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ORIGINAL ARTICLE

Carbon and oxygen isotopic variations in stromatolitic dolomites of Palaeoproterozoic Vempalle Formation, Cuddapah Basin, India

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Abstract The marine stromatolitic dolomites of Palaeoproterozoic Vempalle Formation, of Cuddapah Basin, South India show significantly depleted $\delta^{18}O$ (-8.19 to -18.25‰) and $\delta^{13}C$ (-0.03 to -5.74) values and are consistent with the global Proterozoic data. A comparison of the stable isotope values from major localities of Proterozoic Basins of India has also been attempted in this study. Significantly depleted $\delta^{18}O$ values of Vempalle carbonate samples could not be considered to be post-depositional modifications as there exists an inverse correlation relationship between C and O isotopic values. The Vempalle stromatolitic dolomite is likely to be precipitated in equilibrium with marine waters significantly depleted in oxygen isotopes (-10 to -15‰ SMOW) with respect to modern sea water. The negative $\delta^{13}C$ values of the Vempalle carbonates are likely to be interpreted at the backdrop of global "icehouse" as there is an indication of dropstone-like features in the lower part of the Vempalle Formation just 2 km, southwest of the study area.

Keywords Proterozoic · PDB · Isotope · Huronian · Icehouse · Stromatolite

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Introduction

The stable isotopic compositions of marine carbonates and co-existing organic matter can provide important clues to understand "events" and "tempos" operating on the earth during the Precambrian, which has no biostratigraphic framework. Voluminous data on stable isotopic composition of Proterozoic marine carbonates have already been acquired in many studies (Bartley et al. 2007 and references therein; Nagarajan et al. 2008 and references therein). The central focuses in most of the studies are: (1) Palaeoproterozoic Huronion glaciation and so called "cap carbonate" (Melezhik et al. 1999; Buick et al. 1998). (2) Advent of cyanobacteria leading to the oxygenation of ocean and atmosphere (Kasting 1987; Karhu and Holland 1996; Des Marais 1997). (3) Neoproterozoic "snowball earth" and the break-up of Rodinia supercontinent (Hoffman et al. 1998; Kah and Bartley 1997; Misi et al. 2007). (4) Decline of stromatolites at Precambrian/Cambrian boundary (Melezhik et al. 1997).

From a cursory look at the global Proterozoic $\delta^{13}C_{carb}$ data, it is revealed that the Proterozoic Era is marked by large shifts in $\delta^{13}C$ record (Knoll et al. 1986; Kaufman and Knoll 1995; Melezhik et al. 1999; Shields and Veizer 2002). While Palaeoproterozoic is marked by +ve excursion of $\delta^{13}C_{carb}$ between 2.40 and 2.06 Ma, Mesoproterozoic, however, has been cited as a time of biogeochemical stasis (Buick and Knoll 1995; Brasier and Lindsay 1998;

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Knoll and Canfield 1998) with $\delta^{13}C$ values near 0 ± 1‰. Carbonate strata younger than ~1,200 Ma are characterized by significantly higher $\delta^{13}C$ values ranging between +3.5 ± 1.0‰ (Bartley et al. 2007). To date mechanism proposed by different workers for these C-isotopic shifts in earth's history remain highly debated (Pandit et al. 2003, 2009 and references therein; Melezhik et al. 1999). Therefore, there is a wide scope to work on stable isotope geochemistry on Proterozoic marine carbonates to throw light on Proterozoic ocean–atmosphere system, palaeoclimate and geobiology.

In India, stable isotope studies of marine carbonates of Proterozoic sequences (primarily from Mesoproterozoic and Neoproterozoic) have been reported from the lesser Himalayan Basin (Aharon et al. 1987; Banerjee et al. 1997; Kumar and Tewary 1995), the central Indian Vindhyan Basin (Friedman et al. 1996; Kumar et al. 2002; Ray et al. 2003; Banerjee et al. 2007), Indravati Basin (Maheshwari et al. 2005), Bhima Basin (Nagarajan et al. 2008), and also from the Rajasthan area (Banerjee and Majumdar 1999, Pandit et al. 2001, 2003; Sreenivas et al. 1998, 1999; Maheshwari et al. 1999). However, no stable isotopic studies are reported from the Proterozoic Cuddapah Basin, the second largest intracratonic basin on Dharwar craton (Ramakrishnan and Vaidyanadhan 2008), India. The present work is an attempt to investigate the stable isotopic variations in the marine carbonates of the Palaeoproterozoic Vempalle Formation, Cuddapah Basin, India.

Geological setting

The crescent-shaped Cuddapah Basin of Andhra Pradesh, south-eastern Peninsular India, has a maximum width of 145 km (in the middle) and 440 km long, and is exposed over an area of 44,000 sq km. On the western margin of the basin the undisturbed Proterozoic sediments rest on an Archaean gneissic complex enclosing the greenstone belts of Kadiri, Veligallu and Gadwal (Nagaraja Rao et al. 1987) with a profound nonconformity. Its eastern margin has a thrust contact with both Archaean and Eastern Ghat Mobile belt.

The basin was described as a rift basin resultant from crustal doming, erosion and subsidence (Drury 1984; Jain et al. 1995; Acharya 1997; Chakraborty 2000) or by peripheral foreland basin based on geophysical investigation (Singh and Mishra 2002). This basin consists of well-preserved Palaeoproterozoic–Neoproterozoic sedimentary and associated volcanic succession of ~12 km thickness.

The lithostratigraphy of the Cuddapah Basin (Table 1), basically established by King (1872), is composed dominantly of argillaceous and arenaceous sediments with subordinate calcareous sediments. Palaeoproterozoic is mainly dominated by ~1,900 m thick Vempalle Formation of stromatolitic dolomite with subordinate mudstones, sandstones and cherts cropping out along the western and southwestern margin of the basin (Fig. 1), which overlies conformably on the basal siliciclastic Gulcheru Formation.

Table 1 Stratigraphy of the Cuddapah Basin (after GSI, 1981)

Supergroup	Group	Formation	Th. (m)	Age
	Kurnool	Nandyal shale	50–100	Neoproterozoic
		Koilkuntala limestone	15–50	
		Paniam quartzite	10–35	
		Auk shale	10–35	
		Narji limestone	100–200	
		Banganapalle quartzite	10–57	
		Unconformity		
Cuddapah supergroup	Nallamalai	Srisailam quartzite	620 (+)	Mesoproterozoic
		Cumbum formation	2,000 (+)	
		Bairenkonda (Nagari)		
		Quartzite	1,500	
		Unconformity		
	Chitravati	Gandikota quartzite	1,200	Mesoproterozoic
		Tadpatri formation	4,600	
		Pulivendla quartzite	1–75	
	Papaghni	Vempalle formation	1,500	Palaeoproterozoic
		Gulcheru quartzite	28–250	
		Unconformity		
		Archaean gneissic		
		Complex		

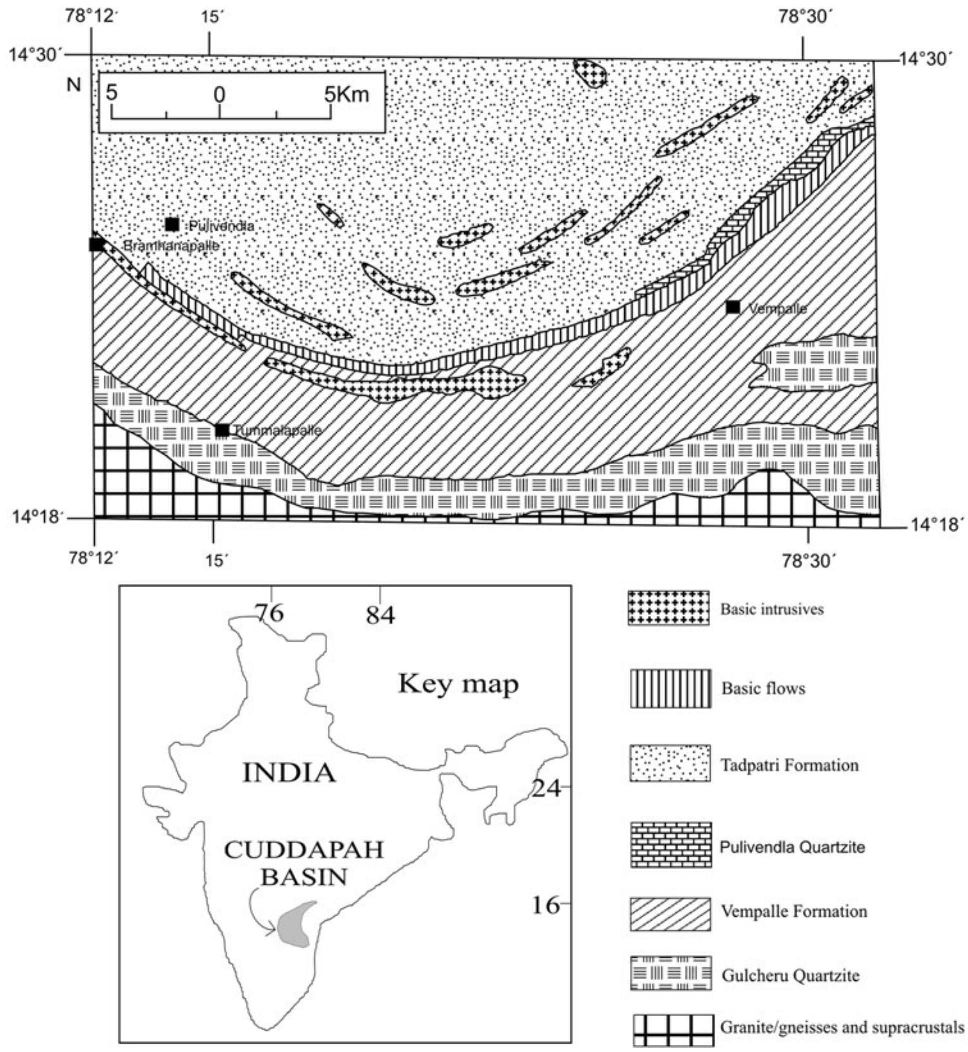

Fig. 1 Geological map of the study area (modified after Zachariah et al. 1999). *Inset* shows the location of Cuddapah Basin in India

Each of the three overlying groups viz, Papaghni Group, Chitravati Group and Nallamalai Group of the Cuddapah Supergroup are composed of quartzite at the base and a shale unit at the top, representing shallow-marine shelf succession with periodic transgressive and regressive events in the basin. Contemporaneous igneous activity is represented by sills, volcanic flows and other intrusives along the western periphery of the basin (particularly in the Vempalle Formation) and the eastern Nallamalai Group (Nagaraja Rao et al. 1987).

The Vempalle Formation, well-exposed in the Pulivendla area belonging to the Southwestern sector of the Cuddapah Basin, is represented by several litho-sections with a complete succession of Stromatolitic dolomite, shale and volcanics. The samples studied for stable isotope analysis are collected from the stromatolitic dolomitic limestone outcrops exposed in the upper portion of the Vempalle Formation in the vicinity of Bramanapalle Asbestos Mine (14°25′15″ N, 78°12′E), near Pulivendla (Fig. 1). Approximately, 50-m thick successions of stromatolitic limestone and intercalated black to grey chert are well-exposed here. At Bramanapalle, circular to oval-shaped closely packed stromatolites, occur within continuous and well-defined zones, are less than one to few meters in thickness and less than 10 cm to more than 1 m in diameter. The spatial and temporal distribution of dome-shaped stromatolites along with profuse development of oolites seems to be indicative of shallow, marine, and probably intertidal to shallow subtidal depositional milieu (Schopf and Prasad 1978).

The Cuddapah Basin has been divided into two broad structural sectors separated by the Rudravaram Line (Meijerink et al. 1984). It is a boundary fault (Normal fault) on the western side of the Nallamalai Formation. The region west of this line displays relatively gentle deformation, except in the vicinity of basin-marginal cross-faults, that dye out toward the interior of the basin east of the Rudravaram line, up to the eastern thrust margin of the Cuddapah Basin. The arcuate belt on the eastern margin is recognized as the Nallamalai Fold Belt (NFB) by Narayanswamy (1966). Granitic intrusions and mineralization are associated with these faults, which exhibit strike-slip motion.

The deep structure of the Cuddapah Basin as interpreted from the DSS profiles and gravity data (Kaila et al. 1979; Kaila and Tewari 1985) shows that the basin can be divided into several blocks and separated by deep faults. The Cuddapah Basin is characterized by gravity low towards the eastern side and gravity high towards the southwestern side (Singh and Mishra 2002). This gravity high towards west is modeled with a high-density basic lopolith above the basement at a depth of 7–8 km, which is primarily responsible for the various sills exposed in this area (Mishra et al. 1987). The gravity low in the eastern part of the basin is modeled with thick sediment and a thick crust of about 40 km.

Age

Rb–Sr radiometric dating by whole rock analysis of the Pulivendla sills intruded into the lower Cuddapah Supergroup has yielded an age of 1704 ± 112 Ma (Bhaskar Rao et al. 1995). Biotite and clinopyroxene analyzed from two samples of the same sill gave an age of 1811 and 1831 Ma, respectively, which may be an absolute upper age limit for sedimentation of the Papaghni and the Chitravati groups into which the sill intrudes (Murthy et al. 1987). Zachariah et al. (1999) determined the Pb, Sr, and Nd, isotopic compositions on uranium mineralized and barren stromatolitic dolomite samples from the Vempalle and Tadpatri Formations. Their analysis yielded a Pb–Pb age of 1,756 ± 29 Ma, which is interpreted as the time of U-mineralization and as a minimum age for carbonate sedimentation and dolomitization. ^{40}Ar–^{39}Ar laser-fusion determined on phlogopite mica, from the Tadpatri Formation mafic–ultramafic sill complex, constrain the extension and volcanism in the initial phase of the Cuddapah Basin at 1.9 Ga. (Anand et al. 2003). However, reported stromatolite biostratigraphy has not been in complete agreement with this age data. According to Gururaja and Chandra (1987) the Vempalle and Tadpatri stromatolites were of Riphean age. However, a diverse ministromatolite assemblage of Palaeoproterozoic aspect is now reported from the Vempalle Formation (Sharma and Shukla 1998).

Methodology

The carbonate samples are sampled at close interval upsection from exposed rock surfaces in the Bramanapalle area. A total number of eight samples were selected for stable isotope analysis and all the sample points are depicted in the litho-log (Fig. 2). The results are listed in Table 2.

For carbon and oxygen isotopic determinations, CO_2 was extracted from powdered carbonates in a high vacuum line after reaction with H_3PO_4 at 25°C, and cryogenically cleaned according to the method described by Craig (1957). CO_2 gas released by this method was analyzed for carbon and oxygen isotopes in a double inlet, triple collector SIRA II mass spectrometer, using the reference gas BSC (Borborema Skarn Calcite) calibrated against NBS-18, NBS-19, and NBS-20, has a value of −11.28 ‰ PDB for $\delta^{18}O$ and −8.58‰ PDB for $\delta^{13}C$. The results are reported as per mil (‰) $\delta^{18}O$ and $\delta^{13}C$ values relative to Pee Dee belemnite (PDB international standard). The conversion of SMOW values to PDB standard have been attempted using the following formula 18Ocalcite $(SMOW) = 1.03086$ 18Ocalcite (PDB) + 30.86 (Friedman et al. 1977).

Isotope composition

A cross-plot of $\delta^{13}C$ versus $\delta^{18}O$ (Fig. 3) shows inverse correlation relationship ($r = -0.64$). One dolomite sample shows near 0 value (−0.03) of $\delta^{13}C$. Other samples show significantly depleted values as low as −5.74‰.

Majority of the samples with respect to $\delta^{18}O$ shows significantly depleted values (~−8.19 to −18.25‰). Marine carbonates with $\delta^{18}O$ value range from −10 to −5‰ can be considered to retain primary oxygen isotope signatures and are compared with the 'best preserved' $\delta^{18}O$ values of ~7.5 ± 2‰ reported for most of the Proterozoic-early Cambrian rocks (Burdett et al. 1990; Hall and Veizer 1996). Post depositional modifications by exchange with meteoric water or interstitial fluids at elevated temperatures (Fairchild et al. 1990) are often proposed to represent such a large depleted $\delta^{18}O$ values. However, $\delta^{13}C$ values are not susceptible to such resetting of values as in the case of $\delta^{18}O$, due to the relatively low CO_2 content in diagenetic water (Banner and Kaufman 1994). Post-depositional thermal alteration of organic matter often preserves primary C-isotope signatures in the carbonate phases too (Kah et al. 1999). It is also further noticed (Table 2) depletion in $\delta^{13}C$ values towards up section and probably the trend starts reversing from top to bottom (Sample nos. 15/1 and 17/1).

Discussion

The $\delta^{13}C$ excursions studied throughout the globe demonstrate a major positive excursion in $\delta^{13}C$ values in marine carbonates happened around 2,200 Ma, perhaps which may be the largest excursion in the geological record (Karhu and Holland 1996; Holland 2002). This Palaeoproterozoic positive excursion of $\delta^{13}C$ is now considered as three positive shifts of $\delta^{13}C$ occurred between 2.40 and 2.06 Ma (Melezhik et al. 1999). At the peak, $\delta^{13}C$ values in

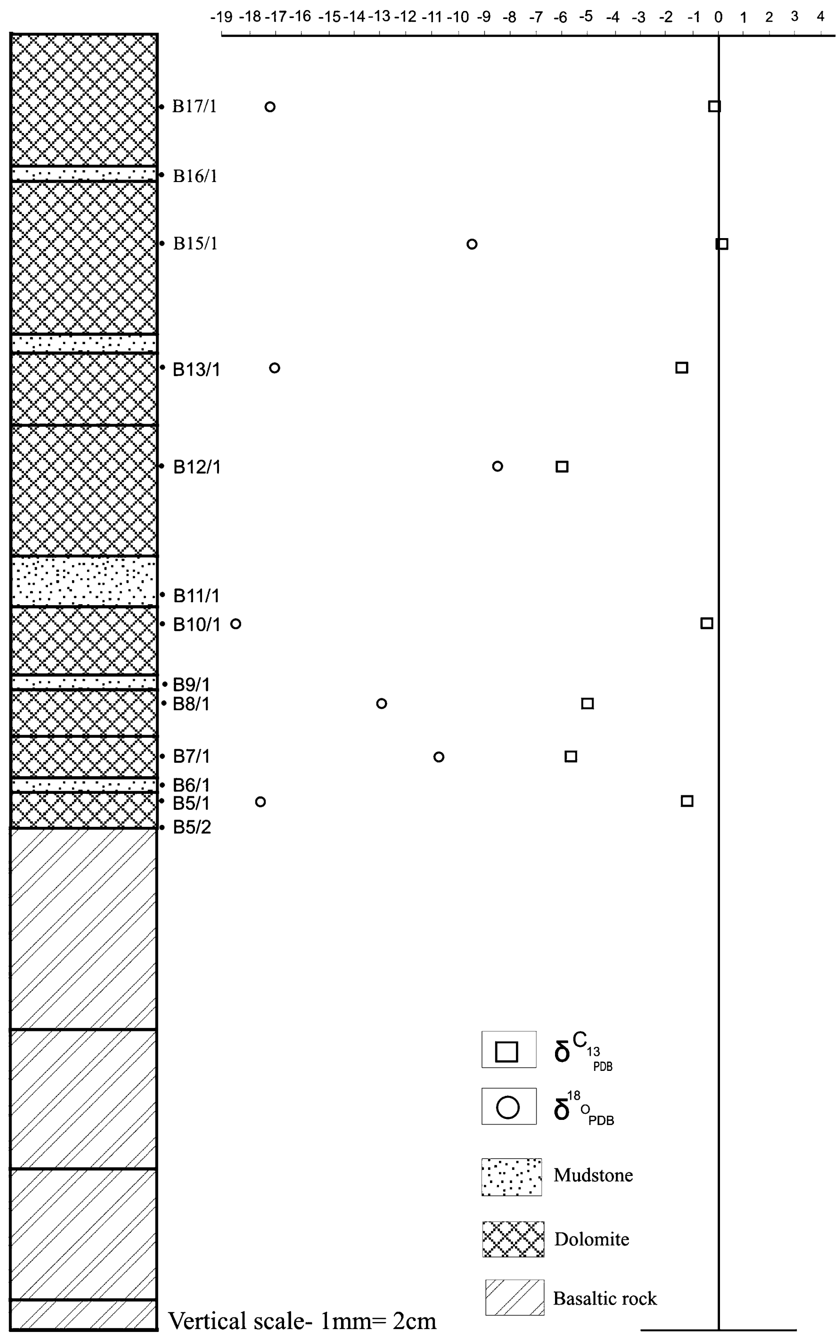

Fig. 2 Litholog, sample points and temporal variation of stable isotope data from Bramanapalle area, Cuddapah Basin, India

marine carbonates was almost +12 with corresponding organic carbonate values, averaged about −24. In modern times, the average δ^{13}C input into the atmosphere has been considered to be about −5‰ and if this value is projected to Palaeoproterozoic dolomites, about 50% of carbon at that time must have been buried as organic carbon (Condie 2005). It has been estimated that the total amount of oxygen released to the atmosphere during this C-burial are 12–22 times higher than the present day oxygen level, suggesting the major period of expansion in atmospheric oxygen around 2.2 Ga (Holland 2002).

The end of the Palaeoproterozoic carbon isotopic excursion is marked by the first appearance of diagenetic CO_3 concretions with negative $\delta^{13}C_{carb}$ values and preceded by a negative carbon isotopic shift (Melezhik et al. 1999). Most continents yield clear evidence of Huronian glaciations during ~2.40–2.35 Ga (Ojakangas 1985). Global data also indicates the development of shallow-

Table 2 C and O-isotope analysis of Vempalle Carbonates from Bramanapalle area, Cuddapah Basin, India

Sample no.	$\delta^{13}C_{V\text{-}PDB}$ ‰	$\delta^{18}O_{V\text{-}PDB}$‰	$\delta^{18}O_{SMOW}$‰
B17/1	−0.03	−17.17	13.16
B15/1	0.27	−9.41	21.16
B13/1	−1.17	−17.75	12.56
B12/1	−5.74	−8.19	22.42
B10/1	−0.24	−18.25	12.05
B8/1	−4.73	−12.43	18.04
B7/1	−5.56	−10.11	20.44
B5/1	−1.13	−17.05	13.29

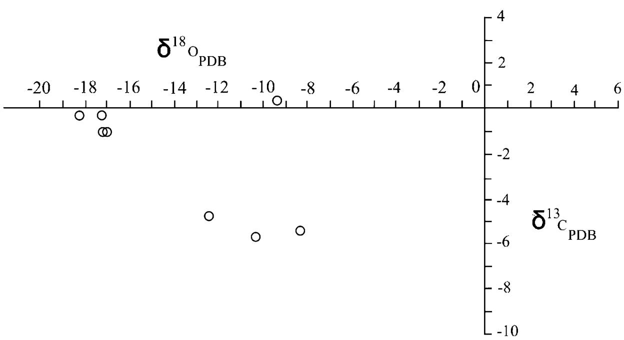

Fig. 3 δ^{13}C versus δ^{18}O plot for the Vempalle Formation stromatolitic dolomites, Bramanapalle area, Cuddapah Basin, India

water CO_3 platform at the onset of isotopic excursion (Grotzinger 1989).

With this framework in mind, the isotopic value of the analyzed samples from Vempalle dolomites in Bramhanapalle area needs to be explained. Available age data indicates that the Vempalle sedimentation began at ~1,900 My ago i.e., at the terminal part of the Palaeoproterozoic, which is marked by negative δ^{13}C values recorded from marine carbonates all over the world (Melezhik et al. 1999). Hence, the δ^{13}C data of this study is consistent with the global data. Considering the model of restricted basin with the high bioproductivity (Melezhik et al. 1999) for Vempalle sedimentation, the negative carbon isotope values indicate the contribution of CO_2 or bicarbonate derived from oxidation of organic matter (Botz et al. 1988) as it is evident from high level of bioproductivity marked by the occurrence of abundant stromatolites. Another point also needs to be mentioned here is that the Vempalle Formation is the only stratigraphic unit of the Cuddapah Basin, which contain a sequence of lava flows (Anand et al. 2003). The thickest lava flows occur in the southern part of the Cuddapah Basin at Pulivendla, Vempalle, Animala (up to 50 m) and Pulivendla areas. Basic lava flows conformably overlies the Vempalle Formation stromatolitic dolomites marking the end of the Vempalle sedimentation in Papaghni Sub Basin. During volcanism, due to enormous heat production, most of the bacteria disappeared and tends to decline the stromatolite types. This leads to the decrease in biological ^{12}C uptake from the inorganic C-pool, which results an increase in ^{12}C in surface water and probably caused the negative $\delta^{13}C_{carb}$ shift in marine carbonate precipitates. Alternatively, there may be a possibility of the impact of terminal period of Huronian glaciation or may be an advent of "snowball earth"—like condition in Indian Peninsular region at the onset of Vempalle sedimentation. Usually, the post glacial marine cap carbonates are associated with negative C isotopic excursions (~−5‰) (Hoffman et al. 1998 and references therein). There is an indication of dropstone-like features in the lower part of the Vempalle Formation just 2 km, southwest of the study area (Fig. 4).

Fig. 4 Drop-stone like features from Vempalle Formation, Bramanapalle area, Vempalle Fm., Cuddapah Basin, India. The bending of carbonate layers around the faceted clast

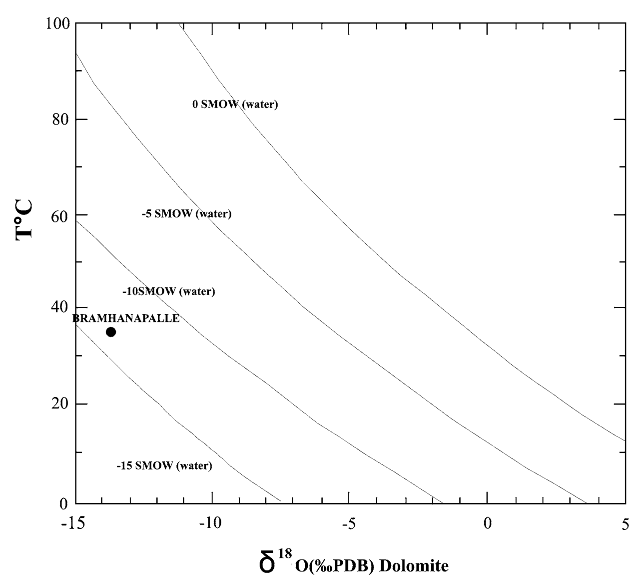

Fig. 5 T versus δ^{18}O plot for the Vempalle Formation stromatolitic dolomites, Bramanapalle area, Cuddapah Basin, India

Table 3 Stable isotope studies from major localities of Proterozoic Basins from India

Geomorphic and geological location and age	Carbonate lithology	Associated sediments and biosedimentary structures	$\delta^{13}c_{carb}$ variation (‰)	$\delta^{18}o$ variation (‰)	Palaeoenvironment	References
1. Vindhyan Basin, Palaeo-Neoproterozoic	Dolomite and limestone	Stromatolites, chert	(1) 0 ± 2‰ (Lr.) to 3 ± 2‰ (Up.) (2) +0.9 to −2.5‰	(1) −8.5 ± 1.5‰ (2) −7.9 to 12.8‰	Shallow marine, shallow lagoonal to tidal setting	Ray et al. (2003)
2. Indrawati Basin, Mid. Neoproterozoic	Shale, limestone and dolomites	Stromatolites	+3 to +4.5‰	−6 to −10.5‰	Shallow-marine, near shore, tidal flat or lagoonal environment	Maheshwari et al. (2005)
3. Bhima Basin, late Neoproterozoic to early Cambrian	Faggy, pale blue limestone, variegated, bluish green or pink/pale blue limestone, massive, dark/bluish grey limestone and flaggy, dark grey/bluish grey argillaceous limestone	Macrostylolites	~1.34–1.96‰	~−6.04 to −7.61‰	–	Nagarajan et al. (2008)
4. Jahazpur belt in SE rn Rajasthan (NW India)	Dolomites	–	−4.8 to +0.9‰	−9.5 to −3.8‰	–	Pandit et al. (2003)
5. Sirohi Gr., Meso-proterozoic, Delhi Supergroup, Rajasthan	Metacarbonates	–	1 to −3.3‰	−20.2 to 101‰	–	Pandit et al. (2009)
6. Kaladgi Basin	Dolomites and Limestones	–	0.3 ± 1.2‰	21.7 ± 1.3‰ SMOW	–	Satyanarayana et al. (1987)
7. Jhamarkotra Fm. of Aravalli craton, Rajasthan (NW India) Palaeoproterozoic	Phosphorites bearing carbonates	Stromatolites	~Up to +4‰	–	–	Seenivas et al. (2001)
8. Buxa dolomite of Eastern lesser Himalaya	Dolomite	–	+3.7 to +5.4‰	−8.9 to −7.2‰ V-PDB	–	Tewari et al. (2007)

The inverse correlation between C and O isotopic values of the vempalle carbonates could not be considered to be post-depositional modifications. According to Kah (2000), isotopically light values must reflect either sea water significantly depleted from present marine compositions or carbonate precipitation at elevated temperature. Isotopically depleted chert and dolomite rocks preserved in Precambrian rocks have been used to suggest Proterozoic Ocean temperature (Knauth and Epstein 1976). However, at higher temperature (>65°C), most of the cyanobacterial species would perish. So it seems quite unlikely that the vempalle dolomites represent elevated depositional temperatures. It is conjectured that the temperature of surface sea water was <35°C, which is much similar to those obtained in the modern Persian Gulf (Emery 1956). If the estimation of maximum surface water temperature (~35°C) is correct then the Vempalle carbonates would have had to be precipitated in equilibrium with marine waters significantly depleted in oxygen isotopes (−10 to −15‰ SMOW) with respect to modern sea water (Fig. 5).

Comparison with other proterozoic marine carbonates of India

A comparison of the stable isotope values from major localities of Proterozoic Basins of India has been attempted in this study (Table 3). The well known Vindhyan depository (Bose et al. 2001) one of the largest Proterozoic intracratonic basins in the Precambrian shield area of India show regular variations in isotopic composition of sea water. The distribution pattern for $\delta^{18}O$ composition of the Vindhyan carbonate shows a mean value of -8.5 ± 1.5‰, which is similar to Palaeo-Neoproterozoic limestone. However, the distribution patterns for $\delta^{13}C$ for the lower and upper Vindhyan carbonate show modes at 0 ± 2‰ and 3 ± 2‰, respectively and are consistent with the global average during this time interval (Ray et al. 2003). The Kajrahat limestone (stromatolite) belongs to the Semri Group (lower part of the two tired Vindhyan Super group; Bose et al. 2001, Rasmussen et al. 2002) shows that $\delta^{13}C$ values range from 0.9 to −2.5‰, and $\delta^{18}O$ values from −7.9 to −12.8‰ (Banerjee et al. 2007). As the cross plot of all the $\delta^{13}C$ and $\delta^{18}C$ values shows negligible correlation, the stable isotopic compositions of shallowing upward CO_3 cycles reflect alteration by the action of the meteoric waters. However, in the case of vempalle dolomites, there exists an inverse correlation between $\delta^{18}O$ and $\delta^{13}C$ values, arguing against such post-depositional alteration by meteoric water.

The Indrawati Basin carbonates of central India have moderately positive $\delta^{13}C$ (up to +4.5‰) and negative $\delta^{18}O$ values (−6 to −10.5‰ PDB), which are comparable with the Bhander limestone, unit of upper Vindhyan Supergroup suggesting deposition in the late Mesoproterozoic to early Neoproterozoic period (Maheshwari et al. 2005). So, the carbonates of Indrawati Basin are much younger than vempalle carbonates of the Cuddapah Basin. Similarly, stable isotope geochemistry of the Neoproterozoic limestones of Sahabad Formation, Bhima Basin, Karnataka, southern India show a narrow range of $\delta^{13}C$ (~1.34–1.96‰ PDB) and $\delta^{18}O$ values (~−6.04 to −7.61‰ PDB) (Nagarajan et al. 2008). They also concluded that their studied samples can be considered as well preserved marine limestone that has retained their primary chemical and isotopic signatures. Identification of $\delta^{13}C$ positive excursions in Palaeoproterozoic Aravalli Super group, Rajasthan, India has been done by several workers like Srinivas et al. (1998, 1999) and Maheshwari et al. (1999). The Palaeoproterozoic Jhazpur Group (NW Indian craton) is considered to be correlative with the Aravalli Super group (Sinha Roy et al. 1998; Malhotra and Pandit 2000). The lower Dolomite unit of this Group have negative to near 0 $\delta^{13}C$ values (−4.8 to +0.9‰ V-PDB) and negative $\delta^{18}O$ values (−9.5 to −3.8‰ V-PDB) (Pandit et al. 2003). These values are consistent with the $\delta^{13}C$ and $\delta^{18}O$ values obtained from the vempalle carbonates proving a significant correlation between these two units. So, a correlation of these data with that of the stromatolitic dolomites of Aravalli Supergroup which is the type area of the Paleoproterozoic rocks in the NW craton would be concluded from this study. The Neoproterozoic Sirohi Group metacarbonates of Delhi Supergroup of Rajasthan area, NW India show $\delta^{18}O$ values ranging between −20.2 and −101‰, and $\delta^{13}C$ values fluctuating from marginally positive (~1‰) to negative (−3.3‰) (Pandit et al. 2009), similarly, the $\delta^{18}O$ values are interpreted to be variably affected by post depositional alterations. However, the $\delta^{13}C$ V-PDB values are interpreted to represent primary sedimentary structures and are typical of normal carbonate sediments suggesting warmer climatic condition during deposition prior to the Neoproterozoic "snowball earth" (Pandit et al. 2009). So the negative $\delta^{13}C$ values of the vempalle carbonates are also likely to be interpreted at the backdrop of global "icehouse".

Conclusions

1. The marine stromatolitic dolomites of Palaeoproterozoic Vempalle Formation, of Cuddapah Basin, South India show significantly depleted $\delta^{18}O$ (−8.19 to −18.25‰) and $\delta^{13}C$ (−0.03 to −5.74) values.
2. The inverse correlation relationship between C and O isotopic values of the Vempalle carbonate samples could not be considered to be post-depositional modifications.

3. If maximum surface water temperature ($\sim$35°C) and composition of primary marine carbonate phase of vempalle carbonate (δ^{18}O mean value ~-13.72‰) are correctly estimated then the Vempalle carbonates would have had to be precipitated in equilibrium with marine waters significantly depleted in oxygen isotopes (-10 to -15‰ SMOW) with respect to modern sea water.
4. As the terminal part of the Palaeoproterozoic is marked by negative δ^{13}C values recorded from marine carbonates all over the world (Melezhik et al. 1999), the δ^{13}C data of the late Palaeoproterozoic Vempalle Formation in the study area is consistent with the global data.
5. The negative δ^{13}C values of the Vempalle carbonates are likely to be interpreted at the backdrop of global "icehouse".

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