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Synsedimentary diagenesis in a Cryogenian reef complex: Ubiquitous marine dolomite precipitation

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ABSTRACT

Analysis of the synsedimentary diagenetic phases from a pervasively dolomitised Cryogenian (~650 Ma) reef complex, South Australia reveals a fundamentally different style of marine diagenesis to that of Phanerozoic carbonates. Textural evidence from dolomitised and undolomitised lithologies of the Oodnaminta Reef Complex indicates that depositional components were precipitated initially as calcium carbonate (aragonite and calcite). Dissolution textures and preserved fabrics in ooids indicate an originally aragonitic mineralogy. Early fibrous marine cements that have well preserved fibrous crystallographic fabrics with a length-fast optical character are likely to have precipitated as high magnesium calcite. However, following this very early phase of diagenesis, the dominant marine process occurring in these reefs was dolomite precipitation. This involved the dolomitisation of earlier depositional and diagenetic phases, as well as the precipitation of fibrous dolomite cements. These fibrous marine cements include the newly described radial slow, fascicular slow, radiaxial slow and rhombic dolomite cements. The cements have optical properties, chemical zonation and cathodoluminescent characteristics indicating that they were direct marine precipitates. Dolomite precipitation during marine diagenesis in this reef complex suggests that the oceans of the Cryogenian were chemically different to those of the Phanerozoic. Abundant dolomite formation appears to be linked to anoxic, magnesium-rich seawater during this time. Marine dolomite precipitation under these conditions may explain the abundance of dolomite in the Precambrian sedimentary record.

1. Introduction

The abundance of dolomite compared to limestone in marine carbonates is generally believed to increase with stratigraphic age (e.g. Chilingar, 1956; Given and Wilkinson, 1987). While Phanerozoic carbonates are largely composed of calcite and aragonite, Precambrian carbonate sequences are almost universally dolomitic. Although this increasing abundance of dolomite with geological age has been attributed to various chemical and physical factors (e.g. Sibley, 1991 and references therein), the reason for such an uneven distribution remains largely unresolved.

Tucker (1982) suggested that Proterozoic carbonates precipitated as primary marine dolomite, as a result of unusual ocean conditions during this time. Although his idea was controversial (e.g. Ricketts, 1982; Zenger, 1982; Tucker, 1983), Tucker's work was influential in calling attention to a fundamental difference between Phanerozoic and Precambrian seawater chemistry. More recently, Hood et al. (2011) have proposed that marine dolomite precipitation was widespread during the Cryogenian. This work on the Oodnaminta Reef Complex, South Australia, suggested that most reefal depositional components were precipitated as aragonite and replaced by dolomite during early marine diagenesis. Hood et al. (2011) further suggested that many of the marine cements in these reefs had a primary dolomite mineralogy.

Here, we provide a detailed account of the synsedimentary diagenesis of the Oodnaminta Reef Complex in order to better constrain primary marine carbonate mineralogy and early diagenetic processes in the Cryogenian. By extension, this study may provide insights into the unusual seawater conditions that promoted such abundant marine dolomite precipitation in the Proterozoic.

2. Regional geology and sedimentology

The Oodnaminta Reef Complex is developed between the Sturtian and Marinoan glacial successions of the Adelaide Fold Belt, South Australia (Fig. 1) (Giddings et al., 2009). The reef complex occurs within the Cryogenian stratigraphy of the upper Umberatana Group (Fig. 2) (Preiss, 1987; Fromhold and Wallace, 2011). Although there are few geochronological constraints on the age of the Umberatana Group, the upper Sturtian diamictites have been dated at approximately 659 ± 6 Ma by U–Pb zircon geochronology (Fanning and Link, 2006). Correlation with the glacials of the Ghaub Formation in Namibia by Hoffmann et al. (2004) suggests that the Marinoan glaciation occurred at approximately 635 Ma. This implies that the Oodnaminta Reef Complex is around 650 Ma in age (Giddings et al., 2009).

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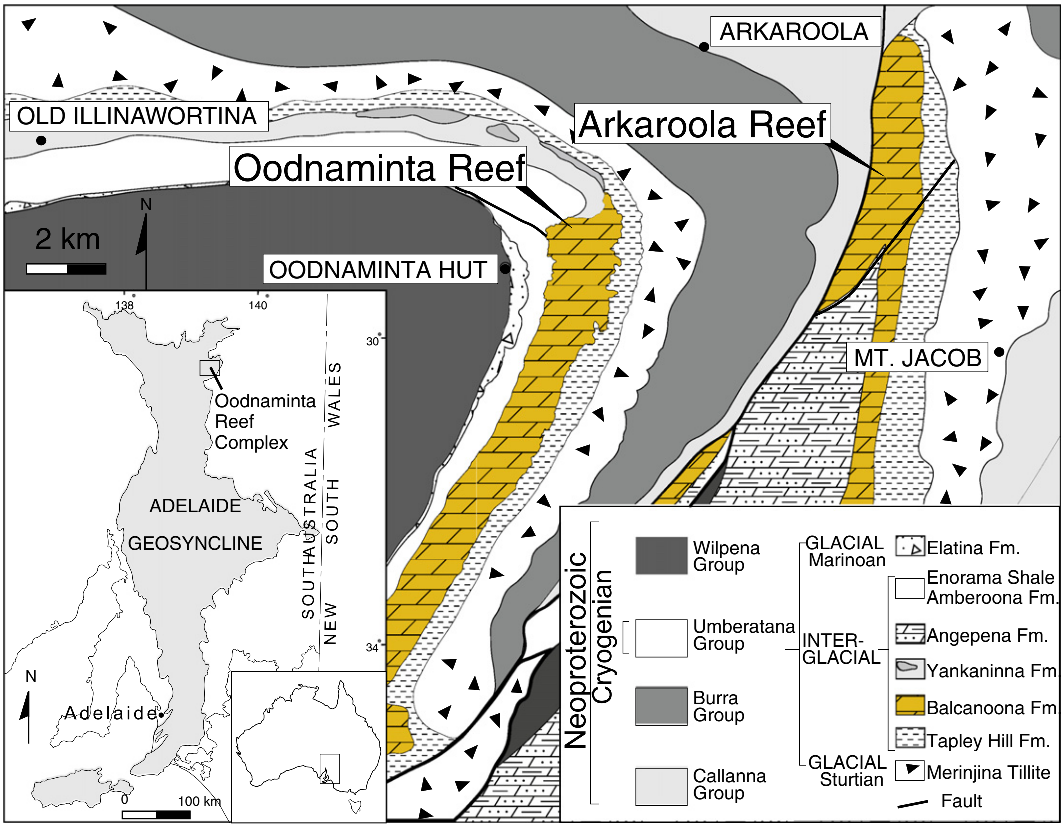

Fig. 1. Simplified geological map showing the location and stratigraphic setting of the Oodnaminta Reef Complex within the Adelaide Fold Belt, South Australia (modified after Giddings and Wallace, 2009).

Large reefal platforms occur near Oodnaminta Hut and Mt. Jacob, and have been respectively named the Oodnaminta and Arkaroola Reefs (Fig. 1) (Giddings et al., 2009). Together with other platforms in the area, these reefs make up the Oodnaminta Reef Complex. The lithostratigraphic units that constitute this complex are the Angepena, Balcanoona and Tapley Hill Formations (Fig. 3). Fromhold and Wallace (2011) suggested that the red dolomitic shales and dolomites of the Angepena Formation are laterally equivalent to the Balcanoona Formation, forming the most landward, peritidal facies of the reef complex. The dolomitic Balcanoona Formation constitutes the platformal, reef framework and proximal reef slope facies. The upper calcareous shales of the Tapley Hill Formation form the slope facies of the complex and extend as the deeper water lateral-equivalent of the Balcanoona Formation (Giddings et al., 2009). Shales of the Tapley Hill Formation host large allochthonous blocks and megabreccias derived from the Balcanoona Formation reef margin.

Unconformably overlying the Balcanoona Formation and separated by a well-defined karst surface, is the carbonate-rich Weetootla Dolomite (Giddings et al., 2009; Fromhold and Wallace, 2011) (Fig. 2). In laterally-equivalent slope settings, limestones and shales of the Yankaninna Formation overlie the uppermost slope facies of the reefs. The Yankaninna Formation also onlaps the northernmost parts of the Oodnaminta Reef near Oodnaminta Hut, representing deeper-water deposition after the termination of reef growth.

The Oodnaminta Reef Complex consists of multiple prograding reefal platforms (Giddings et al., 2009). Each platform can be divided into facies similar to Phanerozoic barrier-reef environments including; back reef, reef margin frameworks and fore-reef slope deposits (Fig. 3) (Giddings and Wallace, 2009; Giddings et al., 2009). The high-energy back-reef facies of the reef platforms are primarily fenestral ooid and peloid grainstones with extensive sheet-cavity networks. Spherical to sub-spherical ooids are generally 0.1–0.5 mm in size and occasionally reach more than a millimetre in diameter (Fig. 4). Within the backreef facies, fenestral fabrics are ubiquitous. Shrinkage cracks, sheet cavities and teepee structures are common. Sheet cavities may reach 5 cm in height and can extend laterally for up to a metre. These cavities may have an irregular roof with pendant micritic protuberances, and often show a laminated base. The majority of back-reef cavities are filled with inclusion-rich, isopachous fibrous cements (Fig. 5A,B).

The reef margin is divided into two different facies: an upper stromatolitic framework of relatively shallow water origin and a lower non-stromatolitic framework considered to have developed in deeper water (Giddings et al., 2009). The stromatolitic facies is typified by basinward-growing stromatolites of branching, columnar or domal morphologies. The stromatolites form a rigid framework that grades over tens of metres into the lower reef framework. The lower non-stromatolitic facies consists of microbial frameworks, carbonate shrubs and chambered structures. It hosts abundant growth cavities filled with fibrous carbonate cements. Well-developed neptunian dykes with multiple crusts of fibrous carbonate cement and internal sediments are relatively common in the reef margin (Hood et al., 2011) (Figs. 5C and 6).

The proximal fore-reef slope facies generally consists of dolomite talus blocks but also develops as bedded, micritic carbonates (Giddings et al., 2009). A series of large fore-reef debrites extends kilometres basinward from the reef margin, cutting into the shales of the Tapley Hill Formation (Fig. 7) (Giddings et al., 2009). These slope facies consist of reefal allochthonous blocks within shales of the Tapley Hill Formation. Allochthonous blocks are generally tens of centimetres to tens of metres in size, but may reach several hundred metres in diameter. The allochthonous blocks normally consist of reef margin framework elements and reworked rip-up debris.

3. Methods

Sedimentological and stratigraphic analysis of the Balcanoona Formation was undertaken in the northern Flinders Ranges, South Australia.