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ORIGINAL ARTICLE

Petrography and stable isotopic variations in Dalmiapuram Formation of Cauvery Basin, South India: implication on OAE1d

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Abstract Petrography, carbon and oxygen isotopic study was carried out to interpret isotopic variations on the predominant carbonate sequence of the Dalmiapuram Formation of the Cauvery Basin, South India. The common petrographic types identified in the Dalmiapuram Formation range from wackestone to boundstone. The gray shale and limestone members show large variations in $\delta^{13}C$ and $\delta^{18}O$ values (Gray shale member: +1.44 to +2.40 ‰ VPDB, −3.05 to −5.92 ‰ VPDB, respectively; Limestone member: −6.07 to +2.93 ‰ VPDB; −7.08 to −0.39 ‰ VPDB; respectively). In the present study, the carbon and oxygen values are not correlated, which supports the fact that these limestones retain their primary isotopic signatures. In carbon isotope curve, one negative shift is identified in the gray shale member and a positive isotopic excursion is detected in the coral algal limestone (CAL). The observed positive isotopic excursion in the lower part of the CAL correlates with OAE1d and suggests the global nature of the late Albian OAE1d in the Cauvery Basin.

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Keywords Carbon and oxygen isotopes · Oceanic anoxic event · Dalmiapuram Formation · Cauvery Basin · South India

1 Introduction

The mid-Cretaceous was a period of warm climates that presented geologically brief episodes of elevated organic-carbon burial occurring in the marine realm at the regional to global scale. This global warming provoked a unique deep-ocean circulation and expansion of anoxic conditions, known as the Oceanic anoxic events (OAEs: Schlanger and Jenkyns 1976; Jenkyns 1980, 2003; Wilson and Norris 2001; Leckie et al. 2002). The most extensive events of the mid-Cretaceous are OAE1a (early Aptian: ~120.5 Ma), OAE1b (Aptian/Albian boundary: ~113–109 Ma) and OAE2 (Cenomanian/Turonian boundary: ~93.5 Ma). Other Cretaceous OAEs such as OAE1c (early late Albian: ~102 Ma) and OAE1d (late Albian: ~99.5 Ma) have been recognized, particularly from the Tethyan domain (Arthur et al. 1990). The warm climates were the result of an enhanced greenhouse effect, widespread Cretaceous volcanism and sea-floor spreading rates, which probably also resulted in increased mantle out-gassing of CO_2 (Berner et al. 1983; Arthur et al. 1985). The carbon isotope variations can be used to establish global organic carbon budgets during the OAEs (Bralower et al. 1999). The variations in the carbon isotopes of the carbonate rocks mainly reflect the changes in the isotopic composition of the global pool of exchangeable carbon in the oceanic, terrestrial and atmospheric reservoirs (Weissert 1989; Beerling et al. 2002). The isotopic studies on the shallow marine carbonates of the Lower Cretaceous age have revealed evidence of paleo-oceanographic changes (Madhavaraju et al. 2004, 2013a, b; Sial et al. 2001; Marquillas et al. 2007; Armstrong-Altrin et al. 2009; Chamberlain et al. 2013; Papp et al. 2013) and global scale tectonic events (Gröcke et al. 2005; Maheshwari et al. 2005; Amodio et al. 2008). Many researchers have documented that the variations in $\delta^{13}C$ seawater composition have been pelagic and hemiplegic carbonates from different locations and time periods (Weissert 1989; Föllmi et al. 1994; Grötsch et al. 1998; Wendler et al. 2009).

Albian sedimentary successions exposed in the Tethyan margin have been studied by many researchers in order to understand the timing and duration of the OAEs (Arthur and Premoli Silva 1982; Premoli Silva et al. 1989; Coccioni et al. 1992; Herrle et al. 2004; Luciani et al. 2004). However, recognition of the late Albian OAE records in the Cauvery Basin of South India has been limited. The term OAE1d (late Albian: ~99.5 Ma) was originally introduced by Erbacher and Thurow (1997) in order to differentiate between the black shale occurrences and the associated positive carbon isotope shift. Subsequently, OAE1d, the so called Breistroffer event (e.g., Erbacher and Thurow 1997; Strasser et al. 2001; Wilson and Norris 2001), was detected in several localities: Vocontian Basin, France (Gale et al. 1996), Mazagan Plateau, Morocco (DSDP site 547: Nederbragt et al. 2001), Blake Nose, USA (ODP site 1052: Wilson and Norris 2001) and Padurea Craiului, Romania (Papp et al. 2013). In the Vocontian Basin, the black shales associated with OAE1d were named Niveau Breistroffer (Breheret 1988). In the Vocontian basin, carbon isotope values strongly fluctuate (1.0–1.5 ‰) in the Niveau Breistroffer interval. In the Mazagan Plateau, OAE1d was associated with a significant positive carbon isotope shift of 1.5 ‰. In the Mount Risou section in the Vocontian Basin, a positive $\delta^{13}C$ shift of 0.5 ‰ was detected in the lower part of the section that correlates with OAE1d. Madhavaraju et al. (2004) have undertaken a carbon and oxygen isotopic study on the carbonate rocks of the Albian-Danian age from the Cauvery Basin. Their study mainly focused on the limestone samples collected from the outcrop area. No detailed isotopic study focusing on late Albian OAEs is available on this formation. In this paper we present new data on the stable isotopes from the Dalmiapuram Formation of the Cauvery Basin exposed in the Vadugarpettai litho-section (Fig. 1). The objectives of the present study are: (a) to provide an isotopic record of the Dalmiapuram Formation deposited in shallow marine environments; (b) to evaluate the possible diagenetic alteration of the isotopic signals; (c) to detect the Albian events (OAEs) in the Vadugarpettai section.

2 Geology and stratigraphy

The Cauvery Basin has been classified as a pericratonic rift basin located along the eastern continental margin of Peninsular India (Biswas et al. 1993). It formed as a consequence of the fragmentation of Gondwanaland during the Late Jurassic and continued evolving until the Tertiary through rift, pull-apart, shelf sag and tilt phases (Prabhakar and Zutshi 1993). This tectonic activity may have produced relative sea level changes in the east coast basins. The sedimentary rocks of the Cretaceous-Tertiary age are well exposed in the Ariyalur area (Fig. 1). These sedimentary successions have been studied by many researchers focusing on stratigraphy, sequence stratigraphy, paleontology, clay mineralogy, geochemistry, depositional environments and tectonic evolution (Srivastava and Tewari 1969; Banerji 1972; Sastry et al. 1972; Sundaram and Rao 1986; Ramasamy and Banerji 1991; Govindan et al. 1996; Madhavaraju and Ramasamy 1999a, b, 2001, 2002; Sundaram et al. 2001; Nagendra et al. 2002, 2011a, b; Madhavaraju et al. 2002, 2004, 2006, 2015; Madhavaraju and Lee 2009, 2010; Ramkumar et al. 2011; Madhavaraju 2015).

The sedimentary rocks in the Ariyalur area of the Cauvery Basin have been divided into three groups, the Uttatur, Trichinopoly and Ariyalur (Blanford 1862). The detailed lithostratigraphic classification of the Cretaceous-Tertiary sedimentary rocks of the Cauvery Basin was presented by Sundaram et al. (2001). Sundaram et al. (2001) have divided the Uttatur Group into four formations, the Terani Formation, Arogyapuram Formation, Dalmiapuram Formation and Karai Formation. The first three formations are considered as Early Cretaceous whereas the last formation is considered as Late Cretaceous. The Kallakudi limestone quarry in the Dalmiapuram village is considered as a type section for the Dalmiapuram Formation. It is divided into lower gray shale member and upper limestone member (biohermal limestone, marl bedded biostromal limestone and marls) (Ramasamy and Banerji 1991; Sundaram et al. 2001; Nagendra et al. 2002; Madhavaraju and Lee 2009).

According to Ramasamy and Banerji (1991), the minimum suggested age of the limestone member of the Dalmiapuram Formation, based on the abundant foraminifers and ammonites, was the early to middle Albian. Kale and Phansalkar (1992) assigned the middle to late Albian age to the Dalmiapuram Formation using characteristic nannofossils like *P. columnata, A. Alnianus* and *T. phacelosus*. However, an Albian to middle Turonian age was assigned to the Dalmiapuram Formation by various workers based on ammonites and planktonic foraminifera (Chiplonkar 1985; Raju et al. 1993; Ravindran and Kalyanasundar 1995). The coral algal limestone (CAL)

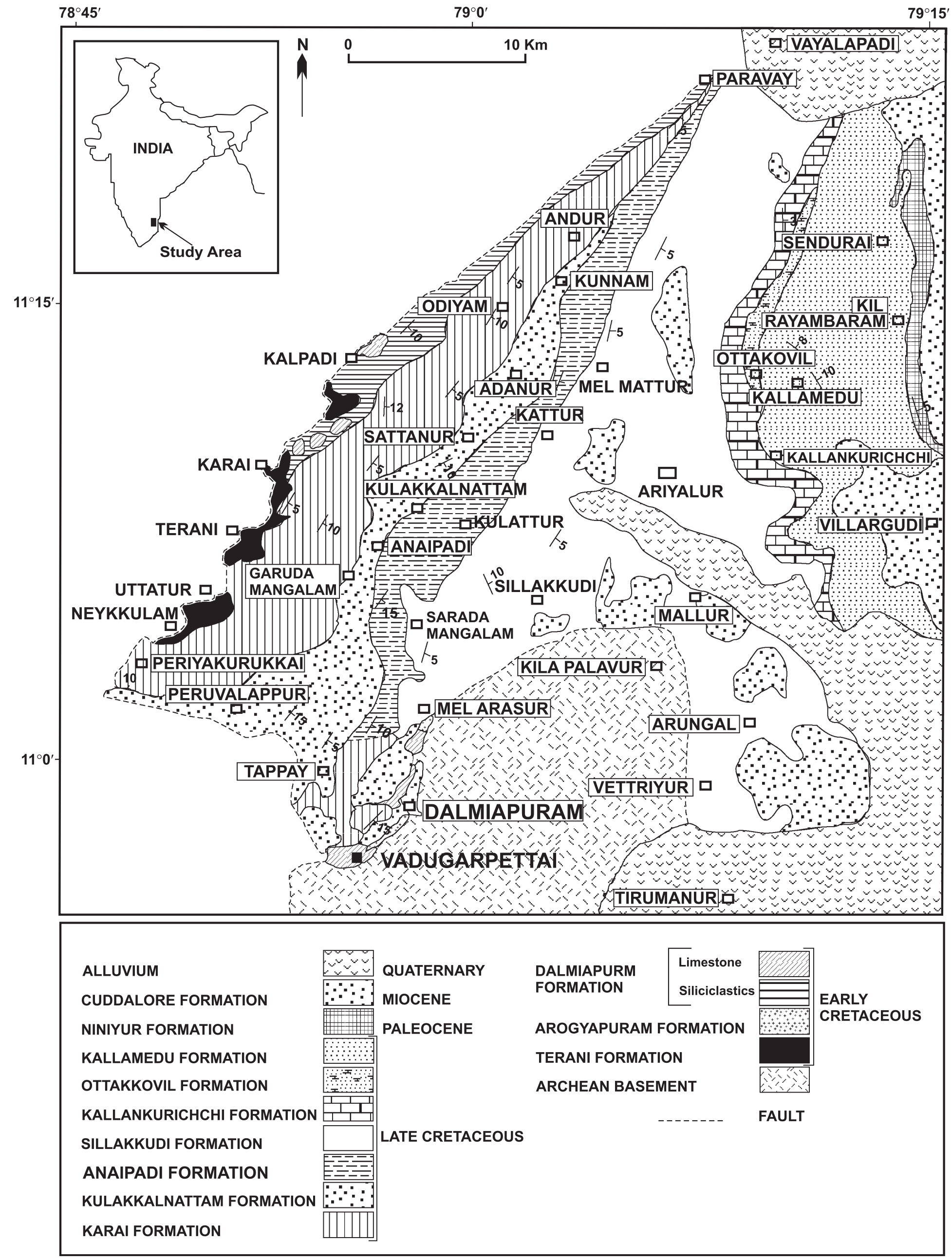

Fig. 1 Geological map of the Ariyalur area of the Cauvery Basin (modified after Sundaram et al. 2001)

unit of the Dalmiapuram Formation contains various species of algae, bryozoans, coral fragments and foraminifera. The bedded limestone encloses macrofossils such as *Acanthoceras* sp., *Mammites conciliatus*, *Nautilus huxleyanus*, and *Turrilites costatus* (Kossmat 1897; Govindan et al. 1998). The marl unit contains planktonic foraminifera *Hedbergella simplex* and several species of dinoflagellate cysts (Nagendra et al. 2002). The occurrence of various fossil assemblages such dinoflagellates and foraminifera in the Dalmiapuram Formation suggests the late Albian to middle Turonian age (Nagendra et al. 2011b). For the present study, we have followed the age proposed by later datation which has been the most recent micropalaeontologic research up to now on this formation.

The gray shale Member (9.0 m thick) is well exposed in the Vadugarpettai Quarry section (Fig. 2). The gray shales are interbedded with the gray coloured limestone beds (Fig. 3A). The color of shale beds varies from ash gray to dark gray and contains a few pyrite grains (Ramasamy and Banerji 1991). It is overlain by 8.2 m thick CAL. It is hard, massive, a pinkish to red color and contains algal and coral grains (Fig. 3B). In fact, the biohermal pink CAL has been considered as a miniscule replica of the giant Waulsortian

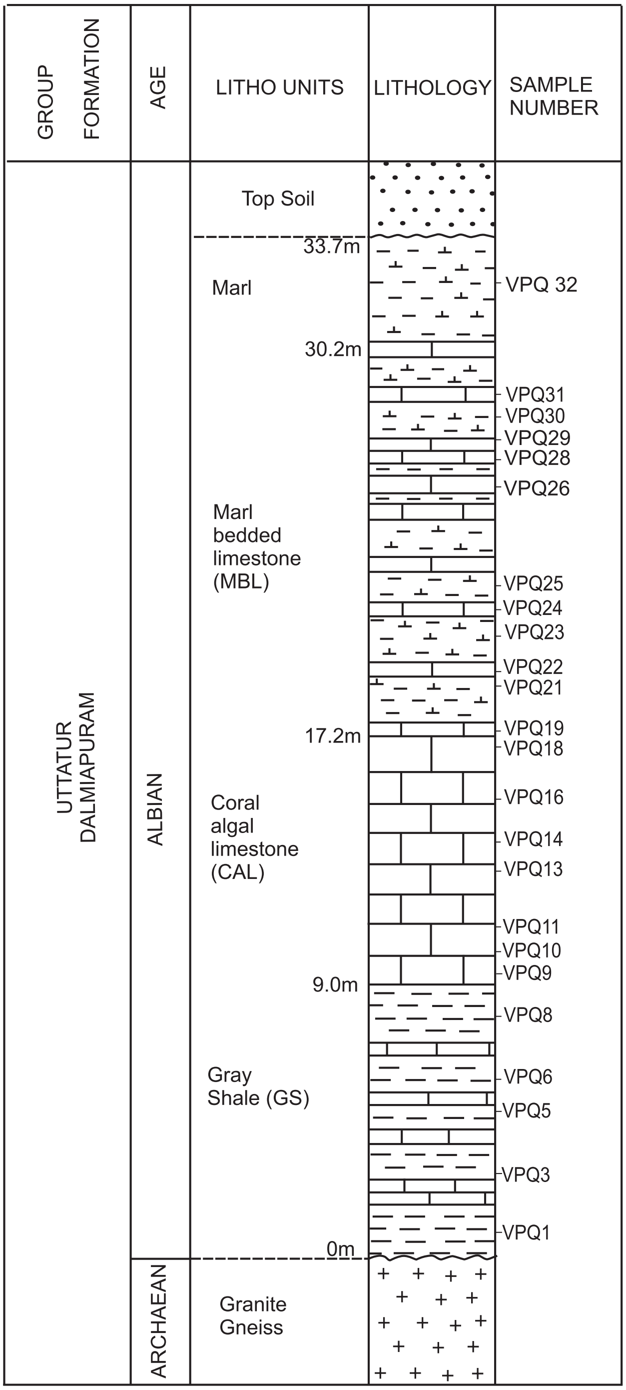

Fig. 2 Lithostratigraphy of the Dalmiapuram Formation in the Vadugarpettai area

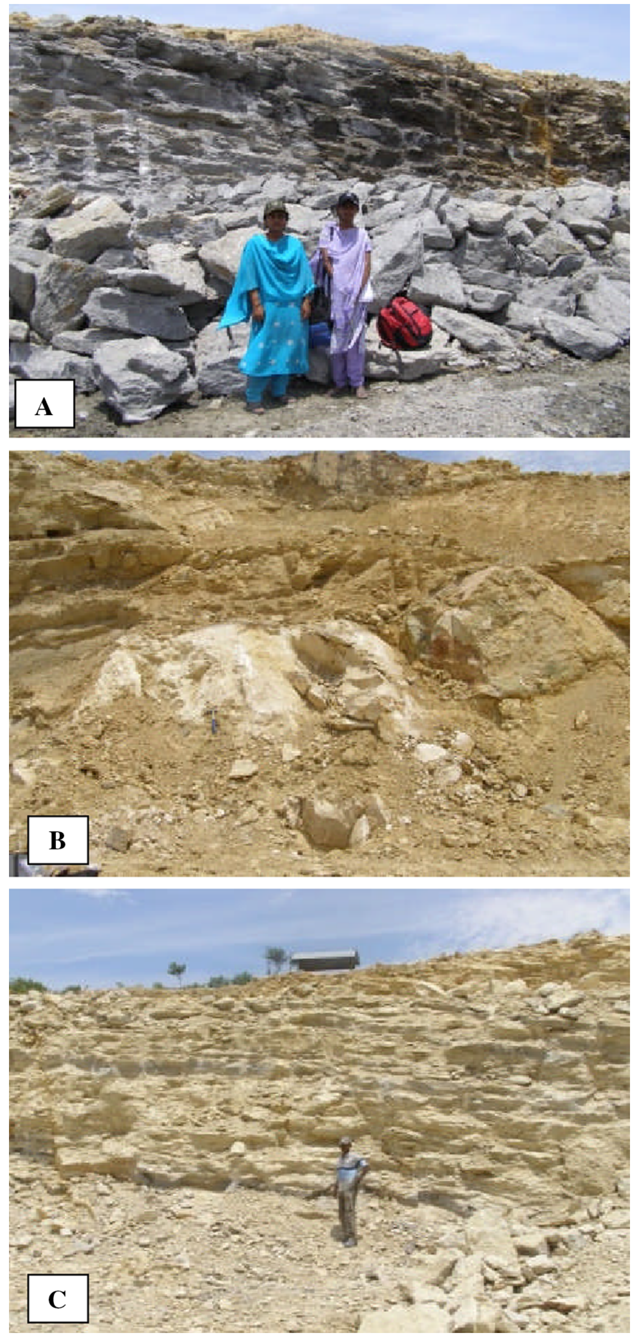

Fig. 3 Field phographs: **A** *Gray shales* interbedded with limestone beds in the Vadugarpettai section, **B** Coral algal limestone well exposed in the Vadugarpettai section, **C** Vertical variations of the marl and bedded limestone sequence

algal mounds of the Lower Carboniferous, Dinant Basin, Belgium (Wilson 1975). The growth of biohermal limestone was terminated due to either sea levels rising and/or environmental changes (Yadagiri and Govindan 2000). The CAL is overlain by marl and bedded limestone (Fig. 3C). The carbonates are soft to friable, white to brownish yellow in color and grades vertically into thin-bedded marl (Yadagiri and Govindan 2000). It also contains abundant foraminifers. The contact between the bedded limestone and marl is clearly seen in the vertical section. The marl and bedded limestone are overlain with a marl sequence of 3.5 m thick.

The CAL contains numerous calcareous algae, coral fragments and bryozoans, which suggests they come from a shallow marine environment (Banerji et al. 1996). The bedded limestone includes abundant benthic foraminifera, which indicates that it was deposited in a moderately deep-water shelf (>50 m water depth) facies (Ramasamy and Banerji 1991; Ramasamy et al. 1995; Yadagiri and Govindan 2000).

3 Methodology

Samples were collected from the Vadugarpettai (33.7 m thick) section of the Dalmiapuram Formation. Twenty-four samples were selected and analyzed: five from the gray shale, seven from the CAL, eleven from the marl bedded limestone and one from the marl. Nineteen thin sections were prepared for petrographic study. A staining test was undertaken to understand the carbonate types (Friedman 1959; Katz and Friedman 1965) that shows the studied limestone samples fall in the non-ferroan calcite variety. Twenty-four samples from the Vadugarpettai section were selected for a stable isotopic study. The carbonate rich samples were treated with H_3PO_4 in a vacuum at 25 °C for 1 day. The resulting CO_2 gas was analyzed for carbon and oxygen isotopic composition with a method described by Craig (1957). The CO_2 gas released from these samples was analyzed in a double inlet, triple collector SIRA II mass spectrometer at the Stable Isotope Laboratory (LABISE) of the Federal University of Pernambuco, Brazil using the reference gas Borborema Skarn Calcite (BSC), which calibrated against NBS-18, NBS-19, and NBS-20 and had a value of -11.28 ± 0.004 ‰ VPDB for $\delta^{18}O$ and -8.58 ± 0.02 ‰ VPDB for $\delta^{13}C$. The results were reported in the notation of δ ‰ (per mil) in relation to the international VPDB scale. To convert the $\delta^{18}O$ VPDB values into SMOW values, we used the following formula: $\delta^{18}O_{calcite}$ (SMOW) = 1.03086 $\delta^{18}O_{calcite}$ (VPDB) + 30.86 (Friedman and O'Neil 1997). The computer program OYNYL (Verma et al. 2006) has been used for the detection of discordant outliers in the bivariate plots (Barnett and Lewis 1994; Verma and Díaz-González 2012).

4 Results

4.1 Petrography

The petrographic description of carbonate rocks was documented based on the carbonate classification of Dunham (1962) and Embry and Klovan (1971). Four major petrographic types were identified in the Dalmiapuram Formation: (i) Wackestone, (ii) Packstone, (iii) Grainstone and (iv) Boundstone.

4.1.1 Wackestone

Two sub-types of wackestone were identified. Most wackestones contained small amounts of angular quartz and feldspar grains.

The *Sandy mollusk algal wackestone* is characterized by algal and mollusk fragments, in addition to a few angular quartz and feldspar grains (Fig. 4A). Most of the quartz grains are monocrystalline, however, a few polycrystalline quartz grains are also seen. Some echinoid spines are also present. It represents the upper part of the section. The lower part of the section is characterized by the *Sandy foraminiferal algal molluscan wackestone*, which consists of algal, foraminifera and a few bryozoans fragments (Fig. 4B). It also contains around 5 % of sand sized quartz and feldspar grains within the micritic matrix. The pore spaces are filled with sparry calcite cement.

4.1.2 Packstone

The *Molluscan coral algal packstone* (Fig. 4C) was located at the lower level of the limestone quarry. It contained gastropods, foraminifera, coral, molluscs and algal grains. Most of the framework grains show point contact between them. The cement is largely sparrite. Many of the molluscan grains were partly filled with sparrite. Echinoid spines occurred in small amounts and demonstrated a radial pattern. Most of the bioclast grains were coated with a micritic layer.

4.1.3 Grainstone

The *Coral algal grainstone* had a framework comprised of algal, coral and molluscan grains. Also present were pore filling iron oxide cement and a few quartz and feldspar grains. Many of the bioclasts were coated with micrite (Fig. 4D). The internal parts of the molluscan fragments were partly filled with sparry calcite cement. It represents the middle part of the section. The *Echinoid algal grainstone* is present in the upper part of the studied section and contains more than 10 % of the organic remains including echinoid, algal and molluscan fragments. The echinoid plates show an internal pore structure (Fig. 4E). The limestone exhibits numerous pore spaces, which were filled with microsparrite and sparry calcite cement.

4.1.4 Boundstone

Algal molluscan boundstone is recognized in the middle part of the studied section. The boundstone exhibits complete growth structures of algae. It shows a sparry calcite layer, an algal growth layer and a bioclast-rich

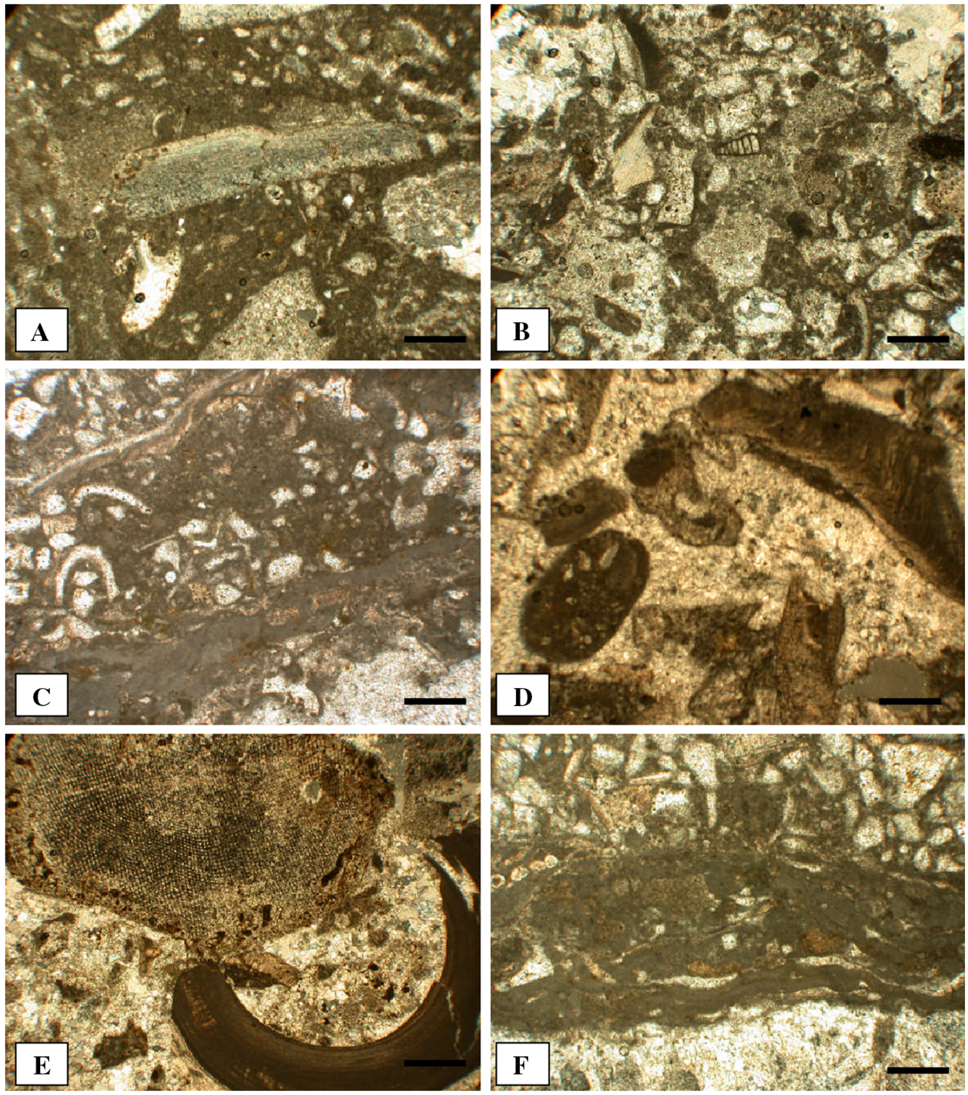

Fig. 4 Photomicrographs: **A** Mollusk and algal grains are floating on the micritic matrix. Few subangular quartz grains are also seen (scale bar = 0.5 mm), **B** The limestone exhibits mollusk, foraminifera and algal grains (scale bar = 0.5 mm), **C** The limestone showing gastropods, foraminifera, coral, mollusk and algal grains (scale bar = 0.5 mm), **D** *Coral algal grainstone* including algal, coral and mollusk grains; pore filling sparry calcite cement are also seen (scale bar = 0.5 mm), **E** The limestone shows echinoid and algal grains; the bioclasts are coated in micrite (scale bar = 0.5 mm), **F** The limestone exhibits the algal growth structure (scale bar = 0.5 mm)

layer (Fig. 4F). The algal growth layer consists of a thinner algal layer and thicker pelloid rich layers. The growth layers show strongly undulating pattern and in certain places are separated by sparry calcite cement. The pelloids are sub-rounded to elongate in shape. Sparry calcite cement is present in the pore spaces and vugs.

4.2 Carbon and oxygen isotopic variations

The carbon and oxygen isotopic variations in the studied litho-section are shown in Fig. 5. The gray shales of the Dalmiapuram Formation exhibit $\delta^{13}C$ values from +1.44 to +2.40 ‰ VPDB. Most of the CAL samples show positive $\delta^{13}C$ values (+0.07 to +2.93 ‰ VPDB; Table 1) except one sample, which show a negative value (−0.56 ‰ VPDB). The marl and bedded limestone (MBL) unit exhibits negative to positive $\delta^{13}C$ values (−3.46 to +1.35 ‰ VPDB). Only one sample collected from the marl unit displays an extreme negative $\delta^{13}C$ value of −6.07 ‰ VPDB. The gray shale member presents negative $\delta^{18}O$ values from −5.92 to −3.05 ‰ VPDB. The calcareous algal limestone and marl and bedded limestone units show large variations in their $\delta^{18}O$ values (−6.50 to −0.39 ‰ VPDB; −5.25 to −1.14 ‰ VPDB; respectively). The marl sample collected from the top of the section displays large negative $\delta^{18}O$ values (−7.08 ‰ VPDB) similar to its $\delta^{13}C$ value (−6.07 ‰ VPDB).

5 Discussion

The gray shale, CAL, bedded limestone and marl samples show negative $\delta^{18}O$ values from −7.08 to −0.39 ‰ VPDB. Such negative $\delta^{18}O$ values indicate meteoric diagenesis (Veizer and Demovic 1973). In addition, negative

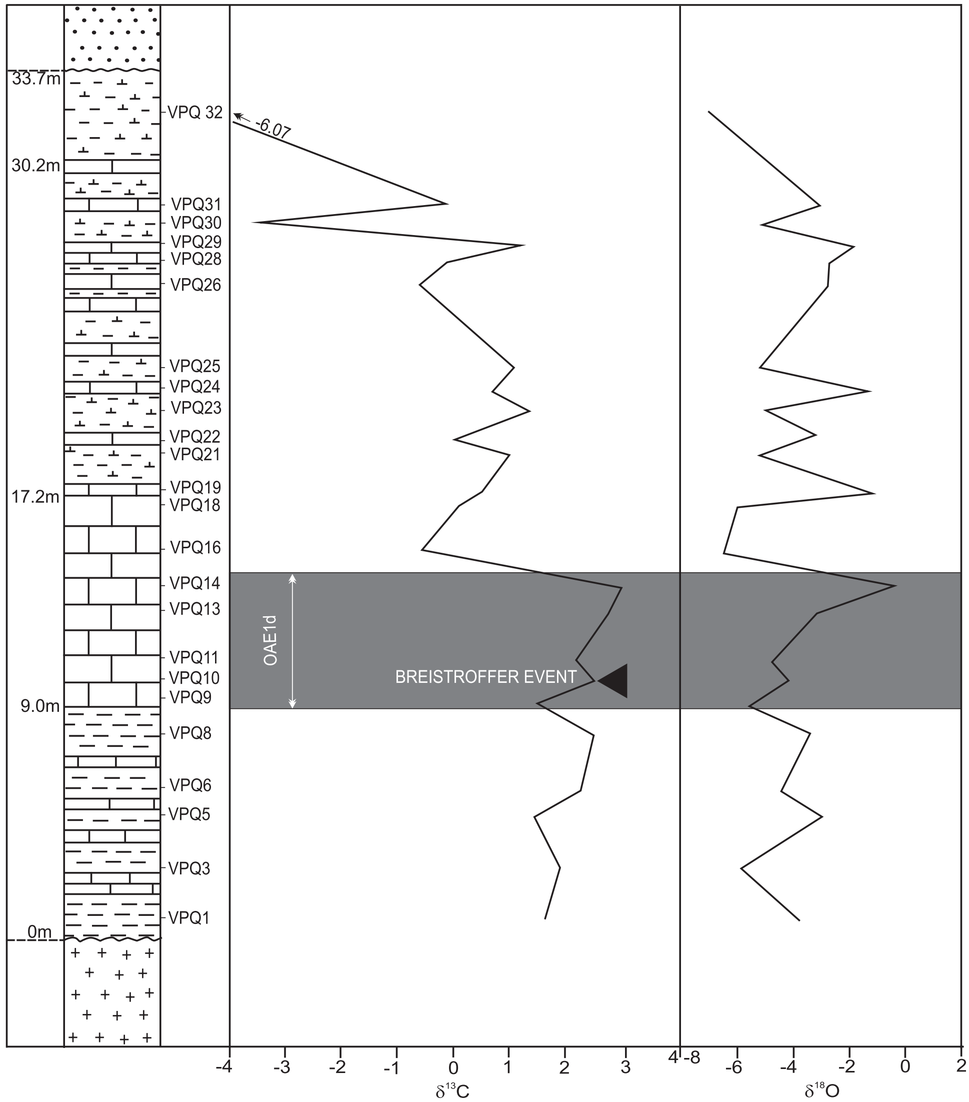

Fig. 5 Carbon and oxygen isotope (‰ VPDB) curves of Vadugarpettai section

$\delta^{18}O$ values are related to decreasing salinity and increasing temperatures (Hudson 1977). In general, oxygen isotopes are more vulnerable to diagenetic alterations, partly due to the temperature-related fractionation common in oxygen isotopes (Morse and Mackenzie 1990; Nagarajan et al. 2013). In addition, carbon isotopes are less prone to diagenetic changes than oxygen isotopes are (Hudson 1977; Anderson and Arthur 1983; Banner and Hanson 1990; Marshall 1992; Frank et al. 1999).

The marine carbonates mainly consist of skeletal and non-skeletal grains, with a certain amount of matrix material, and diagenetic processes may alter their primary isotopic signatures (Allan and Matthews 1982; Veizer 1983; Marshall 1992; Kaufman and Knoll 1995; Madhavaraju et al. 2004, 2013a, b; Armstrong-Altrin et al. 2011). In general, co-varying carbon and oxygen isotope trends in carbonate rocks indicate the infiltration of fluids containing isotopically light carbon and oxygen, such as meteoric water (Hudson 1977; Allen and Matthews 1982; Fisher et al. 2005). However, data from the Dalmiapuram Formation shows no correlation between the $\delta^{13}C$ and $\delta^{18}O$ values (Fig. 6; $r = 0.15$, $n = 23$; except sample VPQ32; lack of statistically significant correlation; Verma 2005), indicating a lack of diagenetic changes of the carbon isotopic values during early or burial diagenesis. This suggests that the studied samples show primary carbon isotopic signatures and are suitable for $\delta^{13}C$ stratigraphy.

The gray shale and CAL samples show positive $\delta^{13}C$ values (+1.44 to +2.40 ‰ VPDB; +0.07 to +2.93 ‰ VPDB; respectively), whereas the marl and bedded limestone samples show both negative and positive $\delta^{13}C$ values (−3.46 to +1.35 ‰ VPDB). This suggests that the shallow water depositional conditions are unstable in their isotopic composition in comparison to when they are in open marine settings and various factors like depositional settings and changes in productivity may significantly alter

Table 1 Carbon and oxygen isotopic values (‰ VPDB) for whole rock gray shale, limestone and marl samples of Vadugarpettai section of the Dalmiapuram Formation

Member/sample no	$\delta^{13}C$ (‰ VPDB)	$\delta^{18}O$ (‰ VPDB)	$\delta^{18}O$ (‰ SMOW)
Marl			
VPQ32	−6.07	−7.08	23.56
Marl bedded limestone			
VPQ31	−0.16	−3.09	27.67
VPQ30	−3.46	−5.25	25.45
VPQ29	1.20	−1.88	28.92
VPQ28	−0.06	−2.75	28.03
VPQ26	−0.58	−2.91	27.86
VPQ25	1.06	−5.13	25.57
VPQ24	0.67	−1.45	29.36
VPQ23	1.35	−5.05	25.65
VPQ22	0.03	−3.26	27.50
VPQ21	0.98	−5.17	25.53
VPQ19	0.52	−1.14	29.69
Coral algal limestone			
VPQ18	0.07	−5.99	24.68
VPQ16	−0.56	−6.50	24.16
VPQ14	2.93	−0.39	30.46
VPQ13	2.79	−3.17	27.59
VPQ11	2.19	−4.84	25.87
VPQ10	2.36	−5.19	25.51
VPQ9	1.52	−5.64	25.04
Gray shale			
VPQ8	2.40	−3.67	27.08
VPQ6	2.26	−4.43	26.29
VPQ5	1.44	−3.05	27.72
VPQ3	1.91	−5.92	24.76
VPQ1	1.65	−3.84	26.90

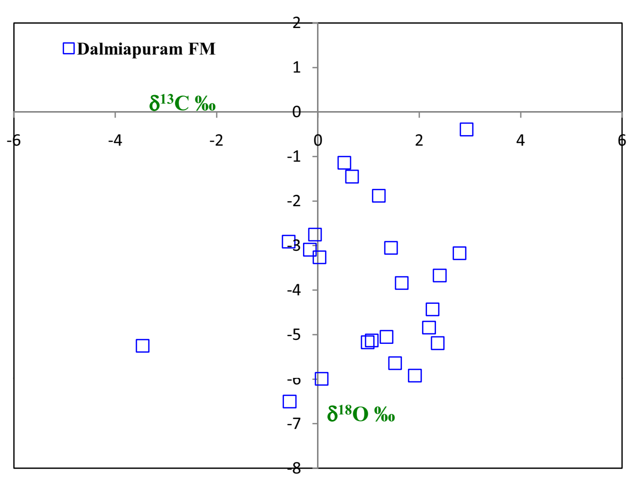

Fig. 6 $\delta^{13}C$–$\delta^{18}O$ bivariate plot for gray shale and limestone members of the Dalmiapuram Formation

the global oceanic carbon reservoir (Jenkyns 1995). Short-term variations in the $\delta^{13}C$ values of shallow marine carbonates are extensively used to interpret the primary variations in the oceanic $\delta^{13}C$ signal of the Early Cretaceous (Jenkyns 1995; Vahrenkamp 1996; Grötsch et al. 1998; Elrick et al. 2009). The carbon isotope curve of the Vadugarpettai section shows two negative excursions in the lower part of the section: one at the gray shale and the other on the CAL. The upper part of the section shows more fluctuation in the $\delta^{13}C$ values and a particularly strong negative shift is recorded in the marl as −6.07 ‰ VPDB.

According to Nagendra et al. (2011b), the age of the Dalmiapuram Formation is late Albian to middle Turonian. The Vadugarpettai section might have registered a single or multiple Albian OAEs (e.g., OAE1c and OAE1d). Isotope stratigraphy has been considered as one of the proxies used to recognize and correlate OAEs. Usually, OAEs have been identified by a positive $\delta^{13}C$ shift of 1.5 ‰ or greater in organic and inorganic carbon (Jenkyns 2010; Herrle et al. 2004). However, OAE1c does not show such diagnostic $\delta^{13}C$ excursions (Erbacher et al. 1999). A significant positive $\delta^{13}C$ shift is observed in the lower part of the CAL, which suggests the occurrence of OAE1d in the studied section. OAE1d is associated with a carbon isotope shift of

0.5–2 ‰ and pelagic biotic turnover events (Leckie et al. 2002). It has been identified in the western Atlantic Blake Nose (ODP Site 1052), offshore Morocco (DSDP Site 545), southern France (Mont Risou Cenomanian GSSP section), Switzerland (Roter Sattel section) and the southern Indian and eastern Pacific oceans (Strasser et al. 2001; Leckie et al. 2002; Herrle et al. 2004; Kennedy et al. 2004; Gale et al. 2011).

The carbon isotope curve of this section is compared with several isotopic curves in order to detect the various OAEs that occurred during the Albian time (Gale et al. 1996; Nederbradgt et al. 2001; Wilson and Norris 2001; Luciani et al. 2004; Bornemann et al. 2005; Petrizzo et al. 2008). The VPQ9 sample in the Vadugarpettai section shows an abrupt negative excursion. Such a negative excursion could indicate an increase in water temperature (Friedman and O'Neil 1997), which may be recorded in the inorganic carbon pool. The $\delta^{13}C$ shows an initial shift in the carbon isotope fraction associated with the re-mineralization of more ^{13}C depleted organic matter, followed by the enrichment in the $\delta^{13}C$ as organic carbon burial increased. Similar trend has been observed in other Cretaceous OAE sections (Menegatti et al. 1998; Scott et al. 2013). The carbon isotope curve of the Vadugarpettai section (VPQ10) shows a significant positive shift ($\sim$0.8 ‰ VPDB) in the lower part of the CAL. The $\delta^{13}C$ record demonstrates that this interval coincides with the initiation of OAE1d. A continuous increase in the $\delta^{13}C$ values is observed in the middle part of the CAL. This interval corresponds to the upper limit of the OAE1d. Likewise, a positive shift is also identified in the oxygen isotope curve. The enrichment in the $\delta^{18}O$ during the 1d event may be indicative of a sea-level fall (Föllmi 2012). The $\delta^{13}C$ curve and the lower and upper tie point of the OAE1d interval at the Vadugarpettai section closely correlates with the upper Albian sequences of the Blake Nose (ODP site 1052) Meagan Plateau (DSDP site 547) and Vocation Basin (Gale et al. 1996; Nederbragt et al. 2001; Bornemann et al. 2005; Petrizzo et al. 2008). Further, a high resolution carbon isotope stratigraphy on the Dalmiapuram Formation in the Cauvery Basin of South India would define the late Albian anoxic events with greater confidence.

6 Conclusions

The whole rock oxygen isotope values in the gray shale and limestone members are depleted in $\delta^{18}O$ values compared with the carbonates precipitated in equilibrium with contemporaneous seawater, indicating that the studied samples were subject to a shallow burial diagenesis. The absence of correlation between the $\delta^{18}O$ and $\delta^{13}C$ values suggests that the gray shale and limestone members of the Dalmiapuram Formation were not subject to post-depositional modification and preserved their primary carbon isotope signatures. The shape of the carbon isotope curve of the Vadugarpettai section is comparable to the late Albian-Cenomanian carbon isotope curve of the Atlantic sites and Vocontian Basin. The positive shift in the lower part of the CAL is comparable to the late Albian OAE1d. The middle part of the CAL shows nearly continuous positive carbon isotope trend, which correlates to the upper limit of the OAE1d.

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