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Nongeniculate Coralline Algae from Early Middle Miocene Offshore Sequence of Kachchh Basin, Western India: Paleoenvironmental Significance

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Abstract: The present paper reports five nongeniculate coralline algal species, viz., *Lithothamnion valens* Foslie, *Mesophyllum roveretoi* Conti, *Phymatolithon calcareum* (Pallas) Adey and Mckibbin, *Melobesioideae* gen. et spec. indet. and *Lithoporella melobesioides* Foslie form the early middle Miocene Chhasra Formation of Offshore Sequence of Kachchh basin, western India. The present day depth distribution of *Lithothamnion* and *Mesophyllum* and growth forms of five nongeniculate coralline algal species points that the two cores belonging to the Chhasra Formation of offshore sequence of Kachchh basin were deposited in inner shelf environment at 60-100m depth in moderate-energy conditions.

Keywords: Nongeniculate coralline algae, Miocene, Paleoenvironment, Kachchh Basin, Western India.

INTRODUCTION

Corallines are defined as carbonate secreting and strongly calcified red algae of the order Corallinales of division Rhodophyta. Corallines are divided into two groups, the nongeniculate and geniculate coralline forms. The geniculate coralline forms have thallus consisting of rigid, calcified segments termed as intergenicula alternating with more flexible rarely calcified segments termed as genicula. The nongeniculate forms do not have genicula (Woelkerling, 1988). Corallines have been important constituents of shallow marine sedimentary sequences all over the world from the early Cretaceous (Hauterivian) to the Pleistocene (Kundal, 2011). Coralline algae are used as a potential tool for paleoenvironments and paleobathymetry. Coralline algae have multifarious applications in hydrocarbon exploration such as a potential tool for reconstruction of paleo-environment, as builder of carbonate reservoir rocks and reefs (Johnson, 1961; Terry and Williams, 1969; Wray, 1977; Kundal and Kundal, 2010, Kundal, 2014; Kundal et al. 2014).

The early middle Miocene Chhasra Formation of onshore sequence of Kachchh basin, western India is rich in calcareous algae as 28 species have been documented by Kundal and Humane (2002, 2003, 2006, 2007a), Humane and Kundal (2005, 2010) and Humane et al. (2006). These 28 species are: Cyanophycean algae (3 species): *Rivularia lissaviensis* (Bornemann) Dragastan, *R. dianae* (Dragastan and Bucur) and *Rivularia* sp.; Nongeniculate Coralline algae (4 species): *Lithophyllum* sp., *Lithoporella melobesioides* (Foslie) Foslie, *Lithothamnion cardinellense* Fravega, Piazza and Vannucci and *Sporolithon affine* Howe; Geniculate Coralline algae (12 species): *Amphiroa anchiverricosa* Johnson and Ferris, *Arthrocardia cretacica* Raineri and *Calliarthron antiquum* Johnson, *Corallina elliptica* Ishijima, *C. hayasaki* Ishijima, *C. kachchhensis* Kundal and Humane, *C. marshallensis* Johnson, *C. matansa* Johnson, *C. prisca* Johnson, *C. raoi* Chatterji and Gururaja, *C. typica* Ishijima, *Metagoniolithon* sp.; Dasycladalean algae (6 species) : *Acroporella* sp., *Broeckella* sp., *Clypeina* sp., *Neomeris plagnensis* Deloffre, *N. ramwadaensis* Kundal and Humane and *Orioporella* sp.; Halimedacean algae (1 species): *Halimeda cylindracea* Decaisne and Udoteacean algae (2 species) : *Ovulites margaritula* Lamarck and *O. pyriformis* Schwager.

The early middle Miocene Chhasra Formation is found both in the onshore sequence and offshore sequence of Kachchh basin, western India. However, only 10 species of *Corallina,* a geniculate coralline alga are known from early middle Miocene Chhasra Formation of offshore sequence of Kachchh basin (Kundal, 2015). The aim of the present paper is to record five nongeniculate coralline algal species, viz., *Lithothamnion valens* Foslie,

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Mesophyllum roveretoi Conti, *Phymatolithon calcareum* (Pallas) Adey and Mckibbin, *Melobesioideae* gen. et spec. indet. and *Lithoporella melobesioides* Foslie from the early middle Miocene Chhasra Formation of offshore sequence of Kachchh basin. The palaeoenvironmental significance of these five species is provided in this paper.

GEOLOGY

The Kachchh basin, the westernmost pericratonic rift basin, is situated at the northern end of the western seaboard of India and this basin represents the earliest rift during the break up of Africa and India (Biswas, 1982) (Fig. 1). The Kachchh basin in onshore and offshore is filled with sediments ranging in age from the middle Jurassic to Holocene. In the onland part, the Mesozoic sediments are very thick than the Cenozoic sediments which are present in the outer part of the basin bordering the Mesozoic uplifts and the thickness of the exposed Cenozoic sequence is 700 m while it is 5500 m offshore (Mishra, 2009). The Cenozoic offshore sequence of Kachchh basin is sub-divided into ten formations, namely, Nakhtarana Formation (late Paleocene), Jakhau Formation (early Eocene), Fulra Limestone Formation (late middle Eocene), Sir Formation (middle to late Eocene), Tuna Formation (early Oligocene), Narayan Sarovar Formation (early Miocene), Godhra Formation (early Miocene), Mitti Nadi Formation (early Miocene), Chhasra Formation (early middle Miocene) and

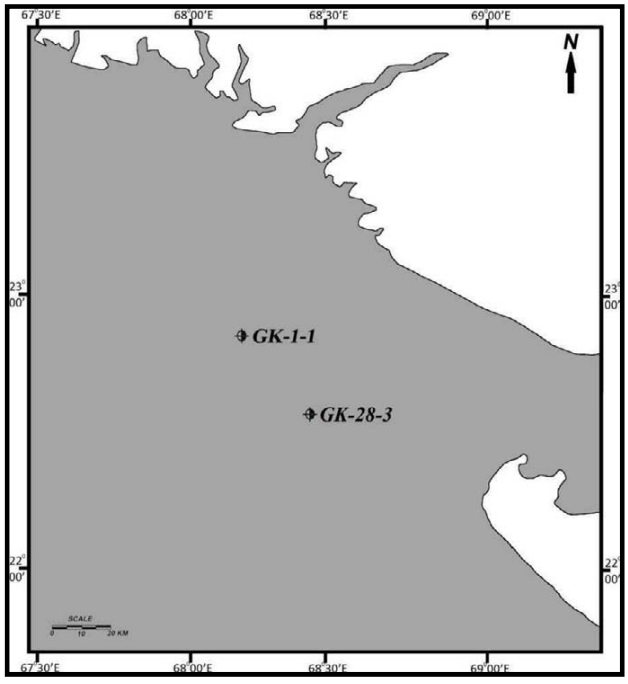

Fig.1. Location map of Kachchh basin showing location of wells.

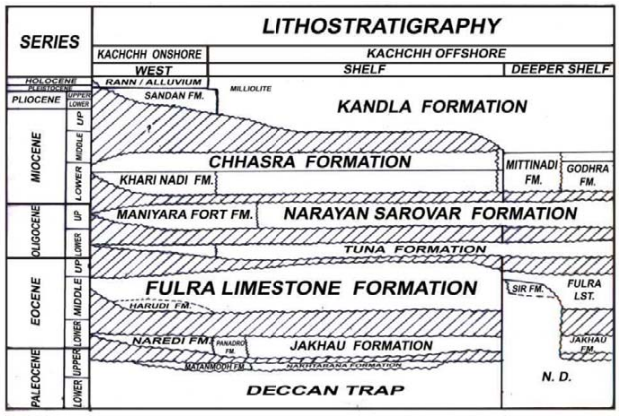

Fig.2. Lithostratigraphy of Kachchh basin (after Biswas, 1992).

Kandla Formation (middle Miocene to Recent) (Biswas, 1992) (Fig. 2).

MATERIAL AND METHODS

The Chhasra Formation is 116 m thick in the offshore portion and comprises alternations of fossiliferous limestone bands and oolitic gypseous claystone/silty clay beds. This formation has presence of biotic constituents such as foraminifers, bivalves, ostracods, ichnofossils, gastropods, echinoids, bryozoa, corals and calcareous algae.

Lithothamnion valens Foslie and *Phymatolithon calcareum* (Pallas) Adey and Mckibbin are discovered in sample C1 and *Mesophyllum roveretoi* Conti and *Lithoporella melobesioides* Foslie are discovered in sample

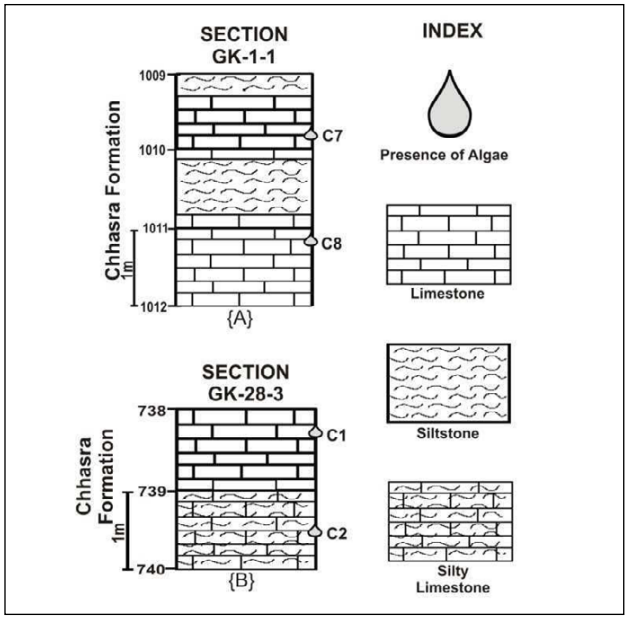

Fig.3. Lithosections denoting samples having presence of nongeniculate algae.

C2 from well GK-28-3 (22°30'N: 68°23'E) (Fig. 3B) (depth 738 to 740m). *Melobesioideae* gen. et spec. indet. and *Lithoporella melobesioides* Foslie is found in two samples C7, C8 from well GK-1-1 (22°50'N: 68°09'E) (Fig. 3A) (depth 1009 to 1012m). Petrographically, the limestone of well GK-28-3 is foram algal packstone and that of GK-1-1 is foram algal grainstone. The samples were collected from Regional Geosciences Laboratory, Oil and Natural Gas Corporation Ltd., Panvel, Navi Mumbai.

Nongeniculate coralline algae are described in this paper are studied in thin sections under petrological microscope. Thin sections are prepared as per routine method. Samples of calcareous rocks are cut parallel and perpendicular to the bedding plane. The thickness of thin section was kept more, i.e. 50-60 microns more than the other thin sections for mineralogical and petrological studies. The specimens studied are kept in the Micropaleontology Laboratory of the Postgraduate Department of Geology, RTM Nagpur University, Nagpur.

SYSTEMATIC PALEONTOLOGY

The five nongeniculate coralline algal species are identified on the basis of modern taxonomic approach of fossil nongeniculate corallines using certain distinguishing features such as arrangement of basal filaments, cell fusions, conceptacle perforations and orientation of filaments around conceptacles of living corallines (Woelkerling, 1988; Braga et al., 1993; Woelkerling et al., 1993; Bassi, 1995, 1998; Braga and Aguirre, 1995; Rasser and Piller, 1999; Braga, 2003; Le Gall and Saunders, 2007 and Kundal, 2010, 2011).

Classification:

Division : Rhodophyta Wittstein, 1901
Class : Florideophyceae Cronquist, 1960
Subclass : Corallinophycidae Le Gall And Saunders, 2007
Order : Corallinales Silva And Johansen, 1986
Family : Hapalidiaceae Gray, 1864
Subfamily : Melobesioideae (Areschoug) Bizzozero, 1885

Genus *Lithothamnion* Philipi, 1837

Lithothamnion valens Foslie
Pl. 1, fig. 1

Lithothamnion valens Foslie: Basso et al., 1997, p. 170-176.
Lithothamnion valens Foslie: Basso et al., 2008, p. 335, pl. 1, figs. 4-6.
Lithothamnion valens Foslie: Kundal and Dharashivkar, 2003, 51-52, pl. 5, figs. 7, 8.

Description: Thallus monomerous branched and fruticose. Core region noncoaxial and very thin having thickness of about 50 μm. Cells of the core region 8-10 μm in length and 4-6 μm in width. Peripheral region exhibits growth zones and having large rectangular cells at places. Cells of peripheral region 16-29 μm in length and 9-20 μm in width. Some cells of contiguous filaments connected by cell fusions but secondary pit connections absent. Conceptacles multiporate. One of the conceptacles has presence of tetrasporangia/ bisporangia. The conceptacles having diameter 134-341 μm while height 72-172 μm.

Remarks: The growth form, peripheral region and conceptacles in the present specimen closely resemble *Lithothamnion valens* Foslie. Specimen Nos. PGTDG/MF/FCA/676.

Stratigraphical and Geographical distribution: Late Eocene (Priabonian) to Recent (Basso et al., 1997); Pliocene Kalyanpur Limestone Member, Dwarka Formation, Gujarat (Kundal and Dharashivkar, 2003) and Miocene of the Croatia (Basso et al., 2008).

Horizon and Locality: Chhasra Formation (early middle Miocene) of well GK-28-3 from Offshore Sequence of Kachchh Basin.

Genus: *Mesophyllum* Lemoine, 1928

Mesophyllum roveretoi Conti
Pl. 3, figs 1,3

Mesophyllum roveretoi Conti: Fravega et al., 1987, p. 52.
Mesophyllum roveretoi Conti: Fravega et al., 1993, p. 203.
Mesophyllum roveretoi Conti: Vannucci et al., 1994, p. 73, fig. C.
Mesophyllum roveretoi Conti: Kundal and Dharashivkar, 2003, p. 53-54, pl. 6, figs. 2,4-8.
Mesophyllum roveretoi Conti: Kundal and Humane, 2007b, p. 149, pl. 1, figs. 2, 5.
Mesophyllum roveretoi Conti: Basso et al., 2008, p. 335, pl. 1, figs. 2-3.
Mesophyllum roveretoi Conti: Mude and Kundal, 2012, p. 72, pl. 1, figs. d, f.

Description: Thallus monomerous encrusting having a protuberance with coaxial core filament and peripheral filament. Some cells of contiguous filaments connected by cell fusions but secondary pit connections absent. The

Plate 1 (1) *Lithothamnion valens* Foslie Sp. No. PGTDG/MF/FCA/676: Monomerous branched and fruticose thallus, core region (c) (arrow) noncoaxial thin with cell fusions and multiporate conceptacle (arrows) from early middle Miocene Chhasra Formation (Well GK-28-3; Sample No. C1). (2) *Melobesioideae* gen. et spec. indet. Sp. No. PGTDG/MF/FCA/670: Monomerous thallus exhibiting coaxial core region (arrow) and peripheral region (arrow) with presence of cell fusions from early middle Miocene Chhasra Formation (Well GK-1-1; Sample no. C7).

thickness of core region 294 µm and that of peripheral region 252 µm. The cells of core region 38-50 µm in length and 8-12 µm in width. The peripheral cells poorly preserved. Conceptacles multiporate having diameter 84-147 µm and height 50-55 µm.

Remarks: The size and shape of cells in core region and conceptacles of present specimen are similar to *Mesophyllum roveretoi* Conti and therefore the present specimen is described as *Mesophyllum roveretoi* Conti. Specimen No. PGTDG/MF/FCA/693.

Stratigraphical and Geographical distribution: Oligocene of Sessello basin, Tertiary Piedmont basin (Fravega et al., 1987), Miocene of Tertiary Piedmont basin, NW Italy (Fravega et al., 1993), Miocene rodoliths of SW sector of Tertiary Piedmont basin (Vannucci et al., 1994), Chaya Formation (late Pleistocene to late Holocene) of Dwarka-Okha area, Gujarat (Kundal and Dharashivkar, 2003), Maniyara Fort Formation (Oligocene) of Kachchh onshore sequence (Kundal and Humane, 2007b), Miocene bioclastic limestone, northern Croatia (Basso et al., 2008), Chaya Formation (late Pleistocene to late Holocene), Porbandar area, Gujarat (Mude and Kundal, 2012). Fravega et al. (1987) opined that *Mesophyllum roveretoi* Conti stratigraphically ranges from late Eocene to Miocene.

Horizon and Locality: Chhasra Formation (early middle Miocene) of well GK-28-3 from offshore sequence of Kachchh basin.

Genus: *Phymatolithon* Foslie, 1898
Phymatolithon calcareum (Pallas) Adey and Mckibbin
Pl. 2, fig. 1

Phymatolithon calcareum (Pallas) Adey and Mckibbin, 1970, p. 100-106.
Phymatolithon calcareum (Pallas) Adey and Mckibbin: Vannucci et al., 1997, p. 417-419, pl. 1.
Phymatolithon calcareum (Pallas) Adey and Mckibbin: Basso et al., 1997, p. 168-170, pl. 36.
Phymatolithon calcareum (Pallas) Adey and Mckibbin: Basso et al., 2008, p. 335, pl. 1, figs. 1.

Description: Thallus monomerous encrusting having a protuberance with noncoaxial core filaments and peripheral filaments. Peripheral region shows growth zones. The thickness of the core region 280-311 µm and that of peripheral region 180-212 µm. The cells of core filaments 19-27 µm in length and 11-19 µm in width while the cells of peripheral filaments 11-19 µm in length and 7-11 µm in width. A single row of epithallial cells having 7-11 µm in length and 11 µm in width preserved. Some cells of contiguous filaments connected by cell fusions but secondary pit connections absent. Conceptacle multiporate and oblate in shape having 152-167 µm diameter and 95 µm height. Cell tissue well preserved over the conceptacle.

Remarks: The present specimen is attributed to *Phymatolithon calcareum* (Pallas) Adey and Mckibbin on the basis of the correspondence of all anatomical features. Rasser and Piller (1999 and 2000) worked on *Phymatolithon* in an elaborated manner. Specimen No. PGTDG/MF/FCA/695.

Stratigraphical and Geographical distribution: Late Miocene of northwestern Italy (Vannucci et al., 1997); Early Eocene of the central Alpine Gosau basin of Krappfeld,

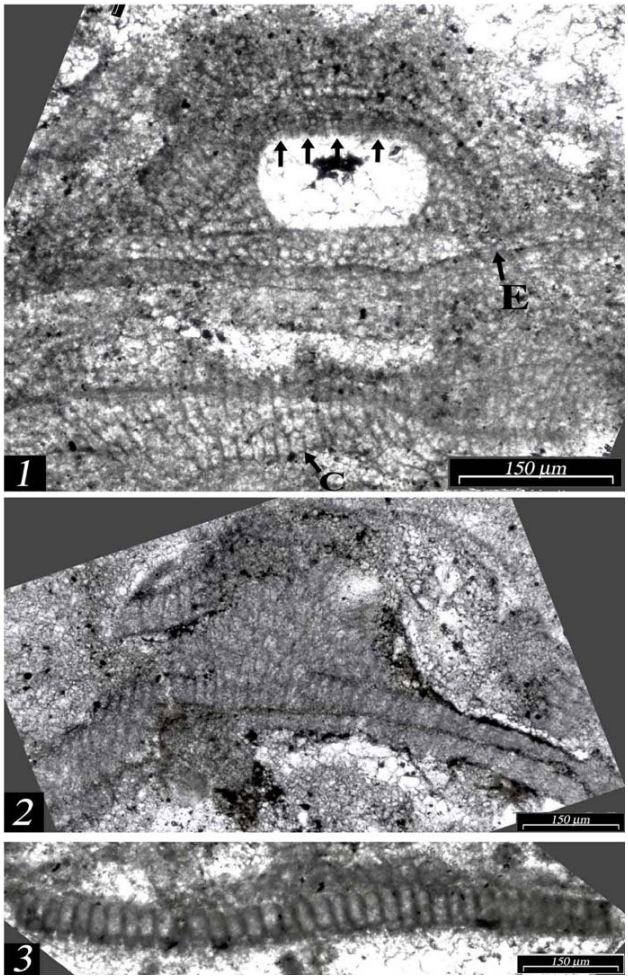

Plate 2. (1) *Phymatolithon calcareum* (Pallas) Adey and Mckibbin Sp. No. PGTDG/MF/FCA/695: Encrusting monomerous thallus with protuberance consisting of noncoaxial core, core filaments (arrow), peripheral filaments (p), cell fusions and presence of epithallial cells (e) (arrow) and multiporate conceptacle (arrow) from early middle Miocene Chhasra Formation (Well GK-28-3; Sample no. C1). **(2)** *Lithoporella melobesioides* Foslie Sp.No. PGTDG/MF/FCA/673: Encrusting dimerous thallus, palisade cells form primigenous filaments while postigenous filaments arising from it from early middle Miocene Chhasra Formation (Well GK-28-3; Sample no. C2). **(3)** 3 *Lithoporella melobesioides* Foslie Sp. No. PGTDG/MF/FCA/675: Encrusting dimerous thallus, palisade cells form primigenous filaments while postigenous filaments arising from it from early middle Miocene Chhasra Formation (Well GK-1-1;Sample no. C8).

Austria (Rasser, 1994); late Eocene of the Alpine Foreland basin in upper Austria (Rasser and Piller, 2000) and Miocene, northern Croatia (Basso et al*.,* 2008),. Basso et al. (1997) indicated that *Phymatolithon calcareum* (Pallas) Adey and Mckibbin is stratigraphically distributed from the Oligocene to Recent while Rasser and Piller (1999 and 2000) opined that these species has early Eocene to Recent age.

Horizon and Locality: Chhasra Formation (early middle Miocene) of well GK-28-3 from Offshore Sequence of Kachchh Basin.

Melobesioideae gen. et spec. indet.
Pl. 1, fig. 2; Pl. 3, fig. 2

Description: Thallus monomerous starts with basal crust from which long and slender repeatedly branches developed. Thallus commences with basal crust from which subcylindrical solitary branch arises. The encrusting portion exhibits coaxial core region. The cells of core region 60-83 µm in length and 90-125 µm in width. The branching portion of thallus shows peripheral filaments. The peripheral cells 83 µm in width and 83 µm in length. Cell fusions present and secondary pit connections absent. Conceptacle absent.

Remarks: Present specimens have monomerous thalli but conceptacle are absent. However, these characteristics of present specimens indicate their affinity with Melobesiods. Hence, the present specimens are identified as *Melobesioideae* gen. et spec. indet. Specimen No. PGTDG/MF/FCA/670,703.

Horizon and Locality: Chhasra Formation (early middle Miocene) of well GK-1-1 from offshore sequence of Kachchh basin.

Subfamily : Mastophoroideae Setchell, 1943

Genus: *Lithoporella* Foslie, 1909

Lithoporella melobesioides Foslie
Pl. 2, figs. 2, 3; Pl. 3, fig. 4

Lithoporella melobesioides Foslie: Bassi, 1995, p. 90, pl. 1, fig. 8
Lithoporella melobesioides Foslie: Bassi and Nebelsick, 2000, p. 104, pl. 2, fig. 1.
Lithoporella melobesioides Foslie: Kishore et al., 2007, p. 619, pl. 1, fig. 4.
Lithoporella melobesioides Foslie: Singh et al., 2009, p. 26, pl. 3, fig. 6.
Lithoporella melobesioides Foslie: Humane and Kundal, 2010, p. 33, pl. 1, figs. 2, 4.
Lithoporella melobesioides Foslie: Kundal et al., 2011*,* p. 190, pl. 4, figs. 1, 5.
Lithoporella melobesioides Foslie: Kishore et al., 2012, p. 222, pl. 3, fig. 3.

Description: Thalli dimerous encrusting and single to double layered. Primigenous filaments collectively forming a unistratose layer and composed of palisade cells.

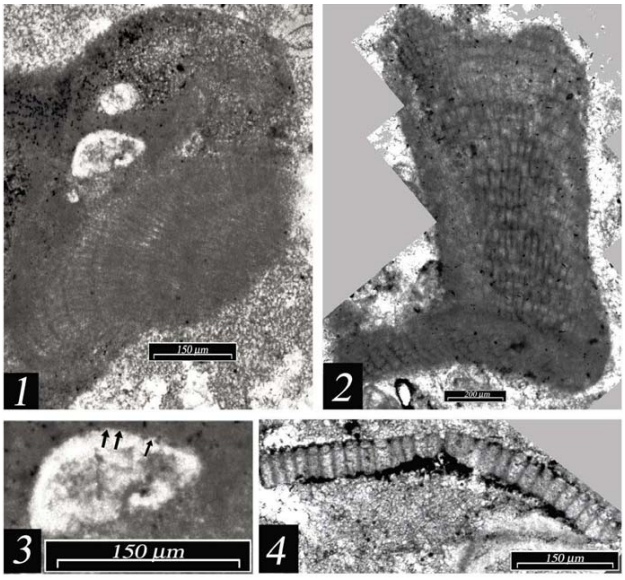

Plate 3. (1) *Mesophyllum roveretoi* Conti Sp. No. PGTDG/MF/FCA/693: Monomerous encrusting protuberated thallus consists of coaxial core filament and peripheral filament with cell fusions from early middle Miocene Chhasra Formation (Well GK-28-3; Sample no. C2). **(2)** *Melobesioideae* gen. et spec. indet. Sp. No. PGTDG/MF/FCA/703: Monomerous thallus exhibiting coaxial core region with presence of cell fusions and peripheral region from early middle Miocene Chhasra Formation (Well GK-1-1; Sample no. C8). **(3)** *Mesophyllum roveretoi* Conti Sp. No. PGTDG/MF/FCA/693: A portion showing mutiporate conceptacles (arrows) from early middle Miocene Chhasra Formation (Well GK-28-3; Sample no. C2). **(4)** *Lithoporella melobesioides* Foslie Sp. No. PGTDG/MF/FCA/674: Encrusting dimerous thallus, palisade cells form primigenous filaments while postigenous filaments arising from it from early middle Miocene Chhasra Formation (Well GK-28-3; Sample no. C2).

Postigenous filaments arising from primigenous filaments, mostly preserved around conceptacle. The palisade cells of primigenous filaments 44-64 µm in length and 15-30 µm in width. The cells of postigenous filaments 60-76 µm in length and 19-26 µm in width. Conceptacle uniporate having diameter 342-420 µm and height upto 304 µm.

Remarks: Bassi (1995) concluded that the cells in filaments are bigger in *Lithoporella melobesioides* Foslie and smaller in *Lithoporella minus* Johnson. The present specimens have bigger cells, therefore the present specimens are described as *Lithoporella melobesioides* Foslie. Specimen Nos. PGTDG/MF/FCA/673-675.

Stratigraphical and Geographical distribution: Early Eocene-Miocene of Colli Berici of northern Italy (Bassi, 1995) and early Oligocene of Gornji Grad Beds, northern Slovenia (Bassi and Nebelsick, 2000); Prang Formation (middle Eocene), Meghalaya, India (Kishore et al., 2007); Maniyara Fort Formation (Oligocene) of Kachchh onshore sequence, Gujarat (Singh et al., 2009); Maniyara Fort Formation (Oligocene); Chhasra Formation (early middle Miocene) of Kachchh onshore sequence, Gujarat (Humane and Kundal, 2010); Miliolite Formation (middle Pleistocene) Diu, Saurashtra, India (Kundal et al., 2011) and Armada Reef Member, Chaya Formation (late Pleistocene) (Kishore et al., 2012).

Horizon and Locality: Chhasra Formation (early middle Miocene) of well GK-28-3 and GK-1-1 from Offshore Sequence of Kachchh Basin.

PALEOENVIRONMENTAL SIGNIFICANCE

The environment of deposition of 118 m thick early middle Miocene Chassra Formation is marginal marine to shallow inner shelf and the age of this formation is early middle Miocene (Zutshi et al., 1993; Zutshi and Panwar, 1997; Pande and Dave, 1998 and Mishra, 2009). Adey and Macintyre (1973) concluded that the corallines are exclusively marine and distributed from tropical to polar regions. Wray (1977) stated that lithophylloids (*Lithophyllum*) are common in warm temperate environment and *Lithoporella* strictly occurs in the tropical regions. Adey (1979) gave the following generic associations of nongeniculate coralline algae for palaeobathymetry.

Depth	Coralline algal assemblage
Intertidal 20m	*Neogoniolithon, Porolithon, Lithophyllum* and *Hydrolithon*
20 – 40m	*Neogoniolithon, Lithophyllum, Hydrolithon, Titanoderma* and *Mesophyllum*
40 – 60m	*Mesophyllum,* dominant with *Sporolithon, Lithothamnion* and *Lithophyllum*
60 – 100m (possibly 200m)	*Mesophyllum* and *Lithothamnion* with *Sporolithon* and *Lithophyllum*

Bosence (1991) and Kundal (2010) elucidated that water turbulence controls the morphology of coralline algae. The coralline algae growing in high-energy conditions have robust fused framework with thick crusts, branches and columns; while those growing in moderate-energy conditions have delicate framework with thin branches and crusts.

The five nongeniculate coralline algae are documented from 3 m and 2 m cores belonging to the Chhasra Formation, therefore, palaeoenvironment of rocks represented by two cores can be deduced. The Chhasra Formation (early middle Miocene) has presence of five species, namely *Lithothamnion valens* Foslie, *Mesophyllum roveretoi* Conti, *Phymatolithon calcareum* (Pallas) Adey and Mckibbin,

Melobesioideae gen. et spec. indet. and *Lithoporella melobesioides* Foslie. More numbers of fragments of *Mesophyllum* and *Lithothamnion* were noticed, however only well preserved fragments are illustrated. The nongeniculate coralline algal assemblage recorded from the Chhasra Formation of offshore sequence of Kachchh Basin has presence of *Mesophyllum* and *Lithothamnion* and absence of *Sporolithon*. Hence presence of *Mesophyllum* and *Lithothamnion* is indicative of depth from 60-100m depth (Adey, 1979). As all the nongeniculate coralline algal species have delicate framework with some branching and concentric crust, they precisely suggest moderate-energy conditions (Bosence, 1991). In view of this, it is inferred that the sediments recovered from 3m and 2 m cores belonging to the Chhasra Formation of offshore sequence of Kachchh basin were deposited in inner shelf environment at 60-100 m depth in moderate-energy conditions.

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