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A new record of calcareous algae from Shella Formation (Jaintia Group) of South Jaintia Hills, Meghalaya, India

Ajanta Sarma^{1,*} and Amit K. Ghosh²

¹Department of Geology, G.C. College, Silchar 788 004, India

²Birbal Sahni Institute of Palaeobotany, 53 University Road, Lucknow 226 007, India

The Shella Formation exposed in the southern part of Jaintia Hills comprises an alternate sequence of sandstone and limestone members. The limestones are fossiliferous with preponderance of benthic foraminifera, e.g. Nummulitids, Alveolinids, Discocyclina, etc. The foraminiferal assemblage suggests a Early Paleocene to Middle Eocene age for the Shella Formation. A rich assemblage of fossil calcareous algae (both non-geniculate and geniculate coralline red algae and halimedacean, udoteacean and dasycladalean green algae) has been recovered from the limestone. The non-geniculate corallines are represented by genera *Lithothamnion*, *Lithophyllum*, *Distichoplax*, *Sporolithon*, *Lithoporella* and *Spongites* and geniculate corallines are represented by the genera *Corallina* and *Jania*. A few green algae, viz. *Ovulites* (family Udoteaceae), *Halimeda* (family Halimedaceae) and *Actinoporella* (family Acetabulariaceae (Dasycladales)) have been recovered from the

study area. The overall algal assemblage indicates a shallow marine environment of normal salinity.

Keywords: Coralline algae, green algae, Jaintia Hills, Palaeocene–Eocene, Shella Formation.

SIGNIFICANT contributions have so far been made on the study of fossil foraminifera from the Cenozoic sequence of Meghalaya shelf. Studies have also been made^{1–5} on the calcareous algae from parts of the East Khasi Hills. However, lime-secreting calcareous algae from the study area (Figure 1) that forms part of the Meghalaya shelf are described here. Samples for the present study were collected from the Shella Formation (Jaintia Group) of South Jaintia Hills, Meghalaya (23°40′–25°9′N and 92°20′–92°35′E). Geologically, the area is part of the Meghalaya shelf, an extension of the Bengal Basin.

Excepting some persistent exposures of Precambrian rocks, most of the area is covered by a thick pile of Tertiary sequences abutting against the Neogene clastics in the south and Precambrian metasediments in the north.

The Jaintia Group is subdivided into two broad divisions, i.e. the Shella Formation and Kopili Formation^{6,7}. The Shella Formation is the lowermost lithounit of the Jaintia Group comprising three alternating sandstone and limestone members, viz. Lakadong Limestone, Umlatdoh Limestone and Prang Limestone respectively, in chronological order (Figure 2). The pinching out of some of the members and interfingering of limestone beds with sandstone and shale made them regionally impersistent.

From the lowermost member of the three limestone units of the Shella Formation, i.e. the Lakadong Limestone, calcareous algae (both geniculate and non-geniculate) have been recovered. Based on the foraminiferal assemblage, the age of this member is considered to be Early Palaeocene to Early Eocene. This member is found to be a regionally persistent horizon in the east and western Khasi Hills and has been equated with the Lakadong Limestone of Cherrapunji area. This member can also be correlated with the Khasian Stage of Kachchh⁸.

The middle limestone member designated as Umlatdoh Limestone is also highly fossiliferous. The red and green algae have been recovered from this unit in association with larger foraminifera. The age for the Umlatdoh limestone is considered as Lower Eocene to Middle Eocene based on foraminiferal assemblage. This unit is well developed in the Shella area but in west Khasi Hills and Garo Hills, this unit does not crop out. This limestone is considered as homotaxial to the Kakdian Stage of Kachchh⁸.

The uppermost of the three limestone members is designated as Prang Limestone in Khasi–Jaintia Hills and Siju Limestone in Garo Hills. This also occurs in Sylhet, Delai and Koilapahar of Karbi Anglong district. The characteristic feature of Prang Limestone is the abundance of calcareous algae and larger foraminifera. The overall assemblage suggests a Middle Eocene (Lutetian) age for the

*For correspondence. (e-mail: ajanta_sarma@rediffmail.com)

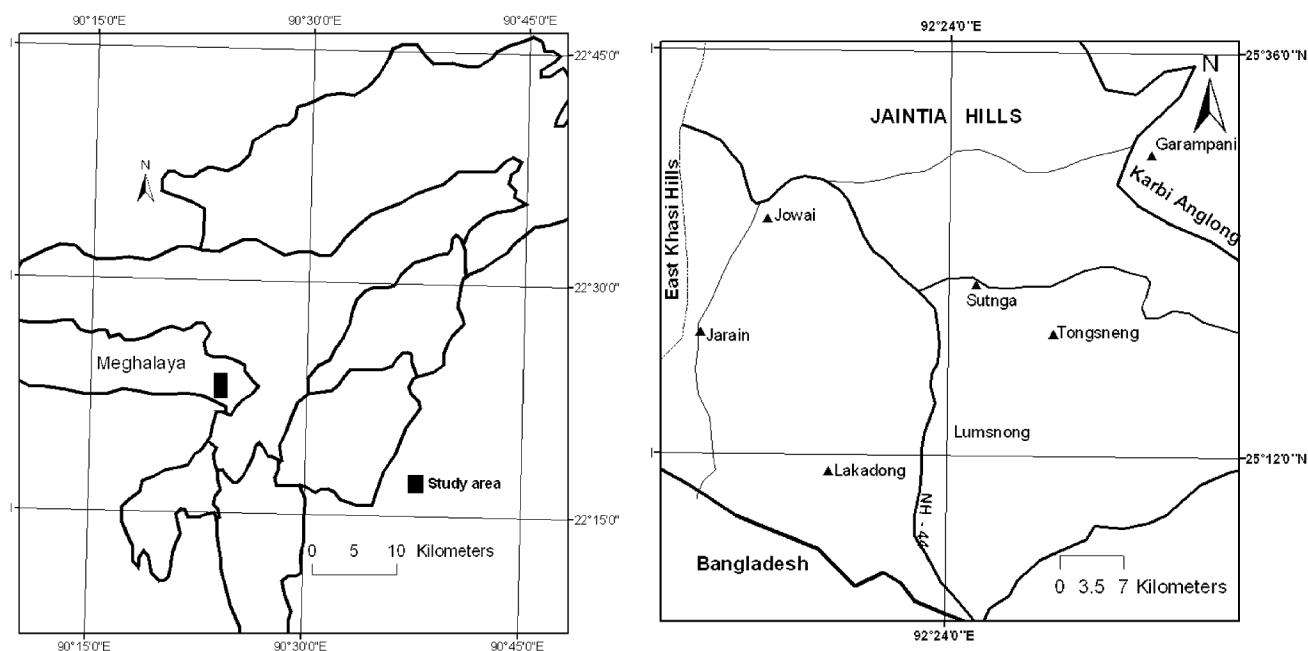


Figure 1. Location map of the study area.

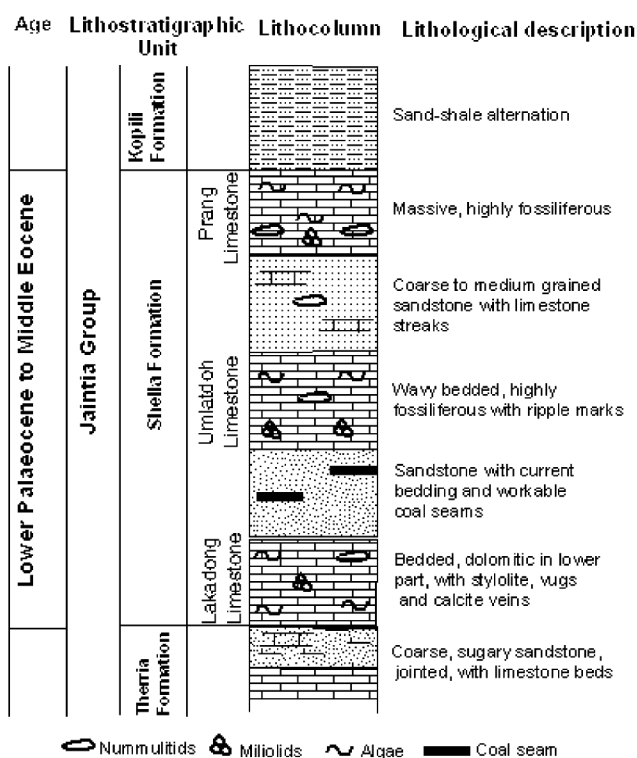


Figure 2. Composite litholog of the study area (not to scale).

Prang Limestone and can be correlated with the Babian Stage of Kachchh⁸.

Study of limestone in thin sections from the study area (Figures 1 and 2) has yielded eleven different genera belonging to both geniculate and non-geniculate coralline red

algae and udoteacean, halimedacean and dasycladalean green algae. These algae have been described here based on the prevailing taxonomic approach employing an open nomenclatural concept.

Lithothamnion sp. 1 (Figure 3a), a non-geniculate coralline red algae belonging to the subfamily Melobesioideae, has been identified from the Umlatdoh Limestone Member of South Jaintia Hills, Meghalaya. The present species is characterized by monomerous thallus with well-developed peripheral region. Core filaments are non-coaxial and peripheral filaments show somewhat zoned appearance. Cells are rectangular, 12.75–17 μm in length and 17–18 μm in diameter. Fusion of cells is common. Conceptacles are numerous and multiporate conceptacles are tetra/bisporangial, 33–42 μm in height and 43–89 μm in diameter. *Lithothamnion* sp. 1 is comparable to *Lithothamnion validum* Foslíe described by Johnson and Stewart⁹ from the Eocene of Meganos Formation, California. However, their⁹ specimens need reassessment based on new taxonomic criteria.

Another melobesoid, non-geniculate algae from the Prang Limestone described here as *Lithothamnion* sp. 2 (Figure 3b) is characterized by encrusting, monomerous thallus and thin non co-axial core filaments. Peripheral filaments consist of regular curved rows of rectangular to squarish cells measuring 40–60 μm in length and 5–12.5 μm in diameter. Cell fusions are common. Multiporate conceptacles are large, tetra/bisporangial, measuring 91–186 μm in height and 130–159 μm in diameter. Epithallial cells are not clearly discernible. In overall appearance, this species is comparable to *L. megalosium* of Johnson and Stewart⁹ from the Eocene, Meganos Formation,

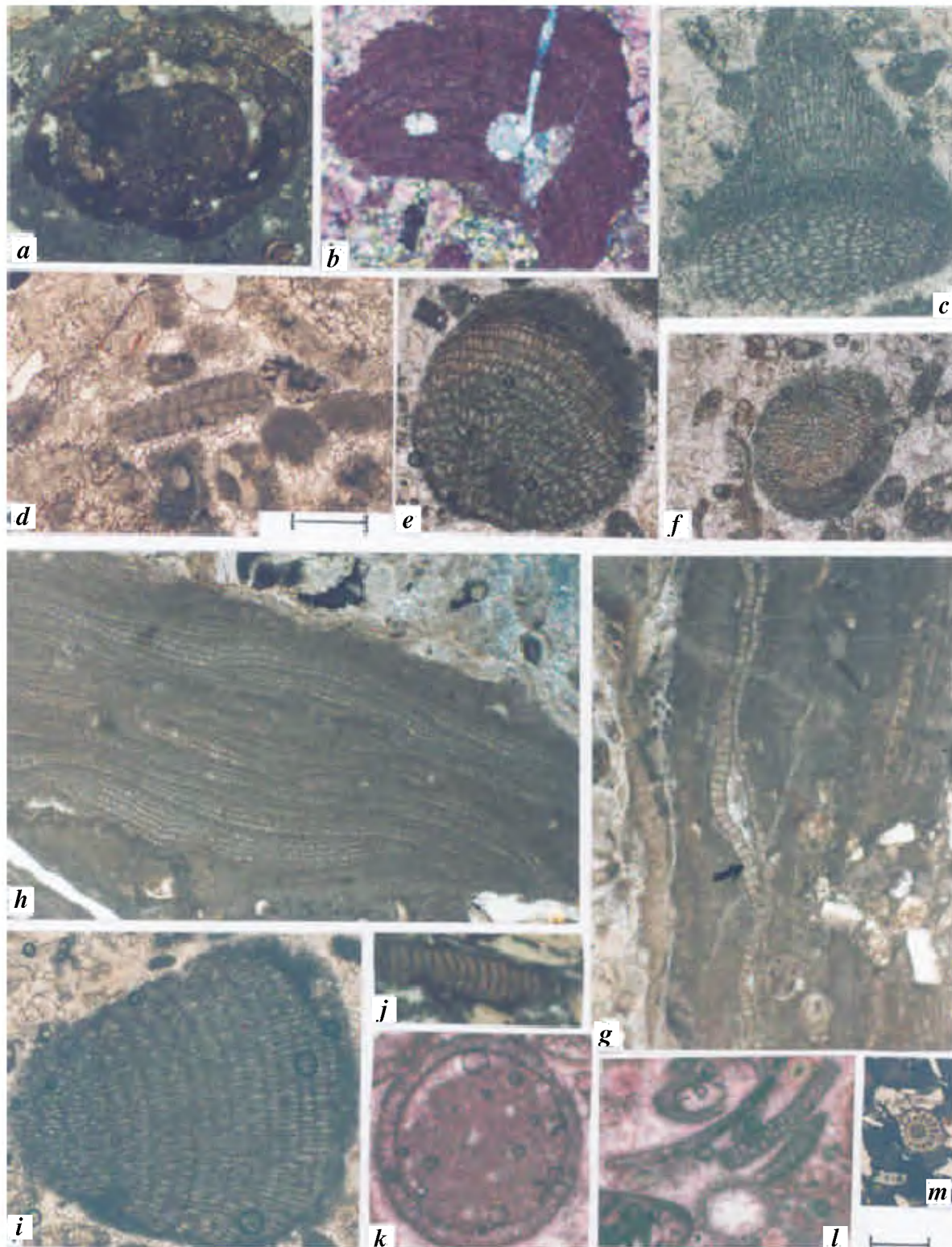


Figure 3. *a*, *Lithothamnion* sp. 1 from the Umlatdoh Limestone showing core and peripheral filaments of thallus with multiporate sporangial conceptacles (slide no. AS/L2C36); *b*, *Lithothamnion* sp. 2 from the Prang Limestone showing thallus with multiporate sporangial conceptacle (slide no. AS/L3B.2.1); *c*, *Lithophyllum* sp. from Lakadong Limestone (slide no. AS/L14.2); *d*, *Distichoplax biserialis* from Lakadong Limestone (slide no. AS/L1 2.2); *e, f*, *Sporolithon* sp. from Lakadong Limestone (slide no. AS/L1 4.1); *g*, *Lithoporella melobesioides* from Prang Limestone showing unistratose thallus with palisade cells (marked by arrow) and uniporate tetra/bisporangial conceptacle (slide no. AS/L3.3); *h*, *Spongites* sp. from Prang Limestone (slide no. AS/L3.3); *i*, *Jania* sp. from Lakadong Limestone (slide no. AS/L1 4.1.1); *j*, *Corallina* sp. from Umlatdoh Limestone (slide no. AS/L2C34); *k*, *Ovulites* sp. from Umlatdoh Limestone (slide no. AS/L2 5.1); *l*, *Halimeda* sp. from Umlatdoh Limestone (slide no. AS/L2 5.1); *m*, *Actinoporella* sp. from Prang Limestone (slide no. AS/L3 C1.3). (Magnification: Scale bar = 200 μ m. All figured slides are stored in the repository of Department of Geological Sciences, Gauhati University.)

California. Similar algal elements were described earlier as *L. bofilli* by Lemoine^{10,11} from Spain and Algeria.

Lithophylloid non-geniculate coralline algae *Lithophylum* sp. (Figure 3c) belonging to the subfamily Lithophylloideae has been recovered from the Lakadong and Umlatdoh Limestone members of South Jaintia Hills, Meghalaya. Growth form of this species is encrusting to branched, where thallus is dorsiventral and core filaments non-coaxial. Cell fusion in the peripheral region has not been observed. Cells are rectangular near the peripheral region and polygonal to circular at the core region, measuring 15–35 µm in length and 12–16.5 µm in diameter. Conceptacles are not preserved. Owing to absence of cell fusions, the present form is assignable under the genus *Lithophylum*. However, conceptacles are not preserved in the studied specimens and are not comparable to any other previously known species of the genus.

The Lakadong Limestone also yielded another controversial lithophylloid algae *Distichoplax biserialis* (Figure 3d). Predominantly this form occurs in groups, but commonly is haphazard in orientation. In longitudinal section it is like a 'fishbone fossil' with two rows of obliquely elongated cells disposed at an obtuse angle. Thallus consists of two rows of cells (40–61 µm long and 30–40 µm wide) oppositely arranged and disposed at right angles to the central axis. Validity of *Distichoplax* as an algae has been questioned by various authors^{12–15}. The genus *Distichoplax* was established by Pia¹⁶, who characterized it by occurrence of calcified thalluses, which formed free-standing plates composed of two rows of cells. The type species *Distichoplax biserialis* (Dietrich) Pia occurs in Paleocene and Eocene sediments from various marine basins. Since the taxon is not known from any horizon except Paleocene and Eocene, palaeoalgalogists attach considerable importance to this species in stratigraphic correlation as an 'index fossil'. Woelkerling *et al.*¹⁷ commented on the relationship between *Tenarea* (Recent non-geniculate coralline algae belonging to Lithophylloideae, sensu Johansen¹⁸) and the fossil genus *Distichoplax*. Woelkerling *et al.*¹⁷ opined that *Distichoplax* like *Tenarea* is organized in an isobilateral manner. Further studies on *Distichoplax* are needed to find out whether these two taxa are related or even possibly congeneric. In view of this situation, for the placement, taxonomy and identification of *Distichoplax*, special attention is needed. However, based on the available anatomical features, the presently studied specimens have provisionally been treated here as *Distichoplax biserialis*, belonging to subfamily Lithophylloideae.

Sporolithacean (family Sporolithaceae) coralline red algae, referable to genus *Sporolithon* (Figure 3e, f), have been recorded from the Lakadong Limestone and from the Prang Limestone members. The presently studied specimens are characterized by lumpy, warty and rarely encrusting forms with monomerous thallus and non-coaxial core filaments. Cells of the core region are rectangular to

trapezoidal and those of the peripheral region are squarish to rectangular, measuring 12–37 µm in length and 22–25 µm in diameter. Cell fusions are occasional and conceptacles are poorly preserved. Based on the anatomy of the vegetative part, the present forms are assignable to the genus *Sporolithon*. However, owing to poor preservation of reproductive structures, these are not comparable to any previously recorded species of the genus *Sporolithon*.

Non-geniculate coralline algae *Lithoporella melobesioides* (Foslie) Foslie¹⁹ (Figure 3g), belonging to the subfamily Mastophoroideae, has been identified from the Prang Limestone. This encrusting alga possesses unistratose thalluses with large cells measuring 26–46 µm in length and 46–53 µm in diameter, and multiple overgrowths of cell filaments (up to 200 µm in thickness). Dimerous plants have characteristic palisade cells (arrow, Figure 3g). Uniporate tetra/bisporangial conceptacle are visible, 53–133 µm in length and about 400 µm in diameter. *Lithoporella* is well represented in fossil material and is commonly identified by the nature of unistratose thallus with large cells. *L. melobesioides* is well known both as a fossil as well as recent material. The present specimens resemble *L. melobesioides* described from the Late Eocene of Austrian Molasse Zone²⁰.

Spongites sp. (Figure 3h), a mastophoroid algae from the Prang Limestone, is characterized by encrusting growth form (about 1200 µm thick) and dimerous thallus organization with unistratose primigenous filaments. Postigenous filaments show somewhat irregular cells with cell fusions. Conceptacles are uniporate in nature. This genus is commonly known from the Eocene sediments. However, the present species is not comparable to any known form of the genus *Spongites*.

Jania sp. (Figure 3i), subfamily Corallinoideae from the Lakadong Limestone has solitary fragment of intergeniculate measuring about 1411 µm long. Its core filaments consist of curving rows of long, straight, rectangular cells measuring 55–88 µm in length and 22–33 µm in diameter. There are 10–18 such rows in this specimen. A well-developed peripheral layer of small, rectangular cells is present. Genicula are not found and conceptacles not observed. The present alga is comparable to *J. mengaudi* Lemoine known from the Paleocene of northern Iraq²¹ and from the Late Paleocene Limestone of Middle Andaman Island, India²².

Corallina sp. (Figure 3j), subfamily Corallinoideae from the Umlatdoh Limestone has fragments of intergeniculate measuring about 666 µm in length. Its core filaments are arranged in rows of long, straight, parallel cells, measuring 41–48 µm in length and 0.7–7 µm in diameter. These cells are essentially of equal length, except the narrow marginal layer of short, nearly square cells. Genicula and conceptacles are not preserved. The presently described species of *Corallina* is closely comparable to *C. prisca* Johnson known from the Upper Eocene, Matansa Limestone, Marina Islands²³; Late Eocene of Eniwetok, Saipan²⁴; Late Paleocene of Lakadong Formation, Shillong, NE

Table 1. Distribution pattern of calcareous algal forms from the study area

Group	Formation	Lithounit	Genera of calcareous algae	Palaeoenvironment/ palaeobathymetry
Jaintia group	Shella Formation	Prang Limestone	<i>Lithoporella</i> (non-geniculate coralline)	> 20 m reefal
			<i>Lithothamnion</i> (non-geniculate coralline)	
			<i>Sporolithon</i> (non-geniculate coralline)	
			<i>Spongites</i> (non-geniculate coralline)	
			<i>Actinoporella</i> (green alga: dasycladalean)	
		Narpuh Sandstone		< 20 m reefal
		Umlatdoh Limestone	<i>Lithophyllum</i> (non-geniculate coralline)	> 20 m reefal
			<i>Lithothamnion</i> (non-geniculate coralline)	
			<i>Corallina</i> (geniculate coralline)	
			<i>Ovulites</i> (green alga: udoteacean)	
			<i>Halimeda</i> (green alga: halimedacean)	
		Lakadong sandstone		< 20 m reefal
		Lakadong Limestone	<i>Lithophyllum</i> (non-geniculate coralline)	< 40 m
			<i>Distichoplax</i> (non-geniculate coralline)	
			<i>Sporolithon</i> (non-geniculate coralline)	
			<i>Jania</i> (geniculate coralline)	

India¹ and Late Miocene of Chhasara Formation, Kachhh, Gujarat²⁵. However, the intergeniculate fragment of the present species is much smaller in size in comparison to *C. prisca* Johnson.

The segment of udoteacean green algae identified in the present assemblage as *Ovulites* sp. (Figure 3 k) is circular in cross-section and more or less cylindrical in transverse section, measuring about 710 µm in diameter. The segments are hollow, suggesting an uncalcified medullary region. A faint network is preserved in the cortical region. The specimens show calcification by both microcrystalline and sparry calcite.

The *Halimeda* sp. (Figure 3 l) is characterized by incomplete segments. Maximum length of the segment is 700 and width 170 µm. Medullary and cortical zone is ill-preserved and diameter of medullary filaments varies from 175 to 295 µm.

The Prang Limestone yielded a dasycladalean green alga *Actinoporella* sp. (Figure 3 m), belonging to the family Acetabulariaceae. The cylindrical main axis of the specimen measures 140–160 µm in diameter, that bears regularly spaced close-set whorls of 14 branches. The branches consist of vestibules followed by club-shaped secondaries, i.e. gametophores.

Generally calcareous algae are considered significant for the interpretation of palaeoenvironment and palaeobathymetry. The most important factor controlling the distribution of marine calcareous algae is sunlight, which is necessary for photosynthesis. Owing to the presence of phycoerythrin pigments in coralline red algae, they can photosynthesize in low light intensity²⁶. As a matter of fact, corallines have wide depth range among red algae. Although several coralline species may show restricted distribution patterns with respect to factors such as depth and temperature, other factors like salinity, light penetration, hydrodynamic condition and nature of substrate considerably

affect the distribution pattern. Coralline red algae are benthic marine plants and are considered to be the important Cenozoic reef builders in tropical and subtropical realms, both as frame-building organisms and as sediment producers²⁷. Non-geniculate corallines, in particular, are one of the best (paleo-)bathymetric indicators owing to their general wide depth distribution²⁸ and light sensitivity. Although they are most diverse in shallow tropical seas (intertidal zone to 10 m), some genera can occur at depths as great as 250 m. Udoteaceans, halimeds and dasyclads (green algae) tolerate somewhat lower salinity in comparison to corallines. They generally occur at a shallow water depth. Sometimes they occur at water depth down to 100 m. However, the overall depth distribution depends on the light permeability of water.

Though there are slight variations in the distribution pattern of calcareous algae in the three limestone members, all the three limestone units are characterized by the occurrence of coralline red algae. Udoteacean and halimedacean green algae are restricted to the Umlatdoh Limestone Member and dasycladalean green algae occur only in the Prang Limestone Member, but the Lakadong Limestone Member is devoid of any green algal forms (Table 1).

The lowermost limestone (Lakadong Limestone Member) shows dominance of *Sporolithon* in association with other non-geniculate genera *Lithophyllum*, *Distichoplax* and geniculate form *Jania*. The Recent species of the genus *Sporolithon* generally grow in warm, shallow tropical and subtropical marine waters. Eventually, their dominance indicates a shallow, warm-water condition for deposition of Lakadong Limestone. *D. biserialis*, which is a common species of this lithounit, indicates a depth between 20 and 40 m and a low energy condition.

In the Umlatdoh Limestone, the algal forms are poorly preserved constituting only ~1% of the total allochems. Among the red algae, both non-geniculate and geniculate

(*Corallina* sp.) along with green algae *Ovulites* and *Halimeda* are present in this lithounit. This generic variation may be due to variation of salinity during the deposition of this limestone. The high diversity of the foraminiferal forms also suggests variable salinity conditions of the sea, which possibly suppressed the growth of algae during this period. Abundance of *Lithothamnion* in this assemblage indicates relatively greater water depth (~40 m). However, udoteaceans and halimeds, which are abundant in this lithounit prefer shallow water depth. Therefore, probably the Umlatdoh Limestone was deposited in fluctuating water conditions with slightly moderate energy environment.

The uppermost unit, i.e. the Prang Limestone Member is dominated by the mastophoroid non-geniculate corallines, e.g. *Lithoporella* and *Spongites*. These algal forms occur mostly in encrusting condition with Orbitoid foraminifera. Dasycladalean green algae (*Actinoporella* sp.) are also found in this lithounit. Presence of dasyclads along with mastophoroid and melobesoid non-geniculate corallines indicates a shallow water depth with more or less low to moderate energy condition.

A perusal of the foregoing account reveals that all the three algal assemblages show an overall dominance of corallinaceans along with sporolithaceans. In all probability the limestone was deposited under shallow, warm shelf environment of normal salinity with some minor sea-level changes within the transgressive phase.

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Palynological constraints on the age of mammal-yielding Deccan intertrappean beds of Naskal, Rangareddi district, Andhra Pradesh

R. S. Singh^{1,*}, Ratan Kar¹ and G. V. R. Prasad²

¹Birbal Sahni Institute of Palaeobotany, 53 University Road, Lucknow 226 007, India

²Department of Geology, University of Jammu, Jammu 180 006, India

A palynological assemblage recovered from the Deccan intertrappean sediments of Naskal, Rangareddi district, Andhra Pradesh on the southern margin of Deccan volcanic province is reported here. The assemblage contains taxa assigned to *Ariadnaesporites*, *Gabonispores*, *Triporoletes*, *Mulleripollis*, *Azolla* and *Minerisporites*, favouring a Maastrichtian age for the eutherian mammal-bearing intertrappean beds of Naskal. Fresh-water ferns dominate this assemblage, which indicates a lacustrine environment of deposition and a warm and humid climate.

Keywords: Deccan intertrappean bed, eutherian mammals, Maastrichtian age, Naskal, palynology.

DECCAN Traps encompassing the Cretaceous–Tertiary (K/T) boundary^{1,2} with estimated duration of volcanism varying from 0.5 to 5 Ma^{3–5}, have attracted worldwide

*For correspondence. (e-mail: rs_singh1957@yahoo.co.in)