palaeotethys as the last sanctuary for late Permian metazoan reef-builders: New evidence from the Bellerophon Formation of Slovenia

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ABSTRACT

The rise and demise of warm-temperate Permian reefs and biostromes reflect the complex geologic history of this dynamic period. Environments suitable for reef-builders were devastated by the Guadalupian/Lopingian crisis, and Lopingian reefs have only been recorded at a small number of localities. The uppermost Permian limestones of the Bellerophon Formation, on the Vojsko Plateau (Slovenia), contain small, lenticular biostromes within a bioclastic wackestone/packstone lithofacies. The major biostrome builders are medium-sized coralline sponges (Demospongea and Calcarea), encrusted by smaller sponges, tube worms, sessile foraminifera, calcareous algae (*Archaeolithoporella*) and *Shamovella* (i.e., *Tubiphytes*), all of which are typically covered by microbial crusts. The biostromes are characteristically composed of bafflestone and bindstone, incorporating sporadic framestone. Narrow belts of floatstone surround the buildups, and sponge debris is also present in lenses within the mud matrix between metazoan bafflestones. The fossils are generally well-preserved, although the fine skeletal microstructure has been partially recrystallized. Sponges are heavily calcified, and ontogenic thickening of the skeleton can be observed in some encrusters. Framboidal pyrite, forming thin films on the inner walls of sponge chambers, suggests the presence of sulphate-reducing bacteria. These microbial symbionts may have enabled the sponges to survive in the anoxic marine environments of the uppermost Permian. The Changshingian sponge biostromes of the Vojsko Plateau represent the westernmost known occurrence of contemporary metazoan boundstones in the Palaeotethys.

1. Introduction

Metazoan reefs and biostromes are highly sensitive ecosystems, and can serve as important indicators of environmental stress in modern and ancient marine environments (Flügel, 1994; Gallagher, 2002; Kiessling, 2009; Cebrian et al., 2011; Kiessling and Simpson, 2011; Bell et al., 2013; Goldberg, 2013; Song et al., 2014). Hermatypic corals in tropical/subtropical areas are especially vulnerable, and under stressful conditions their emptied ecological niches may be occupied by less sensitive reef builders such as sponges, a process that has been observed in both the fossil record and the modern ocean (Bell et al., 2013; Goldberg, 2013; Song et al., 2014). With a further increase in environmental pressure, microbial symbionts may become enemies, and outcompete metazoan reef builders (Cebrian et al., 2011; Webster and Taylor, 2012; Goldberg, 2013; Webster et al., 2013). Encrusting microbes were the last remaining producers of biological sedimentary buildups (bindstones) during the end-Permian "Great Dying".

Permian reefs are particularly interesting due to their hydrocarbon potential, and Middle to early Late Permian reef buildups have been studied all along the Permian equatorial shelves (Ramovš, 1958, 1986; Finks, 1960; Kochansky-Devidé, 1975; Flügel et al., 1984, 1991; Reinhardt, 1988; Senowbari-Daryan and Rigby, 1988; Wu, 1991; Sremac, 1991, 2005; Rigby et al., 1994; Senowbari-Daryan and Ingavat-Helmcke, 1994; Stanley, 1994; Rigby and Senowbari-Daryan, 1996; Rigby et al., 1998; Finks and Rigby, 2004a,b; Pisera, 2004; Shen and Xu, 2005; Senowbari-Daryan et al., 2005, 2006, 2007; Beauchamp et al., 2010; Nakazawa et al., 2015).

The impact of Middle-to-Late Permian environmental stress on shelf biota, including reef builders, has been noted by various authors (Flügel, 1994; Stanley, 1994; Weidlich, 2002, 2012; Weidlich et al., 2003; Finks, 2006; Aljinović et al., 2008; Kiessling, 2009; Fio et al., 2010; Clapham and Payne, 2011; Stanley, 2013). The recovery of reef systems was slow, and Changshingian reefs have been described in only a few locations, namely Greece, South China, and Primorye in Russia (Reinhardt,

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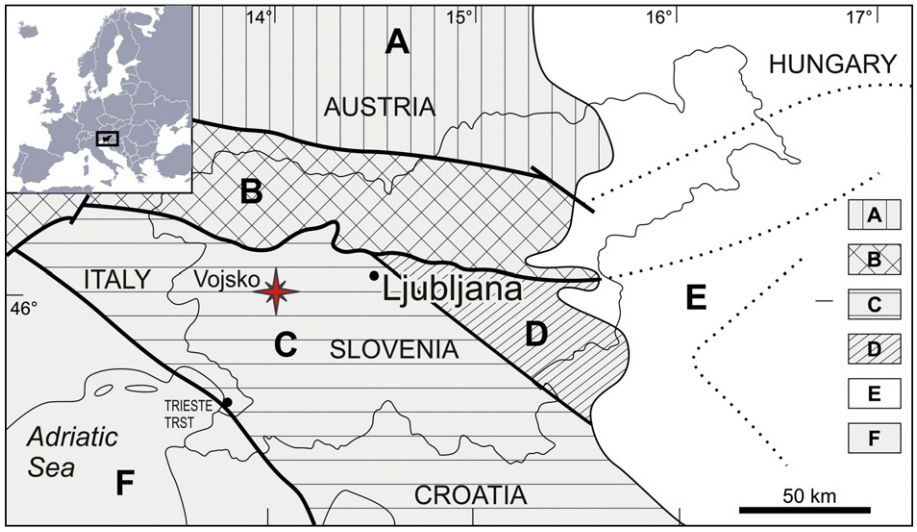

Fig. 1. Geographic position of Slovenia and map of Slovenian geotectonic units, with the location of the Vojsko Plateau marked with an asterisk. Legend: A—Eastern Alps; B—Southern Alps; C—External Dinarides; D—Transitional region between External and Internal Dinarides; E—Pannonian Basin; F—Adriatic–Apulia Foreland (modified after Placer, 1998).

1991; Boiko et al., 1991; Belyaeva et al., 2000; Weidlich et al., 2003; Shi et al., 2012; Meng et al., 2014).

The purpose of this study is to assess the palaeontological and sedimentological characteristics of the uppermost Permian lenticular sponge biostromes of the Vojsko Plateau in Slovenia, and compare them with similar metazoan buildups in the Late Permian oceans in light of their palaeogeographic position in the westernmost Palaeotethys basin.

2. Geologic setting

The studied Permian–Triassic succession is situated along the eastern slope of the Vojsko Plateau (Slovenia; Fig. 1), at an altitude between 770 and 800 m. The Vojsko Plateau is part of the Idrija-Žiri tectonic unit, with a complex nappe structure that was initially described by Mlakar (1969), followed by Placer (1973), who performed a detailed structural analysis of the area. The part of the Idrija Nappe (sensu: Mlakar, 1969) that includes the Vojsko Plateau was identified by Placer (1981) as the Kanomlja Thrust Sheet; it is situated directly below the Trnovo Nappe, and contains overturned strata. The geology of the area was thoroughly investigated during the initial geologic mapping effort (Basic Geologic Map 1:100,000 sheet Tolmin and Videm: Buser, 1986a, b) and during extensive investigation of the Idrija mercury mining area (Čar, 2010). The Permian–Triassic boundary of the Vojsko Plateau has been studied by Kolar-Jurkovšek and Jurkovšek (2007, 2015), Kolar-Jurkovšek et al. (2011a, b) and Nestell et al. (2011), as part of International Geoscience Programme (IGCP) projects 572 and 630.

The base of the section is represented by the Val Gardena Formation, composed of reddish-brown sandstone, micaceous siltstone, and shale (Fig. 2). This is overlain by the 30–50 m thick Bellerophon Formation, a Late Permian dark-grey to black limestone and dolostone unit (Fig. 2). Shale intercalations, typically ranging from 10 to 20 cm in thickness, are common in the Bellerophon limestone. The sponge-bearing samples described in this study were collected from the uppermost Bellerophon Formation, approximately 2 m below the transition to lithologically distinct Early Triassic microbial dolostones (Fig. 2). These dolostones are grey in colour, with prominent laminations, and show increasing bed thickness up-section, with limestone and clastic interbeds. They are overlain by macrocrystalline dolostones, with the uppermost part of the Early Triassic represented by platy, dark-grey limestone with marl intercalations, conformably overlain by Anisian dolostones (Fig. 2). The uppermost portion of the Anisian dolostone sequence was subaerially exposed and partially eroded, with residual sediments and clastic deposits preserved on the erosion surface (Čar, 2010).

3. Materials and methods

Two samples, collected from the Vojsko section in Slovenia (Fig. 1; 46° 1′ 21″ N, 13° 55′ 17″ E), form the basis of this study. Both represent lenticular biostromes, composed of a dark-grey, slightly silicified and dolomitized limestone containing abundant, hypercalcified coralline sponges. The samples were collected ~2 m below the lithologic contact between the limestones of the Bellerophon Formation and the thinly bedded microbial dolostones of the Permian–Triassic transitional interval on the Vojsko Plateau (Fig. 2). The larger rock sample (BJ 2776; ~30 × 50 × 10 cm) was collected from a weathered limestone bed, surrounded by thin beds of clayey siltstone. This sample contains abundant fossil sponges, concentrated in discrete clusters, and sometimes producing a rigid framework. The smaller rock sample (BJ 2800; ~25 × 5 × 10 cm) was not collected from the main transect of the Vojsko section, but represents the same stratigraphic horizon as the larger sample. These two samples are stored in the Jurkovšek Palaeontological Collection (Kamnica 27, Dol pri Ljubljani, inventory numbers BJ 2776 and BJ 2800).

A total of 35 thin sections of Sample BJ 2800 were prepared for detailed palaeontological and sedimentological analysis. The thin sections were examined using an Olympus–SZX10 stereo-microscope and a Leica Laborlux 11 polarizing microscope, and photographed with a Canon EOS 1100 camera and Quick PHOTO CAMERA 3.0 software. Two samples of fossil sponges were examined and photographed with a TESCAN VEGA TS 5136 MM/Oxford scanning electron microscope at the Department of Geology, Faculty of Science in Zagreb.

4. Microfacies and biota from the Vojsko section

The Bellerophon Formation exposed at the Vojsko section is predominantly composed of bioclastic limestones, sporadically interspersed with small, lenticular buildups of bindstone-bafflestone, occasionally with framestone characteristics (Fig. 2). The buildups are composed mainly of sponges (Demospongea, Calcarea), encrusted by other organisms, including microbes, red algae and tube worms.