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Middle Eocene Calcareous Algae from Southwestern Kachchh, Gujarat

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Abstract: The Fulra limestone (middle Eocene) exposed in the areas around Jhadwa and Harudi villages, southwestern, Kachchh reveals presence of a rich assemblage of calcareous algae belonging to the Chlorophyceae and Rhodophyceae along with abundant foraminifera. In the present paper, eight species belonging to eight genera of calcareous algae are described. These include *Dissocladella longijangensis*, *Sporolithon keenani*, *Corallina crossmanni*, *Arthrocardia* sp. Misra et al. 2001, *Lithothamnion ishigakiensis*, *Melobesioideae* gen. et spec. indet. 1, *Melobesioideae* gen. et spec. indet. 2 and *Lithoporella melobesioides*. Out of these, one taxon belongs to the family Dasycladaceae. Among the remaining taxa, one taxon to the family Sporolithaceae, three taxa to the family Corallinaceae and three to the family Hapalidiaceae. Two coralline species, *Corallina crossmanni* and *Lithothamnion ishigakiensis*, are recorded for the first time from India. Another species (*Dissocladella longijangensis*), though known from other areas of India, is new to the study area.

The dominant group of the calcareous algal association in the study area is represented by non-geniculate coralline algae comprising Hapalidiaceae, Corallinaceae and Sporolithaceae; the minor component is represented by dasyclads (chlorophyceae). These algal groups, together with their growth-forms (arbosescent, encrusting to fruticose, warty), and the associated foraminifera indicate that the depositional environment of the Fulra limestone ranged from deeper inner- to mid-ramp environment (40-80 m) in the upper photic zone.

Keywords: Calcareous algae, middle Eocene, Fulra limestone, Kachchh, Gujarat.

INTRODUCTION

Calcareous algae are important constituents of the Palaeogene carbonate deposits of Kachchh. In some stratigraphic units (e.g. Maniyara Fort Formation), they appear as important frame builders and sediment contributors. Such algal beds (as shown by Littler and Littler, 1997) provide habitat for numerous associated macroalgae and invertebrates. As most Cenozoic algal genera range to the present-day environment, they are potentially useful for palaeoenvironmental interpretations. The morphology of coralline crusts and their growth-forms indicate different levels of water energies and depth of deposition both in Recent and fossil examples (Bosence, 1983; Bassi, 1995; Kishore et al. 2007). Previous record of four rhodophycean taxa by Misra et al. (2006) indicates scope of study of calcareous algae in the Fulra Limestone of Kachchh. It contains well-preserved forms of calcareous algae (Chlorophyceae and Rhodophyceae), in which the coralline algae occur in association with larger foraminifera and other macroinvertebrates. The present record of eight algal taxa from the Fulra limestone outcropping near Harudi and Jhadwa villages of southwestern Kachchh, Gujarat (Fig.1), adds to the scope of the study of calcareous algae and gives an idea of taxonomic composition of calcareous algae in this formation. Seven taxa belong to the class Rhodophyceae, while the remaining one is grouped with the class Chlorophyceae. The previous studies on calcareous algae (Kar, 1979; Lakhanpal et al. 1984) of the Fulra limestone (middle Eocene) are based on traditional taxonomic approach. Singh and Kishore (2001) documented six species of dasyclades, while Kundal and Humane (2002, 2003) recorded only articulated corallines from this area. Misra et al. (2006) recorded four species of non-geniculate coralline algae from the Fulra limestone of Kachchh, Gujarat.

The taxonomy of the fossil coralline red algae has undergone major changes in recent years as a consequence of a number of studies involving present-day living calcareous algae. These have introduced changes in the

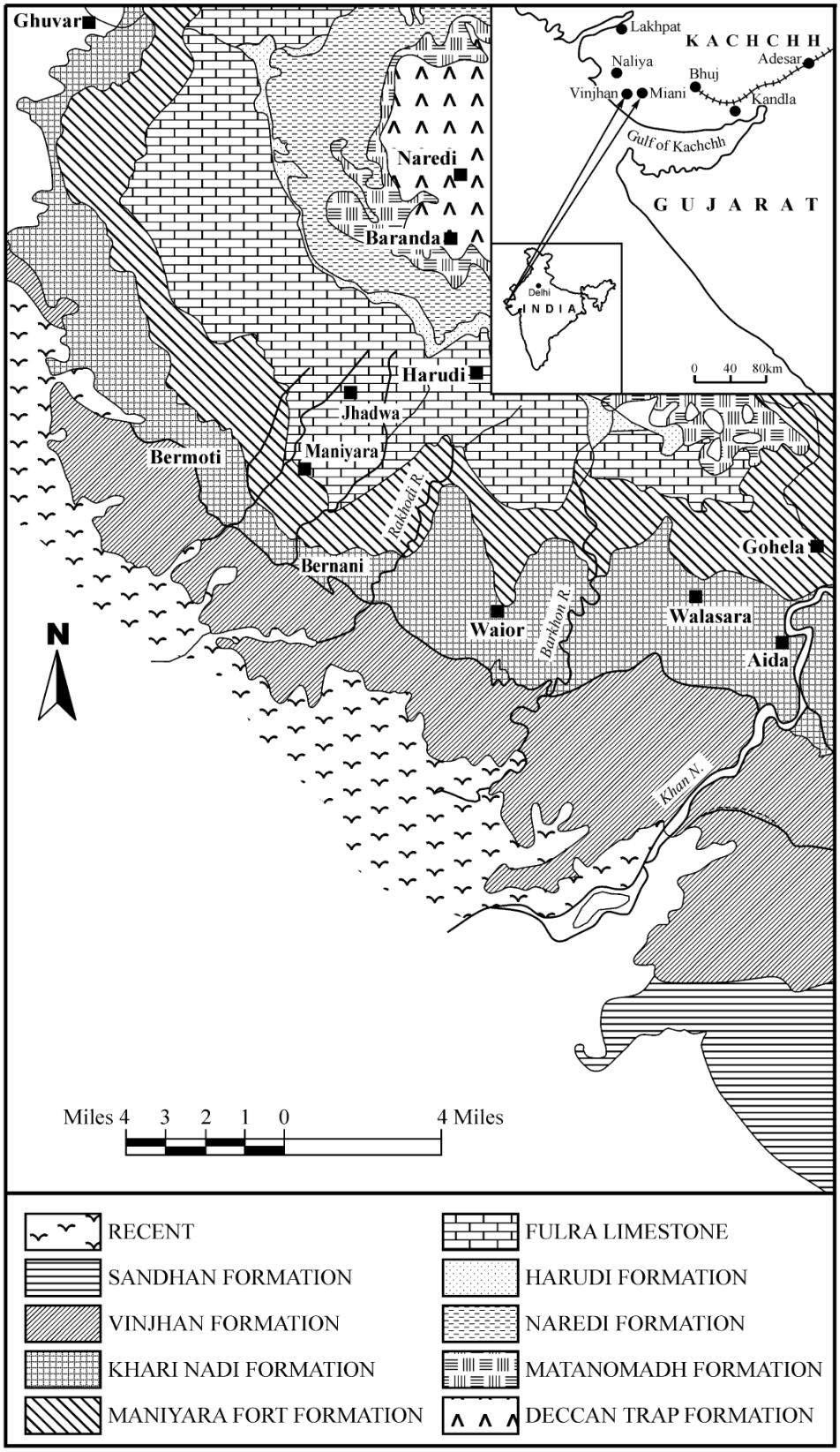

Fig. 1: Geological map showing sampled localities of a part of Kachchh. The inset shows position of Kachchh in India (modified after Biswas, 1992).

concepts of families, subfamilies, genera and species on the basis of vegetative morphology, anatomy and reproductive features (Bassi et al. 2000, 2005; Bassi 2003; Braga et al. 2005; Iryu et al. 2009). As a result of this development, many taxa have been transferred to different genera and/or subfamilies and/or families, while several taxa have been found to be of uncertain taxonomic affinities. Braga et al. (1993), Braga and Aguirre (1995), Rasser and Piller (1999), Misra et al. (2001), Bassi (1998, 2005), Bassi et al. (2007), Nebelsick et al. (2000), Bassi and Nebelsick (2000), Iryu et al. (2009), Woelkerling (1988, 1996), Woelkerling and Lamy (1998) and Harvey et al. (2003) have developed the taxonomic criteria currently applicable in studies on fossil algae. The purpose of this paper is to document the additional taxonomic data of the calcareous algae along with their growth-forms, and to point out their increasing value in palaeoenvironmental interpretations. In the present work, we have also followed the recently changed taxonomic criteria given by Iryu et al. (2009) for classification of Corallinales taxa.

GENERAL GEOLOGY

The study area falls in Kachchh and lies between Lat. 23°26'30" to 20°52' N and Long. 68°45' to 70°7'30" E. The fossil-yielding strata, designated as the Fulra limestone, are extensively developed in Kachchh and continuously exposed in the nala sections from a place about 3.2 km south of Baranda up to Jhadwa. They are predominantly calcareous in nature and consist of limestones and marls. They overlie a unit of marls, clays and shales known as the Harudi Formation. The two units together are 90 m thick and are considered to be middle Eocene in age. The lower boundary of the Harudi Formation with the underlying Naredi Formation (early Eocene) is marked by the laterite bed. The upper limit is also marked by an unconformable contact (a 0.15 m thick limonitic band) between white limestones (middle Eocene) and the base of glauconitic foraminiferal limestone of the Maniyara Fort Formation (lower Oligocene).

Harudi Formation

The formation is well exposed in an impressive escarpment situated west of Harudi village (23°30'30" N: 68°41'10" E). The type section is about 1.5 km NW of Harudi, on the Naliya-Baranda road (Fig.2A). The formation consists of green and greenish grey, splintery shale with yellow limonitic partings in the lower part and calcareous claystone and siltstone with occasional layers of carbonaceous shale in the upper part. The coquina bands

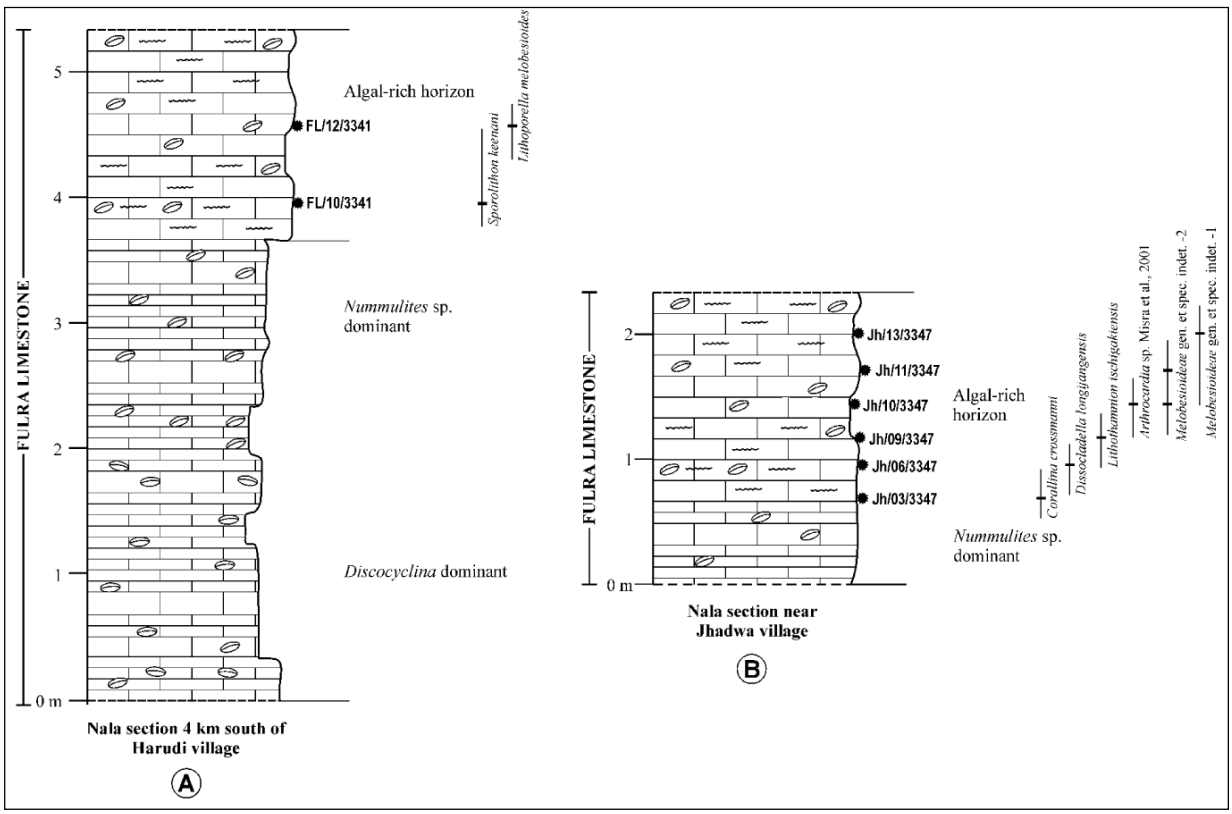

Fig.2. Lithocolum of the Fulra Limestone (Eocene) exposed near Harudi and Jhadwa villages.

which occur near the base, contain varieties of bivalves, gastropods, etc. The foraminiferal assemblage indicates a definite late middle Eocene age. The formation is about 14 m. thick. *Nummulites acutus* and *Nummulites obtusus* are the characteristic fossil species.

Fulra Limestone

This formation is well exposed in the southern flank of the Babia hills, about 1.5 km SW of the village Fulra. Its upper part is also exposed in a nala south of Fulra and in the western part of Kachchh around Narayan Sarovar, Lakhapat, Rodasar, Khari, Harudi, Lakhmirani and Waghopadar.

The Fulra limestone overlies the Harudi Formation and is completely developed in carbonate facies. It is a massive to thickly bedded, white and buff coloured foraminiferal limestone with intercalations of marls. Foraminiferal faunas include species of *Nummulites*, *Discocyclina* and *Alveolina* in great abundance, along with rich assemblages of smaller benthic and planktic foraminifera. They are associated with calcareous nannoplankton and calcareous algae (Tandon et al. 1978; Kar, 1979; Samanta et al. 1990; Jauhri, 1981, 1991, 1994; Singh and Singh, 1986; Rai, 1997; Saraswati et al. 2000). Important species of foraminifera are *Asterigerina* sp., *Biapertorbis swaroopi*, *Turborotalia cerroazulensis*, *Globigerinatheka kugleri*, *Pseudohastigerina micra*, *Acarinina topilensis*, etc. These microfossils suggest a late middle Eocene age equivalent to the tropical zones of Blow (1969, 1979). Biostratigraphically, the Fulra limestone has been considered to correspond to Zone NP17 which correlates with part of both the Zone P13 and Zone P14, Bartonian, the late middle Eocene (Singh, 1980; Rai, 1997).

The samples have been collected from the Harudi-Waior Road Section (Fig.2A) near Harudi village (23°30'30" N: 68°41'10" E) and the Jhadwa Section (Fig.2B) near Jhadwa village (23°30'30" N: 68°36'30" E).

All the thin sections and peelings are preserved at the Algalology Laboratory, Botany Department, University of Lucknow, Lucknow.

SYSTEMATIC DESCRIPTION

Division: Chlorophyta Papenfus, 1946
Class: Chlorophyceae Kützing, 1843
Order: Dasycladales Pascher, 1931
Family: Dasycladaceae Kützing, 1843

Genus *Dissocladella* Pia, 1936

Dissocladella longijangensis Mu and Wang, 1985
(Pl. 1, figs. 1, 2)

Dissocladella longijangensis Mu and Wang, 1985, p. 294-296, pl. 1-3.

Dissocladella longijangensis Kuss and Herbing, 1993, p. 274, pl. 4, figs. 9-12.

Description: Thallus 1.2 mm long, 0.45 mm wide. Width of the cavity 160 μm. Primary laterals are spherical or ovoid and 40-60 μm in length; secondary laterals 30-35 μm in length. The transverse section of the thallus shows central cavity 350 μm in diameter.

Sample no.: Jh/06/3347

Slide no.: Bot/KB- 224

Locality: Jhadwa, SW Kachchh.

Horizon: Fulra limestone.

Remarks: The present specimen is comparable with *Dissocladella longijangensis* Kuss and Herbing in the morphology of primary branches and their arrangement in the central cavity. Kuss and Herbing (1993) reported *Dissocladella longijangensis* from the late Palaeocene of the Eastern Desert, Egypt. Jauhri et al. (2007) also recorded *Dissocladella longijangensis* from the late Palaeocene of the Cauvery Basin, south India.

Division: Rhodophyta Wittstein, 1901
Class: Rhodophyceae Rabenhorst, 1863
Order: Corallinales Silva and Johansen, 1986
Family Sporolithaceae Verheij, 1993

Genus *Sporolithon* Heydrich, 1897

Sporolithon keenani Johnson, 1945
(Pl. 2, figs. 8, 9)

Archaeolithothamium keenani Johnson, J.H., 1945, p. 354, pl. 52, fig. 2.

Description: Growth form encrusting. Thallus organization monomerous, Core filaments non-coaxial, core portion 90-110 μm thick. Cells 15-20 μm in length and 10-14 μm in width. The cells of peripheral filaments 16-20 μm in length and 12-14 μm in width; cell fusions present. Tetrasporangia cylindrical to club shaped, densely arranged in a zone, separated by 1-2 sterile filaments. Sporangia 90-130 μm in length and 40-60 μm in width.

Sample No.: FL/10/3341

Slide No.: Bot./KB- 267

Locality: Near Harudi village, SW Kachchh.

Horizon: Fulra limestone.

Remarks: Following Woelkerling (1988) and Moussavian and Kuss (1990), who established the priority of *Sporolithon* Heydrich (1897) over *Archaeolithothamium* Rothpletz (1891), the present specimen is considered to

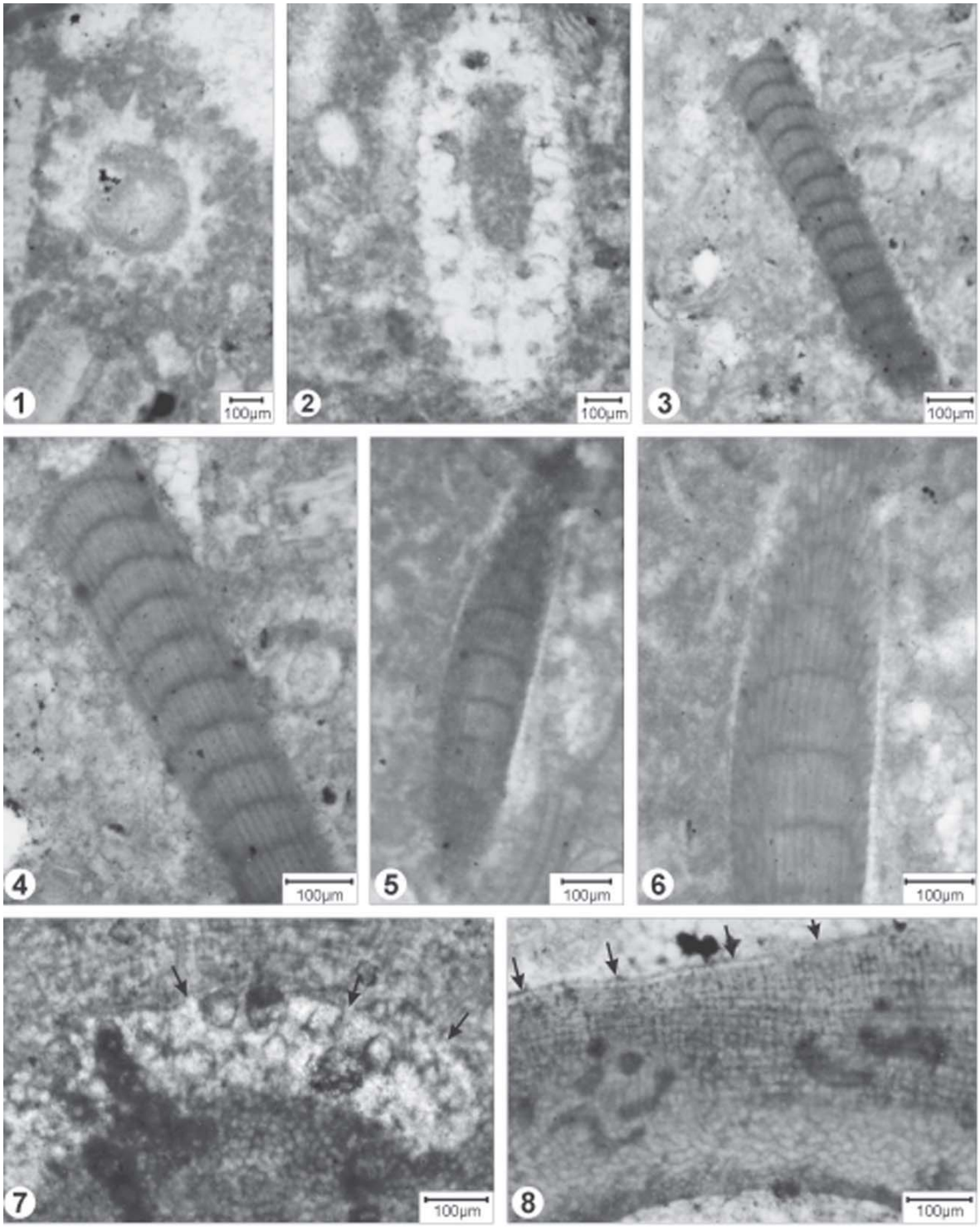

Plate 1. (1) *Dissocladella longijangensis.* **(2)** *Dissocladella longijangensis.* **(3)** *Arthrocardia* sp. Misra et al. 2001. **(4)** *Arthrocardia* sp. Misra et al. 2001. **(5)** *Corallina crossmanni.* **(6)** *Corallina crossmanni.* **(7)** *Lithothamnion ischigakiensis* showing conceptacle. **(8)** *Lithothamnion ischigakiensis* showing Core and peripheral filaments.

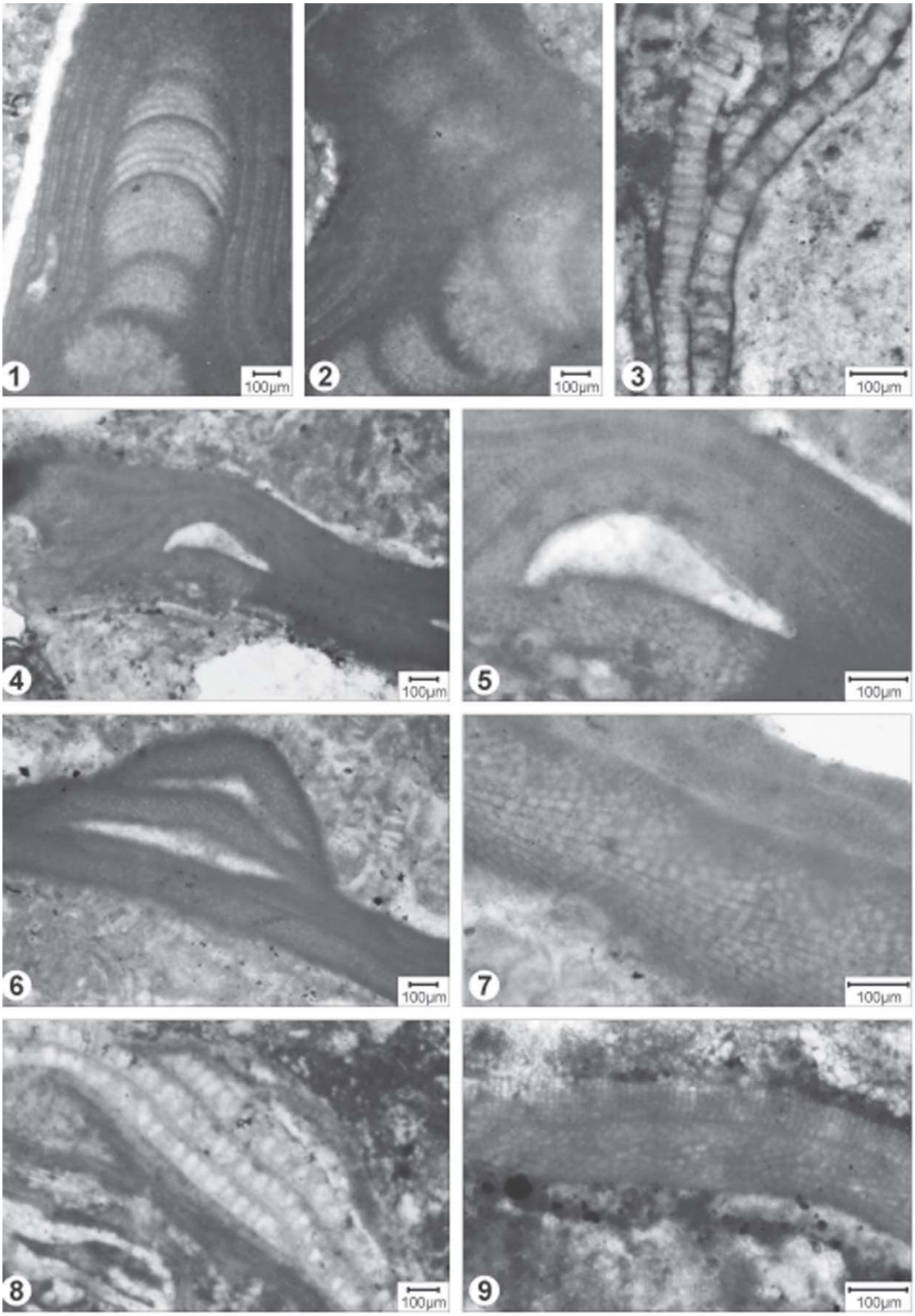

Plate 2. **(1)** *Melobesioideae* gen. et spec. indet 1. **(2)** *Melobesioideae* gen. et spec. indet 1. **(3)** *Lithoporella melobesioides* **(4)** *Melobesioideae* gen. et spec. indet 2. **(5)** *Melobesioideae* gen. et spec. indet 2. **(6)** *Melobesioideae* gen. et spec. indet 2. **(7)** *Melobesioideae* gen. et spec. indet 2. **(8)** *Sporolithon keenani* showing tetra sporangia. **(9)** *Sporolithon keenani* showing non-coaxial core filament.

belong to *Sporolithon* and comparable with *Sporolithon* (*Archaeolithothamium*) *keenani* Johnson in shape and size of sporangia and peripheral cells. Johnson (1945) reported this species from the Eocene of California.

Family: Corallinaceae Lamouroux, 1812
Subfamily: Corallinoideae Gray, 1821

Genus *Corallina crossmanni* Lemoine, 1917
(Pl. 1, figs. 5, 6)

Corallina crossmanni Lemoine, 1917, pp. 265.
Corallina crossmanni Johnson and Ferris, 1949, pp. 197, Pl. 39, fig. 5.

Description: Plant geniculate, fragments of thalli about 1.0 mm in length and mainly 0.28 mm in diameter. Genicula not seen. Intergenicula about 60-90 μm in length and 10-14 μm in diameter, composed of a single tier of elongated cells. The frayed edges have indication of a row of narrow marginal cells. Conceptacles not preserved.

Sample no.: Jh/03/3347
Slide no.: Bot/KB- 223
Locality: Jhadwa, SW Kachchh.
Horizon: Fulra limestone.

Remarks: The present specimen shows similarities with *Corallina crossmanni* in thallus organization and shape of the intergenicula cells of the thallus. It also shows similarity in growth morphology of intergenicula and narrow marginal cells of intergenicula. Johnson and Ferris (1949) reported this species from the Eocene of East Borneo, East Indies.

Genus Arthrocardia (Harvey) Areschoug, 1852
Arthrocardia sp. Misra et al., 2001
(Pl. 1, figs. 3, 4)

Arthrocardia sp. Misra et al. 2001, pp. 73, pl. 1, fig. 3.

Description: Thallus segmented, with nodes between the segments. Thallus length up to 0.8 mm and width up to 150 μm. Segments have straight medullary filaments comprising equal cells. Cells 80-90 μm in length and 10-15 μm in diameter. Cortical tissues not preserved. Conceptacles not found.

Sample no.: Jh/10/3347
Slide no.: Bot/KB- 245
Locality: Jhadwa, SW Kachchh.
Horizon: Fulra limestone.

Remarks: The present specimen shows similarity with *Arthrocardia* sp. Misra et al. 2001 in general morphology, shape, size of medullary cells. Misra et al. (2001) reported this species from the Oligocene of Kachchh.

Subfamily Mastophoroideae Setchell, 1943

Genus *Lithoporella* (Foslie) Foslie, 1909
Lithoporella melobesioides (Foslie) Foslie, 1909
(Pl. 2, fig. 3)

Lithoporella melobesioides (Foslie) Johnson and Ferris, 1950, p. 18-19, pl. 8. fig. A.
Lithoporella melobesioides (Foslie) Foslie; Bosence, 1983, p. 165-166, pl. 18, fig. 2.
Lithoporella melobesioides (Foslie) Foslie, Bassi, 1998, p.19 pl. 7, figs. 4-6.

Description: Growth form encrusting, thallus either single or multiple (overgrowth), often encrusting on other coralline algae and skeletal material. Primigenous filaments show cell fusions. Cell length 40-55 μm, cell diameter 20-28 μm. Epithallial cells and Tetra/biosporangial conceptales not preserved.

Sample No.: FL/12/3341
Slide No.: Bot./KB- 267
Locality: Near Harudi village, SW Kachchh.
Horizon: Fulra limestone.

Remarks: The thallus morphology, cell dimensions of primigenous filaments and shape and size of conceptacles indicate affinity of the present specimen with *Lithoporella melobesioides* (Foslie). It has been reported by Bassi (1998) from the late Eocene of Northern Italy, by Rasser and Piller (1999) from the late Eocene of Austrian Molasse zone and Kishore et al. (2007) from the Prang Formation (middle Eocene) of the Jaintia hills, Meghalaya.

Family: Hapalidiaceae, Grey, 1864
Subfamily: Melobesioideae Bizzozero, 1885

Genus *Lithothamnion* Heydrich,1897
Lithothamnion ishigakiensis Johnson, 1962
(Pl. 1, figs. 7, 8)

Lithothamnion ishigakiensis Johnson, 1962, pp. 62, pl. 13, fig. 2.

Description: Growth form encrusting. Thallus organization monomerous. Core filament non-coaxial, core portion usually 110-140 μm thick, cell fusions present. Cells 10-14 μm in length and 10-12 μm in width. Peripheral cells 14-22 μm in length and 12-14 μm in width. Epithallial cells are flared in shape. Conceptacles 650-850 μm wide, 80-140 μm high.

Sample no.: Jh/09/3347
Slide no.: Bot/KB- 169
Locality: Jhadwa, SW Kachchh.
Horizon: Fulra limestone.

Remarks: The noncoaxial core filament, multiporate conceptacles, cell fusions and flared shape of the epithallial cells (pl. 1, fig. 8) allow to identify the present specimen as genus *Lithothamnion*. These specimens are comparable with *Lithothamnion ishigakiensis* Johnson 1962 in multioporate conceptaceles and shape and size of core and cells of peripheral filaments, but they differ in having flared epithallial cells. Johnson (1962) reported this species from the Eocene of Ishigaki.

Melobesioideae gen. et spec. indet 1
(Pl. 2; figs. 1, 2)

Description: Growth form encrusting to fruticose, diameter of protuberances 0.8-1.1 mm, length up to 2.5-3.2 mm. Thallus organisation monomerous. Core filaments with arched growth zones, with cell fusions. Cell length 20-30 μm, cell diameter 15-20 μm. The marginal peripheral filaments present, about from 320 μm wide, with cells 15-20 μm long, 12-16 μm in diameter.

Sample no.: Jh/13/3347

Slide no.: Bot/KB- 248

Locality: Jhadwa, SW Kachchh.

Horizon: Fulra limestone.

Remarks: Though the present specimens are similar to the forms described by the Beckmann (1982) as *Lithophyllum sierraeblancae* Howe from the Palaeocene of Monte Giglio, Italy in thallus organisation and morphology; our specimens, however, lack conceptacles. As a result, the exact generic identification of the present specimens cannot be made here. The presence of cell fusions in the core filaments (Pl. 2; figs. 1, 2) of thallus indicates its relationship with subfamily Melobesioideae.

Melobesioideae gen. et spec. indet 2
(Pl. 2; figs. 4-7)

Description: Growth form encrusting with a thallus thickness of usually 350-450 μm. Thallus organisation monomerous. Core filaments noncoaxial, core portion usually 110 μm thick. Cell fusions present. Cell length 25-30 μm, cell diameter 15-20 μm. The peripheral region with cell length 20-25 μm, diameter 14-18 μm. Subepithallial initials and epithallial cells not preserved.

Sample no.: Jh/10, 11/3347

Slide no.: Bot/KB-173, 246

Locality: Jhadwa, SW Kachchh.

Horizon: Fulra limestone.

Remarks. Present specimen lack conceptacles, hence, generic identification of this specimen cannot be established here. The presence of cell fusions in the core filaments suggests its relationship with subfamily Melobesioideae.

DISCUSSION

This paper examines the present taxonomic data of the calcareous algae from the Fulra limestone along with four taxa earlier recorded by Misra et al. (2006). The present and previous records together include twelve taxa of calcareous algae which support previous interpretations made in the earlier study. The algal taxa include *Dissocladella longijangensis*, *Sporolithon keenani*, *Sporolithon* sp. 1 Bassi, 1998, *Mesophyllum* sp., *Corallina crossmanni*, *Arthrocardia* sp. Misra et al. 2001, *Lithothamnion ishigakiensis*, *Melobesioideae* gen. et spec. indet., *Melobesioideae* gen. et spec. indet. 1, *Melobesioideae* gen. et spec. indet. 2, *Lithoporella melobesioides* and *Phymatolithon* sp.

This algal association comprises two major groups (Hapladiaceae and Corallinaceae) and two minor groups (Sporolithaceae, and Dasycladaceae). The composition of various types of calcareous algae and diversity of larger foraminifera along with the algal growth-form morphology change with changing environmental conditions and can be a good measure of reconstructing palaeoenvironmental conditions. The occurrence together of *Corallina*, *Arthrocardia*, *Lithoporella*, *Sporolithon*, *Lithothamnion* and foraminifera, e.g. *Nummulites*, etc. indicates shallower to relatively deeper inner- to mid-ramp environment. Using ecological data on larger (eg. *Nummulites*, *Discocyclina*, etc) and smaller benthics (e.g. rotaliids, cibicidids, *Asterigerina*, etc), Misra et al. (2006) interpreted environment of deposition as corresponding to the upper photic zone of sea ranging from 40 to 80m, i.e. deeper ramp environment characterized by dominance of Biofacies 7 of Buxton and Pedley (1989). As indicated earlier, the calcareous algae locally colonize such environments and form small bioherms and biostromes. Though geniculate coralline forms (*Corallina*, *Arthrocardia*), *Sporolithon* and dasyclads occur in tropical to temperate waters at shallow depths (less than 10m) in the inner-ramp environment (Cloud, 1952; Johnson, 1957; Wray, 1977), they constitute only a minor component of the present assemblage. Among the major groups, Hapalidiaceae are dominant and they are relatively deeper-water forms and colonize low-energy shelf environments in tropical and subtropical areas. According to Ladd (1961), Braga and Aguirre (2001) and Lund et al. (2000), Hapalidiaceae with *Sporolithon* are dominant in the deeper environment. The presence of genera *Phymatolithon*, *Lithothamnion* and *Mesophyllum* and their growth-form morphologies indicate low-energy conditions at depths of more than 50 m (Adey, 1979; Kishore et al. 2006). Their ecological data support the earlier interpretation of deeper

inner- to mid-ramp environment ranging from 40-80m depths in the upper photic zone (Misra et al. 2006). Similar association has been recorded by Pomar et al. (2004) in the slope and outer ramp with subordinate *Sporolithon* and *Lithoporella* thalli.

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