Stratigraphical, palaeogeographical and palaeoenvironmental significance of fossil calcareous algae from Nimar Sandstone Formation, Bagh Group (Cenomanian–Turonian) of Pipaldehla, Jhabua Dt, MP

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A rich and diversified assemblage of fossil calcareous algae comprising 72 species accommodated among 26 genera belonging to Cyanophyta, Rhodophyta and Chlorophyta has been discovered from calcareous top of the Nimar Sandstone Formation exposed at Pipaldehla, Jhabua district, Madhya Pradesh. The algal assemblage is analysed for its stratigraphical, palaeogeographical and palaeoenvironmental significance. Eight species occur during Cenomanian–Turonian, thereby suggesting their Cenomanian–Turonian age. Seventeen species from the present assemblage exclusively occur in the Indo-Mediterranean region, pointing to Indo-Mediterranean province of the Tethyan realm. The algal assemblage as a whole indicates that the calcareous top of the Nimar Sandstone Formation must have been deposited in tropical waters at a depth of 10–12 m from below low tide level, in moderate energy setting with moderate turbulence and normal salinity of water.

THE Bagh Group was deposited in the Narmada basin, an intracratonic trough, trending roughly west to east and following the line of the present-day Narmada river[1]. The Bagh Group extends from Barwah in the east to Rajpipla in the west, over a total distance of about 275 km across the states of Madhya Pradesh, Gujarat and Maharashtra[2] (Figure 1 *c*). Taylor and Badve[3] gave the general stratigraphic succession of Bagh Group which from older to younger formations comprises: the Nimar Sandstone Formation, the Nodular Limestone Formation and the Chirakhan Limestone Formation (Figure 1 *b*). Pipaldehla village (Figure 1 *a*), the area selected for the present study, is located 8 km east of Jhabua district, Madhya Pradesh. Here the Bagh Group is represented by only its basal formation, i.e. Nimar Sandstone Formation[4] (Figure 2). Taking into consideration the Bagh fauna as a whole, a Cenomanian–Turonian age is assigned for the Bagh Group, possibly with the parts of the Nimar Sandstone Formation at the base of the sequence being Late Albian[5]. While reviewing the work done on various fossil groups, Chiplonkar *et al.*[5] suggested a detailed study of fossil algae from Bagh Group. In view of this, the authors have researched fossil calcareous algae from various exposures of Bagh Group of Madhya Pradesh. They undertook several field tours and collected a large number of rock samples. The thin section study of the rocks belonging to Bagh Group reveals that algal fragments are present only in Nimar Sandstone Formation. As compared to other outcrops Pipaldehla, Jhabua district, has been quite prolific in variety and numbers as regards the presence of fossil algal fragments. Hence, we chose Pipaldehla for the present study. The principal aim of the present paper is to interpret the fossil calcareous algae for their stratigraphical, palaeogeographical and palaeoenvironmental significance. Only a few algal species important from the point of view of stratigraphy, palaeogeography and palaeoenvironment are illustrated. For the sake of brevity, the taxonomic description of algal species is not given. Specimens of all algal species discussed in the present paper are lodged in the Museum of Geology Department, Govt. Institute of Science, Aurangabad from Nos. ISG/MF/43 to ISG/MF/172.

Previous work on fossil algae

A critical analysis of fossil algal assemblage discovered by earlier workers[6–19] from Bagh Group of Madhya Pradesh reveals that, in all 25 spp. from 13 genera are known. Out of the 25 spp., 12 spp. were doubtful and therefore, *sensu stricto* only 13 spp. are known from Bagh Group of Madhya Pradesh. These are: *Halimeda pipaldehlaensis* Badve and Nayak, *H. robusta* Badve and Nayak, *H. corneola* Badve and Nayak, *H. densituba* Badve and Nayak, *H. triradiata* Badve and Nayak, *Rivularia chiplonkari* Badve and Nayak, *Sporolithon feddeni* Chiplonkar and Borkar, *Acicularia spherica* Badve and Nayak, *Cymopolia brevicaulia* Badve and Nayak, *Linoporella brevistila* Badve and Nayak, *Neomeris pfenderae* Konishi and Epis, *N. circualris* Badve and Nayak and *Neomizzia multiramosa* Badve and Nayak.

Present fossil algal assemblage

The present work significantly contributes to our knowledge of fossil algae from Bagh Group as it discovers

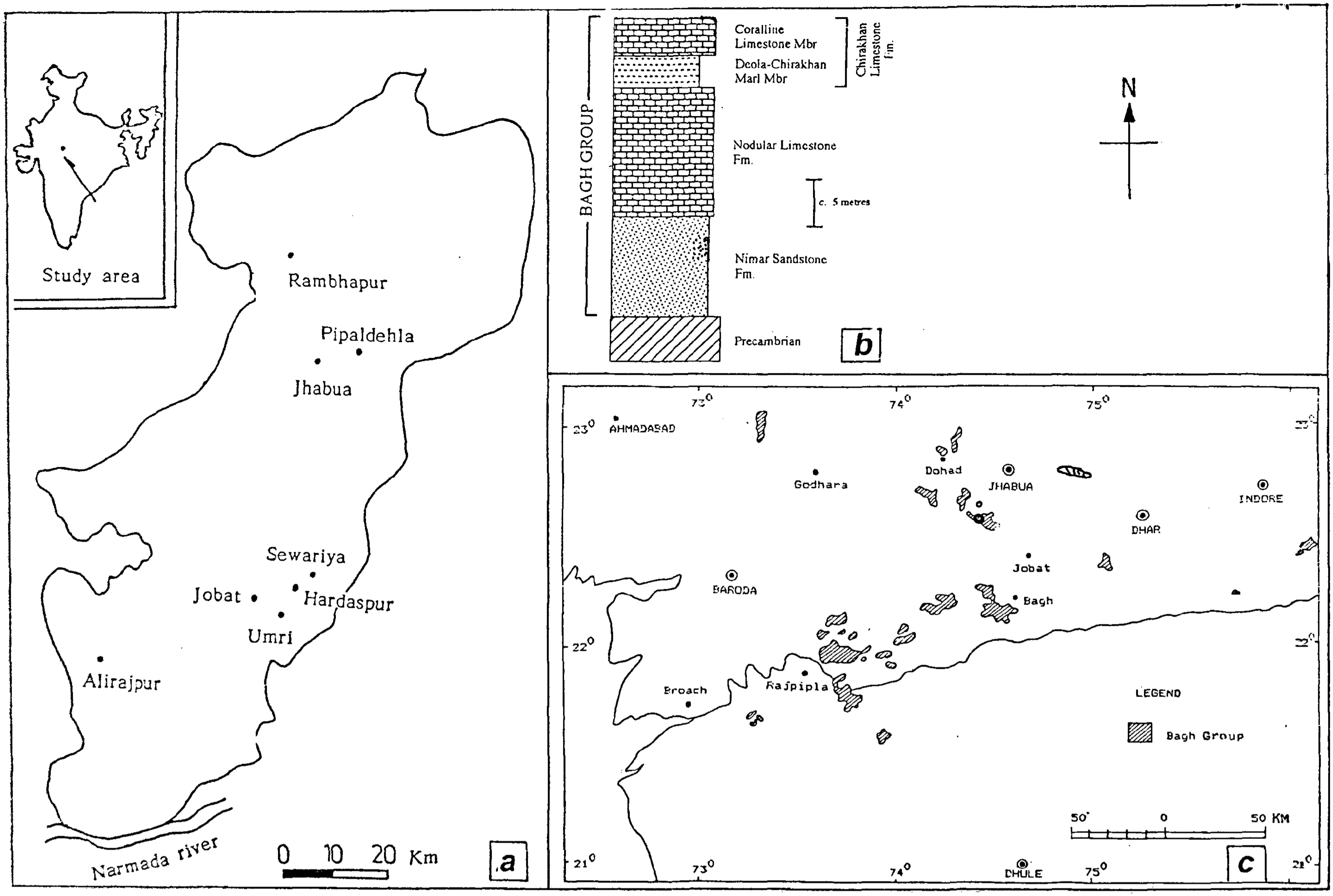


Figure 1. *a*, Outline map of India showing location of Pipaldehla; *b*, Generalized vertical section of Bagh Group as developed in the Man River Valley near Deola, Dhar district, MP; *c*, Outcrop pattern of Bagh Group along Narmada Valley.

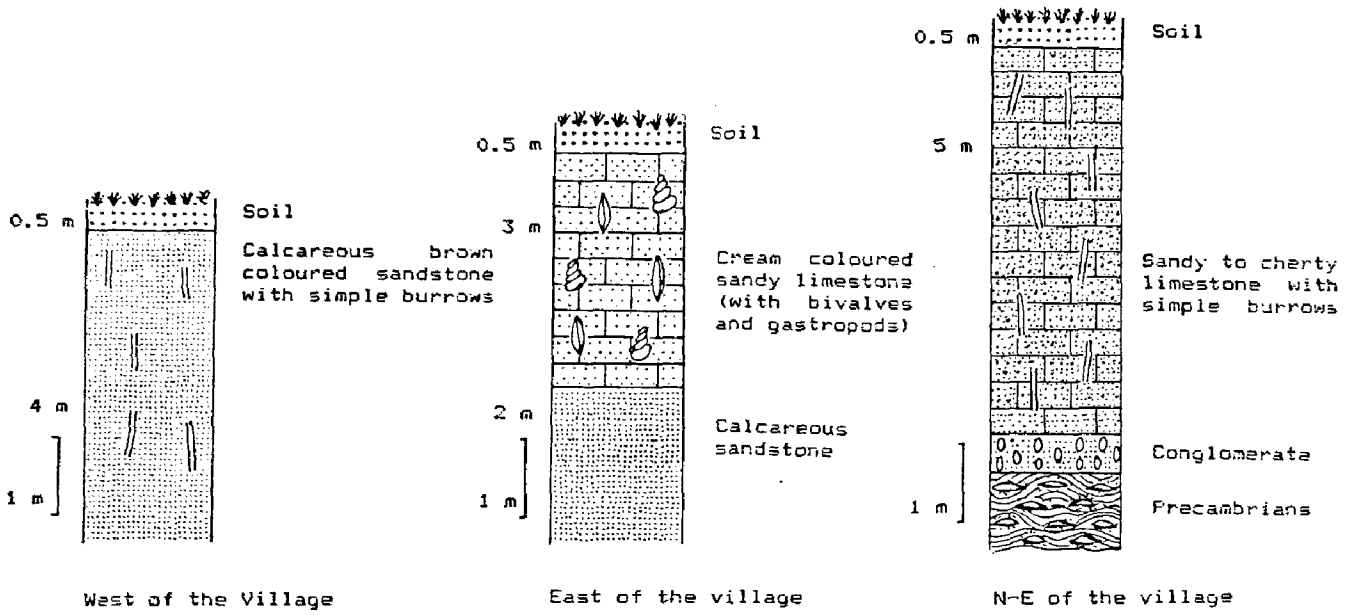


Figure 2. Lithosections at Pipaldehla.

72 spp. accommodated among 26 genera belonging to Cyanophyta, Rhodophyta and Chlorophyta from the calcareous top of the Nimar Sandstone Formation exposed at Pipaldehla. These are:

Division: Cyanophyta
Family: Cyanophyceae

Apophoretella dobunnorum Elliott, *Rivularia fruticulosa* (Johnson and Kaska) Dragastan, *R. lamaitrae* (Dragastan) Dragastan and *R. moesica* (Dragastan)

Division: Rhodophyta
Family: Solenoporaceae

Parachaetetes compactum sp. nov., *P. lobatum* Johnson, *P. poignanti* sp. nov., *Pycnoporidium parvatum* Badve and Kundal, *Solenopora nana* sp. nov., *S. sahnii* Rao and Sambe Gowda and *S. tiruchiensis* Rao and Sambe Gowda.

Family: Squamariaceae

Ethelia alba (Pfender) Massieux and Denizot and *E. nana* Kundal and Badve.

Family: Corallinaceae
Subfamily: Melobesioideae

Sporolithon aschersoni (Foslie) comb. nov., *S. brevium* (Lemoine) comb. nov., *S. flexuosa* sp. nov., S. cf. *S. liberum* (Lemoine) comb. nov., *S. lugeoni* (Pfender) comb. nov., *S. mamillosum* (Lemoine) comb. nov., *S. megasporum* (Johnson) comb. nov., *S. oulianovi* Pfender comb. nov., *S. turonicum* (Rothpletz) comb. nov., *S. zonatum* (Varma) comb. nov., *Lithothamnium aggregatum* Lemoine, *L. bonyense* Johnson, *L. crispithallus* Johnson, *L. elegans* sp. nov., *L. grahmi* Johnson and Stewart, L. cf. *L. lacroixi* Lemoine, *L. marianae* Johnson, *L. quadriramosum* Sanganwar and Kundal, *Lithophyllum* cf. *L. roveretoi* Airoldi, *Lithophyllum* sp. A, *Lithophyllum* sp., *Mesophyllum badvei* sp. nov., *M. pacificum* Johnson, *Lithoporella melobesioides* (Foslie) Foslie and *Melobesia* sp.

Subfamily: Corallinoideae

Amphiroa elliotti Johnson, *A. guatemalense* Johnson and Kaska, *Jania irregularis* sp. nov., and *J. mayei* Johnson.

Division: Chlorophyta
Family: Dasycladaceae

Acicularia antiqua Pia, *Acroporella anceps* Segonzac, *A. occidentalis* Johnson and Kaska, *Cylindroporella elassonos* Johnson and Kaska, *Cymopolia delicata* Johnson, *C. inflataramosa* Segonzac, *C. mayaense* Johnson and Kaska, *Dissocladella densistila* sp. nov., *Dissocladella lunata* Segonzac, *D. undulata* (Raineri) Pia, *Indopolia intermedia* sp. nov., *Linoporella genoti* sp. nov., *Neomeris microsporum* sp. nov., *Neomeris occidentalis* (Johnson and Kaska) Deloffre, *Neomizzia levyi* sp. nov., *Salpingoporella genevensis* (Conrad), *S. istriana* (Gusic) Conrad, Praturlon and Radoicic, *S. melitae* Radoicic, *S. johnsoni* (Dragastan) Conrad, Praturlon and Radoicic, *S. sellii* (Crescenti) comb. nov., *S. tosaensis* (Yabe and Toyama) comb. nov., *S. turgida* (Radoicic) Conrad, Praturlon and Radoicic and *Trinocladus tripolitanus* Raineri.

Family: Codiaceae

Halimeda hillisi sp. nov., *H. megamedulosa* sp. nov., *H. praedistorta* sp. nov., *H. praemicronesica* sp. nov., *H. praemonilis* Morellet, *H. praesimulans* sp. nov. and *H. praetuna* sp. nov.

Stratigraphical significance

In general, the number of index algae is very small, but when an algal assemblage as a whole is considered, algal species may support an existing age conclusion or may even suggest a precise age. The stratigraphic and geographic distribution of algal species discovered from Nimar Sandstone Formation at Pipaldehla reveals that 8 out of 57 spp. (because 15 are newly described) are exclusively known from Cenomanian–Turonian times. These species are: *Sporolithon brevium* (Lemoine) comb. nov. (Figure 3 *b*), *Parachaetetes lobatum* Johnson, *Cylindroporella elassonos* Johnson and Kaska (Figure 3 *d*), *Dissocladella undulata* (Raineri) Pia (Figure 3 *h*), *Neomeris occidentalis* (Johnson and Kaska) Deloffre, *Trinocladus tripolitanus* Raineri, *Acicularia antiqua* Pia (Figure 3 *f*), *Sporolithon turonicum* (Rothpletz) comb. nov. (Figure 3 *a*). Thus these eight species strongly support the Cenomanian–Turonian age. The remaining 49 spp. are long ranging as they are known from Jurassic, Cretaceous and Cenozoic rocks.

Palaeogeographical significance

The geographical distribution of various algal species indicates that 17 spp. exclusively occur in Indo-Mediterranean region, supporting thereby the conclusion arrived at by Chiplonkar *et al.*[5]. These 17 spp. are: *Rivularia lamaitrae* (Dragastan), *R. moesica* Dragastan and Bucar, *Sporolithon zonatum* (Varma) comb. nov., *Solenopora sahnii* Rao and Sambe Gowda, *S. tiruchiensis* Rao and Sambe Gowda, *Amphiroa elliotti* Johnson, *Pycnoporidium parvatum* Badve and Kundal, *Ethelia nana* Kundal and Badve, *Acroporella anceps* Segonzac (Figure 3 *g*), *Cymopolia inflataramosa* Segonzac, *Dissocladella lunata* Segonzac, *Salpingoporella melitae* Radoicic, *S. johnsoni* (Dragastan) Conrad, Praturlon and Radoicic, *S. sellii* (Crescenti) nov. comb., *S. turgida* Conrad, Praturlon and Radoicic, *Trinocladus tripolitanus* Raineri, *Sporolithon turonicum* (Rothpletz) nov. comb. and *Lithophyllum* sp. The remaining species are cosmopolitan in distribution. Hence the geographic distribution of present algae points to an Indo-Mediterranean province of Tethyan realm.

Palaeoenvironmental significance

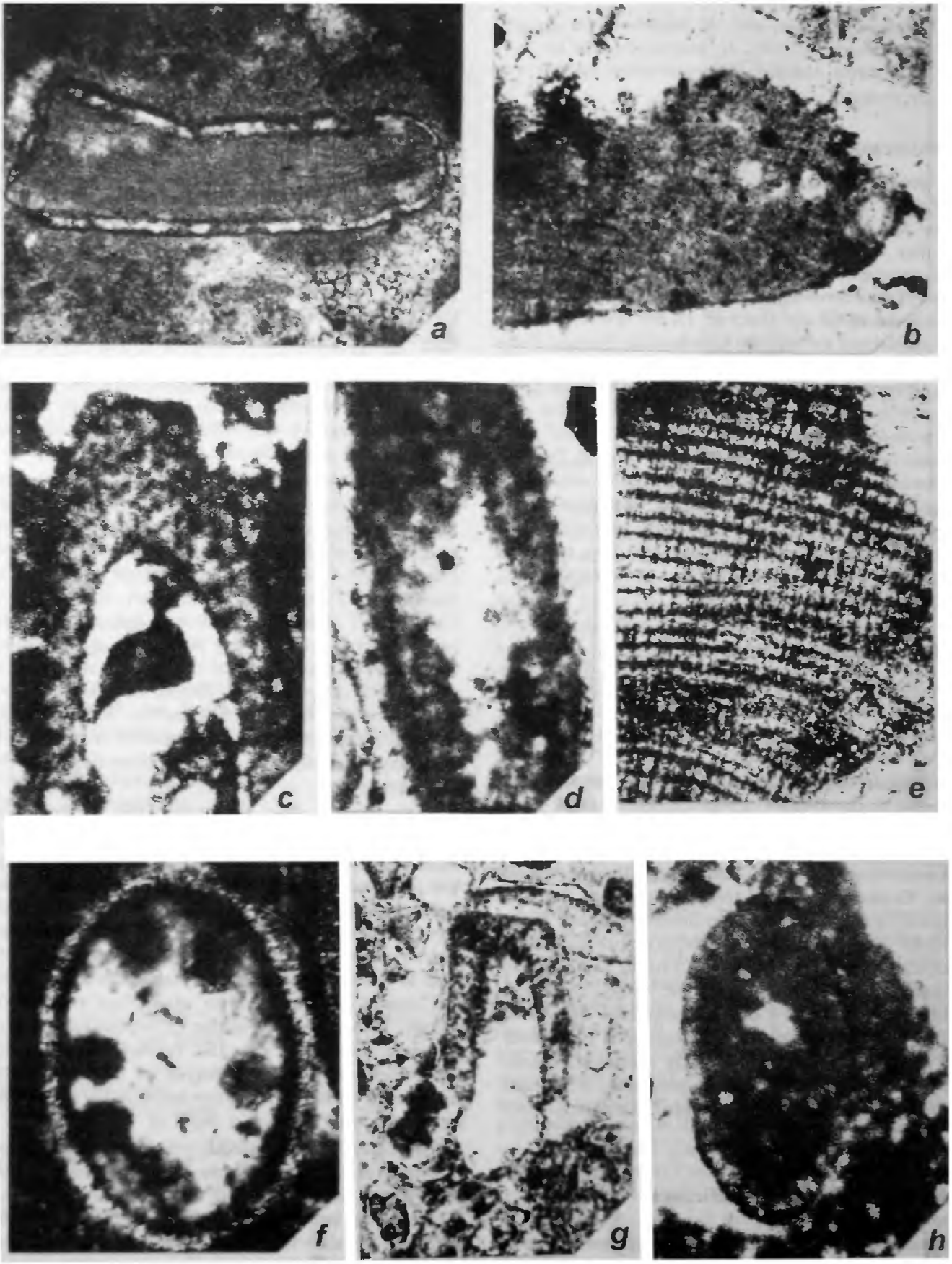
Since the fossil algae come from the calcareous top of the Nimar Sandstone Formation, an analysis of algae is attempted to know the palaeoenvironments of Bagh Group only during the deposition of the top of the Nimar Sandstone Formation. The discovered fossil algal assemblage represents nearly a microcosm of all categories of benthic calcareous algae, i.e. Cyanophyta, Rhodophyta and Chlorophyta. Each category of algae is characterized by a unique set of climatic conditions. But inasmuch as the present algal assemblage is highly rich and highly diversified, as it contains algae from all three categories, it is a must to consider the floral association as a whole while inferring the palaeoenvironments.

The four species of Cyanophyta are not useful for palaeoecological interpretation as Wray[20] has pointed out that living blue-green algae inhabit a wide range of marine and nonmarine environments. The seven species of family Solenoporaceae and two species of family Gymnocodiaceae are not considered here for palaeoecological interpretation as both the families are extinct. But their association with other squamariacean, coralline, dasycladacean and codiacean is significant.

Two species of genus *Ethelia* of family Squamariaceae are useful for studying the palaeoenvironment. The extant *Ethelia* is found in tropical and subtropical marine environment of shallow water with normal salinities[20]. Present algal assemblage is represented by 10 spp. of *Sporolithon*, 8 spp. of *Lithothamnium* and 3 spp. of *Lithophyllum*. Johnson[21] mentioned that many of the coralline algae grow on any substratum at a depth of 10–12 m. However, some of the species are found at considerably greater depths. Hence, these algae do not indicate the precise depth of deposition. Johnson[21] mentioned that coralline algae occur usually from low tide level down to a depth of 25–30 m, depending upon the local conditions.

In the present algal assemblage, the dominance of dasycladacean algae is obvious as they are represented by 23 spp. Pal summarized the information available at that time on the ecology of dasycladacean, and showed that these algae normally occur at a depth ranging from about low tide level down to 10–12 m. Wray[20] indicated that the dasycladacean algae can occur from below tide level to 30 m, but are commonly abundant in less than 5 m depth. The present algal assemblage consists of species belonging to families Corallinaceae, Dasycladaceae, Codiaceae, etc. Out of these families, the species belonging to Dasycladaceae are the most important ones to indicate the precise depth, as dasycladacean algae abundantly grow at a depth of 10–12 m.

The present algal assemblage has seven species of *Halimeda*. *Halimeda* is not the precise indicator of the depth as the recent species of this genus are known to be present in low tide level down to 100 m in depth. *Halimeda* is also found in lagoonal and back reef environment as well as in bathyal depth (300–600 m)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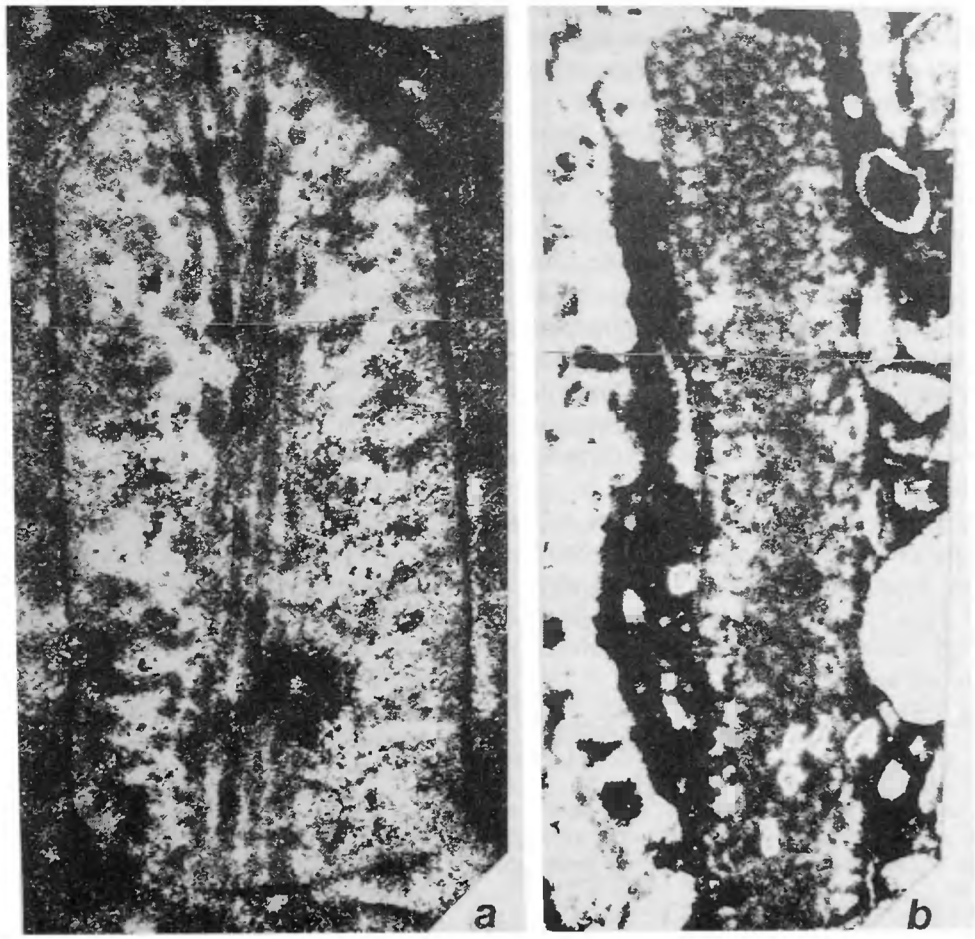

Figure 4. *a*, *Halimeda praetuna* sp. nov. Holotype no. ISG/MF/170 ×75; *b*, *Dissocladella densistila* sp. nov. Holotype no. ISG/MF/113 ×50.

(ref. 22). Species of Melobesioideae grow on any substrate at a depth of 6–12 m. These species seldom grow in stagnant water. Johnson[21] mentioned that melobesioidean algae normally live in euhaline condition of salinity. Therefore the lagoonal environment as may be indicated by *Halimeda* species is out of consideration. However, based upon dasycladacean algae (Figures 3 *c,g* and 4 *b*) and its association with other algal species, it is concluded here that the calcareous top of Nimar Sandstone Formation abounding in these algae must have been deposited at a depth of 10–12 m from low tide level.

Bosence[23] summarized the relationship between morphology of coralline algae and turbulence of waters and showed that the coralline algae which live in high energy condition have thick crust and show radial branching, while the coralline algae which live in moderate energy condition have delicate framework with some branching and concentric crust. The present algal assemblage is characterized by many simple-branched species of *Sporolithon*, *Lithothamnium* (Figure 3 *e*), *Lithophyllum* and *Mesophyllum*. Therefore these species indicate the prevalence of moderate energy condition with moderate turbulence during the deposition of Nimar Sandstone.

Temperature is a major controlling factor for the distribution of algal genera. The melobesioidean algae occur in all marine waters from latitude 80°31′N to latitude 73°S (ref 21). Genus *Lithoporella* essentially occurs in tropical waters while *Sporolithon* is limited to tropical and subtropical waters. *Lithothamnium* and *Lithophyllum* have wide dispersal all over the world. However, the most luxuriant growth, the largest number

Figure 3. *a*, *Sporolithon turonicum* (Rothpletz) comb. nov. specimen no. ISG/MF/35 × 125; *b*, *Sporolithon brevium* (Lemoine) comb. nov. specimen no. ISG/MF/72 × 120; *c*, *Salpingoporella tasaensis* (Yabe and Toyama) specimen no. ISG/MF/48 × 75; *d*, *Cylindroporella elassonos* Johnson specimen no. ISG/MF/106 × 105; *e*, *Lithothamnium quadriramosum* Sanganwar and Kundal specimen no. ISG/MF/88 × 65; *f*, *Acicularia antiqua* Pia specimen no. ISG/MF/94 ×90; *g*, *Acroporella anceps* Segonzac specimen no. ISG/MF/102 × 55; *h*, *Dissocladella undulata* (Raineri) Pia specimen no. ISG/MF/118 ×55.

of species and large branch forms of *Lithophyllum* are found in the tropics[21]. The temperature distribution of *Lithothamnium* in present-day water is just the opposite. Present-day species of *Lithothamnium* occur in cool to cold waters, but during Late Cretaceous and Eocene times, numerous species of *Lithothamnium* thrived in the tropics. In the present algal assemblage *Lithothamnium* and *Lithophyllum* occur in association and this points to tropical warm waters. Wray[20] mentioned that dasycladacean algae occur only under marine condition and are restricted to tropical warm waters. Hillis[22] in her pioneering work on *Halimeda* summarized that the present-day isothermal distribution of *Halimeda* (Figure 4 *a*) is in between 25°C in tropical and 20°C in subtropical on both the sides of the tropics. Therefore the present algal assemblage implies that the Nimar Sandstone Formation must have been deposited in tropical warm waters. Thus, the algal assemblage as a whole indicates that the calcareous top of the Nimar Sandstone Formation must have been deposited in tropical waters at a depth of 10–12 m from below low tide levels, in moderate energy setting with moderate turbulence and normal salinity of waters.

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ACKNOWLEDGEMENTS. We thank the Director, Govt. Institute of Science, Aurangabad, for extending facilities, and the Head, Biophysics Dept. of the same organization for computer facility. We thank an anonymous referee for his many suggestions on the earlier draft of the paper.

Received 29 October 1997; revised accepted 28 July 1998