

# Coralline Algae from the Late Pleistocene Miliolite Formation of Kachchh, Western India

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## ABSTRACT

Coralline algae of the Late Pleistocene Miliolite Formation of Kachchh region, Gujarat, western India are studied in terms of taxonomy and their paleoenvironmental implications. The Quaternary bio-clastic sediments belonging to the Late Pleistocene Miliolite Formation are well exposed in Kachchh, western India and these sediments consist of sandy limestones and calcareous sandstones. The present paper deals with the study of coralline algae from the sediments of the Late Pleistocene Miliolite Formation. Twenty two species of coralline algae are being recorded for the first time from these sediments. Out of twenty two species, eight belong to non-geniculate coralline algae and fourteen belong to geniculate coralline algae. The geniculate coralline algal species are: *Lithophyllum incrustans* Philippi, *Lithophyllum* sp.1, *Lithophyllum* sp.2, *Lithoporella melobesioides* Foslie, *Lithothamnion* sp.1, *Lithothamnion* sp.2, *Lithothamnion* sp.3 and *Lithothamnion* sp.4 and geniculate coralline algal species are: *Amphiroa anchiverricosa* Johnson and Ferris, *A. fortis* Johnson, *A. rigida* Lamouroux; *Arthrocardia cretacica* Raineri, *A. indica* Kundal and Humane, *A. konitaensis* Ishijima; *Calliarthron antiquum* Johnson; *Corallina grandis* Rao, *C. prisca* Johnson, *C. typica* Ishijima; *Jania guamensis* Johnson, *J. mengaudi* Lemoine, *J. sripadaraoi* Kundal and Humane; *J. vetus* Johnson. The present coralline algal assemblage suggests that the sediments containing algae from the Miliolite Formation were deposited in the shallow water marine/ beach environment.

## INTRODUCTION

Corallines are carbonate secreting and strongly calcified red algae of the division Rhodophyta. Corallines have been important constituents of shallow marine sedimentary deposits all over the world from the Early Cretaceous (Hauterivian) to the Pleistocene (Woelkerling, 1988; Womersley, 1996). Corallines architecturally have two groups, the nongeniculate and geniculate coralline forms (Woelkerling, 1988; Womersley, 1996; Kundal, 2011; Hrabovsky et al., 2015). In geniculate coralline forms, the thallus is composed of rigid, calcified segments termed as intergenicula alternating with more flexible rarely calcified segments termed as genicula, whereas in nongeniculate corallines forms, the thallus lacks genicula (Bassi et al. 2000). Coralline algae are among the main carbonate producers in Cenozoic shallow water marine settings (Iryu et al., 2012).

## GEOLOGICAL AND STRATIGRAPHIC SETTING

The Quaternary deposits of Kachchh (Kutch) and Saurashtra (Kathiawar), western India, cover 1 lakh sq km area of the Gujarat state and were deposited during the Pleistocene and Holocene Epochs (Geological Evolution & Mineral Resources of Gujarat, 2002). The Quaternary sediments are exposed in patches in the Kachchh, Western India. The Quaternary sediments of Kachchh region consist of coastal

deposits, lime mud, unconsolidated calcareous sand, tidal flat clays/silt, semi-consolidated to consolidated limestone, shell limestone, pelletal limestone, micritic limestone, calcareous coarse clastics, grits, conglomerate and silty loam conglomerate. These sediments were classified as Kothara Formation, Miliolite Formation, Chaya Formation, Mohadi Formation and Mahuva Formation (Biswas, 1971a, Wadhawan, 1992, Bhatt 2000). However, Geological survey of India (DRM, 2002) has classified the Quaternary sediments of Kachchh into seven formations viz., Kothara Formation, Miliolite Formation, Katpur Formation, Varahi Formation, Rann Formation, Rann Clay Formation and Mahuva Formation.

The sediments belonging to the Late Pleistocene Miliolite Formation of Kachchh and Saurashtra engrossed various geoscientists because of their contentious origin. The Quaternary carbonate deposits of Saurashtra particularly the sediments of the Miliolitic Formation have been extensively studied for the depositional environment (Fedden, 1884; Evans, 1900; Chapman, 1900; Shrivastava, 1968a, 1968b; Hardas and Merh, 1968; Glennie, 1970; Biswas, 1971b; Lele, 1973, 1975; Sperling and Goudie, 1975; Govindan et al., 1975; Mathur and Merh, 1975; Merh, 1975; Marathe et al., 1977; Goudie and Sperling, 1977; Agrawal and Roy 1977; Verma and Mathur, 1977; Mathur, 1978; Verma 1979; Baskaran and Somayajula, 1986). The sediments belonging to the Late Pleistocene Miliolite Formation in the Kachchh region occur on same tract and these sediments are significant in context of their origin (Biswas 1971a, Chakroborti et al. 1993; Maurya et al. 2003, Bhatt, 2003 and Chowksey et al. 2011). However, till date, no documentation of calcareous algae is known. In the present study twenty two species of coralline algae are being recorded for the first time in Late Pleistocene Miliolite Formation and the present study also provides implications of coralline algae on the depositional environment.

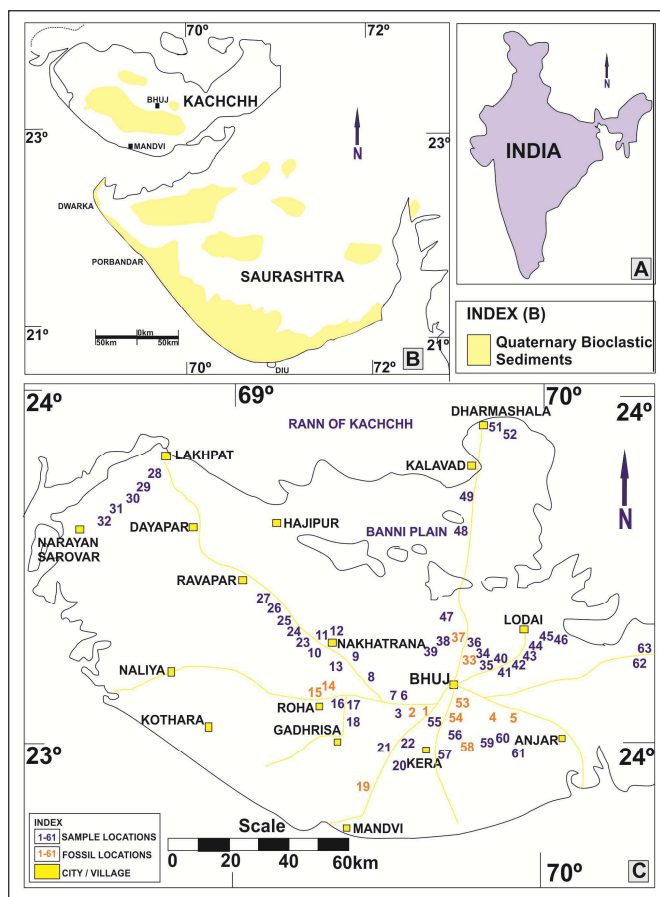
## MATERIAL AND METHOD

Sixty one locations were studied from the Kachchh basin (Fig. 1) and samples of Miliolite Formation were collected. Thin sections of all consolidated and semi-consolidated samples were made. Sixteen locations out of sixty one have yielded coralline algae and multiple thin sections of samples of these sixteen localities were made to understand distribution of coralline algae. The photomicrographs of coralline algae and measurements of thalli, cells and conceptacles have been made using DM 750 trinocular microscope (Leica Make).

## SYSTEMATIC PALAEOLOGY

### Nongeniculate Coralline Algae

Division	: Rhodophyta Wettstein, 1901
Class	: Rhodophyceae Rabenhorst, 1863
Order	: Corallinales Silva and Johansen, 1986



**Fig.1.** (A) Map of the India, (B) Distribution of the Quaternary Bioclastic deposits in the Saurashtra and Kachchh (after Bhatt 2003), (C) Map of the Kachchh with sample and fossil locations.

Family : **Corallinaceae** Lamouroux, 1852  
 Subfamily : **Lithophylloideae** Setchell, 1943  
 Genus : **Lithophyllum** Philippi, 1837

***Lithophyllum incrustans*** Philippi, 1837  
 (Fig.2 B)

**Material:** Specimen No. RTMNU/MF/84/L1/4  
**Morphology:** Thallus massive, encrusting with protuberances.

**Vegetative Anatomy:** Thallus dimerous, primigenous and postigenous filaments are well developed. Cells of primigenous filaments are 8-9mm in width and 12-13mm in height while Cells of postigenous filaments are 8-18mm in height and 6-8 mm in width. Cells of adjacent filaments are joined by secondary pit connections. Cell fusions are absent. Cells are rectangular in shape.

**Reproductive Organs:** Uniporate bi / tetrasporangial conceptacle exhibits height 50 mm and 70mm with pore canal and diameter 85mm. Pore canal is cylindrical to conical. Tetra / bi sporangial conceptacles are recognized by the remains of a columella, a prominent rise of conceptacles bottom at the center.

**Remarks:** The shape and dimension of conceptacle of the present specimen show close similarities with *Lithophyllum incrustans* Philippi. Therefore this specimen is placed under *Lithophyllum incrustans* Philippi.

**Stratigraphic and Geographic Distribution:** Sea bottom of Gulf of Calvi, Corsica (Fravega and Vannucci, 1989) and Neogene of South of Zubia road from Padul to Escuzar in Granada Basin, Spain (Braga and Aguirre, 1995), Porbandar Calc-arenite Member of the Chaya Formation (Kundal and Mude, 2009a).

**Horizon and Locality:** Miliolitic Limestone of Miliolite Formation near Shivparas Temple.

***Lithophyllum sp.1***  
 (Fig.3 E)

**Material:** Specimen No. RTMNU/MF/56/L3/1d

**Morphology:** Thallus massive, encrusting with protuberances.

**Vegetative Anatomy:** Thallus dimerous, primigenous and postigenous filaments are well developed. Cells of primigenous filaments are 8-10 mm in width and 10-12mm in height while Cells of postigenous filaments are 8-20 mm in height and 6-8 mm in width. Cells of adjacent filaments are joined by secondary pit connections. Cell fusion is absent. Cells are rectangular in shape.

**Remarks:** The present specimen consists of massive thallus, encrusting with protuberances and conceptacles are not observed. Therefore, it is kept in open nomenclature and described as *Lithophyllum sp.1*.

**Horizon and Locality:** Miliolitic Limestone of Miliolite Formation at Gunavari River.

***Lithophyllum sp.2***  
 (Fig.2 D)

**Material:** Specimen Nos. RTMNU/ MF/178/L19/1d

**Morphology:** Thallus encrusting, dimerous.

**Vegetative Anatomy:** Thallus dimerous, primigenous and postigenous filaments are well developed. Cells of primigenous filaments are 6-8mm in width and 8-10mm in height while Cells of postigenous filaments are 8-16mm in height and 6-8 mm in width. Cells of adjacent filaments are joined by secondary pit connections. Cell fusion is absent. Cells are rectangular in shape.

**Reproductive Organs:** Two uniporate bi / tetrasporangial conceptacles exhibit height 170mm and 150mm with pore canal. The height of pore canal is 50mm. Pore canal is cylindrical to conical.

**Remarks:** The present specimen consists of massive thallus, encrusting with protuberances. The shape and dimensions of the conceptacles do not match with existing species from available literature. Therefore, it is kept in open nomenclature and described as *Lithophyllum sp.2*.

**Horizon and Locality:** Miliolitic Limestone of Miliolite Formation at Nana Ashambia Gangaji River.

Order : **Hapalidiales** Nelson et al., 2015  
 Subfamily : **Melobesioideae** Bizzozero, 1885  
 Genus : **Lithothamnion** Heydrich, 1897

***Lithothamnion sp.1***  
 (Fig.2A)

**Material:** Specimen Nos. RTMNU/MF/179/L19/1d

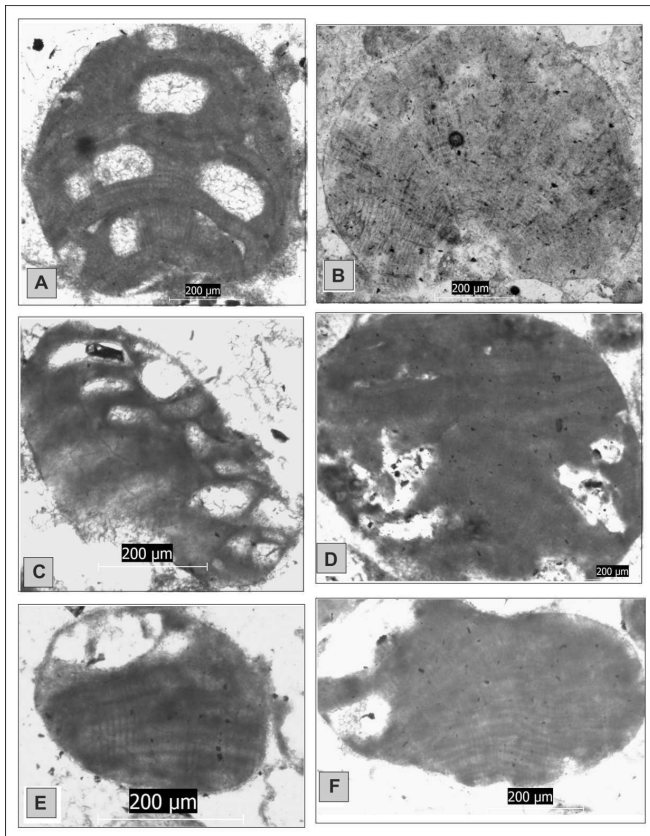
**Morphology:** Thallus encrusting.

**Vegetative Anatomy:** The thallus is monomerous, thin and with noncoaxial core. Cells of the core region are squarish to rectangular. The height of cells of core region varies from 10-12 mm while width ranges from 8-10 mm. Peripheral region is thick and height of cells is in between 12-14 mm and width ranges from 8-6 mm. Cell fusions are present and secondary pit connections are absent.

**Reproductive Organs:** Three conceptacles bi / tetrasporangial multiporate conceptacles were measured. Diameter of conceptacles varies between 100-120mm and height is in between 50-65mm.

**Remarks:** The shape and dimensions of this specimen does not match with existing specie from the available literature. Hence, it is kept in open nomenclature and described as *Lithothamnion sp.1*.

**Horizon and Locality:** Miliolitic Limestone of Miliolite Formation at Nana Ashambia Gangaji River.



**Fig.2.** (A) *Lithothamnion* sp.1, Specimen No. RTMNU/MF/179/L19/1d; (B) *Lithophyllum incrustans*, Specimen No. RTMNU/MF/L1/2A/a; (C) *Lithothamnion* sp.4, Specimen No. RTMNU/MF/216/L37/1d; (D) *Lithophyllum* sp.2, Specimen No. RTMNU/MF/178/L19/1d; (E) *Lithothamnion* sp.3, Specimen No. RTMNU/ MF/202/L33/6c; (F) *Lithothamnion* sp.2, Specimen No. RTMNU/ MF/203/L33/6c

***Lithothamnion* sp.2**  
(Fig.2F, Fig. 3F)

**Material:** Specimen Nos. RTMNU/MF/198/L33/6b; 203/L33/6c  
**Morphology:** Thallus encrusting.

**Vegetative Anatomy:** Thallus monomerous, thin and with noncoaxial core. Cells of the core region are squarish to rectangular. The height of cells of core region varies from 8-10mm while width ranges from 6-8 mm. Peripheral region is thick and height of cells is in between 10-12mm and width ranges from 8-6 mm. Cell fusions are present and secondary pit connections are absent.

**Reproductive Organs:** Two bi / tetrasporangial multiporate conceptacles were measured. Diameter of conceptacles varies between 180-200mm and height is in between 60-70mm.

**Remarks:** The shape and dimensions of this specimen does not match with existing species from the available literature. Hence, it is kept in open nomenclature and described as *Lithothamnion* sp.2.

**Horizon and Locality:** Miliolitic Limestone of Miliolite Formation at Bhujia Hill.

***Lithothamnion* sp.3**  
(Fig.2E)

**Material:** Specimen Nos. RTMNU/ MF/202/L33/6c  
**Morphology:** Thallus encrusting.

**Vegetative Anatomy:** The thallus is monomerous, with noncoaxial core. Cells of the core region are squarish to rectangular. The height of cells of core region varies from 9-10mm while width ranges from

7-8 mm. Peripheral region is thick and height of cells is in between 10-12mm and width ranges from 8-6 mm. Cell fusions are present and secondary pit connections are absent.

**Reproductive Organs:** one bi / tetrasporangial multiporate conceptacle is measured. Diameter of conceptacle is 165mm and height is 55mm.

**Remarks:** The shape and dimensions of this specimen does not match with existing species from the available literature. Hence, it is kept in open nomenclature and described as *Lithothamnion* sp.3.

**Horizon and Locality:** Miliolitic Limestone of Miliolite Formation at Bhujia Hill.

***Lithothamnion* sp. 4**  
(Fig.2C, Fig.3C)

**Material:** Specimen Nos. RTMNU/ MF/216/L37/1d

**Morphology:** Thallus encrusting

**Vegetative Anatomy:** The thallus of the specimen is monomerous, with noncoaxial core. Cells of the core region are squarish to rectangular. The height of cells of core region varies from 10-12mm while width ranges from 8-10 mm. Peripheral region is thick and height of cells is in between 12-14mm and width ranges from 6-8mm. Cell fusions are present and secondary pit connections are not seen.

**Reproductive Organs:** Six bi / tetrasporangial multiporate conceptacles were measured Diameter of conceptacles varies between 60-70mm and height is in between 30-40mm.

**Remarks:** The shape and dimensions of this specimen does not match with existing specie from the available literature. Hence, it is kept in open nomenclature and described as *Lithothamnion* sp.4.

**Horizon and Locality:** Miliolitic limestone of Miliolite Formation near Gangeshwar.

Family : **Mastophoroideae** Setchell, 1943  
Genus : ***Lithoporella*** Foslie, 1909

***Lithoporella melobesioids*** Foslie  
(Fig.3 D and G)

**Material:** Specimen Nos. RTMNU/ MF/51/L3/1c; /68/L3/2a; /155/L14/2b; /194/L33/6a and 206/L33/6d

**Morphology:** Multistratose irregular thalli.

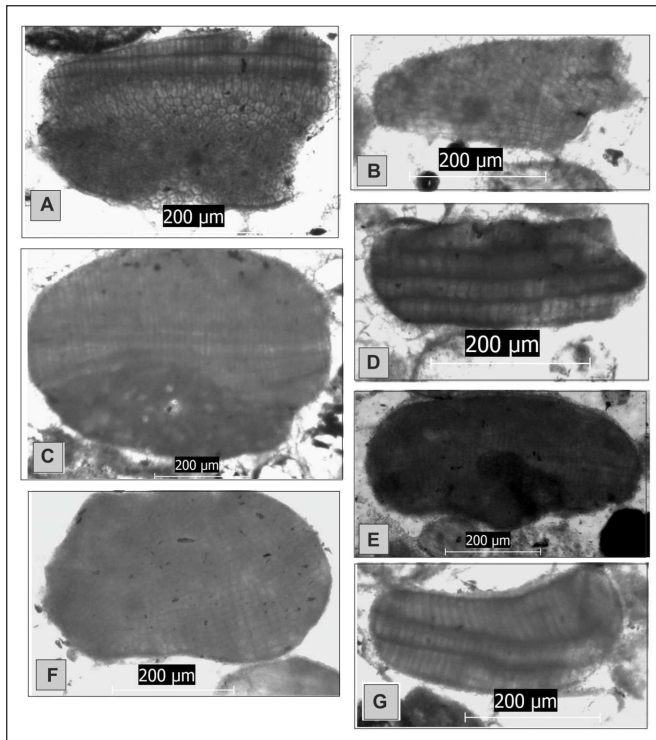
**Vegetative Anatomy:** Thalli dimerous, primigenous filaments are single layered and composed of rectangular palisade cells having 35-60 mm height and 8-25 mm diameters. These single layers are superimposed on one another. The postigenous filaments are restricted to conceptacles. Cell fusions are present and secondary pit connections are absent.

**Reproductive Organs:** Two long semicircular to elongated bi / tetrasporangiate uniporate conceptacles were measured. Diameter of conceptacles varies from 125-350 mm and height ranges from 75-150 mm while pore canal is 20 mm.

**Remarks:** The present specimens show single layer superimposed layers on one another and height of cells is 35-60 mm. Bassi (1998) noted that in *Lithoporella melobesioids* Limoine, height of the cells is more than 27 mm. Hence, these specimens are placed under *Lithoporella melobesioids*.

**Stratigraphic and Geographic Distribution:** Oligocene to Recent sediments of Western Pacific, Japan (Ishijima, 1954); Eocene to Recent sediments from Funafuti, Kita-Diato-Jima and Eniwetok (Johnson, 1961); Eocene limestone of Ishigaki-Shima (Johnson, 1964a); Eocene to Recent sediments from Guam (Johnson, 1964b); Lower Miocene rocks of Guatemala (Johnson an Kaska, 1965); Oligocene rocks of Nullipore Formation ( Vannucci, 1970); Lower Oligocene rocks of Ranzano Formation ( Fravega and Vennuci, 1980); Miocene rocks of





**Fig.3.** (A) Nongeniculate coralline algae, Specimen No. RTMNU/MF/ 225/L51/1c; (B) Nongeniculate coralline algae, Specimen No. RTMNU/ MF/154/L14/2b; (C) *Lithothamnion* sp.4, Specimen No. RTMNU/ MF/228/L53/2a; (D) *Lithoporella melobesioides*, Specimen No. RTMNU /MF/155/L14/2b; (E) *Lithophyllum* sp.1, Specimen No. RTMNU/ MF/56/L3/1d; (F) *Lithothamnion* sp.2, Specimen No. RTMNU/ MF/198/L33/6b; (G) *Lithoporella melobesioides*, Specimen No. RTMNU/ MF/206/L33/6d

Malta (Bosence, 1983); Late Eocene rocks of Colli Berici from Northern Italy ( Bassi, 1995), Lower Oligocene rocks of Gornji Grad beds off Northern Slovenia( Bassi and Nebelsick, 2000) and Dwarka Formation and Miliolite Formation (Kundal and Mude, 2009a).

**Horizon and Locality:** Miliolitic Limestone of Miliolite Formation at Gunavari River, Roha village and Bhujia Hill.

### GENICULATE CORALLINE ALGAE

The following abbreviations are used for the dimensions of various geniculate coralline algal species: SN – Specimen Number, WS – Width of Segment / Fragment, LMC – Length of medullary cells, WMC – Width of medullary cells, LCC – Length of cortical cells, WCC – width of cortical cells, AF – Alternation formula, LLMC – Length of long medullary cells, WLMC – Width of long medullary cells, LSMC – Length of short medullary cells, WSMC – width of short medullary cells, LEC- Length of epithallial cells and WEC-Width of epithallial cell.

Division	: Rhodophyta Wittstein, 1901
Class	: Rhodophyceae Rabenhorst, 1863
Order	: Corallinales Silva and Johansen, 1986
Family	: Corallinaceae Verheij, 1993
Subfamily	: Amphiroideae
Genus	: <i>Amphiroa</i> Lamouroux, 1812

#### *Amphiroa anchiverricosa* Johnson and Ferris (Fig.6 A, B, E)

**Material:** Specimen No. RTMNU/MF/115/L4/2b; 168/L15/1d; 201/L33/6c; 215/L37/1d and 241/L54/1d

**Description:** The intergenicula is cylindrical to sub-cylindrical and medulla exhibit alternation of single row of long cells followed by single row of short cells. The width of the segments ranges from 175 to 325 mm. Cells are rectangular. Long medullary cells and short medullary cells are 50-70mm and 10-25mm respectively in length, while long medullary cells and small medullary cells are 6-8mm and 8-12 mm respectively in width. The cortical region is also noticed in one specimen (sp no.215) where length of cortical cell is 4mm and width is 2 mm.

**Remarks:** The present specimens exhibit alternation formula 1L; 1S i. e. Single row of long cells is in alternation with single row of short cells. *Amphiroa anchiverricosa* has such alternation formula. Therefore these specimens are put under *Amphiroa anchiverricosa* Johnson and Ferris. *Amphiroa averrucosa* Kutzing is also characterized by such alternation formula in medulla.

*Amphiroa anchiverricosa* Johnson and Ferris has priority over *Amphiroa averrucosa* Kutzing. Hence according to principle of priority *Amphiroa averrucosa* Kutzing is placed under *Amphiroa anchiverricosa* Johnson and Ferris. *Amphiroa gautemalense* Johnson and Kaska also exhibits alternation formula 1L, 1S. So according to principle of priority *Amphiroa gautemalense* Johnson and Kaska is grouped under *Amphiroa anchiverricosa* Johnson and Ferris.

**Stratigraphic and Geographic Distribution:** Pleistocene Ryukyulimestone, Jinkoshi, Koshun-gun, Takao-shu, Formosa, Western Pacific (Ishijima, 1954) and Maniyara Fort Formation (Oligocene), Chhasra Formation, (Lower Miocene) and Khari Nadi Formation (Lower Miocene) of Kachchh, Gujarat (Kundal and Humane, 2002), Lower Pliocene of Dwarka Okha area, Gujarat (Kundal and Dharashivkar, 2003)

**Horizon and Locality:** Miliolitic Limestone of Miliolite Formation at Gangeshwar , Bharapar and Roha villages.

#### *Amphiroa fortis* Johnson (Fig.6 C, I)

**Material:** Specimen Nos. RTMNU/MF/23/L1/2b; 84/L1/4; 117/L4/2c; 167/L15/1d; 213/37/1c and 239/L54/1c

**Description:** The intergenicula are cylindrical to sub-cylindrical and medulla exhibit alternation formula 3L, 1S. The width of the segments range from 170- 310mm. Cells are rectangular. The long medullary cells and short medullary cells are 70-45 mm and 28-12 mm respectively in length, while long medullary cells and small medullary cells are 6-10 mm and 8-12 mm respectively in width. The cortical region is observed in one specimen (sp no.84) where the length of cortical cell is 6 mm while the width of cortical cell is 4mm.

**Remarks:** *Amphiroa fortis* Johnson is characterized by alternation formula 3L, 1S. The present specimens exhibit alternation formula 3L, 1S. Therefore, they are described under *Amphiroa fortis* Johnson.

**Stratigraphic and Geographic Distribution:** Pleistocene Ryukyulimestone, Jincoshi, Koshan-gun, Takaushu, Formosa, Western Pacific (Ishijima, 1954); Pleistocene *Halimeda* rich facies of Mariana limestone of Mariana Island (Johnson, 1957) and Palaeocene rocks of Gautemala (Johnson and Kaska, 1965).

**Horizon and Locality:** Miliolitic Limestone of Miliolite Formation exposed near Shivparas Temple, Lanki towards kotda and also at Roha and Gangeshwar, Bharapar village.

#### *Amphiroa rigida* Lamouroux (Fig.6D, 5I)

**Material:** Specimen Nos. RTMNU/ MF/204/L33/6d; 222/L51/1b and 251/L58/2d

**Description:** The intergenicula are cylindrical to sub-cylindrical and medulla exhibit alternation formula 2L, 1S. The width of the

segments vary from 190 to 280mm. Cells are rectangular. The long medullary cells and short medullary cells are 70-46 mm and 14-18 mm respectively in length, while width of long medullary cells and small medullary cells are 6-10 m and 8-12 mm respectively in width.

**Remarks:** The present specimens exhibit alternation formula 2L, 1S like *Amphiroa rigida* Lamouroux and therefore they are described as *Amphiroa rigida* Lamouroux. *Amphiroa pacifica* Johnson and Ferris also shows same alternation formula i.e. 2L, 1S but *Amphiroa rigida* Lamouroux has priority over *Amphiroa pacifica* Johnson and Ferris. Hence *Amphiroa pacifica* Johnson and Ferris will no longer valid species of *Amphiroa* Lamouroux. *Amphiroa kaskella* Johnson and Kaska is also grouped in *Amphiroa rigida* Lamouroux with alternation formula i.e. 2L, 1S or 3L, 1S. *Amphiroa gautemalense* Johnson and Kaska shows alternation formula i.e. 1L, 1S or 2L, 1S. All these alternation shows similarity with *Amphiroa rigida* Lamouroux, therefore, all the specimens with alternation formula i.e. 2L, 1S are now placed under *Amphiroa rigida* Lamouroux.

**Stratigraphic and Geographic Distribution:** Pleistocene Ryukyu limestone exposed near North valley Tako, Takoo-shu, Formosa, Western Pacific, Japan (Ishijima, 1954); Miocene limestone of Babukutsu, Taito-cho, Formosa, Western Pacific, Japan (Johnson and Kaska, 1965).

**Horizon and Locality:** Miliolitic Limestone of Miliolite Formation exposed at Bhujia Hill, near Helipad at the turning of road; Kaladongar and Chakar village.

Subfamily : Corallinoideae  
Genus : *Arthrocardia* (Harvey) Areschoug

***Arthrocardia cretacea* Raineri  
(Fig.5 B, 4 F)**

**Material:** Specimen Nos. RTMNU/ MF/160/L14/2d; 230/L53/2b and 27/L1/2c

**Description:** Thallus shows erect growth habit and ranges in width from 70 to 215 mm. Intergenicula are sub-cylindrical and medullary region displays regular tiers of cells. The medullary cells are more or less flattened or horizontal. The length and width of medullary cells ranges from 50 – 75 mm to 2-8 m respectively. Cortical region is not preserved. Conceptacles are absent.

**Remarks:** The habit, length and width of medullary cells of present specimens exhibit similarity with those of *Arthrocardia cretacea* Raineri. Therefore, they are kept under *Arthrocardia cretacea* Raineri.

**Stratigraphic and Geographic Distribution:** Miocene limestone of Kuboi, oishi-mura, Minamitsuru-gun, Yamanashi Prefecture, Western Pacific (Ishijima, 1954); Maniyara Fort Formation (Oligocene) at Bermoti Nadi section; Chhasra Formation (Late Lower Miocene) at Rampur (Kundal and Humane, 2002); Neogene-Quaternary sediments in and around Porbandar, Gujarat, India (Kundal and Mude, 2009b) and early Miocene Godhra Formation of the Kachchh Offshore Basin, Western India (Kundal and Humane, 2012).

**Horizon and Locality:** Miliolitic Limestone of Miliolite Formation exposed at Roha, Bharapar and Shivpar Temple.

***Arthrocardia indica* Kundal and Humane  
(Fig.5 H, 4H )**

**Material:** Specimen No. RTMNU/ MF/231/L53/2c and 121/L4/2d

**Description:** Thallus exhibits erect growth and is 180mm in width. The intergeniculum is sub-cylindrical and medullary region consists of regular rows of cells. The medullary cell rows are nearly flattened

or horizontal. The length of medullary cells is 38 mm while the width is 2-8 mm. The cortical region is not preserved and conceptacle is absent.

**Remarks:** The length of medullary cells of the present specimen is remarkably less than that of *Arthrocardia cretacea* Johnson and *Arthrocardia konitaensis* Ishijima. But the present specimen has short medullary cells like *Arthrocardia indica* Kundal and Humane. Therefore, it is described under *Arthrocardia indica* Kundal and Humane.

**Stratigraphic and Geographic Distribution:** Fulra Limestone Formation (Late Middle Eocene) at Babia Hill; Maniyara Fort Formation (Oligocene) at Bermoti Nadi Section (Kundal and Humane, 2002).

**Horizon and Locality:** Miliolitic Limestone of Miliolite Formation exposed at Bharapar and Lanki toward Kotda.

***Arthrocardia konitaensis* Ishijima  
(Fig.5 F)**

**Material:** Specimen Nos. RTMNU/ MF/150/L14/2a; 166/L15/1d

**Description:** Thallus exhibits erect growth and the width ranges from 80 to 185mm. The intergenicula are sub-cylindrical and medullary region consists of regular rows of cells. The medullary cell rows are nearly flattened or horizontal. The length and width of the medullary cells are from 60-65 mm and 2-8 um respectively. Cortical region is not preserved and conceptacle is absent.

**Remarks:** The length of medullary cells of the present material is remarkably similar with that of *Arthrocardia konitaensis* Ishijima. Therefore, it is described under *Arthrocardia konitaensis* Ishijima.

**Stratigraphic and Geographic Distribution:** Miocene limestone, Konita, Katsumata-mura, Haibara-gun, Shizuka Prefecture (Ishijima, 1954); Maniyara Fort Formation (Oligocene) at Bermoti Nadi Section (Kundal and Humane, 2002) and late Miocene to late Holocene sediments of Porbandar Group, Gujarat (Mude and Kundal, 2012).

**Horizon and Locality:** Miliolitic Limestone of Miliolite Formation exposed at Roha.

Genus : *Calliarthron* Manza

***Calliarthron antiquum* Johnson  
(Fig.5 A)**

**Material:** Specimen Nos. RTMNU/ MF/159/L14/2d; 157/L14/2c

**Description:** The thalli show erect growth and the width of the thalli ranges from 90 to 170mm. Intergenicula are sub-cylindrical to elliptical and medullary region possesses regular tiers of cells with some intermixing. The medullary cells are irregular, sinuous and interlacing. The length and width of the medullary cells ranges from 30-40 mm and 4-10 mm respectively. Cortical region is not preserved and conceptacle is absent.

**Remarks:** The present specimens have similar length and width like *Calliarthron antiquum* Johnson. Therefore, they are kept under *Calliarthron antiquum* Johnson.

**Stratigraphic and Geographic Distribution:** Early Miocene of Saipan, Mariana Islands (Johnson, 1957); early Miocene of Guam (Johnson, 1964a); late Paleocene of Middle Andaman Island, Andaman (Kundal and Wanjarwadkar, 2000); middle Eocene to early Miocene of Onshore sequence of Kachchh Basin, Gujarat (Kundal and Humane 2002) and Neogene-Quaternary sediments in and around Porbandar, Gujarat, India (Kundal and Mude, 2009b) and early Miocene Godhra Formation of the Kachchh Offshore Basin, Western India (Kundal and Humane, 2012).

**Horizon and Locality:** Miliolitic Limestone of Miliolite Formation exposed at Roha.

Genus: *Corallina* Linnaeus

***Corallina grandis* Rao  
(Fig.5 E)**

**Material:** Specimen No. RTMNU/ MF/182/L33/5a

**Description:** The thallus shows erect growth and the width is 185mm. The intergeniculum is conical with broaden base. Medullary region displays regular rows of cells with smooth outline. The length of the medullary cells is 45mm whereas the width is 4-10mm. The cortical region is thin but conceptacle is unknown.

**Remarks:** The present specimen has similar length and width of medullary and cortical cells as that of *Corallina grandis* Rao. Therefore, they are described under *Corallina grandis* Rao.

**Stratigraphic and Geographic Distribution:** Sylhet Limestone Formation (Eocene), Khasi Hills, Assam (Rao, 1943). Oligocene Maniyara Fort Formation, Onshore sequence of Kachchh Basin (Kundal and Humane, 2003); early Miocene Godhra Formation of Offshore sequence of Kachchh Basin (Kundal and Humane, 2012) early to middle Miocene Dwarka Formation, Porbandar, Gujarat, India (Mude and Kundal, 2012; Kundal et al., 2014) and early middle Miocene Chhasra Formation of Kachchh Offshore sequence of kachchh basin (Kundal, 2014).

**Horizon and Locality:** Miliolitic Limestone of Miliolite Formation exposed at Roha.

***Corallina prisca* Johnson  
(Fig.5G)**

**Material:** Specimen No. RTMNU/ MF/65/L3/2a

**Description:** The thallus shows erect growth and the width of the thallus is 200 mm. The intergeniculum is slender tapering and sub-rectangular having swelling and pinching outline. Medullary region displays regular rows of cells with smooth outline. The length of the medullary cells is 82mm whereas the width is 4-10mm. The cortical region and conceptacle are not preserved.

**Remarks:** The present specimen is described under *Corallina prisca* Johnson because it shows close similarities like dimension of medullary cells, gross appearance, etc., as that of *Corallina prisca* Johnson.

**Stratigraphic and Geographic Distribution:** Late Eocene of Mariana Island (Johnson, 1957); late Eocene of Eniwetok, Saipan (Johnson, 1961a); late Paleocene Lakadong Formation, Shillong, NE India (Misra et al. 2002); early middle Miocene Chhasra Formation, Onshore sequence of Kachchh Basin (Kundal and Humane, 2003; Kundal, 2014); early to middle Miocene Dwarka Formation, Porbandar, Gujarat, India (Kundal and Mude, 2009b; Kundal et al., 2014) and middle to late Eocene Bassein Formation, Mumbai Offshore Basin (Kundal et al., 2013) and early middle Miocene Chhasra Formation of Kachchh Offshore sequence of kachchh basin (Kundal, 2014).

**Horizon and Locality:** Miliolitic Limestone of Miliolite Formation exposed at Khatrol/ Asapura Hill.

***Corallina typica* Ishijima  
(Fig.4 D, G, I)**

**Material:** Specimen Nos. RTMNU/ MF/58/L3/1d; 62/L3/2a; 55/L3/1d and 189/L33/5c

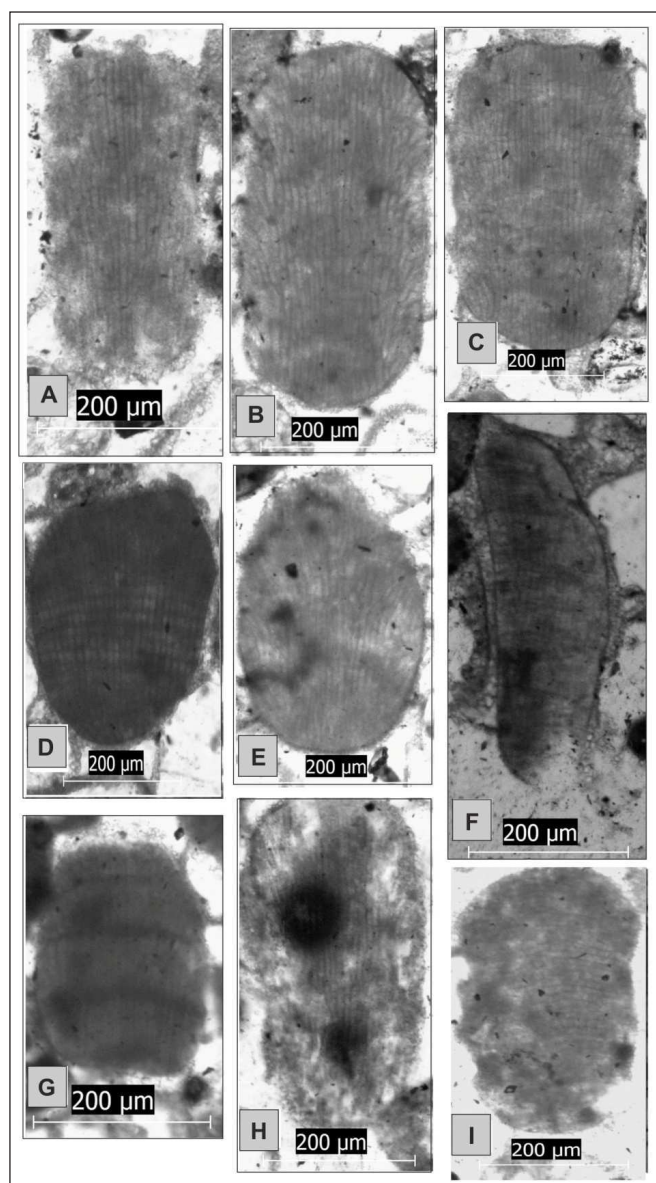
**Description:** The thalli show erect growth and the width vary from 90 to 180 mm. The intergeniculum is typically cylindrical. Medullary region displays regular rows of cells with smooth outline. The length and width of the medullary cells ranges from 75-80 mm and 4-8 mm respectively. Cortical region is thin but conceptacle is unknown.

**Remarks:** Typical cylindrical habit of intergenicula and dimensions

of the medullary cells of present material are similar to that of *Corallina typica* Ishijima. Therefore, the present material is described under *Corallina typica* Ishijima.

**Stratigraphic and Geographic Distribution:** Miocene Limestone of Kawaguchi Formation of Kuboi, Oshi-mura, Minamitsurugun, Yamanshi Prefecture, Western Pacific, Western Pacific (Ishijima, 1954); early middle Miocene Chhasra Formation, Onshore sequence of Kachchh Basin (Kundal and Humane, 2003) and early to middle Miocene Dwarka Formation, Porbandar, Gujarat, India (Kundal and Mude, 2009b) and early middle Miocene Chhasra Formation of Kachchh Offshore sequence of kachchh basin (Kundal, 2014).

**Horizon and Locality:** Miliolitic limestone of Miliolite Formation exposed at Gunavari River and at Bhujia Hill.



**Fig.4.** (A) *Jania mengaudi*, Specimen No. RTMNU/MF/119/L4/2c; (B) *Jania guamensis*, Specimen No. RTMNU/ MF/101/L4/1a; (C) *Jania vetus*, Specimen No. RTMNU/ MF/108/L4/1c; (D) *Corallina* sp.1, Specimen No. RTMNU/ MF/55/L3/1d, (E) *Jania* sp.1, Specimen No. RTMNU/ MF/145/L14/1d; (F) *Arthrocardia* sp.1, Specimen No. RTMNU/ MF/27/L1/2c; (G) *Corallina typica*, Specimen No. RTMNU/ MF/62/L3/2a. (H) *Arthrocardia* sp.2, Specimen No. RTMNU/ MF/121/L4/2d; (I) *Corallina* sp.2, Specimen No. RTMNU/ MF/189/L33/5c



Genus : *Jania* Lamouroux

*Jania guamensis* Johnson  
(Fig.4 B)

**Material:** Specimen Nos. RTMNU/ MF/101/L4/1a; 103/L4/1a; 109/L4/1d

**Description:** The thalli show erect growth and the width of the thalli range from 200 to 225 mm. The intergenicula are sub-cylindrical to elongate. Medullary region displays irregular rows of cells with zig-zag outline. Medullary cells are elongated to wedge shaped. The length and width of the medullary cells vary from 25-65 mm and 4-8 mm respectively. Cortical region and conceptacle are not preserved.

**Remarks:** The present specimens are sub-cylindrical to elongate and length of medullary cells are comparable to that of *Jania guamensis* Johnson. Therefore, they are described under *Jania guamensis* Johnson.

**Stratigraphic and Geographic Distribution:** Early Miocene of Guam, Mariana Island (Johnson, 1964a); late Paleocene of Middle Andaman, India (Kundal and Wanjarwadkar, 2000); middle Eocene to early Miocene Onshore sequence of Kachchh Basin, Gujarat, India (Kundal and Humane, 2006); late Miocene to late Holocene sediments of Porbandar Group, Gujarat (Mude and Kundal, 2012) and early Miocene Godhra Formation of the Kachchh Offshore Basin, Western India (Kundal and Humane, 2012).

**Horizon and Locality:** Miliolitic Limestone of Miliolite Formation exposed near Lanki towards Kotda.

*Jania mengaudi* Lemoine  
(Fig.4 A; Fig.5.D)

**Material:** Specimen Nos. RTMNU/MF/119/L4/2c; 197/L33/5d;211/L37/1b.

**Description:** The thalli show erect growth and the width of thalli range from 90 to 210 mm. The intergenicula are sub-cylindrical to elongated. Medullary region displays irregular rows of cells with zig-zag outline. Medullary cells are elongated to wedge shaped. The length of the medullary cells ranges from 62-70mm whereas the width varies from 4-8 mm .Cortical region and conceptacles are not preserved.

**Remarks:** The present specimens are sub-cylindrical to elongated and length of medullary cells are comparable to that of *Jania mengaudi*. Therefore, they are described under *Jania mengaudi*.

**Stratigraphic and Geographic Distribution:** Paleocene of Northern Iraq (Johnson 1964c).

**Horizon and Locality:** Miliolitic Limestone of Miliolite Formation exposed near Lanki towards kotda, at Bhujia Hill and Gangeshwar.

*Jania sripadaraoi* Kundal and Humane  
(Fig.5C; Fig.6H)

**Material:** Specimen No. RTMNU/ MF/127/L5/1b; 217/L37/1a

**Description:** The thalli shows erect growth and the width vary from 110 to 205 mm. The intergenicula are cylindrical to elongate. Medullary region displays irregular rows of cells with zig-zag outline. Medullary cells are elongate to wedge shaped. The length and width of the medullary cells ranges from 80-90 mm and 4-8 mm respectively. Cortical region and conceptacle are not preserved.

**Remarks:** The present specimens are elongated and wedge shaped with erect thallus. The dimensions of cells of medullary region show close similarities with *Jania sripadaraoi* Kundal and Humane. Therefore, they are described under *Jania sripadaraoi* Kundal and Humane.

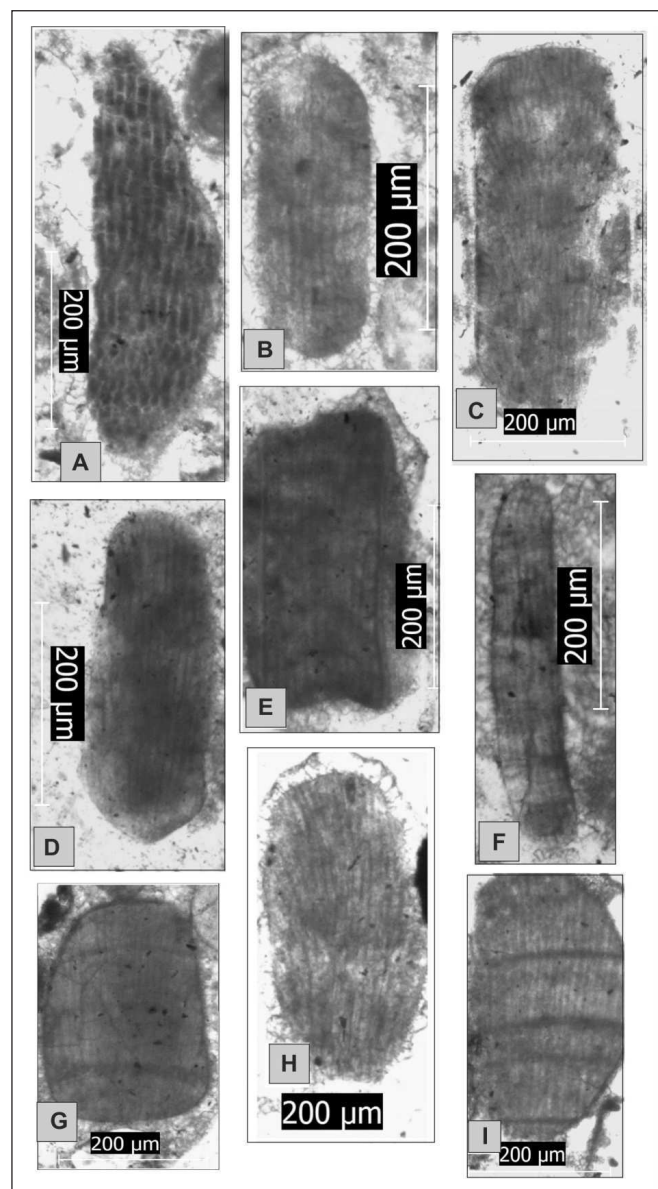
**Stratigraphic and Geographic Distribution:** Fulra Limestone

Formation (Late Middle Eocene) at Babia hill and Maniyara Fort Formation (Oligocene) at Bermoti hill and nadi section (Kundal and Humane, 2006); Neogene-Quaternary sediments in and around Porbandar, Gujarat, India (Kundal and Mude, 2009b) and early Miocene Godhra Formation of the Kachchh Offshore Basin, Western India (Kundal and Humane, 2012).

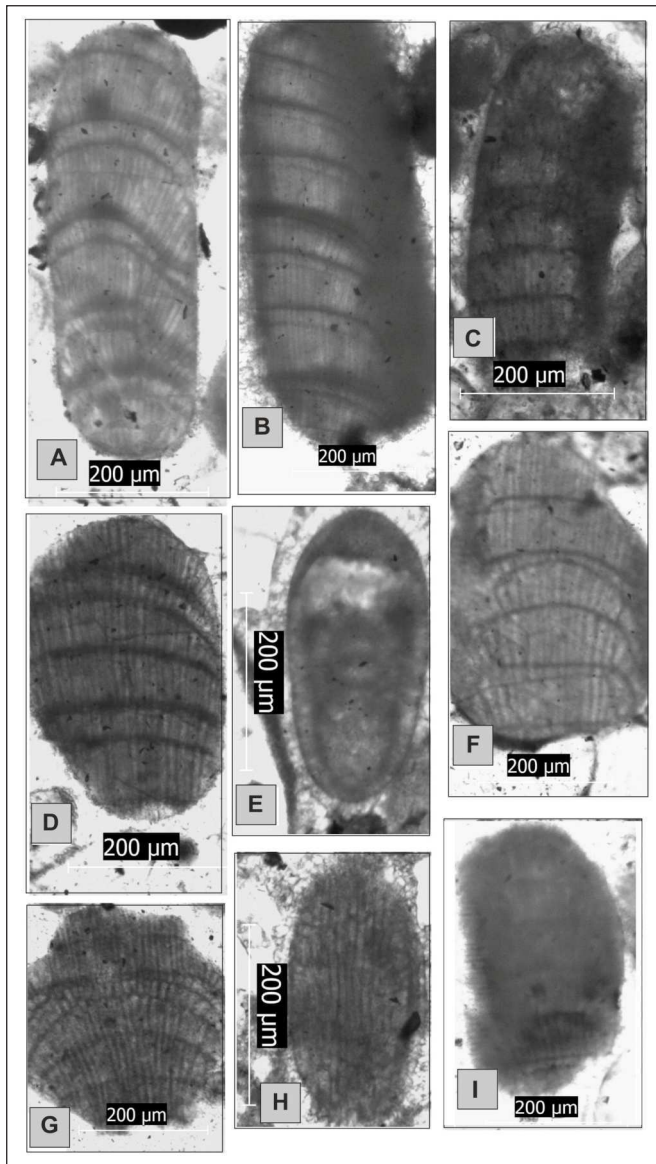
**Horizon and Locality:** Miliolitic Limestone of Miliolite Formation exposed at Khatrol/ Asapura Hill and Gangeshwar.

*Jania vetus* Johnson  
(Fig.4C, E)

**Material:** Specimen No. RTMNU/ MF/108/L4/1c and 145/L14/1d



**Fig.5.** (A) *Calliarthron antiquum*, Specimen No. RTMNU/ MF/159/ L14/2d; (B) *Arthrocardia cretatica*, Specimen No. RTMNU/ MF/160/ L14/2d; (C) *Jania sripadaraoi*, Specimen No. RTMNU/ MF/127/L5/ 1b; (D) *Jania mengaudi*, Specimen No. RTMNU/ MF/197/L33/5d; (E) *Corallina grandis*, Specimen No. RTMNU/ MF/182/L33/5a; (F) *Arthrocardia konitaensis*, Specimen No. RTMNU/ MF/166/L15/1d; (G) *Corallina prisca*, Specimen No. RTMNU/ MF/65/L3/2a; (H) *Arthrocardia indica*, Specimen No. RTMNU/ MF/231/L53/2c, (I) *Amphiroa* sp.3, Specimen No.PGDG/RTMNU/SDR/MF/251/L58/2d



**Fig.6.** (A) *Amphiroa anchiverrucosa*, Specimen No. RTMNU/ MF/ 201/L33/6c; (B) *Amphiroa anchiverrucosa*, Specimen No. RTMNU/ MF/215/L37/1d; (C) *Amphiroa fortis*, Specimen No. RTMNU/ MF/ 84/L1/4; (D) *Amphiroa rigida*, Specimen No. RTMNU/ MF/222/L51/ 1b; (E) *Amphiroa* sp.1, Specimen No. RTMNU/ MF/168/L15/1d; (F) *Amphiroa rigida*, Specimen No. RTMNU/ MF/176/L19/1c; (G) *Amphiroa fortis*, Specimen No. RTMNU/ MF/239/L54/1c; (H) *Jania sripadaraoi*, Specimen No. RTMNU/ MF/217/L37/1a; (I) *Amphiroa* sp.2, Specimen No. RTMNU /MF/167/L15/1d

**Description:** The thallus shows erect growth and the width of the thallus is 205 m. The intergenicula are cylindrical to arched. Medullary region displays irregular rows of cells with zig-zag outline. Medullary cells are elongate to wedge shaped. The length of the medullary cells is 42 mm whereas the width of cells varies from 2-4 mm. Cortical region and conceptacle are not preserved.

**Remarks:** The present specimen has cylindrical to arched intergenicula, erect thallus and medullary cells are elongated to wedge shaped. All characters and dimension of medullary cells of present specimen show close similarities to that of *Jania vetus* Johnson. Hence, they are described under *Jania vetus* Johnson.

**Stratigraphic and Geographic Distribution:** Lower Miocene of Saipan, Mariana Island (Johnson, 1957); Miocene of Eniwetok Atoll, Marshall Island (Johnson, 1961a); early Miocene of Guam, Mariana

Island (Johnson, 1964a); late Paleocene of Middle Andaman Island, India (Kundal and Wanjarwadkar, 2000) and Neogene-Quaternary sediments in and around Porbandar, Gujarat, India (Kundal and Mude, 2009b).

**Horizon and Locality:** Miliolitic Limestone of Miliolite Formation exposed near Lanki towards Kotda and Roha.

## DISCUSSION AND CONCLUSION

Coralline algae occur usually from low tide level down to depth of 25 to 30m (Johnson, 1961). Littler et al. (1986) mentioned that the overall range of calcareous algae is from 0 to 270m. Water turbulence controls the morphology of coralline algae and the coralline algae growing in high-energy conditions exhibit thick crust and radial branching whereas coralline algae growing in moderate energy conditions show delicate framework with some branching and concentric crust (Bosence, 1991). Temperature controls the distribution of algae. Fossil calcareous algae are very useful in paleoecological, paleo-environmental and paleo-bathymetrical studies and they are also of paramount significance in the prospecting of petroleum reservoirs (Kundal, 2010, 2011, 2014; Kundal and Kundal, 2010; Kundal et al., 2014; Sarkar, 2015, 2017; Sarkar and Narasimha Rao, 2018). The Neogene-Quaternary sediments of Saurashtra consists of well preserved and diversified coralline algae (Mude, 2008, Kundal and Mude, 2009a, 2009b, 2010; Mude and Kundal, 2010, 2011, 2012).

In the present study, both geniculate and nongeniculate coralline algae are recognised.

The association of these coralline algae suggests that they were deposited in tropical to sub-tropical shallow water marine environment. The documentation of coralline algae is highly significant because this is first attempt ever to study calcareous algae from these sediments. The present algal assemblage indicates that the sediments (containing algae) of the Miliolite Formation were deposited in near-shore / beach marine environment. Later on, these sediments were windblown to form aeolian Miliolites and further reworked by stream to form fluvial deposits. Chakroborti et al., (1993) have reported ichnofossil viz., *Thalassinoides* isp from the Miliolite Formation exposed at Roha, Kachchh and suggested intertidal marine depositional environment which also support the said conclusion. However, the detailed sedimentological and neo-tectonic studies of the region are required to understand the precise depositional environment.

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