

BLUE-GREEN ALGAL FLORA ON ARCHAEOLOGICAL MONUMENTS OF INDIA

B. PATTANAIK AND S.P. ADHIKARY

Post Graduate Department of Botany
Utkal University, Bhubaneswar - 751 004

A B S T R A C T

Forty-six blue-green algal species belonging to fifteen genera, *e.g.* *Gloeocapsopsis*, *Gloeotheca*, *Myxosarcina*, *Chroococcidiopsis*, *Lyngbya*, *Phormidium*, *Plectonema*, *Nostoc*, *Calothrix*, *Tolypothrix*, *Chlorogloeopsis*, *Fischerella*, *Hapalosiphon*, *Westiellopsis* and *Stigonema* occurred on the exposed surfaces of various archaeological monuments from different regions of India. All these blue-green algal species have been isolated and maintained in the culture collection at the Department of Botany, Utkal University.

I N T R O D U C T I O N

Most of the archaeologically important monuments look blackish-brown due to excessive growth of the blue-green algae as crusts/mats. There are reports that blue-green algae colonise on a wide variety of substratum, *e.g.* buildings coated with cement and lime in the tropics, India (Chadha and Pandey 1982, Tripathi & *al.* 1900), inside the caves on frescoes, Rome (Albertano & *al.* 1991), on rocks inside Inferniglio cave, Italy (Abdelahad 1989), at Colorado plateau, Mexico (Bell & *al.* 1986), on karstic pits of Garraf, Spain (Hernández-Marine and Canals 1994) and sandstone cliffs, South Africa (Wessels and Büdel 1995). We report here the sub-aerial blue-green algae occurring on various substratum of archaeologically important monuments like the exposed rock surfaces of different temples of Orissa, Maharashtra, Karnataka, Tamil Nadu and Delhi, fresco-paintings of Ajanta caves, excavated sites of Sarnath, Uttar Pradesh and Lalitgiri, Orissa, and terracotta structures at Bishnupur temple, West Bengal.

STUDY AREA

Several ancient temples of Bhubaneswar, Hirapur, Niali, Konark and Puri in the coastal region of Orissa state (19° 80' to 20° 24' N, 85° 87' to 86° 9'E), Paikamal in the Western Orissa (20° 68'N, 82° 46'E), brick structures of excavated sites at Lalitgiri and Udaigiri, Orissa state (20° 52'N, 86° 15'E), temples at Mahabalipuram, Kancheepuram, Chidambaram, Tanzavur, Tiruchirapalli and Madurai of Tamil Nadu state (9° 94' to 12° 94', 78° 98' to 80° 15'E), Helebid, Belur, Suavanabelagola, Badami, Aihole and Pattadakal of Karnataka state (12° 64' to 15° 93'N, 73° 73' to 76° 18'E), Delhi (28° 65'N, 77° 11'E), fresco-paintings of Ajanta caves, rock substratum at inside and outside the caves of Elephanta, Lonavala and Ajanta, Maharashtra (18° 56'N to 20° 15'N and 72° 51'E to 76° 05'E) excavated sites of Sarnath, Uttar Pradesh (25° 20'N, 83° 08'E) and terracotta structures at Bishnupur temple, West Bengal (20° 10'N, 86° 45'E) were chosen as the study sites.

MATERIALS AND METHODS

Blackish-brown crusts/mats occurring on these monuments of archaeological importance were collected by scraping the exposed surfaces using sterile needles and stored in screw cap bottles. Morphological features of the organisms in the crusts/mats were not distinct. Hence, these were cultured and unialgal culture of each organism was used for identification. For culturing the material, a pinch of each crust/mat was transferred to BG11 (\pm N) agarized (1% w/v agar-agar) medium (Rippaka & *al.* 1979) and incubated at $25 \pm 1^\circ\text{C}$ under continuous light from fluorescent tubes at an intensity of 7.5 W/m^2 up to 60 days. The organisms appeared in the culture were identified following Desikachary (1959), Rippaka (1979), Komárek and Anagnostidis (1989) and Anagnostidis and Komárek (1990). The unialgal culture of each of the species was given a specific isolate number (UU - Utkal University) and maintained on agar slants in test-tubes in the culture collection at the Department of Botany, Utkal University.

SYSTEMATIC ACCOUNT

Totally forty-six species of blue-green algae appeared in the culture belonging to the genera *Gloeocapsopsis*, *Gloeotheca*, *Myxosarcina*, *Chroococcidiopsis*, *Lyngbya*, *Phormidium*, *Plectonema*, *Nostoc*, *Calothrix*, *Tolypothrix*, *Chlorogloeopsis*,

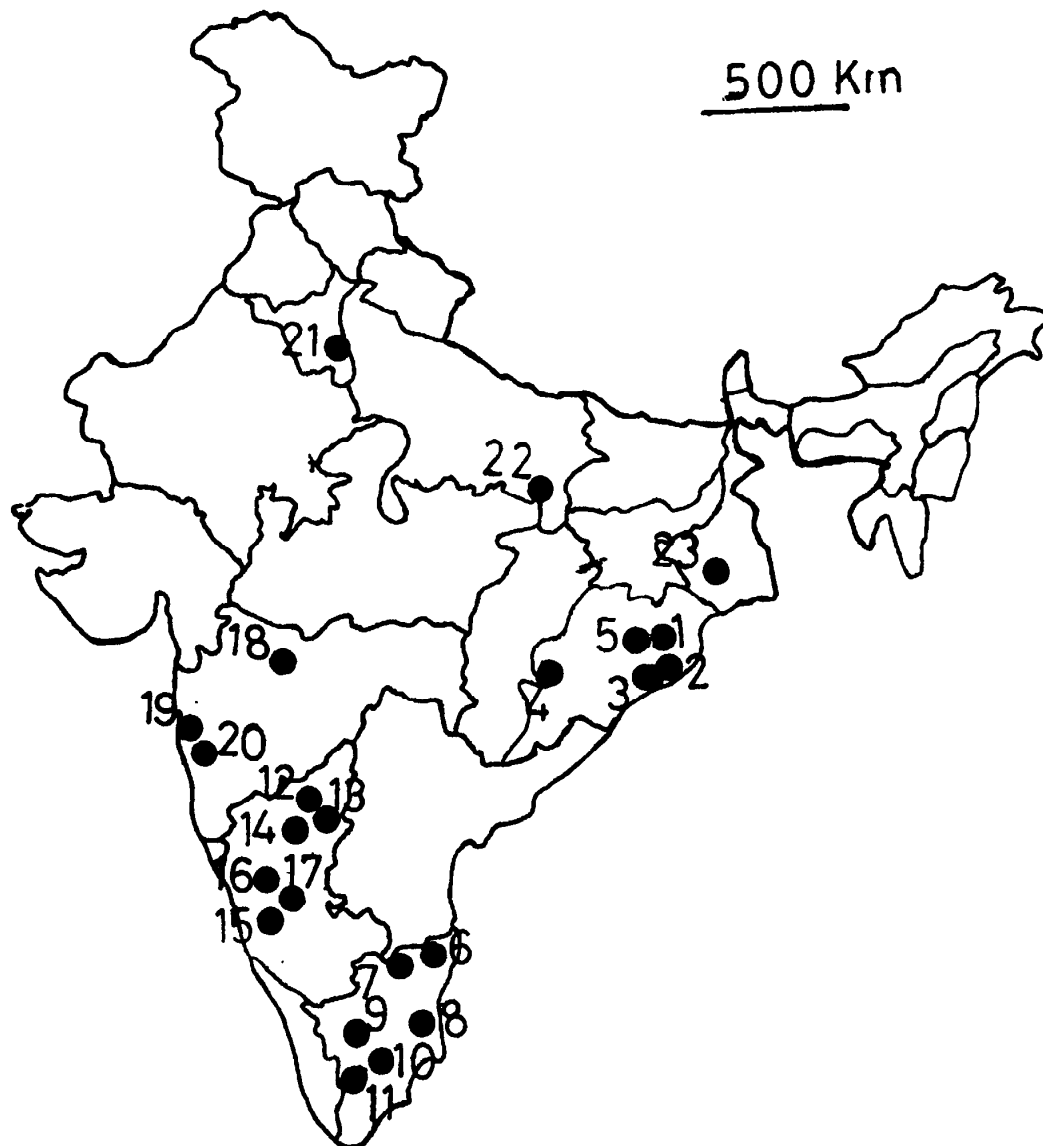


Fig.1 : Map showing the location of study sites in different regions of India.

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|---------------------------------------|---|
| 1. Temples of Bhubaneswar, | 13. Ancient temples of Pattadakal, |
| 2. Sun temple, Konark, | 14. Monuments of Aihole, |
| 3. Jagannath temple, Puri, | 15. Gomateswar temple, Sravanbelagola, |
| 4. Nrushinghanath temple, Paikamal, | 16. Temples of Belur, |
| 5. Excavated sites of Lalitgiri, | 17. Ancient monuments of Helebid, |
| 6. Rock cut temples of Mahabalipuram, | 18. Ajanta caves, |
| 7. Temples of Kancheepuram, | 19. Elephanta caves, |
| 8. Nataraj temple, Chidambaram, | 20. Karla caves, Lonavla, |
| 9. Temples of Tiruchirapalli, | 21. Kutub Minar, Delhi, |
| 10. Brihadeswar temple, Tanzavur, | 22. Excavated sites of Saranath, |
| 11. Meenakshi temple, Madurai, | 23. Terracota surfaces of the temples of Bishnupur. |
| 12. Caves of Badami, | |

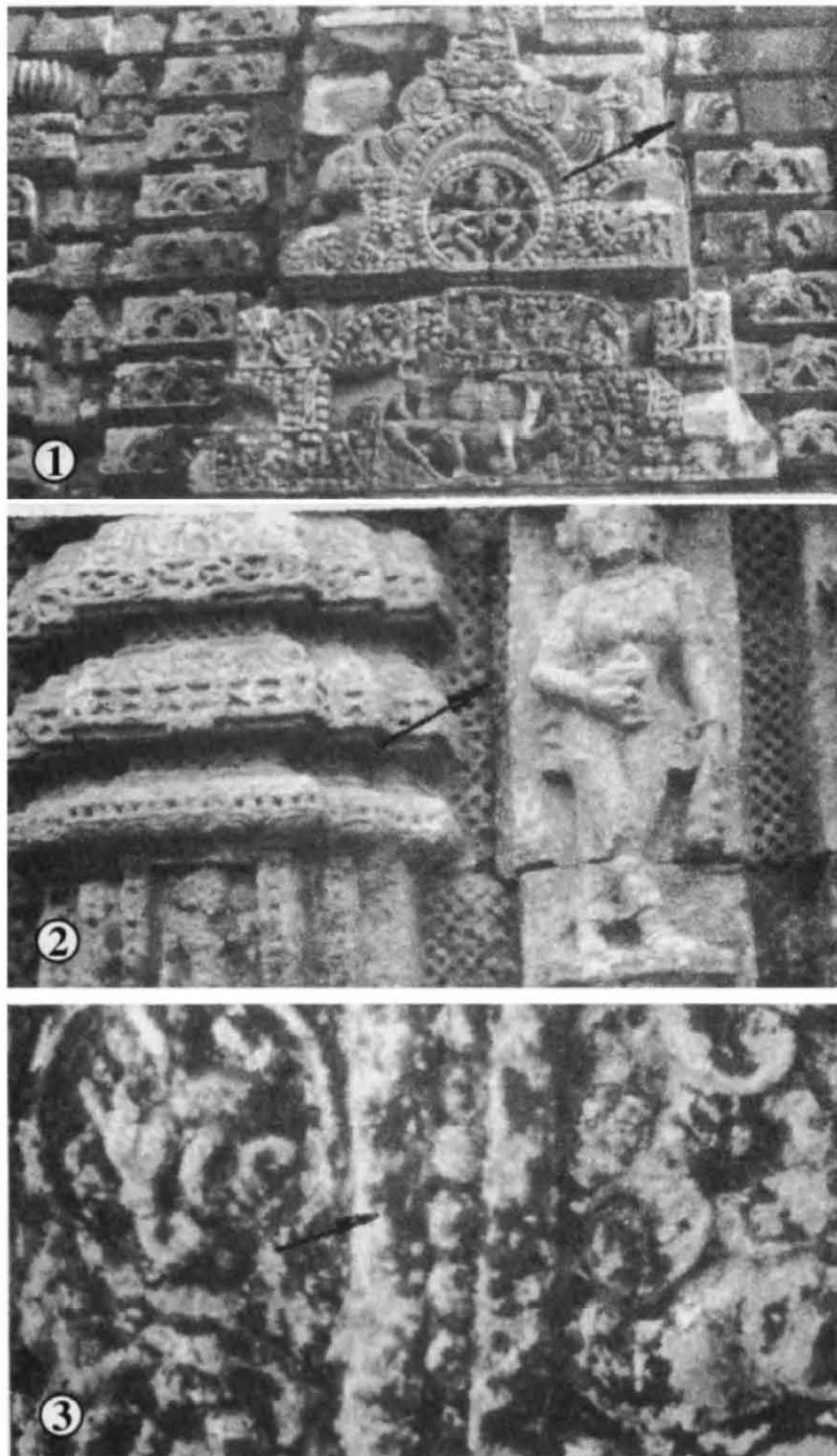


Plate - I. (a-c) : a. Cyanobacterial crust on the exposed surfaces of a temple of Bhubaneswar;
b. Close view of the rock joints on the walls showing occurrence of microbial crusts;
c. Cyanobacterial crust on the architectural stone carvings of temples.

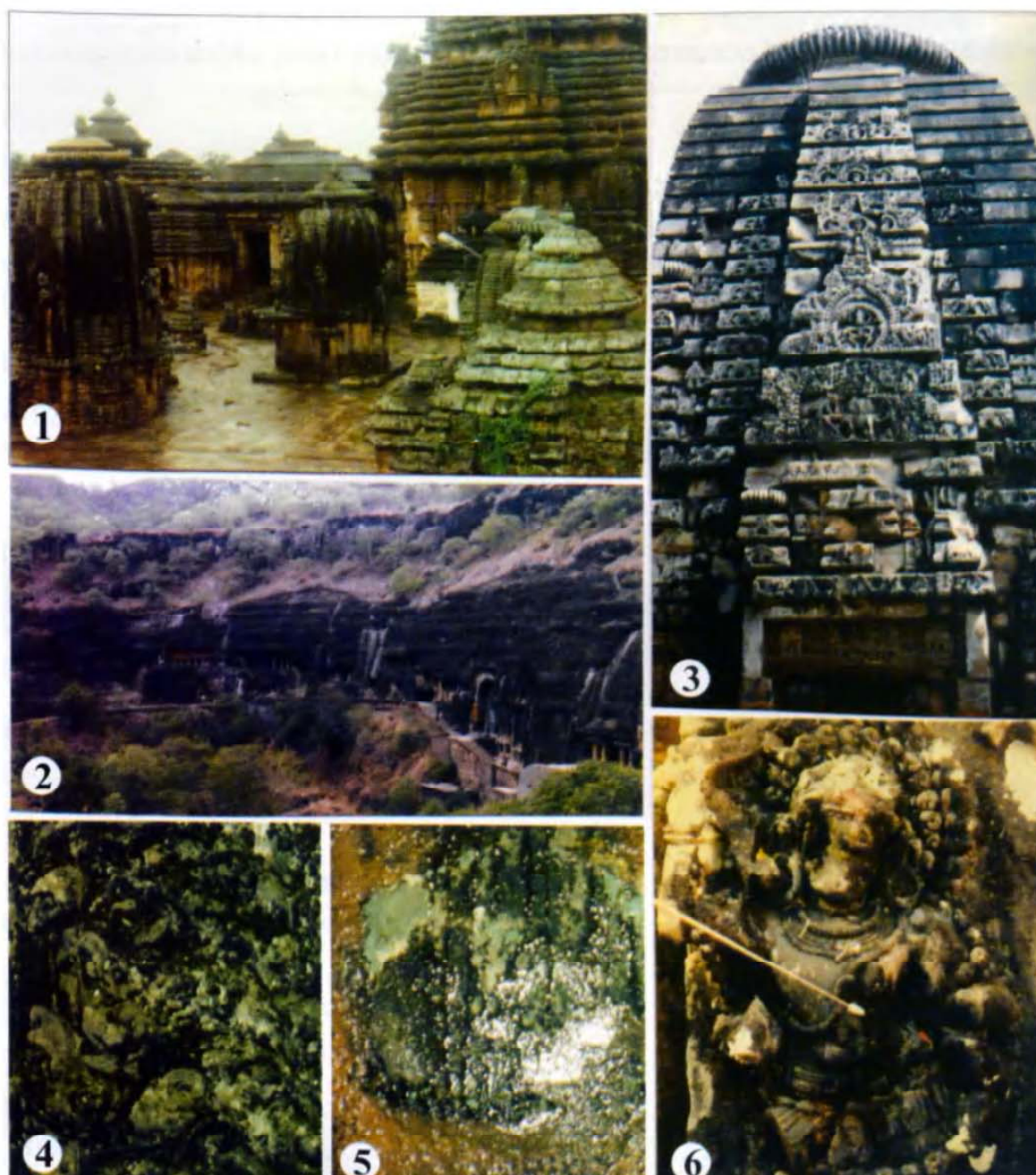


Plate II. [1-6] :

- [1] Lingaraj temple complex, Bhubaneswar showing growth of Cyanobacteria on the exposed surfaces;
- [2] Blackish Cyanobacteria crust on the exposed surfaces of the walls of Ajanta caves;
- [3] Blackish Cyanobacteria crust on the exposed surfaces of Satrughaneswar temple complex, Bhubaneswar;
- [4] Cyanobacteria crust tightly adhering to the fine carvings of the temple walls at Sun temple, Konark;
- [5] Cyanobacteria crust showing bluish green appearance on the rock surfaces of Sun temple, Konark soon after receiving monsoon rain;
- [6] Cyanobacteria crust on a rock monument at Kedar-Gouri temple, Bhubaneswar.

Fischerella, *Hapalosiphon*, *Westiellopsis* and *Stigonema*. List of all these species along with their location of occurrence and the substratum from which they were collected is given in Table 1.

Table 1: List of blue-green algal species occurring on the exposed surfaces of different monuments of archaeological importance from various regions of India. The place(s) of collection and the substratum on which they occur are also given.

Sl. No.	Organism and isolate number	Substratum	Place(s) of collection
GLOEOCAPSOPSIS Geitler			
1.	<i>Gloeocapsopsis dvorakii</i> UU 58153	Rock surface	Bhaskareswar temple, Raja Rani temple, Brahmaswar temple, Bhubaneswar; Madhav temple, Niali; Bhutanath cave temple, Badami; Meenakshi temple, Madurai.
GLOEOTHECE Nágeli			
2.	<i>Gloeotheca rupestris</i> UU57152	Rock surface	Meenakshi temple, Madurai; Bhutanath cave temple, Badami.
3.	<i>Gloeotheca rhodochlamys</i> UU 523215	Brick structure	Excavated sites of Udaigiri, Orissa.
MYXOSARICINA Printz			
4.	<i>Myxosaricina spectabilis</i> UU 514154 UU 522214	Rock surface, terracotta surface	Megheswar and Raja Rani temples, Bhubaneswar; Virupaksha temple, Pattadakal and Ladkhan temple, Aihole; Bishnupur temple, West Bengal.
CHROOCOCCIDIOPSIS Geitler			
5.	<i>Chroococcidiopsis indica</i>	Rock surface	Kedar Gouri and Rameswar

Sl. No.	Organism and isolate number	Substratum	Place(s) of collection
	UU 512155 UU 57162		temple, Bhubaneswar; Madhav temple, Niali; Rock Fort temple, Tiruchirapalli and Arjun's Pennance, Mahabalipuram; Bhutanath cave temple, Badami.
6.	LYNGBYA Agardh <i>Lyngbya corticola</i> UU 53161	Rock surface	Jagannath temple, Puri; Parasurameswar temple, Bhubaneswar; Channekeshwara temple, Belur; Gomateshwar temple, Sravanabelagola; Nataraj temple, Chidambaram and Arjun's pennance, Mahabalipuram.
7.	PHORMIDIUM Kützing <i>Phormidium truncicola</i> UU 511160	Rock surface	Lingaraj and Brahmeswar temple, Bhubaneswar; Meenakshi temple, Madurai; Rock Fort and Sri Rangaswamy temple, Tiruchirapalli; Virupaksha temple, Pattadakal and Bhutanath cave temple, Badami.
8.	PLECTONEMA Thuret <i>Plectonema gracillimum</i> UU 57162	Rock surface	Khandagiri and Udaigiri cave temple, Bhubaneswar; Meenakshi temple, Madurai and Rath temple, Mahabalipuram.
9.	<i>Plectonema hansgirgi</i> UU 56164	Rock surface	Sun temple, Konark; Virupaksha temple, Pattadakal; Nataraj temple, Chidambaram and Kailashnath temple, Kancheepuram.

Sl. No.	Organism and isolate number	Substratum	Place(s) of collection
10.	<i>Plectonema puteale</i> UU 58163	Rock surface	Khandagiri and Udaigiri cave temples, Bhubaneswar; Qutub Minar, Delhi; Bribadeswara temple, Tanjavur and Rath temple, Mahabalipuram.
	NOSTOC Voucher		
11.	<i>Nostoc carneum</i> UU 55158	Rock surface	Channekeshwar temple, Belur.
12.	<i>Nostoc ellipsosporum</i> UU 62188	Rock surface	Lingaraj temple, Bhubaneswar; Sun temple, Konark.
13.	<i>Nostoc muscorum</i> UU 516193	Rock surface	Bhaskareswar temple, Bhubaneswar.
14.	<i>Nostoc paludosum</i> UU 57157	Rock surface	Brihadeswar temple, Tanjavur; Meenakshi temple, Madurai; Natraj temple, Chidambaram; Arjuna's Penance, Mahabalipuram.
15.	<i>Nostoc punctiforme</i> UU 513183 UU 592210	Rock surface, on the rock inside the cave	Bhaskareswar, Raja Rani and Kedar Gouri temple, Bhubaneswar; Lonavala caves, Maharashtra.
16.	<i>Nostoc spongiaeforme</i> UU 52182	Rock surface	Sun temple, Konark.
17.	<i>Nostoc commune</i> UU 591200, UU 591216 UU 521217, UU 523218 UU 593219, UU 522220	Fresco paintings, exposed rocks outside the cave, brick structure at excavated sites, on the rock inside the cave, on terracotta surface	Ajanta caves, Maharashtra; excavated sites of Sarnath, Uttar Pradesh and Lalitgiri, Orissa Elephanta caves, Maharashtra; Bishnupur temples, West Bengal.

Sl. No.	Organism and isolate number	Substratum	Place(s) of collection
18.	<i>Nostoc microscopicum</i> UU 591207	Exposed rocks outside the caves	Ajanta caves, Maharashtra.
19.	<i>Nostoc piscinale</i> UU 592211	On the rock inside the cave	Lonavala caves, Maharashtra.
20.	CALOTHRIX Agardh <i>Calothrix brevissima</i> UU 55168	Rock surface	Holysaleswar temple, Helebid.
21.	<i>Calothrix ghosei</i> UU 512169	Rock surface	Parasurameswar temple, Bhubaneswar.
22.	<i>Calothrix marchica</i> UU 519167	Rock surface	Khandagiri cave temple, Bhubaneswar; Hoysaleswar temple, Helebid; Bhutanath cave temples, Badami.
23.	<i>Calothrix scytonemicola</i> UU 512166	Rock surface	Mukteswar and Megheswar temple, Bhubaneswar.
24.	<i>Calothrix gardneri</i> UU 591208	Exposed rock surface outside the cave	Ajanta caves, Maharashtra.
25.	TOLYPOTHRIX Kützing <i>Tolypothrix byssoidea</i> UU 53170	Rock surface	Sun temple, Konark; Jagannath temple, Puri; Lingaraj, Bramheswar, Megheswar, Bhaskareswar, Rameswar and Khandagiri cave temples, Bhubaneswar; Madhav temple, Niali.
26.	<i>Tolypothrix compylonemoides</i> UU 53171	Rock surface	Udaigiri cave temple, Bhubaneswar; Jagannath temple, Puri.

Sl. No.	Organism and isolate number	Substratum	Place(s) of collection
27.	<i>Tolypothrix crassa</i> UU 511174	Rock surface	Lingaraj temple, Bhubaneswar; Kailasnath temple, Kancheepuram; Brihadeswar temple, Tanjavur; Nrusinghanath temple, Paikamal.
28.	<i>Tolypothrix distorta</i> UU 512176	Rock surface	Kedar Gouri temple, Bhubaneswar, Jogin temple, Hirapur.
29.	<i>Tolypothrix nodosa</i> UU 55175	Rock surface	Hoysaleswara temple, Helebid; Channekeshwara temple, Belur.
30.	<i>Tolypothrix rechingeri</i> UU 513172	Rock surface	Raja Rani and Vaital temple, Bhubaneswar; Ladkhan temple, Aihole; Virupaksha temple, Pattadakal.
31.	<i>Tolypothrix scytonemoides</i> UU 512173	Rock surface	Mukteswara and Kedar Gouri temple, Bhubaneswar.
32.	<i>Tolypothrix fragilis</i> UU 521201	Brick surface	Excavated site of Saranath, Uttar Pradesh.
33.	<i>Tolypothrix conglutinata</i> UU 522202	Terracotta surface	Bishnupur temples, West Bengal.
34.	<i>Tolypothrix arenophila</i> UU 523203	Brick surface	Excavated sites of Lalitgiri, Orissa.
35.	<i>Tolypothrix tenuis</i> UU 54205	Exposed rock surface	Simhachalam temple and excavated site of Udaigiri, Orissa.
36.	<i>Tolypothrix bouteillei</i> UU 591206	Fresco-paintings	Ajanta caves, Maharashtra.

Sl. No.	Organism and isolate number	Substratum	Place(s) of collection
37.	<i>Tolypothrix magna</i> UU 592209	Rock surface inside the cave	Lonavala caves, Maharashtra.
	CHLOROGLOEOPSIS Mitra and Panday		
38.	<i>Chlorogloeopsis fritschii</i> UU 57178	Rock surface	Brihadeswar temple, Tanjavur.
	FISCHERELLA Gomont		
39.	<i>Fischerella muscicola</i> UU 512180	Rock surface	Parasurameswar temple, Bhubaneswar.
40.	<i>Fischerella tenuis</i> UU 523204	Brick surface	Excavated sites of Lalitgiri, Orissa.
	HAPALOSIPHON Nägeli		
41.	<i>Hapalosiphon flagelliformis</i> UU 57179	Rock surface	Rath temple, Mahabalipuram; Rock fort temple, Tiruchirapalli.
42.	<i>Hapalosiphon stuhlmannii</i> UU 512177	Rock surface	Kedar Gouri temple, Bhubaneswar.
	WESTIELLOPSIS Janet		
43.	<i>Westiellopsis prolifica</i> UU 592212	Rock surface inside the cave	Lonavala caves, Maharashtra.
	STIGONEMA Agardh		
44.	<i>Stigonema hormoides</i> UU 593213	Rock surface inside the cave	Elephanta caves, Maharashtra.

The organisms were isolated after culturing the crusts/mats in BG 11 \pm medium at 25 \pm 1°C under 7.5 W/m² light intensity.

Isolate number was assigned after isolation and culture of each organism in unialgal state.

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DISCUSSION

Blue-green algal forms were the major components in the crusts/mats occurring on the exposed surfaces of several archaeological monuments of India. The other algal members never occur as crust on the rock or brick surfaces exposed to direct sunlight. Further, the blue-green algal forms which colonise the monuments invariably possess thick sheath layers around their trichomes or were encysted by copious mucilage layers which provide protection to these organisms from intense solar radiation and desiccation stress (Roy & *al.* 1997).

Presence of blue-green algae is considered as biodeteriogenic on rock surfaces of different monuments and on works of art (Singh 1993). Considerable corrosion have also been observed under epilithic microbial vegetation at several regions of the globe (Krumbein and Jens 1981, Marathe and Choudhuri 1975). In the present study corrosion of rocks under epilithic crusts/mats on the fine architectural carvings of the monuments of archaeological importance in various parts of India was also observed which can be attributed to these algal forms. Blue-green algae remain attached very tightly to the material surfaces especially at uneven or precorroded sites. The means of attachment was the extracellular polymeric substances released by these organisms (Adhikary 1998). These exopolymers fill up the pores of the stones and keep water fixed making it available to the organisms during the dry periods. Moisture contributes to the weakening of stones texture together with thermal stress like the freezing and thawing process. In addition, such organisms have also been found excreting organic acids, which degrade the carbonaceous binding material of the stone (Diercks & *al.* 1991). All these phenomenon possibly occur on the exposed rock surface of the monuments under epilithic blue-green algal vegetation leading to their weathering.

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