Rock building Cretaceous-Tertiary algae from India—an ecological perspective

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Fossil benthonic photosynthetic algae capable of calcification contributed to the formation of Indian Cretaceous-Tertiary carbonate deposits. A comparative assessment of different marine calcareous algal assemblages known from various sedimentary basins and their ecological requirements have been highlighted. A comprehensive synthesis and retrospect of researches on calcareous algae demonstrate extensive growth of green and red algae during Cretaceous-Tertiary times in India. The calcareous blue-green algae are feebly represented in the Cretaceous deposits and not recorded from the Tertiary deposits. Various ecological factors determined the distribution of different calcareous algal groups. An apparent extinction of calcareous algae is attributed to gaps in our knowledge and evolutionary changes.

Key-words—Calcareous algae, Marine realm, Calcification, Evolution, Palaeoenvironment, Cretaceous-Tertiary.

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सारांश

भारत से क्रीटेशी-तृतीयक युगीन चट्टान निर्माण करने वाले शैवाल : पारिस्थितिक दृष्टिक्षेप

अन्नमराजु रजनीकान्थ

चूनाभवनीकरण में सक्षम अश्मित बैन्थोनी प्रकाश-संश्लेषी शैवाल की भारतीय क्रीटेशी-तृतीयक कार्बोनेट निक्षेपों के निर्माण में महत्वपूर्ण भूमिका रही है। विभिन्न अवसादी द्रोणीयों से विदित समुद्री चूनामय शैवाल समुच्चयों के तुलनात्मक मूल्यांकन तथा उनकी पारिस्थितिकीय आवश्यकताओं पर प्रकाश डाला गया है। चूनामय शैवालों पर किये गये अध्ययन से पता चलता है कि भारत में क्रीटेशी-तृतीयक काल में हरित एवं लाल शैवालों का अत्याधिक विकास हुआ है। क्रीटेशी निक्षेपों में नील-हरित शैवाल बहुत ही कम मिलते हैं तथा तृतीयक निक्षेपों से अभी तक अभिलिखित नहीं किये गये हैं। विभिन्न चूनामय शैवाल-समूहों के वितरण के लिए पारिस्थितिक कारकों की भूमिका रही है। चूनामय शैवालों के विलुप्तीकरण के अध्ययन से विकासीय परिवर्तनों के बारे में महत्वपूर्ण जानकारी मिल सकती है।

CALCAREOUS algae constitute benthonic and planktonic forms whose thalli contain biochemically precipitated skeletal material (Wrey, 1977). These forms inhabit both marine and non-marine realms and are primarily preserved in carbonate sediments. Their study proves useful to decipher ancient sedimentary environments and also to understand their role in limestone building (Johnson, 1957).

Knowledge on rock building calcareous algae dates back to 1599 when first record of calcareous alga *Halimeda* (under the name of *Sertolara*) appeared in Dell *Historia Naturale* by Imperato published in Napples (see Wrey, 1977). Mention of other rock building forms are known as early as in ninteenth century through the publications of Lamouroux, Philippi, Lamarck, Rothpletz, Seward and others. It was in the early twentieth century that Garwood (1913) in his Presidential Address to the Geological Society of London highlighted the importance of calcareous algae in limestone building which opened new vistas. Since then, monumental contributions were made by Madame Lemoine (France), V. P. Maslov (USSR), Julius Pia (Vienna), Harlan J. Johnson (USA), L. Rama Rao (India), and others.

The Indian freshwater calcareous algae were known as early as in 1830, and the members assigned to Charales were reported from the Deccan Intertrappean beds (Malcomson, 1837; Carter, 1857).

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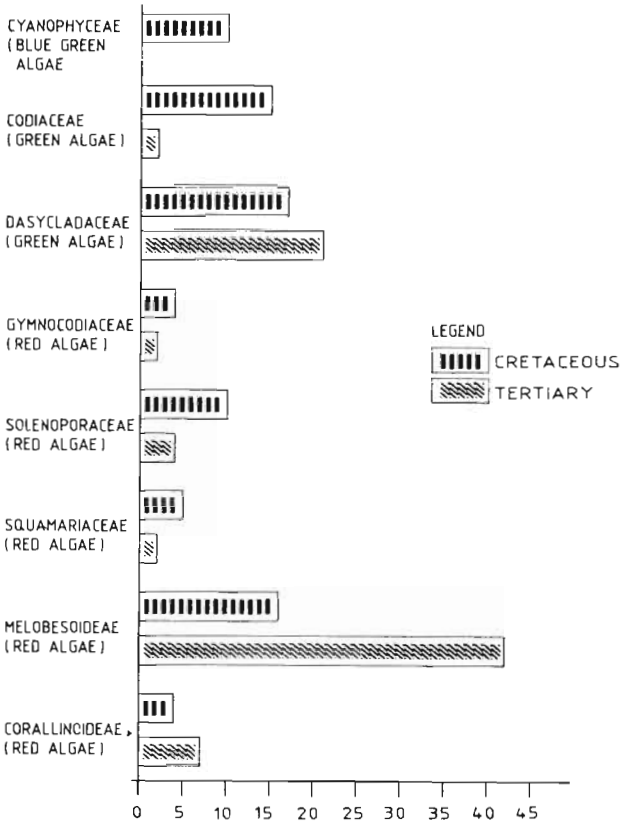
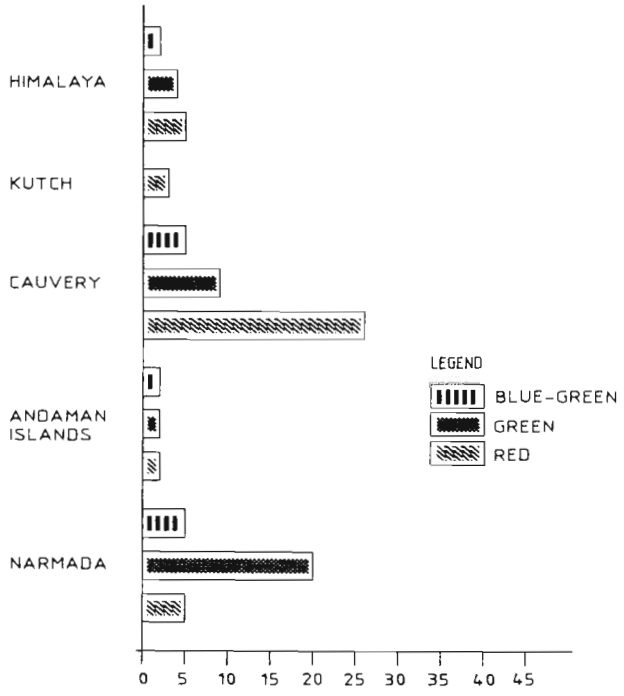
A marine dasycladacean alga was also reported from the oceans of Sindh (Walton, 1925). The period from 1931-1960 witnessed a spurt of research publications, particularly calcareous algae of Cretaceous-Tertiary sediments of south India, north-east India and Salt Range (see Gowda & Pal, 1971). Since 1960, there has been a lull in this area of study and only sporadic reports appeared with a little inferences on stratigraphy and ecology of rock building calcareous algae (see Lakhanpal *et al.*, 1976; Rajanikanth, 1991). While compiling advances in Indian Palaeobotany, Sahni (1938) rightly remarked "Evidently the algal remains of the Indian strata offer a vast field of research of which only the fringe has yet been touched. It is not improbable that their investigation will yield results of importance both to the botanist and the stratigraphical geologist". A need for concerted efforts in this area of study is also re-emphasised (Venkatachala, 1986).

The Indian marine Cretaceous-Tertiary deposits are mainly distributed in the East Coast, West Coast, central India, North-east India, Andaman Islands and Himalayan regions (Text-figure 4). Calcareous algae are common constituents in many of these marine deposits. Different groups and taxa of calcareous



Text-figure 1—Indian Cretaceous-Tertiary calcareous algae.



Text-figure 2—Distribution of Indian Cretaceous calcareous algae.

algae have specific ecological requirements. Various ecological factors—physical, chemical and biological, determine the distribution of these algae (Text-figure 5; Wilson, 1975). Attempts to explain these factors and their influence on distribution of calcareous algae are very few. A careful analysis of different Indian marine fossil calcareous algal assemblages helps to understand their pragmetic value in the formation of limestone in different sedimentary basins. A comprehensive synthesis and retrospect of the rock building marine Cretaceous-Tertiary algae from India and their ecological implications including K/T transition behaviour has been attempted. The present synthesis includes calcareous algal records known during the last four decades and also earlier records to arrive at reasonable conclusions.

Cretaceous calcareous algae

Indian marine Cretaceous sediments encompassing limestone building algae are distributed in the northern (Indus-Flysch), central (Narmada), western (Saurashtra) and southern (Cauvery, Andamans-Nicobar Islands) parts of the country. About 83 species belonging to 30 genera of calcareous algae assignable to blue-green, green and red algal groups have been known from these different regions (Table 1)

Table 1—Basin-wise distribution of Indian Cretaceous calcareous algae

SPECIES	HIMALAYA	KUTCH	NARMADA	CAUVERY	ANDAMAN ISLANDS
Cyanophyta (Blue-green algae)					
Baratangia densituba	–	–	–	–	+
Cayeuxia andamanica	–	–	–	–	+
Cayeuxia chiplonkari	–	–	+	–	–
Cayeuxia chirakhanensis	–	–	+	–	–
Cayeuxia fruticulosa	+	–	+	+	–
Cayeuxia cf. *kurdistanensis*	–	–	–	+	–
Cayeuxia minuta	–	–	+	–	–
Cayeuxia sp.	+	–	+	+	–
Palaeomastigocladus indicus	–	–	–	+	–
Picnoporidium lobatum	–	–	–	+	–
Chlorophyta (Green algae)					
Codiaceae					
Arabicodium indica	–	–	+	–	–
Arabicodium texana	–	–	+	–	–
Arabicodium sp.	–	–	+	–	–
Boueina chirakhanensis	–	–	+	–	–
Boueina pygmaea	–	–	+	–	–
Boueina sp.	–	–	+	–	–
Halimeda agharkari	–	–	–	–	+
Halimeda chiplonkari	–	–	–	–	+
Halimeda corneola	–	–	+	–	–
Halimeda densituba	–	–	+	–	–
Halimeda johnsonni	–	–	+	–	–
Halimeda pipaldehlaensis	–	–	+	–	–
Halimeda robusta	–	–	+	–	–
Halimeda triradiata	–	–	+	–	–
Halimeda sp.	–	–	+	+	–
Dasycladaceae					
Acicularia antiqua	–	–	–	+	–
Acicularia cf. *A. comanenense*	+	–	–	–	–
Acicularia khalsiensis	+	–	–	–	–
Acicularia sphaerica	–	–	+	–	–
Clypeina sahnii	–	–	–	+	–
Cylindroporella sp. cf. *C. segdeni*	–	–	–	+	–
Cymopolia brevicaulia	–	–	+	–	–
Gymnopora indica	+	–	–	–	–
Indopolia sp. cf. *satyavantii*	–	–	–	+	–
Larvaria occidentalis	–	–	–	+	–
Larvaria sp.	–	–	–	+	–
Linoporella brevistila	–	–	+	–	–
Neomeris circularis	–	–	+	–	–
Neomeris cretaceae	–	–	–	+	–
Neomeris de terrae	+	–	–	–	–
Neomeris pfenderae	–	–	+	–	–
Neomeris sp.	–	–	+	+	–
Neomizzia multiramosa	–	–	+	–	–
Rhodophyta (Red algae)					
Gymnocodiaceae					
Permocalculus budaensis	+	–	–	–	–
Permocalculus irenae	–	–	–	+	–
Permocalculus ladakhensis	+	–	–	–	–
Permocalculus cf. *P. taxana*	+	–	–	–	–

Contd.

Table 1—Contd.

SPECIES	HIMALAYA	KUTCH	NARMADA	CAUVERY	ANDAMAN ISLANDS
Solenoporaceae					
Parachaetetes asvapatii	–	–	–	+	–
Parachaetetes sp.	–	–	–	+	–
Solenopora coromandalensis	–	–	–	+	–
Solenopora filiformis	–	–	–	+	–
Solenopora jurassica	–	–	–	+	–
Solenopora sahnii	–	–	–	+	–
Solenopora tiruchiensis	–	–	–	+	–
Solenopora sp.	–	–	–	+	–
Thomatoporella incrustata	–	–	–	+	–
Thaumatoporella sp.	+	–	–	–	–
Squamariaceae					
Ethelia alba	–	–	–	+	–
Ethelia indica	–	–	–	–	+
Ethelia sp.	–	–	–	+	–
Peyssonnelia antiqua	–	–	+	–	–
Peyssonnelia baratangensis	–	–	–	–	+
Corallinaceae					
Melobesoideae (Crustose Corallines)					
Archaeolithothamnium feddeni	–	+	–	–	–
A. feddeni var *bhadukaensis*	–	+	–	–	–
Archaeolithothamnium lugeoni	–	–	–	+	–
Archaeolithothamnium nonsteinensis	–	–	–	+	–
Archaeolithothamnium parsiense	–	–	–	+	–
Archaeolithothamnium rude	–	–	–	+	–
Archaeolithothamnium saurastraensis	–	+	–	–	–
Archaeolithothamnium sp.	–	–	+	+	–
Archaeolithophyllum sp.	–	–	–	+	–
Distichoplax biserialis	–	–	+	+	–
Distichoplax raoi	–	–	+	–	–
Lithophyllum cf. *L. antiquum*	+	–	–	–	–
Lithophyllum sp.	–	–	–	+	–
Lithoporella indica	–	–	+	–	–
Mesophyllum varians	–	–	–	+	–
Mesophyllum sp. cf. *M. daviesi*	–	–	–	+	–
Corallinoideae (Articulated corallines)					
Amphiroa elliottii	–	–	–	+	–
Amphiroa guatemalense	–	–	–	+	–
Amphiroa varagurense	–	–	–	+	–
Amphiroa sp.	–	–	–	+	–

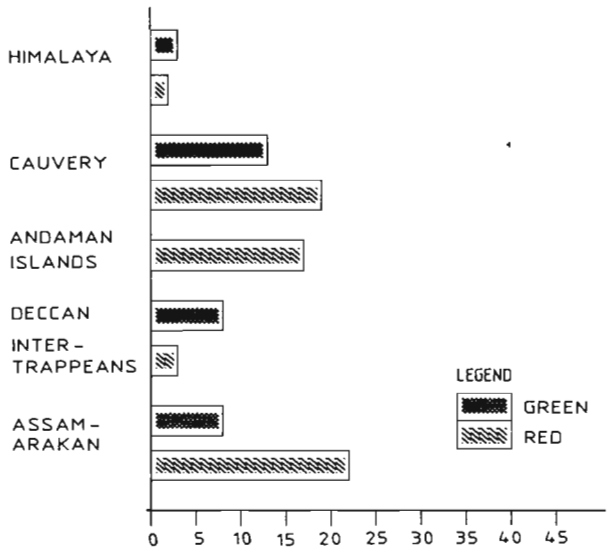
Northern region (Himalaya)

The Upper Cretaceous calcareous algae known from the Himalayan region include two blue-green algae, four green algae and five red algae (Table 1). Two calcareous algal assemblages attributed to Albian-Cenomanian and Campanian-Maastrichtian horizons were reported from the "Indus-Flysch". The former assemblage was recorded from the oolitic limestone and *Orbitolina* limestone near Khalsi and includes *Acicularia comanchense, A. khalsiensis, Lithophyllum antiquum, Permocalculus budaensis, P ladakhensis, P* cf. *P texana* and *Gymnopora indica*. On the basis of the presence of *Acicularia* it was suggested that the limestone deposition was on the continental shelf as the depth at which this alga flourishes does not normally exceed ten meters. Other calcareous algal assemblage known from Raldong Nala Section, near Sumdo attributed to Campanian-Maastrichtian horizon was characterised by *Neomeris de terrae, Thaumatoporella, Cayeuxia fruticulosa* and

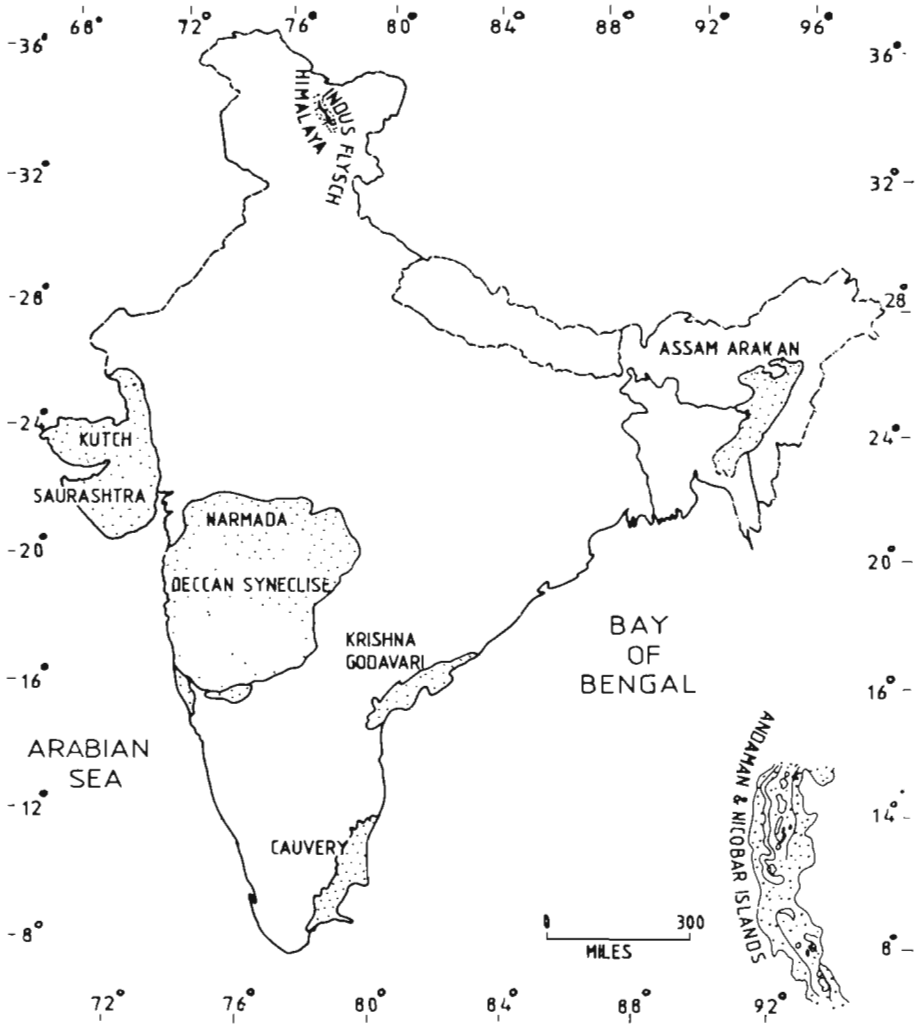
Cayeuxia sp. It was inferred that deposition could have occurred in the shallower parts of the basin as the algae known are rarely found below 15 meters (Pal & Chatterji, 1978). Most of these algae reported probably inhabited lower tidal zone with low water energy (calm waters) and occupied similar shelf environments.

Western region (Saurashtra)

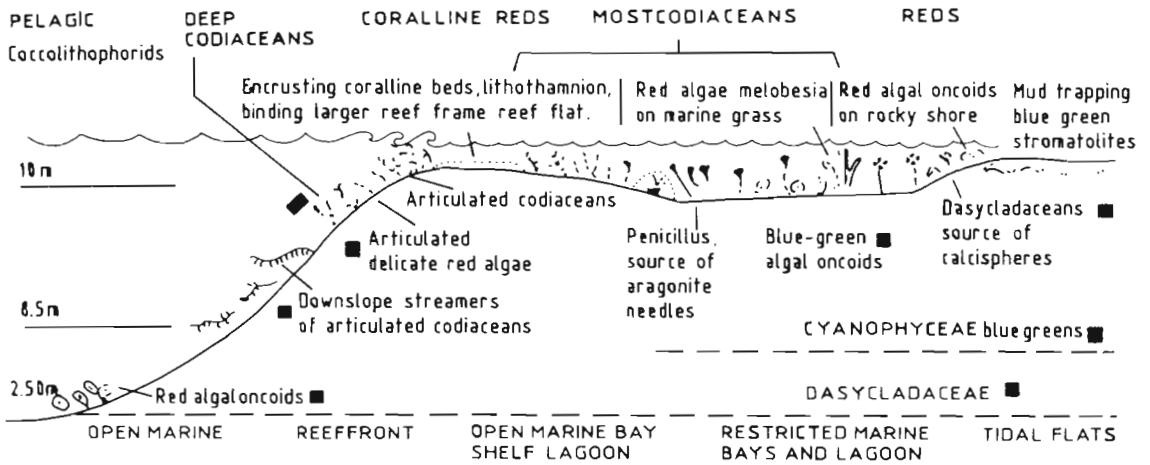
Three red algal species of *Archaeolithothamnium, A. saurashtraensis* Chiplonkar & Borkar 1972 from Surendranagar Sandstone, *A. feddeni* Chiplonkar & Borkar 1972 and *A. feddeni* Chiplonkar & Borkar var. *bhadukaensis* var. nov. from Bhaduka Limestone were known from the Wadhwan Formation attributed to Cenomanian-Turonian age affinity. These algae reported considered alongwith



Text-figure 3—Distribution of Indian Tertiary calcareous algae.



Text-figure 4—Distribution of Indian Cretaceous-Tertiary sedimentary deposits containing calcareous algae.



Text-figure 5—Ecology of calcareous algae (after Wilson, 1975; Flügel, 1982).

the nature of sediments indicate shallow water conditions (Chiplonkar & Borkar, 1972). *Archaeolithothamnium*, a crustose coralline is a dominant reef alga which performs cementing and frame work functions. Intensive efforts are needed to find out more algal remains to decipher the palaeoenvironment of these sediments.

Central Region (Narmada)

Thirty species represented by 13 genera of calcareous algae were reported from the coralline limestone of Bagh Group, Narmada Valley (Table 1). Various workers have reported rock building calcareous algae from the Bagh beds. Chiplonkar (1944) recorded *Archaeolithothamnium*, *Dissocladella* and *Indopolia*. Singh (1950) reported *Neomeris* sp. and *Archaeolithothamnium minimum*. Durge (1965) recorded *Archaeothamnium*. Ghosh and Pal (1968) recorded *Cayeuxia fruticulosa* of Maastrichtian age affinity. Pal (1968a, 1968b, 1969, 1970a, 1970b, 1971) recorded *Cayeuxia fructilosa*, *C. minuta*, *C. chirakhanensis*, *Arabicodium* sp., *A. indica*, *A. taxana*, *Boueina* sp., *B. chirakhanensis*, *B. pygmaea*, *Halimeda* sp., *H. johnsonii*, *Distichoplax raoi*, *D. biserialis* and *Lithoporella indica*. Ghosh and Pal (1969) recorded *Peyssonnelia antiqua* from the Upper Coralline Limestone, Chirakhan Sitapuri, Madhya Pradesh. Besides, the occurrence of oysterbanks and bryozoan rich coralline limestone beds indicate shallow depth of mid Cretaceous sea in the Narmada trough (Acharyya & Lahiri, 1991).

Four species of calcareous Codiaceae were reported from the *Jhabotrigonia-Turritella* Bed developed around Pipaldehla forming local top of the Nimar Sandstone. The algae reported include *Halimeda pipaldehlaensis*, *H. robusta*, *H. corneola*, *H. densituba* and *H. triradiata*. Occurrence of these taxa in the calcareous facies of Nimar Sandstone indicate a shallow and calm water deposition (Badve & Nayak, 1983). Besides, nine species of calcareous algae were described from the sandy limestone developed towards the top of Nimar Sandstone at Pipaldehla. These include *Cayeuxia chiplonkari* Chiplonkar & Borkar 1972, *Archaeolithothamnium feddeni* Chiplonkar & Borkar var. *bhadukaensis* Chiplonkar & Borkar 1972, *Acicularia spherica* Badve & Nayak 1984, *Cymopolia brevicaulia* Badve & Nayak 1984, *Linoporella brevistila* Badve & Nayak 1984, *Neomeris circularis* Badve & Nayak 1984, *N. pfenderae* Konishi & Epis and *Neomizzia multiramosa* Badve & Nayak 1984. This flora indicates existence of shallow marine waters of tropical region during the time of deposition of sediments (Badve & Nayak, 1984).

A critical analysis of Bagh calcareous algal assemblage suggests the following observations. Though the age assignments were differently considered as Cretaceous-Palaeocene the former age affinity appears to be more appropriate. Out of the 30 species, only 5 species of red algae were observed in the Bagh Group of rocks. The algal assemblage under discussion is abundant in the presence of codiaceans and other green algae. Besides, *Cayeuxia*, a rivulariacean skeletal blue-green alga made its last appearance in the Cretaceous times. Occurrence of five species of filamentous *Cayeuxia* indicates prevalence of lower water energy currents with mud and sand water. The green algae represented by 20 species of eight genera dominated by codiaceans probably survived in tropical normal marine waters and were restricted to lower tidal zones. The dasycladaceans represented by six species of *Cymopolia*,

Linoporella, Neomeris and *Neomizzia* which survived alongwith the above codiaceans reflect their widespread occurrence in shallow shelf environments. As these groups of algae have maximum absorption of light in the red sector and capable of efficient photosynthesis, they usually restricted to first thirty meters of the depth inhabiting on a soft substrate like sand and mud (Flügel, 1982). The red algae are poorly represented by *Archaeolithothamnium, Distichoplax, Lithoporella* (Melobesoideae) and *Peyssonnelia* (Squamariaceae). These forms suggest existence of tropical-subtropical sea waters. The living Squamariceans are known to occur in normal marine sedimentaries at shallow depths from just below low tidal to a few meters (Wrey, 1977). The genus *Distichoplax* reported from the Bagh beds is often suggested as an index fossil alga for the Palaeocene-Eocene age (Varma, 1960; Pal, 1968). In this connection the recent report of *Distichoplax biserialis* from the Upper Cretaceous sediments of the Varagur Limestone, Cauvery Basin is significant (Misra & Kumar, 1989). The record of both *Peyssonnelia* and *Distichoplax* suggests that these forms or their ancestors probably survived in the Cretaceous seas too.

Southern Region

Andaman Islands—A calcareous algal assemblage consisting of two species of Cyanophyta (*Cayeuxia andamanica, Baratangia densituba*), two species of Chlorophyta (*Halimeda chiplonkari, H. agharkari*) and three species of Rhodophyta (*Ethelia indica, Peyssonnelia baratangensis, Permocalculus* sp. cf. *P. irrenae* Elliot) was recorded from the Baratang Formation, Andaman Islands. They were provisionally considered to have a Cretaceous age affinity (Badve & Kundal, 1986). These forms usually occur in similar shelf environments and for further palaeoecological inferences more data needs to be accumulated.

Cauvery Basin—A rich calcareous algal assemblage represented by 39 species assigned to 20 genera was reported from the marine Cretaceous succession of the Cauvery Basin. These include species of 5 Cyanophyta, 7 Chlorophyta and 25 Rhodophyta (Table 1).

Calcareous algae reported from the Coralline limestone of the Dalmiapuram Formation (Kallakudi Limestone) were represented by *Cayeuxia* sp., *C. fruticulosa, Acicularia antiqua, Larvaria occidentalis, Neomeris* sp., *Halimeda* sp., *Solenopora jurassica, S. coromandelensis, S. Sahnii* and *Archaeolithothamnium lugeonii* (Rao 1944, 1947; Rao & Kumar 1932; Rao & Gowda 1954; Rajanikanth, 1988). These forms were known from the reefoidal limestone unit which got deposited in a restricted shallow basin. The reef development was fringing reef type as the reef developed along the margin of the sea got transgressed into the land area during Albian times (Banerji, 1972). Absence of articulated corallines in the Kallakudi algal assemblage is significant as these forms probably appeared in the Middle Cretaceous times. Most of these recorded forms are known to contribute to reef formation with codiaceans occupying deeper fore reef slope, dasycladaceans in the protected reef flats and other red algae in the reef areas and bays with reefs.

The Uttatur Group is poorly known for its calcareous algal contents except the reported occurrence of *Solenopora* and *Amphiroa* sp. in the Varagapaudy Limestone (Gowda, 1978). The Tiruchirapalli group of rocks are known to contain comparatively rich algae. *Clypeina sahnii* was reported by Varma (1952). Recently an Upper Cretaceous calcareous algal assemblage comprising 31 species of 17 genera was described from the Varagur Limestone (Misra & Kumar, 1988). The blue-green algae were represented by *Cayeuxia* cf. *C. kurdistanensis, Palaeomastigocladus indicus, Pycnoporidium lobatum*; green algae by *Cylindroporella* sp. cf. *C. sugdeni, Indopolia* sp. cf. *I. satyavanti, Neomeris cretaceae, Larvaria* sp.; red algae by *Ethelia alba, Ethelia* sp., *Solenopora filiformis, Solenopora tiruchiensis, Solenopora* sp., *Parachaetetes asvapatii, Parachaetetes* sp., *Thaumatoporella incrustata, Archaeolithothamnium lugeoni, A. nonsteinensis, A. parisiense, A. rude* cf. *Archaeolithothamnium* sp., *Mesophyllum varians, Mesophyllum* sp. cf. *M. daviesi*, cf. *Archaeolithophyllum* sp., *Lithophyllum* sp., *Distichoplax biserialis, Amphiroa elliottii, A. guatemalense* and *A. varagurense*. A shallow warm sea conditions promoting the growth of these algae was suggested at the depositional site. Calcareous algae of the Ariyalur group are comparatively less known except the records of *Lithothamnium, Archaeolithothamnium* and *Mesophyllum* (Rao, 1931; Mamgain *et al.*, 1968).

Tertiary calcareous algae

The Indian Tertiary deposits encompassing marine calcareous algae are distributed in the northern (Himalaya), north-eastern (Assam-Arakan), western (Kutch), central (Deccan intertrappeans) and southern (Cauvery Basin, Andaman Islands) regions of the country. Altogether about 79 species represented by 31 genera are known, amongst which

Table 2—Distribution of Indian Tertiary calcareous algae

SPECIES	HIMALAYA	KUTCH	DECCAN INTER-TRAPPEANS	CAUVERY	ANDAMAN ISLANDS	ASSAM-ARAKAN
Chlorophyta (Green algae)						
Codiaceae						
Halimeda sp.	–	–	+	–	–	+
Dasycladaceae						
Acicularia sp.	–	–	+	+	–	–
Acicularia dyumatsenae	–	–	–	+	–	–
Acicularia indica	–	–	–	+	–	–
Acitabularia sp.	–	–	+	–	–	–
Clypenia sahnii	–	–	–	+	–	–
Clypenia sp.	–	–	–	+	–	–
Cymopolia sp.	–	–	–	–	–	+
Dissocladella intertrappea	–	–	+	–	–	–
Dissocladella lakadongensis	–	–	–	–	–	+
Dissocladella savitriae	+	–	–	+	–	–
Dissocladella undulata	–	–	–	+	–	–
Dissocladella sp.	–	–	+	+	–	–
Griphoporella arabica	–	–	–	–	–	+
Furcoporella diplopora	–	–	–	–	–	+
Holosporella siamensis	–	–	+	+	–	–
Holosporella sp.	–	–	+	–	–	–
Indopolia satyavantii	–	–	–	+	–	–
Indopolia sp.	+	–	–	–	–	–
Neomeris sp.	–	–	+	+	–	+
Orioporella malaviae	–	–	–	+	–	–
Pianiae niniyurensis	–	–	–	+	–	–
Trinocladus umlatodobensis	–	–	–	–	–	+
Rhodophyta (Red algae)						
Gymnocodiaceae						
Permocalculus sp. cf. *P. irrenae*	–	–	–	–	+	–
Solenoporaceae						
Neosolenopora ramaraoi	–	–	–	–	+	–
Parachaetetes asvapatii	–	–	–	+	–	–
Solenopora tiruchiensis	–	–	–	+	–	–
Solenopora sp.	–	–	+	–	–	–
Squamariaceae						
Peyssonnelia antiqua	–	–	+	–	–	–
Corallinaceae						
Melobesoideae (Crustose Corallines)						
Aethesolithon cutchensis	–	+	–	–	–	–
A. problematicum	–	+	–	–	–	–
Aethesolithon sp.	–	–	–	–	+	–
Archaeolithothamnium archisporangia	–	–	–	–	–	+
A. hemchandrae	–	–	–	–	–	+
A. sp. aff. *A. keenani*	–	–	–	–	–	+
A. langrinensis	–	–	–	–	–	+
A. lugeonii	–	–	–	+	–	–
A. cf. *lycaperdioides*	–	–	–	+	–	–
A. nonsteinensis	–	–	–	–	–	+
A. pondicherriensis	–	–	–	+	–	–

Contd.

Table 2—Contd.

SPECIES	HIMALAYA	KUTCH	DECCAN INTER-TRAPPEANS	CAUVERY	ANDAMAN ISLANDS	ASSAM-ARAKAN
A. sp. cf. aff. *provinciale*	–	–	–	+	–	–
A. saipanens	–	–	–	+	–	–
A. sp. cf. *A. samanensis*	–	–	–	+	–	–
A. torulosum	–	–	–	+	–	–
A. zonatum	–	–	–	+	–	–
Archaeolithothamnium sp.	–	–	–	–	–	+
Audouinella membrances	–	–	–	–	+	–
Distichoplax biserialis	–	–	–	+	+	+
Distichoplax raoi	–	–	+	+	–	+
Lithophyllum bermotiensis	–	+	–	–	–	–
L. sp. *L. fosliei*	–	–	–	–	+	–
Lithophyllum indicum	–	–	–	+	–	–
L. sp. aff. *L. kladosum*	–	+	–	–	–	–
L. sp. aff. *L. prelichenoides*	–	–	–	–	+	–
Lithophyllum sp.	–	+	–	+	+	–
Lithoporella melobesioides	+	–	–	–	+	+
Lithothamnium andamanensis	–	–	–	–	+	+
L. sp. cf. *L. bofilli*	–	+	–	–	–	+
Lithothamnium malthi	–	–	–	–	–	+
L. sp. cf. *L. moretii*	–	–	–	–	–	+
L. nummuliticum	–	–	–	–	–	+
L. pecki	–	–	–	–	–	+
L. raoi	–	–	–	+	–	–
L. suganum	–	–	–	–	+	–
L. sp. cf. *L. validum*	–	+	–	–	–	–
Lithothamnium wilsonensis	–	–	–	–	+	–
Lithothamnium sp.	–	–	–	+	–	+
Mesophyllum commune	–	+	–	–	–	–
Mesophyllum meghalayensis	–	–	–	–	–	+
Mesophyllum sp.	–	–	–	+	–	+
Melobesia assamica	–	–	–	–	–	+
Melobesia sp.	–	–	–	–	–	+
Corallinoideae						
(Articulated corallines)						
Amphiroa sp.	–	–	–	+	+	–
Amphiroa sp. cf. *A. prefragilissima*	–	–	–	–	+	–
Corallina grandis	–	–	–	–	–	+
Corallina nagappa	–	–	–	+	–	–
Corallina raoi	–	–	–	–	+	–
Jania occidentalis	–	–	–	–	–	+
Jania sp.	–	–	–	–	+	–

green algae constitute 23 species with 14 genera and red algae 56 species with 17 genera (Table 2). Blue-green algae are not recorded.

Northern Region (Himalaya)

Lithoporella melobesioides (Foslii), a crustose coralline alga was known from the nummulite shales and limestones of Mahe and Nidar valleys, Indus Flysch, Ladakh assignable to Palaeocene-Eocene (Danian-Lutetian) age affinity. Along with this comparable forms of *Dissocladella savitriae* Pia and *Indopolia* sp. were also noticed. A calm shallow and warm sea environment of deposition was inferred (Pal & Chatterji, 1978). *Lithoporella* is known to encrust other algae and skeletal constituents. It is one of the pre-dominant corallines of tropical reefs. Serious efforts are needed to explore the Himalayan tectonic zone for calcareous algal studies.

North-eastern Region (Assam-Arakan Basin)

About 28 calcareous algae represented by 7 green algae and 21 red algae are known from the

Sylhet Limestone Formation (Table 2). Rao (1943) described 4 species of *Archaeolithothamnium*, 5 species of *Lithothamnium* and one species of each of *Mesophyllum, Melobesia, Distichoplax* and *Corallina* belonging to Corallinaceae from the Eocene sediments of Sylhet Limestone Formation. Calcareous algal remains were also known from the Mikir Hills, Assam. Three different assemblages—*Distichoplax-Dissocladella* assemblage (Lakadong Member), *Furcoporella-Griphoporella* assemblage (Umlatodoh Member), and *Lithothamnium-Halimeda* assemblage (Prang Member) were reported suggesting Landenian, Ypresian and Leutetian (Early Tertiary) ages respectively. 16 species of algae belonging to 14 genera were described. The green algae were represented by Codiacean members *Halimeda* sp., *Griphoporella arabica* Pfender, *Neomeris* sp., *Furcoporella diplopora* (Pia), *Trinocladus umlatodobensis, Cymopolia* sp. and *Dissocladella lakadongensis*. The red algae consist of *Archaeolithothamnium* aff. *A. keenani* Howe, *Lithothamnium andamanensis* Chatterji & Gururaja 1972, *L.* aff. *L. bofilli* Lemoine, *Mesophyllum meghalayensis* Pal & Dutta 1979, *Lithoporella melobesiodes* (Foslie) Foslie, *Melobesia* sp., *Distichoplax biserialis* (Diet.) Pia, *D. raoi* belonging to Melobesioideae and *Jania occidentalis* Johnson belonging to Corallinoideae. The occurrence of these algae in the Sylhet Limestone Formation indicates that the deposition probably took place under warm conditions in a shallow open sea during the Early Tertiary times (Pal & Dutta, 1979). The reported occurrence of *Jania* suggests existence of tropical-subtropical sea water. The presence of *Lithothamnium* and *Mesophyllum* which mostly inhabit greater depths of 50 meters or more suggests variable distribution of algal forms in the sea waters. *Melobesia* is known to grow as an epiphyte on marine grasses and fleshy algae.

Western Region (Kutch)

Nine species of red algae (Corallinaceae) have been recorded from the Tertiary sediments of Kutch. Pal and Ghosh (1974) recorded *Lithophyllum* aff. *L. kladosum, Mesophyllum commune, Aethesolithon problematicum, A. cutchensis* and *Archaeoporolithon miocenicum* from the Khari Series exposed near Waior in south-western Kutch. *Lithophyllum bermotiensis* was reported from the Oligocene (Chattian) rocks exposed in a stream section near Ber Moti Village, south-western Kutch (Tandon *et al.*, 1978). *Lithothamnium* cf. *L. validum, Lithothamnium* cf. *L. bofilli* and *Lithophyllum* sp. were known from the Fulra Limestone (Middle Eocene) exposed at Babia Hill (Kar, 1979; Lakhanpal *et al.*, 1984). The preponderance of corallines suggests reef building activity during the Tertiary times in the Kutch Basin. Some of the forms vary from warm to cold waters.

Central Region (Deccan Intertrappeans)

Eleven species of calcareous algae belonging to green (8 species) and red (3 species) algae were recorded from the Deccan intertrappean beds (Table 2). The green algae, recorded from the Rajahmundry intertrappean beds, Godavari Basin, include *Acicularia* sp., *Acitabularia* sp., *Dissocladella intertrappea, Dissocladella* sp., *Halimeda* sp., *Terquemella lenticularis, Holosporella* sp. cf. *H. siamensis* and *Holosporella* sp. (Pia, 1937; Rao & Rao, 1938). The existence of tropical open marine waters during the deposition of Deccan Intertrappean sediments in the Godavari Basin is suggested. Three red algal species *Solenopora* sp., *Peyssonnelia antiqua* and *Distichoplax raoi* were described from the Deccan Intertrappean sediments, Mohgaonkalan, Chhindwara District, Madhya Pradesh. The prevalence of marine conditions at Mohgaonkalan and nearby areas during the Palaeogene was suggested by Bande, Prakash and Bonde (1981) and Mehrotra (1988) As the two red algae *Peyssonnelia* and *Distichoplax* are also known from the Cretaceous sediments (Table 1), the age assignment of intertrappean beds needs revision. It is also suggested that wide spread Deccan volcanism in western and central India was mainly confined to the Maastrichtian period (Acharyya & Lahiri, 1991).

Southern Region (Cauvery Basin)

Fourteen species of green algae and 18 species of red algae were recorded from the Tertiary sediments of Cauvery Basin. These were known from the Tertiary sediments of Nerinea beds of Pondicherry and Niniyur beds. The former beds yielded a rich coralline calcareous assemblage characterised by *Archaeolithothamnium pondicherriensis, A. saipanens, A.* sp. cf. *A. samanensis, A. zonatum, Lithothamnium* sp., *L. raoi, Corallina nagappae, Distichoplax biserialis* and *Mesophyllum* sp. (Rao, 1953; Sastry *et al.*, 1963). The Niniyur assemblage consists of *Acicularia* sp., *A. dyumatsenae, A. indica, Acitabularia* sp., *Clypenia sahnii, Dissocladella* sp., *D. undulata, D. savitriae, Indopolia satyavantii, Neomeris* sp., *Orioporella malaviae* and *Pianiae niniyurensis* (Dasycladaceae) : *Parachaetes asvapatii, Solenopora tiruchiensis* (Solenoporaceae), *Archaeolithotham-*

nium lugeoni, A. sp. cf. *Iycoperdioides, A.* aff. *provinciale, A. torulosum, Distichoplax raoi* (Melobesoideae) and *Corallina raoi* (Corallineae) (Rao & Pia, 1936; Rao & Gowda, 1953, 1954; Chiplonkar, 1944; Gowda, 1953, 1959; Varma, 1952, 1954; Pal, 1972). It was suggested that there was a prevalence of marine environment with normal salinity, quite and calm waters ranging from 10-20 fathoms in depth and also observed that Dasycladaceae and Corallineae seem to be mutually exclusive ecologically (Rao & Pia, 1936).

Andaman Islands

The Tertiary sediments of these Islands are known for their red algal flora represented by 19 species. Gee (1926) recorded *Lithothamnium nummuliticum* and *L. suganum* from the Eocene sediments of West bank of Tugapur River, Middle Andaman Island. A solenoporoid alga—*Neosolenopora ramaraoi* (Gururaja, 1977) and two species of *Aethesolithon*, a rare crustose and branching coralline alga (Venkatachalapathy & Gururaja, 1984), were described from the Hut Bay Biohermal limestone, Little Andaman Islands, Bay of Bengal. Occurrence of these algae suggests existence of shallow marine environment during the deposition of Hut Bay Limestone. Mathur (1980) recorded *Audouinella membrances* (*magnus*) Papenfuss from the ?Oligocene sediments of Baratang Formation, Middle Andaman. Chatterji and Gururaja (1972) described seven genera represented by 11 species of red algae belonging to Melobesioideae and Corallinoideae. These include *Lithothamnium wilsonensis, Lithophyllum* cf. *fosliei* (Hydr.) Hydr, *Lithophyllum* aff. *prelichenoides, Lithophyllum* sp., *Jania* sp. and *Corallina raoi* from the Lower Limestone and *Amphiroa* cf. *prefragilissima* Lemoine and *Amphiroa* sp. from the Upper Limestone (Chitamalae) of Archipelago Series, Western Coast, Wilson Island of Lower Miocene (Aquitanian) age. *Lithothamnium andamanensis, Lithoporella (Melobesia) melobesoides* (Foslie) Foslie and *Distichoplax biserialis* (Dietrich) were reported from the Cheria Tapu, South Andamans of Palaeocene age. The recovery of articulated corallines indicates shallow depths of water and a high energy regimes.

DISCUSSION

A critical analysis and evaluation of the above synthesis brings out the following epitome.

1. A total of 165 species of 42 genera belonging to different groups of calcareous algae are known from the different Indian Cretaceous and Tertiary sedimentary units; out of which only 15 species flourished during these periods (Table 3).

Table 3—Common Cretaceous-Tertiary calcareous algae

Chlorophyta (Green Algae)

Clypenia sahnii
Halimeda sp.
Indopolia satyavantii
Neomeris sp.

Phodophyta (Red Algae)

Archaeolithothamnium lugeonii
Archaeolithothamnium nonsteinensis
Archaeolithothamnium sp.
Distichoplax biserialis
Distichoplax raoi
Lithophyllum sp.
Parachaetes asvapatii
Permocalculus irenae
Peyssonnelia antiqua
Solenopora tiruchiensis
Solenopora sp.

2. Calcareous marine blue-green algae (Cyanobacteria) constituted by 4 genera and 10 species flourished during the Cretaceous times. Their records from the Indian Tertiary sediments are wanting. The taxa reported were mainly skeletal encrusting forms which probably occupied the shallow tides. They were inhabiting marginal marine environment with restricted ecological requirements. Their explicit role in the Indian Cretaceous carbonate sedimentation was not much pronounced (Text-figure 1); except that, *Cayeuxia*, an encrusting blue-green alga, considered as a member of Rivulariaceae (Dragastan, 1985) significantly contributed to the carbonate deposition during the Cretaceous times. Calcium carbonate in most of these blue-green algae generally gets deposited on outside the colony or cell or between the tissues, but not in the cell wall. The calcification process generally gets promoted by thick mucilage sheaths by favouring the physico-chemical precipitation of calcium carbonate (Riding, 1991).
3. The green algae (Chlorophyta) were fairly well represented in the Indian Cretaceous deposits, consisting of 33 species and 13 genera. Forms like *Arabicodium, Boueina* (Codiaceae), *Cylindroporella, Gymnopora, Larvaria, Linoporella* and *Neomizzia* (Dasycladaceae) were only recorded from the Cretaceous

deposits. On the other hand, the Tertiary deposits were represented by 23 species of 14 genera of green algae. Forms like *Acitabularia, Griphoporella, Furcoporella, Holosporella, Orioporella, Pianiae* and *Trinocladus* (Dasycladaceae) were reported only from the Tertiary deposits. Only three forms *Halimeda, Neomeris* and *Indopolia* occurred both in Cretaceous and Tertiary deposits.

4. The preponderance of green algae in the Indian Cretaceous and Tertiary deposits suggests their significant contribution to carbonate rock building. It is known that *Halimeda* (Codiaceae) in recent lagoons is an important producer of carbonate silt and carbonate mud. Recent studies have demonstrated its role in shelf sands and coral reef sediments of Atlantic continental margins (Milliman, 1977). These forms usually bind the loose mud and contribute to reef building. The Codiaceans had reasonably contributed to the Indian Cretaceous carbonate sediments whereas they are feebly represented in the Tertiary deposits (Text-figure 1).
5. The relative abundance of Dasycladaceae in both Cretaceous and Tertiary deposits indicates shelf facies. These probably survived under normal marine calm water conditions and inhabited on sand and mud bottoms. Their distribution generally vary with the depth. Usually they live below the tidal zone (3-5 meters) and also found up to 100 meters, and are much pronounced in the protected lagoons and reef flats. In *Acitabularia* calcium carbonate usually accumulates within the algal cells and tolerates wide variations in salinities and temperatures. In other dasycladaceans it gets deposited outside the cell. Their widespread distribution in the Indian Cretaceous-Tertiary deposits suggests the contribution to lagoonal and back reef facies. The existence of morphologically advanced forms like *Furcoporella* in the Tertiary deposits together with other less differentiated forms like *Cymopolia, Neomeris, Trinocladus*, etc. indicates evolutionary changes coupled with environmental requirements (Herak *et al.*, 1977).
6. The Indian Cretaceous-Tertiary deposits in general were enriched with members of Gymnocodiaceae, Solenoporaceae, Squamariaceae, Melobesoideae and Corallineae (Text-figure 1). The Cretaceous red algal assemblage consists of 14 genera of 39 species dominated by crustose corallines (Melobesoideae). Members of two extinct families Gymnocodiaceae and Solenoporaceae survived in normal saline waters in open marine conditions. Their contribution to the Indian Tertiary rock building was insignificant as compared to Cretaceous. Encrusting members of Squamariaceae *Ethelia* and *Peyssonnelia* occur in tropical and sub-tropical marine environments. Their presence in Caribbean reefs and Hawaiian Islands at greater depths (30-90 meters) was noticed (Wray, 1977). The crustose corallines dominated the Tertiary calcareous algal flora (Text-figure 1). The articulated forms were not well represented and they usually occurred in high water energy regimes. They were probably not much diversified in the Indian seas during the Cretaceous-Tertiary times. The Indian Tertiary calcareous algal flora is characterised by the presence of seven red algal genera not known from the Cretaceous sediments. These include *Lithothamnium, Aethesolithon, Audouinella, Corallina, Melobesia, Neosolenopora* and *Jania*. The reported occurrence of *Audouinella* from the Andaman Islands is significant as some of these species are known to live as symbiotic algae which penetrate deeply into the tissues of the host members of Bonnamaisoniaceae. Similarly *Melobesia* is known as an epiphyte on *Gymnogongrus, Laurencia, Phyllospadix* and *Zostera; Mesophyllum* lives as an epiphyte on *Calliarthron* (Goff, 1983). These probably suggests growth of marine grasses and exemplifies the diversity and versatility of angiosperms even in the marine realm. Many ecological factors determine the distribution of red algae. Distribution of the corallines varied with temperature and light. Latitudinal differentiations coupled with temperature changes affect their distribution. The availability of light also was one of the important factors in their depth distribution. As a group the red algae have phycoerythrin pigment due to which these algae could exist at greater depths. Amount of suspended and dissolved matter also affect light availability, which inturn influence the distribution of red algae. Some of these factors could have been responsible for the differential distribution of calcareous algae in different Indian sedimentary basins. For example it is observed that the corallines usually decrease in abundance down slope towards the basin where planktonic foraminifera and coccolithophorids dominates the scene.
7. Apparent extinction of many forms from Cretaceous to Tertiary is attributed to gaps in our knowledge. Systematic exploration of Indian Cretaceous-Tertiary deposits and serious studies

on calcareous algae are required to arrive at rational inferences. The continuity of 15 species up to the Tertiary times reflects "pseudo-extinctions" (Table 3). The evolution of red algae was probably at a much higher pace during the Tertiary times with corallines dominating the scene. Though Dasycladaceans evolved both in Cretaceous and Tertiary times, their abundance in the latter deposits suggests their diversity.

8. Data on the variety and abundance of Indian calcareous algae needs to be accumulated through concerted efforts and this promising field of study still awaits serious attention.

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