Halimedacean and Udoteacean calcareous algae from the Early Eocene subsurface carbonates platform of the Bengal Basin, India: paleoenvironmental aspects

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ABSTRACT: The calcareous algae are widespread in the early Eocene, shallow marine subsurface Sylhet Limestone Formation of the Bengal Basin, India. The study of these limestones revealed the presence of 07 Halimedacean algal species such as *Halimeda incrassata* (Ellis) Lamouroux, *Halimeda tuna* (Ellis and Solander) Lamouroux, *Halimeda cylindracea* Decaisne, *Halimeda nana* Pia, *Halimeda simulans* Howe, *Halimeda opuntia* (Decaisne) Agardh and *Halimeda* sp. and 03 Udoteacean algal species such as *Ovulites pyriformis* Schwager, *Ovulites arabica* (Pfender) Massieux and *Ovulites margaritula* Lamarck for the first time. The possible reason for the prolific growth of the *Halimeda* in the early Eocene carbonates of the Bengal Basin may be the nutrients brought by the then river runoff and the currents existed along the shelf. The dominance of halimedacean and udoteacean algae associated with dasycladaleans indicate that the early Eocene Sylhet Limestone of the Bengal Basin was deposited under shallow, warm, tropical, open lagoonal to shelf environment at the depth of 5-6 m below low tide level with Tethyan affinity.

Keywords: Early Eocene, Sylhet Limestone Formation, Paleoenvironments, Bengal Basin.

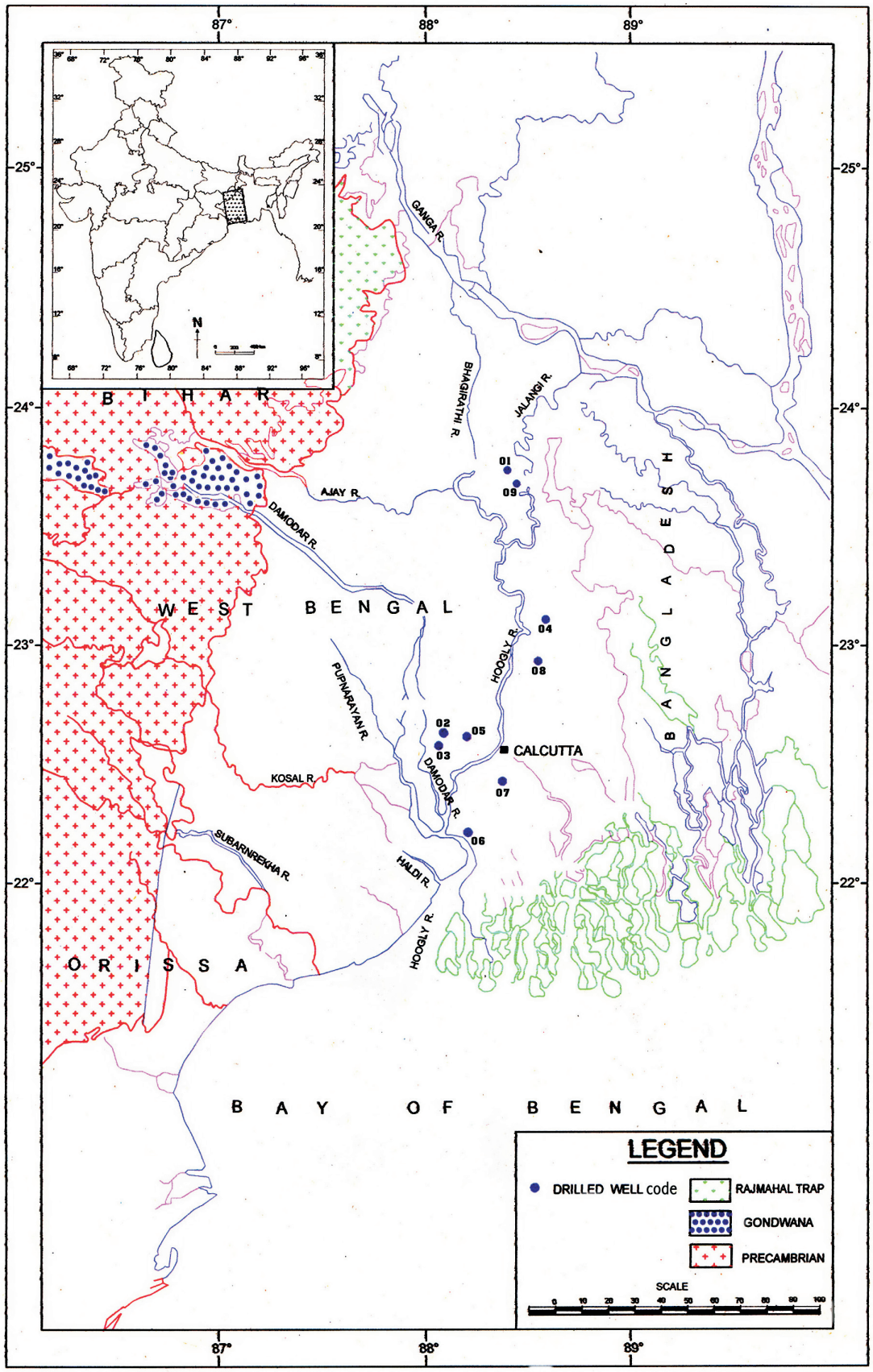
INTRODUCTION

The Bengal Basin falls in the West Bengal, India and Bangladesh and covers an area of 90,700 sq. km and considered as one of the major sedimentary basins in the Indian subcontinent with the longitudes E 87°30' to 90° 30' and the latitude N 25° 00' to 20° 30'. The study area is limited to both the onshore in the West Bengal state and the offshore in the northern part of the Bay of Bengal i.e. western part of the Bengal Basin. A very scanty work was carried out particularly on calcareous algae from the Bengal Basin of India till 2000. Srivastava (1982 a, b, c; 1984, 1985) reported the fossil calcareous algae from the Sylhet Limestone Formation of the Bengal Basin. Banerjee et al. (1990) have described few taxa of coralline algae from the Bengal Basin with dubious single fragment of *Neomeris*. Of the late, Chaurpagar et al. (2009, 2012) provided the detailed study of middle Eocene geniculate and non-geniculate coralline algae respectively from the subsurface limestones of the Bengal Basin. Humane et al. (2010) recorded several dasycladalean algal taxa from the early-middle Eocene Sylhet Limestone Formation such as *Cymopolia inflataramosa* Segonzac, *C. mayaenese* Johnson and Kaska, *C. paronai* Raineri, *Cymopolia* sp., *Dissocladella lunata* Segonzac, *Dissocladella* sp., *Jodotella sloveniaensis* Deloffre and Radoicic, *Clypeina socanensis* Deloffre and Radoicic, *Clypeina* sp., *Terquemella* sp. and *Neomeris* sp. and provided their depositional environments. About 25 wells have been drilled in the Bengal Basin during the past several decades for the petroleum exploration (Bannerjee et al. 1990). Out of these twenty five wells, the ten wells were drilled under Indo-Stanvac Petroleum Project and about fifteen by the Oil and Natural Gas Corporation (Banerjee et al. 1990). The limestone samples were recovered from the cores of three wells of the Bengal Basin i.e. well code- 02 (E 88°2'42", N22°36'13"); well code – 04 (E 88°32'43", N 23°6'13") and well code- 08 (E 88°30', N 22°53'44") (text-fig. 1). The details of the halimedacean and udoteacean algae are studied for the first time from the Sylhet Limestone Formation, Bengal Basin, India and their paleoenvironmental implications are discussed in the present paper.

GEOLOGICAL SETTING

Biswas (1961, 1963) and Ramaswamy and Sengupta (1960) have studied the subsurface geology of the Bengal Basin for the first time and gave the standard lithostratigraphic classification of the Bengal Basin. The further geological investigations of the Bengal basin were done by Roybarman (1983). Chandra et al. (1993 a) have also put forth the generalized lithostratigraphy of the Bengal Basin and classified the Paleogene sediments into the oldest Jalangi Formation followed by the younger Sylhet, the Kopilli and the Burdwan Formations. Further, Chandra et al. (1993 b) have proposed that the clastics are intertonguing with the limestones in the Bengal Basin. The upper part of the Jalangi Formation consists of coarser clastics with glauconitic and lignitic material and has an intertonguing relationship with the lower part of the Sylhet Limestone Formation Chandra et al. (1993 b). The several other workers like Biswas 1963; Roybarman 1983; Venkatraman 1984 have also opined that the clastics of upper part of the Jalangi has intertonguing relationship with the lower part of the Sylhet Limestone.

The subsurface rocks within the study area consist of the Paleogene sediments, which are mainly limestone with interclastic beds. The sandstone lies in the upper part, while the fine to medium, coarse sand with light to dark gray shale and siltstone are present at lower part. These rock types stratigraphically constitute "the Jalangi Formation", "the Sylhet Limestone Formation", "the Kopili Formation" and "the Burdwan Formation" having the age Paleocene to Oligocene re-



TEXT-FIGURE 1
Well location map of the Bengal Basin, India.

TABLE 1
The generalized lithostratigraphic column of the Bengal Basin (Unpublished ONGC Report)

Epoch	Age	Formation	Thickness (in m)	Lithology
Quaternary	Recent to sub-recent	Bengal alluvium	270	Mostly loose unconsolidated medium to coarse sand and sticky clay
	Pleistocene	Debagram	1115	Predominantly light gray, fine to medium and coarse sand with minor clay and claystone
Neogene	Pliocene			
	Miocene	Pandua	650	Predominantly light gray, fine to medium and coarse sand with minor clay and claystone
Paleogene	Oligocene	Burdwan	75	Alternations light gray fine to medium, coarse sand and light to dark gray shale
	Upper Eocene	Kopili	135	Dominantly siderite shale with minor sand
	Middle Eocene	Sylhet Limestone	255	Mainly limestone with 22m interclastic bed
	Lower Eocene			
	Paleocene	Jalangi	150	Mostly sand in the upper part of shale and siltstone at lower part
Cretaceous		Ghatal	179	Siltstone at the top followed by Shale and sandstone at lower part

spectively. The Paleogene sediments of the Bengal Basin consist of mostly sand in the upper part with minor limestone belonging to the Jalangi Formation of Paleocene age. Lithologically, the Sylhet Limestone is comprised of mainly limestone with 22m interclastic bed of early Eocene to middle Eocene age. The Kopili Formation contains sideritic shale with minor sand representing the Upper Eocene age. The Burdwan Formation of the Oligocene age is made up of alternate light gray, fine to medium, coarse sand with light to dark gray shale (Table 1).

The Sylhet Limestone Formation consists of dominant carbonates and minor shale with the sandstone inter-bands. A basin architect of stable shelf, slope and deep basin is the main characteristic of the Eocene period (Chandra et al. 1993 b). The Eocene section is overlain by clastic sediments of the Oligocene epoch and named as the Burdwan/ Matla Formations depending upon the sandy/ shaly nature of the sediments due to the change of lithofacies from the platform to deeper basin side (Chandra et al. 1993 b).

METHODS

For the study of fossil calcareous algae more than 200 thin sections were prepared manually. The thin sections were cut in the two directions. First they are studied parallel to the direction of filament growth and the other perpendicular to the direction of filament growth for measuring cell diameter. The fossil calcareous algae were studied using "Nikon Trinocular Petrological Microscope" in the Post Graduate Department of Geology, RTM Nagpur University, Nagpur.

SYSTEMATIC PALEOALGOLOGY

The systematic description of the order Bryopsidales followed here was adapted from Dragastan and Soliman (2002), Dragastan and Herbig (2007) and Humane and Kundal (2005). The following abbreviations are used for the measurement of halimedacean and udoteacean algae. SN- Specimen number, LT- Length of the thallus/ Segment, WT- Width of the thallus/ Segment, LMR- Length of medullary region, WMR- Width of medullary region, WCR- Width of cortical region, LPU- Length of primary uricles, WPU- Width of primary utricles, LSU- Length of secondary utricles, WSU- Width of secondary utricles, LTU- Length of tertiary utricles, WTU- Width of tertiary utricles.

Halimedacean Algae

Division Chlorophyta
Class Bryopsidophyceace Round 1963
Order Bryopsidales Schaffner 1922
Suborder Halimedineae Hills-Colinvaux 1984
Family Halimedaceae Link 1832
Genus *Halimeda* Lamouroux 1812

Halimeda incrassata (Ellis) Lamouroux 1816
Plate 1, figures a, b, i, k; Plate 2, figure g

Halimeda incrassata (Ellis) Lamouroux. – DRAGASTAN and HERBIG (2007), p. 18, pl. 4, figs. 1-9; pl. 5, figs. 1-4; pl. 16, figs. 5-6.

TABLE 2
Measurements of Halimedacean algae, in µm.

Halimeda incrassata (Ellis) Lamouroux 1816

SN	LT	WT	LMR	WMR	WCR	LPU	WPU	LSU	WSU	LTU	WTU
111	812	464	603	116	133	58	42	42	40	29	17
112	392	224	252	64	70	56	28	28	17	20	11
113	1224	495	900	180	153	111	56	34	30	---	---
114	630	230	167	46	83	45	34	34	22	34	22
115	575	363	360	202	110	644	78	18	5	---	---

Halimeda tuna (Ellis and Solander) Lamouroux 1816

SN	LT	WT	LMR	WMR	LPU	WPU	LSU	WSU	LTU	WTU
116	870	640	500	278	83	56	78	50	56	30
117	1220	972	333	278	167	83	76	40	---	---
118	1027	483	250	134	112	45	56	34	---	---

Halimeda nana Pia 1932

SN	LT	WT	LS	WS	WMR	WCR	LPU	WPU	LSU	WSU	LTU	WTU
119	3332	1271	205	34	722	278	222	56	39	22	34	20
120	1111	475	117	139	139	139	139	83	83	56	56	56

Halimeda cylindracea Decaisne 1842

SN	LT	WT	LS	WS	WMR	WCR	LPU	WPU	LSU	WSU	LTU	WTU
121	490	496	29	29	219	109	73	36	43	26	---	---
122	1076	585	47	23	374	351	35	30	23	28	---	---
123	671	573	55	79	237	292	95	23	79	23	23	8
124	1008	676	10	--	260	278	167	67	56	45	34	22
125	135	90	83	75	90	30	67	45	45	30	---	---
126	1027	1014	34	34	750	90-120	107	64	52	34	20	15

Halimeda simulans Howe 1907

SN	LT	WT	LS	WS	WMR	WCR	LPU	WPU	LSU	WSU	LTU	WTU
127	1870	1178	130	37	617	280	205	37	37	37	---	---
128	863	---	---	---	---	863	293	41	50	37	---	---

Halimeda opuntia (Decaisne) Agardh 1887

SN	LT	WT	LS	WS	WMR	WCR	LPU	WPU	LSU	WSU	LTU	WTU
129	972	444	34	12	694	139	139	56	56	36	---	---

Halimeda sp.

SN	LT	WT	LS	WS	WMR	WCR	LPU	WPU	LSU	WSU	LTU	WTU
130	1119	714	---	---	238	250	139	56	83	56	37	20
131	190	190	---	---	167	196	130	56	83	56	---	---

– LAMOUROUX 1816, p. 307. – HILLIS-COLINVAUX 1980, p. 93, fig. 22. – LITTLER and LITTLER 2000 p. 402-403; figs. 1-2. – DRAGASTON, LITTLER and LITTLER 2002, p. 10; pl. 3,fig. 7. – DRAGASTON et al. 2003, p. 21; pl. 1, figs. 1-11; pl. 2, figs 6-7; pl.5, figs. 3-4, 7; pl. 6, fig. 3. – HUMANE and KUNDAL 2005, p. 14, pl. 1, figs. 7, 8; pl. 2, figs. 1-5.

Material: PGDG/MF/FCA/BB/111-115

Dimensions: See Table 2.

Vegetative anatomy: Thalli are mostly cylindrical and flattened. The segments crossed the medullar area with large variability in dimensions. Long cylindrical, parallel siphons disposed in 8-10 rows pierced the medullary region. Cortical region is comparatively thick than the medullary region. The primary utricles are sturdy, cylindrical, conical, well inflated towards the distal end and have large width. The secondary utricles emerged from the primary utricles. These utricles are dichotomously branched from which tertiary utricles evolved.

Remarks. Thallus is cylindrical and in some specimens flattened. The thallus is crossed by large medullary area and series of three utricles is present. The dimensions of utricles are comparable to the *Halimeda incrassata* (Ellis) Lamouroux 1816, and hence, the name is given as *Halimeda incrassata* (Ellis) Lamouroux 1816.

Horizon and Locality: Buff white to gray colored hard and massive limestone belonging to the Sylhet Limestone Formation of early Eocene age.

Halimeda tuna (Ellis and Solander) Lamouroux 1816
Plate 1, figures c, f, l

Halimeda tuna (Ellis and Solander) Lamouroux. – MARTIN et al. 1996, p. 447, fig. 7a. – DRAGASTAN and SOLIMAN 2002, p. 6, figs. 1-4, 6. – HUMANE and KUNDAL 2005, pl.3, figs. 1, 4, 5.

Material: PGDG/MF/FCA/BB/116-118

TABLE 3
Measurements of Udoteacean algae, in µm.

Ovulites pyriformis Schwager 1883

SN	LT	WT	WMR	WCR	LCS	WCS
132	3358	3443	3184	259	240	22
133	785	809	702	107	11	7
134	306	337	296	41	25	7
135	375	375	347	17	45	23
136	233	192	146	22	9	3
137	354	333	255	52	26	10
138	699	733	633	56	45	22
139	293	293	212	50	18	9
140	1517	1517	1359	63	45	22

Ovulites arabica (Pfender) Massieux 1966

SN	LT	WT	WMR	WCR	LCS	WCS
141	2257	1372	1266	63	42	21
142	210	188	157	25	6	3
143	417	328	245	39	15	5
144	2331	1661	1587	74	50	25
145	330	233	187	22	15	8
146	419	270	214	28	20	8

Ovulites margaritula Lamarck 1816

SN	LT	WT	WMR	WCR	LCS	WCS
147	1390	931	834	83	42	14
148	1859	2002	1659	114	86	27
149	1375	838	725	63	38	25
150	990	624	564	50-99	30	10
151	781	435	288	64-77	26	6

Dimensions: See Table 2.

Vegetative anatomy: Thalli shapes are varying and changes from elongated to flattened. The calcified sediments are flat and disc-like. The medullary region is moderate in size, pierced by long medium to large medullary siphons distributed in round to oval and compact bundles. The cortical region consists of 2-3 utricles series. Primary utricles emerging from medullary region support the secondary utricles. The conical tertiary utricles are very small.

Remarks: The disc like segment of thallus crossed by a narrow medullary zone with two parallel, tabular siphons and a cortex system having three utricle series is comparable to the species *Halimeda tuna* (Ellis and Solander) Lamouroux 1816, and hence the name is given.

Horizon and Locality: Buff white to gray, hard and massive, fine to medium grained limestone belonging to the early Eocene Sylhet Limestone Formation of the Bengal Basin.

Halimeda nana Pia 1932
Plate 1, figures d, h

Halimeda nana Pia. – PIA et al. 1932, pl. 2, fig. 4.– ELLIOT 1955, p. 126, p. 128; pl.1, fig. 3. – SEGONZAC et al. 1986, P. 502; pl. 1, figs. 1, 2, 4, 5-8. – BASSOULLET et al. 1983, p. 488; pl. 7, figs. 5-6. – TRAGELEHN 1996, pl.48, fig. 1. – KUSS and HERBIG 1993, p. 277; pl. 5, figs. 1-5, pl. 8, figs. 4-5.

Material: PGDG/MF/FCA/BB/119-120

Dimensions: See Table 2.

Vegetative anatomy: Thalli are cylindrical and branched. The medullary areas are narrow and crossed by the segments. Siphons are fine and more or less parallel to each other. Two utricles series are common, but in both the specimens three utricle series is seen. The secondary utricles are short and branched. The tertiary utricles are very small.

Remarks: The thallus shape, medullary region and series of utricle support the name *Halimeda* and these characters are comparable to the species *Halimeda nana* Pia 1932.

Horizon and Locality.- Buff white to gray, hard and massive, fine to medium grained limestone belonging to the Sylhet Limestone Formation of early Eocene age of the Bengal Basin.

Halimeda cylindracea Decaisne 1842
Plates 1, figures e, g, j; Plate 2, figures a, b

Halimeda cylindracea Decaisne. – DECAISNE 1842, p. 103. – HILLIS COLLINVAUX 1980, p. 100; figs. 4-5, 104. – DRAGASTAN et al. 2002, pl. 2, figs. 1-3. – LITTLER and LITTLER 2003, p. 244-245.

Material: PGDG/MF/FCA/BB/121-126

Dimensions: See Table 2.

faauto*Vegetative anatomy:* Thalli are cylindrical to nearly circular and in one specimen it is slightly compressed. The central medullary region consists of tubular siphons. But, in many specimens the siphons are partly preserved. The cortex is moderately thick and has three to four series of utricles. In the present specimens up to 3 series is clear and the 4th one is not clear. The primary utricles are long cylindrical and roughly conical in shape. The primary utricles support the secondary utricles,

which are dichotomously branched, small and tabular. The tertiary utricles are also small.

Remarks: The thallus organization and presence of medullary region consisting of siphons supports the name *Halimeda*. The siphon arrangement, utricle series and shape of utricles resemble the species *Halimeda cylindracea* Decaisne, therefore, the specimen is named as *Halimeda cylindracea* Decaisne.

Horizon and Locality: Buff white to gray, hard and massive, fine to medium grained limestone belonging to the early Eocene Sylhet Limestone Formation of the Bengal Basin.

Halimeda simulans Howe 1907
Plate 2, figures e, f

Halimeda simulans Howe. – HOWE 1907, p. 503, pl. 29. – HILLIS and COLLINVAUX 1980, p. 103; fig. 26. – LITTLER and LITTLER 1997 p. 112; fig. 163. – LITTLER and LITTER 2000, p. 11; pl.7, figs. 6-8; pl. 9, figs. 3-4. – DRAGSTAN et al. 2003, p. 23; p. 3, figs. 4-6; pl. 5, fig. 5; pl. 7, fig. 5.

Material: PGDG/MF/FCA/BB/127-128

Dimensions: See Table 2.

Vegetative anatomy: Thalli are cylindrical to oval and flat. Segments are well calcified, with a medium to large medullary area. The medullary siphons are long, more or less parallel, cylindrical and loosely disposed. But, in another specimen the medullary region is not preserved and only cortical region is seen. Cortical region is thick. This region is crossed by two utricle series. The primary utricles are conical in shape and support small secondary utricles. The secondary utricles are bulbous in form.

Remarks: The thallus morphology and central medullary region suggest that these specimens belong to the genus *Halimeda*. The two-utricle series present in the specimen is comparable to the species *Halimeda simulans* Howe 1907, and hence it is named as *Halimeda simulans* Howe.

Horizon and Locality: Buff white to gray, hard and massive, fine to medium grained limestone belonging to the Sylhet Limestone Formation of early Eocene age of the Bengal Basin.

Halimeda opuntia (Decaisne) Agardh 1887
Plate 2, figures h, o

Halimeda opuntia (Decaisne) Agardh. – AGARDH 1887, p. 84. – LITTLER and LITTLER 2000, p. 406-407. – DRAGASTAN et al. 2000. p. 12; pl. 10, fig. 6-9; pl. 11, figs. 1, 4; pl. 12, fig. 8.

Material: PGDG/MF/FCA/BB/129

Dimensions: See Table 2.

Vegetative anatomy: Thallus is disc like and flat. The upper margin is entirely undulated and ornamented by ribs. The medullary region is not very well preserved. It is partly calci-

PLATE 1

Figs. a, b, i, k - *Halimeda incrassata* (Ellis) Lamouroux 1816

a Thallus flattened, medullary siphons and primary branching pattern is shown (arrow) (PGDG/MF/FCA/BB/112)

b Thallus flattened, medullary siphons (arrow at centre) and primary branching pattern is seen (arrow) (PGDG/MF/FCA/BB/111)

i Thallus cylindrical. Medullary siphons are distinct (lower arrow) and thick primary branches (arrow, top) (PGDG/MF/FCA/BB/113)

k Medullary region not preserved. Cortical region shows thic primary branches from which secondary branches are emerged. (PGDG/MF/FCA/BB/114)

Figs. c, f, l - *Halimeda tuna* (Ellis and Solander) Lamouroux 1816

c Thallus oval to cylindrical with medullary siphons and primary branching pattern (PGDG/MF/FCA/BB/116)

f Thallus cylindrical to oval. Medullary region is thick with many siphons and primary branches (PGDG/MF/FCA/BB/117)

l Thallus cylindrical to oval. Long flattened medullary siphons present at center (arrow) (PGDG/MF/FCA/BB/118)

Figs. d, h- *Halimeda nana* Pia 1932

d Thallus kidney shaped with some medullary siphons (PGDG/MF/FCA/BB/121)

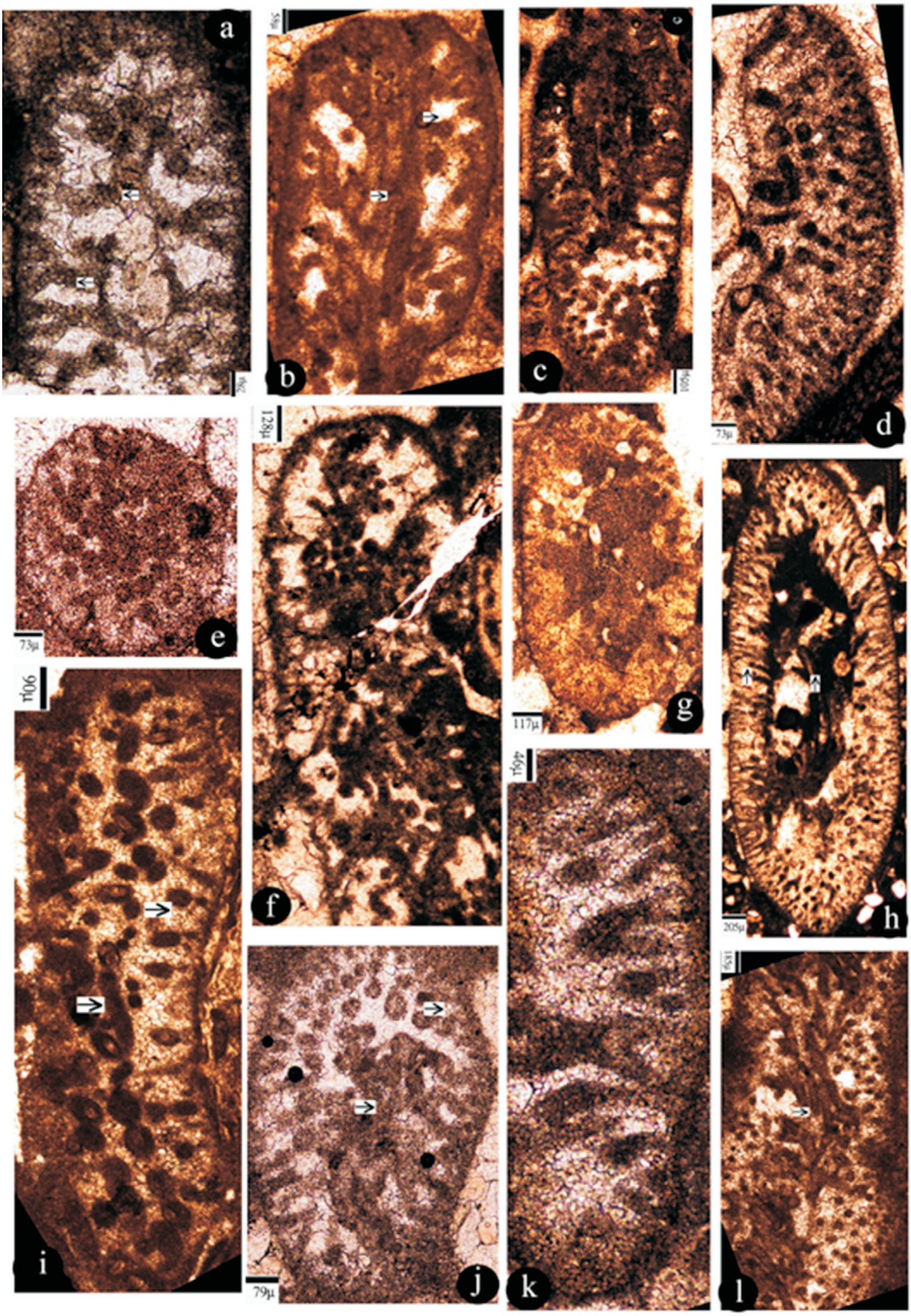
h Thallus long, cylindrical to oval. The medullary siphons (center, arrow) and branches in the cortical region are seen (arrow) (PGDG/MF/FCA/BB/120)

Figs. e, g, j - *Halimeda cylindracea* Decaisne 1842

e Thallus circular in shape with medullary siphons and primary branches (PGDG/MF/FCA/BB/122)

g Thallus oval to cylindrical with medullary siphons and primary branches (PGDG/MF/FCA/BB/126)

j Thallus semicircular in shape. Medullary siphons are thick (arrow, center) from which primary branches are evolved in cortex (arrow, right) (PGDG/MF/FCA/BB/123)


a
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73µ
128µ
117µ
205µ
90µ
79µ

fied, but at places long cylindrical medullary siphons are present, and from the medullary region three utricle series evolved.

Remarks: The thallus position and central medullary region suggest the genus name *Halimeda*. The disc like thallus segment with undulose margins and ribs ornamentation is comparable to the species *Halimeda opuntia* (Decaisne) Agardh. Hence, the name *Halimeda opuntia* (Decaisne) Agardh, is given to this specimen.

Horizon and Locality: Buff white to gray, hard and massive, fine to medium grained limestone belonging to the Sylhet Limestone Formation of early Eocene age of the Bengal Basin.

Halimeda sp.
Plate 2, figures c, d

Material: PGDG/MF/BB/130, 131

Dimensions: See Table 2.

Vegetative anatomy: The thalli are cylindrical, circular and flattened. The central medullary regions are circular in shape, ill preserved and completely recrystallized. The cortical regions are moderately thick and partly recrystallized. From the medullar region utricle series evolved. The primary utricles are thick and somewhat circular in shape. They support the secondary utricles. The secondary utricles are dichotomously branched. From these branching small tertiary utricles evolved.

Remarks: The thallus organization and utricle system suggest that these specimens are broadly similar to *Halimeda*. The medullary regions are not well preserved, so these specimens are not comparable to any known species of the *Halimeda,* therefore, it is kept in an open nomenclature as *Halimeda* sp. 1.

Horizon and Locality: Buff white to gray, hard and massive, fine to medium grained limestone belonging to the Sylhet Limestone Formation of early Eocene age of the Bengal Basin.

Udoteacean (Green) Algae

Division Chlorophyta.
Class Bryopsidophyceace Round 1963.
Order Bryopsidales Schaffner 1922
Suborder Halimedineae Hillis-Colinvaux 1984.
Family Udoteaceae Endlicher 1843 emend. Agardh 1887
Genus *Ovulites* Lamarck 1816

Ovulites pyriformis Schwager 1883
Plate 2, figures k, m, n

PLATE 2

Figs. a, b - *Halimeda cylindracea* Decaisne 1842

a Thallus semicircular in shape. Medullary siphons are thick (arrow, center) from which primary branches evolved in cortex (arrow, right) (PGDG/MF/FCA/BB/124)

b Thallus oval in shape. Medullary region obscure and primary branches distinct. (PGDG/MF/FCA/BB/125)

Figs. c, d - *Halimeda* sp.

c Medullary region obscure and distinct primary branches

d Thallus circular with indistinct medullary siphons and calcified cortical branches (PGDG/MF/BB/130, 131)

Figs. e, f - *Halimeda simulans* Howe 1907

e Thallus oval. Medullary siphons large and long (arrow, center). Cortical branches long and wide at one end (arrow, left) (PGDG/MF/FCA/BB/127)

f Thallus poorly preserved. Only branches of cortical region widening at one end (PGDG/MF/FCA/BB/128)

Halimeda incrassata (Ellis) Lamouroux 1816

g Thallus calcified and poorly preserved. Medullary siphons calcified. Primary and secondary utricles of cortical region thick and distinct. Tertiary utricles very small. (PGDG/MF/FCA/BB/115)

Figs. h, o- *Halimeda opuntia* (Decaisne) Agardh 1887

h Thallus oval. Medullary siphons thin to thick and partly calcified. Three distinct branching of utricles (arrow)

o Enlarged portion of branching utricle series (PGDG/MF/FCA/BB/129)

Figs. i, l - *Ovulites arabica* (Pfender) Massieux 1966

i Thallus oval in shape. Large medullary and highly calcified. Cortical region thin with siphon (arrow) (PGDG/MF/FCA/BB/143)

l Thallus oval in shape. Cortex thin with siphons (arrow) (PGDG/MF/FCA/BB/146)

Ovulites margaritula Lamarck 1816

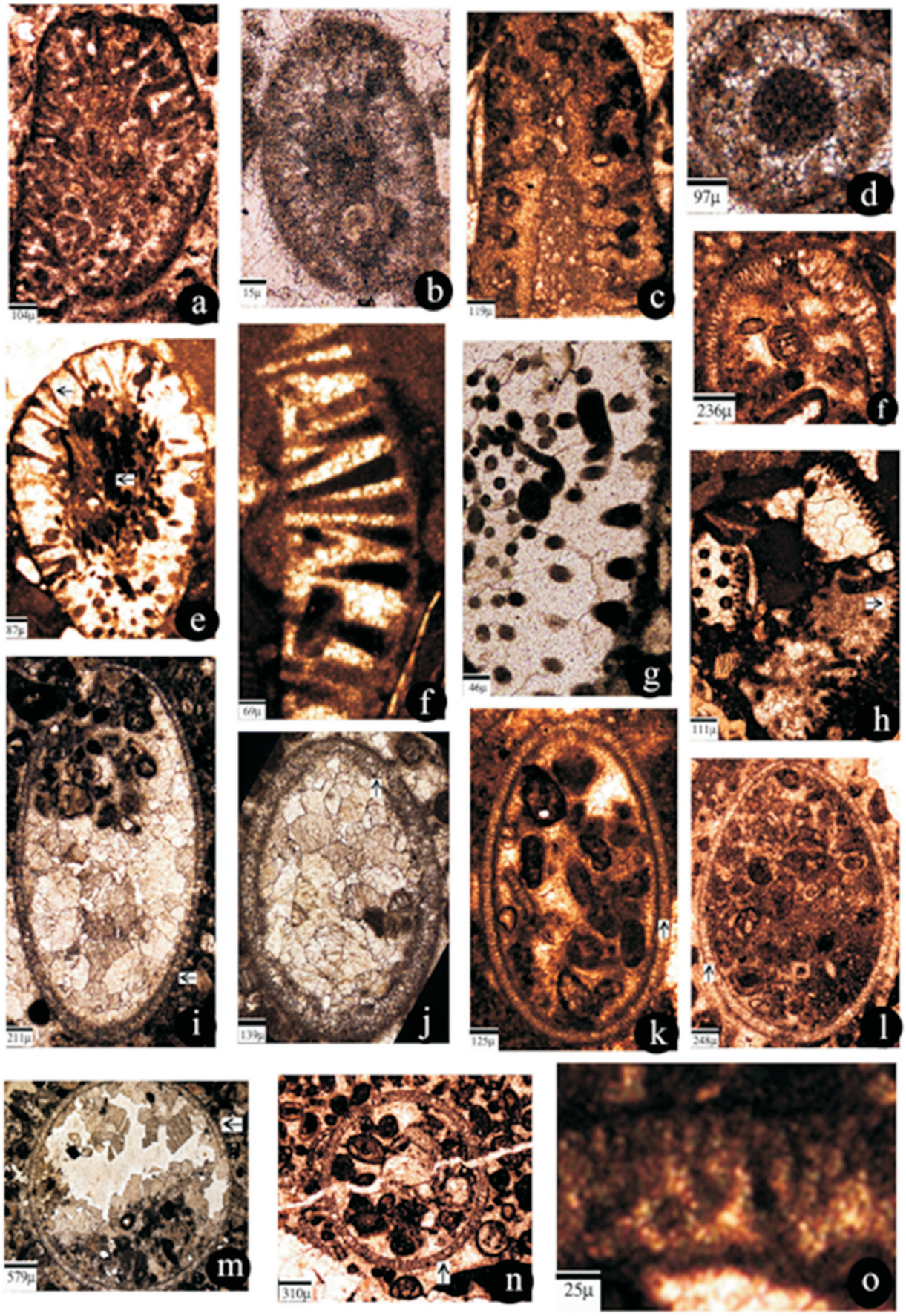
j Thallus oval. Medullary region highly calcified. Cortical region small and partly calcified (PGDG/MF/FCA/BB/149)

Figs. k, m, n - *Ovulites pyriformis* Schwager 1883

k Thallus oval shaped. Distinct cortical siphons (arrow) in thin cortex. Pellets seen in center. (PGDG/MF/FCA/BB/141)

m Thallus circular. Cortical region much smaller than medullary region (arrow). Medullary region highly calcified. (PGDG/MF/FCA/BB/134)

n Thallus circular. Thin cortex with small cortical siphons (arrow) (PGDG/MF/FCA/BB/140)


a
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c
97µ
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Ovulites pyriformis Schwager. – SCHWAGER 1883, p. 146, pl. 29, figs. 21 figs a-d. – KUSS and HERBIG 199, p. 277, pl. 5, fig. h. – HUMANE and KUNDAL 2005, p.17, pl. 4, figs. 5- 9; Pl. figs.2, 3,5

Material: PGDG/MF/FCA/BB/132-140

Dimensions: See Table 3.

Vegetative anatomy: The thallus is pyriform or pear shaped. But, in some cases it is tapered at the lower portion. The medullary region is larger than the cortical region. The small tubes shaped siphons are present in the cortical region. These siphons penetrate the cortical region.

Remarks: Diameter of medullary region is greater than the cortical region and pear shape of thallus confirms the name *Ovulites pyriformis* Schwager 1983.

Horizon and Locality: Buff white to gray colored, hard and massive, limestone belonging to the Sylhet Limestone Formation of early Eocene age of the Bengal Basin.

Ovulites arabica (Pfender) Massieux 1966
Plate 2, figures i, l

Ovulites arabica (Pfender) Massieux. – KUSS and HERBIG 1993, p. 277, pl. 5, figs. 10, 13-14, pl. 18, fig. 6. – DRAGASTAN and SOLIMAN 2002, p. 12-13, Pl. 4, figs. 1-3.

Material: PGDG/MF/FCA/BB/141-146

Dimensions: See Table 3.

Vegetative anatomy: Thallus is ovoid. The cortical region is short and medullary region is large. The siphons are present in the cortical region. They are cylindrical to flat and increase in diameter towards distal end.

Remarks: The cortical siphons of this species are larger in diameter towards the distal end as mentioned by Dragaston and Soliman 2002. Hence, it is named as *Ovulites arabica* (Pfender) Massieux.

Horizon and Locality: Buff white to gray, hard, compact, and massive limestone belonging to the Sylhet Limestone Formation of the early Eocene age.

Ovulites margaritula Lamarck 1816
Plate 2, figure j

Ovulites margaritula Lamarck. – DELOFFRE 1970, p. 355, pl. 1, figs. 1-8.

Material: PGDG/MF/FCA/BB/147-151

Dimensions: See Table 3.

Vegetative anatomy: The thallus is oval to sub-cylindrical. The medullary region is large and oval. In some specimens the medullary region is locally filled by sparitic calcite. The medullary region sometimes shows presence of siphons (pore) rows in oblique sections. Cortical siphons are short and wide and regularly arranged along margins.

Remarks: This species was earlier reported from the early Eocene of the French Pyrenees (Deloffre 1970) and from Paleogene rocks of Egypt (Dragastan and Soliman 2002). The present specimens are similar in appearance, arrangement of cortical siphons and pores as that of *Ovulites margaritula* Lamarck 1801, described by Dragastan and Soliman 2002.

Horizon and Locality: Buff white to gray, hard, compact, and massive limestone belonging to the Sylhet Limestone Formation of early Eocene age of the Bengal Basin.

DISCUSSION AND CONCLUSIONS

The early Eocene Sylhet Limestone Formation of the Bengal Basin revealed the dominance of *Halimeda* i.e. *H. opuntia*, *H. incrassata, H. tuna, H. nana, H. cylindracea* and *Halimeda* sp. and *Ovulites* i.e. *O. pyriformis, O. arabica*, and *O. margaritula* associated with dasycladalean elements (Humane et al. 2010). Most of the halimedacean and udoteacean algae are well preserved indicating their autochthonous origin. Dasycladaleans grow abundantly just below the low tide level down to 5-6 m (Badve and Kundal 1998). The Great Barrier Reef bears non-reefal *Halimeda* meadows in the recent time (Dragastan and Herbig 2007; Drew and Abel 1985, 1988; Orme and Salama 1988). The growth of *Halimeda* is found at outer shelf environments without forming the reefs or bioherm mounds at the great Barrier reef (Dragastan and Herbig 2007). *Ovulites* of the early Eocene Sylhet Limestone Formation of the Bengal Basin are associated with rounded to ellipsoidal grains of *Halimeda* and faecal pellets. However, Rao et al. (1994) have demonstrated that the faecal pellet- dominated sediments are very common on the carbonate platform of the continental shelf. Profusion of *Halimeda* fragments in the limestone may have assisted in the development of mounds on the early Eocene carbonate platform of the continental shelf of the Bengal Basin. A great amount of carbonates particularly aragonite has been contributed by the *Halimeda* having sand and mud size particles (Rao et al. 1994; Orme 1977; Harris et al. 1990; Shinn et al. 1990). Some species of *Halimeda* such as *H. tuna* and *H. opuntia* prefer hard substrate (Hillis-Colinvaux 1980). Presence of faecal pellets with these algal elements point the predation of crustaceans on algal fragments and organic matter originated from these detritus.

The halimedacean algae always thrive in marine conditions and restricted in tropical and subtropical region and generally abundant from the depths below low tide level to depths of 10-12 m (Hillis 1959; Hillis-Colinvaux 1980 and Kundal 2010). The halimedacean fragments are also substantially accumulated in the deep-water environments along the ocean shelf (Wray 1977; Humane and Kundal 2005). The luxuriant growth of *Halimeda* was observed in the warm tropical waters of lagoonal coast and ocean shelf (Hillis 1991). The early Eocene Sylhet Limestone Formation revealed predominance of assemblage of halimedacean (32%), dasycladalean (36%) and udoteacean algae (18%) that suggest their luxuriant growth in the open lagoonal to ocean shelf carbonate platform. The recent halimedacean genera are dominating on the 25^{o}C isotherm on both the sides of the equator (Hillis 1959; Flugel 1988). India was surrounded by warm tropical waters close to north of the equator during the Eocene Epoch (Krutzsch 1989; Humane and Kundal 2005) providing favorable conditions for the luxuriant growth of *Halimeda.* The abundance of foraminiferal assemblage and associated biota suggests the occurrence of the warm marine waters for the deposition of the Sylhet Limestone Formation in the open lagoonal to shelf environment (Ahmed and Zaher 1965; Rey et al. 1993; Reimann 1993). The possible reason for the prolific growth of the *Halimeda* in the early Eocene carbonates of the Bengal Basin may be the nutrients brought by the then river runoff and the currents existed along the shelf.

The north eastern part of India was in the corridor of the Tethyan Ocean till the early Miocene (Krutzsch 1989). The early Eocene foraminiferal- green algal assemblage indicates the existence of the northern Egypt along the southern shelf of the Mediterranean Tethys (Kuss and Herbig 1993). Dragastan and Soliman (2002) discovered 3 halimedacean and 4 udoteacean algal species from the Paleogene of Egypt. Subsequently, Dragastan and Herbig (2007) recorded 14 dasycladalean algal species from the Paleogene of Morocco. The present early Eocene halimedacean and udoteacean algal assemblage is closely comparable to the Paleogene halimedacean and udoteacean algal elements of Morocco and Egypt as many species are common, thus indicating the similar possible paleoenvironmental setting. Hence, the association of halimedacean and udoteacean algae with dasycladalean elements in the present study indicate that the early Eocene Sylhet Limestone of the Bengal Basin was deposited under shallow, warm, tropical, open lagoonal to shelf environment at the depth of 5-6 m below low tide level with Tethyan affinity.

REPOSITORY

The algal specimens studied in the present work are kept in the Applied Micropaleontology Laboratory, Post Graduate Department of Geology, Rashtrasant Tukadoji Maharaj Nagpur University, Nagpur.

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