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Microbial facies in a Sturtian cap carbonate, the Rasthof Formation, Otavi Group, northern Namibia

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ABSTRACT

Microbial structures in Neoproterozoic cap carbonates record the environmental processes present in the aftermath of global glaciation. The Rasthof Formation of northern Namibia is a unique carbonate depositional sequence that formed during post-glacial transgression and highstand following the Chuos glaciation. Carbon isotope profiles from four examined localities reveal that onlap was diachronous over post-glacial, syn-rift topography. The lower Rasthof Formation consists primarily of dark gray thinly (<mm) and thickly (1–4 mm) laminated microbialites that exhibit different rheological responses to the emplacement of syndepositional dikes. The thinly laminated microbialaminite facies commonly host cm-sized syndepositional folds of microbially laminated sediment called roll-up structures. In more thickly laminated facies, layers are deformed into broad decimeter-sized folds, but roll-up structures are absent. Large syndepositional carbonate clastic dikes (0.5–1 m wide) and smaller veins (0.1–0.5 m) cut across bedding in both the thinly and thickly laminated facies, but are conspicuously absent from underlying and overlying beds. These carbonate clastic dikes and veins contain convoluted microbial mats and abundant marine cements. The lack of evidence for wave action or current scouring in the form of bedforms, scour marks, or intraclasts indicates that these microbialaminites formed below storm wave base.

The close spatial association of deep-water microbialaminite facies in the Rasthof cap carbonate with carbonate clastic dikes suggests that the emplacement of dikes produced both dm-sized broad folds and cm-scale laterally discontinuous roll-up structures. The emplacement of the dikes, most likely due to the release of fluids into incompletely lithified mats, deformed cement-rich thick laminites into broad folds, while thinly laminated and more slowly lithifying mats were rolled into roll-up structures. Microbialaminite facies in the Rasthof cap carbonate thus not only reflect the depositional and environmental processes that operated in the aftermath of the Sturtian glaciation, but may also provide clues for the formation of roll-up structures found in even older Precambrian carbonates.

1. Introduction

The Earth experienced at least two global glaciations during the Neoproterozoic, as suggested by the presence of Neoproterozoic diamictites on nearly every paleo-continent, including those at low paleo-latitudes (Evans, 2000; Hoffman and Li, 2009). Neoproterozoic glacial deposits are typically capped by carbonate rocks. In spite of presumably similar mechanisms operating in the aftermath of these two global glaciations (Hoffman and Schrag, 2002), the Sturtian and basal Ediacaran (Marinoan) cap carbonate sequences contain distinct facies that may provide clues to the nature of the environmental conditions and biotic recovery in the aftermath of global glaciations. Facies in the comparatively well-studied basal Ediacaran cap carbonate characteristically contain a basal portion composed of a buff to pink colored dolomite that hosts tubestone stromatolites (Cloud et al., 1974; Corsetti and Grotzinger, 2005) and giant wave ripples (Allen and Hoffman, 2005), and an upper limestone that contains pseudomorphosed formerly aragonite crystal fans (Grotzinger and James, 2000; James et al., 2001). Tubestone stromatolites have been described on several paleocontinents and are exposed in Death Valley (Cloud et al., 1974), Namibia (Hegenberg, 1987; Kennedy et al., 2001; Corsetti and Grotzinger, 2005), Brazil (Rodrigues-Nogueira et al., 2003), Mongolia (Macdonald et al., 2009a), and Arctic Alaska (Macdonald et al., 2009b). These microbialites are certainly rare in the geological record, if not unique to basal Ediacaran cap carbonates (Corsetti and Grotzinger, 2005). In contrast, older Cryogenian 'Sturtian' cap carbonates have not been described extensively. In Arctic Alaska

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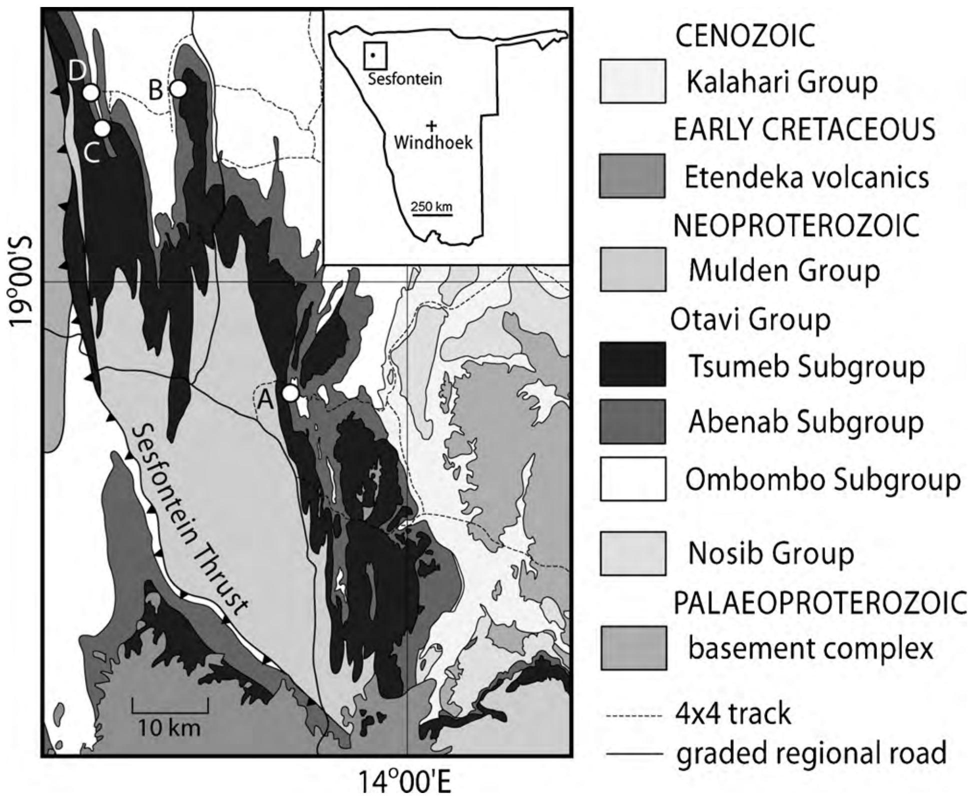

Fig. 1. Geological locality map of study area. Inset of Namibia shows location of locality map in box. (A) Ongongo; (B) Okaaru; (C) South Ombepera; and (D) Ombepera.

(Macdonald et al., 2009b), Mexico (Corsetti et al., 2007), on the Congo Craton of northern Namibia (Hoffman and Halverson, 2008) and on the Kalahari Craton of southern Namibia, Sturtian cap carbonates typically consist of dark microbialaminites. In the Neoproterozoic stratigraphy of northern Namibia, these dark-colored microbialaminites are unique to the Rasthof Formation.

Here we describe two distinct microbialite facies preserved in the Rasthof cap carbonate of northern Namibia on the western platform of the Otavi fold belt. This report focuses on exposures of the Rasthof Formation along an east-west transect off the western margin of the Congo Craton (Fig. 1). Here we use carbon isotope profiles to correlate these sections that contain well-preserved microbial facies. These facies have been described previously at the outcrop scale; the thickly laminated facies that contain 1–4-mm thick light and dark laminae and are commonly folded in 0.1–0.5 m wide folds were characterized as stromatolites because of the apparent doming of the folds (Hoffman and Halverson, 2008). The thinly laminated (<1-mm thick laminae) dark microbialites with roll-up structures have previously been recognized but have not been described in detail (Hoffman and Halverson, 2008). Here we present new field observations and the results of petrographic and geochemical analyses to address the chemical, biological and deformational processes operating in the aftermath of the first global glaciation.

2. Geologic setting

The Neoproterozoic Otavi Group is a 2–4-km thick carbonate-dominated succession exposed in northern Namibia that was deposited on a rifted passive margin of the Congo Craton (Gevers, 1931; Le Roex, 1941; Hoffmann and Prave, 1996; Hoffman and Halverson, 2008). The Chuos, Rasthof, Gruis and Ombaatjie Formations (not shown) are well-exposed along the western Kamanjab inlier (Fig. 1) and are preserved between erosion surfaces below glacial diamictites of the Chuos and Ghaub Formations (Hoffman et al., 1998; Hoffman and Halverson, 2008). Evidence for syndepositional normal faulting is present in the Chuos, Rasthof, and Gruis Formations (Hoffman and Halverson, 2008). In northern Namibia, the Rasthof Formation (Hedberg, 1979) overlies diamictite and conglomerate of the Chuos Formation of presumed Sturtian age. The age of the Rasthof Formation is constrained below by 746 ± 2 Ma (U-Pb TIMS zircon age) volcanic rocks in the Naauwpoort Formation (Hoffman et al., 1996) and above by a 635.6 ± 0.5 Ma (U-Pb TIMS zircon age) rhyolite in the Ghaub Formation (Hoffmann et al., 2004). The Rasthof Formation consists of 200–400 m of dark gray carbonate preserved in the Otavi fold belt, which rims the Northern Platform (e.g. Miller, 1983; Hoffman et al., 1998; Hoffman, 2002; Hoffman and Halverson, 2008). The contact of the Rasthof with the underlying Chuos Formation is knife-sharp, with the diamictite overlain by dark gray mechanically laminated dolomite and dolomitic rhythmite.

3. Methods

At all localities, samples were collected at meter-scale from the lower Rasthof Formation for carbon isotope analysis. We collected hand samples for petrographic observation of microbial fabrics and analyses of carbon isotope composition of microfacies. Microfacies were analyzed to determine the source of carbonate ions during production and lithification of carbonate phases. Upon discovery of small circular features in light laminae of thickly laminated microbialaminite thin sections, we performed Raman spectroscopy (Vibrational Spectroscopy Lab, University of Massachusetts Amherst) to test whether these were composed of organic matter. These thin sections were also viewed under UV fluorescence (excitation at 370/40 nm, emission at 425 nm) using a Zeiss Axio Imager M1 microscope. Carbon isotope ratios were measured on a VG Optima gas source mass spectrometer and a Finnigan