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Coralline Algae from the Aramda Reef Member of the Chaya Formation, Mithapur, Gujarat

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Abstract: The Quaternary sediments of the Aramda Reef Member of the Chaya Formation exposed in the Mojap coast near Mithapur, Gujarat are characterized by well-developed coralline algal build-ups. These algal build-ups are exceptionally rich in coralline algae and corals. In the present paper, thirteen species belonging to eight genera of coralline algae are described. Out of these, seven species (*Titanoderma nataliae, Lithophyllum nitorum, Lithophyllum quadratum, Spongites* sp. Brandano et al., 2005, *Sporolithon lvovicum, Mesophyllum fructiferum* and *Lithothamnion praefruticulosum*) are the new records for India. Four species (*Titanoderma pustulatum, Sporolithon intermedium, Mesophyllum commune* and *Phymatolithon* sp.) are first time recorded from the study area. Among the major framework builders of coralline algae of the Aramda Reef Member are *Lithophyllum, Titanoderma, Sporolithon*, *Mesophyllum* and *Lithothamnion*.

Two associations of the coralline algal assemblages can be distinguished: one indicating shallow water, high-energy conditions is developed in the upper part, while the other suggesting deposition in low-energy conditions is characteristic of the lower part of the succession. These algal associations, together with their growth-forms (encrusting, warty to fruticose, layered) come from stratigraphically separate beds. They indicate that the temperature, depth and hydrodynamic energy conditions also fluctuated during deposition of the Aramda Reef Member. It is concluded that the lower Hapalidiaceae-Sporolithaceae association dominated during warmer interval, whereas the upper lithophylloids association flourished in relatively low-temperature conditions. The associated corals indicate that minimum winter sea surface temperature remained above 18°-20° C.

Keywords: Coralline algae, Aramda Reef Member, Chaya Formation, Mojap, Gujarat.

INTRODUCTION

The Neogene-Quaternary sediments have been studied in the study area for sea-level and palaeoclimate changes (Mathur et al. 1988, Pant and Juyal, 1993, Jain, 1997; Bhatt, 2000; Pandey et al. 2003). Associated fossil groups such as corals have been examined for taxonomic composition (Pandey and Singh, 2010). However, coralline algae, despite the fact that they are important constituents of the Armada Reef Member of the Chaya Formation (late Pleistocene), have remained unstudied. Though the main organism of reef-building activity is coral, coralline algae are also a major contributor to the formation of coral reef; in some cases, they comprise almost the whole of the biomass of the reef framework. It may be mentioned here that the structural complexity of coral reef supports high marine biodiversity and also protects shoreline as they act as natural barriers to waves and currents.

Coralline algae are sensitive to light intensity, temperature, water energy, depth, etc. and are distributed according to changing conditions of these factors. The well-developed algal build-ups of the Quaternary sediments of the Chaya Formation provide an opportunity to study coralline taxa, their growth forms and their palaeo-environmental significance. The nomenclature and systematics of the fossil coralline red algae have undergone major changes in recent years as a consequence of studies involving living coralline algae. Consequently, 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. Harvey et al. (2003), Bassi et al. (2007) and Iryu et al. (2009) have developed the taxonomic criteria currently applicable in studies on fossil algae.

Previous records of algae by Mathur et al. (1988), Kundal

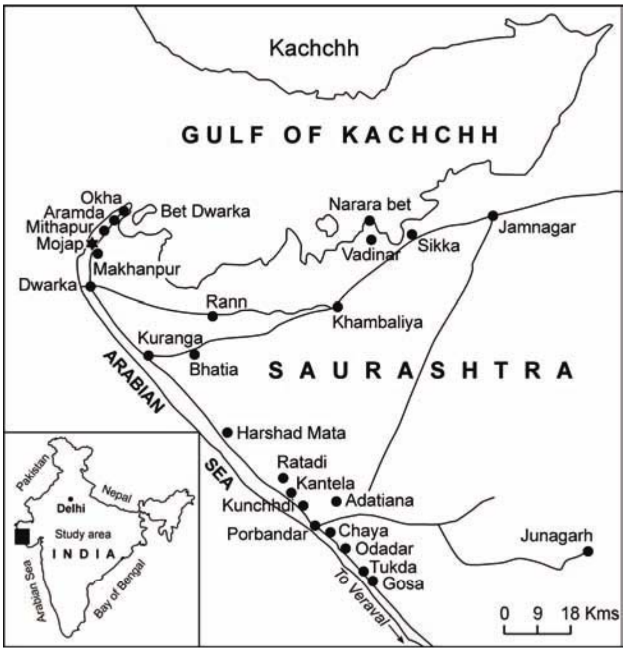

Fig.1. Location map of the study area (*) (Pandey et al. 2007).

and Dharashivkar (2003a, b, 2005), Pandey et al. (2007) and Kundal and Mude (2009, 2010) indicate the scope of study of coralline algae in the coral reef of the study area. They described geniculate and non-geniculate coralline algae from the Neogene to Quaternary sediments of the Okha, Dwarka and Porbandar areas. The principal aim of the present paper is to provide basic morphotaxonomic data along with their growth-forms, and to present their palaeoenvironmental interpretations. This study also includes observations on ultrastructural (SEM) morphological features (such as cell fusions, pit connections, epithallial cells, etc.) of *Sporolithon*, *Lithophyllum* and *Phymatolithon*. In the present work, we have followed the recently changed taxonomic criteria given by Iryu et al. (2009) and Singh et al. (2010) for the classification of Corallinales taxa. The present taxonomic investigation is based on the material from the Aramda Reef Member exposed near Mojap (Fig. 1). The radiocarbon dating of the samples of this coralline algal-yielding member suggests late Pleistocene age (27160±610 yrs BC). Coral-algae reef is locally well exposed during low tide along the coast of Mojap (N 22°22'030": E 068°57'446").

GENERAL GEOLOGY AND STRATIGRAPHY

The Saurashtra Basin is a pericratonic basin along the northwestern coast of India. It is bounded by the Kachchh Basin to the north, the Cambay Basin to the east and the Surat depression to the south and lies within 69° and 72° Latitude East. The basin continues into the offshore as its western extension. Structurally, a horst block, the basin witnessed sedimentation during the Lower Cretaceous followed by Deccan volcanic activity in the Upper Cretaceous and marine deposition during the Neogene and the Quaternary (Biswas and Deshpande, 1983; Merh, 1995; Pandey et al. 2008). The basin is largely covered by the Deccan Traps which are underlain by the Lower Cretaceous sediments of the Dharangdhara Formation and overlain by the the Neogene-Quaternary sequence.

The Neogene-Quaternary sediments have been subdivided (in ascending order) into the Gaj, Dwarka, Miliolite, Chaya, Katpur and Mahuva formations. Pandey et al. (2007) gave a detailed stratigraphic account of the Chaya Formation. Accordingly, the Chaya Formation is subdivided into the Okha Shell Limestone, the Armada Reef Member and the Porbander Calcarenite Member (Table 1).

The Okha shell Limestone, exposed near Mojap coast, consists of cross-bedded, bioturbated packstones. The dominant fossils belong to colonial scleractinian corals, large turbinellid gastropods and large venerid bivalves.

The Aramda Reef Member, exposed in vicinity of Mojap coast, is a reefal unit mainly consisting of coral-algal skeletal material. It directly overlies the Okha shell material. It comprises corals, coralline algae, turbinate gastropods, bivalves, benthic foraminifera. Among the corals, *Porites* and *Acropora* are predominant. The dominant representatives of coralline algae belong to lithophylloids,

Table 1. Lithostratigraphy of the Chaya Formation of Saurastra (modified after Pandey et al. 2007)

Stratigraphic unit			Lithology	Age
Group	Formation	Member		
Porbandar Group	Chaya Formation	Porbandar Calcarenite Member	Semi consolidated to consolidated calcarenite with megafossils (pack to grainstone/rudstone)	Late Pleistocene to Late Holocene
		Aramda Reef Member	Coral-algal reef, coral bafflestone and algal rudstone with micro and mega-fossils	
		Okha Shell Limestone Member	Cross-bedded pack to rudstone, bioturbated shell limestone with mega-fossils	

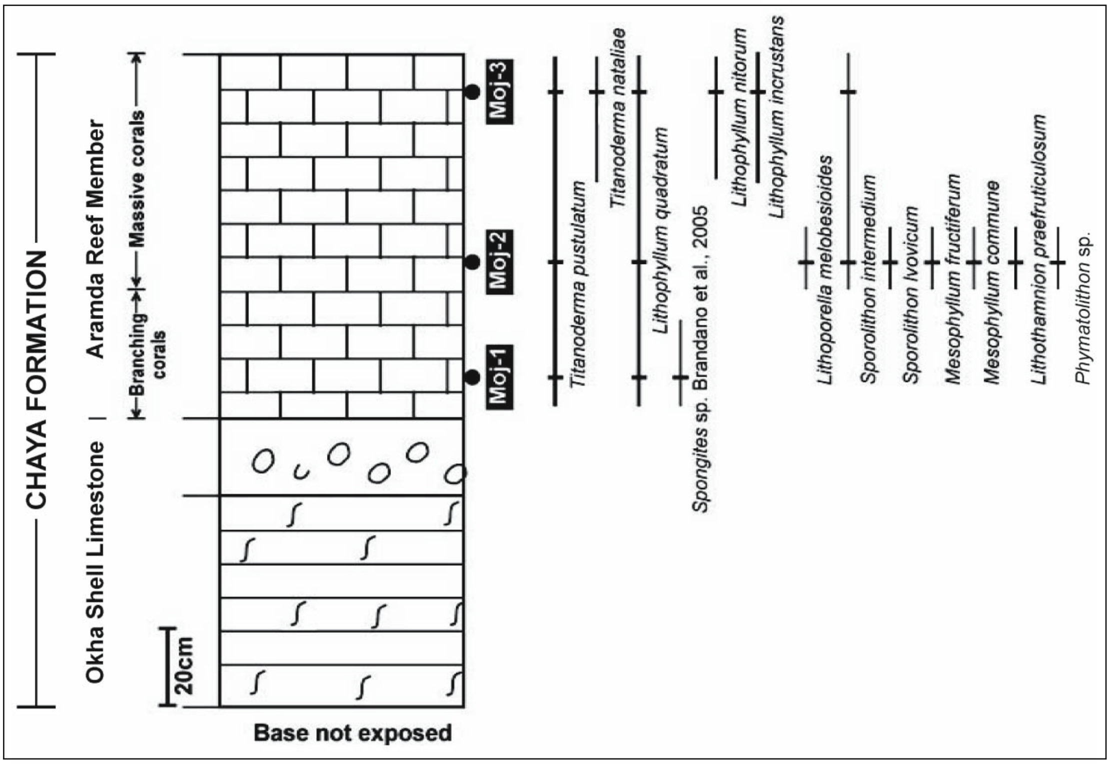

Fig.2. Litholog of the study area (Mojap Coast).

melobesioids, mastophoroids and subordinate sporolithaceans.

The Porbandar Calcarenite Member is exposed about 6.5 km south of Porbandar on the Porbandar-Somnath Highway and also exposed in the Makanpur area. It is a calcarenite facies represented by packstones-grainstones/rudstones and contains megafossils, such as gastropods, echinoderm spines, etc., and microfossils, e.g. foraminifera (rotaliids, miliolids, etc) and articulated algae (*Amphiroa*).

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

SYSTEMATIC DESCRIPTION

Division Rhodophyta Wettstein, 1901
Class Rhodophyceae Rabenhorst, 1863
Order Corallinales Silva and Johansen, 1986
Family Corallinaceae Lamouroux, 1812
Subfaimly Lithophylloideae (Setchell) Bailey, 1999

Genus *Titanoderma* Näegeli, 1858
Titanoderma pustulatum (Lamouroux) Näegeli, 1858
(Pl. 1, figs. 1-3)
Titanoderma pustulatum Näegeli, 1858, p. 624.

Description: Growth form encrusting. Thallus dimerous. Primigenous filaments composed of palisade cells (10-15 μm in length). The diameter of these cells are variable from 28 to 60 μm.

Cells of postigenous filaments are rectangular in shape, measuring 6-14 μm in diameter. Their length frequently changes due to substrate irregularities, as does cell height of primigenous filaments (from 14 to 40 μm). Postigenous filaments consist of up to six or more cells with well-defined vertical and horizontal cell alignments. Cell fusions absent. No epithallial cells have been recognized in the studied samples.

Tetra/bisporangial conceptacles are uniporate, hemispherical-conical in shape with cylindrical pore canal, measuring 192-340 μm in diameter and 80-150 μm in height. No columella remains have been found in any sample.

Sample No.: Moj-1, 2, 3 (Aramda Reef Member, Chaya Formation)

Slide No.: B-1, M-2, T-8, 17

Remarks: The taxonomic status of *Titanoderma* has been controversial for about 80 years. *Titanoderma* was distinguished from *Lithophyllum* on the basis of a single feature, i.e. size and shape of cells comprising basal (i.e. primigenous) filaments (Campbell and Woelkerling, 1990). The molecular results of Bailey (1999) also indicate that *Titanoderma* and *Lithophyllum* are the phylogenetically distinct genera and should be treated as separately. The

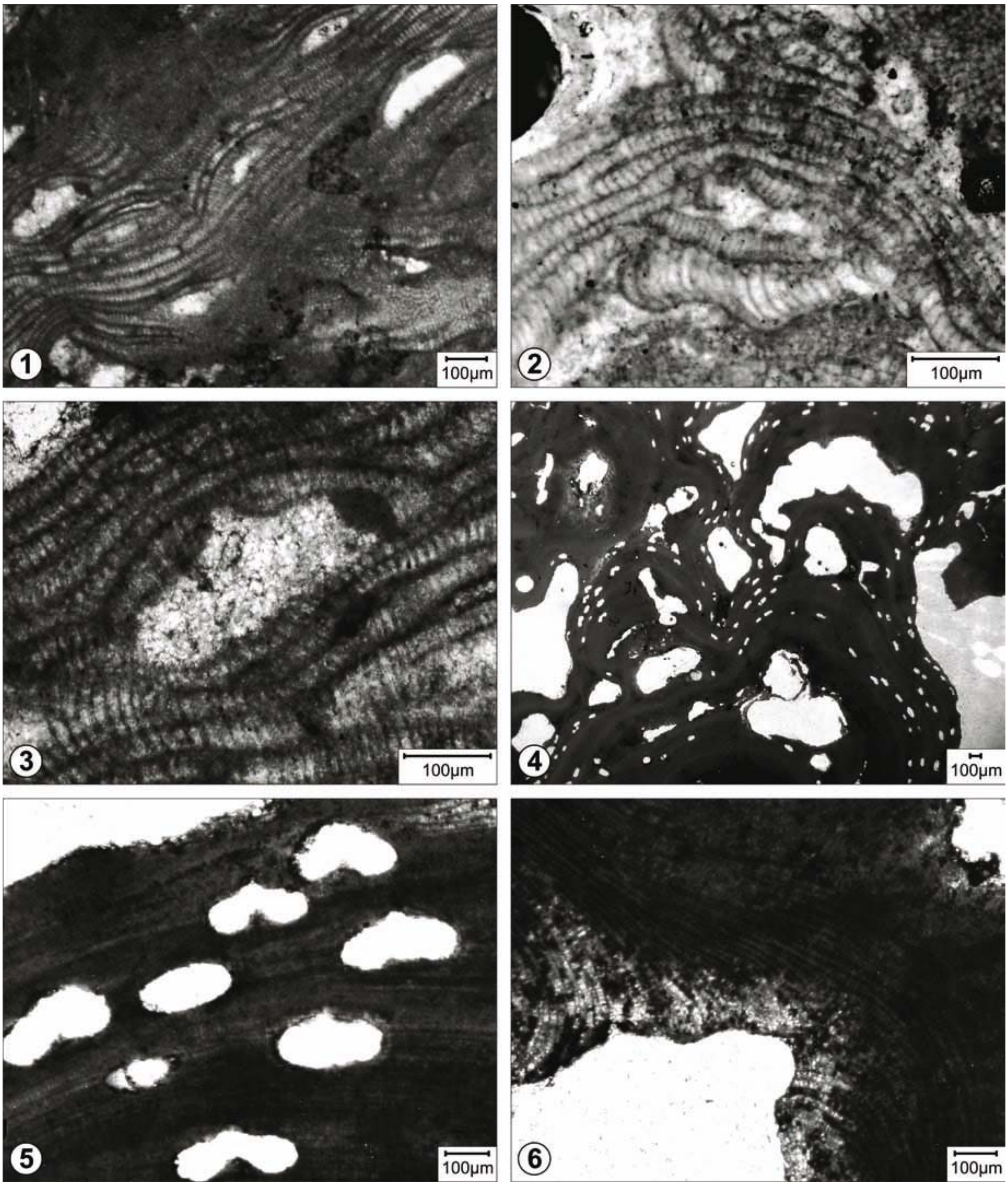

Plate 1. Figs.1-3. *Titanoderma pustulatum*. **(1)** Showing postigenous filaments and conceptacles. **(2)** Showing postigenous and primigenous filaments (palisade cells). **(3)** Showing uniporate conceptacles. **Figs.4-6.** *Lithophyllum incrustans*. **(4)** Showing fruticose growth-form. **(5)** Showing uniporate conceptacle. **(6)** Showing postigenous and primigenous filaments.

present specimen is identified as *T. pustulatum* on the basis of its characteristic palisade cells of the primigenous filaments. *T. pustulatum* occurs as dominant species and is present in all samples from base to top of the Armada Reef Member. *T. pustulatum* is known from the Pleistocene deposits of southern Italy (Nalin et al. 2006).

Titanoderma nataliae (Maslov) Studencki, 1988
(Pl. 3, figs. 1, 2)

Titanoderma nataliae Studencki, 1988, p. 46.

Titanoderma nataliae Studencki: Pisera and Studencki, 1989, pl. 12, figs. 1-2, p. 202.

Description: Growth form encrusting. Thallus dimerous.

Primigenous filaments are composed of palisade cells, which are 10-15 µm in length. The diameter of these cells is very variable, 20-35 µm.

Cells of postigenous filaments are rectangular in shape, measuring 15-20 µm in diameter. Their length frequently changes due to substrate irregularities, cell height 25-30µm. Cell fusions absent. No epithallial cells have been recognized in the studied samples.

Tetra/bisporangial conceptacles are uniporate, conical in shape, pore canal not clear, measuring 250-270 µm in diameter and 100-120 µm in height. No columella remains have been found in any samples.

Sample No.: Moj-1 (Aramda Reef Member, Chaya Formation)

Slide No.: T-3

Remarks: The present specimen is identified as *T. nataliae* on the basis of its characteristic shape and size, palisade cells and conceptacles as described by Pisera and Studencki (1989) from the middle Miocene of Poland. Thalli of *T. nataliae* grow as epiphyte on other coralline algae and have common, raised but well-sheltered conceptacles. This species is also known from the Miocene of the Ukraine. *Titanoderma nataliae* differs from *Titanoderma pustulatum* in shape and size of uinporate conceptacles.

Genus *Lithophyllum* Phillippi, 1837

Lithophyllum incrustans Philippi, 1837
(Pl. 1, figs. 4-6; Pl. 4, fig. 3)

Lithophyllum incrustans Philippi, 1837, p. 388.

Lithophyllum incrustans Philippi: Braga and Aguirre, 1995, p. 273, pl. 1, fig. 6.

Description: Growth forms encrusting, warty to fruticose. Thallus dimerous. Cells of the primigenous filaments are 8-12 µm in diameter and 10-14 µm in length.

Postigenous filaments are well-developed; cell fusions are absent (Pl. 4, fig. 3). Cells are 12-24 µm long and 6-10 µm in diameter. Epithallial cells not observed.

Tetra/bisporangial conceptacles are recognizable by the remains of distinct columella. They are sunken, bean-shaped in section and uniporate with cylindrical pore canal. Conceptacle size ranges from 180 to 240 µm in diameter and from 75 to 110 µm in height.

Sample No.: Moj-3(Aramda Reef Member, Chaya Formation)

Slide No.: T-9

Remarks: The present specimen is identified on the basis of its growth-form and shape and size of the conceptacles. Braga and Aguirre (1995) reported this species from the Neogene of southern Spain.

Lithophyllum nitorum Adey and Adey, 1973
(Pl. 2, figs. 1, 2; Pl. 4, figs.1, 2)

Lithophyllum nitorum Adey and Adey, 1973, p. 386.

Lithophyllum nitorum Adey and Adey: Braga and Aguirre, 1995, p. 277, pl. 2, figs. 5-6.

Description: Growth form encrusting. Thallus dimerous. Primigenous filaments are formed by rectangular cells, which are usually 8-15 µm in length and 10-20 µm in diameter.

Postigenous filaments are conspicuous and well developed. There is clear lateral alignment of cells of adjacent filaments, thallus has a net-like appearance. Cells of the postigenous filaments are quadrangular in shape and measure 6-22 µm in length and 6-22 µm in diameter. Cell fusions are absent (Pl. 4, fig. 2). Epithallial cells not seen.

Tetra/bisporangial conceptacles are uniporate; pore canals, tapering to the conceptacle roof; some with a raised floor which can be interpreted as the remnants of a columella (Pl. 4, fig.1). They measure 216-396 µm in diameter and 84-168 µm in height.

Sample No.: Moj-3 (Aramda Reef Member, Chaya Formation)

Slide No.: T-14

Remarks: The present specimen shows similarity with *Lithophyllum nitorum* Braga and Aguirre in shape, size of primigenous, postigenous filaments and shape and size of Tetra/bisporangial conceptacles. Braga and Aguirre (1995) reported this species from the Neogene of southern Spain.

Lithophyllum quadratum Ishijima, 1954
(Pl. 2, figs. 3-6; Pl. 4, fig. 4)

Lithophyllum quadratum Ishijima, 1954, p. 37-38, pl. 22, fig. 5a-b, pl. 23, figs. 1-4.

Lithophyllum quadratum Ishijima: Iryu et al., 2009, p. 404, pl. 1, figs. 1-3.

Description: Growth form encrusting to warty. Thallus organization dimerous. Primigenous filaments formed by square to rectangular cells, which are usually 8-15 µm in length and 10-20 µm in diameter.

Postigenous filaments are well developed. Well defined cell walls separate adjacent filaments; only secondary pit-connections are present (Pl. 4, fig. 4). Cells of the postigenous filaments rectangular in shape and measure 6-22 µm in length and 6-22 µm in diameter. Epithallial cells not observed.

Male and tetra/biosporangial conceptacles usually occur in separate plants. Spermatangial conceptacles (Male

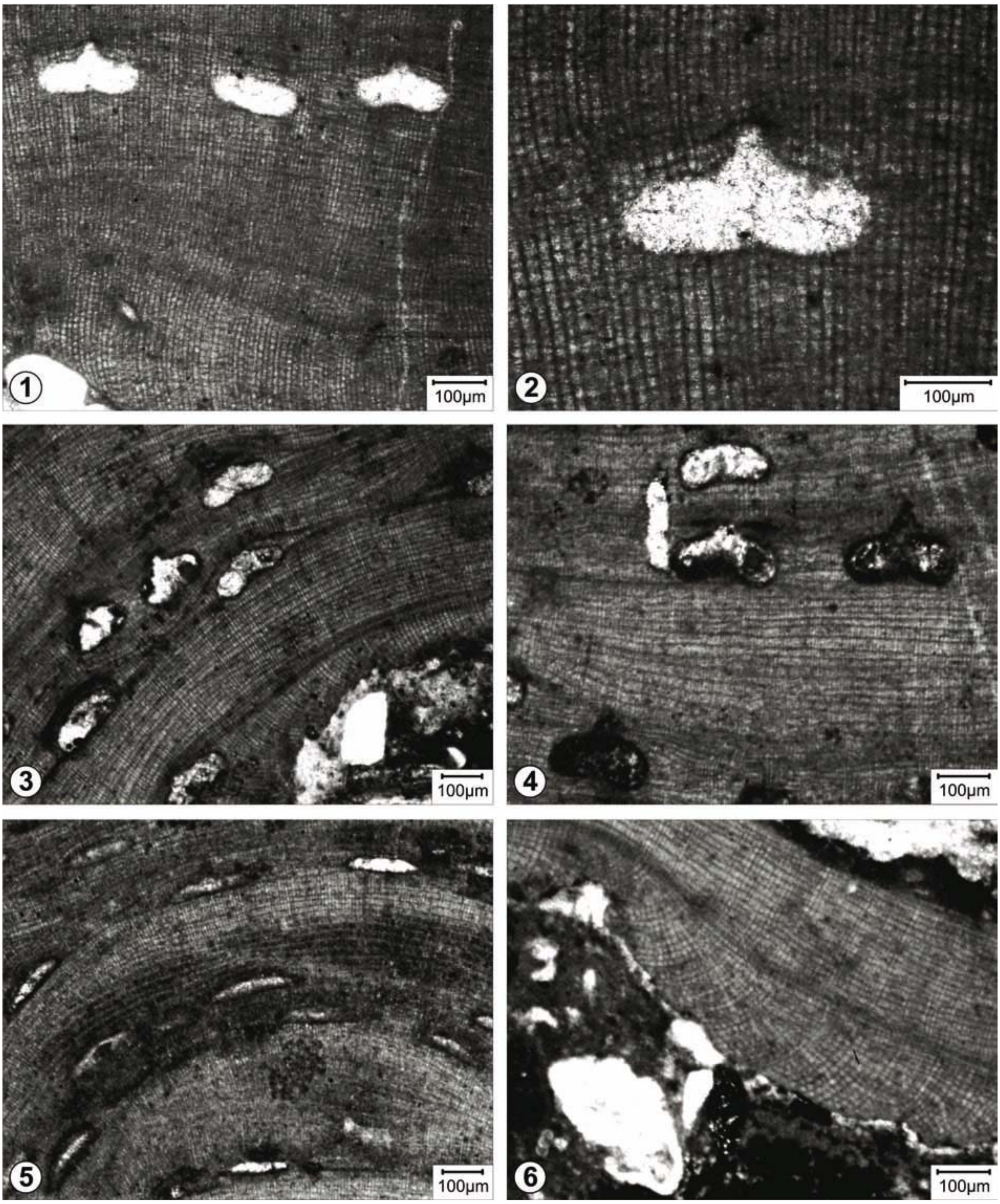

Plate 2. Figs.1-2. *Lithophyllum nitorum*. **(1)** Showing uniporate conceptacle and postigenous and primigenous filaments. **(2)** Showing enlarged view of unioprate conceptacle. **Figs.3-6.** *Lithophyllum quadratum* **(3-4)** Showing Tetra/biosporangial conceptacles with postigenous and primigenous filaments. **(5)** Showing Spermatangial conceptacles (Male conceptacles). **(6)** Showing dimerous organization.

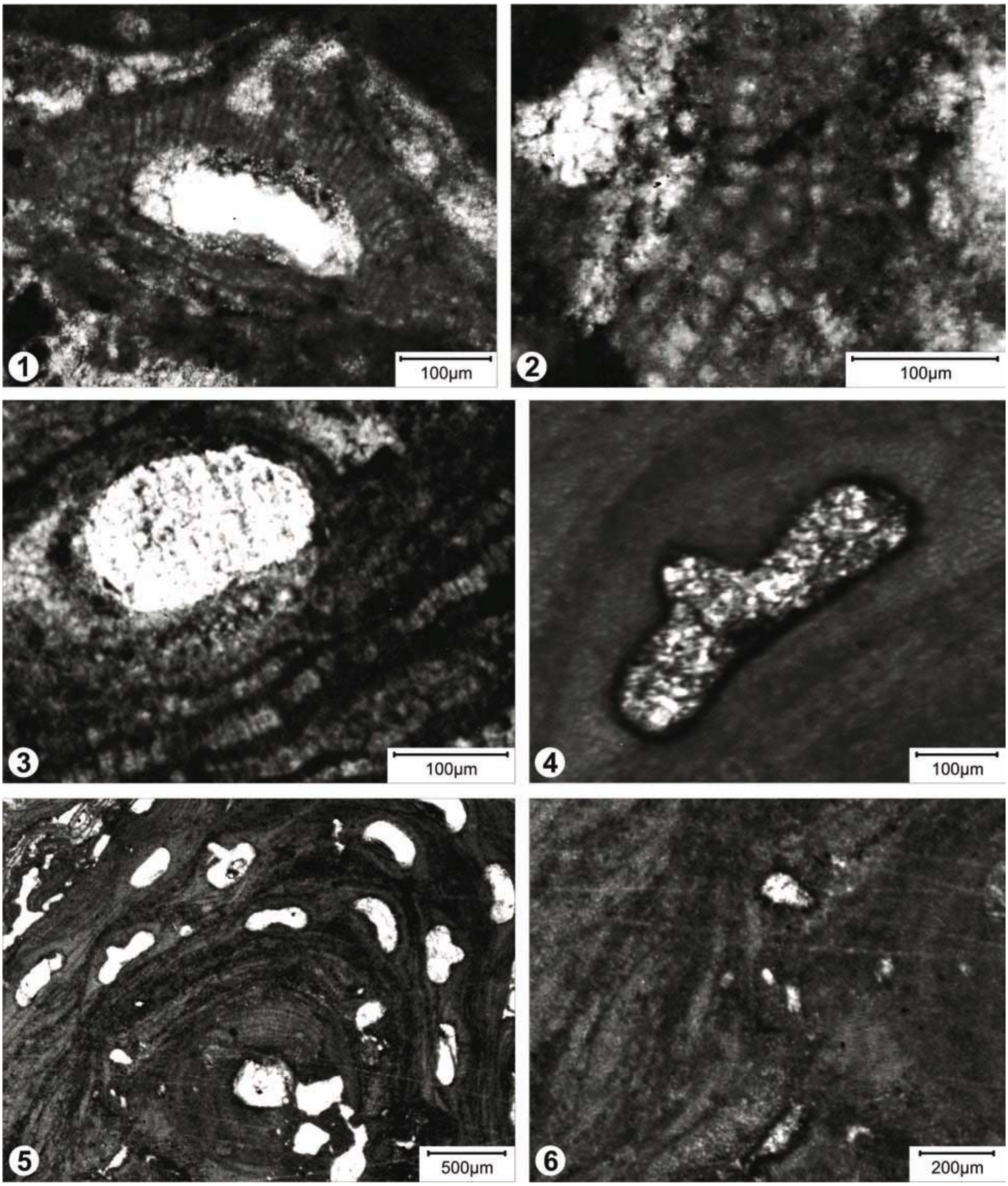

Plate 3. Figs.1-2. *Titanoderma nataliae*. **(1)** Showing postigenous filaments and uniporate conceptacles. **(2)** Showing primigenous filaments. **Fig.3.** *Lithoporella melobesioides*: Showing primigenous filaments and conceptacles. **Figs.4-6.** *Spongites* sp. (after Brandano et al. 2005). **(4)** Showing enlarged view of uniporate conceptacle. **(5)** Thallus with numerous uniporate conceptacles. **(6)** Showing non-coxial core filaments.

conceptacles) are sunken, triangular in section, and small, 72-108µm in diameter and 24-30µm in height (Pl. 2, fig. 5).

Tetra/biosporangial conceptacles (Pl. 2, figs, 3-4) are recognizable by the remains of a columella (columella present above conceptacle floor), a prominent rise of the conceptacle bottom at its center. Tetra/bisporangial conceptacles uniporate, pore canal conical in shape (with a base 30-40µm in diameter and 60-80µm in length) and is lined by filaments parallel to it. They measure 216-396 µm in diameter and 84-168 µm in height.

Sample No.: Moj-1, 2, 3 (Aramda Reef Member, Chaya Formation)

Slide No.: B-1, M-2, T-13, 7

Remarks: The present specimen is comparable with *Lithophyllum quadratum* Iryu et al. (2009) on the basis of morphology, cell dimensions of primigenous and postigenous filaments of the thallus. Besides these characters, tetra/biosporangial conceptacles also show similarity in shape, size and their arrangement in the thallus. Ishijima (1954) reported *Lithophyllum quadratum* from the Pleistocene of Taiwan.

Subfamily Mastophoroideae Setchell, 1943

Genus *Spongites* Kützing, 1841
Spongites sp. Brandano et al., 2005
(Pl. 3, figs. 4-6)

Spongites sp. Brandano et al., 2005, p. 316, fig. 9.

Description: Growth form encrusting to warty. Thallus organisation monomerous with non-coaxial core filaments. Cells of core filaments are 20-30 µm in length and 12-20 µm in width.

Postigenous filaments well developed. Cells of the filaments are not clearly distinct, hence cell fusions are not observed. Cells are 18-28 µm in length and 12-18 µm in width. Epithallial cells not observed.

Tetra/bisporangial conceptacles are recognizable by the remains of distinct columella. They are numerous, sunken, bean-shaped in section and uniporate with cylindrical pore canal. Pore canal 101-105 µm long and 33-37 µm in diameter, lined by numerous small cells arranged in 10-11 filaments subparellel to the roof surface. The conceptacles buried within the thallus. Conceptacle size ranges from 200 to 260 µm in diameter and from 80 to 140 µm in height.

Sample No.: Moj-1 (Aramda Reef Member, Chaya Formation)

Slide No.: B-1

Remarks: The non-coaxial core filaments and uniporate conceptacles suggest inclusion of the present specimen in *Spongites*. It is comparable with *Spongites* sp. Brandano et al. (2005) on the basis of shape and size of conceptacles and their arrangement in the peripheral filaments. Brandano et al. (2005) reported *Spongites* sp. from the lower Tortonian carbonate ramp of Menorca (Spain).

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

Lithoporella melobesioides Foslie: Johnson and Ferris, 1950, p. 18-19, pl. 8. fig. A.

Lithoporella melobesioides Foslie: Bosence, 1983, p. 165-166, pl. 18, fig. 2.

Lithoporella melobesioides Foslie: Bassi, 1998, p. 19, pl. 7, figs. 4-6.

Description: Growth form encrusting, thallus showing multiple growth, often encrusting on other coralline algae and skeletal material. Thallus organization dimerous. Primigenous filaments show cell fusions. Cell length 35-40 µm, cell diameter 18-22 µm. Postigenous filaments not preserved.

Tetra/biosporangial conceptales completely raised above the thallus surface. Conceptacle pores indistinct, conceptacle height 160-180 µm, diameter 340-360 µm.

Sample No.: Moj-2 (Aramda Reef Member, Chaya Formation)

Slide No.: M-2

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) Foslie reported by Bassi (1998) from the late Eocene of Northern Italy and by Rasser and Piller (1999) from the late Eocene of Austrian Molasse zone. Kishore et al. (2007) reported it from the Eocene of the Prang Formation, Meghalaya and Singh et al. (2009) reported this form from the Oligocene of Kachchh, India.

Family Sporolithaceae Verheij, 1993

Genus *Sporolithon* Heydrich, 1897
Sporolithon lvovicum (Maslov) Pisera, 1985
(Pl. 5, figs. 1, 2, 5-7)

Archaeolithothamnium lvovicum Pisera, 1985, p. 9, pl. 1, figs. 5-6.

Archaeolithothamnium lvovicum Pisera: Pisera and Studencki, 1989, p. 193, pl. 5, figs. 1a-1b.

Description: Growth form encrusting to warty, thickness of encrusting thalli up to 1.5 mm. Thallus organization monomerous. Core filaments non-coaxial, core portion 250 µm thick. Cells 20-28 µm in length and 08-10 µm in width, cell fusions present.

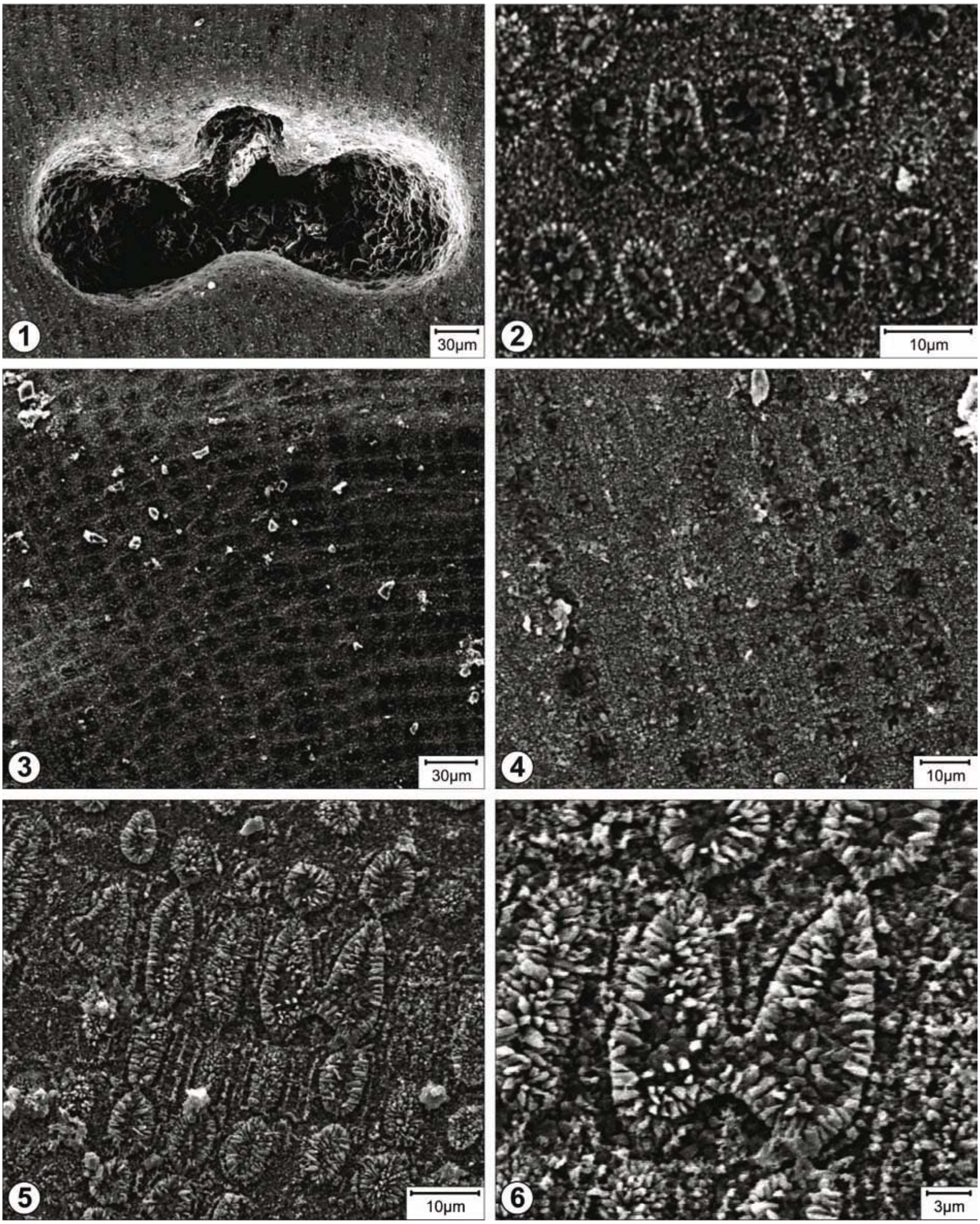

Plate 4. (1) SEM of *Lithophyllum nitorum*: showing uniporate conceptacle with columella. **(2)** SEM of *Lithophyllum nitorum*: showing postigenous cell without cell fusion. (3) SEM of *Lithophyllum incrustans*: showing postigenous cell filaments without any cell fusion. **(4)** *Lithophyllum quadratum*: showing postigenous cell filaments without any cell fusion. **(5-6)** SEM of *Phymatolithon* sp.: showing cell fusion and rounded epithallial cells.

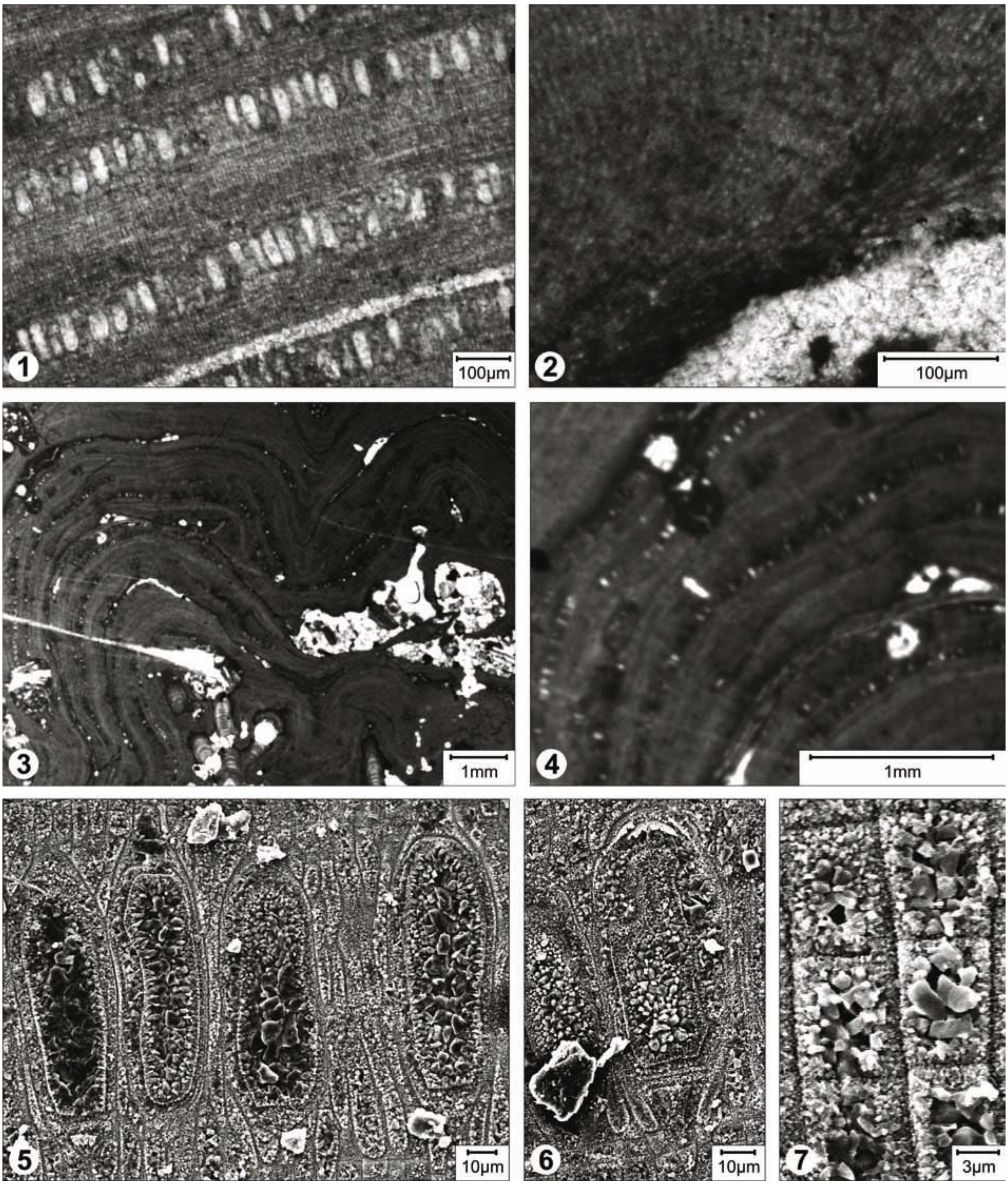

Plate 5. (Figs.1-2) *Sporolithon lvovicum*. **(1)** Showing sporangial compartments. **(2)** showing non-coaxial core filaments. **(Figs.3-4)** *Sporolithon intermedium*. **(3)** showing warty growth-form. **(4)** showing peripheral filaments with sporangial compartments. **(Figs.5-7).** SEM of *Sporolithon lvovicum*. **(5)** SEM of sporangial compartments with paraphyses. **(6)** SEM of single sporangial compartment. **(Fig.7)** Showing shape of peripheral cells.

The peripheral region of encrusting portion of thallus usually 650 µm. Cell length 14-18 µm and width 8-12 µm, cells are rectangular in shape (Pl. 5, fig. 7) cell fusions present.

Uniporate sporangial compartments arranged in sori (Pl. 5, fig. 5). Individual sporangial compartments with rounded to elliptical or ovoid corners in longitudinal section and circular in transverse section; sporangia 80-90 µm in height and 40-50 µm in width. Trapezoidal stalk cells occur at the base of some compartments. Sori usually arise from a layer of elongated cells (Pl. 5, fig. 6). 1-3 filaments (paraphyses) are interspersed between the sporangial compartments (Pl. 5, fig. 5). Up to 32 sporangial compartments can be counted in a single sorus. Old sori buried in the thallus.

Sample No.: Moj- 2 (Aramda Reef Member, Chaya Formation)

Slide No.: M-10

Remarks: Following Woelkerling (1988), Moussavian and Kuss (1990) who established the priority of *Sporolithon* Hydrich, 1897 over *Archaeolithothamium* Rothpletz, 1891, the present specimen is assigned to *Sporolithon.* The present species resembles Pisera and Studencki's (1989) species, described as *Sporolithon* (*Archaeolithothamnion*) *lvovicum*, mainly in sporangial compartments' shape, size and their arrangement from the basal layer. Pisera and Studencki (1989) reported this species from the middle Miocene of Poland. This species is also known from the middle Miocene of Ukraine and Bulgaria (Pisera and Studencki, 1989).

Sporolithon intermedium Raineri, 1923
(Pl. 5; figs. 3-4)

Archaeolithothamnium intermedium Raineri, 1923, p.29.

Archaeolithothamnium intermedium Raineri: Johnson, 1966, p. 262, pl. 1, fig. 6.

Archaeolithothamnium intermedium Raineri: Pisera and Studencki, 1989, p. 193, pl. 5, figs. 3-4.

Description: Growth form encrusting to warty, thickness of encrusting thalli up to 1.2 mm. Thallus organization monomerous. Core filaments non-coaxial, core portion 230 µm thick. Cells 20-22 µm in length and 12-14 µm in width, cell fusions present.

The peripheral region of encrusting portion of the thallus usually 1.3 mm. Cell length 14-18 µm and width 8-12 µm, cell fusions present.

Uniporate sporangial compartments arranged irregularly in sori. Individual sporangial compartments rounded to oval in longitudinal section and circular in transverse section; sporangia 90-100 µm in height and 50-60 µm in width. Sori usually arise from a layer of elongated cells. 1-4 filaments (paraphyses) are interspersed between the sporangial compartments. Up to 20 sporangial compartments can be counted in a single sorus. Old sori buried in the thallus.

Sample No.: Moj-2,3 (Aramda Reef Member, Chaya Formation)

Slide No.: M-2, T-3

Remarks: The present species shows similarity with *Sporolithon intermedium* in growth form, cell dimensions of core and peripheral filaments of the thallus. Besides these characters, sporangial compartments also show similarity in shape, size and their arrangement in the thallus. Pisera and Studencki (1989) reported this species from middle Miocene of Poland. This species is also known from the Miocene of France, Malta, Libya and Borneo.

Family Hapalidiaceae Gray, 1864
Subfamily Melobesioideae Bizzozero, 1885

Genus *Mesophyllum* Lemoine, 1928
Mesophyllum fructiferum Airoldi, 1932
(Pl. 6; figs. 1-3)

Mesophyllum fructiferum Airoldi, 1932, p. 76, fig. 2, pl. 12: 1.

Mesophyllum fructiferum Airoldi: Pisera and Studencki, 1989, p. 198, pl. 8, fig. 3.

Description: Growth form encrusting to layered, thallus organisation monomerous. Coaxial core filaments are well developed, 90-100 µm thick, cells 18-20 µm in length and 10-15 µm in width, cell fusions present.

Peripheral filaments well developed but cells of the filaments are not clearly distinct, hence, cell fusions are not observed. Cells of the peripheral filaments 15-20 µm in length and 10-12 µm in width.

Tetra/biosporangial conceptacles multiporate, filled with spores (Pl. 6, fig. 2), ellipsoidal to reniform in section, 130-170 µm in height and 450-500 µm in width.

Sample No.: Moj-2 (Aramda Reef Member, Chaya Formation)

Slide No.: M-13

Remarks: The specimen's growth form, conceptacle shape and size as well as the coaxial morphology of core filaments indicate affinity with *Mesophyllum fructiferum*. Pisera and Studencki (1989) reported this species from middle Miocene of Poland. This species is also known from the Oligocene of Italy (Pisera and Studencki, 1989).

Mesophyllum commune Lemoine, 1939
(Pl. 6; fig. 4)

Mesophyllum commune Lemoine, 1939, p. 86, fig. 54, 56, 57.

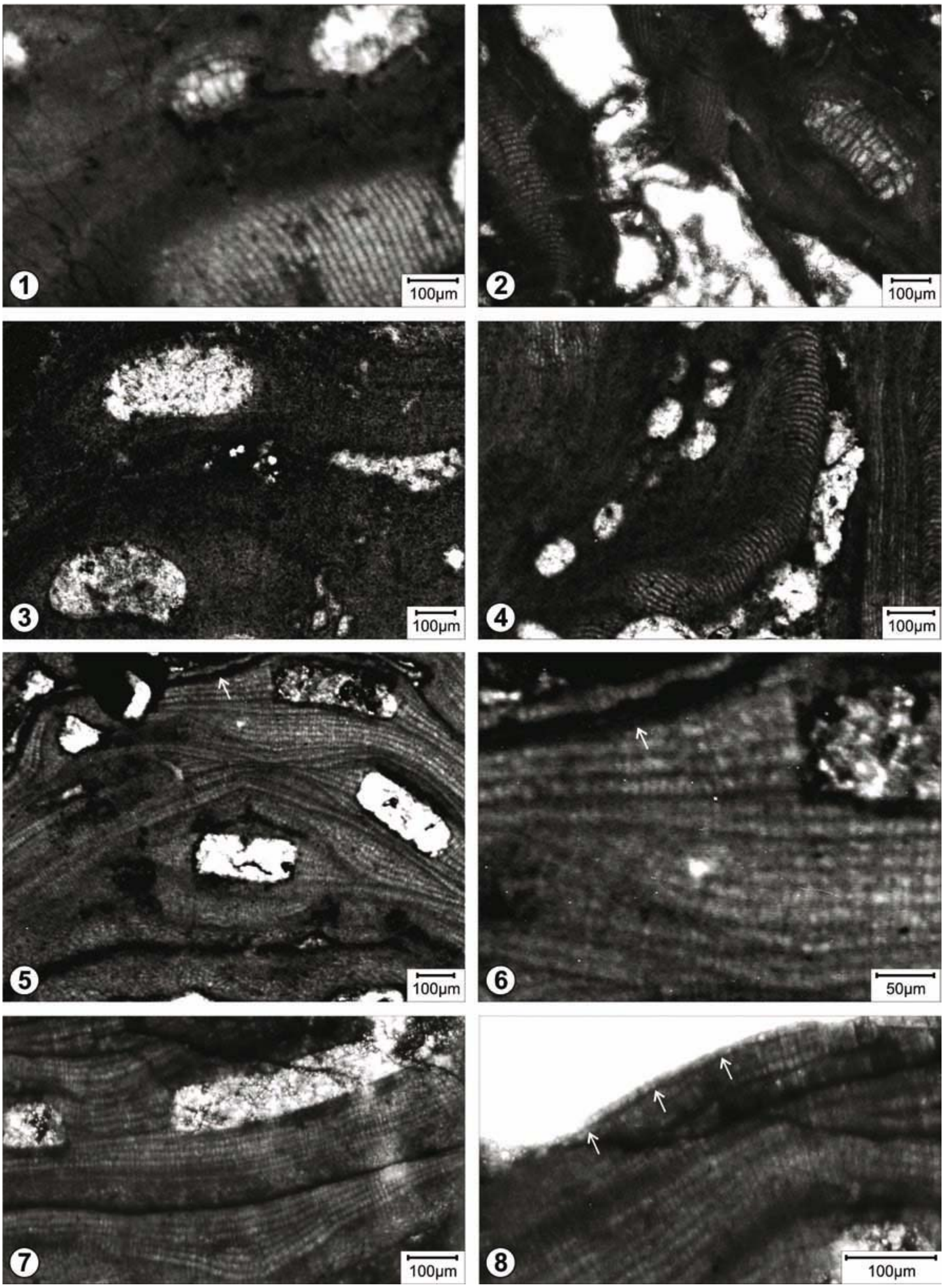

Plate 6. (Figs.1-3) *Mesophyllum fructiferum*. **(1-2)** Showing coaxial core filaments with conceptacles. **(3)** Showing multiporate conceptacles. **(Fig. 4)** *Mesophyllum commune*: showing coaxial core filaments with many conceptacles. **(Figs.5-6)** *Lithothamnion praefruticulosum*. (5) Showing peripheral, non-coaxial core filaments and multiporate conceptacles. **(6)** showing flared epithallial cells indicated by arrow. **(Figs.7-8)** *Phymatolithon* sp., **(7)** Showing multiporate conceptacles. **(8)** showing rounded epithallial cells indicated by arrow.

Mesophyllum commune Lemoine: Bosence, 1983, p. 156, pl. 16, figs. 3-7.

Description: Growth form encrusting to layered, thallus organisation monomerous. Coaxial core filaments well developed, 90-100 µm thick, cells 18-20 µm in length and 10-15 µm in width, cell fusions present.

Peripheral filaments are also well developed. Cells of the peripheral filaments 15-20 µm in length and 10-12 µm in width.

Tetra/biosporangial conceptacles numerous in peripheral portion but pores are not distinct. Conceptacles 130-170 µm in height and 450-500 µm in width.

Sample No.: Moj-2 (Aramda Reef Member, Chaya Formation)

Slide No.: M-35

Remarks: The specimen's growth form and predominantly coaxial morphology of core filaments indicate affinity with *Mesophyllum commune* Lemoine (1939). However, conceptacle pores are not distinct but their shape and size, together with thallus organization, suggest their similarity to *Mesophyllum commune* described by Bosence (1983) from the Miocene of Malta.

Genus *Lithothamnion* Heydrich,1897

Lithothamnion praefruticulosum Maslov, 1956

(Pl. 6, figs. 5-6)

Lithothamnion praefruticulosum Maslov: Pisera, 1985, p. 101, pl. 20, figs. 1-3.

Lithothamnion praefruticulosum Maslov: Pisera and Studencki, 1989, p. 196, pl. 7, fig. 4; pl. 8, fig. 5.

Description: Growth form encrusting to warty. Thallus organization monomerous. Core filament non-coaxial, core portion usually 110-140 µm thick, cell fusions occur. Cells 10-14 µm in length and 10-12 µm in width.

Peripheral filaments also well developed. Peripheral cells are rectangular in shape, 14-22 µm in length and 12-14 µm in width. Cell fusions present. Epithallial cells flared in shape (indicated by arrow in Pl. 6, figs. 5, 6).

Tetra/biosporangial conceptacles multiporate. Conceptacles variable in shape and size, subrectangular to reniform in section, 130-170 µm in height and 350-400 µm in width.

Sample No.: Moj-2 (Aramda Reef Member, Chaya Formation)

Slide No.: M-13

Remarks: The noncoaxial core filaments, multiporate conceptacles, cell fusions and flared epithallial cells (pl. 6, fig, 5, 6) allow to identify the present specimen as genus *Lithothamnion*. These specimens are comparable with *Lithothamnion praefruticulosum* Maslov, 1956 mainly in shape and size of multiporate conceptaceles, but differ in having flared epithallial cells. Pisera and Studencki (1989) reported this species from the middle Miocene of Poland. This species is also known from the Miocene of Ukraine and Malta and the Oligocene of Italy (Pisera and Studencki, 1989).

Genus *Phymatolithon* Foslie, 1898

Phymatolithon sp.

(Pl. 6, figs. 7, 8; Pl. 4, figs. 5, 6)

Description: Growth form encrusting with a thallus thickness of usually 230 µm. Thallus monomerous. Core portion non-coaxial, 100-120 µm thick. Cell fusions present. Cells 14-20 µm in length and 8-12 µm in width.

The peripheral region of encrusting portions is restricted to the dorsal part of the thallus, it is usually 200 µm thick. Cells 8-14 µm in length and 8-12 µm in width. Cell fusions present (Pl. 4, fig. 6). Epithallial cells rounded in shape (Pl. 6, fig 8; Pl. 4, figs. 5-6).

Tetra/biosporangial conceptacles multiporate, conceptacles subrectangular in section, 100-120 µm in height and 500-550 µm in width.

Sample No.: Moj-2 (Aramda Reef Member, Chaya Formation)

Slide No.: M-9

Remarks: The non-coaxial core filament, multiporate conceptacles, cell fusions and shape of the epithallial cells (Pl. 4, figs. 5-6) allow the genus to be identified as *Phymatolithon*. The present material is comparable with *Phymatolithon* sp. Rasser and Piller (1999) in its morphology but differs in its growth form, cells of the filaments and shape and size of conceptacles. Hence, the present specimen is described without specific status.

DISCUSSION AND CONCLUSIONS

The present paper records thirteen species of coralline algae from the Aramda Reef Member of the Chaya Formation exposed in the Mojap coast (late Pleistocene) near Mithapur, Gujarat (Fig. 2). These include *Titanoderma pustulatum, Titanoderma nataliae, Lithophyllum incrustans, Lithophyllum nitorum, Lithophyllum quadratum, Spongites* sp. Brandano et al. 2005, *Lithoporella melobesioides, Sporolithon lvovicum, Sporolithon intermedium, Mesophyllum fructiferum, Mesophyllum commune, Lithothamnion praefruticulosum, Phymatolithon* sp. Out of these, seven species belong to the family Corallinaceae. Two are assigned to the family Sporolithaceae and four to the family Hapalidiaceae. Seven coralline species (*Titanoderma nataliae, Lithophyllum nitorum, Lithophyllum quadratum,* *Spongites* sp. Brandano et al., 2005, *Sporolithon lvovicum, Mesophyllum fructiferum* and *Lithothamnion praefruticulosum*) are recorded for the first time from India, whereas *Titanoderma pustulatum, Sporolithon intermedium, Mesophyllum commune* and *Phymatolithon* sp. are new to the study area. The coralline algae are associated with foraminifera, e.g. *Operculina* and other rotaliids, and corals such as *Acropora*, *Porites*, etc.

The stratigraphic distribution of the algal species shows that ten species, namely *Titanoderma pustulatum, Titanoderma nataliae, Lithophyllum incrustans, Lithophyllum nitorum, Lithophyllum quadratum, Spongites* sp. Brandano et al., 2005, *Sporolithon lvovicum, Sporolithon intermedium, Mesophyllum fructiferum* and *Mesophyllum commune* are known from the Neogene formations and three (*Lithoporella melobesioides, Lithothamnion praefruticulosum,* and *Phymatolithon* sp.) range from Palaeogene to Neogene in different parts of the world.

The coralline algal assemblages can be broadly differentiated into two associations: one developed in the lower part of the studied succession shows deposition in warm, low-energy conditions and the other developed in the upper part of the study area indicates shallow water, high energy conditions. The lower Hapalidiaceae and Sporolithaceae-dominated association consists of *Mesophyllum*, *Lithothamnion* and *Sporolithon* and their warty to layered growth forms which prefer warm, moderate to low-energy, lower photic environment. *Mesophyllum* is characteristic of the lower photic zone. The upper Lithophylloideae-dominated association consists of *Lithophyllum* and *Titanoderma* and is adapted to shallow water environment (possibly intertidal reef flat and the back-reef). *Lithophyllum* commonly grows in the upper photic zone (well-illuminated, high-energy water). Its fruticose growth-forms prefer high-energy conditions.

These two associations along with their growth-forms in the Mojap area suggest that the depth, temperature and hydrodynamic conditions may have fluctuated during deposition of the Aramda Reef Member of the Chaya Formation. It seems that *Lithopyllum* flourished during relatively cool water conditions, while *Spongites, Mesophyllum* and *Sporolithon* may have dominated during the warmer interval. The associated corals indicate that minimum winter sea surface temperature may have remained above 18ú-20ú C.

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