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CORALLINE ALGAE FROM THE HUT BAY FORMATION (MIDDLE MIOCENE), LITTLE ANDAMAN, INDIA

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ABSTRACT

The sediments of Hut Bay Formation (Middle Miocene), Little Andaman are characterized by coralline algae, corals and foraminifera. In the present paper, thirteen species belonging to nine genera of coralline algae are described. Out of these, one species (*Harveylithon rupestris*) is a new record for India. Eight species (*Mesophyllum obsitum, M. curtum, M. koritzae, M. commune, Phymatolithon calcareum, Aethesolithon problematicum, Harveylithon munitum* and *Sporolithon lvovicum*) are first time recorded from the study area.

The coralline algal assemblages can be broadly differentiated into two associations: one developed in the lower part of the studied succession deposited in deep, cool-water under low-energy conditions, and the other developed in the upper part indicating deposition in shallow, warm-water with high energy conditions. These two associations along with their growth-forms in the study area suggest that the depth, temperature, and hydrodynamic conditions might have fluctuated during deposition of the Hut Bay Formation. It seems that *Lithopyllum* and *Phymatolithon* flourished in relatively cool water environment, while *Sporolithon, Harveylithon, Lithoporella*, and *Aetesolithon* might have dominated during the warmer interval.

Keywords: Non-geniculate coralline algae, palaeoenvironment, Hut Bay Formation, South Andaman.

INTRODUCTION

Coralline algae showed their maximum diversification during the middle Miocene (Aguirre *et al*., 2000; Halfar and Mutti, 2005) and have been globally studied by several authors (Johnson and Ferris, 1949; Johnson, 1964; Buchbinder, 1977; Bosence, 1983; Studencki, 1999; Kroeger *et al*., 2006; Basso *et al*., 2008; Braga *et al*., 2010; Rebelo *et al.,* 2014; Rösler *et al*., 2015; Hrabovský *et al*., 2015). Coralline algae were poorly known in the Indian subcontinent due to lack of suitable facies in the rocks of this age (except Western India) caused by major climatic changes such as the global Miocene cooling effect in the depositional environment on shallow shelves of India. The early Miocene Global Cooling mainly affected the assemblages of the tropical areas, such as India and showed little effect on the temperate coralline algal assemblages. Besides this, the influx of large amount of clastic material from the rising Himalaya was another key factor which was mainly responsible for the destruction of carbonate environment in the peninsular parts of India. Closely associated with carbonate environments, the coralline algal assemblages began to undergo decline in response to increased influx of clastic material in the lower Miocene successions of western India and the Andaman areas. The change in the environment due to clastic influx and temperature decline reduced the carbonate habitats and adversely affected the associated flora and fauna (the coralline algae and corals).

Non-geniculate coralline algal diversity was quite high from the Palaeogene successions of India, but Miocene successions characterized by mixed carbonate-siliclastic material show poor non-genicualte coralline algal diversity and favoured the development of geniculate corallines. However, it is observed that, when the climates improved considerably in late early to middle Miocene, non-geniculate coralline algae reappeared in large numbers. To explore this possibility, we have selected Middle Miocene sequence of Little Andaman which is a part of uplifted Miocene-Pliocene deep sea sequences of Andaman-Nicobar Islands. The outcrops of Little Andaman are well developed in comparison to Western India and yet are still poorly studied (Kundal, 2014).

Venkatachalapathy and Gururaja, (1984), published the first paper on coralline algae of this area in which they described only two unidentified species of *Aethesolithon*. The second paper published was by Sarkar and Ghosh (2014) in which they described nine species of coralline algae. Out of these, four species such as *Mesophyllun, Lithoporella, Lithothamnion* and *Titanoderma* are taxonomically incorrect. Recently, Sarkar *et al*. (2016) published another paper on coralline algae and associated foraminifera, but they again do not provide correct taxonomic details of *Spongites*. In view of above facts that previously described non-geniculate coralline algal species of various authors of the Little Andaman area need critical revision for their correct genetic identification and their systematic position too. We provide new correct generic identification data on coralline algae from the Hut Bay Formation (middle Miocene) Little Andaman, note their distribution in the studied succession and point to their significance for palaeoenvironmental interpretation.

GEOLOGICAL SETTING

The Andaman and Nicobar Islands comprise 319 islands forming an island arc system located between 6ºN and 14ºN latitudes in the northeast Indian Ocean. The Andaman group of 258 islands is separated from the Nicobar group of 61 islands

†Deceased

by a channel at 10º N latitude, popularly known as ten degree channel. The arc forms a dividing line between the Bay of Bengal in the west and the Andaman Sea in the east. These islands are a part of a large geotectonic unit extending from the Arakan-Yoma in the north to the Indonesian islands (Java-Sumatra) in the south. The Andaman-Nicobar Islands were formed as a result of northward movement of the Indian plate and its collision with Eurasian plate, giving rise to subduction and right lateral slip along the Sumatran sector (Roy, 1983). The subduction zone is considered to lie west of the Andaman-Nicobar Islands Ridge and is represented in the south by the Sunda Trench lying to the west and south of Sumatra-Java. The subduction is supposed to have started in the Late Mesozoic due to breaking of the Gondwana land and gave rise to a depression, the fore-arc basin, between the "main ridge" and the volcanic arc, in which the sediments brought from the rapidly rising main ridge were deposited (Curray *et al.,* 1978). The end of the Oligocene witnessed the emergence of the main ridge above the sea. The Neogene sediments which accumulated in the fore-arc basin contain a large amount of biogenic sediments deposited mainly at great depths.

STRATIGRAPHY

The Andaman and Nicobar Islands in the Bay of Bengal show development of thick marine sequences ranging from Late Mesozoic to the Quaternary. They are divisible into five lithostratigraphic units, i.e. Porlob, Serpentine, Baratang, Port Blair and Archipelago Group, in ascending order (Chatterjee, 1967; Karunakaran *et al.,* 1968; Srinivasan, 1986; Sharma and Srinivasan, 2007). The Neogene sediments grouped as the Archipelago Group overlie the Palaeogene Port Blair Group with unconformity. They are distributed in the Andaman and Nicobar Islands in a north-south trend nearly parallel to the axis of the islands. These are primarily composed of deep-water marine sediments of variable thickness and are well developed in the Ritchie's Archipelago that includes a group of islands lying from 16-25 kms to the east of the Middle and South Andaman Island in the Andaman Sea, between latitudes 12° 20' N and 11° 46' N. The main islands of the group are Neil, Havelock, John Lawrence, Henry Lawrence, Nicholson and Outram, and run in a general north to south direction; however, there are a number of small islands (such as Sir Huge, Rose, Inglis, Peel, Wilson, Button, Long, Guitar, Round, Strait, North Passage, and Colebrook islands) that also constitute Ritchie's Archipelago.

The Archipelago Group ranges in age from early Miocene to Pleistocene. Lithologically, the lower part of the group is represented by the Strait, Round and Inglis formations, and mainly comprises sandy limestone, light coloured siliceous and nanoforam chalk and silt. The upper part, on the other hand, is represented by Hut Bay, Long, Sawai Bay, Guitar and Neill West Coast formations which are predominantly grey, calcareous mudstone, and limestone. The stratigraphic and micropalaeontological studies in the last few decades have shown that the Neogene of the Andaman and Nicobar appears to be an almost continuous sequence of Miocene to Holocene age. It comprises predominantly fluctuating mudstones, siltstones, chalk and limestones which were deposited under shallower to deep water conditions. Lithologically, the Neogene strata are easily separated from the older rocks which are mainly greywacke, shales, intrusives, extrusives and metamorphic rocks (Sharma and Srinivasan, 2007).

The Little Andaman Island, lying between South Andaman and Car Nicobar, is the southernmost island of the Andaman Group. It is located at a distance of 120 km by sea from the Port Blair. Duncan Passage separates Little Andaman from South Andaman, whereas Ten Degree Channel separates Andaman group from Nicobar group (Fig. 1).

The studied limestone sequences of the Little Andaman belong to the Hut Bay formation. This formation is divisible into two litho-logical units, i.e. the lower calcareous mudstone and the upper yellowish molluscan rich limestone units (Srinivasan, 1975). The mudstone is overlain unconformably by the limestone unit. Srinivasan (1969), suggests middle Miocene age for this formation on the basis of the *Globorotalia foshi lobata* and *Globorotalia foshi robusta* zones.

MATERIAL AND METHODS

The present work is based on seven samples collected at different intervals from a 5.5 m thick sequence of the Upper limestone unit of the Hut Bay Formation, exposed in a Quarry section (10° 34' 707" N: 92° 32' 527" E) of Saw Mill road, Little Andaman. It is a creamish yellow and gray massive limestone (bedding not visible) and highly fossiliferous. The lithology with fossil contents varies from place to place. This formation is characterized by the coralline algal lithofacies in association with corals, mollusc, larger benthic foraminifera, echinoids, etc. The coralline algal percentage is also changes within in 600m area.

The samples were processed for the study of coralline algae in random thin sections as they were not suitable for separation of isolated material. More than 275 thin sections were prepared, and the effort was made to obtain desired orientation by sectioning the samples along and across the bedding planes. The morphotaxonomic features of coralline algae and associated foraminifera were studied under the light microscope. Taxonomic observations were made in light of current taxonomic criteria developed through studies by Woelkerling (1988), Braga *et al.* (1993), Rasser and Piller (1999), Harvey *et al.* (2003), Bassi *et al.* (2007), Iryu *et al.* (2009), Lee Gall and Saunders (2007) and Lee Gall *et al*. (2010).

SYSTEMATIC DESCRIPTION

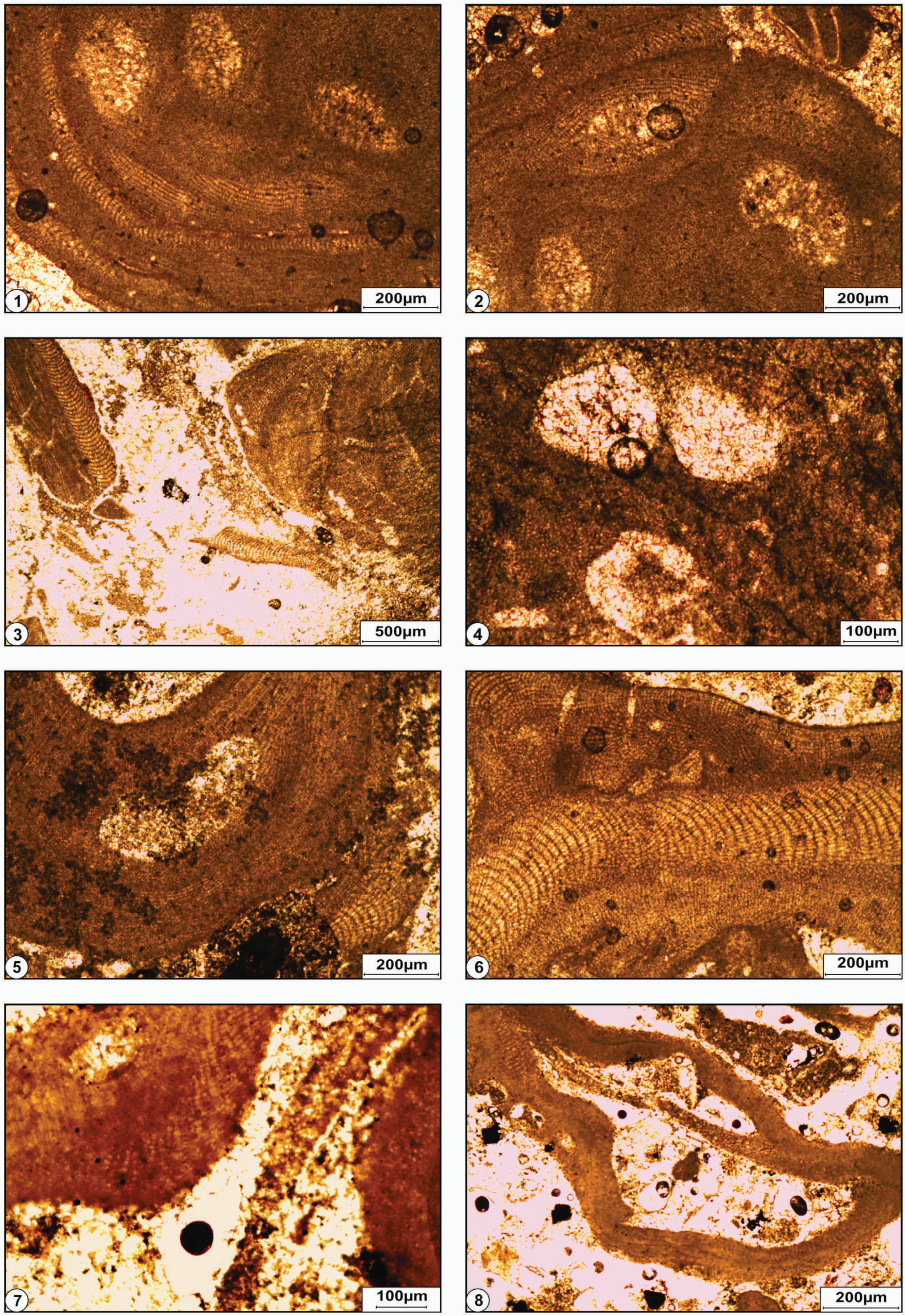
Division **Rhodophyta** Wettstein, 1901
Class **Rhodophyceae** Rabenhorst, 1863
Order **Corallinales** Silva and Johansen, 1986
Family **Hapalidiaceae** Gray, 1864
Subfamily **Melobesioideae** Bizzozero, 1885
Genus ***Mesophyllum*** Lemoine, 1928

Mesophyllum obsitum Airoldi, 1932
(Pl. I, figs. 1-2)

EXPLANATION OF PLATE I

Figs.1-2. ***Mesophyllum obsitum***. 1. Laminar growth-form and peripheral region with sporangial conceptacles. 2. Enlarged view of sporangial conceptacles. Figs. 3-4. ***Mesophyllum curtum***. 3. Warty to laminar growth-forms, coaxial core and peripheral filaments. 4. Enlarged view of conceptacles. Figs. 5-6. ***Mesophyllum koritzae***.5. Multiporate conceptacle, coaxial core and peripheral filaments. 6. Enlarged view of coaxial core and peripheral filaments. Figs.7-8. ***Mesophyllum commune***. 7. Non-coaxial core filaments and conceptacle. 8. Laminar growth-form and peripheral region with sporangial conceptacles.

Plate I



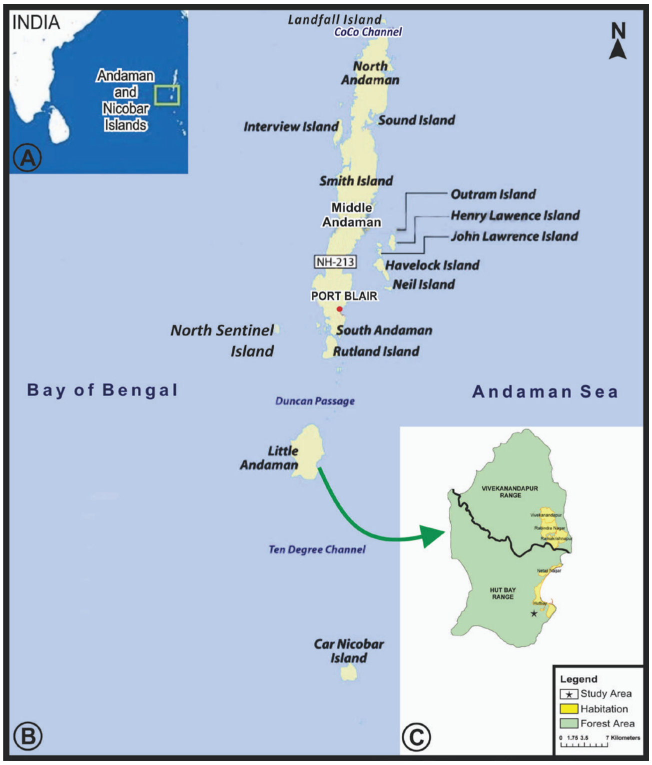


Fig. 1. A: Inset shows position of Andaman and Nicobar Islands. B: Geographical position of little Andaman. C: Sample location of the study area.

Mesophyllum obsitum Airoldi, 1932, p. 78, pl. 7, fig. 2. - Studencki, 1988, p. 34, pl. 11, fig. 5. - Basso *et al.*, 1998, p. 89, pl. 2, figs. 1-9.

Description: Growth form encrusting to layer, thallus organization monomerous. Coaxial core filaments well developed 75-130 µm thick, cells of core filaments 16-18 µm in length and 10-12 µm in width; cell fusions present. Peripheral filaments well developed with cell fusions. Cells are 16-18 µm in length and 10-12 µm in width. Tetra/bisporangial conceptacles variable in shapes and multiporate, 15-180 µm in height and 270-300 µm in width.

Remarks: The specimen's growth form, conceptacle shape and size as well as the coaxial core filaments indicate affinity with *Mesophyllum obsitum* Airoldi, 1932. Basso *et al.* (1998) revised and redocumented this species on the basis of coaxial to non-coaxial core filaments. Studencki (1988) reported this species from middle Miocene of Poland.

Slide No.: LA/L-6

Locality: Lower part of the sequence at Quarry no. 4 section of Saw Mill road, Little Andaman Island.

Mesophyllum curtum Lemoine, 1939
(Pl. I, figs. 3-4)

Mesophyllum curtum Lemoine, 1939, p. 92, pl. 2, fig. 13. - Aguirre and Braga, 1998, p. 497, pl. 2, figs. 3-7. – Hrabovský *et al.*, 2015, p. 12, fig. 12.

Description: Growth form encrusting to layer, thallus organization monomerous. Coaxial core filaments well developed 200-250 µm thick, cells 18-20 µm in length and 10-12 µm in width, cell fusions present. Peripheral filaments are also well developed. Cells of the peripheral filaments 10-12 µm in length and 8-10 µm in width. Tetra/biosporangial conceptacles multiporate, roundish to elliptical in sections and numerous in the peripheral region. Conceptacles 130-170 µm in height and 200-220 µm in width.

Remarks: The specimen's growth form, vegetative morphology, conceptacle shape and their size indicate its affinity with *Mesophyllum curtum* Lemoine (1939). *Mesophyllum curtum* described by Hrabovský *et al.* (2015) from the Early Langhian of Czech Republic.

Slide No.: LA/L-12

Locality: Lower part of the sequence at Quarry no. 4 section of Saw Mill road, Little Andaman Island.

Mesophyllum koritzae Lemoine, 1939
(Pl. I, figs. 5-6)

Mesophyllum koritzae Lemoine, 1939, p. 84, text-figs. 49-51. - Bosence, 1983, p. 158, pl.16, figs. 8-10.

Description: Growth form encrusting to layer, thallus organization monomerous. Core filaments distinctly coaxial and well developed, 200-230 µm thick, cells of core filaments 20-22 µm in length and 12-15 µm in width with cell fusions. Peripheral filaments are also well developed. Cells of the peripheral filaments 10-14 µm in length and 8-12 µm in width. Tetra/bisporangial conceptacles multiporate and variable in shape, 120-130 µm in height and 520-550 µm in width.

Remarks: The specimen's growth form, conceptacle shape and coaxial core filaments indicate affinity with *Mesophyllum koritzae* Lemoine, 1939. Bosence (1983) reported this species from Miocene of Malta.

Slide No.: LA/L-14

Locality: Lower part of the sequence at Quarry no. 4 section of Saw Mill road, Little Andaman Island.

Mesophyllum commune Lemoine, 1939
(Pl. II, figs. 7-8)

Mesophyllum commune Lemoine, 1939, p. 86, pl. 3, text-figs. 54, 56, 57. - Bosence, 1983, p. 156, pl.16, figs. 3-7.

Description: Growth form encrusting to layer, thallus organization monomerous. Core filaments coaxial to non-coaxial, 100-120 µm thick. Cells of core filaments are variable 15-22 µm in length and 12-15 µm in width with cell fusions. Cells of the peripheral filaments 10-15 µm in length and 8-13 µm in width. Tetra/bisporangial conceptacles multiporate and variable in shape, 100-120 µm in height and 150-200 µm in width.

Remarks: The specimen's growth form, conceptacle shape and size as well as the nature of core filaments indicate affinity with *Mesophyllum commune* Lemoine, 1939. Bosence (1983) reported this species from Miocene of Malta.

EXPLANATION OF PLATE II

Figs.1-3. ***Phymatolithon calcareum***. 1. Peripheral filaments with conceptacles. 2. Core and peripheral filaments with cell fusions. 3. Thallus with multiporate conceptacle. Fig. 4. ***Lithophyllum nitorum***: dimerous organization with uniporate conceptacles. Figs.5-6. ***Titanoderma pustulatum***. 5. Thallus with uniporate conceptacles. 6. Enlarged view of palisade cells of primigenous filaments. Fig. 7. ***Amphiroa*** sp.: showing alternation of long and short cells in medullary region. Fig. 8. ***Lithoporella melobesioides***: primigenous filaments of the thallus.

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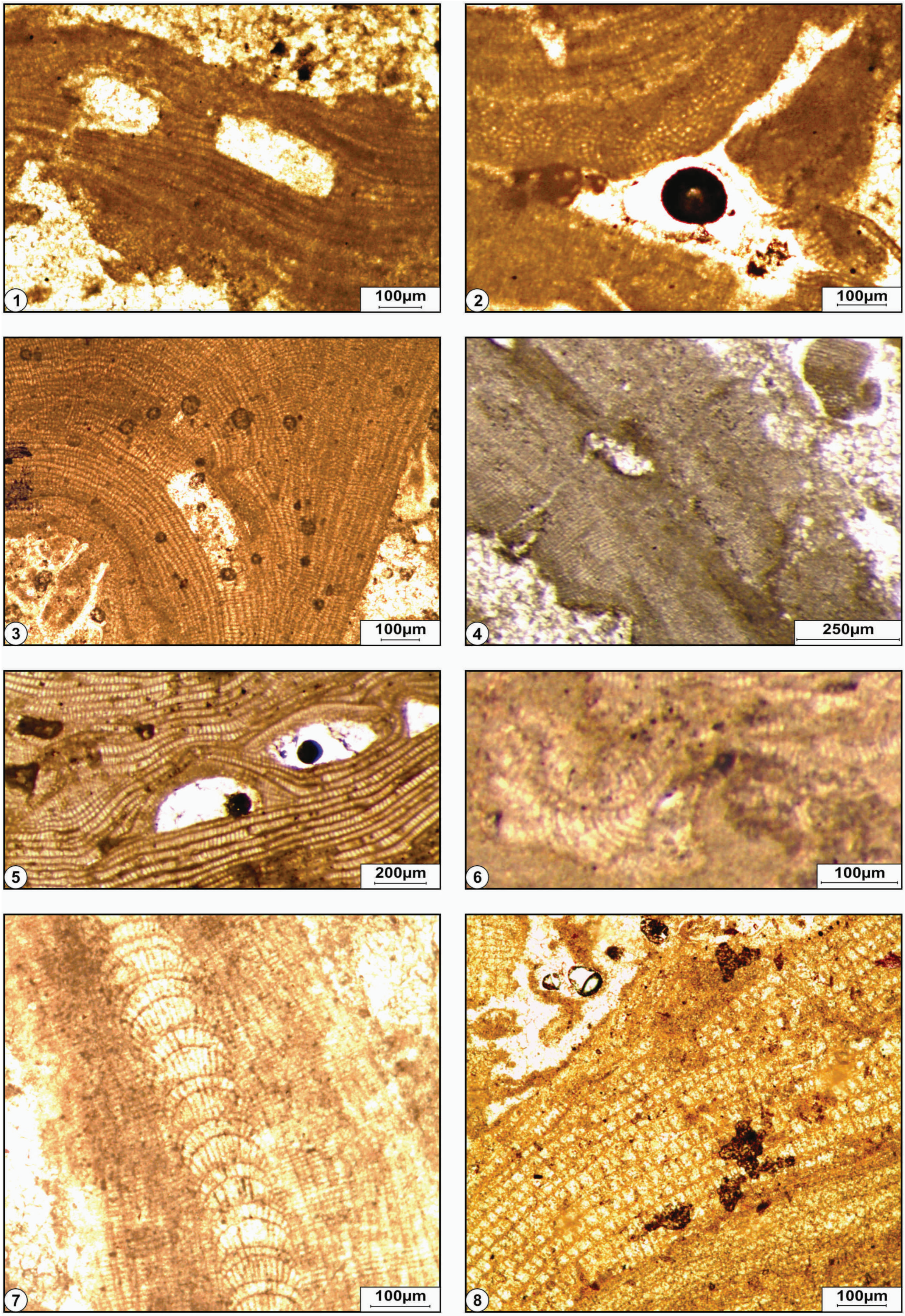
Plate II



Slide No.: LA/L-22

Locality: Lower part of the sequence at Quarry no. 4 section of Saw Mill road, Little Andaman Island.

Genus ***Phymatolithon*** Foslie, 1898

Phymatolithon calcareum (Pallas) Adey and McKibbin, 1970 (Pl. II, figs. 1-3)

Phymatolithon calcareum (Pallas) Adey and McKibbin, 1970, p. 100, fig. 1. - Rebelo *et al.*, 2014, p. 376, figs. 4 A-D.

Description: Growth form encrusting to warty with a thallus thickness of usually 450 µm. Thallus organization monomerous. Core portion non-coaxial, 100-120 µm thick, cell fusions present. Cells 18-22 µm in length and 10-12 µm in width. The peripheral region of encrusting portions restricted to the dorsal part of the thallus. Cells of the peripheral region 18-20 µm in length and 8-12 µm in width. Cell fusions present. Epithallial cells rounded in shape. Tetra/bisporangial conceptacles multiporate, rectangle shape with rounded corners, 100-110 µm in height and 380-400 µm in width.

Remarks: The non-coaxial core filament, multiporate conceptacles, cell fusions and shape of the epithallial cells indicate that it is *Phymatolithon calcareum*. Rebelo *et al.* (2014) reported this species from the Pliocene of Santa Maria Island (Azores, NE Atlantic), Braga and Aguirre (2001) from the Pliocene of Spain and Kishore *et al.* (2015) recorded it from the Pleistocene of the South Andaman.

Slide No.: LA/L-36

Locality: Lower part of the sequence at Quarry no. 4 section of Saw Mill road, Little Andaman Island.

Family **Corallinaceae** Lamouroux, 1812
Subfaimly **Lithophylloideae** (Setchell) Bailey, 1999
Genus ***Lithophyllum*** Phillippi, 1837

Lithophyllum nitorum Adey and Adey, 1973 (Pl. II, fig. 4)

Lithophyllum nitorum Adey and Adey, 1973, p. 386. - Braga and Aguirre, 1995, p. 277, pl. 2, figs. 5-6. - Kishore *et al.,* 2012, p. 219, pl. 2, figs. 1-2.

Description: Growth form encrusting, thallus organization dimerous. Primigenous filaments are formed by rectangular cells, which are usually 10-15 µm in length and 10-12 µm in diameter. Postigenous filaments are conspicuous and well developed. There is clear lateral alignment of cells of adjacent filaments; cells of the postigenous filaments are rectangular in shape and measure 16-22 µm in length and 8-12 µm in diameter without cell fusions. Epithallial cells are also not preserved in thallus. Tetra/bisporangial conceptacles are uniporate; conceptales are rectangles in shape with rounded corner, pore canals, tapering to the conceptacle roof; columella absent. They measure 125-150 µm in diameter and 70-80 µm in height.

Remarks: The present specimen shows similarity with *Lithophyllum nitorum* Braga and Aguirre (1995) in shape, size of primigenous, postigenous filaments and shape and size of tetra/bisporangial conceptacles. Sarkar *et al.* (2016) have reported this species from middle Miocene of Little Andaman. Braga and Aguirre (1995) reported this species from the Neogene of southern Spain. Kishore *et al.* (2012, 2015) have reported this species from the Pleistocene of Dwarka and Neil Island, India.

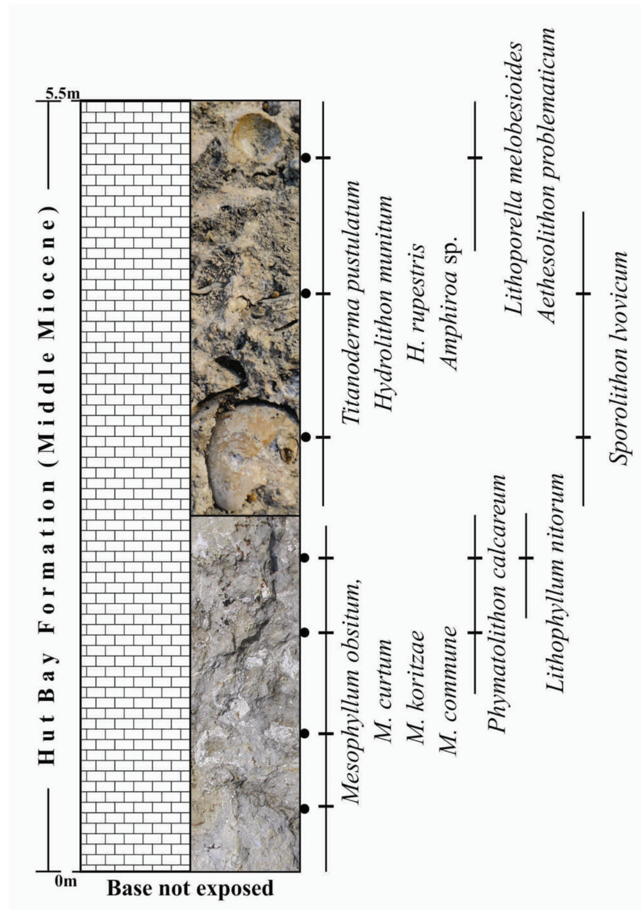


Fig.2. Distribution of coralline algal species in the upper limestone unit of Hut Bay, Little Andaman, India.

Slide No.: LA/L-48

Locality: Lower part of the sequence at Quarry no. 4 section of Saw Mill road, Little Andaman Island.

Genus ***Titanoderma*** Näegeli, 1858

Titanoderma pustulatum (Lamouroux) Näegeli, 1858 (Pl. II, figs. 5-6)

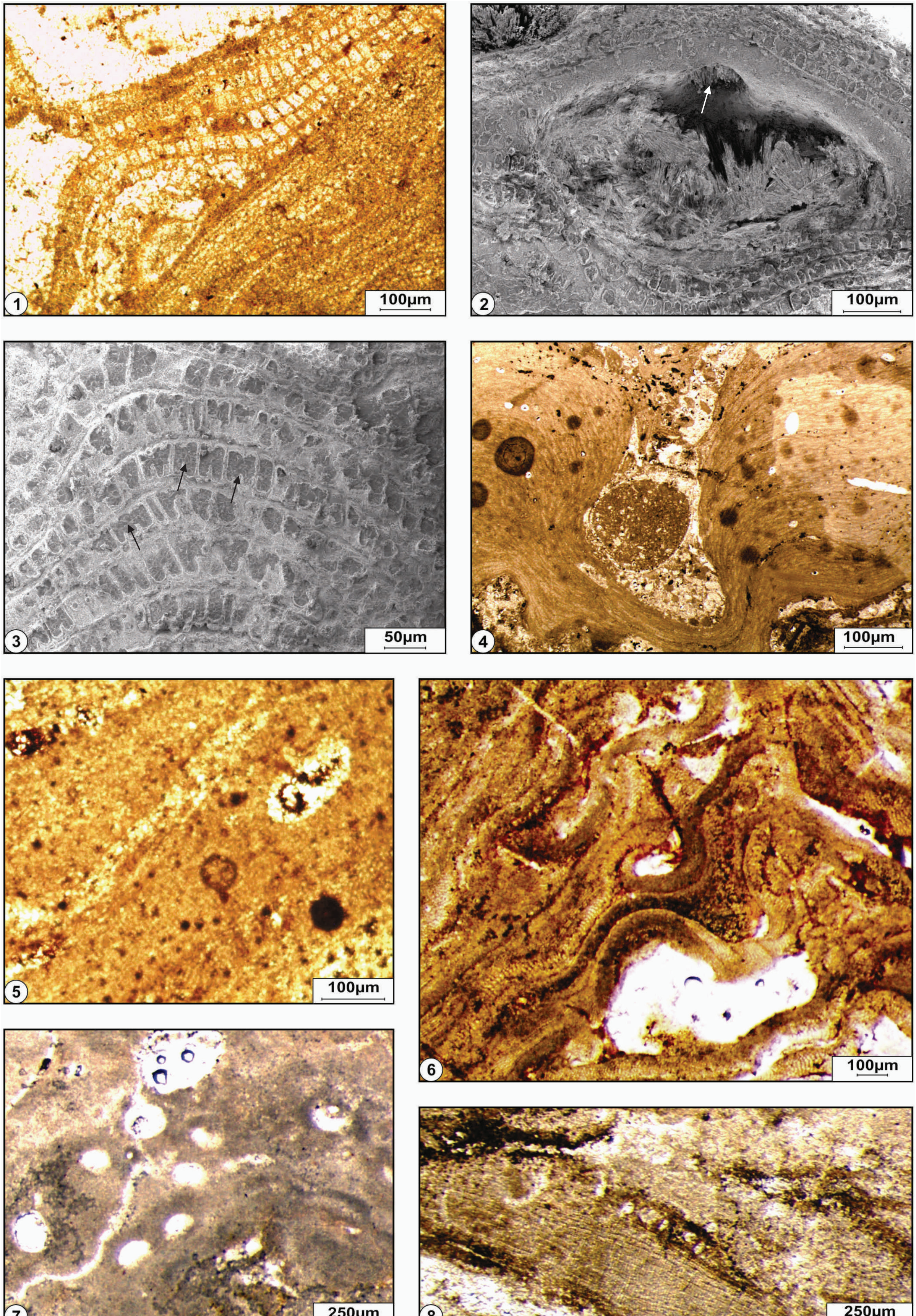
Titanoderma pustulatum Näegeli, 1858, p. 624. - Kishore *et al.,* 2012, p. 217, pl. 1, figs. 1-3. - Kishore *et al.,* 2015, p. 62, pl. 1, fig. 7.

Description: Growth form encrusting. Thallus organization dimerous. Primigenous filaments composed of palisade cells, which are 16-18 µm in length. The diameter of these cells is variable, from 60 to 80 µm. Cells of postigenous filaments

EXPLANATION OF PLATE III

Figs.1-3. ***Lithoporella melobesioides***. 1. Primigenous filaments with conceptacle. 2. Details of uniporate conceptacle (SEM) indicated by an arrow. 3. Showing cell fusions in the thallus indicated by an arrows (SEM). Fig.4. ***Aethesolithon problematicum***: Warty growth-form. Fig. 5. ***Harveylithon munitum***: encrusting growth-form with uniporate conceptacle. Figs. 6-7. ***Harveylithon rupestris***. Fig. 6. Laminar growth-form of the thallus. 7. Uniporate conceptacles in thallus. Fig.8. ***Sporolithon lvovicum***: encrusting growth-form with sporangial compartments.

Plate III



rectangular in shape, measuring 30-40 µm in length and 14-18 µm in width; their length frequently changes due to substrate irregularities. Postigenous filaments consist of well-defined vertical and horizontal cell alignments with flattened epithallial cells. Cell fusions absent. Tetra/bisporangial conceptacles uniporate and variable in shape, measuring 400-450 µm in diameter and 80-100 µm in height. No columella remains were found.

Remarks: The present specimen is identified as *T. pustulatum* (Lamouroux) Nägeli, 1858 on the basis of its palisade cells on the primigenous filaments. *T. pustulatum* is known from the Pleistocene deposits of southern Italy and India (Nalin *et al.*, 2006; Kishore *et al.,* 2012, 2015).

Slide No.: LA/U-73, 78, 85, 118

Locality: Upper part of the sequence at Quarry no. 4 section of Saw Mill road, Little Andaman Island.

Amphiroa sp.
(Pl. II, fig. 7)

Description: Thallus about 700 µm long and up to 600 µm broad, medullary filaments showing alternating rows of long and short cells with the following formula (2L, 1S). Long cells 55-50 µm in length and 8-10 µm in width, short cells 18-20 µm long and 8-10 µm broad, peripheral filaments about 100-120 µm in diameter and cells 8-10 µm in length and 10-12 µm in width. Conceptacles not preserved.

Remarks: The present specimen is identified as *Amphiroa* on the basis of its characteristic alternations of long and short cells in the thallus. The present specimen morphologically resembles with *A. ephedraea* on the basis of alternation of two long and one short cells in the thallus. As our specimen lacks conceptacles, hence, it is left in open nomenclature.

Slide No.: LA/U-122, 131

Locality: Upper part of the sequence at Quarry no. 4 section of Saw Mill road, Little Andaman Island.

Subfamily **Mastophoroideae** Setchell, 1943
Genus *Lithoporella* (Foslie) Foslie, 1909

Lithoporella melobesioides (Foslie) Foslie, 1909
(Pl. II, fig. 8; Pl. III, figs. 1-3)

Lithoporella melobesioides Foslie, 1909, p. 1-63. -Johnson and Ferris, 1950, p. 18-19, pl. 8. fig. A. - Bosence, 1983, p. 165-166, pl. 18, fig. 2. - Bassi, 1998, p. 19, pl. 7, figs. 4-6.

Description: Growth form encrusting to warty. Thallus organization dimerous. Primigenous filaments formed by rectangular cells with many cell fusions. Cell length 35-40 µm, cell diameter 22-28 µm. Postigenous filaments not preserved. Tetra/biosporangial conceptales completely raised above the thallus surface. Conceptacle uniporate, more or less oval in shape, conceptacle height 340-350 µm, diameter 640-650 µm.

Remarks: The thallus morphology, the cell fusions in the primigenous filaments, and the uniporate nature of conceptacles indicate affinity of the present specimen with *Lithoporella melobesioides* (Foslie) Foslie. It is a well known Palaeogene species of of India and other parts of the world. Bassi (1998) reported it from the late Eocene of Northern Italy, and Rasser and Piller (1999) from the late Eocene of the 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.

Slide No.: LA/U-145

Locality: Upper part of the sequence at Quarry no. 4 section of Saw Mill road, Little Andaman Island.

Genus ***Aethesolithon*** Johnson, 1964

Aethesolithon problematicum Johnson, 1964
(Pl. III, fig. 4)

Aethesolithon problematicum Johnson, 1964, p. 50,64, pl. 10A.,fig.1.

Description: Growth form encrusting to warty. Thallus organization monomerous, core filaments poorly preserved. Peripheral filaments well preserved. Cells of the peripheral filaments distinct hence cell fusions abundant. Cells are polygonal or rounded in shape, 18-20 µm in length and 12-16 µm in width. Epithallial cells not observed. Tetra/bisporangial conceptacles' pore not distinct; its size ranges from 220- 250 µm in diameter and 170-180 µm in height.

Remarks: The present specimens are identified as *Aethesolithon problematicum* on the basis of polygonal shape of cells of peripheral filaments and referable to *Aethesolithon problematicum* in general shape, size of peripheral filaments. In the present study, we included this genus under subfamily Mastophoroideae according to taxonomic classification of Harvey *et al*., 2003. Johnson (1964) has reported this species from the Miocene of Guam and Philippine Islands. Rösler *et al.* (2015) reported this species from the Miocene of the Southeast Asia.

Slide No.: LA/U-85

Locality: Upper part of the sequence at Quarry no. 4 section of Saw Mill road, Little Andaman Island.

Subfamily **Metagoniolithoideae** (Johansen) Rösler *et al.,* 2016
Genus ***Harveylithon*** Rösler *et al.,* 2016

Harveylithon munitum (Foslie and Howe) Rösler *et al*., 2016
(Pl. III, fig. 5)

Lithophyllum munitum Foslie and Howe, 1906, p. 132.

Hydrolithon munitum (Foslie and Howe) Penrose, 1996, p. 263.

Harveylithon munitum Rösler et al., 2016, p. 425.

Description: Growth form encrusting, with a thallus thickness of encrusting portion usually 330-350 µm. Thallus organization monomerous and their core filaments non-coaxial. Core portion usually 100-120 µm thick with cell fusions. Cell length 10-12 µm, cell diameter 8-10 µm. The cells of peripheral region restricted to the dorsal part of the thallus. Cell length 6-8 µm, diameter 6-8 µm. The epithallial cells not preserved. Cells of adjacent filaments joined by cell fusions; secondary pit-connections not observed. Trichocytes occurring singly on the thallus surface, commonly becoming buried within the thallus. Tetra/bisporangial conceptacles uniporate, rectangular with rounded corner in shape. Conceptacle height 80-90 µm, diameter 160-180 µm.

*Remarks***:** The thallus morphology, presence of cell fusions, trichocytes, and the uniporate conceptacles indicate affinity of the present specimen with *Harveylithon munitum*. The thallus organization and the shape and size of the cells also suggest closeness with this taxon. Malakar *et al.* (2016) reported this species from the shallow reef of the South Andaman, India. Recently, Rösler et al. (2016) transferred this taxon (*Hydrolithon* *samöense*) to *Harveylithon*, a new genus created by them in the subfamily Metagoniolithoideae.

Slide No.: LA/U-156

Locality: Upper part of the sequence at Quarry no. 4 section of Saw Mill road, Little Andaman Island.

Harveylithon rupestris (Foslie) Rösler *et al*., 2016
(Pl. III, figs. 6-7)

Lithophyllum rupestre Foslie, 1906, p. 132.
Hydrolithon rupestris (Foslie) Penrose, 1996, p. 265.
Haryveylithon rupestris (Foslie) Rösler *et al*., 2016, p. 424.

Description: Growth form encrusting to layer, with a thallus thickness of encrusting portion usually 230-250 µm. Thallus organization monomerous and their core filaments non-coaxial. Core portion usually 70-80 µm thick with cell fusions. Cell length 10-12 µm, cell diameter 8-10 µm. The cells of peripheral region restricted to the dorsal part of the thallus. Cell length 8-10 µm, cell diameter 6-8 µm. The epithallial cells not preserved. Cells of adjacent filaments joined by cell fusions; secondary pit-connections not observed. Trichocytes occurring singly on the thallus surface, commonly becoming buried within the thallus. Tetra/bisporangial conceptacles uniporate and their shape vary from rounded to oval or other shape. Conceptacle height 120-130 µm, diameter 160-180 µm.

*Remarks***:** The present specimens are identified on the basis of its tetra/bisporangial conceptacles nature. The uniporate conceptacles shape and size indicate its closeness with *Harveylithon rupestris*. Rösler *et al.* (2015) reported this species from the Miocene of the Southeast Asia. Rösler *et al*. (2016) transferred this taxon (*Hydrolithon rupestris*) to *Harveylithon*, a new genus created by them in the subfamily Metagoniolithoideae.

Slide No.: LA/U-176, 210

Locality: Upper part of the sequence at Quarry no. 4 section of Saw Mill road, Little Andaman Island.

Family **Sporolithaceae** Verheij, 1993
Genus ***Sporolithon*** Heydrich, 1897

Sporolithon lvovicum (Maslov) Pisera, 1985
(Pl. III, fig. 8)

Archaeolithothamnium lvovicum Pisera, 1985, p. 9, pl. 1, figs. 5-6. - Pisera and Studencki, 1989, p. 193, pl. 5, figs. 1a-1b. Kishore *et al.,* 2012, p. 222, pl. 5, figs. 1-2.

Description: Growth form encrusting to warty, thickness of encrusting thalli up to 500 µm. Thallus organization monomerous. Core filaments non-coaxial, core portion 70-80 µm thick. Cells 20-24 µm in length and 08-10 µm in width, cell fusions present. The peripheral region of encrusting portion of thallus usually 650 µm. Cell length 14-16 µm and width 8-12 µm, cells are rectangular in shape, cell fusions present.

Uniporate sporangial compartments arranged in sori. Individual sporangial compartments with rounded to elliptical or ovoid corners in longitudinal section and circular in transverse section; sporangia 60-70 µm in height and 40-50 µm in width. 1-3 filaments (paraphyses) are interspersed between the sporangial compartments.

Remarks: Following Woelkerling (1988), and 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). Kishore *et al.* (2012) have reported this species from the Pleistocene of Dwarka, India.

Slide No.: LA/U-170, 195, 235

Locality: Upper part of the sequence at Quarry no. 4 section of Saw Mill road, Little Andaman Island.

DISCUSSION

The present paper records thirteen species of coralline algae from the upper limestone member of the Hut Bay Formation, Little Andaman. These include *Mesophyllum obsitum, M. curtum, M. koritzae, M. commune, Phymatolithon calcareum, Lithophyllum nitorum, Titanoderma pustulatum, Amphiroa* sp., *Lithoporella melobesioides, Aethesolithon problematicum, Harveylithon munitum, H. rupestris* and *Sporolithon lvovicum* (Fig. 2). Out of these, seven species belong to the family Corallinaceae, five are assigned to the family Hapalidiaceae and one to the family Sporolithaceae. *Harveylithon rupestris* is here recorded for the first time in India, while the other eight species: *Mesophyllum obsitum, M. curtum, M. koritzae, M. commune, Phymatolithon calcareum, Aethesolithon problematicum, Harveylithon munitum,* and *Sporolithon lvovicum* are new to the study area. The stratigraphic distribution of the recorded coralline algal species shows that they range from the Neogene to Recent in different parts of the world.

The coralline algal assemblages of Hut Bay Formation can be broadly differentiated into two associations (Fig. 2): first association developed in the lower part of the limestone unit which appears to indicate deposition in deep cool water environment with low-energy conditions, and second association developed in the Upper part of the limestone unit which indicates shallow warm water environment characterized by high energy conditions.

The lower association is less diverse in comparison to the upper one. Planktic foraminifera are common in the lower part where corals are absent. This association is dominated by *Mesophyllum*, and *Phymatolithon* with their layered growth-forms. The strictly warm-water taxa such as *Sporolithon,* is missing in the lower association indicating cool environment conditions which prevent the growth of *Sporolithon* during this time. The presence of cool water taxa such as *Lithophyllum* and *Phymatolithon* also supports our view. The dominant melobesioid coralline algae and their growth-forms indicate a depositional environment under cool water, lower photic zone with low-energy conditions (Kroeger *et al*., 2006; Braga *et al*., 2010).

The upper association is more diverse than the lower association, and it contains coralline algae, foraminfera, corals, molluscs, echinoids, etc. The varying composition of the communities in the upper part may suggest a variation in light, temperature, depth and energy conditions. The presence of corals and diversified coralline algal forms indicate that the depositional environment was suitable for reefal organisms such as corals and coralline algae. This association is dominated by the typical tropical coralline algal assemblage (*Sporolithon*, *Lithoporella*, and *Aethesolithon*) with their encrusting to warty growth-forms. The presence of corals also supports the warm water condition. This association indicates shallow, warm-water environment with high energy conditions. This environment favoured development of warm-water coralline algal taxa (e.g. *Sporolithon*, *Lithoporella*), corals and encrusting foraminifera (Braga *et al.,* 2010).

CONCLUSIONS

All the coralline algal genera recorded in the Middle Miocene of the Little Andaman are still living and have a well known geographical and ecological distribution. Even certain species of coralline assemblages of Middle Miocene are still extant such as *Phymatolithon calcareum, Lithophyllum nitorum, Titanoderma pustulatum, Lithoporella melobesioides, Harveylithon munitum* and *H. rupestris*. Most of the recorded species are common components of the crustose coralline algae (CCA) assemblages of present-day Indo-Pacific reefs. The recorded assemblage of coralline algae is characterized by the presence of *Lithoporella, Sporolithon* and *Aethesolithon,* which indicate a tropical environment since these plants occur in present-day tropical waters (Brandano *et al.,* 2005; Braga *et al.,* 2010). The presence of temperate water genus such as *Lithophyllum* (Lithophylloideae) suggests a cooler climatic condition. The present algal data indicates that the cool climate prevailed in the lower part of limestone while warm climatic condition prevailed in the upper part of limestone unit of the Hut Bay Formation. The presence of corals in the upper part of limestone of this formation also supports our view.

The Hut Bay Formation is characterized by diverse assemblages of corals, coralline algae, foraminifera, echinoids and molluscs assemblages that colonized the carbonate platform during the Middle Miocene in the study area. The changes noticed in the coralline algal associations, in the studied sequence shows sea-level fluctuations, temperature and hydrodynamic conditions. The Hut Bay Formation was deposited in cool and warm climatic conditions which favour both the development of temperate and tropical coralline algal assemblages. Cooling effect hampered the warm coralline algal taxa in the lower part of the study area until the climatic optimum as seen in the upper part where tropical environments expanded and facilitated the growth of warm-water taxa of coralline algae. The upper part of the limestone member is well developed in Little Andaman Island, where the carbonate-precipitating organisms (e.g. corals, molluscs, larger benthic foraminifera and corallines) appear in abundance. This data may useful in future studies of coralline algae of this area in the context of climatic change. The depositional environment of this formation appears to have shifted from the deeper out-ramp to shallow subtidal inner-ramp setting which resulted in increased hydrodynamic energy of the study area. A clear shallowing-upward trend is indicated by the deeper to shallow water coralline algal associations. Decreasing water depths, increasing hydrodynamic energy and change in temperature might have also caused changes in habitat conditions resulting in the development of depth-controlled benthic communities of corals, larger foraminifera, molluscs and coralline algae.

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