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CORALLINE ALGAE FROM THE NEILL WEST COAST FORMATION (PLEISTOCENE), NEIL ISLAND, SOUTH ANDAMAN, INDIA

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ABSTRACT

The Pleistocene sediments represented by the Neill West Coast Formation (Upper Limestone Member, raised to the rank of formation named as the Neill Formation) exposed at Natural Bridge, Neil Island, South Andaman are characterized by coralline algae, corals and foraminifera. In the present paper, eleven species belonging to eleven genera of coralline algae are described. Out of these, one species (*Sporolithon kuboiensis*) is a new record for India. Ten species (*Metagoniolithon* sp., *Corallina* sp., *Jania* sp., *Lithophyllum nitorum, Amphiroa* sp., *Hydrolithon* sp., *Titanoderma pustulatum, Spongites fruticulosus, Mesophyllum obsitum* and *Phymatolithon calcareum*) 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 shallow, cool-water under very high-energy conditions, and the other developed in the upper part indicating deposition in shallow, warm-water environment with moderate energy conditions.

Keywords: Coralline algae, Upper Limestone Member (= Neill Formation) of the Neill West Coast Formation, Pleistocene, Neil Island, South Andaman.

INTRODUCTION

Recently, considerable interest has been growing among micropalaeontologists for studying carbonate fossils (e.g. coralline algae and foraminifera) of all ages and areas in the world (Rasser and Piller, 1999; Nebilsick *et al.,* 2000; Misra *et al.,* 2002; Brandano *et al.,* 2005; Amen *et al.,* 2005; Jauhri *et al.,* 2006; Vannucci *et al.,* 2006; Consigliere, 2007; Iryu *et al.,* 2009; Braga et al., 2009; Bassi and Nebelsick, 2010; Singh *et al.,* 2011; Agiurre *et al.,* 2011, 2012; Kishore *et al.,* 2012; Nebelsick *et al.,* 2013; Kundal, 2014 and Rebelo *et al.,* 2014). However, little detailed studies on these fossils have so far been carried out from the sediments of the Andaman and Nicobar Islands. The planktic microfossil groups (e.g. foraminifera, diatoms coccoliths and radiolarians) from the Mio-Pliocene sediments have received considerable attention (Srinivasan and Azmi, 1976; Singh *et al.,* 1978; Sharma and Sharma, 1988; Jafar and Singh, 1999). The coralline algae, on the other hand, have sporadically been reported from the Neogene sequences of these islands (Gee, 1927; Narayana Rao, 1942; Chatterji and Gururaja, 1972; Venkatachalapathy and Gururaja, 1984 and Chandra *et al.,* 1999). Moreover, their studies are also not based on the present day taxonomic concept of non-geniculate coralline algae. Recently, Ghosh and Sarkar (2013) and Sarkar and Ghosh (2014) have carried out facies analysis and palaeoenvironmental interpretations of the Guitar Formation (late Pliocene) of Car Nicobar Island and the Serravallian sediments of Little Andaman Island on the basis of coralline algae and associated foraminifera, but they do not provide taxonomic details of the studied coralline taxa such as *Mesophyllun, Phymatolithon, Lithothamnion* and *Titanoderma.* Hence, their generic identifications cannot be considered precise. We are of opinion that the previously described coralline algal species of various authors of the Andaman-Nicobar areas need critical revision for their correct generic identification and systematic position. We provide new data on coralline algae from the Upper Limestone Member (which, according to Pandey *et al*., 1993, can be raised to the rank of a formation: Neill Formation) of the Neill West Coast Formation, 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 by a channel at 10^0N 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 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 (Fig. 1).

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 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 mudstones, siltstones, chalk and limestones which were deposited under fluctuating 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 sequence at Neil Island can be subdivided into the Round Formation, the Guitar Formation, and the Malacca Limestone Formation (Singh *et al.*, 1978). The West Coast Limestone, Malacca Limestone and Neill Island Limestone in Singh and Vimal (1974, 1976) and Singh *et al.* (1978) correspond here to the Neill West Coast Formation. According to Sharma and Srinivasan (2007), the Malacca Limestone Formation of Car Nicobar Island and Chowra Limestone Formation of Chowra Island correspond in age to a part of the Neill West Coast Formation. Srinivasan and Azmi (1976) suggested that Neil Island is a type locality for the Neill West Coast Formation which is divisible into two units, i.e. the Lower Silty Mudstone Member and the Upper Limestone Member, the latter disconformably overlying the former. Pandey *et al.* (1993) indicated that the Limestone Member can be considered to represent the rank of formation. It was designated as the

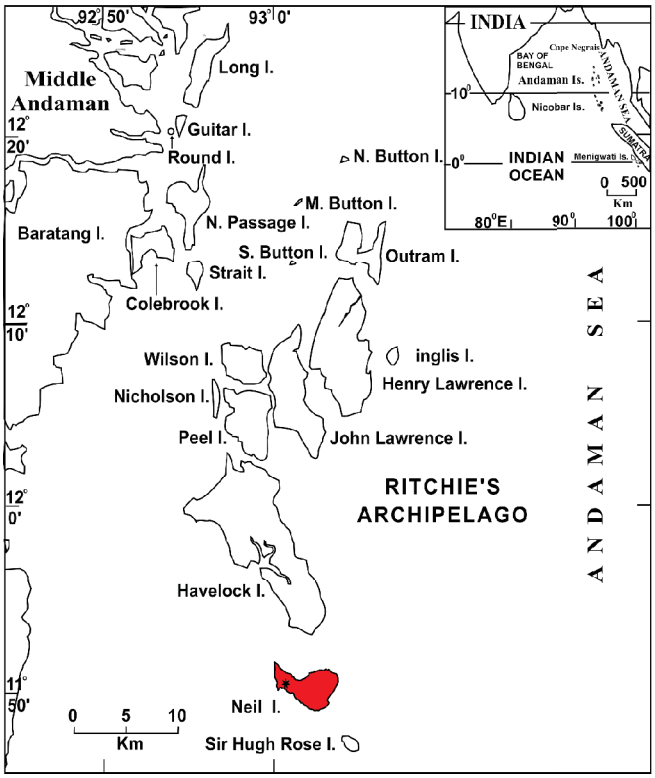


Fig.1. Location map of the study area (*) in the Andaman Islands.

Neill Formation with west coast section as its type section. The formation is made up of fine to medium, compact to porous, buff coloured limestone comprising fragments of foraminifera, corals, algae and quartz grains. It is conformably overlain by Subrecent to Recent Shell limestone and coral rags. Pandey *et al.* (1993) suggested the Pleistocene age to this formation on the basis of *Globorotalia truncatulinoides*.

MATERIAL AND METHODS

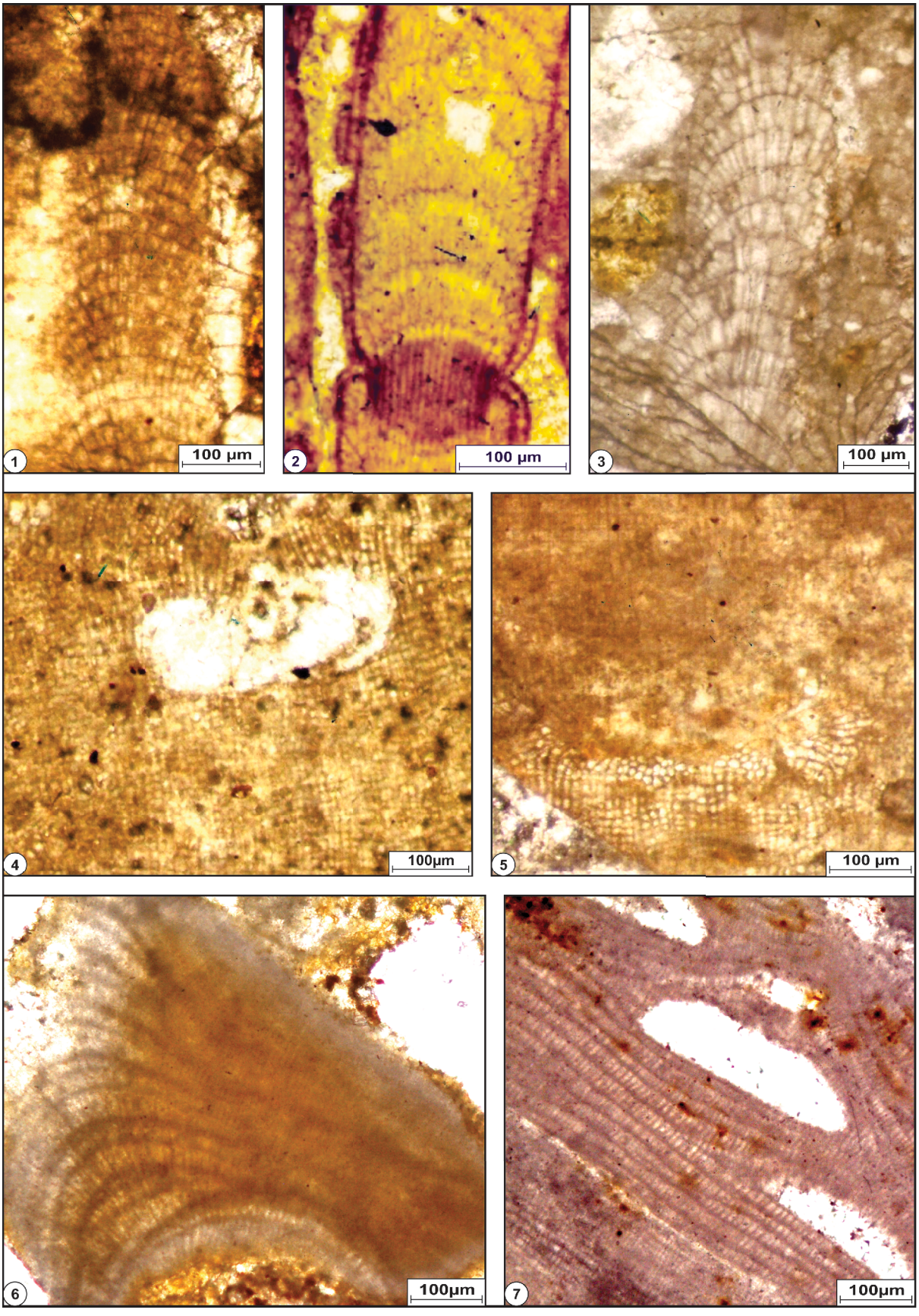
The present work is based on the study of samples collected from 6.5 m thick sequence of the Upper Limestone Member (= Neill Formation) of the Neill West Coast Formation exposed at the Natural Bridge section of Neil Island (11° 49' 933" N: 93° 00' 845" E), South Andaman (Fig. 2). Its thickness is variable, but maximum thickness is observed in the central part near the bridge. The lower part is partially consolidated and weathered in a honeycomb fashion and dips west to slightly northwest at 20° and the upper white argillaceous part is variable in thickness (1.5 m). It is a buff coloured, fossiliferous, argillaceous, limestone containing corals, foraminifera, and coralline algae. 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 35 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, while

EXPLANATION OF PLATE I

Figs. 1-7. Coralline algae.

1. ***Metagoniolithon*** sp.; 2. ***Corallina*** sp.; 3. ***Jania*** sp.; 4, 5. ***Lithophyllum nitorum***.; 4. Uniporate conceptacle in postigenous filaments; 5. Dimerous thallus organization (postigenous and primigenous filaments); 6. ***Amphiroa*** sp., showing medullary and peripheral filaments; 7. ***Titanoderma pustulatum***, showing uniporate conceptacle in postigenous filaments.

Plate I



some important taxonomic features such as cell connections, epithallial cells and conceptacles were studied under Scanning Electron Microscopy (SEM). SEM observations of the polished and etched specimens allowed recognition of all the above-mentioned characters which are significant in taxonomic determination of fossil algal taxa. We follow the SEM method as given by Woelkerling (1988) and Braga *et al*. (1993) with some modifications as desired by the specimens.

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 **Florideophyceae** Cronquist, 1960
Subclass **Corallinophycidae** Le Gall and Saunders, 2007
Order **Corallinales** Silva and Johansen, 1986
Family **Corallinaceae** Lamouroux, 1812
Subfamily **Metagoniolithoideae** Johansen, 1969
Genus ***Metagoniolithon*** Weber-van Bosse, 1904
Metagoniolithon sp.
(Pl.I, fig. 1)

Description: Plant geniculate, fragments of thalli about 690 µm in length and 160-180 µm in diameter. Genicula not preserved. Cells of intergenicular region 20-25 µm in length and 6-8 µm in diameter, rectangular in shape and in regular tiers with cell fusions. Cells of cortical region poorly preserved. Conceptacles not preserved.

Remarks: The present specimen is identified as *Metagoniolithon* sp. on the basis of its morphological characters (e.g. cell shape and size). It is the only genus of the Metagoniolithoideae that shares some characters with *Amphiroa* (such as conceptacle development), but markedly differs from the latter in cells being joined by cell-fusions rather than by secondary pit-connections. It also differs from other geniculate coralline taxa by its characteristic morphology of cell shape, size and their arrangement in tiers in the intergeniculum region. It is comparable with a form described from the late lower Miocene (Burdigalian) of the Chhasra Formation of the Kachchh district Gujarat, India (Kundal and Humane, 2006).

Slide No.: N/M-5B

Locality: Lower part of the sequence at Natural Bridge section of Neil Island.

Subfamily **Corallinoideae** (Areschoug) Foslie, 1908
Genus ***Corallina*** Linnaeus, 1758
Corallina sp.
(Pl. I, fig. 2)

Description: Plant geniculate, fragments of thalli about 600-650 µm in length and 200-225 µm in diameter. Genicula well preserved. Cells of intergenicular region 60-75 µm in length and 8-10 µm in diameter. Only two layers of cells of the cortical tissue preserved, rounded in shape. Conceptacles not preserved.

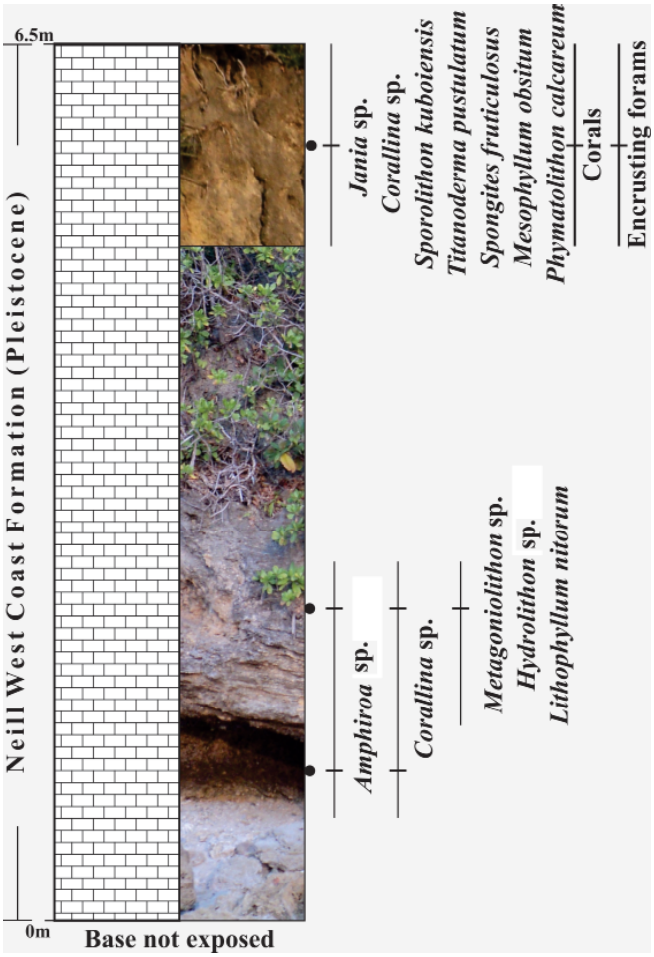


Fig.2. Distribution of coralline algal species in the Neill West Coast Formation, Natural Bridge, Neil Island, South Andaman.

Remarks: The present specimen is identified as *Corallina* on the basis of its cell shape and size. The present specimen shows resemblance with *Corallina typica* Ishijima in cell shape and size of the intergenicular region as described by Ishijima (1954). However, the present specimen lacks conceptacles, and is therefore kept in an open nomenclature.

Slide No.: N/M-6; N/U-35

Locality: Lower and upper parts of the sequence at Natural Bridge section of Neil Island.

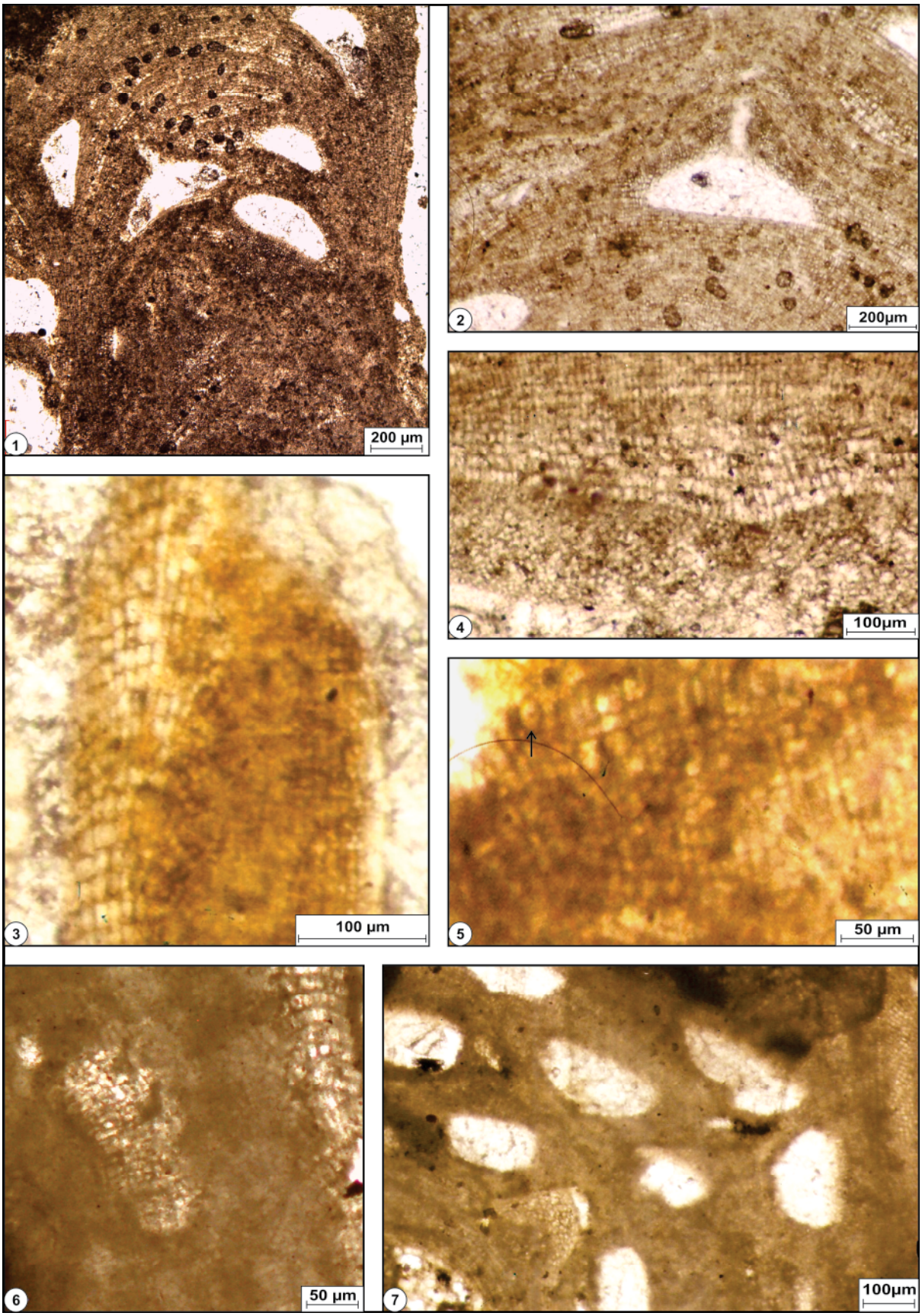
Genus **Jania** Lamouroux, 1812
Jania sp.
(Pl. I, fig. 3)

Description: Plant geniculate, fragments of thalli about 700-750 µm in length and 250-280 µm in diameter. Genicula not preserved. The medullary tissue consists of layers of cells like inverted saucer. The cells are longest at the center of the layer, becoming slightly smaller toward the margins. Center cells of intergenicular region 40-50 µm in length and 8-12 µm in width. Conceptacles not preserved.

EXPLANATION OF PLATE II

Figs. 1-7. Non-geniculate coralline algae.
1, 2, 4. ***Spongites fruticulosus***; 1. Fruticose growth-form; 2. Uniporate conceptacle in the peripheral region; 4. Monomerous organization of thallus; 3, 5. ***Hydrolithon*** sp.; 3. Monomerous thallus organization; 5. Enlarged view of postigenous filaments with trichocytes (indicated by arrow); 6-7. ***Mesophyllum obsitum***; 6. Multiporate conceptacles and co-axial filaments; 7. Thallus with many conceptacles.

Plate II



Remarks: The present specimen is identified as *Jania* on the basis of its inverted, saucer-shaped cells in the medullary region. The present specimen resembles *Jania vetus* Johnson in shape and size of cells in the medullary region of the thallus, as described by Johnson (1966). Because of absence of conceptacles, it is kept in an open nomenclature.

Slide No.: N/U-9

Locality: Upper part of the sequence at Natural Bridge section of Neil Island.

Subfamily **Lithophylloideae** Setchell, 1943

Genus ***Lithophyllum*** Phillippi, 1837

Lithophyllum nitorum Adey and Adey, 1973

(Pl. I, figs. 4, 5; Pl. IV, fig. 1)

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 formed by rectangular cells, which are usually 8-10 µm in length and 15-20 µm in diameter. Postigenous filaments are conspicuous and well developed. Cells of the postigenous filaments rectangular in shape and measuring 10-12 µm in length and 8-10 µm in diameter. Primary pit-connections observed (Pl. IV, fig. 1), cell fusions are absent. Epithallial cells not seen. Tetra/bisporangial conceptacles are uniporate, pore canals tapering to the conceptacle roof. They measure 320-330 µm in diameter and 120-125 µm in height.

Remarks: The present specimen shows similarity with *Lithophyllum nitorum* 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. Kishore *et al.* (2012) have reported this species from the Pleistocene Chaya Formation, Dwarka area, Gujarat, India.

Slide No.: N/M-5B

Locality: Lower part of the sequence at Natural Bridge section of Neil Island.

Amphiroa sp.

(Pl. I, fig. 6)

Description: Thallus about 700 µm long and up to 750-790 µm broad, medullary filaments showing alternating rows of long and short cells with following formula (2L, 1S). Long cells 55-60 µm in length and 6-8 µm in width, short cells 18-20 µm long and 6-8 µm broad, peripheral filaments about 120-150 µm in diameter and cells 5-8 µm in length and 8-10 µm in width. Conceptacles not preserved.

Remarks: As our specimen lacks conceptacle, it is left in open nomenclature and identified as *Amphiroa* on the basis of alternations of long and short cells in the thallus, though it morphologically it seems close to *A. pacifica* Johnson and Ferris; see Johnson and Ferris (1950).

Slide No.: N/B-6

Locality: Lower part of the sequence at Natural Bridge section of Neil Island.

Genus ***Titanoderma*** Nägeli, 1858

Titanoderma pustulatum (Lamouroux) Nägeli, 1858

(Pl. I, fig. 7; Pl. IV, figs, 2-3)

Titanoderma pustulatum Nägeli, 1858, p. 624. - Kishore *et al.,* 2012, p. 217, pl. 1, figs. 1-3.

Description: Growth form encrusting. Thallus organization dimerous. Primigenous filaments composed of palisade cells (Pl. IV, fig. 2), which are 12-16 µm in length. The diameter of these cells is variable, from 50 to 80 µm. Cells of postigenous filaments 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 up to six or more cells with well-defined vertical and horizontal cell alignments with flattened epithallial cells (Pl. IV, fig. 3). Cell fusions absent. Tetra/bisporangial conceptacles uniporate, measuring 350-500 µm in diameter and 120-150 µm in height. No columella remains have been found in any sample.

Remarks: The taxonomic status of *Titanoderma* has been controversial for many 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 phylogenetically distinct genera and should be treated as separately. The present specimen is identified as *T. pustulatum* (Lamouroux) Nägeli, 1858 on the basis of its palisade cells of the primigenous filaments. *T. pustulatum* is known from the Pleistocene deposits of southern Italy and western India (Nalin *et al.*, 2006; Kishore *et al.,* 2012).

Slide No.: N/U-4

Locality: Upper part of the sequence at Natural Bridge section of Neil Island.

Subfamily **Mastophoroideae** Setchell, 1943

Genus ***Spongites*** Kützing, 1841

Spongites fruticulosus Kützing, 1841

(Pl. II, figs. 1, 2, 4; Pl. IV, fig. 4)

Spongites fruticulosus Kützing, 1841, p. 33. - Woelkerling, 1985, p. 135–139, 150, figs 23–32. - Penrose, 1991, p. 440, figs.1–3. - Amen *et al.,* 2005, p. 65, figs, 4A-d. - Basso and Rodondi, 2006, p. 404, figs. 1-6.

Description: Thallus about 5.5 cm long and up to 3.8 cm broad, warty to fruticose, growing as rhodoliths. Thallus organization monomerous with non-coaxial core filaments (Pl. IV, fig. 4). Core filaments one to five or more cells thick, running more or less parallel to the substrate and rectangular in sections. Cells of core filaments 16-18 µm in length and 8-10 µm in width. Postigenous filaments well developed, cell fusions observed. Cells are 14-16 µm in length and 10-12 µm in width. Epithallial cells not observed.

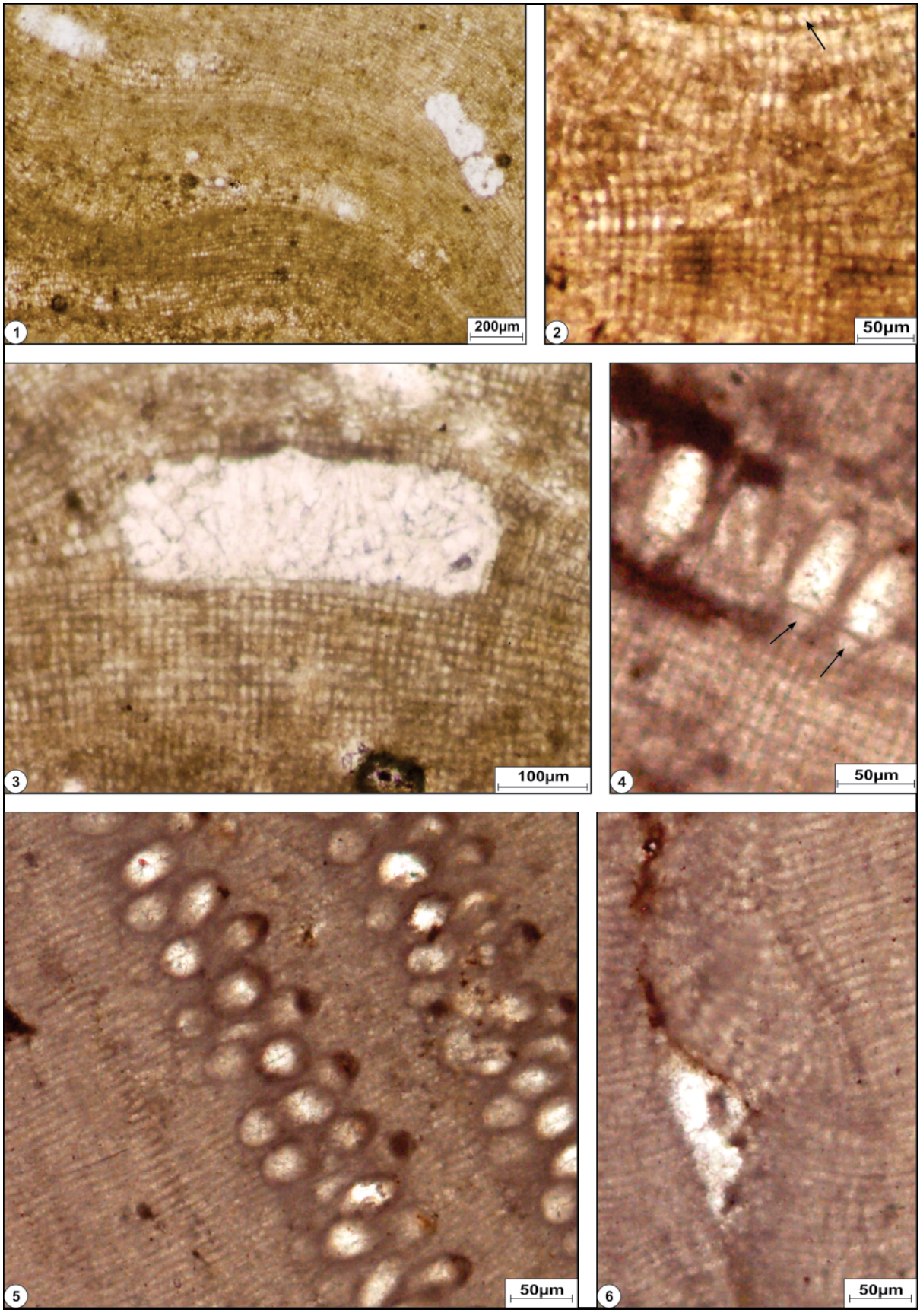
Tetra/bisporangial conceptacles numerous, sunken, bean-shaped in section and uniporate with cylindrical pore canal. Pore canal 150-170 µm long and 40-50 µm in diameter, lined by numerous small cells arranged in 10-11 filaments subparellel to the roof surface. The conceptacles buried within the thallus. Conceptacle size ranges from 450-500 µm in diameter and from 180 to 205µm in height.

EXPLANATION OF PLATE III

Figs. 1-6. Non-geniculate coralline algae.

1-3. ***Phymatolithon calcareum***; 1. Multiporate conceptacles in thallus; 2. Rounded epithallial cells (indicated by arrow); 3. Enlarged view of multiporate conceptacles in peripheral filaments; 4-6. ***Sporolithon kuboiensis***; 4. Trapezoidal stalk cells occur at the base of some tetrasporanial compartments (indicated by arrows); 5. Rounded tetrasporanial compartments in transverse section; 6. Monomerous thallus organization.

Plate III



Remarks: The present specimen is comparable with *Spongites fruticulosus* Kützing described from the Mediterranean region on the basis of its fruticose morphology, non-coaxial core filaments, cell fusions and several uniporate conceptacles buried in the peripheral region (Basso and Rodondi, 2006). Pore canal lined by cells oriented parallel to the thallus surface also supports inclusion of the present specimen in *Spongites fruticulosus* (see Basso and Rodondi, 2006). Braga and Aguirre (2001) reported it from the Upper Pliocene of Southern Spain, and Amen *et al.* (2005) from the Quaternary of Santa Maria Island (Azores, NE Atlantic).

*Slide No.:*N/U-23

Locality: Upper part of the sequence at Natural Bridge section of Neil Island.

Subfamily **Hydrolithoideae** Kato and Baba in Kato *et al.* 2011

Genus ***Hydrolithon*** (Foslie) Foslie, 1909

Hydrolithon sp.

(Pl. II, figs. 3, 5)

Description: Growth form encrusting, attached to hard substrate, mostly on other coralline thalli. Thallus thickness is variable, from 225-445 μm. Thallus organization monomerous with non-coaxial core filaments. Cells of the core filaments mainly rectangular, measuring 18–20 μm in length and 10–12 μm in diameter. Cells of peripheral filaments are irregular with trichocytes, 20-22 μm in height and 12-15 μm in diameter (Pl. II, fig. 5). Cells of peripheral filaments, 8-10 μm in length and 10-12 μm in diameter. Conceptacles not preserved.

Remarks: The thallus morphology, presence of cell fusions and trichocytes indicate affinity of the present specimen with genus *Hydrolithon*. Though our specimen lacks conceptacles, the presence of well-preserved trichocytes in the peripheral region indicates some affinity with *Hydrolithon breviclavium*. Thallus organization and the shape and size of the cells also suggest closeness with this taxon. Henriques *et al.* (2014) reported it from the Brazilian continental shelf. Recently, Kato *et al*. (2011) split Mastophoroideae subfamily on the basis of molecular data and vegetative and reproductive anatomy of modern coralline algae into three new subfamilies, Porolithoideae, Neogoniolithoideae and Hydrolithoideae, while retaining Mastophoroideae as one of the related subfamilies. However, the taxonomic placement of *Spongites* has been left unresolved (Hrabovský *et al*., 2015).

Slide No.: N/M-5

Locality: Lower part of the sequence at Natural Bridge section of Neil Island.

Family **Hapalidiaceae** Gray, 1864

Subfamily **Melobesioideae** Bizzozero, 1885

Genus ***Mesophyllum*** Lemoine, 1928

Mesophyllum obsitum Airoldi, 1932

(Pl. II, figs. 6-7; Pl. IV, fig. 5)

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, thallus organization monomerous. Coaxial to non-coaxial core filaments well developed, 50-150 μm thick, cells of core filaments 18-20 μm in length and 12-15 μm in width; cell fusions present. Peripheral filaments well developed with cell fusions (Pl. IV, fig. 5). Cells are 15-20 μm in length and 10-12 μm in width. Epithallial cells rounded in shape. Tetra/bisporangial conceptacles variable in shapes and multiporate, 120-130 μm in height and 200-250 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. It was reported from the Oligocene of Italy. Basso *et al.* (1998) have revised and re-documented this species on the basis of coaxial to non-coaxial core filaments. Studencki (1988) reported this species from middle Miocene of Poland.

Slide No.: N/U-31

Locality: Upper part of the sequence at Natural Bridge section of Neil Island.

Genus ***Phymatolithon*** Foslie, 1898

Phymatolithon calcareum (Pallas) Adey and McKibbin, 1970

(Pl. III, 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 1.2 mm. Thallus organization monomerous. Core portion non-coaxial, 120-150 μm thick, cell fusions present. Cells 21-25 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 (Pl. III, fig. 2). Tetra/bisporangial conceptacles multiporate, 140-150 μm in height and 400-450 μm in width.

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

Slide No.: N/U-24

Locality: Upper part of the sequence at Natural Bridge section of Neil Island.

Order **Sporolithales** Le Gall, Payri, Bittner and Saunders, 2010

Family **Sporolithaceae** Verheij, 1993

Genus ***Sporolithon*** Heydrich, 1897

Sporolithon kuboiensis (Ishijima) Iryu, Bassi and Woelkerling, 2009

(Pl. III, figs. 4-6; Pl. IV, fig. 6)

Archaeolithothamnium kuboiensis Ishijima, 1942, p. 358, pl. 2, figs. 1-3.

Sporolithon kuboiensis (Ishijima) Iryu *et al.,* 2009, p. 418, pl. 4, figs. 1-3.

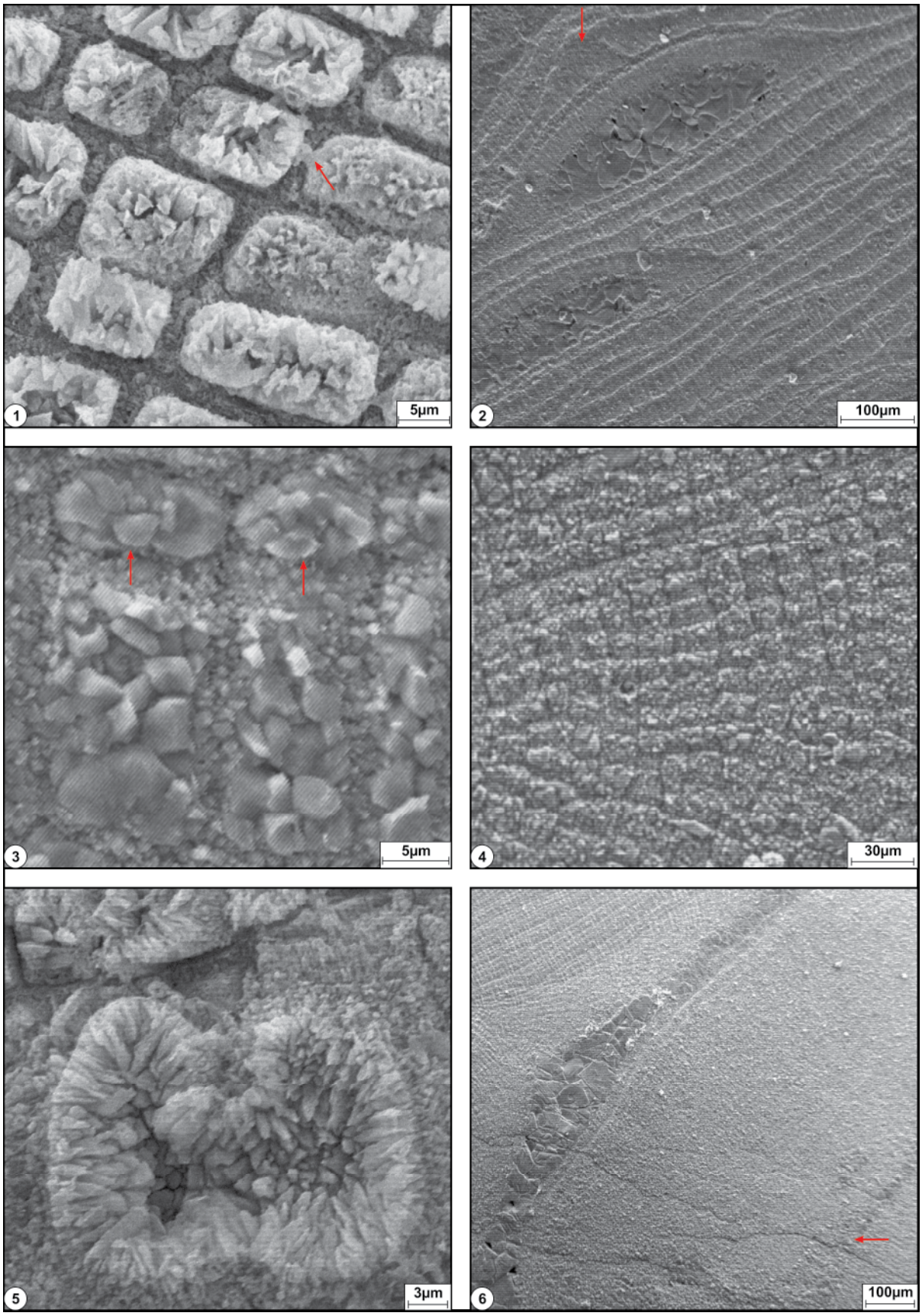
Description: Growth form encrusting to warty, thickness of encrusting thalli up to 1.2 mm. Thallus organization monomerous (Pl. IV, fig. 6). Core filaments non-coaxial, core portion 180-210 μm thick. Core cells 12-15 μm in length and 8-10 μm in width, cell fusions present. The peripheral region of encrusting

EXPLANATION OF PLATE IV

Figs. 1-6. Non-geniculate coralline algae.

1. ***Lithophyllum nitorum***, shows postigenous (small) and primigenous (large) cells and primary pit-connections (indicated by arrow); 2, 3. ***Titanoderma pustulatum***; 2. Showing uniporate conceptacle and palisade cells (indicated by arrow); 3. Postigenous filaments show flattened epithallial cells; 4. ***Spongites fruticulosus***, non-coaxial core filaments and peripheral filaments; 5. ***Mesophyllum obsitum***, cell fusion; 6. ***Sporolithon kuboiensis***, non-coaxial core filaments, peripheral filaments and tetrasporanial sori (indicated by arrow).

Plate IV



portion of thallus usually 430 μm. Cell length 10-12 μm and width 6-8 μm, cells are rectangular in shape, cell fusions present. Sporangial compartments arranged in sori, mostly sectioned in transverse oblique direction. The compartments, 50-60 μm in height and 35-40 μm in width. Trapezoidal stalk cells occur at the base of some compartments. 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* Heydrich, 1897 over *Archaeolithothamium* Rothpletz, 1891, it is noted that the calcified sporangial compartments are diagnostic of *Sporolithon*, family Sporolithaceae (Verheij, 1993). Recently, Lee Gall *et al*. (2010) separated Sporolithaceae family from the order Corallinales and placed it into a separate order Sporolithales on the basis of multiple phlylogenetic analysis.

The present species resembles *Sporolithon kuboiensis* (Ishijima) Iryu *et al*., 2009 mainly in sporangial compartments, their shape, size and arrangement in the peripheral region. Besides these characters, presence of stalk cells at the base of the compartments also indicates this affinity. Iryu *et al.* (2009) revised the taxonomy of this species reported from the Miocene of Japan (Ishijima, 1942).

Slide No.: N/U-2

Locality: Upper part of the sequence at Natural Bridge section of Neil Island.

DISCUSSION

The present paper records eleven species of coralline algae from the Upper Limestone Member of the Neill West Coast Formation exposed at Natural Bridge (Pleistocene), Neil Island, South Andaman (Fig. 2). These include *Metagoniolithon* sp., *Corallina* sp., *Jania* sp., *Lithophyllum nitorum, Amphiroa* sp., *Titanoderma pustulatum, Spongites fruticulosus, Hydrolithon* sp., *Mesophyllum obsitum, Phymatolithon calcareum* and *Sporolithon kuboiensis*. Out of these, eight species belong to the family Corallinaceae, two are assigned to the family Hapalidiaceae and one to the family Sporolithaceae. One coralline species (*Sporolithon kuboiensis*) is recorded for the first time for India, while the remaining ten species are new to the study area. The coralline algae are associated with foraminifera and corals.

The stratigraphic distribution of the coralline algal species shows that nine species (*Metagoniolithon* sp., *Mesophyllum obsitum, Sporolithon kuboiensis*, *Lithophyllum nitorum, Titanoderma pustulatum, Spongites fruticulosus, Phymatolithon calcareum, Amphiroa* sp. and *Hydrolithon* sp.) range from the Neogene to Recent in different parts of the world, while the remaining two species (i.e. *Corallina* sp. and *Jania* sp.) range from the Palaeogene to Recent.

The coralline algal assemblages can be broadly differentiated into two associations: one developed in the lower 5 m part of the succession which appears to indicate deposition in shallow, cool-water environment with very high-energy conditions, and the other developed in the upper 1.5 m part which indicates shallow warm-water environment characterized by moderate energy conditions.

The lower association is less diverse and poorly developed in comparison to the upper one. Benthic foraminifera (Pl. V, figs. 1-6) are well represented in the lower part where corals are absent. These include *Neorotalia* sp., *Operculinoides* sp., *Assilina ammonoides*, *Amphistegina* sp., *Amphisorus hemprichii* and *Elphidium macellum*. The absence of corals and poor development of coralline algal forms indicate a depositional environment not suitable for reefal organisms such as corals and coralline algae. The coralline algae of the lower association are mostly fragmented, vegetative or with rare conceptacles. They include *Metagoniolithon* sp., *Corallina* sp., *Lithophyllum nitorum, Amphiroa* sp., *Hydrolithon* sp. and are dominated by *Lithophyllum* and *Amphiroa* which are adapted to shallow water environment. This association commonly grows in the upper photic zone noted for well-illuminated, high-energy water conditions. The dominant algal taxa (Lithophylloideae) and absence of corals suggest relatively cool water conditions. Lithophylloids are dominant today in shallow-water environment in the Mediterranean and have been noted to be quite common in the temperate shallow water coralline algal assemblages of the upper Neogene of southern Spain (Bressan and Babbini, 2003). The dominance of lithophylloids is also observed in the temperate shallow-water carbonates from Gulf of California and Australia (Braga and Aguirre, 2001, 2004; Checconi *et al*., 2007; Braga *et al*., 2010). The typical warm-water coralline algal taxa such as *Sporolithon* and *Lithoporella* are absent. The inferred cool-water environment (temperate) is not supportive of warm water coralline taxa. The absence of planktic foraminifera in this association is also noteworthy. The fragmented nature of the recorded taxa indicate that they may have been transported and deposited under very high-energetic conditions.

The upper association of well-developed and diversified coralline algal assemblage with numerous conceptacles indicates deposition under shallow, warm-water environment with moderate-energy conditions. This environment favoured development of warm-water coralline algal taxa (e.g. *Sporolithon* and *Spongites*) (Vannucci *et al*., 2006), corals (Pl. V, fig. 9) and encrusting foraminifera (Pl. V, figs. 7-8). The associated corals also suggest that minimum winter sea surface temperature may have been above 20°C. The upper Hapalidiaceae- and Sporolithaceae-dominated association consisting of *Mesophyllum*, *Phymatolithon, Sporolithon* and *Spongites* with their warty to fruiticose growth forms may have lived possibly on hard substrate under warm-water, lower photic environment with moderate-energy conditions (Kroeger *et al*., 2006; Braga *et al*., 2010).

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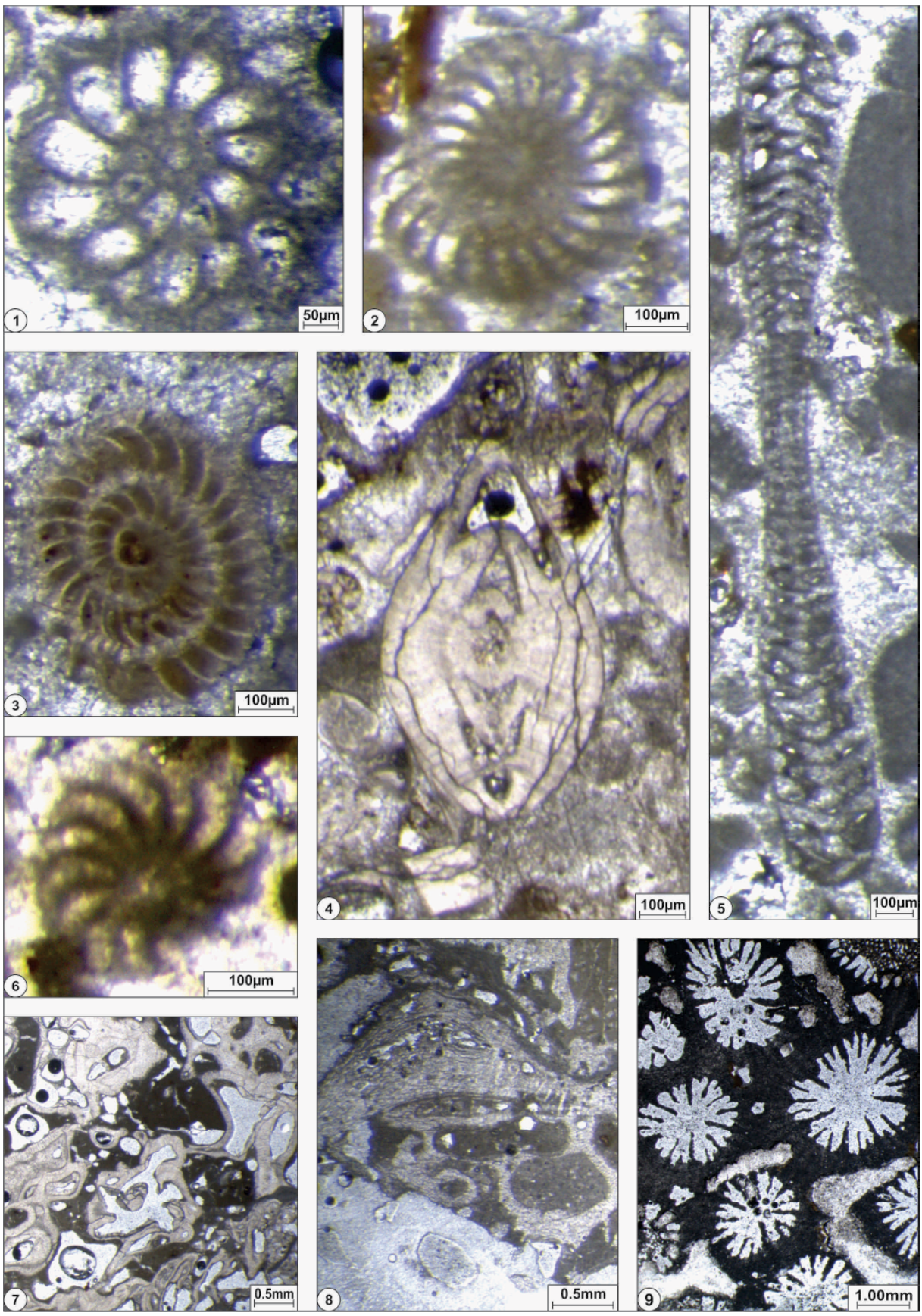
EXPLANATION OF PLATE V

Figs. 1-8. Benthic foraminifera, 9. Corals.

1. ***Neorotalia*** sp., sample no. N-B-1; 2. ***Operculinoides*** sp., sample no. N-B-1; 3. ***Assilina ammonoides***, sample no. N-M-2; 4. ***Amphistegina*** sp., sample no. N-B-1; 5. ***Amhisorus hemprichi***, sample no. N-M-2; 6. ***Elphidium macellum***, sample no. N-B-1; 7, 8. Encrusting foraminifera, sample no. N-T-3; 9. Transverse sections of corals, Sample No. N-T-3.

Plate V


1
50µm
2
100µm
3
100µm
4
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5
100µm
6
100µm
7
0.5mm
8
0.5mm
9
1.00mm

in the field. We also thank the Principal Chief Conservator of Forests, Andaman and Nicobar Islands, Port Blair for permission to collect samples for this study. This work was supported by the grants from the Department of Science and Technology, New Delhi (Project No. SR/S4/ES-623/2012).

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