

Cenozoic coralline algal assemblage from southwestern Kutch and its importance in palaeoenvironment and palaeobathymetry

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Little contribution has been made on the study of coralline algae from the Cenozoic sediments of southwestern Kutch. Some of the limestone units belonging to Oligocene and Miocene sediments of southwestern Kutch were known to be potential sources for the recovery of coralline algae. There are some reports on the occurrence of coralline red algae from the early Oligocene, late Oligocene and early Lower Miocene rocks of southwestern Kutch. Taxonomic revision of majority of these taxa has to be made following the diagnostic characters used in present-day taxonomy. Presently, the extinct coralline algae are being studied based on new anatomical characters applicable to extant coralline algae. The present study has been carried out following current methodology of taxonomic consideration on freshly collected samples from the late Oligocene (Chattian) limestone belonging to Bermoti Member of Maniyara Fort Formation. The assemblage is dominated by the genera *Lithophyllum* and *Mesophyllum*. Both these taxa have been analysed with the concept of open nomenclature. Attempts have been made to interpret the palaeoenvironment and palaeobathymetry based on the analysis of recovered algal assemblage. The distribution pattern of coralline red algae recorded so far from the Cenozoic sediments of southwestern Kutch has been summarized.

CORALLINE algae, one of the most significant carbonate producers, are characterized by calcified cell walls forming a rigid skeleton. Skeletons of the encrusting coralline algae (Rhodophyta) construct the reef core, together with corals and encrusting foraminifers. Encrusting coralline algae may also solely form algal reefs in addition to their binding function in coral reefs¹. Abundance of corallines enhances towards the outer edge of the reef and declines away from the reef core. Generally, the coralline algal forms are useful in interpreting palaeoenvironment and palaeobathymetry. In addition to depth and light penetration, other features like agitation of water, nature of the bottom, presence or absence of sediments in suspension and salinity of water considerably affect the distribution of algae. In the present seas, crustose (non-geniculate) coralline algae are found in intertidal zone down to 200 m depth² and even deeper³. However, their overall depth range is 0 ~ 270 m (ref. 4). In fact, crustose coral-

line algae are considered as one of the best palaeobathymetric indicators because of their wide range of depth distribution³. Eventually most of the studies on palaeo-depth distributions of encrusting biota focus on coralline algae⁵.

The taxonomy of fossil coralline algae has normally been based upon calcified characters with a high fossilization potential. However, Recent coralline algal taxonomy uses some additional characters such as cell fusions of adjacent filaments, secondary pit connections, nature of sporangial conceptacle pores and presence or absence of spore plugs, etc. (significant subfamily characters of non-geniculate corallines are briefly summarized in Table 1)⁶⁻⁹. Uniform taxonomic treatment for both Recent and fossil corallines needs to be adopted to understand their phylogeny and palaeoecology¹⁰. In view of this situation re-evaluation of coralline algal taxonomy has become essential. It is noteworthy that the status of most fossil species is not transparent¹⁰ because of scanty description and different evaluations of diagnostic criteria. Only a few Recent species of coralline algae have been traced back to the fossils¹¹⁻¹³. Many species and genera known only from fossil record are based on characters that are now known to be of no taxonomic value for delimiting living corallines, and thus their implications are of questionable value for delimiting fossil taxa¹⁴.

Present-day workers on fossil corallines⁹⁻¹⁴ opine that most fossil species and genera considered to be coralline algae require taxonomic reassessment in the context of current knowledge of living corallines. Recently, all the diagnostic features that are known from fossil algae have been summarized¹⁰ and some of these contributions have proved that Recent coralline algal taxonomy is safely applicable to the fossil forms⁹⁻¹⁴. Most of the important features (viz. cell fusion, secondary pit connection, uni-

Table 1. Classification of subfamilies belonging to non-geniculate coralline algae

Subfamily	Cell fusion joining contiguous filaments	Secondary pit connection joining contiguous cells	Sporangial conceptacles; tetraspores
Lithophylloideae	No	Yes	Uniporate; tetraspores lacking plugs
Melobesioideae	Yes	No	Uniporate; tetraspores lacking plugs
Mastophoroideae	Yes	No	Multiporate; tetraspores with plugs
Choreonematoideae	No	No	Uniporate; tetraspores with plugs

From refs 6-9.

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porate or multiporate conceptacle pore, conceptacle roof formation, etc.) used to identify Recent species are easily observable in fossil coralline algae and these characters should be taken into consideration to trace back Recent species to the fossil record¹⁰. A revised classification of subfamilies of non-geniculate coralline algae has been suggested (Table 1)⁶⁻⁹. Taxonomic reassessment of the coralline algae can be more effectively used for palaeoenvironmental and palaeobathymetrical interpretations. Detailed taxonomic study for better understanding of the algal flora from this part of the globe will enable a better and more accurate interpretation of the palaeoenvironment, palaeobathymetry and palaeogeography. It should be mentioned here that the study of corallines is significant from the evolutionary point of view, because it is evident from 18 S rRNA gene sequence analysis¹⁵ that this represents a major primitive group in the line of evolution within the red algae.

Detailed investigations of present-day benthic algal floras have shown that encrusting coralline red algae are widely distributed with distinct environmental requirements. In spite of ecological sensitivity of coralline red algae and their subsequent recognition as useful indicators for interpretative palaeoenvironmental analysis, variations in the palaeogeographic occurrence and distribution of this significant algal group have, until recently, commanded relatively little attention from micropalaeontologists. Till date, there exist almost no published data elucidating the discernible provincial characteristics displayed by palaeogeographically isolated assemblages of this important algal group. Recently, diversity patterns of coralline red algae from early Cretaceous to Pleistocene have been studied¹⁶ based on global data from a comprehensive literature survey. The study¹⁶ reveals that members of the family Corallinaceae increased rapidly from latest Cretaceous to early Miocene due to increase in the species number of subfamily Melobesioideae during Paleocene–Oligocene. It is evident from the interpretation of Aguirre *et al.*¹⁶ that melobesioids reached their zenith in the late Oligocene and the family Corallinaceae as a whole attained its acme in the earliest Miocene. The species number of coralline red algae can be correlated¹⁶ with published $\delta^{18}\text{O}$ isotopic value¹⁷ from benthic foraminifers. Corallinacean diversity varies inversely with temperature. The species richness of Corallinaceae became diversified as global temperature reduced from the Turonian. Encrusting calcareous algae and foraminifera are abundant and important stabilizers for secondary framebuilders in modern and fossil reefs. Crustose coralline algae, in particular, are quoted as one of the best (palaeo-) bathymetric indicators owing to their general wide-depth distribution³ on one hand, but sensitive reaction to changing light conditions on the other. Only rare case studies are available in modern examples dealing with depth distribution of calcareous encrusters¹⁸⁻²¹. Considering the fossil record, examples are even less

abundant²² and provide only very rough estimations. Even in exceptional cases, as in the Late Miocene reefs of Mallorca which provide the possibility of absolute reconstruction of water depths, the accuracy of the results is limited². The main reason for the small number of studies of fossil calcareous encrusting communities in respect to their depth distribution is the lack of a good database of modern examples from different biogeographical regions.

In this backdrop detailed taxonomic study is being carried out for better understanding of the coralline algal flora on freshly collected samples from southwestern Kutch. In the present paper an attempt has been made to provide information on the palaeoenvironment and palaeobathymetry (depth distribution) of calcareous encrusting associations from the late Oligocene of southwestern Kutch.

In the western margin of India, Kutch Basin is a pericratonic rift basin that has preserved almost a complete sequence from Triassic to Recent²³. The Kutch Basin extends far to the west over the present continental shelf. A revised classification for the sedimentary basins of India with special reference to hydrocarbon prospect has been recently proposed²⁴. The Kutch Basin has been included in the category of basins with hydrocarbon accumulation, but without commercial production (Category 2)²⁴. The Kutch Basin with its well-developed fossiliferous Cenozoic sequence is considered as a Cenozoic stratotype for shallow marine sediments of India and the type sections or stratotypes of the Cenozoic rocks are recognized in southwestern Kutch Mainland (Kutch District, Gujarat)²³. Significant contributions have so far been made on the biostratigraphic studies of Cenozoic sequence of southwestern Kutch. In contrast, record of coralline algae from the Cenozoic rocks of southwestern Kutch is indeed scanty. Though it is evident that some of the limestone units belonging to Oligocene and Miocene sediments potentially contain coralline algae, little contributions have so far been made on this aspect. A new species of the genus *Lithophyllum* was described earlier²⁵ from the Chattian (late Oligocene) rocks exposed near Ber Moti Village. Lately, three non-geniculate coralline algal genera have been described²⁶ from the early Oligocene of southwestern Kutch (Waior), attempting a new taxonomic approach. Moreover, Misra *et al.*²⁶ have described two geniculate coralline algae based on traditional taxonomic criteria. Earlier, an early Lower Miocene algal assemblage (from the Khari Nadi Formation of Waior) has been described²⁷, represented by five species belonging to four genera, viz. *Lithophyllum*, *Mesophyllum*, *Aethesolithon* and *Archaeoporolithon*. The overall distribution pattern of Cenozoic coralline algae reported from southwestern Kutch has been shown in Table 2. However, in many instances, status of the previously described coralline algae is questionable and taxonomic revisions of these taxa should be done considering the diagnostic



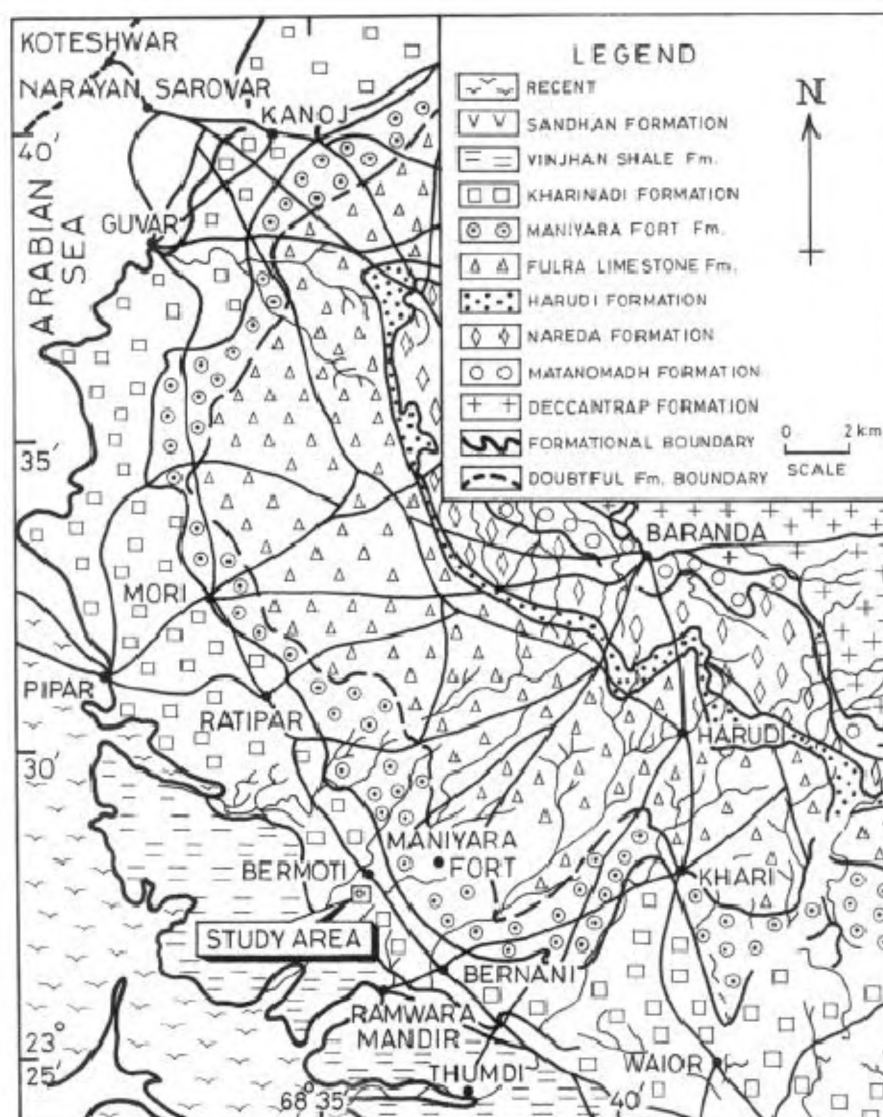
Figure 1. *a*, Topographic view of the Ber Moti Member of Maniyara Fort Formation exposed in the type section; People sitting on the top indicate the location of yielding samples; *b*, *Lithophyllum* sp. 'A', showing the branching pattern, $\times 20$ (BSIP Museum Locality No. 5209), BSIP slide no. 12685; *c*, *Lithophyllum* sp. 'B', $\times 40$ (BSIP Museum Locality No. 5209), BSIP slide no. 12686; *d*, *Lithophyllum* sp. 'C', $\times 60$ (BSIP Museum Locality No. 5209), BSIP slide no. 12687; *e*, *Mesophyllum* sp. 'A', $\times 60$ (BSIP Museum Locality No. 5209), BSIP slide no. 12688; *f*, *Mesophyllum* sp. 'B', $\times 60$ (BSIP Museum Locality No. 5209), BSIP slide no. 12687. All the figured slides and negatives of *b-f* are stored in the Museum of Birbal Sahni Institute of Palaeobotany, Lucknow.

characters used in present-day taxonomy. But, in majority of the cases the typed and figured slides are not traceable. Efforts are now being made to study the coralline algae based on freshly collected samples from the type sections. In the present contribution, coralline algae have been studied considering the new anatomical characters

comparable to Recent coralline algae. The study has been carried out on the samples from the late Oligocene (Chatian) limestones belonging to Ber Moti Member of Maniyara Fort Formation, Kutch Basin. Samples were collected from the type section (Figure 1*a*). The type section is continuously exposed along the Ber Moti

Table 2. Distribution of coralline red algae in the Cenozoic sediments of southwestern Kutch

Age	Formation	Outcrop section	Coralline algal genus	Probable interpretation on palaeo-environment/palaeobathymetry	Reference
Late Lower Miocene (Late Aquitanian)	Khari Nadi Formation	Exposed along nala sections in and around the villages Waior and Cheropodi	<i>Lithophyllum</i> , <i>Mesophyllum</i> , <i>Aethesolithon</i> and <i>Archaeoporolithon</i>	Shallow marine inner-shelf environment, gradually transgressive sea	27
Late Oligocene (Chattian)	Maniyara Fort Formation	Exposed in the type section of Ber Moti Member, near village Ber Moti	<i>Lithophyllum</i> and <i>Mesophyllum</i>	Shallow marine, moderate to high energy open shelf environment	Present work
Late Oligocene (Chattian)	Maniyara Fort Formation	Exposed in a stream section near village Ber Moti	<i>Lithophyllum</i>	Shallow marine, moderate to high energy open shelf environment	25
Early Oligocene (Rupelian)	Maniyara Fort Formation	Exposed along the Dhobi Ghat in the vicinity of village Waior	<i>Lithoporella</i> , <i>Lithothamnion</i> , <i>Mesophyllum</i> , <i>Corallina</i> and <i>Arthrocardia</i>	Possibly marginal marine, shallow inner-shelf environment	26

**Figure 2.** Geological map of part of southwestern Kutch showing the study area (after Raju, 1971; Biswas and Raju, 1973).

stream flowing between Maniyara Fort and Ber Moti Village, from a locality about 1.6 km NNE of Ber Moti to a locality about 450 m SE of the Ber Moti village (Figure 2). Lithologically, the Maniyara Fort Formation consists of bedded, yellow-to-ochre coloured foraminiferal limestone with a basal grayish-green, glauconitic siltstone. Based on the characteristic foraminiferal assemblage an Oligocene age has been assigned for the Maniyara Fort Formation. This formation overlies the Fulra Limestone Formation of late Middle Eocene age. The Maniyara Fort Formation is further divided into four members. Ber Moti Member is the uppermost one in this formation and is about 11 m thick. Rusty-brown, friable, glauconitic argillaceous sandstones with pseudo-oolites characterize the lower part of Ber Moti Member. The upper part (Figure 3) is composed of thinly bedded, hard, grey-to-yellowish foraminiferal limestone (biomicrites) which yielded a fairly rich algal assemblage. Ber Moti Member has been dated as late Oligocene (Chattian) on the basis of typical foraminiferal assemblage²⁸, e.g. *Miogypsia* (*Miogypsionoides*) *complanata-formosensis*, *M. bermudezi*, *Planolinderina freudanthali*. The algal forms recovered in petrographic thin sections from the late Oligocene (Chattian) limestones of Ber Moti Member belong to the gen-

era *Lithophyllum* and *Mesophyllum* of subfamily Lithophylloideae and Melobesioideae respectively. Both the subfamilies belong to the family Corallinaceae. The genus *Lithophyllum* recorded in the present assemblage is characterized by dorsiventral thallus, non-coaxial primigenous filaments, absence of cell fusions; however, characteristic secondary pits and uniporate tetra/bisporangial conceptacles are not preserved. The three species, viz. *Lithophyllum* sp. 'A' (Figure 1b), *Lithophyllum* sp. 'B' (Figure 1c) and *Lithophyllum* sp. 'C' (Figure 1d) are not comparable to any previously known species of *Lithophyllum*. The genus *Mesophyllum* is represented by two species and the characteristic feature of the genus is monomerous thallus with numerous cell layers, coaxial primigenous filaments, cell fusions present, secondary pits and multiporate tetra/bisporangial conceptacles are absent. The two species, i.e. *Mesophyllum* sp. 'A' (Figure 1e) and *Mesophyllum* sp. 'B' (Figure 1f) cannot be compared with any previous species of *Mesophyllum*. The frequency distribution analysis based on sixty specimens reveals that qualitatively the species of the genus *Lithophyllum* is preponderant compared to *Mesophyllum*. However, statistical analysis reveals quantitative dominance of the representatives of the genus *Mesophyllum*.

It has already been discussed that the global diversity pattern of coralline red algae indicates that the members of subfamily Melobesioideae (e.g. *Mesophyllum*) reached their acme in the late Oligocene and the representatives of the subfamily Lithophylloideae (e.g. *Lithophyllum*) gradually became abundant from the early Oligocene. So, the algal assemblage recorded from the late Oligocene (Chattian) of southwestern Kutch corresponds to the global diversity pattern of Corallinaceae. The depth/abundance charts for coralline floras from the Caribbean and Pacific sites²⁹ reveal the great potential that the coralline algae have for deducing palaeobathymetry³⁰. Following that bathymetric ranges it may be suggested that dominance of *Mesophyllum* in association with *Lithophyllum* prevailed in water depth down to ~40 m. Both these algal genera recovered from the late Oligocene (Chattian) limestones of Ber Moti Member are typically branched (Figure 1a) in many instances. The reef frameworks of medium energy reefs and buildups are generally formed of leafy and branching coralline algae³⁰, viz. *Mesophyllum* and *Lithophyllum* in various occasions. Bathymetric analysis of the algal forms recorded from the late Oligocene (Chattian) limestones of Ber Moti Member as well as the typical foraminiferal assemblage indicate a shallow marine condition. In all probability, a rather moderate to high energy open shelf environment existed during late Oligocene period in the southwestern part of Kutch Basin.

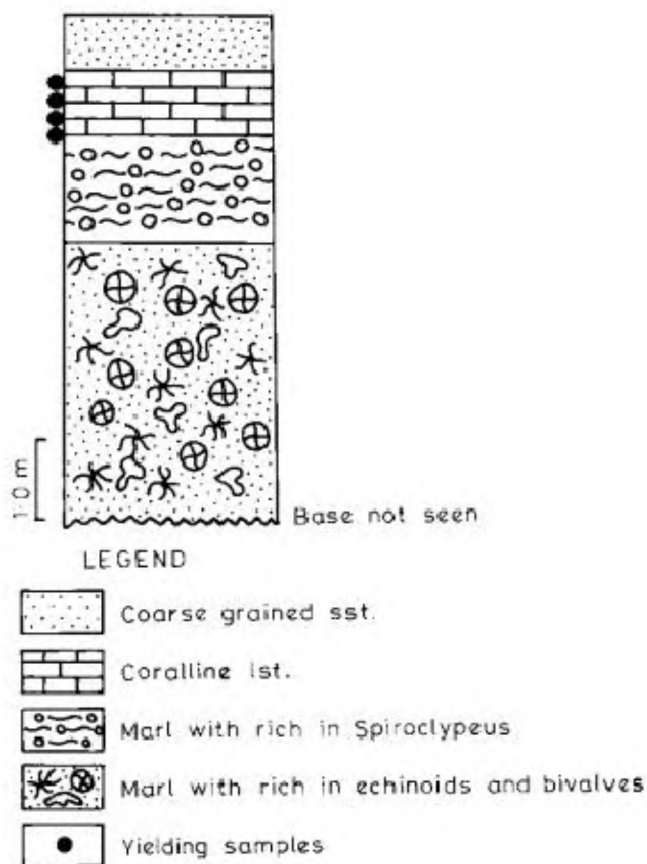


Figure 3. Litholog of the type section of Ber Moti Member belonging to the Maniyara Fort Formation.

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Mitochondrial DNA diversity among five tribal populations of southern India

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DNA samples from 160 unrelated individuals belonging to five Dravidian tribal populations of southern India were analysed for ten mitochondrial DNA (mtDNA) restriction site polymorphisms (RSPs) and one insertion/deletion polymorphism. There is extensive sharing of mtDNA haplotypes among all the tribal populations studied, indicating that there was a small female founding population in India. The 9-bp deletion analysed was observed only in the Kadar population with a low frequency. The Asian-specific haplogroup M is found at a higher frequency in all the populations, thus supporting the hypothesis that this haplogroup arose in India and was carried to Africa from India. Haplogroup U is also found in all the populations and it is consistent with the theory that Dravidian-speaking populations were more widespread in India and that the Aryan-speakers pushed them to their present habitat.

CONTEMPORARY ethnic populations of India manifest a great deal of biological and cultural variability¹. Based on cultural patterns, the tribal populations of India are clearly distinguished from the non-tribal groups, such as the populations belonging to the Hindu caste fold. The tribals constitute about 8.08% (2001 census) of the total Indian population. They are considered to be the original inhabitants of India. Tribals may represent relic populations of unknown origin, but potentially of great genetic interest². The origins and migrational histories of the tribal populations of the Indian subcontinent are not clearly understood. Some tribal populations of southern India bear many Negroid physical characteristics^{3,4}, and may therefore be the representatives arriving in India on an ancient wave of out-of-Africa migration. Most ethnic populations of southern India are linguistically Dravidian. Some researchers have proposed that the contemporary Dravidian-speaking tribes of southern and central India may be descendants of the original inhabitants of the Indian subcontinent⁵, although we have recently provided genomic evidence that the Dravidian-speaking tribals may have arrived in India after the Austro-Asiatic-speaking tribals⁶.

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