



CORALLINE ALGAE FROM THE OLIGOCENE OF KACHCHH, GUJARAT, INDIA

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ABSTRACT

A rich assemblage of the coralline algae has been recorded from the Maniyara Fort Formation exposed on Babia Hill and in the areas near Waior village, Kachchh. Fifteen species of the coralline algae belonging to nine genera are described in this paper. In the present material of the early Oligocene, *Sporolithon*, *Lithoporella*, *Neogonolithon*, *Spongites*, *Lithothamnion*, *Mesophyllum*, *Corallina*, *Arthrocardia* and *Amphiroa* are recognized and studied in thin sections, using some key features of the taxonomy of Recent coralline algae emphasized by phycologists in recent years, e.g. growth form, cell fusions, and nature of conceptacle pore. The potential value of these neontological features is discussed with reference to the coralline material from Kachchh.

Key words : Coralline algae, Oligocene, systematic description, Kachchh, India.

INTRODUCTION

The present paper deals with the taxonomic description of the coralline algae recorded from the Maniyara Fort Formation of Kachchh, Gujarat, India. The investigation covers outcrops exposed in the areas around Babia Hill, north-western Kachchh and Waior village, south-western Kachchh (fig. 1). The rock samples were systematically collected from these areas in the years 1995 and 1997.

Biswas (1965, 1971, 1972, 1992), Biswas and Raju (1973) and Tandon (1974) made significant contributions to the Geology and stratigraphy of Kachchh. Singh and Singh (1986) gave a short account of the geology of the area of Babia Hill. Bajpai, Singh and Singh (1987) described the stratigraphic setting of the area around Waior village. The Palaeogene sequence in the Kachchh area is represented by the non-marine Matanomadh Formation (Palaeocene), and the shallow, neritic rocks referable to the Naredi Formation (Palaeocene-early Eocene), the Harudi Formation and the Fulra Limestone (middle Eocene) and the Maniyara Fort Formation (Oligocene). The Maniyara Fort Formation overlies the Fulra Limestone and is

overlain by the Khari Nadi Formation (Miocene). See table 1.

The studied samples were collected from the carbonate horizons of the Maniyara Fort Formation of the Oligocene age (Biswas, 1971, 1972, 1992). It is exposed on Babia Hill (north-western Kachchh) and along the Dhobi Ghat in the vicinity of the village Waior (south-western Kachchh). Babia Hill ($23^{\circ} 42' 10''$: $68^{\circ} 46' 20''$) is about 15 km south of Lakhpat, and Waior ($23^{\circ} 05' 02''$: $68^{\circ} 41' 45''$) lies at a distance of about 25 km north of Naliya, a place about 94 km SSW of Bhuj (fig. 1). The beds at Babia Hill are nearly horizontal, whereas those exposed in the vicinity of Waior are dipping at 3° - 5° to the southwest. They unconformably overlie the Fulra Limestone (middle Eocene). The samples studied in this paper belong to the lower part of the Maniyara Fort Formation. The associated microfossils from this part include a rich assemblage of *Nummulites fichteli*, *Heterostegina* and *Eulepidina* which suggests an early Oligocene age for the lower part of the formation. The lower part of the Maniyara Fort Formation has been referred to the Ramanian Stage of the Bermoti Series (Oligocene) of Kachchh (Biswas, 1972).

TIME IN M.Y.	SERIES	STAGE	LITHOSTRATIGRAPHY FORMATION	MEMBERS	FORAMINIFERAL ZONE
	Miocene	— 25.2			
30	OLIGOCENE	UPPER CHATTIAN	MANIVARA FORT	BERMOTI	<i>M. (M.) complanata-formosensis</i> <i>M. (M.) bermudezi</i> <i>P. freudenthali</i>
	LOWER RUPELIAN	— 30		CORAL LIMESTONE LUMPY CLAY BASAL MEMBER	<i>N. fichteli</i> / <i>E. dilata</i> <i>N. fichteli</i>
40	EOCENE	UPPER PRIABONIAN			
		— 39.4 BARTONIAN			
		42 LUTETIAN	FULRA LIMESTONE		<i>T. rohri</i> <i>O. becknami</i>
			HARUDI		<i>T. toplensis</i> <i>N. obtusus</i>
50		— 49 YPRESIAN			
		54 THANETIAN	NAREDI	FERR. CLAYSTONE ASSLINA LIMESTONE GYPSEOUS SHALE	Poorly Fossiliferous <i>A. granulosa</i> <i>A. spinosa</i> Ostracod Zone
60	PALEOCENE	UPPER MATANOMADH			
	LOWER DANIAN	— 60.2			
		66.5 MAASTRICHTIAN	DECCAN TRAP		
3	CRETACEOUS				

In the context of recent development in the coralline red algal taxonomy, the taxonomic status of previously documented species from Kachchh has become questionable as it has been based on traditional characters (such as the arrangement of basal cell filaments, the perforation of asexual conceptacle, etc.). These characters have been the sole basis of earlier taxonomic concepts emphasized by Wray (1977,

RECENT TAXONOMIC CRITERIA OF FOSSIL CORALLINES

Taxonomy of fossil coralline species usually refers to a few anatomical characters, mainly the general shape, size, and thickness of the thallus,

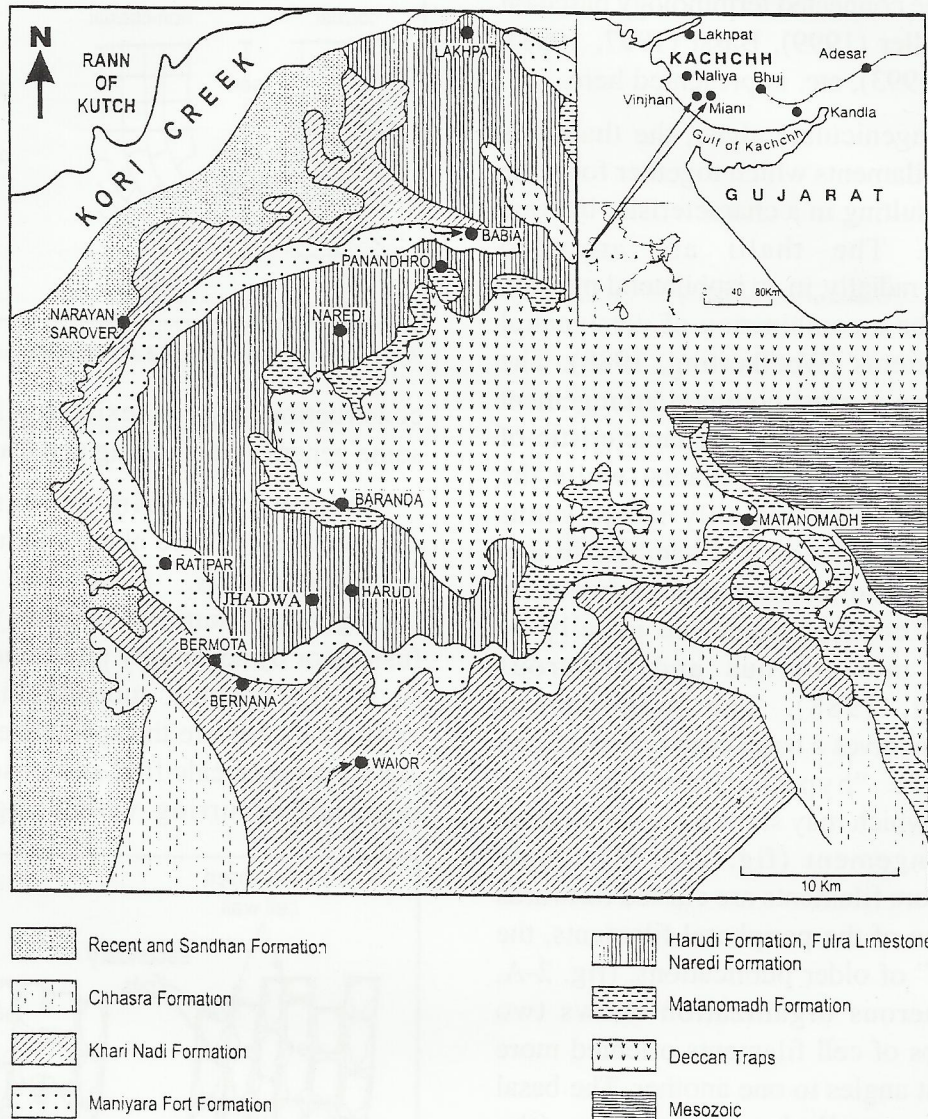


Fig.1. Geological map of a part of Kachchh showing sampled localities near Babia Hill and Waior village. The inset shows position of Kachchh in India (modified after Bajpai, Singh and Singh, 1987).

and the size and arrangement of cells. In some cases, the shape and size of the conceptacles are also described. According to Bosence (1983), the cell size and conceptacle size are considered to be the main taxonomic criteria at the species level in most cases. Majority of coralline species have been established mainly on the basis of cell size; sometimes conceptacle and cell size and their shape and arrangement are also taken into consideration. The description of the new

species, however, used to refer to cell sizes only by giving their range, in the best of cases, making further comparisons almost impossible (Bosence, 1983).

The new approach to taxonomic differentiation of fossil coralline algae, however, considers evaluation of certain diagnostic anatomical features of living corallines, which have been found to be preserved even in the fossil material. A brief summary of these

features and the connected terminology based on Rasser and Piller (1999), Bassi (1997, 1998), Braga *et al.* (1993), etc. is presented here.

In the nongeniculate algae, the thallus is composed of filaments which together form the plant body, resulting in a characteristic internal arrangement. The thalli are arranged dorsiventrally, radially, in an isobilateral manner, or there may be a combination of dorsiventral and radial systems (Woelkerling, 1988). The dorsiventral one is most common arrangement and the radial arrangement is characteristic of the protuberances of most plants, while the isobilateral one is known only in the genus *Tenarea* Bory (Woelkerling, Chamberlain and Silva, 1985). In the dorsiventral arrangement, two types of constructions can usually be recognized: monomerous and dimerous (Woelkerling, 1988). The monomerous organization involves a basal core system of cell filaments (the "hypothallium" of older publications) which may show a coaxial or non-coaxial arrangement (fig. 2-A, B). Some derivatives of core filaments are curved outwards to form a zone of the peripheral filaments, the "perithallium" of older publications, (fig. 2-A, B). The dimerous organization shows two distinct groups of cell filaments oriented more or less at right angles to one another. The basal filaments are called primigenous (the "hypothallium of older publications"), from which the postigenous filaments arise dorsally at right angles (the "perithallium" of older publications) (fig. 2-C). Both types of

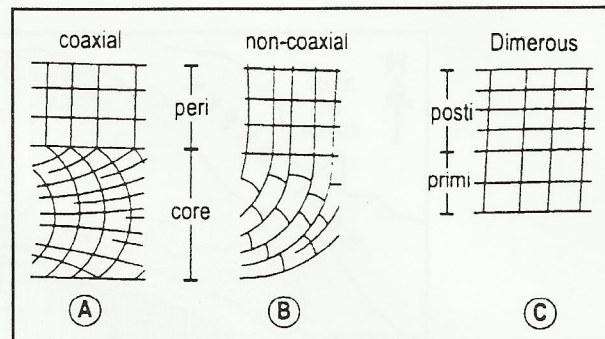


Fig. 2. Thallus organization. A&B - Monomerous. C - Dimerous

constructions may co-exist in a single plant in some genera (Woelkerling and Campbell, 1992).

Within the primigenous filaments, consecutive cells are always joined by primary pit-connections. Cells of contiguous primigenous filaments may be joined by cell fusions or by secondary pit-connections (fig. 3-A, B). Trichocytes, subepithallial initials and epithallial cells are the specialized cells (which are sometimes calcified and observed in fossil material) occurring within vegetative thalli

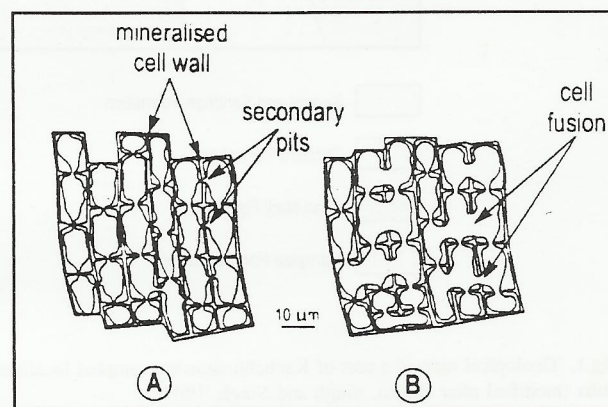
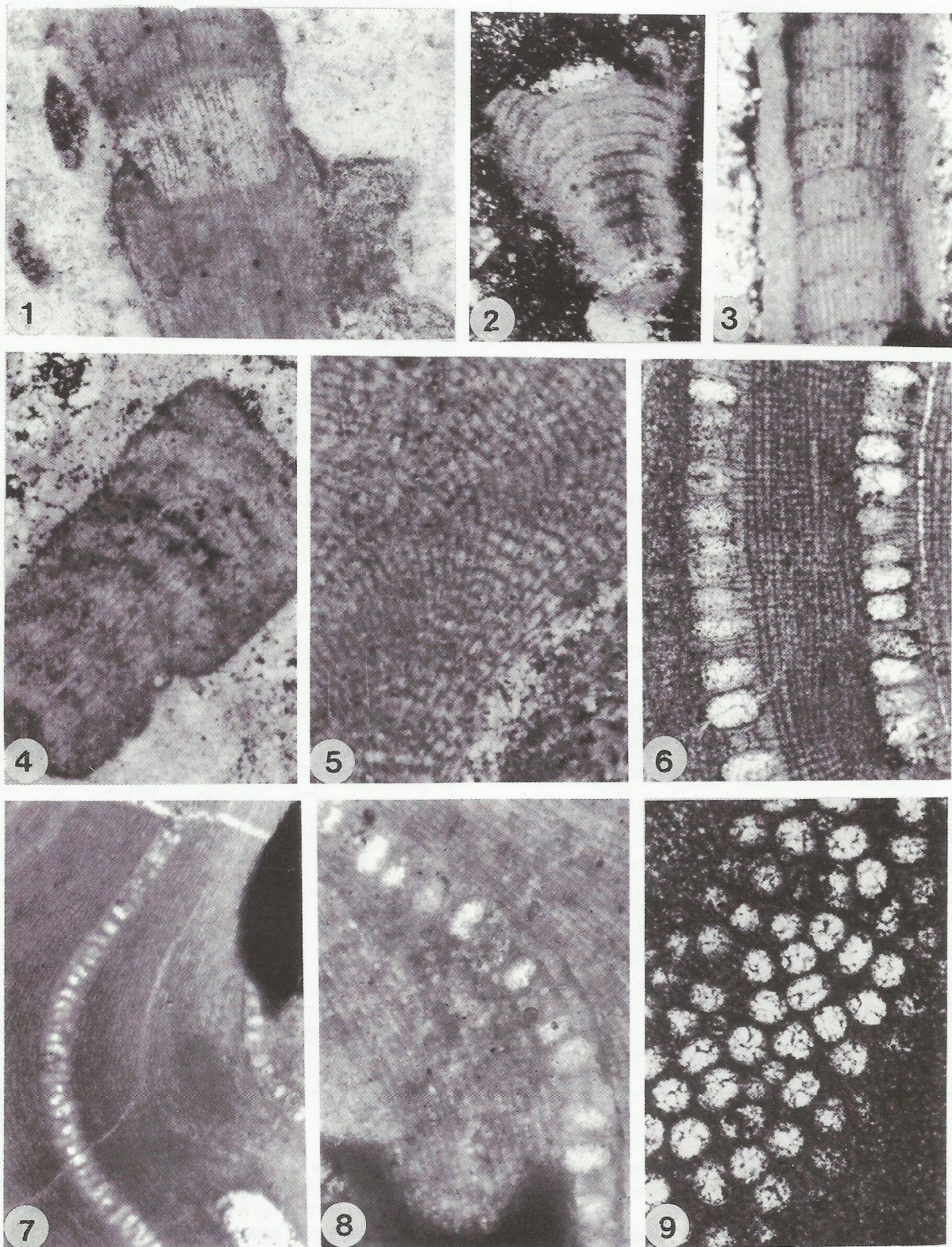


Fig. 3. Cell connections. A - Secondary pit-connections B - Cell fusions (after Bassi, 1998).

EXPLANATION OF PLATE I

1. *Corallina* sp. 1-showing geniculum (slide no. Bot./KB-57; sample no. 76/3339), x 100.
2. *Corallina* sp. 2 (slide no. Bot./KB-46; Sample no. 58/3341), x 50.
3. *Arthrocardia* sp. (slide no. Bot./KB-39; Sample no. 42/3341), x 100.
4. *Amphiroa* sp. (slide no. Bot./KB-32; sample no. 76/3339), x 100.
5. *Sporolithon* sp., - showing non-coaxial core filaments (slide no. Bot./KB-42; sample no. 65/3339), x 130.
6. *Sporolithon* sp. (slide no. Bot./KB-42; sample no. 65/3339), x 130.
7. *Sporolithon* sp. (slide no. Bot./KB-34; sample no. 68/3339), x 50.
8. *Sporolithon* sp., (slide no. Bot./KB-34; sample no. 68/3339), x 100.
9. *Sporolithon* sp., - showing rounded sporangia in a transverse section, (Slide no. Bot./KB-43; sample no. 61/3339), x 130.



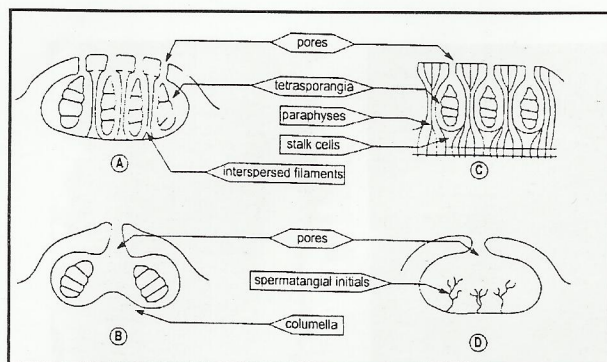


Fig. 4. Reproductive organs. A - Multiporate - Asexual. B - Uniporate - Asexual. C - Sori - Asexual. D - Sexual (after Rasser & Piller, 1999).

(Chamberlain, 1983; Woelkerling, 1985 a,b, 1988; Bassi, 1998; Rasser and Piller, 1999); they can be adequately understood only under SEM.

The reproductive organs of corallines include both sexual gametes, asexual carposporangia and asexual sporangia (Woelkerling, 1988). Gametes (sexual) are produced by spermatangial initials and are borne in uniporate conceptacles (fig. 4-D). Tetra/bisporangia (asexual) can be borne either in uniporate or in multiporate conceptacles, or they are grouped in sori and formed by stalk cell (fig. 4-A, B). Tetra/bisporangia conceptacles are formed by specialized groups of cells (initials) termed the conceptacle primordial. Conceptacle roofs are formed by a columella (a group of decalcified filaments arising centrally from the conceptacle floor as in fig. 4-B) through an elongation of decalcified filaments interspersed between the sporangia, or by filaments which surround the conceptacle chamber (Rasser and Piller, 1999).

Differences in growth-forms have

sometimes been used in the systematics to recognise genera and species of nongeniculate coralline algae. It has been demonstrated that there is a considerable variation of growth forms both at generic and specific levels. The determination of such a range of growth forms has led to the proposal of a comprehensive system of terminology : arborescent, unconsolidated, encrusting, warty, lumpy, fruticose, discoid, layered, foliose, and ribbon-like plants (fig. 5) (Woelkerling, Irvine and Harvey, 1993; Bassi, 1998).

The early calcification of coralline algae enables both the thallus growth forms and the anatomical details (e.g. secondary pit-connections, cell fusions, and conceptacles), to be preserved in the fossil material. These features are important in the systematic identification of the fossil material (Braga and Aguirre, 1995; Aguirre *et al.*, 1996; Bassi, 1995a,b, 1996) and also in the context of palaeoecology, paleobiogeography and

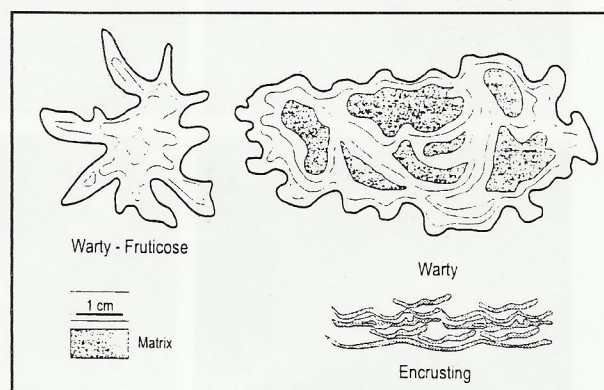
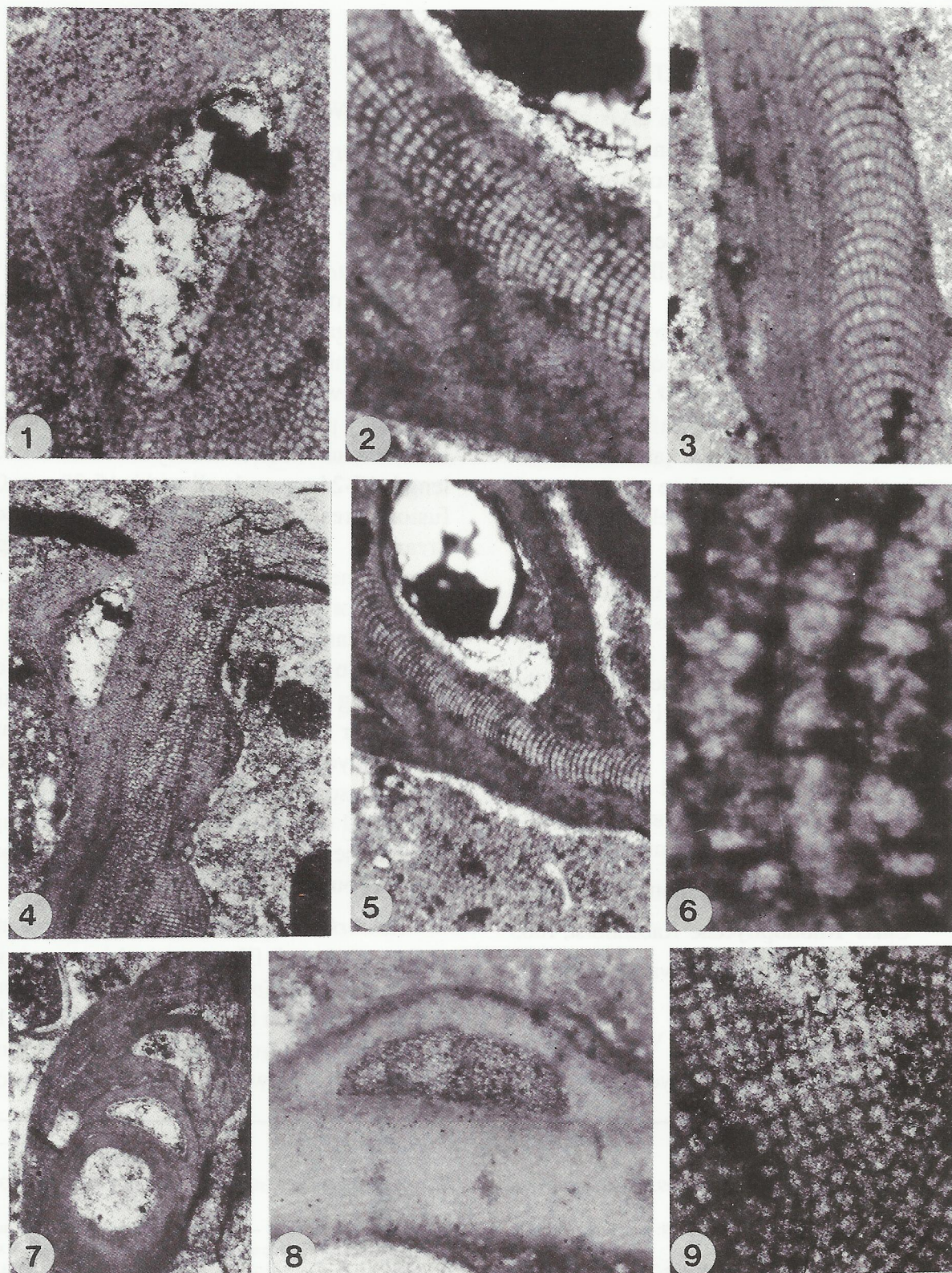


Fig. 5. Some common growth-forms in coralline algae. (after Bassi, 1998).

EXPLANATION OF PLATE II

1. *Spongites* sp. (slide no. Bot/KB-56; sample no. 38/3339), x 150.
2. *Neogonolithon* sp. (slide no. Bot/KB-31; sample no. 76/3339), x 150.
3. *Neogonolithon* sp. (slide no. Bot/KB-32; sample no. 76/3339), x 50.
4. *Spongites* sp. (slide no. Bot/KB-56, sample no. 38/3339), x 50.
5. *Neogonolithon* sp. (slide no. Bot/KB-31, sample no. 76/3339), x 50.
6. *Neogonolithon* sp., - showing primary pit-connections and cell fusions (slide no. Bot/KB-31; sample no. 76/3339), x 400.
7. *Spongites* sp. (slide no. Bot/KB-56; sample no. 38/3339), x 50.
8. *Neogonolithon* sp. (slide no. Bot/KB-57; sample no. 76/3339), x 60.
9. *Lithoporella* sp. (slide no. Bot/KB-125; sample no. 30/3341), x 120.



evolutionary studies.

SYSTEMATIC DESCRIPTION

The family Corallinaceae is divisible into seven subfamilies : Choreonematoideae, Lithophylloideae, Mastophoroideae, Melobesioideae, Amphiroideae, Corallinoideae and Metagoniolithoideae (Johansen, 1969, 1981; Johansen and Silva, 1978; Woelkerling, 1988; Bassi, 1998). Of these, the latter three subfamilies are characterized by a genicular anatomy. Thus, the presence or absence of genicula (uncalcified segments of the vegetative thallus) allows to divide informally the Corallinaceae into geniculate (articulate) and nongeniculate (non-articulate or crustose) groups (Chamberlain, 1983; Woelkerling, 1988, Bassi, 1998).

Taxonomic discrimination of the studied corallines was made on the basis of some of the criteria proposed by Braga *et al.* (1993), Rasser and Piller (1999) and others cited in the text. See identification key given after the systematic description.

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

Division Rhodophyta Wittstein, 1901

Class Rhodophyceae Rabenhorst, 1863

Order Corallinales Silva & Johansen, 1986

Family Sporolithaceae Verheij, 1993

Genus Sporolithon Heydrich, 1897

Sporolithon sp.

(Pl. I, figs. 5, 6-9)

Slide No.: Bot./KB-34, 42 & 43.

Locality: Babia Hill, nw Kachchh.

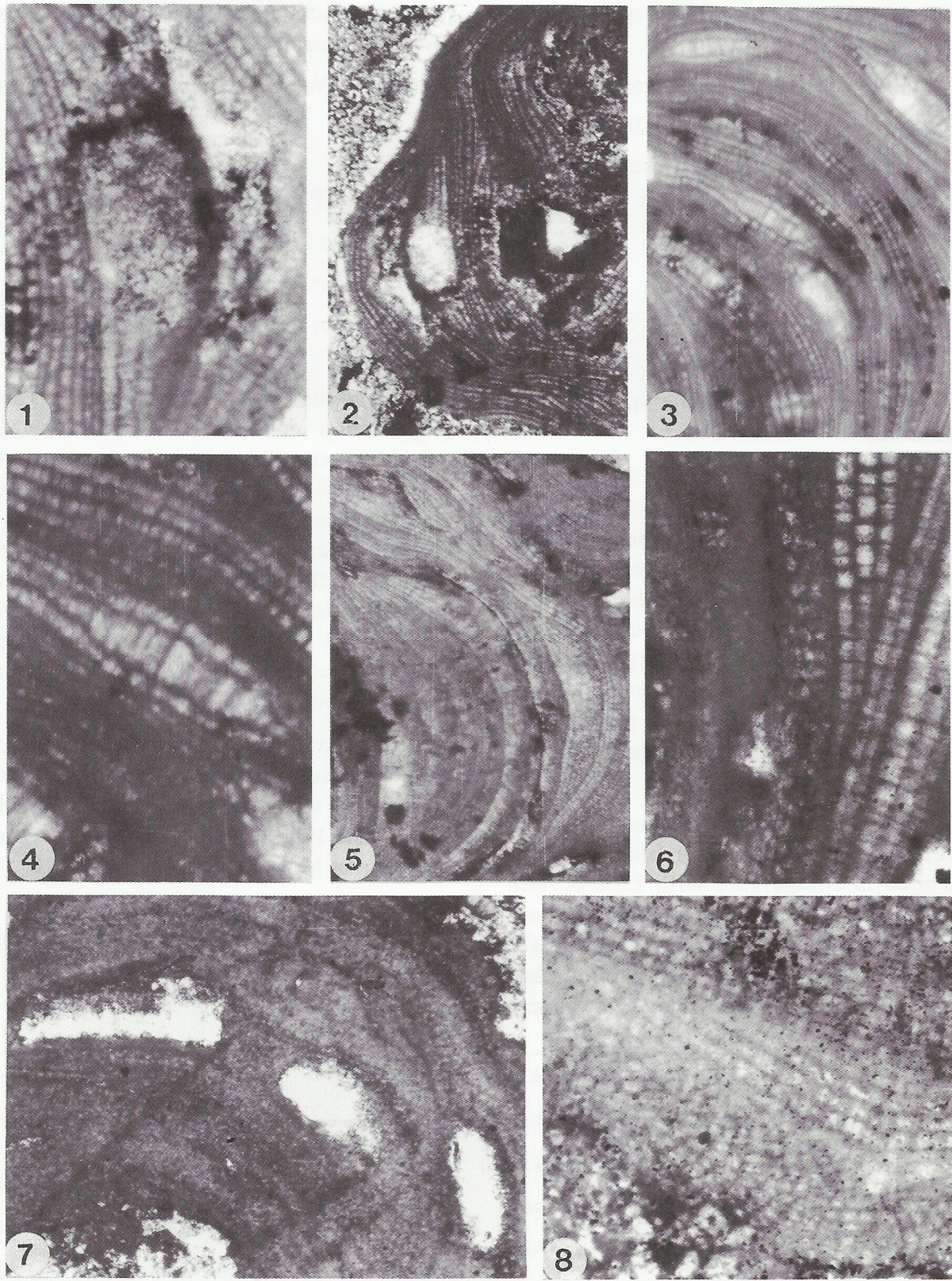
Horizon: Lower part of the Maniyara Fort Formation.

Diagnosis : Growth form encrusting, thickness of encrusting thalli up to 2.7 mm. Thallus organization monomerous. Core portion 0.37 mm thick. Cells 12-17µm in length and 14-15µm in width. The peripheral region of encrusting portion is restricted to the dorsal part of the thallus which is usually 2.1 mm thick. Cell length 17-24 µm and cell width 15-22 µm. Cell fusions present. Tetrasporangial conceptacles arranged in sori. Individual sporangial compartments rectangular, with rounded to elliptical or ovoid shape in longitudinal section and circular in transverse section. They are 70-75 µm long and 45-56 µm wide. Cells underlying the sporangial compartments longer than other peripheral cells. Sori usually arise from a layer of elongated cells. 1-6 filaments (paraphyses) are interspersed between the sporangial compartments. Up to 63 sporangial compartments can be counted in a single sorus. Old sori buried in the thallus.

Remarks: In the shape and size of sporangia and peripheral filaments, this species is comparable with *Sporolithon* cf. *gunteri* Johnson & Ferris, reported by Beckmann (1982, p. 133, pl. 11, figs. 2,5) from the Palaeocene of Monte Giglio, Italy. However, in our specimens core

EXPLANATION OF PLATE III

- | | |
|---|--|
| 1. <i>Lithothamnion</i> sp. 3 (slide no. Bot./KB-129; sample no. 93/339), x 100. | 5. <i>Lithothamnion</i> sp. 2 (slide no. Bot./KB-163; sample no. 46/3341), x 50. |
| 2. <i>Lithothamnion</i> sp. 3 (slide no. Bot./KB-129; sample no. 93/3339), x 50. | 6. <i>Lithothamnion</i> sp. 2 – showing non-coaxial core filament and peripheral cells, (slide no. Bot./KB-163; sample no. 46/331), x 100. |
| 3. <i>Lithothamnion</i> sp. 2 (slide no. Bot./KB-163; sample no. 46/3341), x 50. | 7. <i>Mesophyllum</i> sp. 2 (slide no. Bot./KB-85; sample no. 2/3341), x 60. |
| 4. <i>Lithothamnion</i> sp. 2 (slide no. Bot./KB-163; sample no. 46/3341), x 100. | 8. <i>Mesophyllum</i> sp. 2 - showing coaxial core filament and peripheral cells (slide no. Bot./KB-85; sample no. 2/3341), x 100. |



filaments are not preserved and sporangia are slightly larger.

Family **Corallinaceae** Lamouroux, 1816

Subfamily **Mastophoroideae** Setchell, 1943

Genus **Lithoporella** (Foslie) Foslie, 1909

Lithoporella sp.

(Pl. II, fig. 9)

Slide no.: Bot./KB-125.

Locality: Waior, sw Kachchh.

Horizon: Lower part of the Maniyara Fort Formation.

Diagnosis: Growth form encrusting, thallus either single or multiple (overgrowth). Its plants often encrust on other coralline algae and skeletal constituents. The cells are normally much longer than those of other crustose coralline algae. The primigenous filaments single layered and composed of large, vertically elongated cells, about 25-30 μm in length and 15-20 μm in width; cell fusions present. The postigenous filaments and conceptacles not preserved.

Remarks: In the thallus morphology and cell dimensions of primigenous filaments, our specimen is comparable with *Lithoporella melobesioides* (Foslie) Foslie reported by Bassi (1998) from the late Eocene of Northern Italy, and by Rasser and Piller (1999) from the late Eocene of Austrian Molasse zone. As the present

specimen lacks conceptacle, it is not presently possible to confirm its specific affinities.

Genus **Neogonolithon** Setchell & Mason, 1943

Neogonolithon sp.

(Pl. II, figs. 2, 3, 5, 6, 8)

Slide no.: Bot./KB-31, 32 & 57.

Locality: Babia Hill, nw Kachchh.

Horizon: Lower part of the Maniyara Fort Formation.

Diagnosis: Growth form encrusting. Thallus organisation monomerous. Thallus about 278 μm thick, core filaments coaxial, core portion 178 μm thick, filaments curved towards ventral and dorsal surface; cell fusions present, cells 28-34 μm in length and 14-19 μm in diameter. Peripheral filaments restricted to dorsal and ventral surface. Peripheral portion 120 μm thick, cell length 8-14 mm and cell diameter 10-12 μm . Conceptacles uniporate, 225 μm in length and 675 μm in width.

Remarks: In the general morphology of core and peripheral filaments, this species is comparable with *Neogonolithon* sp. reported by Rasser and Piller (1999) from the late Eocene of Austrian Molasse Zone.

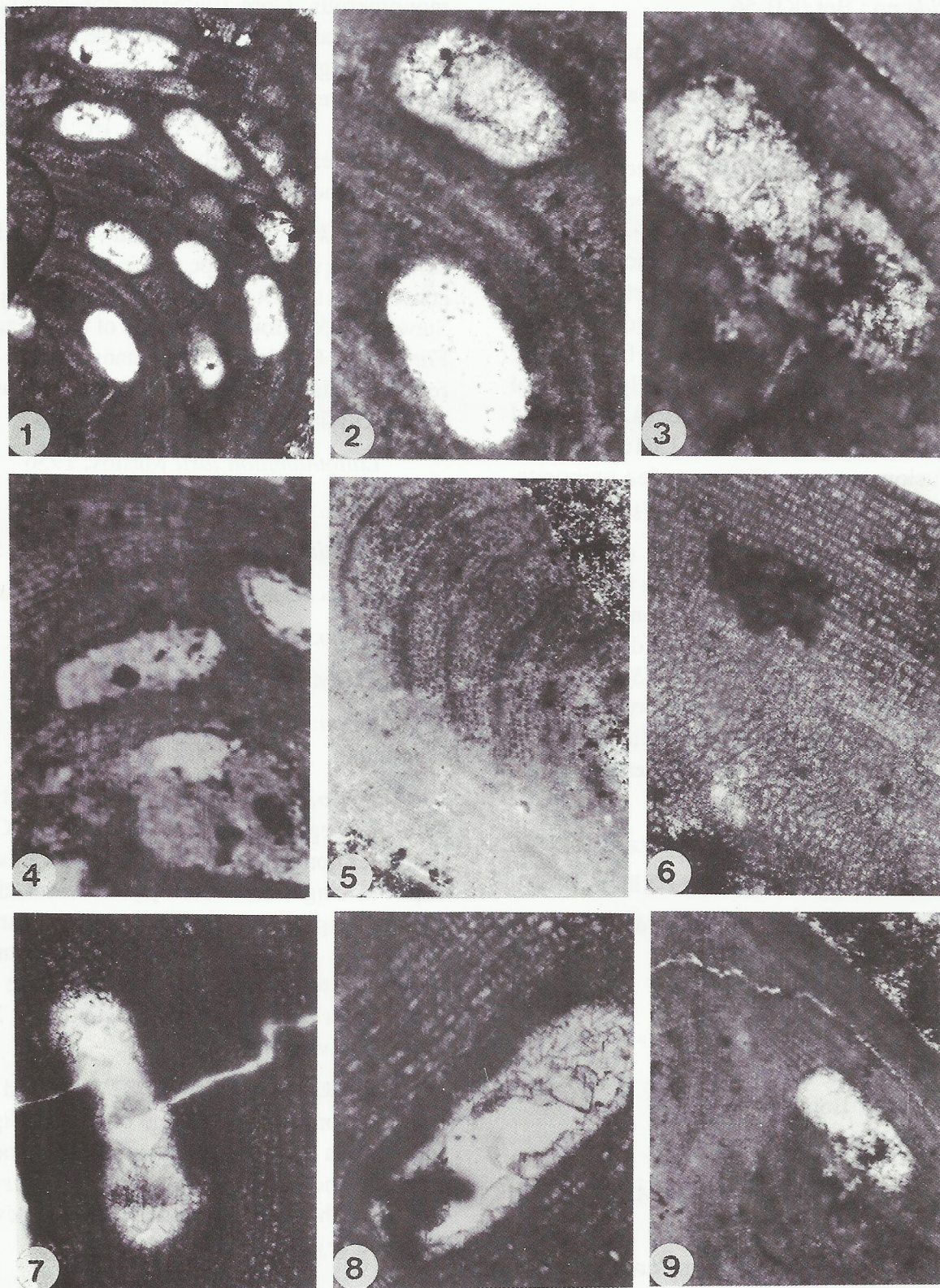
Genus **Spongites** Kützing, 1841

Spongites sp.

(Pl. II, figs. 1, 4, 7)

EXPLANATION OF PLATE IV

1. *Lithothamnion manni* Johnson & Stewart (slide no. Bot./KB-33; sample no. 23/3341), x 50.
2. *Lithothamnion manni* Johnson & Stewart (slide no. Bot./KB-33; sample no. 23/3341), x 130.
3. *Lithothamnion* sp. 1 (slide no. Bot./KB-144; sample no. 29/3341), x 150.
4. *Lithothamnion* sp. 1 (slide no. Bot./KB-144; sample no. 29/3341), x 50.
5. *Mesophyllum* sp. 1 (slide no. Bot./KB-171; sample no. 14/3341), x 50.
6. *Lithothamnion iorii* Maslov - showing non-coaxial core filament and peripheral cells (slide no. Bot./KB-136; sample no. 11/3341), x 100.
7. *Lithothamnion iorii* Maslov (slide no. Bot./KB-136; sample no. 11/3341), x 100.
8. *Lithothamnion* sp. 1 (slide no. Bot./KB-144; sample no. 29/3341), x 100.
9. *Mesophyllum* sp. 1 (slide no. Bot./KB-171; sample no. 14/3341), x 50.



Slide no.: Bot./KB-56.

Locality: Babia Hill, nw Kachchh.

Horizon: Lower part of the Maniyara Fort Formation.

Diagnosis: Growth form encrusting to warty, 380-435 μm thick. Protuberances are 475-720 μm in length and 150-360 μm in diameter. Thallus organisation monomerous, core filaments non-coaxial, core portion 165 μm thick; cells 20-30 μm in length and 12-18 μm in width, cell fusions present. The filaments of the branches regular, formed of nearly horizontal to gently arched layer of long cells. Peripheral filaments 14-18 μm long and 13-16 μm wide. Cell fusions present. Conceptacles uniporate, 175-182 μm in length and 500-520 μm in width.

Remarks: This specimen is comparable with genus *Spongites* Kutzing on the basis of its coaxial core filament, cell fusions, uniporate conceptacles. In the size and shape of conceptacle, it is comparable with *Spongites* sp. 2 of Rasser and Piller (1999) reported from the late Eocene of Austrian Molasse Zone. However, it differs in the size of peripheral and core filament cells.

Subfamily Melobesioideae Bizzozero, 1885

Genus Lithothamnion Philippi, 1837

Lithothamnion manni Johnson & Stewart, 1953

(Pl. IV, figs.1-2)

Lithothamnium manni Johnson & Stewart, 1953, p. 133. Beckmann, 1982, p.134, Pl. 11, fig.10.

Slide no.: Bot./KB-33.

Locality: Waior, sw Kachchh.

Horizon: Lower part of the Maniyara Fort Formation.

Diagnosis: Growth form encrusting to warty, protuberances 1.9 mm in diameter and up to 2.4 mm in length. Thallus organisation

monomerous. Core filaments non-coaxial or curved towards the thallus surface, cells 14-19 μm in length and 10-16 μm in diameter. Peripheral region with cells which are 12-18 μm in length and 12-16 μm in diameter. Conceptacles apparently multiporate, 195-425 μm wide and 135-165 μm high.

Remarks: The present material is comparable with the type species in the cell and conceptacle size. It was reported by Johnson and Stewart (1953) from the Eocene of the Meganos Formation, California. Beckmann (1982) also reported this species from the Palaeocene of Monte Giglio, Italy.

Lithothamnion iorii Maslov, 1956

(Pl. IV, figs. 6-7)

Lithothamnium (?) iorii Maslov, 1956, p. 115.

Lithothamnion iorii Beckmann, 1982, p.134, Pl. 12, fig. 5&6.

Slide no.: Bot./KB-136.

Locality: Waior, sw Kachchh.

Horizon: Lower part of the Maniyara Fort Formation.

Diagnosis: Growth form encrusting. Thallus organisation monomerous. Core filaments non-coaxial, 315 μm thick. Cells 18-22 μm in length and 10-14 μm in width, those of the peripheral filaments are 11-14 μm in length and 10-12 μm in width. Conceptacles without internal partitions, multiporate and relatively wide, 90-120 μm in length and 330-528 μm in width.

Remarks: Beckmann (1982) reported this species from the Palaeocene of Monte Giglio, Italy. In his specimen, the conceptacle floor is straight and the roof more or less curved. However, the Waior specimens have somewhat rectangular conceptacles.

Lithothamnion sp. 1

(Pl. IV, figs. 3-4, 8)

Slide no.: Bot./KB-144.

Locality: Waior, sw Kachchh.

Horizon: Lower part of the Maniyara Fort Formation.

Diagnosis: Growth form encrusting; thallus organisation monomerous. Core filaments non-coaxial, 240 μm thick, cells 12-16 μm in length and 10-14 μm in width, cell fusions present; cells of the peripheral filaments 15-22 μm in length and 14-18 μm in width. Conceptacles multiporate, 390-519 μm in width and 180-195 μm in length.

Remarks: This species is comparable with *Lithothamnion* sp. 2 Bassi, in the morphology of thallus and in the shape and size of conceptacles but differs in the size of peripheral and core filament cells. *Lithothamnion* sp. 2 Bassi was reported from the upper Eocene of Calcare di Nago, Northern Italy (Bassi, 1998).

Lithothamnion sp. 2

(Pl. III, figs. 3-6)

Slide no.: Bot./KB-163.

Locality: Waior, sw Kachchh.

Horizon: Lower part of the Maniyara Fort Formation

Diagnosis: Growth form encrusting to warty and lumpy. Protuberances 1.8 μm in diameter and up to 3.2 μm in length. Thallus organisation monomerous. Core filament non-coaxial, core portion usually 0.12 μm thick, cell fusions occur. Cells 15-20 μm in length and 12-14 μm in width. Peripheral cells rectangular or squarish, distinct, arranged in somewhat undulating rows, about 16-22 μm in length and 28-30 μm in width. In the peripheral region, the horizontal walls are more distinct than the vertical ones. Conceptacles immature, showing various developmental stages, sunken, 390-570 μm wide, 130-145 μm high.

Remarks: This specimen seems to be comparable with *Palaeothamnium archaeotypum* Conti in the immature conceptacles. Basso *et al.* (1997) reported morphologically similar specimens from the Miocene of Leithakalk and assigned them to *Palaeothamnium archaeotypum* on the basis of developmental stages of conceptacles. Aguirre *et al.* (1996) and Basso *et al.* (1997) recommended that identification of different species of the genus *Palaeothamnium* Conti be made not only on the basis of developmental stages of conceptacles but also on the growth form, flat epithallial cells, long subepithallial initials and peripheral region. However, the majority of the workers still give due importance to the developmental stages of conceptacles (c.f. Moussavian, 1991). Aguirre *et al.* (1996) have regarded the genus *Palaeothamnium* Conti as the younger heterotypic synonym of the genus *Lithothamnion* Heydrich. Hence, the present specimen is being placed under the genus *Lithothamnion*.

Lithothamnion sp. 3

(Pl. III, figs. 1-2)

Slide no.: Bot./KB-129.

Locality: Babia Hill, nw Kachchh.

Horizon: Lower part of the Maniyara Fort Formation.

Diagnosis: Growth form encrusting. Core filaments indistinct. The cells of peripheral filaments 18-21 μm long and 14-16 μm wide, cell fusions present. Conceptacle sub-spherical, with multiporate roof, 180-192 μm in length and 280-300 μm in width.

Remarks: In the morphology of conceptacle, peripheral filaments and presence of cell fusions, this specimen compares with the genus *Lithothamnion* Philippi. *Lithothamnion* sp. 3 differs from *L.* sp. 1 and *L.* sp. 2 in having smaller conceptacles.

Genus *Mesophyllum* Lemoine, 1928

Mesophyllum sp. 1

(Pl. IV, figs. 5, 9)

Slide no.: Bot./KB-171.

Locality: Waior, sw Kachchh.

Horizon: Lower part of the Maniyara Fort Formation.

Diagnosis: Growth form encrusting, thickness of encrusting portion of thallus 1.5-1.6 mm, thallus organisation monomerous, core filaments coaxial made up of cells which are 14-18 μm in length, 20-24 μm in diameter. It is surrounded by the peripheral filaments, whose cells are arranged in layers parallel to the surface and are 10-14 μm in length and 10-12 μm in width. Conceptacles apparently multiporate, 210-215 μm in length and 560-575 μm in width.

Remarks: The present specimens are comparable to *Mesophyllum* cf. *pfenderae* Beckmann (1982) on the basis of the organisation of core and peripheral filaments. Beckmann (1982) reported this species from the Palaeocene of Monte Giglio, Italy. Our specimen, however, is characterised by larger conceptacles than *Mesophyllum* cf. *pfenderae*.

Mesophyllum sp. 2

(Pl. III, figs. 7-8)

Slide no.: Bot./KB-85.

Locality: Waior, sw Kachchh.

Horizon: Lower part of the Maniyara Fort Formation.

Diagnosis: Growth form encrusting; thallus organisation monomerous. Core filaments coaxial, 180 μm thick, cells 20-25 μm in length and 15-25 μm in width, cell fusions present; cells of the peripheral filaments 14-22 μm in length and 10-12 μm in width. Conceptacles multiporate, 550-600 μm in width and 170-185

μm in length.

Remarks: The present specimens are comparable to *Mesophyllum fructiferum* Basso *et al.* (1998) in the shape and size of multiporate conceptacles and in the shape and size of the cells of core and peripheral filaments. Basso *et al.* (1998) reported this species from the Tertiary of NW Italy.

Genus *Corallina* Linnaeus, 1758

Corallina sp. 1

(Pl. I, fig. 1)

Slide no.: Bot./KB-57.

Locality: Babia Hill, nw Kachchh.

Horizon: Lower part of the Maniyara Fort Formation.

Diagnosis: Plant geniculate. Genicula distinct, intergenicula about 1.2 mm in length and 230-260 μm in diameter and made up of medullary rays. Genicula 155 μm in diameter and 125-138 μm in length, cell fusions indistinct. The core cells of intergenicula 70-80 μm in length and 10-15 μm in diameter and composed of a single tier of elongated cells. Conceptacles not preserved.

Remarks: This specimen is poorly preserved. The genicula consist of uncalcified layers of core cells. As the conceptacles occur externally in the genicula of thallus, they are usually lost during preservation. Thallus organisation of the present specimen suggests its similarity with *Corallina*; however, its specific identification is not possible due to absence of conceptacles.

Corallina sp. 2

(Pl. I, fig. 2)

Slide no.: Bot./KB-46.

Locality: Waior, sw Kachchh.

Horizon: Lower part of the Maniyara Fort

Formation.

Diagnosis: Plant geniculate, fragments of thalli about 900 μm in length and 375-712 μm in diameter. Genicula indistinct. Core cells of intergenicula 66-75 μm in length and 12-18 μm in diameter, composed of a single tier of elongated cells. Conceptacles not preserved.

Remarks: Though the present form is comparable with *Corallina matansa* Johnson (Johnson and Kaska, 1965, p. 54, pl. 21, fig. 1) reported from the lower Eocene of Guatemala in branching pattern and tissue differentiation of thallus, it lacks conceptacles; hence, it is kept in open nomenclature.

Genus *Arthrocardia* (Harvey) Areschoug,
1852

Arthrocardia sp.

(Pl. I, fig.3)

Slide no.: Bot./KB-39.

Locality: Waior, sw Kachchh.

Horizon: Lower part of the Maniyara Fort Formation

Diagnosis: Thallus segmented, with nodes between the segments. Segments have straight medulary filaments comprising equal cells. Cells 76-84 μm in length and 14-21 μm in diameter. Cortical tissues not preserved. Segments attained length up to 76-84 μm and width up to 195 μm . Conceptacles not found.

Remarks: This vegetative specimen is not comparable with any known species of *Arthrocardia* (Harvey) Areschoug.

Genus *Amphiroa* Lamouroux, 1812

Amphiroa sp.

(Pl. I, fig. 4)

Slide no.: Bot./KB-32.

Locality: Babia Hill, NW Kachchh.

Horizon: Lower part of the Maniyara Fort Formation.

Diagnosis: Intergenicula relatively slender. Medial portion consisting of alternations of a single row of long cells and a single row of short cells. Long cells 76-82 μm long and 12-17 μm wide; short cells 30-42 μm long and 12-16 μm wide. Conceptacles absent. Thallus about 270-375 μm thick.

Remarks: This species can be compared with *Amphiroa regularis* Johnson and Ferris (1950) in the alternate arrangement of long and short cells. In our specimen, the short cells, however, are relatively larger than those in *A. regularis* recorded from the Miocene of Lau, Fiji.

IDENTIFICATION KEY

Tetra/bisporangial conceptacles arranged in sori: Family **Sporolithaceae** (1)

Tetra/bisporangial conceptacles not arranged in sori: Family **Corallinaceae** (2)

(1) Family **Sporolithaceae**

(a) Core filaments non-coaxial, length of peripheral cells 17-24 μm : *Sporolithon* sp.

(2) Family **Corallinaceae**

(1) Cells of contiguous filaments connected by cell fusions, Tetra/bisporangial conceptacles uniporate: Subfamily **Mastophoroideae** (1).

(2) Cells of contiguous filaments connected by cell fusions, Tetra/bisporangial conceptacles multiporate: Subfamily **Melobesoideae** (2).

(3) Presence or absence of genicula and intergenicula, tetra/bisporangial conceptacles uniporate: Subfamily: **Corallinoideae** (3).

(4) Core filaments have one to several tiers of cells, tetra/bisporangial conceptacles

uniporate: Subfamily **Amphiroideae** (4).

(1) Subfamily **Mastophoroideae** (1).

(a) Thallus dimerous with palisade cells:
Lithoporella sp.

(b) Thallus monomerous, core filaments coaxial, cells of peripheral filaments are 8-14 μm in length and 10-12 μm in diameter, tetra/bisporangial conceptacles uniporate, 675 μm wide and 225 μm high: *Neogonolithon* sp.

(c) Thallus monomerous, core filaments non-coaxial, Tetra/bisporangial conceptacles uniporate, 500-520 μm wide and 175-180 μm high: *Spongites* sp.

(2) Subfamily **Melobesoideae** (2)

(a) Thallus monomerous, core filaments non-coaxial, tetra/bisporangial conceptacles multiporate, 195-425 μm wide and 135-165 μm high: *Lithothamnion manni*.

(b) Thallus monomerous, core filaments non-coaxial, tetra/bisporangial conceptacles multiporate, 330-528 μm wide and 90-120 μm high: *Lithothamnion iorri*.

(c) Thallus monomerous, core filaments non-coaxial, tetra/bisporangial conceptacles multiporate, 390-515 μm wide and 189-195 μm high: *Lithothamnion* sp. 1.

(d) Thallus monomerous, core filaments non-coaxial, tetra/bisporangial conceptacles multiporate, showing various developmental stages, 390-570 μm wide and 130-145 mm high: *Lithothamnion* sp. 2.

(e) Thallus monomerous, core filaments non-coaxial, tetra/bisporangial conceptacles multiporate, 280-300 μm wide and 180-192 μm high:

Lithothamnion sp. 3.

(f) Thallus monomerous, core filaments coaxial, tetra/bisporangial conceptacles multiporate, 560-575 μm wide and 210-215 μm high: *Mesophyllum* sp. 1.

(g) Thallus monomerous, core filaments coaxial, tetra/bisporangial conceptacles multiporate, 550-600 μm wide and 170-180 μm high: *Mesophyllum* sp. 2.

(3) Subfamily: **Corallinoideae** (3)

(a) Presence of genicula and intergenicula: *Corallina* sp. 1.

(b) Genicula absent and intergenicula present: *Corallina* sp. 2.

(c) Cells of intergenicula 78-84 μm long and 14-21 μm wide : *Arthrocardia* sp.

(4) Subfamily **Amphiroideae** (4)

(a) Alternation of long and short cells of intergenicula: *Amphiroa* sp.

CONCLUSIONS

The present study of the corallines from the Oligocene of Kachchh attempts to employ three of the Rasser and Piller's (1999) six taxonomic criteria used to describe fossil taxa. The six taxonomic features are the arrangement of basal filaments, the presence or absence of cell fusions, the relative length of subepithallial initials, conceptacle perforation, the orientation of filaments around the conceptacle pore and the type of conceptacle roof formation (Rasser and Piller, 1999). The present work is basically a thin section study and employs the following characters: growth form, cell fusions and type of conceptacle. Possibly because of preservation factors in the studied material, we could not make observations relating to epitallial cells and subepithallial initials.

Growth form characters (encrusting, warty, lumpy, etc) and thallus organisation characters (monomerous, dimerous organisation, coaxial and non-coaxial core filaments) are the

important taxonomic features used for identification at generic and specific levels of the present-day coralline algae. In the fossil forms, such as *Mesopyllum* and *Lithothamnion* (the genera reported in the present study), the taxonomic differentiation is actually based on the presence of coaxial or non-coaxial core filaments as well as the form of epithallial cells (not used in this study) as both the genera have multiporate conceptacles and cell fusions. Inter-filament cell connections (cell fusions) can be recognised in fossil corallines and are important for identification at family level. This is well indicated by *Lithophyllum* (not present in the studied assemblage) and *Neogonolithon*. Both the genera have coaxial core filaments and uniporate conceptacles but can be differentiated only on the basis of presence of cell fusions. In the case of *Mesopyllum* and *Neogonolithon* (the genera reported in the present study), the taxonomic differentiation is based on the multiporae or uniporate conceptacles, because both possess coaxial core filaments and show cell fusions (see identification key).

The traditional taxonomic criteria were employed for *Corallina*, *Arthrocardia* and *Amphiroa*. The geniculate coralline taxa have been differentiated on growth form, method of branching, internal and external characters of the genicula and intergenicula. The features of genicula, though distinct only in one form (*Corallina* sp. 1), have not been used for other geniculates (*Corallina* sp. 2 and *Arthrocardia* sp.) in this work.

This study indicates that the depositional facies of the Palaeogene sequences of Kachchh are suitable for the growth of algal flora in abundance. This is especially true for the carbonate-dominated deposits of the Maniyara Fort Formation of the Oligocene age. These deposits are noted to be rich in the calcareous algal assemblages in addition to the abundant animal remains. The algal assemblages need to

be studied in detail for documenting a complete picture of their taxonomic composition. Such studies are important as they can be helpful in the context of palaeoecology and palaeobiogeography of the Kachchh biota in view of the key position of Kachchh in the upper Palaeogene palaeogeography.

ACKNOWLEDGEMENTS

The authors express a deep sense of gratitude to the Heads of the Departments of Botany and Geology, University of Lucknow, Lucknow for encouragement and library and laboratory facilities. Dr. Davide Bassi (Università di Ferrara, Italy) is gratefully thanked for sending useful literature and reviewing the original manuscript and offering helpful comments for its improvement. We are extremely grateful to Prof. J.C. Braga (Granada, Spain) and Dr. M. Rasser (Vienna, Austria) for providing us with the relevant literature on the coralline algae. We are also grateful to Prof P. De Castro, Napoli, Italy, for going through the manuscript and suggesting necessary changes. The field work for this research was funded by U.G.C. (New Delhi) in the form of a project to A. K. J.

REFERENCES

- Aguirre, J., Braga, J.C. and Piller, W.E. 1996. Reassessment of *Palaeothamnium* Conti, 1946 (Corallinales, Rhodophyta). *Rev. Palaeobot. Palynol.* **94**:1-9.
- Bajpai, S., Singh, M.P. and Singh, P. 1987. A new Sirenian from the Miocene of Kachchh, western India. *Jour. Pal. Soc. India*, **32**: 20-25.
- Beckmann, J. P. 1982. Displaced Late Cretaceous and Palaeocene microfossils, p. 120-141. In : *Micropalaeontology and biostratigraphy of the Campanian to Palaeocene of the Monte Giglio, Bergamo Province, Italy*. (Beckmann, J. P., Bolli, H. M., Kleboth, P. and Proto Decima, F.), *Memoire Di Scienze Geologiche*, **XXXV**.
- Bassi, D. 1995a. Crustose Coralline Algal Pavements from Late Eocene Colli Berici of Northern Italy. *Riv. Ital. di Palaeontol. Stratigr.* **101**(1):81-92.
- Bassi, D. 1995b. *Sporolithon*, *Hydrolithon*, *Corallina* and *Halimeda* in the Calcare di Nago (Eocene, Trento, Northern Italy). *Annali dell' Università di Ferrara*, **6** (2):11-25.
- Bassi, D. 1996. Le Corallinacee del Calcare di Nago: Sistematica e Paleocologia (Eocene superiore; Trentino meridionale). *Unpublished Ph. D. Thesis, Univ. Ferrara*.

- Bassi, D. 1997. Vegetative anatomy and palaeoecology of *Polystrota alba* (PFENDER), 1968 (Cryptonemiales, Peyssonneliaceae) from the Upper Eocene of northern Italy. *Rev. Paléobiol. Genève*. 16(2) : 309-320.
- Bassi, D. 1998a. Coralline red algae (Corallinales, Rhodophyta) from the upper Eocene Calcare di Nago (Lake Garda, Northern Italy). *Annali dell' Università di Ferrara*, 7:1-50.
- Bassi, D. 1998b. Coralline algal facies and their palaeoenvironments in the late Eocene of Northern Italy (Calcare di Nago, Trento). *Facies*, 39: 179-202.
- Basso, D., Fravega, P. and Vanucci, G. 1996. Fossil and Living Corallineans related to the Mediterranean endemic species *Lithophyllum racemus* (Lamarck) Fosl. *Facies*, 35: 275-292.
- Basso, D., Fravega, P. and Vanucci, G. 1997. The Taxonomy of *Lithothamnium ramosissimum* (Gümbel non Reuss) Conti and *Lithothamnium operculatum* (Conti) Conti (Rhodophyta, Corallinaceae). *Facies*, 37:167-182.
- Basso, D., Fravega, P., Piazza, M. and Vanucci, G. 1998. Revision and re-documentation of M. Airoidi's species of *Mesophyllum* from the Tertiary Piedmont Basin (NW Italy). *Rivista Italiana di Paleontologia e Stratigrafia*, 104(1): 85-93.
- Biswas, S.K. 1965. A new classification of the Tertiary rocks of the Kutch, western India. *Bull. Geol. Min. Soc. India*, 35 : 1-6.
- Biswas, S.K. 1971. Note on the Geology of Kutch. *Quart. Jour. Geol. Min. Met. Soc. India*, 43 (4) : 223-235.
- Biswas, S.K. 1972. Time-stratigraphic classification of the Tertiary Rocks of Kutch – revision and amendments. *Quart. Jour. Geol. Min. Met. Soc. India*, 44 (3) : 221-224.
- Biswas, S.K. 1992. Tertiary Stratigraphy of Kutch. *Jour. Pal. Soc. India*, 37 : 1-29.
- Biswas, S.K. and Raju, D.S.N. 1973. The rock-stratigraphic classification on the Tertiary sediments of Kutch. *Bull. O. N. G. C.* 10 (1&2) : 37- 46.
- Bosence, D.W.J. 1983. Coralline algae from the Miocene of Malta. *Palaeontol.* 26(1):147-173.
- Bosence, D.W.J. 1984. Construction and preservation of two modern coralline algal reefs, St. Croix, Caribbean. *Palaeontol.* 27:549- 574.
- Bosence, D.W.J. 1991. Coralline Algae : Mineralization, Taxonomy and Palaeoecology, p. 98-113. In: *Calcareous Algae and Stromatolites* (Ed. : Riding, R.), Springer - Verlag, Berlin.
- Braga, J.C., Bosence, D.W.J. and Steneck, R.S. 1993. New anatomical characters in fossil coralline algae and their taxonomic implications. *Palaeontol.* 36:535-547.
- Braga, J.C. and Aguirre, J. 1995. Taxonomy of fossil coralline algal species: Neogene Lithophylloideae (Rhodophyta, Corallinaceae) from southern Spain. *Rev. Palaeobot. Palynol.* 86:265-285.
- Chamberlain, Y.M. 1983. Studies in the Corallinaceae with special reference to *Fosliella* and *Pneophyllum* in the British Isles. *Bull. Brit. Mus. (Nat. Hist.)*, Bot. Ser. 11 : 291-463.
- Johnson, J.H. and Kaska, H.V. 1965. Fossil Algae from Guatemala. *Colorado Schools of Mines Prof. Contribution*, 1:152 p.
- Johnson, J.H. and Stewart, W.A. 1953. Eocene Coralline Algae from the Meganos Formation, California. *Jour. Pal.* 27(1): 130-136.
- Johnson, J.H. and Ferris, B.J. 1950. Tertiary and Pleistocene coralline algae from Lau, Fiji. *Bernice P. Bishop Mus. Bull.* 201:1-27.
- Johansen, H.W. 1969. Morphology and systematics of Coralline algae with special reference to *Calliarthron*. *Univ. Calif. Publ. (Bot.)*, 49:1-98.
- Johansen, H.W. 1981. *Coralline algae, a first synthesis*. CRC Press, Boca Raton, Florida.
- Johansen, H.W. and Silva, P.C. 1978. Janiae and Lithotricheae: two new tribes of articulated Corallinaceae (Rhodophyta): *Phycologia*, 17 (4): 413-417.
- Kar, R.K. 1979. Fossil algae from Fulra Limestone (Middle Eocene) Kutch, Gujarat. *Geophytol.* 9 : 88-90.
- Lakhanpal, R.N., Guleria, J.S. and Awasthi, N. 1984. The fossil floras of Kachchh - III. Tertiary megafossils. *Palaeobot.* 33: 228-319.
- Maslov, V.P. 1956. Fossil calcareous algae of the U.S.S.R. *Acad. Sci. Trudy.* 160:301.
- Moussavian, E. 1991. New aspects of the phylogeny of Coralline red algae (Rhodophyta): Cretaceous-Recent. 5th Int. Symp. Fossil Algae, Capri, 1991 (abstr.).
- Pal, A.K. and Ghosh, R.N. 1974. Fossil algae from the studies of type and other nomenclatorial reassessment of *Tenarea*, *Titanoderma* and *Dermatolithon* (Corallinaceae, Rhodophyta) based on studies of type and other critical specimens: *Phycologia*, 24: 317-337.
- Poignant, A.F. 1984. La notion de genre chez les algues fossiles. A. Les Corallinacées. *Bulletin dela Société Géologique de France*, 26: 603-604.
- Rasser, M. and Piller, W.E. 1999. The coralline algae of the Upper Austrian Molasse zone (Late Eocene): application of neontological taxonomy to the fossil record. *Jour. Micropalaeont.* 18 : 67-80, London.
- Singh, P. and Singh, M.P. 1986. Late Middle Eocene calcareous nannoplankton from Babia Hill, Kutch, Gujrat, India. *Geosci. Jour.* 7 (2): 145-162.
- Tandon, K.K., Gupta, S.K. and Saxena, R.K. 1978. A new species of *Lithophyllum* from Oligocene of South western Kutch. *Jour. Pal. Soc. India*, 21 & 22 : 74-77.
- Tandon, K.K. 1974. Classification of Oligocene rocks of a part of SW Kutch, India. *Publ. Cent. Adv. Stud. Geol. Punjab Univ. Chandigarh*, 10:191-206.
- Woelkerling, W.J. 1985a. Proposal to conserve *Lithothamnium* against *Lithothamnium* (Rhodophyta, Corallinaceae). *Taxon*, 34(2): 302-303.
- Woelkerling, W.J. 1985b. A taxonomic reassessment of *Spongites* (Corallinaceae, Rhodophyta) based on studies of Kutzing's original collections. *Brit. Phycol. Jour.* 20: 123-153.
- Woelkerling, W.J. 1988. The Coralline Red algae: an analysis of the genera and subfamilies of nongeniculate Corallinaceae. *Brit. Mus. (Nat. Hist.)*, Oxford University Press, London & Oxford : 268 p.
- Woelkerling, W.J. and Campbell, S.J. 1992. An account of southern Australian species of *Lithophyllum* (Corallinaceae, Rhodophyta). *Bull. Brit. Mus. (Nat. Hist.)*, 22:1-107.
- Woelkerling, W.J., Irvine, L.M. and Harvey, A.S. 1993. Growth-forms in non-geniculate coralline red algae (Corallinales, Rhodophyta). *Aust. Jour. Syst. Bot.* 6: 277-293.
- Woelkerling, W.J., Chamberlain, Y.M. and Silva, P.C. 1985. A taxonomic and nomenclatorial reassessment of *Tenarea*, *Titanoderma* and *Dermatolithon* (Corallinaceae, Rhodophyta) based on studies of type and other critical specimens. *Phycologia*, 24: 317-337.
- Wray, J.L. 1977. *Calcareous Algae*. Elsevier, Amsterdam.
- Wray, J.L. 1978. Calcareous Algae, p. 171-187. In: *Introduction to Marine Micropalaeontology* (Haq, B.U. and Boersma, Anne Eds.), Elsevier, New York.