Journal of Asian Earth Sciences 91 (2014) 263–279

Contents lists available at ScienceDirect

Journal of Asian Earth Sciences

journal homepage: www.elsevier.com/locate/jseaes

Carbonate platform development in a Paleoproterozoic extensional basin, Vempalle Formation, Cuddapah Basin, India

Gopal Chakrabarti [a,*], Debasish Shome [b], Subhasish Kumar [b], George M. Stephens III [c], Linda C. Kah [c]

[a] Education Directorate, Government of West Bengal, India, Kolkata 700091, India
[b] Department of Geological Sciences, Jadavpur University, Kolkata 700032, India
[c] Department of Earth and Planetary Sciences, University of Tennessee, Knoxville, TN 37996, USA

ARTICLE INFO

Article history:
Received 29 January 2013
Received in revised form 29 August 2013
Accepted 17 September 2013
Available online 2 October 2013

Keywords:
Paleoproterozoic
Carbonate ramp
Microbialites
Carbon isotopes
Restricted circulation

ABSTRACT

Sedimentological investigation of the late Paleoproterozoic (Orosirian) Vempalle Formation of the Cuddapah Basin, Dharwar craton, India, reveals three facies association that range from supratidal to deep subtidal. Sedimentary rocks of this succession are dominated by heterolithic carbonate mudstone, intraformational carbonate conglomerate, and a variety of columnar, domal, and stratiform microbialite facies. Deposition occurred in an extensional regime during development of a low-gradient ramp, where the distribution of microbialite facies is distinctly depth-partitioned. A gradual increase in synoptic relief of columnar stromatolites through the section, and the upward transition from stratiform to columnar microbialites, record a prolonged marine transgression with little or no influx of terrigenous detritus. Siliciclastic influx along the northeastern side of the shelf reflects the redistribution of topographic highs concomitant with large scale volcanic activity. Redistribution of topographic highs eventually led to progradation of peritidal facies and shutting down of the carbonate factory. Earthquake-induced ground shaking and voluminous volcanism experienced by this platform point to the reactivation of a deep-seated mantle-plume that resulted in thermal doming of the Dharwar crust prior to the onset of Cuddapah deposition. Isotopic and elemental chemistry of a selection of Vempalle Formation carbonate rocks record elevated Mn^{2+} and Fe^{2+} concentrations and depleted carbon isotope values in inner ramp lagoonal facies, relative to more open marine stromatolitic facies. Patterns of isotopic and elemental variation suggest the presence of geochemically distinct water masses—either within the water column or within substrate pore fluids—that resulted from a combination of globally low marine oxygenation and restricted oceanographic circulation in inner ramp environments. These data suggest that, even in the aftermath of Early Paleoproterozoic oxygenation, that ocean chemistry was heterogeneous and strongly affected by local basin conditions.

1. Introduction

The Paleoproterozoic (2.5–1.6 Ga) represents an era of Earth's history in which surficial environments experienced profound environmental change (Holland, 2006; Canfield, 1989; Wilson et al., 2010; Bekker and Holland, 2012 Young, 2013a,b). Perhaps most importantly, surficial environments of the Paleoproterozoic experienced a rapid, and ultimately irreversible, transition between approximately 2.4 and 2.0 Ga from an ocean–atmosphere that was dominantly reducing (Rasmussen and Buick, 1999) to one in which surface environments were dominantly oxidizing (Farquhar and Wing, 2003; Bekker et al., 2004; Guo et al., 2009). Although the mechanism and the extent of surface oxygenation remains controversial, it is clear that initial oxygenation of surface environments had profound impact on the Earth's geologic and biologic records, including the appearance, by ~2.1 Ga, of marine gypsum and anhydrite minerals (Melezhik et al., 2005; Schröder et al., 2008; Zentmyer et al., 2011), the reduction and eventual disappearance (by ~1.8 Ga) of marine iron formation (Poulton et al., 2004; Wilson et al., 2010), and potentially profound changes in the distribution of biologically important redox-sensitive elements (Canfield, 1989; Brocks et al., 2005; Guo et al., 2009) that set in motion a nearly billion-year interval of protracted environmental evolution (Anbar and Knoll, 2002; Kah et al., 2001; Kah and Bartley, 2011; Hazen et al., 2013). Increasingly, these dramatic changes in the marine environment have been associated with an equally complex marine carbon cycle, which is represented by dramatic isotopic variation in the Early Paleoproterozoic (Bekker and Holland, 2012, and references therein), followed by nearly 600 million years of relatively modest carbon isotopic variation (Lindsay and Brasier, 2000; Hotinski et al., 2004; Wilson et al., 2010).

* Corresponding author. Tel.: +91 33 24843143.
E-mail address: gl_chak@yahoo.co.in (G. Chakrabarti).

1367-9120/$ - see front matter
http://dx.doi.org/10.1016/j.jseaes.2013.09.028

Variation in the marine carbon cycle has been attributed to a number of causes, including climate change (Bekker and Holland, 2012), changes in biological production and recycling (Kump et al., 2011), and global tectonics (Lindsay and Brasier, 2002). The Paleoproterozoic marks the first recognizable supercontinent cycle, from the dispersal of a possible Neoarchaean supercontinent to the formation of the 1.9–1.8 Ga supercontinent Nuna/Columbia (Zhao et al., 2002, 2004; Rogers and Santosh, 2002a,b, 2009; see also review in Reddy and Evans, 2009; Meert, 2012). It is within this context of supercontinent formation, that the Paleoproterozoic also preserves extensive development of carbonate platforms (Grotzinger, 1989; and references therein). Extensive carbonate platforms likely reflect a combination of globally high sea level, elevated marine carbonate saturation (Grotzinger, 1989; Bartley and Kah, 2004) and generally temperate climates in the aftermath of the ~2.3 Ga Huronian Glaciation (Eriksson et al., 1998; Bekker et al., 2005). Unlike modern carbonate platforms, Paleoproterozoic carbonate platforms were marked by a wide variety of microbialite morphologies, an abundance of seafloor precipitates (Hofmann and Jackson, 1987; Grotzinger, 1989; Sami and James, 1996), and only rare deposition of authigenic gypsum evaporites (Pope and Grotzinger, 2003; Zentmyer et al., 2011).

The Vempalle Formation represents development of an extensive, late Paleoproterozoic (Orosirian period, 2.0–1.8 Ga) carbonate platform within the extensional Cuddapah Basin, Dharwar craton, southern India. Strata comprise a thick succession of stromatolitic dolomite with minor siliciclastic and volcanic lithologies. Here we describe constituent facies, as well as the sedimentary and geochemical evolution of Vempalle strata, in order to better understand the development of a carbonate platform in a tectonically active Paleoproterozoic setting, and to provide a more detailed view on the geochemical development of late Paleoproterozoic marine systems.

2. Geologic setting and age

2.1. Geologic setting of the Cuddapah Basin

Peninsular India is composed of a number of cratonic nuclei—the Dharwar, Bastar, Singhbhum, and Aravalli-Bundelkhand cratons—and an extensive southern granulite province (Naqvi, 2005). Cratonization of India was polyphase, but largely complete by 2.5 Ga (Naqvi, 2005; Ramakrishnan and Vaidyanadhan, 2008; Meert et al., 2010), providing a large, relatively stable cratonic framework for the genesis of the widespread intracratonic ‘‘Purana’’ basins (Ramakrishnan, 2003). The term ‘‘Purana’’ is ascribed to all unfossiliferous sedimentary deposits that unconformably overlie penetratively deformed and metamorphosed cratonic elements of India. These deposits include both major basins as well as a number of smaller regions that may represent erosional remnants of primary basins (Kale and Phansalkar, 1991; Chakrabarti et al., 2006; Ramakrishnan and Vaidyanadhan, 2008).

The distinctly crescent-shaped Cuddapah Basin preserves nearly 12 km of sedimentary and volcanic strata that are assigned to the Cuddapah Supergroup and the unconformably overlying Kurnool Group (Nagaraja Rao et al., 1987; Fig. 1). These strata rest unconforably on basement rocks of the Dharwar craton, which is composed of Archean-aged TTG gneisses and greenstone belts, as well as several Early Paleoproterozoic mafic dike swarms (Nagaraja Rao et al., 1987; Murthy et al., 1987).

The origin of the Cuddapah Basin is uncertain, with basin development generally believed to reflect a series of thermal upwarping, rifting, and crustal thinning events (Nagaraja Rao et al., 1987; Chakraborty, 2000; Chatterjee and Bhattacharji, 2001; Choudhuri et al., 2002; Mohanty, 2011; Saha and Tripathy, 2012a,b), although a foreland basin scenario has also been suggested (Singh and Mishra, 2002). A combination of deep seismic profiling (Deep Seismic Sounding of Kaila et al., 1979, 1987), seismic tomography (Gupta et al., 2003), and gravity analysis (Singh and Mishra, 2002) indicate that the majority of Cuddapah strata in the western basin overlies thick, continental crust that contains a number of steep basement faults. Block faulting has been attributed, in part, to emplacement of a large mafic–ultramafic body under the southwestern part of the basin, from which a variety of mafic sills emanate (Mishra et al., 1987). Strata in the western basin (Papaghni, Srisailam, and Kurnool sub-basins) remain unmetamorphosed and relatively undeformed (Meijerink et al., 1984). The original structure in the eastern part of the basin (Nallamalai and Palnad sub-basins) is obscured by deformation and metamorphism within the Nallamalai Fold Belt (Saha and Chakraborty, 2003), which is associated with the uplift of lower crustal rocks during development of the Cambrian Eastern Ghats Mobile Belt (Biswal et al., 2007).

2.2. Regional stratigraphy of the Cuddapah Basin

Strata within the Cuddapah Basin include the Cuddapah Supergroup and the unconformably overlying Kurnool Group. The Cuddapah Supergroup consists, in turn, of the Papaghni, Chitravati and Nallamalai groups, each separated by regional unconformities (Table 1). Each of these groups is composed, broadly, of a fining upward succession from quartzite at the base to shale at the top, and is interpreted to represent a shallow-marine shelf that underwent periodic transgressive and regressive events (Saha and Tripathy, 2012a,b; Chakrabarti and Shome, 2007, 2010, 2011; Chakrabarti et al., 2009) associated with a combination of tectonic reorganization and eustatic sea level changes (Patranabis-Deb et al., 2012). Whereas the relatively undeformed Papaghni and Chitravati groups, exposed in the western part of the basin, were deposited during successive thermal upwarping and rifting events, the highly-deformed Nallamalai Group exposed in the eastern part of the basin likely represents development of active convergence along the eastern margin of the basin (Mishra, 2011, and references therein). Deposition of the overlying Kurnool Group likely represents resumption of an extensional regime via reactivation of basement normal faults in the western basin (Chakraborty et al., 2010).

Within this context, the Vempalle Formation (~1500 m thick) of the lowermost Papaghni Group, represents the only regional carbonate deposition within the Cuddapah Supergroup. The Vempalle Formation conformably overlies basal siliciclastic strata of the Gulcheru Formation and is associated with a number of basic volcanic flows in its upper reaches (Murthy et al., 1987). The Vempalle Formation is then overlain—with possible unconformity—by coarse-grained siliciclastic strata of the basal Chitarvati Group. The Vempalle Formation contains stromatolitic dolomite and dolomitic shale, with subordinate sandstone, and represents development of a regional carbonate ramp (Nagaraja Rao et al., 1987; Roy et al., 1990; Dhana Raju et al., 1993).

2.3. Geochronological constraints on stratigraphic development

The age of the Vempalle Formation is broadly constrained by radiogenic isotope ages of a series of mafic dikes and sills. Two distinct mafic dike swarms occur in the basement rocks that unconformably underlie the western part of the Cuddapah Basin, and have been associated with thermal doming of the Dharwar crust prior to the onset of Cuddapah deposition (Bhattacharji and Singh, 1984; Murthy et al., 1987; Chatterjee and Bhattacharji, 2001; Meert et al., 2010, 2011). These dikes provide ages of 2.4–2.1 Ga (Ikremuddin and Stueber, 1976; Murthy et al., 1987; Zachariah et al., 1999; Halls et al., 2007), and constrain the maximum age of deposition (Papaghni Group) within the Cuddapah Basin.