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PALAEOENVIRONMENTAL RECONSTRUCTION BASED ON CORALLINE ALGAL ASSEMBLAGES IN THE OLIGOCENE OF KACHCHH, GUJARAT, WESTERN INDIA

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ABSTRACT

The present paper examines the coralline algal assemblages of the Oligocene successions of Kachchh, western India to explore possibilities of their use in palaeoenvironmental interpretation. The coralline algae are facies dependent and in Kachchh their distribution appears to be controlled lithofacies characteristics. The Oligocene sequences of Kachchh are divided into a lower carbonate-dominated Ramanian stage (lower Oligocene) characterised by dominance of mastophoroids which occur in association with nummulites and corals, and an upper mixed carbonate-siliciclastic Waiorian stage (upper Oligocene) showing abundant fragmented forms of coralline algae, infaunal echinoids, *Heterostegina*, *Spiroclypeus, Miogypsinoides*. Mastophoroids along with the associated biota of the Ramanian stage are indicative of patch-reefal environment (shallow ramp build-up), while fragmented forms of melobesioids in association with *Spiroclypeus* of the Waiorian stage suggest a deposition in a relatively deeper ramp environment setting. Both the lower and upper coralline algal assemblages show distinct relations with water depth and substrate relationship. This makes them potentially useful indicators for paleoenvironment reconstructions. The observed distribution of the corallines in the study area is consistent with general distribution and diversity patterns of melobesioids and mastophoroids in the Palaeogene. The mastophoroids dominated corallines and the associated coral assemblage correspond to a general trend of increased diversity of mastophoroids and corals in the warmer early Oligocene, whereas the melobesioid-dominated assemblage along with the co-occurring *Spiroclypeus* represents the acme of melobesioids in the late Oligocene when relatively lower temperatures prevailed.

This differentiation of algal assemblages and faunal distribution is attributed to a change in depositional environment due to fluctuating climate, sea-level and influx of terrigenous clastic material. The composition of the corallines and the associated invertebrate faunal groups in the Kachchh Oligocene succession tends to reflect this change.

Keywords*:* Coralline algae, mastophoroids, melobesioids, Ramanian stage, Waiorian stage, Maniyara Fort Formation, *Spiroclypeus*, Oligocene, Kachchh, India.

INTRODUCTION

The Oligocene Epoch in general is marked by maximum development of coral and coralline algal reefs in the western Tethys with high diversity and cosmopolitan faunas (Frost, 1977). The Oligocene coralline algal assemblages have been studies from worldwide (Basso *et al*., 1998; Bassi and Nebelsick, 2000; Nebelsick *et al*., 2000; Nebelsick and Bassi, 2000; Misra *et al*., 2001; Ghosh, 2002; Rasser and Nebelsick, 2003; Singh *et al.,* 2009; Braga *et al*., 2010; Singh *et al.,* 2011). Such studies are valuable for palaeobiogeographic reconstructions or evolutionary scenarios (Rasser and Nebelsick, 2003). The Oligocene of Kachchh, western India represents some features of this development in its fossil record. The Oligocene stratigraphic successions in the Kachchh Basin comprise the carbonate and mixed carbonate-siliciclastic units characterised by rich invertebrate fauna (including the larger foraminifera) and coralline algal flora. The biostratigraphy of these deposits is critical to understanding signals of palaeoenvironmental fluctuations because of the unique palaeogeographic position of Kachchh in late Palaeogene times (Fig. 1 A). Like other western Indian Palaeogene basins, the Kachchh Basin was connected to the eastern Tethys (originally described as the "… eastern region comprising everything east of Iran and Iraq"; Adams, 1967) and was in a like manner subjected to changes in palaeoenvironmental setting due mainly to fluctuating climate and sea level (Sahni and Kumar, 1974). The demand for palaeoenvironmental information from this area has resulted in detailed palaeontological investigations on its sedimentary successions. Though larger foraminifera provide biostratigraphical controls and useful palaeoenvironmental information, the associated coralline algae are important as supportive evidence in this context both as a tool in inferring palaeoclimate (Braga and Aguirre, 2001; Kroeger *et al.,* 2006; Braga *et al*., 2010) and interpreting depth and hydrodynamic conditions (Buxton and Pedley, 1989; Bassi, 1998).

The Oligocene sedimentary succession of Kachchh is represented by the Maniyara Fort Formation which can be divided into two parts (Biswas, 1992). The lower unit is carbonate dominated and made up of greenish grey marl with glauconite and massive limestone characterised by typical early Oligocene reticulate *Nummulites*. The upper unit is basically a mixed carbonate siliciclastic part characterised by yellowish green clays, highly burrowed sandy limestone, marl with *Spiroclypeus* and rusty brown hard limestone (at places overlain by poorly fossiliferous, coarse grained sandstone). The

foraminiferal fauna dominated by reticulate *Nummulites* and coralline algae, together with other invertebrates such as corals, form reef-like build-ups in the carbonate-dominated lower part of the formation dated by larger foraminifera as Rupelian (lower Oligocene) and referable to the Ramanian Stage (Biswas, 1971, 1992). In the upper part of this formation dated as the Chattian by foraminifera and grouped as the Waiorian Stage (Biswas, 1971, 1992), a different larger foraminiferal fauna characterised by *Heterostegina*, *Miogypsinoides* associated with echinoids and bivalves characterise the mixed carbonate-siliciclastic succession, in which the coralline algae mostly occur as fragmented forms. The topmost carbonate bed, however, shows their maximum occurrence of this algal group.

The reef-like build-ups and fossil fauna and flora of the Ramanian carbonate-dominated part and the foraminiferal and invertebrate fauna and flora of the Waiorian mixed carbonate-siliciclastic part have been considered to be the consequence of changes in depositional environment due to sea-level and climate fluctuations (Ghose, 1982; Kumar and Saraswati, 1997). The present paper notes differences in the composition of the coralline algal assemblages at family and subfamily levels in the carbonate and the carbonate-siliciclastic units of the Oligocene of Kachchh and discusses their environmental adaptations to demonstrate their significance as a tool in interpreting climate and marine oscillations in the Kachchh sections.

METHODS

The samples used in the present study were collected from the five selected stratigraphic sections of the lower and upper Oligocene units of the Maniyara Fort Formation exposed in the Babia Hill, Bermoti River Section near Maniyara Fort, Stream and Khalsar dam secctions of Waior and Bermoti section in Bermoti village Kachchh (Figs. 2, 3). The general geology of the area and the age and stratigraphic position of these units have been described in considerable detail in a number of previous publications (Biswas, 1971, 1972, 1992; Biswas and Raju, 1971; Raju, 1974, 1993; Raju and Misra, 1993). The coralline algal samples were collected both from the carbonate-dominated lower part and the mixed carbonate-siliciclastic upper part. In the lower carbonate-dominated coralline algal forms are often encrusting on other coralline algae or corals. Such association indicates the primary occurrence of coralline algae (autochthonous occurrence). While in the mixed carbonate-siliciclastic upper part, coralline algae occur mostly as fragmented forms but abundantly occur in certain horizons of the top part of this unit. These fragmented forms of coralline algae along with primary occurrence of coralline algae (autochthonous occurrence) indicate a high degree of reworking, which may have caused a mixture of debris from different environments (allochthonous occurrence). The presence of both autochthonous and allochthonous associations in upper part indicate atypical assemblage. Thus, these beds constitute a prominent foraminiferal and algal facies in the study area.

The coralline algae presented here are recorded from the Maniyara Fort Formation (Oligocene), which is described in detail in Misra *et al*. (2001) and Singh *et al.* (2002, 2009, 2011). The morphotaxonomic features of coralline algae and associated foraminifera were studied under the light microscope. Taxonomic observations were made in light of current taxonomic criteria developed through studies by Woelkerling (1988), Braga *et al.* (1993), Rasser and Piller (1999), Harvey *et al.* (2003), Bassi *et al.* (2007), Iryu *et al.* (2009).

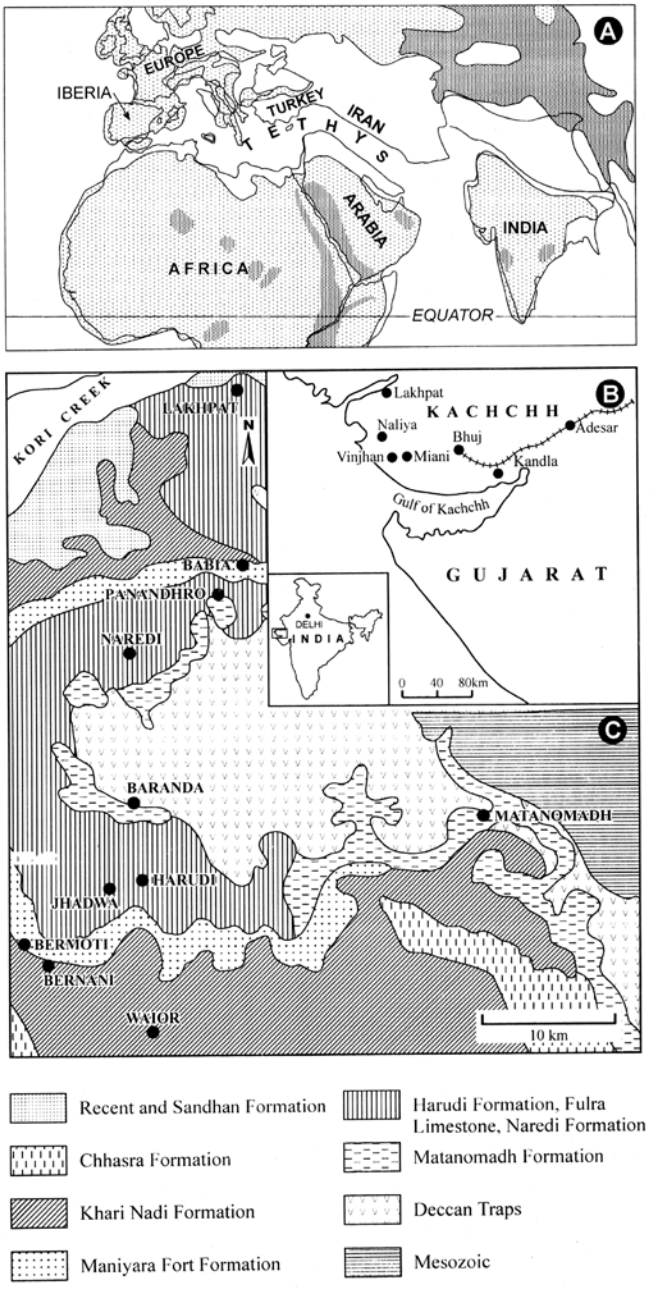

Fig. 1. A. Generalised palaeogeographic map of the Tethyan region showing position of India during the Oligocene, 30 Ma ago (modified after Smith *et al*., 1994); B. Location map of Kachchh in India (inset); C. Geological map of Kachchh showing the localities from where the samples were collected.

RESULTS

Carbonate-dominated lower unit (Lower Oligocene)

This part of the Maniyara Fort Formation, referable to the Ramanian Stage, is well exposed near the top of the Babia Hill section and in the Bermoti stream section near Maniyara Fort (Biswas, 1992; Misra *et al.,* 2001; Singh *et al.,* 2009) and

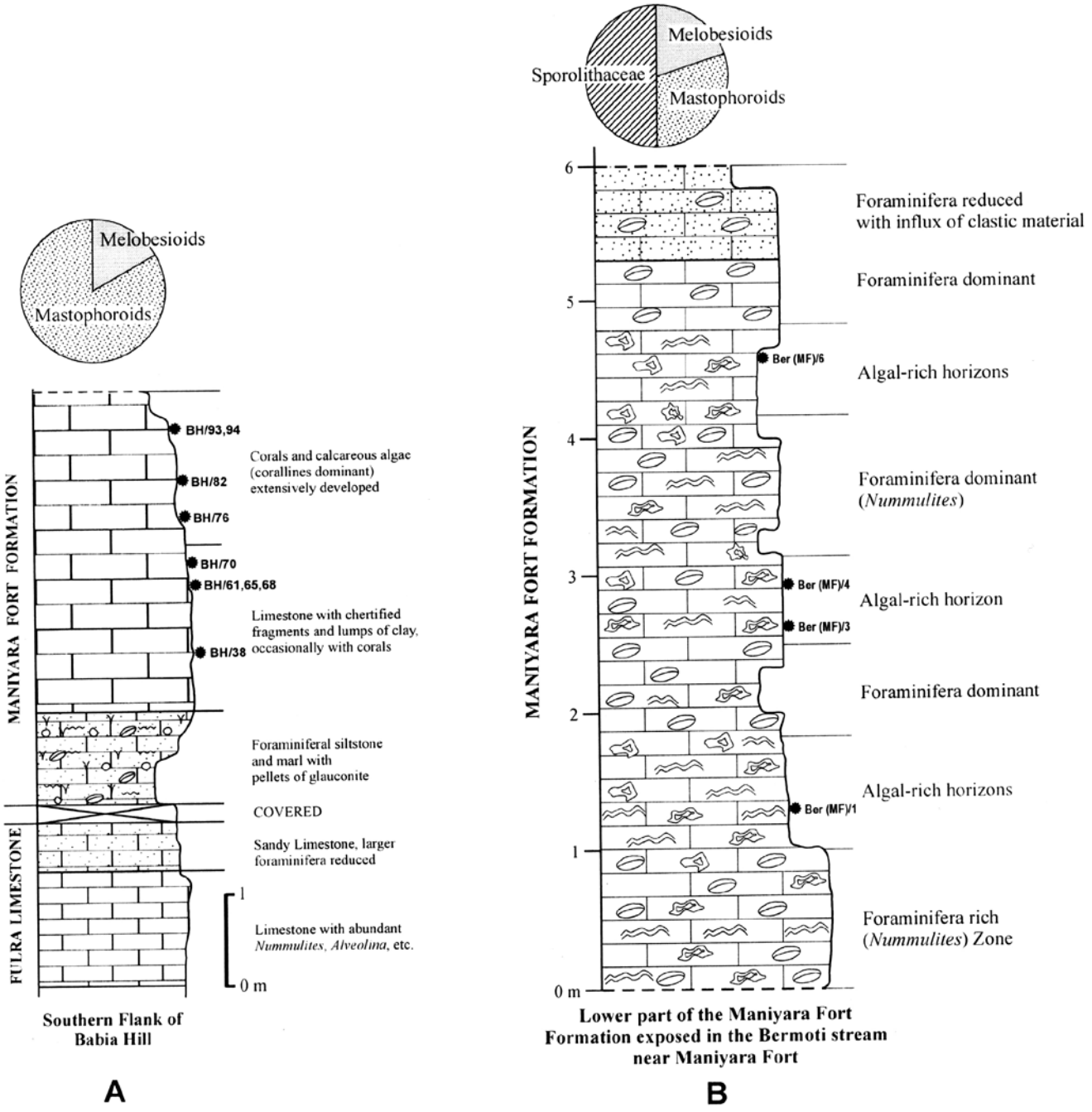

Fig. 2. Lithostratigraphic columns of the Maniyara Fort Formation (carbonate-dominated part = Ramanian Stage, lower Oligocene), at the Babia Hill (A) and Bermoti stream (B) sections, near Maniyara Fort, showing position of algal horizons in the successions and diagrammatic representation of the occurrence of sporolithaceae, mastophoroids and melobesiods.

comprises three lithological members of the Maniyara Fort Formation (Biswas, 1992): (i) the Basal Member, consisting of foraminiferal glauconitic, brownish yellow siltstone interbedded with calcareous claystone, (ii) the Lumpy Clay Member, made up of cement coloured to brownish calcareous claystone containing thin limestone and marl beds with lumps of clay; and (iii) the Coral Limestone Member comprising white nodular limestone and claystone near the base and white massive limestone with corals, coralline algae and nummulites above (Fig. 2). The presence of *Nummulites fichteli* indicates an early Oligocene (Rupelian) age for the carbonate-dominated unit. The coralline algal assemblage of this unit is dominated by mastophoroids, such as *Neogoniolithon, Lithoporella, Spongites*, and *Sporolithon* over melobesioids occurring as minor constituents (Plate I). The distribution patterns of coralline algae of this unit show a lateral changes within shallow water environment and they influenced by water depth and hydrodynamic energy. The presences of encrusting to warty coralline algal growth-forms on corals and other coralline indicate the low energy environment. Mastophoroids coralline algae (*Neogoniolithon*,

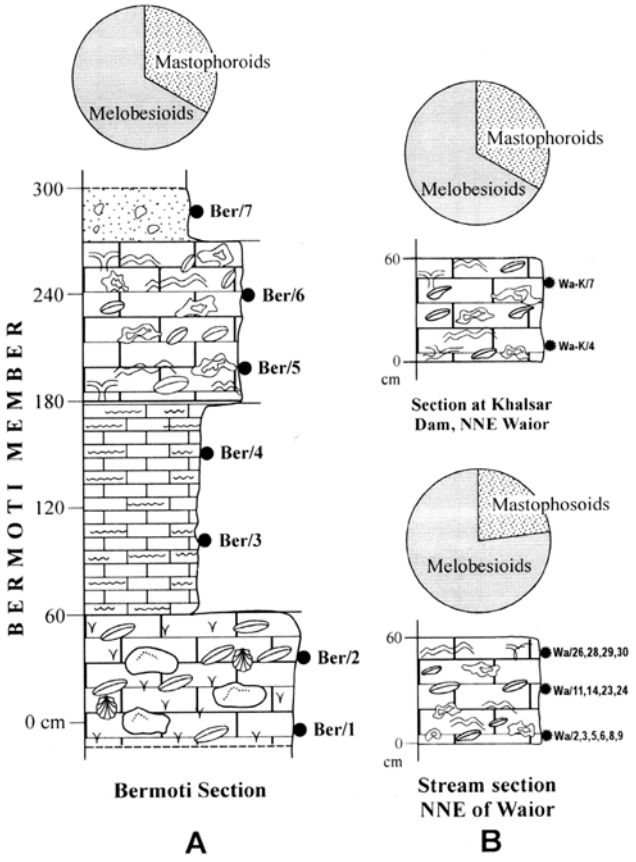

Fig. 3. Lithostratigraphic columns of the Maniyara Fort Formation (mixed carbonate-siliciclastic part, Bermoti Member = Waiorian Stage, upper Oligocene), at the Bermoti (A) and Waior (B) sections, showing position of algal horizons in the successions and diagrammatic representation of the occurrence of Mastophoroids and Melobesioids.

Spongites, *Lithoporella*) and corals are common in shallow water environment while *Sporolithon* along with other melobesioids indicate relatively deeper water environment. This shows a lateral transition from shallow to relatively deeper water environments. Towards deeper water, they change into the Coral-mastophoroids associations to *Sporolithon*-melobesioids associations.

Mixed carbonate-siliciclastic upper unit (Upper Oligocene)

A lithologically distinct unit of the Maniyara Fort Formation, it is represented by the Bermoti Member and is well exposed in the Bermoti stream section near Bermoti village and in a dry river section near Waior village (Fig. 3). It consists of friable, glauconitic, argillaceous sandstone followed by thinly bedded, hard foraminiferal limestone interbedded with marl beds full of *Spiroclypeus* and overlain by rusty brown, hard limestone and very thin coarse-grained, poorly fossiliferous calcareous sandstone (Biswas, 1992). *Miogypsinoides bermudezi*, *M. complanatus* and *Spiroclypeus ranjanae* suggest a late Oligocene (Chattian) age for the mixed carbonate-siliciclastic unit. The distribution patterns of coralline algae are also varied from the *Spiroclypeus* bed to the top of the rusty brown, hard limestone of this unit. The coralline algal species occur horizontally as thin layered forms on the *Spiroclypeus* bed without any fragmentation (as minor component). But rusty brown, hard lime stone of this unit contains abundant fragmented forms (fruticose growth-form) as well as well developed warty to lumpy growth forms of coralline algae. The chief elements of the coralline algal assemblage from these algae-bearing horizons belong to melobesioids and include *Lithothamnion*, *Phymatolithon*, *Mesophyllum* and other unidentifiable Melobesioidean forms (Plate II). Lithophylloids and mastophoroids, however, constitute a minor component of the algal flora in this bed. The presence of mixture algal forms (primary coralline algal association i.e. autochthonous as well as a high degree fragmented forms of coralline algae i.e. allochthonous) in the rusty brown hard limestone indicate the transport of algal debris from the different environments under high energy condition.

DISCUSSION

Coralline algal assemblage

The coralline algal assemblages differ mainly in their composition at the family and subfamily levels in relation to lithofacies characteristics of the respective lithounits in the Oligocene succession. The lithounits of the Ramanian Stage (early Oligocene) represented by carbonate facies are characterised by the dominance of mastophoroids (mainly *Spongites, Lithoprella* and *Neogoniolithon*) and *Sporolithon* (Fig. 2), whereas melobesioids (mainly *Lithothamnion*, *Phymatolithon* and *Mesophyllum*) predominate in the carbonates of the siliciclastic-dominated Waiorian Stage (late Oligocene) (Fig. 4).

Mastophoroids and *Sporolithon* are the predominant constituents of the tropical/subtropical shallow-water algal assemblages from the reefal deposits, particularly in coralgal patch-reef belt (shallow ramp build-up) (Braga and Aguirre, 2001; Buxton and Pedley, 1989). As a general observation with respect to the use of corallines as temperature and depth indices, mastophoroids (dominated by *Lithoporella*, *Neogoniolithon* and *Spongites*) are found to show preference for warmer and shallow-water environment (Kroeger *et al.,* 2006). Associated biota include corals, nummulites (in the Tertiary Tethyan realm), boring and nestling bivalves, sedentary gastropods, encrusting forams, etc. (Buxton and Pedley, 1989). During the early Oligocene, the reef development was a widespread phenomenon in the Tethyan region well indicated by extensive development of reef-coral and coralline algal associations along with nummulites in the deposits of this epoch (Frost, 1977). This fossil association is indicative of warmer temperatures of the sea waters in the photic zone. Though a sharp drop in temperature in the late Eocene is reported, climate became slightly warmer and stabilised during early Oligocene promoting development of warm-water biota (Adams, 1983). The carbonate-dominated stratigraphic units of lower Oligocene age in Kachchh bear testimony to this (Fig. 4).

Melobesioids, on the other hand, make up a large proportion of the coralline assemblages in the temperate platform deposits and occupy deep-water habitats with relatively lower temperature range as compared with mastophoroids (Braga and Aguirre, 2001; Kroeger *et al.,* 2006). The upper Oligocene has been noted to be different from than the lower Oligocene with respect to foraminiferal and macrofossil composition and sediment lithology. The carbonate successions of the upper Oligocene are seen to be siliciclastic-mixed and characterised by changed fauna and flora which includes many

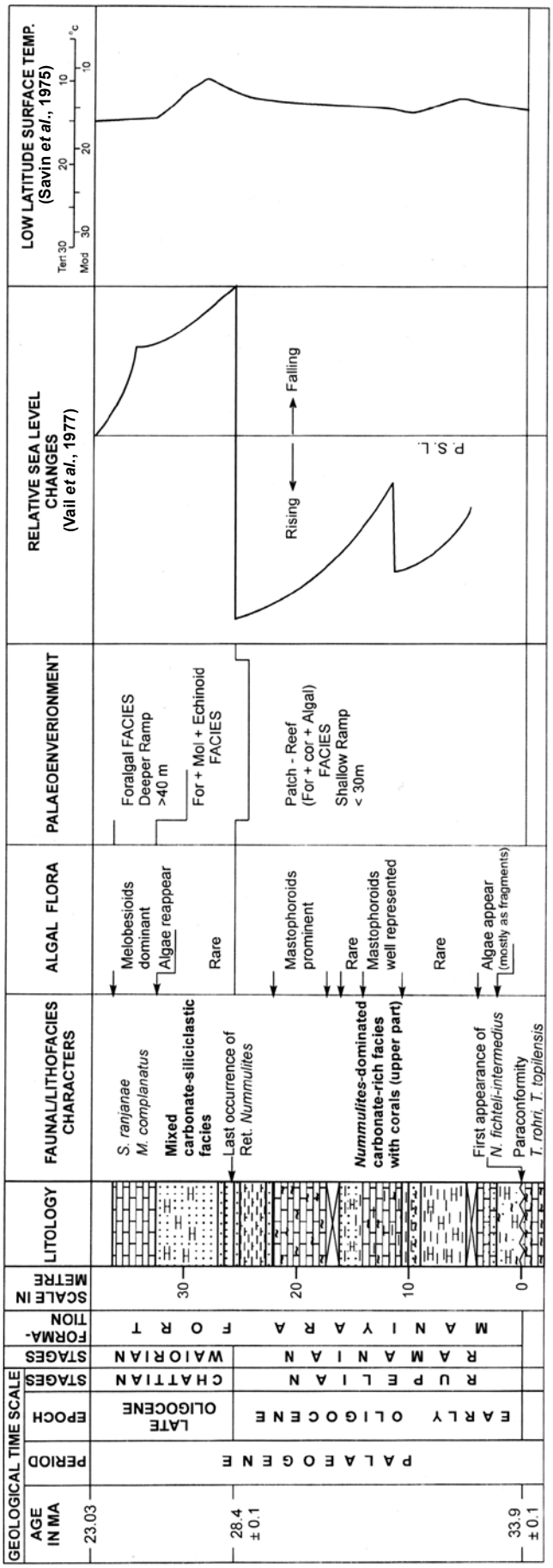

Fig. 4. Summary of faunal, floral (coralline algae) and lithofacies characters in the Oligocene (Maniyara Fort Formation) of Kachchh Basin, India (lithostratigraphic column based on, Biswas, 1992).

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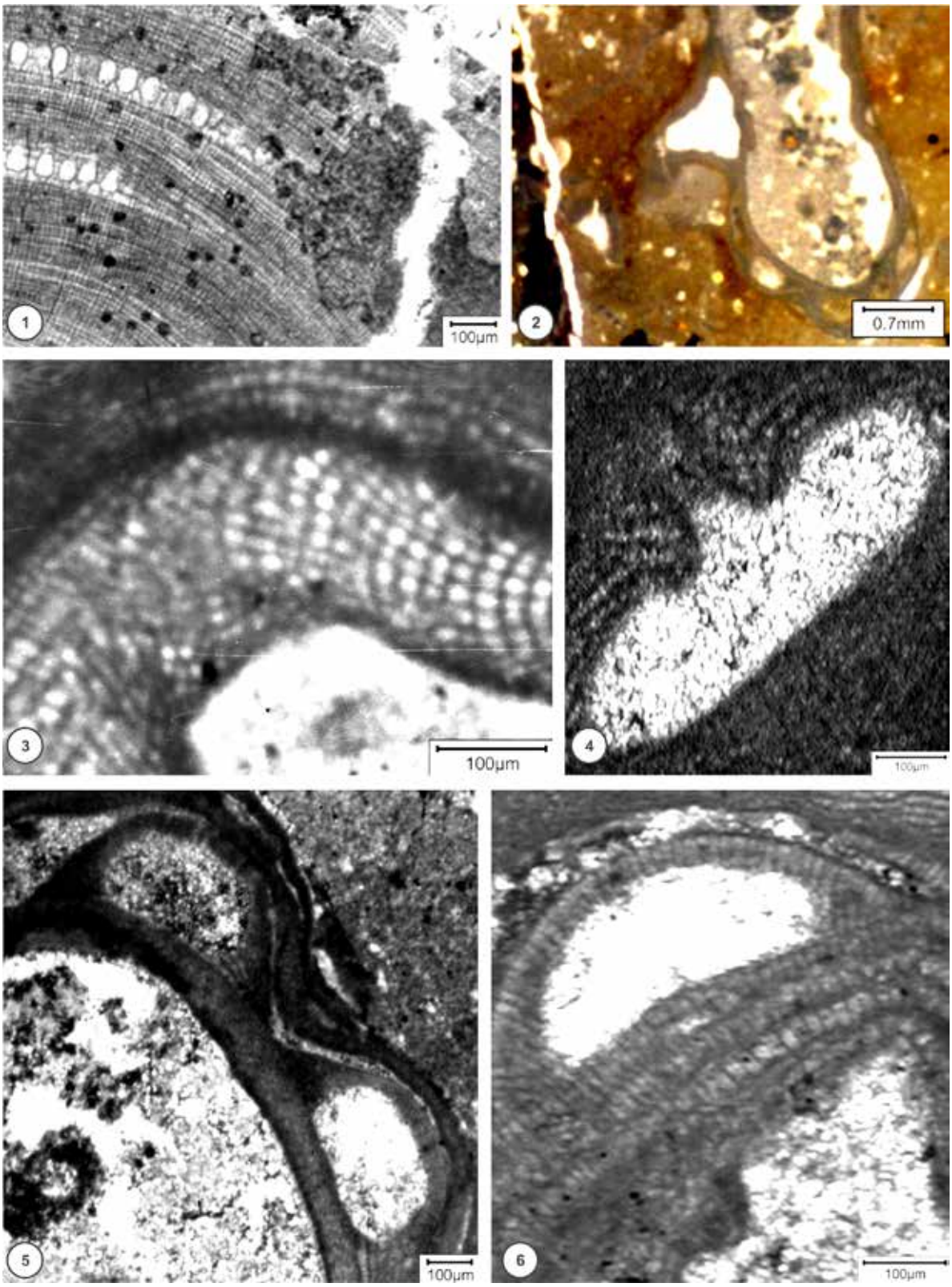
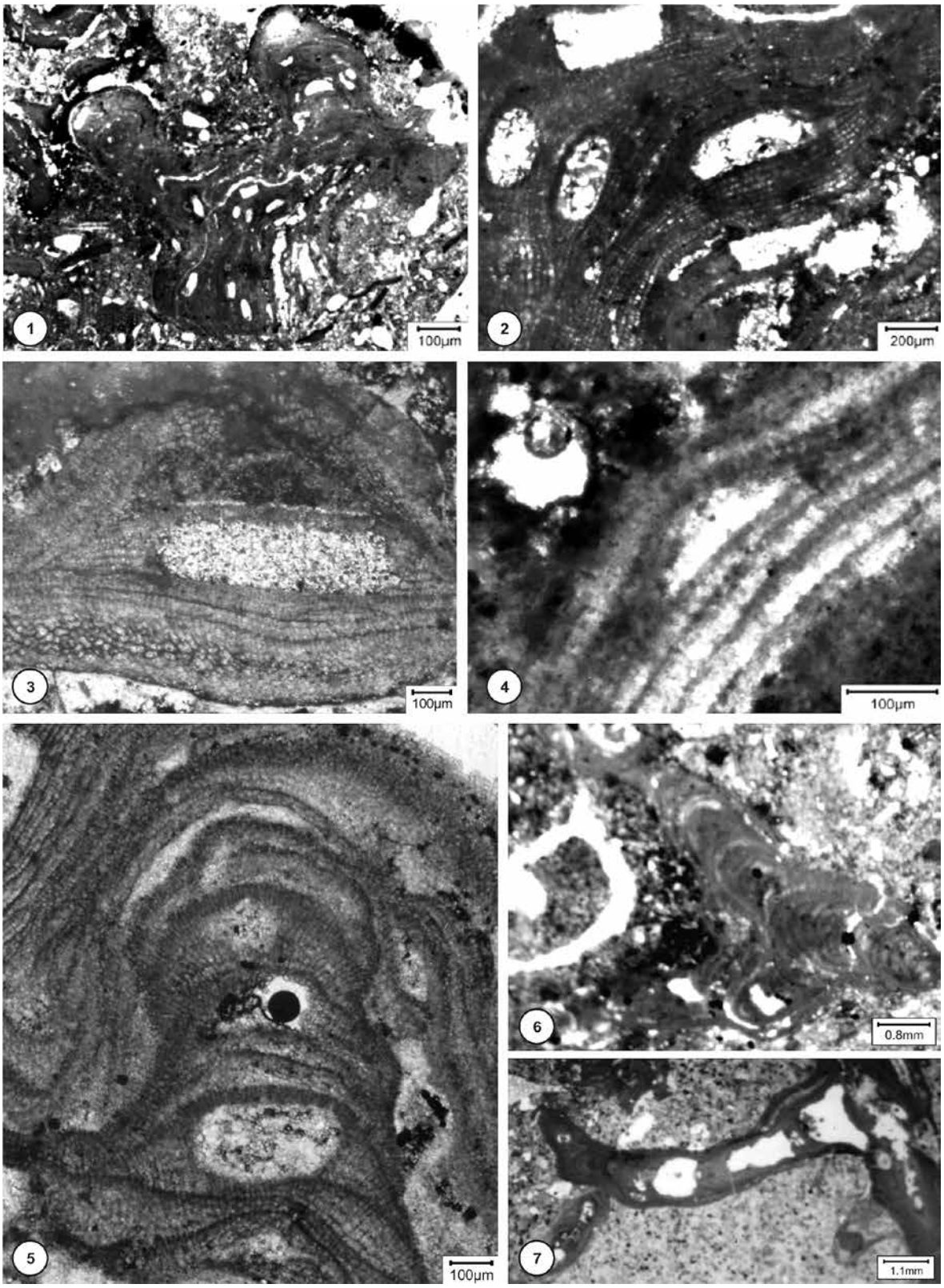


EXPLANATION OF PLATE I

Figs. 1-6. Coralline algae of Lower Oligocene Member of Maniyara Fort Formation. Fig. 1. ***Sporolithon brevium*** thallus showing tetrasporangium, Fig. 2. Encrusting growth-form of coralline algae on corals, Figs. 3-4. ***Neogoniolithon*** sp., Fig. 3. ***Neogoniolithon*** showing co-axial core filaments and peripheral filaments, Fig. 4. ***Neogoniolithon*** sp. showing uniporate conceptacle, Fig. 5. Melobesioideae gen. et spec. indet showing multiporate conceptacles, Fig. 6. ***Lithoporella melobesioides*** showing primigenous filaments and conceptacle.

Plate II



EXPLANATION OF PLATE II

Figs. 1-7. Coralline algae of Upper Oligocene of Maniyara Fort Formation. Figs. 1-2. Melobesioideae gen. et spec. indet 1 showing multiporate conceptacles and warty growth-forms, Fig. 3. ***Phymatolithon*** sp. showing multporate conceptacles, Fig. 4. ***Lithophyllum dentatum*** showing male conceptacle, Figs. 5. Melobesioideae gen. et spec. indet Rasser and Piller, 1997 showing warty-growth forms with multiporate conceptacles, Figs. 6-7. Melobesioideae gen. et spec. indet 2 showing fruticose growth-forms.

representatives among foraminifera, macrofauna and coralline algal flora which are capable of tolerating siliciclastic input in their habitats. However, those having preference for carbonate environments, e.g. typical patch-reef builders such as corals, nummulites, etc. (dominant in the lower Oligocene) are absent here. Among the coralline algae, melobesioids predominate in the carbonate deposits associated with siliciclastic sequences (Hallock *et al.,* 1991; Aguirre *et al.,* 2000). A truly comparable picture is also noticed in the upper Oligocene of Kachchh, e.g. occurrence in abundance of faunal elements tolerant of influx of clastic material, such as *Heterostegina*, *Miogypsinoides* and *Operculina,* among foraminifera (Kumar and Saraswati, 1997) and spatangoids (echinoids) among invertebrates; and a larger proportion of melobesioids. The absence of strictly warm-water coralline taxa such as *Sporolithon* in the late Oligocene assemblage indicates cool environment conditions while the presence of cool water taxa such as *Lithophyllum*, *Lithothamnion* and *Phymatolithon* supports our cooler climatic condition in the late Oligocene (Kroeger *et al.,* 2006; Braga *et al.,* 2010; Kishore *et al*., 2017). Sahni and Kumar (1974) attribute this change in sedimentary, faunal and floral characteristics of marine deposits of this age in India to the fall in temperature and fluctuating sea-level conditions (Fig. 4). The decrease in temperature conditions has also been noted by Adams (1983) during late Oligocene.

Depositional environment of algal beds

Mastophoroids, *Sporolithon* and the associated nummulitids and corals indicate that the lower carbonate-dominated unit represents a reef-like environment on shallow ramp and corresponds to coralgal patch-reef facies (biofacies **6** of Buxton and Pedley, 1989). It developed in response to warmer and reduced nutrient flux (reduced clastic influx) conditions during a transgressive phase in the early Oligocene following the late Eocene marine regression in Kachchh (represented by a hiatus) (Biswas, 1992). With change in the depositional regime to mixed carbonate-siliciclastic sedimentation as a result of increased nutrient flux (increased clastic input) during the late Oligocene transgression, when the upper unit was deposited, *Nummulites,* corals and the coralline algae disappeared, and a new suite of larger foraminifera tolerant to influx of terrigenous material (represented by *Heterostegina* and *Miogypsinoides*) appeared in response to mesotrophic conditions. These forms are inhabitants of relatively deeper ramp environment (Hallock *et al.,* 1991; Buxton and Pedley, 1989). This was followed, a little later, by the appearance of *Spiroclypeus* in great profusion when the supply of the terrigenous clastic material was relatively reduced (noticeable in the Kachchh area as a *Spiroclypeus*-bearing bed). The latter continued in the uppermost Oligocene and was accompanied by a rich assemblage of melobesioid corallines. *Spiroclypeus* has been interpreted to be characteristic biofacies 7 of Buxton and Pedley (1989) while rusty brown hard limestone shows similarity with debris flow facies of Rasser and Nebelsick (2003). Melobesioids and the abundant *Spiroclypeus* indicate that the late Oligocene deposits containing them represent a relatively deeper ramp environment with relatively lower range of temperatures than the underlying unit of early Oligocene age with different fossil composition. The environmental adaptations of algal, coral and foraminiferal assemblages of the Kachchh Oligocene successions are thus indicative of a deepening trend of depositional environment from mastophoroid-nummulites-coral dominated carbonate deposits to melobesioid-*Spiroclypeus* dominated successions (Fig. 4). A similar trend has also been reported by Bassi and Nebelsick (2003) in the Oligocene successions of North-Eastern Italy and in the Oligocene of the Austria (Rasser and Nebelsick, 2003).

CONCLUDING REMARKS

The stratigraphical distribution of the coralline assemblages in the Oligocene of Kachchh is consistent with the general diversity patterns of melobesioids and mastophoroids in the Palaeogene studied by Aguirre *et al*. (2000). The mastophoroid-coral-dominated Ramanian lower succession of the Oligocene Maniyara Fort Formation corresponds to a general trend of increased diversity of mastophoroids and corals in the early Oligocene (Aguirre *et al.,* 2001), whereas the algal assemblage of the Waiorian upper part of this formation stage correspond to the general acme of melobesioids (Aguirre *et al*., 2000). They attribute the changing trends in the diversity of corallines during the late Palaeogene to environmental change. It has been shown that the distribution of algal species is related to palaeoecological parameters including substrate relationships, hydrodynamic energy and sedimentation rates. Thus, the occurrence of authochtonous to allochthonous coralline algal assemblages of the Maniyara Fort Formation serves as valuable indicators of environments. The change in the deposional regime brought about by fluctuating climate, sea-level and terrigenous clastic flux conditions is well reflected in the studied successions by the composition of the fossil coralline assemblages as well as other associated fossil groups. The fossil corallines can, therefore, be used, alongside the co-occurring larger foraminifera, to identify signatures of climate and sea level change in the context of palaeoenvironmental scenario of Kachchh during Oligocene.

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