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Carbonate rocks and related facies with vestiges of biomarkers: Clues to redox conditions in the Mesoproterozoic ocean

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ABSTRACT

The Raipur Group of the Chattisgarh Basin preserves two major Late Mesoproterozoic carbonate platforms. The lower platform is about 490-m thick, separated from the upper platform (~670 m thick) by a 500-m thick calcareous shale. Carbonate strata cover almost 40% of the Chattisgarh Basin outcrop and represent two major platform types: a) a non-stromatolitic ramp (the Charmuria/Sarangarh Limestone) and b) a platform developed chiefly in the intertidal to shallow subtidal environment with prolific growth of stromatolites (the Chandi/Saradih Limestone). The first platform consists primarily of the black Timarlaga limestone that is locally replaced by early diagenetic dolomite. This carbonate platform experienced strong storm waves and was subsequently drowned by a major transgression, during which extensive black limestone–marl rhythmite was deposited, followed by deposition of the Gunderdehi Shale. The carbonate factory was later re-established with development of an extensive stromatolite-dominated Charmuria/Sarangarh platform that ranged from restricted embayment to open-marine conditions. Sea-level change played a major role in controlling the broad facies pattern and platform evolution. The $\delta^{13}C$ signatures of the Chattisgarh limestones, falling within a relatively narrow range (0 to +4‰) are typical for Upper Mesoproterozoic carbonate rocks. $\delta^{18}O$ values, however, have a greater range (−5.7 to −13.3‰) indicating significant diagenetic alteration of some samples. Likely dysoxic or anoxic conditions prevailed during deposition of the black Timarlaga limestone and well-oxygenated conditions during deposition of the Gunderdehi Shale and Saradih/Chandi stromatolite. The lack of 17β,21α (moretanes) and high T_{max} values suggest mature organic matter in the non-stromatolitic ramp. A paucity of diagnostic eukaryotic steroids indicates that algae were rare in the Chattisgarh Basin. A high content of hopanes supports a generally bacterially-dominated Proterozoic ocean in which various stromatolites flourished.

1. Introduction

During the Great Oxidation Event (2500–2200 Ma) sustained oxygenation of Earth's surface environments began and although the shallow oceans became mildly oxygenated, the deep oceans continued to be anoxic at least until 1850 Ma (Holland, 2006). The following Mesoproterozoic (1600–1000 Ma) has been regarded as a relatively quiet time in Earth history (Buick et al., 1995; Isley and Abbott, 1999; Holland, 2006; Bekker et al., 2010). However, even though distal shelf and basinal settings of the Mesoproterozoic appear to have been anoxic and euxinic (Shen et al., 2002, 2003; Poulton et al., 2004) or ferruginous (Poulton et al., 2010; Planavsky et al., 2011; Scott et al., 2012), there is a moderate increase in biospheric oxygen variability in the late Mesoproterozoic evidenced from increased carbon isotopic variability (Frank et al., 1997; Kah et al., 1999; Frank et al., 2003), an increase in marine sulphate concentration (Kah et al., 2004) from low sulphate concentrations in early Mesoproterozoic (Luo et al., 2015), the widespread appearance of marine gypsum (Kah et al., 2001, 2012), and increased oxidative sulphur cycling in marine and terrestrial environments (Johnston et al., 2005; Parnell et al., 2010). From a sedimentological point of view, the Mesoproterozoic was a time of extensive epeiric and epicratonic seas and a relative highstand of sea level, wherein thick successions of shallow-water carbonate strata were deposited in broad intracratonic basins, as in China (Guo et al., 2013; Mei and Tucker, 2013), Siberia (Bartley et al., 2001), West Africa (Kah et al., 2012; Gilleaudeau and Kah, 2013a,b, 2015), and the Canadian Arctic (Kah et al., 2001). Biologically, cyanobacteria were well established in the Mesoproterozoic but heterogeneity of redox conditions in the shallow oceans may have had fundamental implications for the

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evolution of unicellular and multicellular eukaryotes, which were evolving at a modest rate towards the end of the Mesoproterozoic–early Ediacaran (Butterfield, 2001; Knoll et al., 2006; Javaux, 2007; Parfrey et al., 2011). Moreover, despite evidence that early eukaryotes were abundant in some nearshore settings (Butterfield, 2000; Javaux et al., 2001; Knoll et al., 2006), similar environments from other basins but with euxinic conditions record a distinct absence of eukaryotic biomarkers (Brocks et al., 2005; Blumenberg et al., 2012). This could have limited the zone of habitability for early eukaryotes, providing an explanation for the fragmentary nature of their early evolution and diversification. Anbar and Knoll (2002) have suggested that oxygenation of the mid-Proterozoic surface environment may have resulted in increased delivery of essential nutrients to the marine system thereby fostering eukaryotic diversification in nearshore settings. It also seems that spatial heterogeneity of redox-sensitive trace metals in the Mesoproterozoic ocean resulted in offshore micronutrient limitation which would have prevented eukaryotes from being widespread (Gilleaudeau and Kah, 2013b; Stüeken, 2013).

In this project, we explore two carbonate platforms of the Raipur Group, central India, with the aim of evaluating the controls on the development of two distinctly different platforms through time, one dominated by stromatolites, the other not. Thick carbonate successions are reported from all the Proterozoic cratonic basins of the Indian subcontinent (Das et al., 1992; Mukhopadhyay et al., 1996; Patranabis-Deb, 2001; Chakraborty et al., 2002, 2015; Jiang et al., 2002; Saha and Patranabis-Deb, 2014). Combined sedimentological, isotope and organic geochemical data are used to assess the source and character of preserved organic matter. Redox conditions within the Chattisgarh Basin are evaluated in the context of the palaeogeographical position of the basin and its contribution to the understanding of redox heterogeneity in Mesoproterozoic oceans.

2. Regional geological setting

The Chattisgarh Basin developed within the Bastar craton, an Archean crystalline block. The Baster craton is bounded by the Godavari and Mahanadi rifts to the southwest and northeast respectively, and bordered by the Central Indian Tectonic Zone (CITZ) to the northwest and the Eastern Ghats Mobile Belt to the southeast (Fig. 1). The Chattisgarh Basin covers an area of ~33,000 km^2, which unconformably overlies the Archean crystalline basement, the Neoarchean to Paleoproterozoic Sonakhan granite–greenstone belt and Dongargarh-Kotri volcanics (Fig. 1). Detailed geological mapping suggests that the Chattisgarh succession, which exceeds 2300 m in thickness, represents two unconformity-bound sequences. The lower unit is designated the Chandarpur-Raipur Sequence (CR sequence) and the upper unit is the Kharsiya Sequence (Patranabis-Deb and Chaudhuri, 2008) (Fig. 2). Radiometric dating indicates a Mesoproterozoic age for the Chandarpur Raipur Group, with the upper Kharsiya Group representing deposition in the early Neoproterozoic.

The CR sequence, the focus of this study, is characterised by a lower thick wedge of an immature assemblage of conglomerate, coarse feldspathic sandstone and shale, deposited in a fan delta-prodelta setting (Patranabis-Deb and Chaudhuri, 2007; Chakraborty et al., 2009), and a more stable upper assemblage of quartzose sandstone deposited in a shallow-marine shelf bar to intertidal location (Patranabis-Deb, 2005; Chakraborty and Paul, 2008). Intense storms and tides played an important role in sculpturing the sediments in the wide open shelf of the

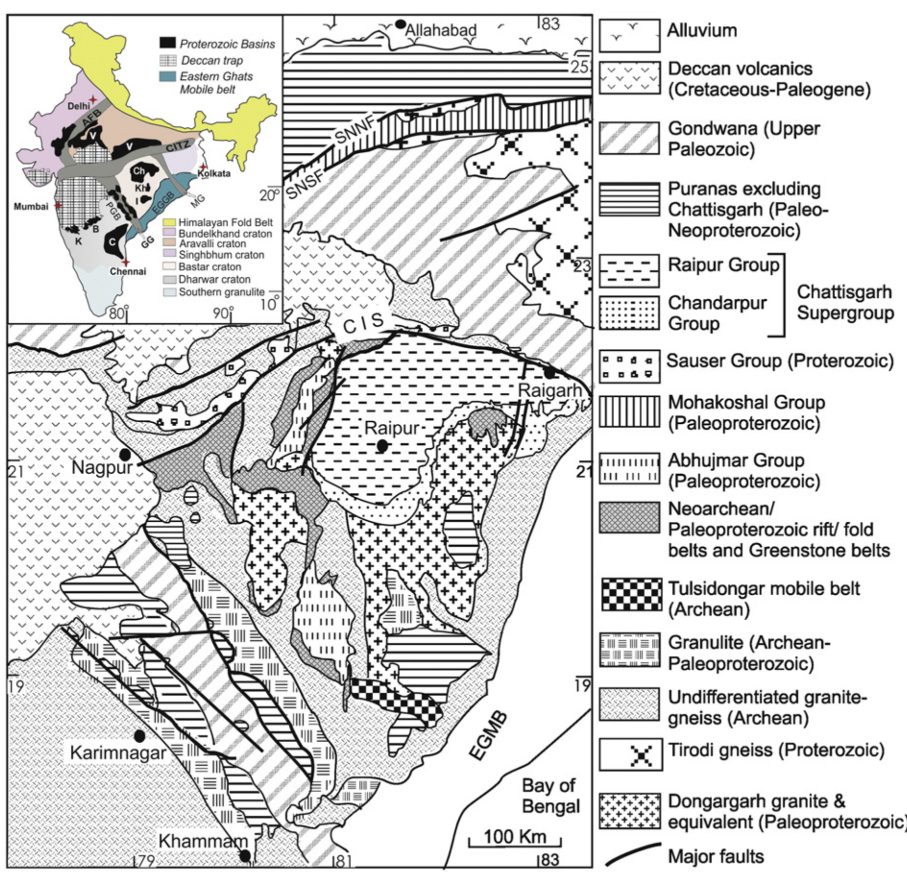

Fig. 1. Generalised geological map of part of the peninsular India showing mobile belts and major tectonic lineaments. Inset map shows distribution of cratons, mobile belts and the Proterozoic cratonic basins on the Indian craton, Chattisgarh (Ch); Khariar (Kh); Indravati (I); Pranhita-Godavari Basin (PGB); Cuddapah (C); Vindhyan (V); Kaladgi (K); Bhima (B), Aravalli Fold Belt (AFB); Central Indian Shear Zone (CIS); Godavari Graben (GG); Mahanadi Graben (MG); Son-Narmada North Fault (SNNF) and Son-Narmada South Fault (SNSF). Modified after Ramachandra et al. (2001) and Chakraborty and Paul (2008).