

Diversity of Micro-algae and Cyanobacteria on Building Facades and Monuments in India

Lakshmi Kumari Samad and Siba Prasad Adhikary*

P.G. Department of Botany and Biotechnology, Utkal University, Bhubaneswar – 751004, India

Fifty seven taxa of Cyanobacteria and 15 taxa of Chlorophyta were recorded from the exterior of buildings and rock surfaces of monuments in different regions in India. Four cyanobacteria, e.g. *Chroococcidiopsis kashayi*, *Pseudophormidium indicum*, *Plectonema puteale* and *Scytonema geitleri*, and the green alga *Trentepohlia abietina* var. *tenuis* occur on the sub-aerial habitats throughout the year. In addition, five other green algae: *Chlorococcum infusionum*, *Scenedesmus arcuatus*, *Trentepohlia aurea*, *Gloeocystis polydermatica* and *Printzina effusa*, and 18 other cyanobacteria taxa of the genera *Chroococcus* (5), *Asterocapsa* (1), *Cyanosarcina* (2), *Gloeocapsa* (7), *Gloeotheca* (2) and *Scytonema* (1) occur on the sub-aerial surfaces enduring extreme temperature and desiccation during summer months of the tropics. During the rainy season, the warm and humid climatic regime coupled with availability of moisture supported an additional ten green algae and 29 cyanobacteria in eight and 17 genera, respectively. The green algal genera *Klebsormidium*, *Stichococcus* and *Trebouxia*, which are dominant in temperate regions, did not occur on the sub-aerial habitats in India, however, species of *Gloeocapsa*, *Chroococcus*, *Chroococcidiopsis*, *Phormidium*, *Leptolyngbya*, *Nostoc*, *Scytonema*, *Chlorella* and *Trentepohlia* showed global occurrence in similar habitats.

Key Words: building facades, cyanobacteria, distribution, micro-algae, monuments

INTRODUCTION

Terrestrial algae have been reported – as biofilms on the exposed surfaces of solid substrata in almost all climatic zones (Tripathi *et al.* 1991; Ortega-Calvo *et al.* 1993; Gaylarde and Gaylarde 2000; Darienko and Hoffmann 2003; Noguerol-Seoane and Rifón-Lastra 2003; Rindi and Guiry 2004; Crispim *et al.* 2004, 2006; Rindi *et al.* 2005; Ortega-Morales *et al.* 2005; Uher *et al.* 2005; Peraza Zurita *et al.* 2005; Barberousse *et al.* 2006; Gaylarde *et al.* 2006; Rindi and López-Bautista 2007). These organisms grow as epiphytes on tree bark, as epiliths on rocks and stones, and also on anthropogenic surfaces such as facades, concrete floors of roofs and other artificial surfaces of buildings where they cause aesthetically unacceptable discoloration of the structures (Tomaselli *et al.* 2000; Videla *et al.* 2000; Crispim *et al.* 2006; Barberousse *et al.* 2007). Such growths are common in humid places on uneven surfaces such as holes, crevices and also on damp building walls due to leaking, roof guttering, inadequate drainage of flat areas or from adjacent water courses. The

growth is rarely uniform, frequently forming streaks that follow areas of dampness. In general, in temperate regions such as Northern Europe and Korea, eukaryotic green micro-algae (Chlorophyta) are the frequently occurring terrestrial forms (Videla *et al.* 2000; Darienko and Hoffmann 2003; Rindi and Guiry 2004; Klochkova and Kim 2005; Barberousse *et al.* 2006), whereas cyanobacteria dominate the sub-aerial surfaces in warm temperate to tropical regions (Videla *et al.* 2000; Crispim *et al.* 2003, 2004; Ortega-Morales *et al.* 2005). Colonization by communities of terrestrial cyanobacteria, green algae and other microorganisms are reported to accelerate weathering of their substrata (Kováčik 2000; Peraza Zurita *et al.* 2005). Though the immediate consequence of such algal growth is disfigurement, the microbial bio-coenoses, including fungi and bacteria, develop on the surfaces by utilizing organic molecules formed by primary production. Such communities act as biodeteriogens of concrete, mortar and stones by producing organic and inorganic acids (Gaylarde and Morton 1999; Brehm *et al.* 2005). Though such problems are important in humid and tropical climates there has been little information on algal diversity and cyanobacteria colonizing building facades and archaeologically important monuments in

*Corresponding author (adhikary2k@hotmail.com)

Table 1. List of the sampling sites, voucher number and the nature of habitat

Site	Voucher no.	Place of collection	Nature of the habitat
1.	1260	Utkal University Campus, Bhubaneswar, Orissa	Lime surfaces wall
2.	1261	Utkal University Campus, Bhubaneswar, Orissa	Cement surfaces
3.	1262	Hatigumpha cave, Khandagiri, Bhubaneswar, Orissa	Rock surfaces
4.	1263	Sarat, Mayurbhanj, Orissa	Cement surfaces
5.	1264	Sarat, Mayurbhanj, Orissa	Brick surfaces
6.	1265	Khandagiri cave, Bhubaneswar, Orissa	Rock surfaces
7.	1267	Shivsagar temple, Assam	Cement wall
8.	1268	Jorhat, Assam	Cement surfaces
9.	1269	Jorhat, Assam	Cement wall
10.	1273	Parasurameswar temple, Bhubaneswar, Orissa	Rock wall
11.	1274	Mukteswar temple, Bhubaneswar, Orissa	Crust on wall
12.	1278	Khandagiri cave, Bhubaneswar, Orissa	Rock surfaces
13.	1279	Utkal University Campus, Bhubaneswar, Orissa	Paint wall surfaces
14.	1280	Utkal University Campus, Bhubaneswar, Orissa	Yellowish paint wall surfaces
15.	1283	Utkal University Campus, Bhubaneswar, Orissa	Cement surfaces
16.	1285	Temple, Koraput, Orissa	Rock surfaces
17.	1287	Parasurameswar temple, Bhubaneswar, Orissa	Wetted rocky wall
18.	1288	Bhaskareswar temple, Bhubaneswar, Orissa	Rock surfaces
19.	1289	Bhaskareswar temple, Bhubaneswar, Orissa	Crust on wall surfaces
20.	1290	Bhaskareswar temple, Bhubaneswar, Orissa	Limestone
21.	1292	Khandagiri cave, Bhubaneswar, Orissa	Rock surfaces
22.	1294	Khandagiri cave, Bhubaneswar, Orissa	Rock surfaces
23.	1296	Talopadeswar temple, Vanivihar, Bhubaneswar, Orissa	Cement wall
24.	1297	Gandhi park, Jaydev vihar, Bhubaneswar, Orissa	Cement wall
25.	1298	Utkal University Campus, Bhubaneswar, Orissa	Lime washed cement surfaces
26.	1299	Utkal University Campus, Bhubaneswar, Orissa	Wall surfaces
27.	1302	Saheed Nagar, Bhubaneswar, Orissa	Lime washed wall
28.	1303	Utkal University Campus, Bhubaneswar, Orissa	Lime washed wall
29.	1304	Maniakati, Ganjam, Orissa	Roof surfaces
30.	1305	Athagarh, Ganjam, Orissa	Lime coating surfaces
31.	1306	Unit – III, Rajmahal square, Bhubaneswar, Orissa	Painted wall
32.	1307	Unit – III, Rajmahal square, Bhubaneswar, Orissa	Cement wall
33.	1308	Baramunda, Bhubaneswar, Orissa	Cement surfaces
34.	1309	Jaydev vihar, Bhubaneswar, Orissa	Lime washed wall
35.	1310	Rasulgarh, Bhubaneswar, Orissa	Lime washed wall
36.	1317	Jaydev vihar, Bhubaneswar, Orissa	Lime washed wall
37.	1318	Utkal University Campus, Bhubaneswar, Orissa	Roof floor
38.	1319	AG old colony, Jaydev vihar, Bhubaneswar, Orissa	Water leakage wall
39.	1323	Utkal University Campus, Bhubaneswar, Orissa	Wall surfaces
40.	1325	Utkal University Campus, Bhubaneswar, Orissa	Wall surfaces
41.	1326	Baripada, Mayurbhanj, Orissa	Cement tile surfaces
42.	1248	Maplong Dam, Shillong, Meghalaya	Rock surface
43.	1249	Quarry, Shillong, Meghalaya	Limestone
44.	1312	Fort, Nahargarh, Jaipur, Rajasthan	Building wall
45.	1313	Fort (bottom floor), Nahargarh Jaipur, Rajasthan	Building wall
46.	1314	Fort, Nahargarh, Jaipur, Rajasthan	Mortar paste
47.	1315	Puskar, Rajasthan	Wall surface

India (Tripathi 1984; Tripathy *et al.* 1999; Pattanaik and Adhikary 2002). Here we report the cyanobacteria and micro-algal forms occurring on the exposed surfaces on rocky walls and buildings from various regions of India during the hot summer and after the monsoon rains.

MATERIALS AND METHODS

One hundred and eight crust samples were collected from 47 sub-aerial sites including new and old building

facades and monuments. Substrata included limestone, sandstone, cement, concrete, brick, rock and lime washed building surfaces during monsoon, post monsoon and summer seasons. Sampling was carried out by gentle scraping with a sterile blade and needle, and the resulting material was stored in screw-cap specimen bottles. Each specimen was given a voucher number and stored in desiccated state at Utkal University, Bhubaneswar (Table 1). The crusts were soaked with sterile distilled water for 12-24 h, and examined for the presence of algae. A pinch of crust material was transferred to BG – II medium with or without combined nitrogen (Rippka *et al.* 1979) and to agar plates (1.1% w/v agar in the same medium) and incubated at $28 \pm 1^\circ\text{C}$ under continuous light for up to 15 days. Photomicrographs of the organisms appearing in the cultures were taken using a Meiji trinocular research microscope fitted with a Nikon Coolpix 4500 digital camera. The organisms were identified based on the following monographs: West and West (1905), Tilden (1910), Thompson (1959), Desikachary (1959), Philipose (1967), Hindák (1977), Komárek and Fott (1983), Krishnamurthy (1998), Ortega-Calvo *et al.* (1993), Branco and Júnior (1996), Aboal *et al.* (2003), Mishra and Srivastava (2003), Uher *et al.* (2005), Rindi *et al.* (2005), Barberousse *et al.* (2006) and Gaylarde *et al.* (2004, 2006).

RESULTS

A total of 57 taxa of Cyanobacteria belonging to 23 genera and 15 taxa of Chlorophyta representing ten genera were recorded from the exteriors of buildings, tree trunks and exposed rock surfaces of monuments in different regions of India. A description of each of these organisms is presented. Voucher number, date of collection, place of collection and nature of the habitat of their occurrence is also given.

Chlorophyta

Class: Chlorophyceae

Order: Chlorococcales

Family: Chlorococcaceae

Genus: *Chlorococcum* Meneghini

1. *Chlorococcum infusionum* (Schrank) Meneghini (Pl. 1, Fig. 1)

[Synonym: *Chlorococcum humicola* (Nägeli) Rabenhorst 1868]

(Basionym: *Cystococcus humicola* Nägeli)

Komárek and Fott, 1983, p. 36, fig. 3; Philipose, 1967, p.

72, pl. 74, fig. 3b.

Cells spherical, light green in color, solitary or a number of cells crowded together to form a stratum; chloroplast with a hallow sphere with a lateral notch; cells 7-20 μm diameter.

Occurred as greenish crust on a cement wall, Jorhat, Assam; Voucher no. 1269; Date of collection: 24/02/2007.

Genus: *Coenochloris* Korshikov

2. *Coenochloris pyrenoidosa* Koršikov (Pl. 1, Fig. 5)

Hindák, 1977, p. 19, pl. 3

Cell spherical; one parietal and cup shaped chloroplast with one pyrenoid; cell 3.6-4.0 μm diameter.

Occurred as greenish crust on lime washed wall surfaces, Jaydev vihar, Bhubaneswar, Orissa; Voucher no. 1309; Date of collection: 14/08/2007.

Genus: *Bracteacoccus* Tereg

3. *Bracteacoccus minor* (Chodat) Petrová (Pl. 1, Figs 2-3)

[Synonym: *Botrydiopsis minor* Chodat 1913]

(Basionym: *Botrydiopsis minor* Chodat)

Komárek and Fott, 1983, p. 136, pl. 37, figs 2a-d; Barberousse *et al.* 2006, p. 88 fig. 1. 48.

Cells spherical, single or in group; globose; polygonal parietal chloroplasts many, without pyrenoid; 6.8-23.0 μm diameter.

Occurred as greenish crust on lime washed wall surfaces, Jaydev vihar, Bhubaneswar, Orissa; Voucher no. 1317; Date of collection: 14/08/2007.

Reported from limestone, ceramics and brick surface of cultural monument, Ukraine (Darienko and Hoffmann, 2003); bed rock surface, Great Smoky Mountain, USA (Gomez *et al.*, 2003).

Genus: *Radiococcus* Schmidle

4. *Radiococcus nimbatu*s (De Wildmann) Schmidle (Pl. 1, Fig. 4)

[Synonym: *Pleurococcus nimbatu*s De Wildman]

(Basionym: *Pleurococcus nimbatu*s De Wildman)

Komárek and Fott, 1983, p. 399, pl. 120, fig. 3; Thompson, 1959, P. 137, fig. 6. 155.

Colonies 4 celled, 14-20 μm diameter; chloroplast single, parietal without pyrenoid; cells more or less pyramidal and angular remaining in a group; cell 5-12 μm diameter.

Occurred as greenish crust on lime washed wall surfaces, Jaydev vihar, Bhubaneswar, Orissa; Voucher no. 1317; Date of collection: 14/08/2007.

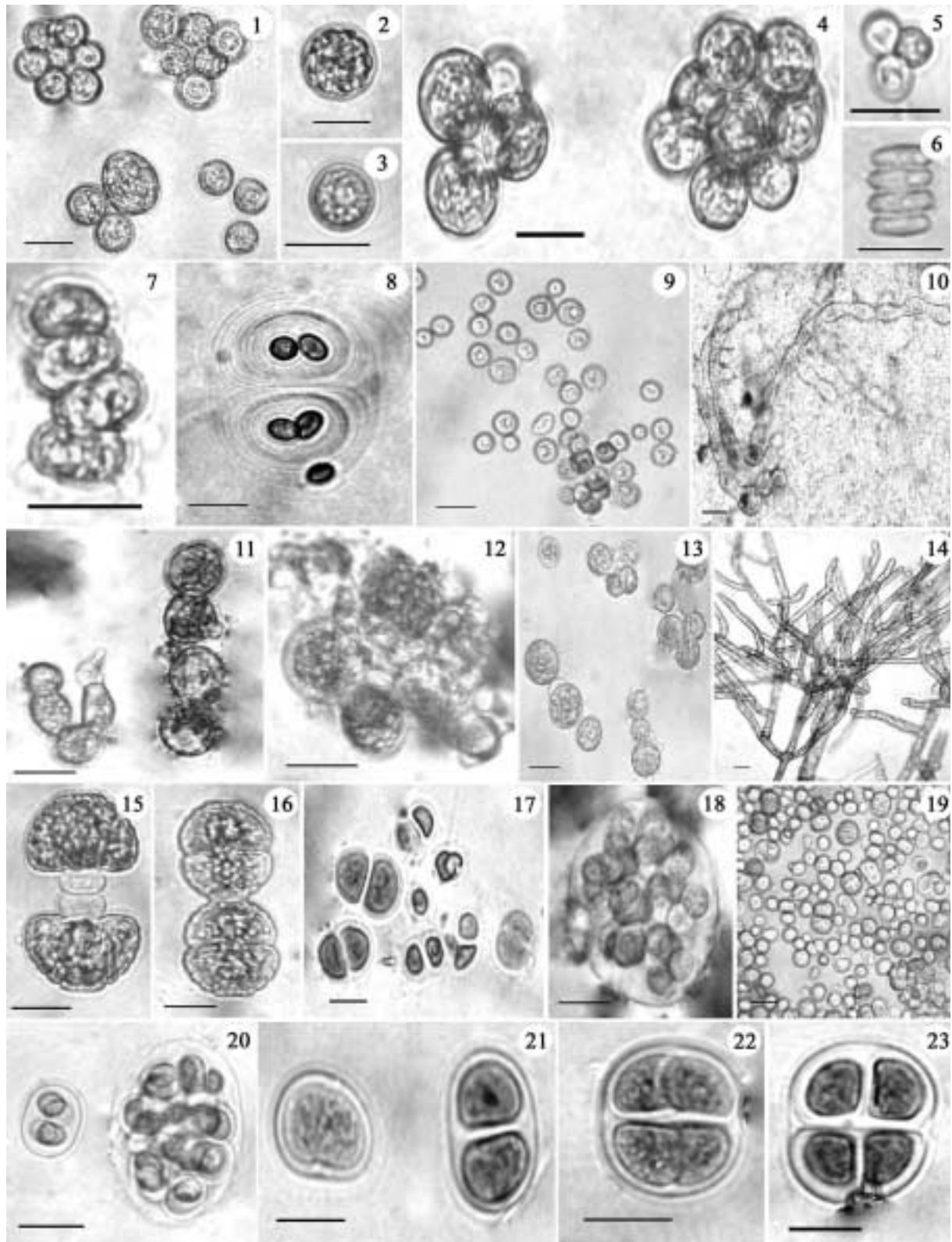


Plate 1. Fig. 1. *Chlorococcum infusionum*, Figs 2-3. *Bracteacoccus minor*, Fig. 4. *Radiococcus nimbatu*s, Fig. 5. *Coenochloris pyrenoidosa*, Fig. 6. *Scenedesmus bijugatus* var. *bicellularis*, Fig. 7. *Scenedesmus arcuatus*, Fig. 8. *Gloeocystis polydermatica*, Fig. 9. *Chlorella vulgaris*, Fig. 10. *Trentepohlia aurea*, Fig. 11. *Trentepohlia abietina* var. *tenu*e, Fig. 12. *Trentepohlia rigidula*, Fig. 13. *Trentepohlia umbrina*, Fig. 14. *Printzina effusa*, Fig. 15. *Cosmarium misellum*, Fig. 16. *Cosmarium nitidulum*, Fig. 17. *Chroococcus indicus*, Fig. 18. *Chroococcus limneticus*, Fig. 19. *Cyanosarcina burmensis*, Fig. 20. *Chroococcus lithophilus*, Figs 21-23. *Chroococcus minor* (Fig. 21. Showing colony forms of initial stages, Figs 22-23. Cell division and colony formation). Scale bar: Figs 1-23 = 10 μ m.

Family: Scenedesmaceae

Genus: *Scenedesmus* Meyen

5. *Scenedesmus arcuatus* (Lemmermann) (Pl. 1, Fig.7)

[Synonym: *Scenedesmus bijugus* var. *arcuatus* Lemmermann; *Scenedesmus bijugatus* f. *arcuatus* Lemmermann]

Philipose, 1967, p. 256, pl. 258, fig. 166 (b).

Colonies 4 or 16 celled, curved, cell oblong or ovoid, cells wall smooth, cells 5.0-7.5 μm broad, 9.9-12.0 μm long.

Occurred as greenish crust on cement walls, Jorhat, Assam; Voucher no. 1269; Date of collection: 24/02/2007.

6. *Scenedesmus bijugatus* Kützing var. *bicellularis* Chodat (Pl. 1, Fig. 6)

Philipose, 1967, P. 253, fig. 164, fig. 7d.

Colonies flat, 2-4-8 celled, arranged in a single linear series, cell oblong - ellipsoidal to ovoid with the ends broadly rounded, 2.6-3.5 μm broad, 6-11 μm long.

Occurred as greenish crust on cement walls, Gandhi park, Bhubaneswar, Orissa; Voucher no. 1297;

Date of collection: 19/08/2007.

Order: Tetrasporales

Family: Gloeocystaceae

Genus: *Gloeocystis* Nägeli

7. *Gloeocystis polydermatica* (Kützing) Hindák (Pl. 1, Fig. 8)

[Synonym: *Gleocapsa polydermatica* Kützing 1846]

Desikachary, 1959, p. 115, pl. 25, fig. 1.

Cells spherical, without sheath 3.0-4.0 μm diameter, blue green; sheath colorless, very thick, distinctly lamellated.

Occurred as blackish crust on rock surface of Khandagiri cave, Bhubaneswar, Orissa; Voucher no. 1294; Date of collection: 17/04/2007.

Reported from window shade, Varanasi, India (Tripathi, 1984).

Class: Trebouxiophyceae

Order: Chlorellales

Family: Chlorellaceae

Genus: *Chlorella* Beijerinck

8. *Chlorella vulgaris* Beijerinck (Pl. 1, Fig. 9)

[Synonym: *Chlorella pyrenoidosa* var. *duplex* (Kützing) West; *Pleurococcus beijerinckii* Artari 1892; *Chlorella communis* Artari 1906; *Chlorella vulgaris* var. *viridis* Chodat 1913; *Chlorella terricola* Gollerbach 1936; *Chlorella Candida* Shihira & Krauss 1965]

Komárek and Fott, 1983, p. 594, pl. 168, fig. 2;

Philipose, 1967, p. 173, pl. 174, fig. 82d.

Cells spherical; one parietal and cupshaped chloroplast with one pyrenoid; cells 7.5-10.0 μm diameter.

Occurred as greenish crust on cement wall, Jorhat, Assam; Voucher no. 1269; Date of collection: 24/02/2007.

Reported from ceramics and white washing surfaces of cultural monument, Ukraine (Darienko and Hoffmann, 2003); Urban wall, Europe (Rindi and Guiry, 2004); building stone, Salamanca and Toledo, Spain (Ortega-Calvo *et al.*, 1993).

Class: Ulvophyceae

Order: Trentepohliales

Family: Trentepohliaceae

Genus: *Trentepohlia* Martius

9. *Trentepohlia aurea* (Linnaeus) Martius (Pl. 1, Fig. 10)

[Synonym: *Byssus cryptarum* Linnaeus 1753; *Byssus aurea* Linnaeus 1759; *Chroolepus aureum* Kützing 1843; *Chroolepus oleiferum* Kützing 1843; *Chroolepus aureus* var. *tomentosus* Kützing 1845; *Chroolepus aureus* var. *pulvinatus* Kützing 1845; *Chroolepus aureus* var. *glomeratus* Kützing 1845; *Chroolepus aureus* var. *incrassatus* Kützing 1845; *Chroolepus aureus* var. *alpinus* Kützing 1845; *Chroolepus velutinum* Kützing 1845; *Trentepohlia capitellata* Ripart 1876; *Trentepohlia velutina* (Kützing) Hansgirg 1886; *Trentepohlia maxima* Karsten 1891; *Trentepohlia germanica* Glück 1896; *Trentepohlia gobii* Meyer 1936]

(Basionym: *Byssus aurea* Linnaeus)

Krishnamurthy, 1998, p. 186, pl. 152, fig. 29a.

Filament well branched, yellowish - green; cells cylindrical, slightly inflated, 8-10 μm broad and 20-22 μm long; several chloroplast, discoid; apical cell obtuse.

Occurred as greenish crust on cement walls, Shivsagar temple, Assam; Voucher no. 1267; Date of collection: 24/02/2007.

10. *Trentepohlia abietina* var. *tenuis* (Zeller) Cribb (Pl. 1, Fig. 11)

[Synonym: *Trentepohlia tenuis* (Zeller) de Toni 1889]

(Basionym: *Chroolepus tenuis* Zeller)

Krishnamurthy, 1998, p. 191, pl. 29, fig. 29f.

Cells elongate - ellipsoidal, sub - cylindrical, 6-8 μm broad and 8-14 μm long.

Occurred as pinkish paint surface of building wall, Department of Botany, Utkal University, Bhubaneswar, Orissa; Voucher no. 1279; Date of collection: 25/05/2007.

11. *Trentepohlia rigidula* (Müller) Hariot (Pl. 1, Fig. 12)

[Synonym: *Trentepohlia monilia* de Wildeman 1891]

Krishnamurthy, 1998, p. 189, fig. 29: I. J, pl. 1, fig. 4.

Thallus dark green; filament differentiated into prostrate and erect system; cells of erect system barrel shaped, less deeply constricted, 23-33 μm long. 15-20 μm broad.

Occurred as greenish crust on cement walls, Talapadeswar temple, Utkal University campus, Bhubaneswar, Orissa; Voucher no. 1296; Date of collection: 16/08/2007.

12. *Trentepohlia umbrina* (Kützing) Bornet in Wille (Pl. 1, Fig. 13)

[Synonym: *Trentepohlia odorata* var. *umbrina* (Kützing) Hariot; *Chroolepus umbrinum* Kützing 1843; *Phycopeltis umbrina* (Kützing) Thompson and Wujek 1997]

(Basionym: *Chroolepus umbrinum* Kützing)

Krishnamurthy, 1998, p. 190; Gaylarde *et al.* 2006, p. 120, fig. 2.

Filaments form a thin, crustaceous and fairly granular layer, reddish - brown; cell of prostrate system rounded or ellipsoid, separating from one another, 13-20 μm diameter with smooth wall; sporangia stalked, terminal, erect filaments.

Occurred as greenish crust on cement walls, Gandhi park, Bhubaneswar, Orissa; Voucher no. 1297; Date of collection: 19/08/2007.

Reported from limestone, Historic building, Mayan site of Edzna, Campeche, Mexico (Gaylarde *et al.* 2006); painted cement of cottage, Waipio valley, Hawaii Island (Rindi *et al.* 2005).

Genus: *Printzina* Thompson and Wujek

13. *Printzina effusa* (Krempelhuber) Thompson and Wujek (Pl. 1, Fig. 14)

[Synonym: *Coenogonium effusum* Krempelhuber 1876; *Trentepohlia effusa* (Krempelhuber) Hariot 1889; *Trentepohlia setifera* (Farlow) Hariot 1889]

(Basionym: *Coenogonium effusum* Krempelhuber)

Rindi *et al.*, 2005, p. 273-276, figs 13-22.

Filament prostrate or erect, abundantly branched, irregular; cell elliptical or cylindrical, 6-9 μm wide in upper parts, 9-12 μm in the lower parts, 2 to 3 times longer than wide.

Occurred as greenish crust on cement surface of building wall, Jorhat, Assam; Voucher no. 1268; Date of collection: 25/02/2007.

Reported from bark of a tree, Makiki valley, Oahu (Rindi *et al.* 2005).

Class: Zygnematophyceae

Order: Zygnematales

Family: Desmidiaceae

Genus: *Cosmarium* Ralfs

14. *Cosmarium misellum* Skuja (Pl. 1, Fig. 15)

Mishra and Srivastava, 2003, p. 87. pl. 2, figs 3 & 22.

Cell solitary, green; deeply constricted sinus, narrowly linear; semi cells broad at base, slightly less broad at apex, apex slightly compressed; cell wall smooth; showed enlarged cell in dividing stage; cells 140-155 μm broad and 268-280 μm long; isthmus constricted, 80 μm broad and 123 μm long.

Occurred as greenish crust on water leakage walls, AG old colony, Jeydev vihar, Bhubaneswar, Orissa; Voucher no. 1319; Date of collection: 19/10/2007.

15. *Cosmarium nitidulum* De Notaris (Pl. 1, Fig. 16)

West & West, 1905, p. 197, pl. 64, figs 1-3.

Cell solitary, longer than broad; sinus less deep and closed, linear; semicells semicircular; cell wall crenulate; apex round or slight straight; cells 28-29 μm broad and 32-33 μm long; isthmus 6-7 μm broad.

Occurred as greenish crust on water leakage walls, AG old colony, Jeydev vihar, Bhubaneswar; Orissa; Voucher no. 1319; Date of collection: 19/10/2007.

Cyanophyta (Cyanobacteria)

Class: Cyanophyceae

Order: Chroococcales

Family: Chroococcaceae

Genus: *Chroococcus* Nägeli

16. *Chroococcus indicus* Zeller (Pl. 1, Fig. 17)

Desikachary, 1959, p. 107, pl. 26, fig. 5.

Thallus gelatinous, thin, pale brownish; cells single, oblong to sub-spherical, 3.5-7.5 μm in diameter, sheath hyaline.

Occurred as blackish crust on cement wall surface, Sarat, Mayurbhanj, Orissa; Voucher no. 1263; Date of collection: 24/04/2007.

Reported from roof top, Varanasi, India (Tripathi, 1984).

17. *Chroococcus limneticus* Lemmermann (Pl. 1, Fig. 18)

[Synonym: *Chroococcus limneticus* var. *carneus* (Chodat) Lemmermann 1904; *Gloeocapsa limnetica* (Lemmermann) Hollerbach 1938; *Anacystis limnetica* (Lemmermann) Drouet and Daily 1952; *Anacystis thermalis* f. *major* (Lagerheim) Drouet and Daily 1956]

Desikachary, 1959, p. 107, pl. 26, fig. 2.

Cells spherical, surrounded by individual mucilagi-

nous envelope, embedded in colorless and spherical gelatinous slime; 4.5-5.5 μm diameter.

Occurred as blackish crust on cement wall surface, Sarat, Mayurbhanj, Orissa; Voucher no.1263; Date of collection: 26/04/2007.

Reported from building facades, France (Barberousse *et al.*, 2006).

18. *Chroococcus lithophilus* Ercegović (Pl. 1, Fig. 20)

Barberousse *et al.*, 2006, p. 94 fig. 26, 67.

Cells spherical, hemispherical after division, surrounded by a thin, colorless to yellowish brown sheath; 4-8 μm diameter.

Occurred as greenish crust on lime surface of building wall; Utkal University campus, Bhubaneswar, Orissa; Voucher no. 1260; Date of collection: 02/03/2007.

Reported from building wall of Nosa Señora da Esclavitude, Galicia, Spain (Noguerol-Seoane and Refón-Lastra, 2003); building façade, France (Barberousse *et al.*, 2006).

19. *Chroococcus minor* (Kützing) Nägeli (Pl. 1, Figs 21-23)

[Synonym: *Protococcus minor* Kützing 1845; *Pleurococcus minor* (Kützing) Rabenhorst 1863]

(Basionym: *Protococcus minor* Kützing)

Desikachary, 1959, p. 105, pl. 26, fig. 4, 15.

Thallus slimy, gelatinous, dirty blue-green, cells spherical or hemispherical, 3-4 μm diameter; singly or in pairs; sheath colorless, very thin, hardly visible.

Occurred as greenish crust on lime surface of building wall; Utkal University campus, Bhubaneswar, Orissa; Voucher no. 1260; Date of collection: 02/03/2007.

20. *Chroococcus pallidus* (Nägeli) Nägeli (Pl. 2, Fig. 24)

Desikachary, 1959, p. 109, pl. 26, fig. 5.

Colonies with 2-8 or 16 cells when overlap; cells spherical or ellipsoidal, 4.2-6.0 μm diameter; sheath thick; with sheath 5-10 μm broad and without sheath 5-7 μm broad.

Occurred as brownish crust on cement wall, unit - 3, Bhubaneswar, Orissa; Voucher no. 1307; Date of collection: 12/10/2007.

Reported from bedrock surface, Great Smoky Mountain, USA (Gomez *et al.*, 2003).

21. *Chroococcus schizodermaticus* West and West (Pl. 2, Figs 25-26)

Desikachary, 1959, p. 103, pl. 26, fig. 17.

Thallus globose or triangular, sometimes kidney -

shaped, associated in colonies of two or three; colonies solitary or in small groups; sheath very thick, straw coloured or dark coloured, strongly lamellated, finally and irregularly peeling off; cell 5-9 μm in diameter; cells somewhat thick; content granular, bluish green.

Occurred as greenish crust on lime surface of building wall; Utkal University campus, Bhubaneswar, Orissa; Voucher no. 1260; Date of collection: 02/03/2007.

22. *Chroococcus varius* A. Braun in Rabenhorst (Pl. 2, Fig. 27)

Desikachary, 1959, p. 108, pl. 24, fig. 5.

Cells spherical, 2-3 μm in diameter, grouped in a small number of coenobia, mucilaginous sheath, multilayered, occasionally indistinct.

Occurred as greenish crust on lime surface of building wall; Utkal University campus, Bhubaneswar, Orissa; Voucher no. 1260; Date of collection: 02/03/2007.

Genus: *Asterocapsa* Chu

23. *Asterocapsa divina* Komárek (Pl. 2, Fig. 28)

Aboal *et al.*, 2003, p. 59, figs 3-8.

Cells spherical, yellowish-green to bluish green in colour enveloped by thick or firm granular sheath, sheath coloured, filaments 14.4-16.8 μm broad with sheath; cell 6.0-9.6 μm broad and 12.0-13.5 μm long.

Occurred as blackish crust on cement surface of boundary wall; Utkal University campus, Bhubaneswar, Orissa; Voucher no. 1283; Date of collection: 02/03/2007.

Reported from lime stone rock cave, South Eastern, Spain (Aboal *et al.*, 2003).

Family: Xenococcaceae

Genus: *Cyanosarcina* Kováčik

24. *Cyanosarcina burmensis* (Skuja) Kováčik (Pl. 1, Fig. 19)

[Synonym: *Myxosarcina burmensis* Skuja 1949]

Desikachary, 1959, p. 178, pl. 32, figs 20-22.

Colonies gelatinous, cells spherical or ellipsoidal, closely arranged to form colonies in transverse or vertical series, pale blue green, homogeneous, individual sheath very thin, colonial mucilage colourless; cells 2.0-3.8 μm diameter.

Occurred as greenish crust on building wall, Nahargarh fort, Jaipur, Rajasthan; Voucher no. 1313; Date of collection: 25/10/2007.

25. *Cyanosarcina parthenonensis* Anagnostidis (Pl. 2, Fig. 29)

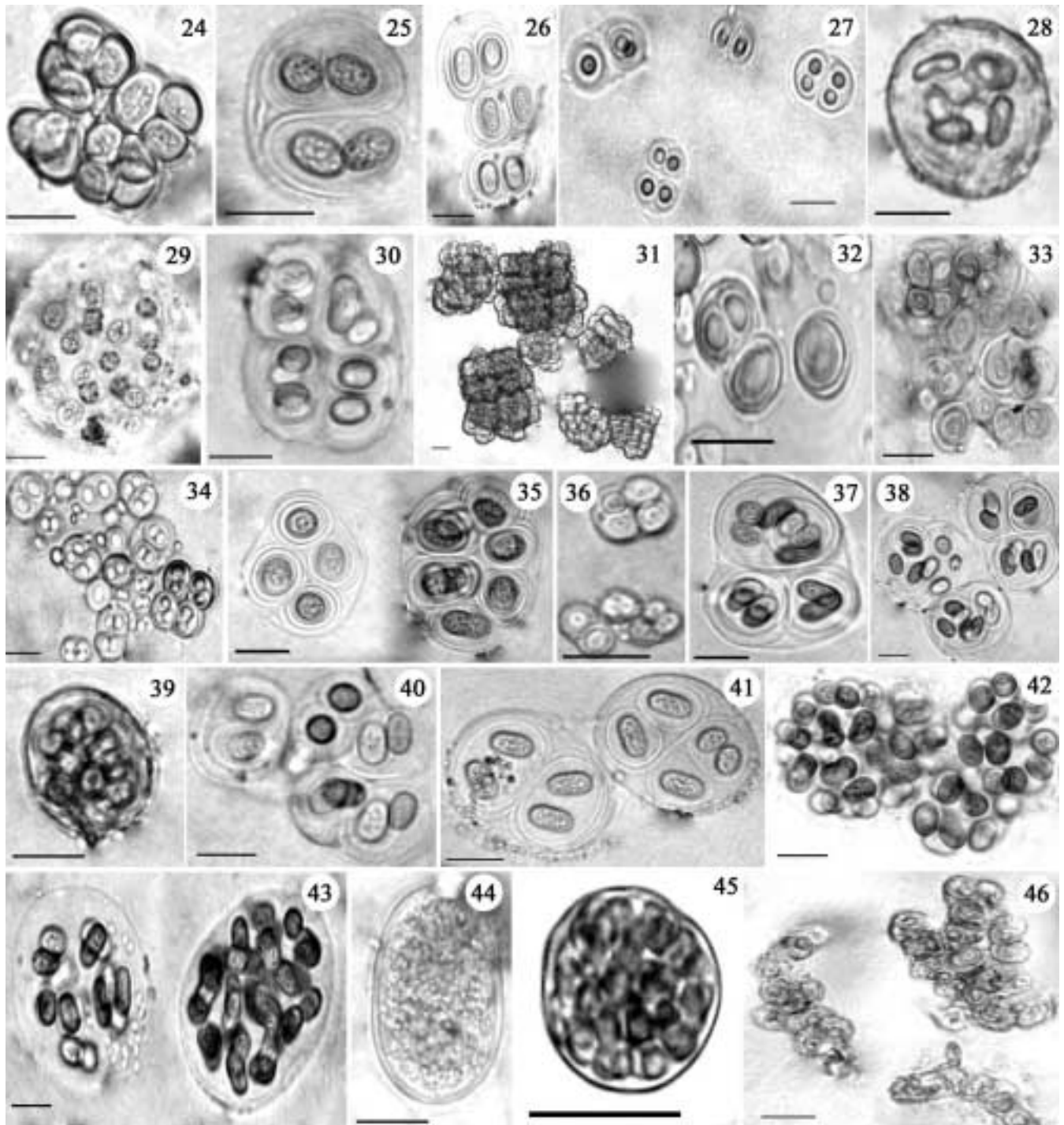


Plate 2. Fig. 24. *Chroococcus pallidus*, Figs 25-26. *Chroococcus schizodermaticus* (Fig. 25. young cell in colony, Fig. 26. colonies showing outer sheath layer often broken), Fig. 27. *Chroococcus varius*, Fig. 28. *Asterocapsa divina*, Fig. 29. *Cyanosarcina parthenonsis*, Fig. 30. *Cyanosarcina spectabilis*, Fig. 31. *Gloeocapsopsis crepidinum*, Fig. 32. *Gloeocapsa atrata*, Fig. 33. *Gloeocapsa kuetzingigiana*, Fig. 34. *Gloeocapsa livida*, Fig. 35. *Gloeocapsa muralis*, Fig. 36. *Gloeocapsa punctata*, Figs 37-38: *Gloeocapsa rupestris* (Fig. 37. colony, Fig. 38. colonies showing cell division), Fig. 39. *Gloeocapsa sanguinea*, Fig. 40. *Gloeothece rhodochlamys*, Fig. 41. *Gloeothece rupestris*, Fig. 42. *Aphanothece pallida*, Fig. 43. *Aphanothece stagnina*, Fig. 44. *Cyanothece aeruginosa*, Fig. 45. *Chroococcidiopsis kashayi*, Fig. 46. *Chroococcopsis fluviatilis*. Scale bar: Figs 24-46 = 10 μ m.

Barberousse *et al.*, 2006, p. 94, fig. 27.

Cells sub-spherical, olive green, arranged in more or less cubic and dense aggregates up to 20 μm in diameter; cells 2-4 μm diameter.

Occurred as blackish crust on cement surface, Sarat, Mayurbhanj, Orissa; Voucher no.1263; Date of collection: 24/04/2007.

Reported from building facades, France (Barberousse *et al.* 2006).

26. *Cyanosarcina spectabilis* (Geitler) Kováček (Pl. 2, Fig. 30)

[Synonym: *Myxosarcina spectabilis* Geitler 1933]

Desikachary, 1959, p. 178, pl. 30, figs 1 & 5.

Colony rounded, sometimes oval, divide in three planes, deep blue green to yellow green, colony 10-20 μm in diameter; densely packed, containing variously pressed cells, 6.7-10.0 μm in diameter; sheath thin.

Occurred as blackish crust on brick surface, Sarat, Mayurbhanj, Orissa; Voucher no.1264; Date of collection: 25/04/2007.

Genus: *Gloeocapsopsis* Geitler ex Komárek

27. *Gloeocapsopsis crepidinum* (Thuret) Geitler ex Komárek (Pl. 2, Fig. 31)

[Synonym: *Gloeocapsa crepidium* (Thuret) Thuret 1876]

(Basionym: *Protococcus crepidium* Thuret)

Desikachary, 1959, p. 117, pl. 27, fig. 4.

Thallus gelatinous, olive - green (when dried blackish), gelatinous, soft; colonies spherical, 12-24 μm diameter, closely arranged in the peripheral region and loosely arranged in the middle; cell in group of 2-4, rarely more, 4-8 μm diameter, sheath thin; yellowish - brown or colourless.

Occurred as greenish crust on limestone, Bhaskareswar temple, Bhubaneswar, Orissa; Voucher no. 1290; Date of collection: 13/07/2007.

Genus: *Chroococcidiopsis* Geitler

28. *Chroococcidiopsis kashayi* Friedmann (Pl. 2, Fig. 45)

Uher *et al.*, 2005, p. 283, figs 5a-f.

Colonies blue or olive green, 10-20 μm diameter; cell 2.5-7 μm diameter; granules present in the cell.

Occurred as greenish crust on lime coating surfaces of building wall, Athagarh, Ganjam, Orissa; Voucher no. 1305; Date of collection: 14/10/2007.

Reported from monument and building, South Eastern, Spain (Uher *et al.* 2005).

Genus: *Chroococcopsis* Geitler

29. *Chroococcopsis fluviatilis* (Lagerheim) Komárek and Anagnostidis (Pl. 2, Fig. 46)

[Synonym: *Pleurocapsa fluviatilis* Langerheim 1888]

Branco and Júnior, 1996, p. 39 & 41, fig. 12.

Thallus hemispherical, firm, crusted, dark blue green, when older turning yellowish - orange; filaments short, radiating or parallel; sheath colourless; cell spherical or polygonal, 5.2-8.0 μm broad, 3.0-8.0 μm long, mostly broader than long.

Occurred as greenish crust on lime coated surface on wall of temple, Athagarh, Ganjam, Orissa; Voucher no.1305; Date of collection: 14/10/2007.

Family: Microcystaceae

Genus: *Gloeocapsa* Kützing

30. *Gloeocapsa atrata* Kützing (Pl. 2, Fig. 32)

[Synonym: *Gloeocapsa montana* Kützing 1843; *Anacystis montana* (Lightfoot) Drouet and Daily 1952] Desikachary, 1959, p. 116, pl. 24, fig. 8.

Thallus mucilaginous; cell 3.5-4.5 μm diameter, with sheath 9-15 μm diameter, pale blue-green, sheath colorless, indistinctly lamellate.

Occurred as greenish crust on cement surface of building wall; Utkal University campus, Bhubaneswar, Orissa; Voucher no. 1261; Date of collection: 02/03/2007.

31. *Gloeocapsa kuetzingigiana* Nägeli (Pl. 2, Fig. 33)

Desikachary, 1959, p. 119, pl. 23, fig. 4.

Cells densely aggregated in colonies up to 150 μm diameter, cells without sheath 3-4 μm diameter, blue-green, sheath yellow to brown, lamellated.

Occurred as blackish crust on rock surface, Khandagiri cave, Bhubaneswar, Orissa; Voucher no. 1278; Date of collection: 17/04/2007.

Reported from building facades, France (Barberousse *et al.*, 2006); wall building and temples, Varanasi, India (Tripathi 1984).

32. *Gloeocapsa livida* (Carmichael) Kützing (Pl. 2, Fig. 34)

Desikachary, 1959, p. 116, pl. 27, fig. 8.

Cells spherical, small, bluish - green to olive in color, 3-4 μm diameter, with sheath 6-7 μm diameter.

Occurred as greenish crust on cement surface of building wall; Utkal University campus, Bhubaneswar, Orissa; Voucher no. 126; Date of collection: 02/03/2007.

33. *Gloeocapsa muralis* Kützing (Pl. 2, Fig. 35)

Tilden, 1910, p. 19, pl. I, fig. 23.

Cells usually 4-6 together, blue green, 6-8 μm diameter, cell contents somewhat granulose; sheath spherical or elliptical, haline, colourless or yellowish.

Occurred as greenish crust on cement surface of building wall; Utkal University campus, Bhubaneswar, Orissa; Voucher no. 1261; Date of collection: 02/03/2007.

34. *Gloeocapsa punctata* Nägeli (Pl. 2, Fig. 36)

Desikachary, 1959, p. 115, pl. 23, fig. 2.

Thallus gelatinous, light blue green; cells 0.7-2.5 μm diameter, with sheath 3.5-6.5 μm broad, bluish green; sheath colorless, scarcely lamellated; cells 2-16 in group forming colonies.

Occurred as blackish crust on wall of Mukteswar temple, Bhubaneswar, Orissa; Voucher no. 1274; Date of collection: 17/04/2007.

35. *Gloeocapsa rupestris* Kützing (Pl. 2, Figs 37-38)

Tilden, 1910, p. 19, pl. 1, fig. 24.

Cells single or 2-4 together, spherical, in few celled colonies, blue-green; cells without sheath 6-8 μm in diameter and with sheath 12-15 μm diameter; very distinctly lamellated; colonies 40-47 μm diameter.

Occurred as blackish crust on cement tiles at Baripada, Mayurbhanj, Orissa; Voucher no. 1326; Date of collection: 26/05/2007.

Reported from wall surface, Varanasi, India (Tripathi 1984); rock surface, Great Smoky Mountain, USA (Gomez *et al.* 2003).

36. *Gloeocapsa sanguinea* (Agardh) Kützing (Pl. 2, Fig. 39)

[Synonym: *Haematococcus sanguineus* C. Agardh; *Gloeocapsa etzigsohnii* Bornet 1882]

(Basionym: *Haematococcus sanguineus* C. Agardh)

Barberousse *et al.*, 2006, p. 94, fig. 33, 72.

Cells spherical to oval, surrounded by distinctly stratified envelopes and distributed in intensely red, spherical mucilaginous colonies; 3-6 μm diameter.

Occurred as blackish crust on cement wall surface, Sarat, Mayurbhanj, Orissa; Voucher no. 1263; Date of collection: 24/04/2007.

Reported from building facades, France (Barberousse *et al.* 2006).

Family: Cyanobacteriaceae

Genus: *Gloeothece* Nägeli

37. *Gloeothece rhodochlamys* Skuja (Pl. 2, Fig. 40)

Desikachary, 1959, p. 125, pl. 25, figs 13-14.

Colonies more or less rounded to spherical, blue green to reddish brown, 7.5-25.0 μm diameter; cells rounded to cylindrical, 2.5-3.7 μm broad, 2.5-7.5 μm long; sheath prominent, colourless or reddish brown, ensheathed cells 5.0-7.5 μm broad, 5-10 μm long.

Occurred as blackish crust on brick surface, Sarat, Mayurbhanj, Orissa; Voucher no. 1264; Date of collection: 25/04/2007.

38. *Gloeothece rupestris* (Lyngbye) Bornet (Pl. 2, Fig. 41)

[Synonym: *Palmella rupestris* Lyngbye 1819; *Gloeothece ruspestris* var. *maxima* (W. West) Hollerbach 1938]

(Basionym: *Palmella rupestris* Lyngbye)

Desikachary, 1959, p. 127, pl. 25, fig. 4.

Cells ellipsoidal to long cylindrical, 4.4-5.5 μm broad and 8.8-9.9 μm long, with envelope 9.0-13.2 μm broad and 14.3-18.0 μm long, blue-green; usually 2-4, sometimes 8 together in oval or sub-globose colony; colonies 22-24 μm broad and 35-41 μm long; envelope hyaline, distinctly lamellated.

Occurred on pinkish paint surface of building wall, Utkal University, Bhubaneswar, Orissa; Voucher no. 1279; Date of collection: 25/05/2007.

Reported from bed rock surface, Great Smoky Mountain, USA (Gomez *et al.* 2003).

Genus: *Aphanothece* Nägeli

39. *Aphanothece pallida* (Kützing) Rabenhorst (Pl. 2, Fig. 42)

[Synonym: *Palmella pallida* Kützing 1845]

(Basionym: *Palmella pallida* Kützing)

Desikachary, 1959, p. 140, pl. 22, fig. 3.

Thallus gelatinous, soft, somewhat transparent, pale blue green; cell 5.5-7.0 μm diameter, oblong-elliptical, usually scattered; cell content pale blue green.

Occurred as greenish crust on cement walls, Jorhat, Assam; Voucher no. 1269; Date of collection: 24/02/2007.

Reported from wetted wall, Lal Palma (Hrouzek and Šoun, 2004).

40. *Aphanothece stagnina* (Sprengel) A. Brown (Pl. 2, Fig. 43)

[Synonym: *Coccochloris stagnina* Sprengel 1807; *Aphanothece prasina* A. Braun 1863; *Aphanothece piscinalis* Rabenhorst 1865; *Aphanothece mooreana* (Harvey) Lagerheim 1883; *Aphanothece tuberculata* (Areschoug) Forti 1907]

Desikachary, 1959, p. 137, pl. 21, fig. 10.

Thallus gelatinous, spherical or ellipsoidal; cell oblong or cylindrical, 4.0-5.5 μm broad, 6-8 μm long, dirty blue green, sparsely or densely arranged in the colony, without individual envelope, mucilage homogeneous.

Occurred on yellowish paint surface of building wall; Utkal University campus, Bhubaneswar, Orissa; Voucher no. 1280; Date of collection: 25/05/2007.

Genus: *Cyanothece* Komárek

41. *Cyanothece aeruginosa* (Nägeli) Komárek (Pl. 2, Fig. 44)

[Synonym: *Synechococcus aeruginosus* Nägeli 1849]

Desikachary, 1959, p. 143, pl. 25, fig. 6.

Cells cylindrical, 6-16 μm broad, up to 25 μm long, single or 2-4 together, pale blue green.

Occurred as brownish crust on wall, Utkal University campus, Bhubaneswar, Orissa; Voucher no. 1309.

Date of collection: 12/10/2007.

Order: Oscillatoriales

Family: Phormidiaceae

Genus: *Phormidium* Kützing ex Gomont

42. *Phormidium aerugineo-coeruleum* (Gomont) Anagnostidis and Komárek (Pl. 3, Fig. 47)

[Synonym: *Lyngbya aerugineo-coerulea* Gomont 1892]

Desikachary, 1959, p. 315, pl. 48, fig. 9.

Filament flexuous, single or forming dark blue green aggregates; sheath thin; trichomes pale blue green, 3.6-6.8 μm broad, not constricted at the cross walls; cells quadrate, $1\frac{1}{2}$ long as broad, 2.3-4.0 μm long, pale blue green; end cell rounded.

Occurred as brownish crust on the limestone of Bhaskareswar temple, Bhubaneswar, Orissa; Voucher no. 1290; Date of collection: 13/07/2007.

Reported from bed rock surface, Great Smoky Mountain, USA (Gomez *et al.*, 2003).

43. *Phormidium autumnale* (Agardh) Gomont (Pl. 3, Fig. 48)

[Synonym: *Phormidium autumnale* (C. Agardh) Gomont 1892]

(Basionym: *Oscillatoria autumnalis* C. Agardh)

Desikachary, 1959, p. 276, pl. 44, fig. 24.

Thallus expanded, dark blue green or brownish green, sometimes yellowish; filament straight, rarely flexuous, variously entangled; sheath firm; trichomes not constricted at the cross wall, 4.8-5.0 μm broad, ends attenuated, straight or scarcely curved, prominently capitate; cell 5-6 μm long; end cell with a rounded or truncated conical

calyptra.

Occurred as blackish green on cement surface of building wall, Baramunda, Bhubaneswar, Orissa; Voucher no. 1308; Date of collection: 02/06/2007.

Reported from building wall, Nosa Señora da Esclavitude, Galicia, Spain (Noguerol-Seoane and Rifón-Lastra, 2003); wetted wall Lal Palma (Hrouzek and Šoun, 2004); brick and whitewashing surface of cultural monuments, Ukraine (Darienko and Hoffmann, 2003); Urban wall, Europe (Rindi and Guiry, 2004); moist wall, Varanasi, India (Tripathi, 1984); building stone, Salamanca and Toledo, Spain (Ortega-Calvo, 1993).

44. *Phormidium retzii* (Agardh) Gomont (Pl. 3, Fig. 49)

[Synonym: *Oscillatoria retzii* C. Agardh 1812; *Conferra retzii* (C. Agardh) Sommerfelt 1826; *Phormidium retzii* (C. Agardh) Kützing 1843; *Microcoleus retzii* (C. Agardh) Rabenhorst 1847; *Lyngbya retzii* (C. Agardh) Hansgirg 1892]

(Basionym: *Oscillatoria retzii* C. Agardh)

Desikachary, 1959, p. 268, pl. 44, fig. 15.

Thallus blue green; filament straight, not constricted at the cross walls, not attenuated at the ends; cells 4.0 -5.5 μm long and 6-9 μm broad.

Occurred as greenish mat on cement surface of building wall, Utkal University, Bhubaneswar, Orissa; Voucher no. 1308; Date of collection: 02/06/2007.

Genus: *Pseudophormidium* (Forti) Anagnostidis and Komárek

45. *Pseudophormidium indicum* (Dixit) Anagnostidis and Komárek (Pl. 3, Fig. 50)

[Synonym: *Plectonema indica* Dixit]

Desikachary, 1959, p. 435, pl. 83, fig. 2.

Thallus expanded; filament irregularly curved; blue-green; sheath firm; trichome 6.6-7.5 μm broad; cell quadratic or cylindrical, slightly constricted at the joints; end cells rounded.

Occurred as brownish crust on limestone quarry, Shillong, Meghalaya; Voucher no.1249; Date of collection: 10/12/2007.

46. *Pseudophormidium radiosum* (Gomont) Anagnostidis and Komárek 1892 (Pl. 3, Fig. 51)

[Synonym: *Plectonema radiosum* Gomont]

Desikachary, 1959, p. 437, pl. 83, fig. 8.

Filaments irregularly curved, rounded or spherical, about $\frac{1}{2}$ long, dull green; richly false branching, sheath in lower part of the filament; cells distinctly constricted

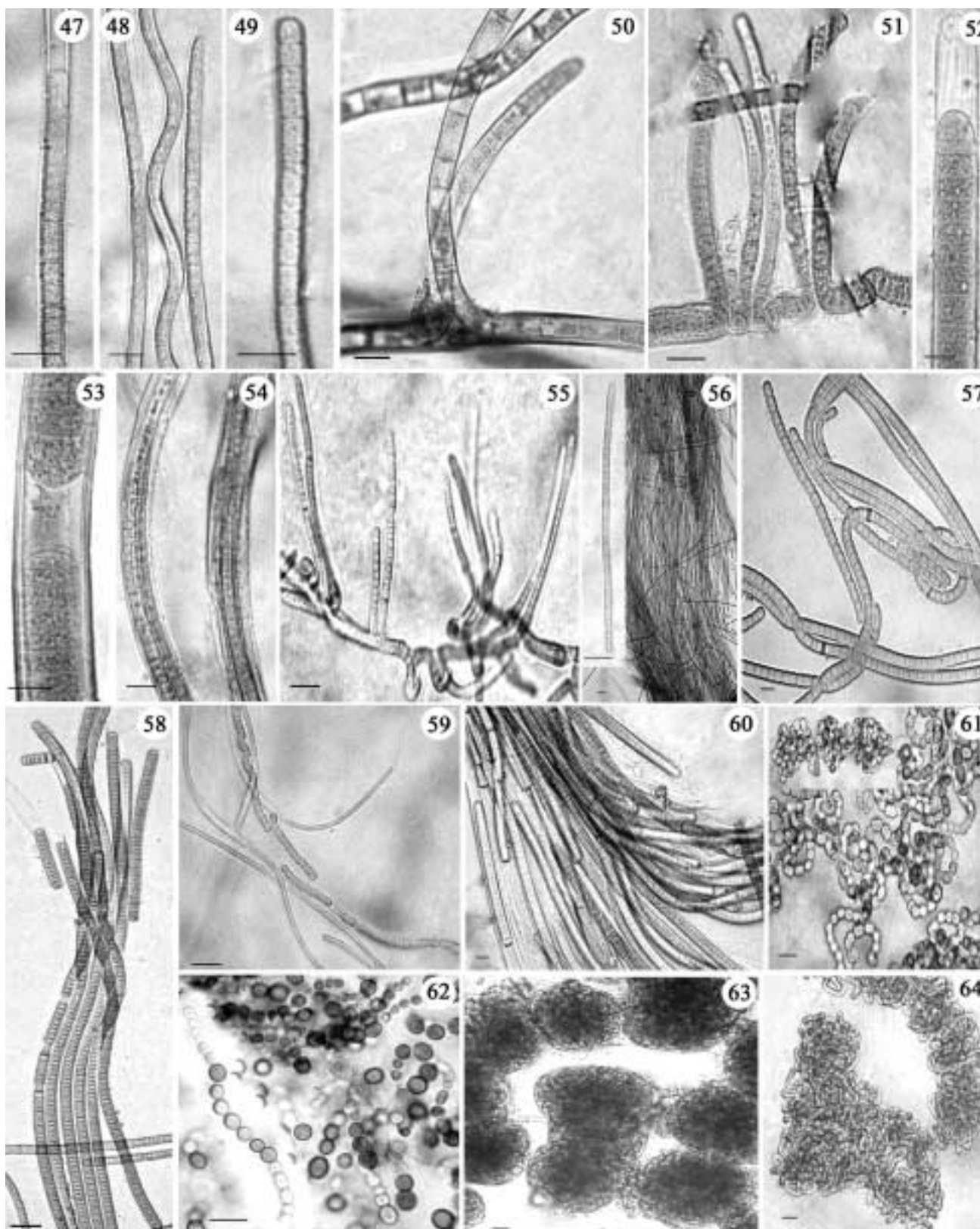


Plate 3. Fig. 47. *Phormidium aerugineo - coeruleum*, Fig. 48. *Phormidium autumnale*, Fig. 49. *Phormidium retzii*, Fig. 50. *Pseudophormidium indicum*, Fig. 51. *Pseudophormidium radiosum*, Figs 52-53. *Porphyrosiphon ceylanicus*, Fig. 54. *Microcoleus paludosus*, Fig. 55. *Leptolyngbya boryana*, Fig. 56. *Leptolyngbya fragilis*, Fig. 57. *Leptolyngbya nostocorum*, Fig. 58. *Leptolyngbya polysiphoniae*, Fig. 59. *Leptolyngbya notata*, Fig. 60. *Schizothrix lateritia*, Fig. 61. *Nostoc commune*, Fig. 62. *Nostoc linckia*, Fig. 63. *Nostoc microscopicum*, Fig. 64. *Nostoc punctiforme*. Scale bar: Figs 47-64 = 10 μ m.

at the cross walls, 11-20 μm broad, 3-10 μm long, blue green, end cell rounded.

Occurred as dark greenish crust on cement walls, Barg, Zorhat, Assam: Voucher no. 1268; Date of collection: 24/02/2007.

Genus: *Porphyrosiphon* Kützing ex Gomont

47. *Porphyrosiphon ceylanicus* (Wille) Anagnostidis & Komárek (Pl. 3, Figs 52-53)

[Synonym: *Lyngbya ceylanica* Wille 1914]

Desikachary, 1959, p. 299, pl. 54, fig. 4.

Thallus extensive, dark blue green; filament with sheath 13-14 μm broad; sheath thin, colorless, when old often red, trichome blue green, not constricted at the joints, not attenuated at the end; cell quadrate, 13-16 μm broad, 7-10 μm long; end cell round.

Occurred as blackish crust on rock surface of Khandagiri cave, Bhubaneswar, Orissa; Voucher no. 1265;

Date of collection: 17/04/2007.

Genus: *Microcoleus* Desmazières ex Gomont

48. *Microcoleus paludosus* (Kützing) Gomont (Pl. 3, Fig. 54)

[Synonym: *Chthonoblastus paludosus* Kützing]

Desikachary, 1959, p. 344, pl. 56, fig. 2.

Filament single or composed of transparent sheath containing 4-7 trichomes, cells in the trichome not constricted at joints, parallel, straight or twisted, cell 4-6 μm broad and 5-7 μm long; blue green, apical cell not capitate.

Occurred as brownish crust on wall, Utkal University campus, Bhubaneswar, Orissa; Voucher no. 1325; Date of collection: 15/10/2007.

Family: Schizotrichaceae

Genus: *Schizothrix* Kützing ex Gomont

49. *Schizothrix lateritia* (Kützing) Gomont (Pl. 3, Fig. 60)

[Synonym: *Hypheothrix lateritia* Kützing 1849; *Lyngbya lateritia* (Kützing) Kirchner 1878; *Lyngbya lateritia* (Kützing) Kirchner ex Hansgirg 1892]

(Basionym: *Hypheothrix lateritia* Kützing)

Desikachary, 1959, p. 330, pl. 57, figs 9-10.

Thallus brownish green, filament arranged in creeping bundle; sheath golden yellow or gelatinous; trichome slightly constricted at the cross walls; cells 7-9 μm broad, 4-5 μm long; end cells obtuse.

Occurred as brownish crust on the lime washed wall, temple boundary, Rasulgarh, Bhubaneswar, Orissa;

Voucher no. 1310; Date of collection: 19/07/2007.

Family: Oscillatoriaceae

Genus: *Plectonema* Thuret ex Gomont

50. *Plectonema puteale* (Kirchner) Hansgirg (Pl. 4, Fig. 65)

[Synonym: *Glaucothrix putealis* Kirchner]

Desikachary, 1959, p. 439.

Filament pale blue or yellow-green; false branches mostly short; slightly constricted at the cross wall; sheath thin; cells 3.0-4.5 μm broad.

Occurred as brownish crust on wall, Utkal University campus, Bhubaneswar, Orissa; Voucher no. 1323;

Date of collection: 12/10/2007.

Order: Pseudanabaenales

Family: Pseudanabaenaceae

Genus: *Leptolyngbya* Anagnostidis and Komárek

51. *Leptolyngbya boryana* (Gomont) Anagnostidis and Komárek (Pl. 3, Fig. 55)

[Synonym: *Plectonema boryanum* Gomont 1899]

Ortega-Calvo *et al.* 1993, p. 244, fig. 9.

Thallus pale green; trichome variously curved or straight, constriction at the cross-walls, especially in younger zones; cells 3-4 μm broad, shorter than broad, quadrate.

Occurred as brownish crust on the wall, Bhaskareswar temple, Bhubaneswar, Orissa; Voucher no. 1289; Date of collection: 13/07/2007.

Reported from building stone, Salamanca and Toledo, Spain (Ortega-Calvo *et al.* 1993).

52. *Leptolyngbya fragilis* (Gomont) Anagnostidis and Komárek (Pl. 3, Fig. 56)

[Synonym: *Phormidium fragile* Gomont 1892]

Desikachary, 1959, p. 253, pl. 44, fig. 2.

Thallus mucilaginous, dark blue green; sheath gelatinous, fibrous, diffluent into mucus; trichome 1-2 μm diameter, more or less flexuous, entangled or somewhat parallel to each other, constricted at the joints; apical cell acute conical; cells 1.2-2.3 μm broad, 1.2-3.0 μm long.

Occurred as greenish mat on rock surface of Khandagiri cave entrance, Bhubaneswar, Orissa; Voucher no. 1292; Date of collection: 13/07/2007.

Reported from building stone, Salamanca and Toledo, Spain (Ortega-Calvo *et al.* 1993).

53. *Leptolyngbya nostocorum* (Borent ex Gomont) Anagnostidis and Komárek (Pl. 3, Fig. 57)

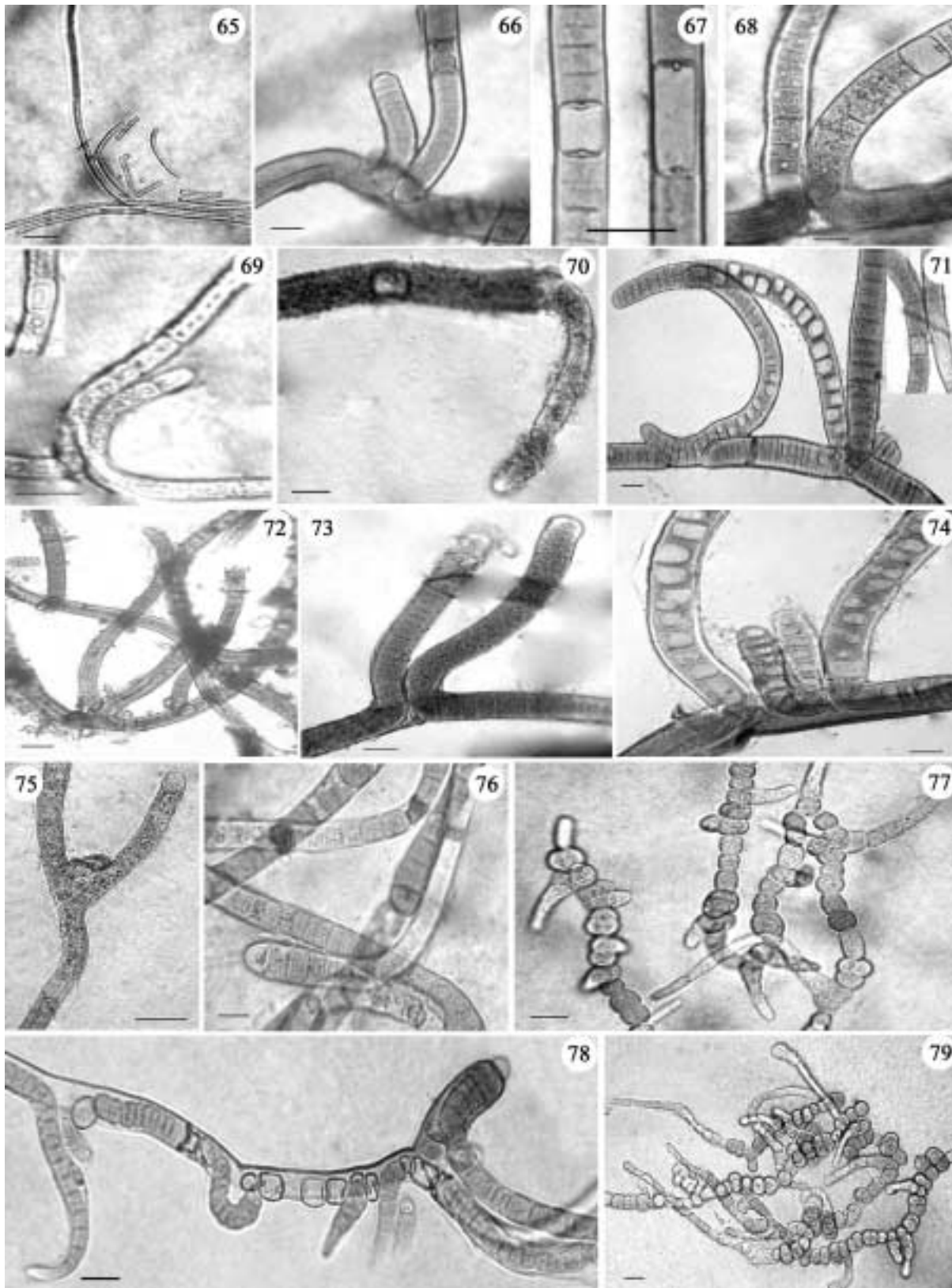


Plate 4. Fig. 65. *Plectonema puteale*, Figs 66-67. *Scytonema bohneri*, Fig. 66. Filament with false branch, Fig. 67. Showing heterocyst, ellipsoidal to cylindrical, Fig. 68. *Scytonema crispum*, Fig. 69. *Scytonema geitleri*, Fig. 70. *Scytonema hofman-bangii*, Fig. 71. *Scytonema millei*, Fig. 72. *Scytonema multiramosum*, Fig. 73. *Scytonema ocellatum*, Fig. 74. *Scytonema pseudoguyanense*, Fig. 75. *Tolypothrix fragilis*, Fig. 76. *Calothrix fusca*, Fig. 77. *Westiellopsis prolifica*, Fig. 78. *Calothrix wembaerensis*, Fig. 79. *Stigonema tomentosum*. Scale bar: Figs 65-79 = 10 μ m.

[Synonym: *Plectonema nostocorum* Bornet ex Gomont 1892]

(Basionym: *Plectonema nostocorum* Bornet ex Gomont) Uher *et al.*, 2005, p. 285, fig. 11.

Thallus dark green; filament with necridic cells, hormogonia flexuous, with a very thin sheath; cells isodiametric or wider than long, 3-5 μm diameter, slightly constricted at the cross wall; apical cells widely conical, with round apex.

Occurred as greenish crust on the rock surface, Bhaskareswar temple, Bhubaneswar, Orissa; Voucher no.1288; Date of collection: 13/07/2007.

54. *Leptolyngbya notata* (Schmidle) Anagnostidis and Komárek (Pl. 3, Fig. 59)

[Synonym: *Plectonema notatum* Schmidle 1901] Desikachary, 1959, p. 440, pl. 83, fig. 5.

Filament yellowish - green, short branched; sheath firm, thin, colourless; cells disc - shaped, 2.5-4.0 μm broad.

Occurred as brownish crust on the lime washed wall, temple boundary, Rasulgarh, Bhubaneswar, Orissa; Voucher no. 1310; Date of collection: 19/07/2007.

55. *Leptolyngbya polysiphoniae* (Frémy) Anagnostidis (Pl. 3, Fig. 58)

[Synonym: *Lyngbya polysiphoniae* Frémy] Desikachary, 1959, p. 287, pl. 53, figs 4-5.

Filament straight or curved, single or in bundle; sheath very thin, delicate, papyraceous, colourless; trichome pale blue-green; constricted at the cross walls, about 2 μm broad, apics not attenuated; cell as long as broad; end cells rounded.

Occurred as brownish crust on limestone quarry, Shillong, Meghalaya; Voucher no.1249; Date of collection: 10/12/2007.

Order: Nostocales

Family: Nostocaceae

Genus: *Nostoc* Vaucher ex Bornet and Flahault

56. *Nostoc commune* Vaucher ex Bornet & Flahault (Pl. 3, Fig. 61)

[Synonym: *Nostocella communis* (Vaucher) Gaillon; *Tremella nostoc* Linnaeus 1753; *Nostoc commune* Vaucher 1803; *Nostoc kurzianum* Zeller 1873]

Desikachary, 1959, p. 378, pl. 68, fig. 3.

Thallus blue green, olive or brown in colour; filament flexuous, entangled; distinct thick sheath; cell small, depressed, spherical or barrel-shaped, 4-6 μm diameter;

heterocyst intercalary, sub-spherical, 4-5 μm diameter.

Occurred as brownish patches on building roof surface, Village - Maniakati, Ganjam, Orissa: Voucher no. 1304; Date of collection: 14/10/2007.

Reported from building facades, France (Barberousse *et al.*, 2006); bedrock surface, Great Smoky Mountain, USA (Gomez *et al.*, 2003).

57. *Nostoc linckia* (Roth) Bornet ex Bornet & Flahault (Pl. 3, Fig. 62)

[Synonym: *Nostoc linckia* (Roth) Bornet 1880; *Stratonostoc linckia* (Roth) Elenkin 1938]

Desikachary, 1959, p. 377, pl. 69, fig. 4.

Thallus small in size, punctiform, globose first later expanding, blue green in colour, becoming dirty green; trichome much entangled, twisted; cells barrel shaped, 3-4 μm diameter; heterocyst sub- spherical to ovate, 4-6 μm diameter.

Occurred on lime washed of building wall, Utkal University, Bhubaneswar, Orissa: Voucher no. 1303; Date of collection: 25/05/2007.

Reported from limestone cultural monuments, Ukraine (Darienko and Hoffmann, 2003); bedrock surface, Great Smoky Mountain, USA (Gomez *et al.*, 2003).

58. *Nostoc microscopicum* Carmichael ex Bornet and Flahault (Pl. 3, Fig. 63)

[Synonym: *Nostoc microscopicum* Carmichael 1833] Barberousse *et al.*, 2006, p. 96, fig. 46, 81-82.

Trichomes composed by short barrel-shaped cells, deeply constricted at the cross walls, densely entangled, surrounded by spherical, firm and yellow mucilage; heterocyst sub-spherical, terminal or intercalary; cells 4-5 μm diameter.

Occurred as greenish crust on lime washed cement surface, Utkal University, Bhubaneswar, Orissa: Voucher no. 1298; Date of collection: 16/08/2007.

Reported from building wall, Nosa Señora da Esclavitude, Galicia, Spain (Noguerol - Seoane and Rifón — Lastra 2003); building façade, France (Barberousse *et al.* 2006); bed rock surface, Great Smoky Mountain, USA (Gomez *et al.* 2003).

59. *Nostoc punctiforme* (Kützing) Hariot (Pl. 3, Fig. 64)

[Synonym: *Nostoc hederulae* Meneghini 1849]

Desikachary, 1959, p. 374, pl. 69, fig. 1.

Colonies spherical, olive or dark blue green, finally becoming brownish; filament short, united to form a globose mass, coiled, densely entangled; sheath distinct,

colourless or rarely yellowish; cell small, spherical to sub-spherical, 4 μm diameter.

Occurred on brownish patch on building roof surface, Village - Maniakati, Ganjam, Orissa: Voucher no. 1304; Date of collection: 14/10/2007.

Reported from building wall, Nosa Señora da Esclavitude, Galicia, Spain (Nogueroles-Seoane and Rifón—Lastra, 2003); whitewashing surfaces of cultural monument, Ukraine (Darienko and Hoffmann 2003).

Family: Scytonemataceae

Genus: *Scytonema* Agardh ex Bornet and Flahault

60. *Scytonema bohneri* Schmidle (Pl. 4, Figs 66-67)

Desikachary, 1959, p. 457, pl. 87, fig. 1.

Thallus dark blue green; filament long, partly creeping, false branched, 10-13 μm broad, narrow at the apex, 6-7 μm broad; sheath colourless and thick; trichome blue green, not constricted at the cross walls; cell rectangular 5-8 μm broad; heterocyst intercalary, ellipsoidal to cylindrical, colourless or yellowish, 8-10 μm broad, 6-12 μm long.

Occurred as brownish crust on painted wall of building, Rajmahal square, Unit-III, Bhubaneswar, Orissa; Voucher no. 1306; Date of collection: 12/10/2007.

61. *Scytonema crispum* (Agardh) Bornet (Pl. 4, Fig. 68)

[Synonym: *Scytonema cincinnatum* Thuret ex Bornet and Flahault]

(Basionym: *Lyngbya cincinnata* Kützing)

Desikachary, 1959, p. 453, pl. 93, fig. 1.

Thallus brownish green, olivaceous; filaments long, variously bent or curved, false branched; sheath firm, hyaline, brownish; trichome 14-20 μm broad, 13-14 μm long.

Occurred as greenish crust on Maplong Dam, Shillong, Meghalaya; Voucher no. 1248; Date of collection: 10/12/2007.

62. *Scytonema geitleri* Bharadwaja (Pl. 4, Fig. 69)

Desikachary, 1959, p. 481, pl. 94, fig. 5.

Thallus brownish or dark green; filament irregularly curved; sheath firm; trichome 4.0-5.5 μm broad, slightly constricted at the joints; cell cylindrical, sometimes rounded or barrel-shaped at the short branches; heterocyst cylindrical or rectangular, 5-7 μm broad, 6-7 μm long.

Occurred as blackish crust on building wall, Utkal University campus, Bhubaneswar, Orissa; Voucher no. 1298; Date of collection: 16/08/2007.

Reported from wall and roof top, Varanasi, India (Tripathi, 1984).

63. *Scytonema hofman-bangii* Agardh ex Silva (Pl. 4, Fig. 70)

[Synonym: *Scytonema hofmanni* C. Agardh ex Bornet and Flahault 1887]

Desikachary, 1959, p. 476, pl. 91, fig. 2.

Thallus olive to blue green; filament long, false branched, aggregated in vertical fascicles; cells unequal in length, 7.7-14.3 μm broad, 4.0-5.5 μm long.; heterocyst oblong.

Occurred as brownish crust on rock surface, Temple, Koraput, Orissa; Voucher no. 1285; Date of collection: 19/05/2007.

Reported from wetted wall, Lal Palma (Hrouzek and Šoun, 2004).

64. *Scytonema millei* Bornet ex Bornet and Flahault (Pl. 4, Fig. 71)

Desikachary, 1959, p. 460, pl. 93, figs 2-3.

Thallus expanded, brownish; filament long, false branched; sheath firm, yellowish-brown; cell 10-15 μm broad, compressed; heterocyst nearly quadratic or longer than broad, 8.0-9.5 μm broad, 8 μm long.

Occurred as blackish crust on moist building wall, Utkal University campus, Bhubaneswar, Orissa; Voucher no. 1303; Date of collection: 19/08/2007.

65. *Scytonema multiramosum* Gardner (Pl. 4, Fig. 72)

Desikachary, 1959, p. 475, pl. 92, fig. 4.

Thallus blue-green; filaments long, 10-14 μm broad, 1.5-2.5 μm long, false branching, sheath thick, slightly gelatinous; cell at the apex slightly barrel shaped; heterocyst oblong, yellowish, 14 μm broad.

Occurred as blackish crust on rock surface, Hatigumpha cave, Khandagiri, Bhubaneswar, Orissa; Voucher no. 1262; Date of collection: 20/03/2007.

66. *Scytonema ocellatum* (Lyngbye) Bornet and Flahault (Pl. 4, Fig. 73)

[Synonym: *Scytonema cinereum* Meneghini 1837; *Scytonema murale* Zeller 1873]

Desikachary, 1959, p. 467, pl. 92, fig. 3.

Thallus expanded, grayish blue; filaments 10.0-16.5 μm broad, erect, false branched, less constricted at the cross walls; sheath firm; trichome 6-14 μm broad; apical cell rounded; heterocyst sub-quadratic or cylindrical to discoid, yellowish, 12.0-13.2 μm broad, 9.9-12.0 μm long.

Occurred as brownish crust on the wall, Bhaskareswar temple, Bhubaneswar, Orissa; Voucher no. 1289; Date of collection: 17/04/2007.

67. *Scytonema pseudoguyanense* Bharadwaja (Pl. 4, Fig. 74)

Desikachary, 1959, p. 472, pl. 89, fig. 2.

Thallus erect, brownish green; filaments irregularly curved and densely entangled, 16 μm broad, false branching numerous, narrower than the main filament; heterocyst yellowish, prominent, quadratic, 13 μm broad, 7-13 μm long.

Occurred as dark greenish crust on wall, Parasurameswar temple, Bhubaneswar, Orissa; Voucher no. 1273; Date of collection: 17/04/2007.

Family: Microchaetaceae

Genus: *Tolypothrix* Gardner

68. *Tolypothrix fragilis* (Gardner) Geitler (Pl. 4, Fig. 75)

[Synonym: *Hassallia fragilis* Gardner 1927]

Desikachary, 1959, p. 500, pl. 103, fig. 1.

Thallus dark blue green; filament straight, forming a thin thallus; sheath thin, colourless; trichome not constricted at the cross wall; cell 5-7 μm broad; heterocyst spherical or ellipsoidal.

Occurred as blackish crust on building wall, Utkal University campus, Bhubaneswar, Orissa; Voucher no. 1299; Date of collection: 16/08/2007.

Reported from building terraces and walls, Varanasi, India (Tripathi 1984).

Family: Rivulariaceae

Genus: *Calothrix* Agardh ex Bornet and Flahault

69. *Calothrix fusca* (Kützing) Bornet and Flahault (Pl. 4, Fig. 76)

Desikachary, 1959, p. 527, pl. 107, fig. 10.

Thallus gelatinous; filament single, unbranched, straight or slightly bent, 11-12 μm broad; sheath broad, colourless; cell often discoid, shorter than broad; heterocyst basal or hemispherical, yellowish.

Occurred as blackish crust on roof floor of building; Utkal University campus, Bhubaneswar, Orissa; Voucher no. 1318; Date of collection: 14/10/2007.

70. *Calothrix wembaerensis* Hieronimus and Schmidle (Pl. 4, Fig. 78)

Desikachary, 1959, p. 526, pl. 110, figs 1-7.

Filament branched, caespitose, 10-15 μm broad; sheath thick, colourless, gelatinous; trichome 6-8 μm broad; cells

at the base of filament about 8-10 μm broad, barrel shaped; heterocyst basal, mostly two; spores cylindrical with rounded ends, separated from each other by heterocyst.

Occurred as blackish crust on fort wall (on mortar paste), Nahargarh, Jaipur, Rajasthan; Voucher no. 1314; Date of collection: 25/10/2007.

Family: Hapalosiphonaceae

Genus: *Westiellopsis* Janet

71. *Westiellopsis prolifica* Janet (Pl. 4, Fig. 77)

Desikachary, 1959, p. 596, pl. 131, figs 1-12.

Thallus blue green; filament with prostrate and erect branches, lateral branch thinner than main branch, 6-7 μm broad, 9-12 μm long; cell spherical or elliptical 5-6 μm diameter; heterocyst intercalary, light yellow, rectangular, 4-6 μm broad, 8-10 μm long.

Occurred as greenish patch on lime washed building wall, Saheed nagar, Bhubaneswar, Orissa; Voucher no. 1302; Date of collection: 13/10/2007.

Family: Stigonemataceae

Genus: *Stigonema* Agardh ex Bornet and Flahault

72. *Stigonema tomentosum* (Kützing) Hieronymus (Pl. 4, Fig. 79)

[Synonym: *Sirosiphon tomentosus* Kützing 1847

(Basionym: *Sirosiphon tomentosus* Kützing)

Desikachary, 1959, p. 475, pl. 92, fig. 8.

Thallus greenish, spongy, branched, 20-28 μm broad; trichome long, primary branch 2-3 celled only at few portion of the thallus; cell spherical, elongated, 4-5 μm broad, 5-9 μm long, secondary branch single celled; heterocyst on both primary and secondary branches, 6-10 μm broad, 10-14 μm long.

Occurred as dark greenish crust on wetted rocky wall, Parasurameswar temple, Bhubaneswar, Orissa; Voucher no. 1287; Date of collection: 17/08/2007.

DISCUSSION

The micro-algae and cyanobacteria recorded from the exterior of several buildings and monuments in India during the hot summer months (March - June) and soon after monsoon rain (July - August) have been given in Table 2. Analysis of these results showed that only one species of *Trentepohlia*, *T. abietina* var. *tenuis* under chlorophyta and four species of cyanobacteria e.g. *Chroococciopsis kashayi*, *Pseudophormidium indicum*, *Plectonema puteale* and *Scytonema geitleri* occur on the

Table 2. List of Cyanobacteria and micro-algae occurred as crust on exposed surfaces of building facades and rocky walls of monuments during summer and after monsoon rain

Site	Organism	Summer	After rain
	Chlorophyta		
1.	<i>Chlorococcum infusionum</i>	+	-
2.	<i>Bracteacoccus minor</i>	-	+
3.	<i>Radiococcus nimbatus</i>	-	+
4.	<i>Coenochloris pyrenoidosa</i>	-	+
5.	<i>Gloeocystis polydermatica</i>	+	-
6.	<i>Chlorella vulgaris</i>	-	+
7.	<i>Scenedesmus arcuatus</i>	+	-
8.	<i>Scenedesmus bijugatus</i>	-	+
9.	<i>Trentepohlia aurea</i>	+	-
10.	<i>Trentepohlia abietina</i> var. <i>tenuis</i>	+	+
11.	<i>Trentepohlia rigidula</i>	-	+
12.	<i>Trentepohlia umbrina</i>	-	+
13.	<i>Printzina effusa</i>	+	-
14.	<i>Cosmarium misellum</i>	-	+
15.	<i>Cosmarium nitidulum</i>	-	+
	Cyanophyta (Cyanobacteria)		
16.	<i>Chroococcus indicus</i>	+	-
17.	<i>Chroococcus limneticus</i>	+	-
18.	<i>Chroococcus lithophilus</i>	-	+
19.	<i>Chroococcus minor</i>	+	-
20.	<i>Chroococcus pallidus</i>	-	+
21.	<i>Chroococcus schizodermaticus</i>	+	-
22.	<i>Chroococcus varius</i>	+	-
23.	<i>Asterocapsa divina</i>	+	-
24.	<i>Cyanosarcina burmensis</i>	-	+
25.	<i>Cyanosarcina parthenonensis</i>	+	-
26.	<i>Cyanosarcina spectabilis</i>	+	-
27.	<i>Gloeocapsopsis crepidium</i>	-	+
28.	<i>Chroococcidiopsis kashayi</i>	+	+
29.	<i>Chroococcopsis fluviatilis</i>	-	+
30.	<i>Gloeocapsa atrata</i>	+	-
31.	<i>Gloeocapsa kuetzingiana</i>	+	-
32.	<i>Gloeocapsa livida</i>	+	-
33.	<i>Gloeocapsa muralis</i>	+	-
34.	<i>Gloeocapsa punctata</i>	+	-
35.	<i>Gloeocapsa rupestris</i>	+	-
36.	<i>Gloeocapsa sanguinea</i>	+	-
37.	<i>Gloeothece rhodochlamys</i>	+	-
38.	<i>Gloeothece rupestris</i>	+	-
39.	<i>Aphanothece pallida</i>	-	+
40.	<i>Aphanothece stagnina</i>	-	+
41.	<i>Cyanothece aeruginosa</i>	-	+
42.	<i>Phormidium aerugineo-coeruleum</i>	-	+
43.	<i>Phormidium autumnale</i>	-	+
44.	<i>Phormidium retzii</i>	+	+
45.	<i>Pseudophormidium indicum</i>	-	+
46.	<i>Pseudophormidium radiosum</i>	-	+
47.	<i>Porphyrosiphon ceylanicus</i>	+	+
48.	<i>Microcoleus paludosus</i>	-	+
49.	<i>Leptolyngbya boryana</i>	-	+
50.	<i>Leptolyngbya fragilis</i>	-	+
51.	<i>Leptolyngbya nostocorum</i>	-	+

Table 2. (continued)

Site	Organism	Summer	After rain
52.	<i>Leptolyngbya notata</i>	-	+
53.	<i>Leptolyngbya polysiphoniae</i>	-	+
54.	<i>Schizothrix lateritia</i>	-	+
55.	<i>Nostoc commune</i>	-	+
56.	<i>Nostoc linckia</i>	-	+
57.	<i>Nostoc microscopicum</i>	-	+
58.	<i>Nostoc punctiforme</i>	-	+
59.	<i>Plectonema puteale</i>	+	+
60.	<i>Scytonema bohneri</i>	-	+
61.	<i>Scytonema crispum</i>	-	+
62.	<i>Scytonema geitleri</i>	+	+
63.	<i>Scytonema hofman-bangii</i>	-	+
64.	<i>Scytonema millei</i>	-	+
65.	<i>Scytonema multiramsum</i>	+	-
66.	<i>Scytonema ocellatum</i>	+	+
67.	<i>Scytonema pseudoguyanense</i>	+	+
68.	<i>Tolypothrix fragilis</i>	-	+
69.	<i>Calothrix fusca</i>	-	+
70.	<i>Calothrix wembaerensis</i>	-	+
71.	<i>Westiellopsis prolifica</i>	-	+
72.	<i>Stigonema tomentosum</i>	-	+

exterior of building walls all through the year. On the contrary, on the exposed rock surface of temples and monuments, where the temperature can exceed 60°C during summer months, only three cyanobacteria species e.g. *Porphyrosiphon ceylanicus*, *Scytonema ocellatum* and *S. pseudoguyanense* occur. These species form a characteristic blackish-brown crust, and develop into a thick mat up to 3 to 4 mm thick upon receiving water during the rainy season.

In addition to the above species, five other green algal species (*Chlorococcum infusionum*, *Scenedesmus arcuatus*, *Trentepohlia aurea*, *Gloeocystis polydermatica* and *Printzina effusa*) and 18 other cyanobacterial taxa in the genera *Chroococcus* (5), *Asterocapsa* (1), *Cyanosarcina* (2), *Gloeocapsa* (7), *Gloeotheca* (2), and *Scytonema* (1) occur in the biofilms during summer months showing their ability to thrive under conditions of high desiccation and heat stress prevailing on the buildings facades and exterior of rocks of monuments (Table 2). However, with the onset of monsoon rains when these biofilms receive water along with a humid microenvironment, 10 green algal taxa belonging to eight genera, e.g. *Chlorella* (1), *Brateacoccus* (1), *Radiococcus* (1), *Coenochloris* (1), *Gloeocystis* (1), *Scenedesmus* (1), *Trentepohlia* (2), *cosmarium* (2), and 29 cyanobacteria taxa in 17 genera, e.g. *Chroococcus* (2), *Gloeocapsopsis* (1), *Aphanothece* (2), *Cyanothece* (1), *Cyanosarcina* (1), *Chroococciopsis* (1),

Phormidium (2), *Pseudophormidium* (1), *Microcoleus* (1), *Leptolyngbya* (4), *Schizothrix* (1), *Nostoc* (4), *Scytonema* (4), *Tolypothrix* (1), *Calothrix* (1), *Westiellopsis* (1) and *Stigonema* (1) occurred and formed the characteristic flora on the sub-aerial habitats of different regions in India (Table 2). Of the total 72 algal taxa, 22 species have not been recorded from sub-aerial habitats of other countries in the tropical and temperate regions: *Brateacoccus minor*, *Chlorella vulgaris*, *Trentepohlia umbrina*, *Printzina effusa*, *Chroococcus lithophilus*, *C. pallidus*, *Asterocapsa divina*, *Gloeocapsa kuetzingiana*, *G. rupestris*, *G. sanguiana*, *Gloeotheca rupestris*, *Aphanothece pallida*, *Chroococciopsis kashayi*, *Cyanosarcina parthenonensis*, *Phormidium autumnale*, *Leptolyngbya fragilis*, *Nostoc commune*, *N. linckia*, *N. micropicum*, *N. punctiforme*, *Leptolyngbya boryana* and *Scytonema hoffman-bangii*. Hence these results show a tropical diversity pattern of sub-aerial micro-algae and cyanobacteria in the Indian subcontinent quite different from other regions of the globe.

Occurrence of almost similar cyanobacteria taxa and the relative absence of green algal forms on the building facades of several localities in India, Brazil and Mexico under tropical conditions have been reported earlier (Table 3). On the contrary, in temperate regions, except for the sub-tropical and warm temperate zones of Spain and Italy, the algal forms occurring in similar habitats of Ukraine, France, Ireland, England and Denmark are

Table 3. (continued)

Class / Order/ Genus	Tropical region			Temperate region				8 Ireland, Denmark, England
	1 India	2 Brazil	3 Mexico	4 Ukraine	5 Spain	6 France	7 Italy	
<i>Cladophora</i>	-	+	+	-	-	-	-	-
Trentepohliales								
<i>Trentepohlia</i>	+	+	-	-	+	+	+	-
<i>Printzina</i>	-	-	-	-	-	-	-	+
Conjugales								
<i>Cosmarium</i>	+	-	-	-	+	-	-	-
Bacillariophyceae								
Pennales								
<i>Achnanthes</i>	-	-	-	-	+	-	-	-
<i>Navicula</i>	-	-	-	+	+	-	-	-
<i>Nitzschia</i>	-	-	-	+	-	-	+	-
<i>Hantzschia</i>	-	-	-	+	+	-	-	-
<i>Diadesmis</i>	-	-	-	-	+	-	-	-
Xanthophyta								
Heterosiphonales								
<i>Botrydiopsis</i>	-	-	-	+	+	-	-	-
<i>Eustigmatos</i>	-	-	-	+	-	-	-	-
<i>Xanthonema</i>	-	-	-	+	+	-	-	-
<i>Heteropedia</i>	-	-	-	-	+	-	-	-
<i>Heterococcus</i>	-	-	-	+	-	-	-	-
Cyanophyta (Cyanobacteria)								
Chroococcales								
<i>Chroococcus</i>	+	+	-	-	+	+	+	+
<i>Gleocapsa</i>	+	+	+	+	+	-	+	+
<i>Gloeotheca</i>	+	+	+	-	-	-	-	-
<i>Aphanocapsa</i>	+	-	-	-	+	-	-	-
<i>Aphanothece</i>	+	-	-	-	+	-	-	-
<i>Synechococcus</i>	+	+	+	-	+	-	+	-
<i>Synechocystis</i>	-	+	+	-	+	-	-	-
<i>Chlorogloeo</i>	-	+	+	-	+	-	-	-
<i>Asterocapsa</i>	+	-	-	-	+	-	-	-
Chamaesiphonales								
<i>Chroococciopsis</i>	+	+	+	-	+	+	+	-
<i>Cyanosarcina</i>	+	-	-	-	-	+	-	-
<i>Cyanobacterium</i>	-	-	-	-	+	-	-	-
<i>Chamaesiphon</i>	-	-	-	-	+	+	-	-
Pleurocapsales								
<i>Pseudocapsa</i>	-	-	-	-	+	-	+	-
<i>Myxosarcina</i>	+	+	+	-	-	-	+	-
<i>Pleurocapsa</i>	+	+	+	-	+	-	-	-
<i>Xenococcus</i>	-	+	+	-	+	-	-	-
<i>Hyella</i>	-	-	+	-	+	-	-	-
<i>Hydrococcus</i>	-	-	+	-	-	-	-	-
Nostocales								
<i>Oscillatoria</i>	-	+	-	-	+	-	+	-
<i>Arthrospira</i>	-	-	+	-	-	-	-	-
<i>Phormidium</i>	+	+	+	+	+	+	+	+
<i>Pseudophormidium</i>	-	-	-	-	+	+	-	-
<i>Lyngbya</i>	+	+	+	+	-	-	-	-
<i>Leptolyngbya</i>	+	+	+	-	+	+	+	-
<i>Schizothrix</i>	+	-	-	-	+	-	-	-

Table 3. (continued)

Class / Order/ Genus	Tropical region			Temperate region				8 Ireland, Denmark, England
	1 India	2 Brazil	3 Mexico	4 Ukraine	5 Spain	6 France	7 Italy	
<i>Symploca</i>	-	-	-	+	+	-	+	-
<i>Microcoleus</i>	+	+	-	-	+	+	+	-
<i>Anabaena</i>	-	-	-	-	+	-	-	-
<i>Pseudoanabaena</i>	-	-	-	-	+	-	-	-
<i>Nostoc</i>	+	+	+	+	+	+	+	-
<i>Cylindrospermum</i>	-	-	-	-	-	-	-	-
<i>Plectonema</i>	+	+	+	-	-	-	+	-
<i>Scytonematopsis</i>	-	+	-	-	-	-	-	-
<i>Scytonema</i>	+	+	+	-	+	+	+	-
<i>Tolypothrix</i>	+	+	-	-	+	-	-	-
<i>Calothrix</i>	+	+	-	-	+	+	-	-
Stigonematales								
<i>Mastigocladus</i>	-	+	-	-	-	-	-	-
<i>Westiellopsis</i>	+	-	-	-	-	-	-	-
<i>Fischerella</i>	-	-	+	-	+	-	-	-
<i>Stigonema</i>	+	-	-	-	+	-	-	-

1. Tripathi *et al.* (1991); 2. Crispim *et al.* (2004, 2006), Gaylarde and Gaylarde (2000); 3. Gaylarde *et al.* (2006), Ortega-Morales *et al.* (2005), Videla *et al.* (2000); 4. Darienko and Hoffmann (2003); 5. Aboal *et al.* (2003), Noguerol-Seoane and Rifón-Lastra (2003), Ortega-Calvo *et al.* (1993), Peraza Zurita *et al.* (2005), Uher *et al.* (2005); 6. Barberousse *et al.* (2006, 2007); 7. Rindi and López Bautista (2007), Tomaselli *et al.* (2000); 8. Crispim *et al.* (2003), Gaylarde and Gaylarde (2005), Rindi and Guiry (2004), Rindi *et al.* (2005).

principally green algae with cyanobacterial forms bring sparce. On the exteriors of the cathedral and buildings of Spain the cyanobacteria and green algae were almost equal in number, and both the groups of algae were dominant in the sub-aerial habitats of warm temperate locality. In addition, though the green algal genera *Klebsormidium*, *Stichococcus* and *Trebouxia* were dominant in the temperate regions, these did not occur on the exteriors of buildings of tropical countries. However, species of *Gloeocapsa*, *Chroococcus*, *Chroococciopsis*, *Phormidium*, *Leptolyngbya*, *Nostoc*, *Scytonema*, *Chlorella* and *Trentepohlia* occurring in the sub-aerial habitats of temperate locations also colonize similar habitats in India and other tropical countries have a global occurrence. These findings are consistent with the few previous studies, in which green algae were shown to be dominant in temperate regions, whereas cyanobacteria dominant in the tropics, especially the forms with well developed sheaths and /or mucilage in their outer envelope. These differences are based on the requirement for humidity and moderate light intensity on the part of green algae, and the capability to withstand high temperature, desiccation and protecting themselves from intense solar insolation on the part of cyanobacteria.

ACKNOWLEDGEMENTS

The authors thank the Ministry of Environment and Forests, Govt. of India for financial assistance through an All India Coordinated Project (AICOPTAX) on the Taxonomy of Algae. We also thank the Heads of the P. G. Departments of Botany and Biotechnology, Utkal University for providing laboratory facilities.

REFERENCES

- Aboal M., Asencio A.D. and López-Jiménez E. 2003. Morphological, ultra structural and ecological study of *Asterocapsa divina* Komárek (Chroococcaceae, Cyanobacteria) from a cave of Southeastern Spain. *Algolog. Stud.* **109**: 57-65.
- Barberousse H., Tell G., Yéprémian C. and Couté A. 2006. Diversity of algae and cyanobacteria growing on buildings facades in France. *Algolog. Stud.* **120**: 81-105.
- Barberousse H., Rout B., Yéprémian C. and Boulon G. 2007. An assessment of facades coatings against colonization by aerial algae and cyanobacteria. *Building Environ.* **42**: 2555-2561.
- Branco C.C.Z. and Júnior O.N. 1996. Survey of stream macroalgae of eastern Atlantic rain forest of São Paulo State, South eastern Brazil. *Algolog. Stud.* **80**: 35-57.

- Brehm U., Gorbushina A.A. and Motterhead D. 2005. The role of microorganisms and biofilms in the breakdown and dissolution of quartz and glass. *Paleogeogr. Paleoclimat. Paleocol.* **219**: 117-129.
- Crispim C.A., Gaylarde P.M. and Gaylarde C.C. 2003. Algal and cyanobacteria biofilms on calcareous historic buildings. *Curr. Microbiol.* **46**: 79-82.
- Crispim C.A., Gaylarde C.C. and Gaylarde P.M. 2004. Biofilms on church walls in Porto Alegre, RS, Brazil, with special attention to cyanobacteria. *Int. Biodeterior. Biodegrad.* **54**: 121-124.
- Crispim C.A., Gaylarde P.M., Gaylarde C.C. and Neilan B.A. 2006. Deteriogenic cyanobacteria on historic buildings in Brazil detected by culture and molecular techniques. *Int. Biodeterior. Biodegrad.* **57**: 239-243.
- Desikachary T.V. 1959. *Cyanophyta*: Indian Council of Agricultural Research, New Delhi, 686 pp.
- Darienko T. and Hoffmann L. 2003. Algal growth on cultural monuments in Ukraine. *Biologia Bratislava* **58**: 575-587.
- Gaylarde C.C. and Gaylarde P.M. 2005. A comparative study of the major microbial biomass of biofilms on exteriors of buildings in Europe and Latin America. *Int. Biodeterior. Biodegrad.* **55**: 131-139.
- Gaylarde C.C., Gaylarde P.M., Copp J. and Neilan B. 2004. Polyphasic detection of cyanobacteria in terrestrial biofilms. *Biofouling* **20**: 71-79.
- Gaylarde C.C. and Morton L.H.G. 1999. Deteriogenic biofilms on buildings and their control: a review. *Biofouling* **14**: 59-74.
- Gaylarde P.M., Englert G., Ortega-Morales O. and Gaylarde C.C. 2006. Lichen-like colonies of pure *Trentepohlia* on limestone monuments. *Int. Biodeterior. Biodegrad.* **58**: 119-123.
- Gaylarde P.M. and Gaylarde C.C. 2000. Algae and cyanobacteria on painted buildings in Latin America. *Int. Biodeterior. Biodegrad.* **46**: 93-97.
- Gomez S.R., Johansen J.R. and Lowe R.L. 2003. Epilithic aerial algae of Great Smoky Mountains national park. *Biologia, Bratislava* **58**: 603-615.
- Hindák F. 1977. *Studies on the Chlorococcal algae/ Chlorophyceae*: VEDA. Publishing House of the Slovak Academy of Science, Bratislava, 186 pp.
- Hrouzek P. and Šoun J. 2004. Some finds of subaerophytic cyanobacteria on wetted walls of La Palma (Canary islands). *Czech Phycology Olomouc* **4**: 155-162.
- Klochkova T.A. and Kim G.H. 2005. Ornamented resting spores of a green alga, *Chlorella* sp., collected from the stone standing Buddha statue at Jungnon Miruksazi in Korea. *Algae* **20**: 295-298.
- Komárek J. and Fott B. 1983. Das Phytoplankton des Süßwassers, 7. Teil: E. Schweizerbart' Sche Verlagsbuchhandlung, Stuttgart, 1001 pp.
- Kováčik L. 2000. Cyanobacteria and algae as agents of biodeterioration of stone substrate of historical buildings and other cultural monuments. In: Choi S. and Suh M. (eds), *Proceedings of the New Millennium International Forum on Conservation of Cultural Property*, Daejeon, Korea. pp. 44-58.
- Krishnamurthy V. 1998. *Algae of India and neighbouring countries I. Chlorophycota*, Oxford and IBH Publishing Co. Pvt. Ltd., New Delhi, 205 pp.
- Mishra P.K. and Srivastava A.K. 2003. Some desmids (Chlorophyceae) from North - Eastern Uttara Pradesh, India. *J. Ind. Bot. Soc.* **82**: 85-92.
- Noguerol-Seoane A. and Rifón-Lastra A. 2003. Spatial and temporal distribution of Cyanoprokaryota in edified granite walls. Taxonomical consideration. *Algolog. Stud.* **109**: 443-454.
- Ortega - Calvo J.J., Sanchez-Castillo P.M. and Hernandez-Marine M. 1993. Isolation and characterization of epilithic chlorophytes and cyanobacteria from two Spanish cathedrals (Salamanca and Toledo). *Nova Hedwigia* **57**: 239-253.
- Ortega - Morales B.O., Gaylarde C.C., Englert G.E. and Gaylarde P.M. 2005. Analysis of salt - containing biofilms on limestone buildings of the Mayan culture at Edzna, Mexico. *Geomicrobiol. J.* **22**: 261-268.
- Pattanaik B. and Adhikary S.P. 2002. Blue-green algal flora at some archaeological sites and monuments of India. *Feddes Repertor.* **113**: 289-300.
- Peraza Zurita Y., Cultrone G., Sánchez-Castillo P., Sebastián E. and Bolivar F. C. 2005: Microalgae association with deteriorated stone work of the fountain of Bibatauin in Granada, Spain. *Int. Biodeterior. Biodegrad.* **55**: 55-61.
- Philipose M.T. 1967. *Chlorococcales*: Indian Council of Agricultural Research, New Delhi, 345 pp.
- Rindi F. and Guiry M.D. 2004. Composition and spatial variability of terrestrial algal assemblages occurring at the base of urban walls in Europe. *Phycologia* **43**: 225-235.
- Rindi F. and López-Bautista J.M. 2007. New and interesting records of *Trentepohlia* (Trentepohliales, Chlorophyta) from French Guiana, including the description of two new species. *Phycologia* **46**: 698-708.
- Rindi F., Sherwood A.R. and Guiry M.D. 2005. Taxonomy and distribution of *Trentepohlia* and *Printzina* (Trentepohliales, Chlorophyta) in the Hawaiian Islands. *Phycologia* **44**: 270-284.
- Rippka R. Deruelles J, Waterbury J.B, Herdman M and Stanier R.Y. 1979. Generic assignments, strain histories and properties of pure cultures of cyanobacteria. *J. Gen. Microbiol.* **111**: 1-61.
- Thompson R.H. 1959. Fresh Water Biology. In: Edmondson W.T. (ed.), *Algae*. Chapman and Hall Ltd., London. pp. 115-168.
- Tilden J. 1910. *Minnesota Algae: Vol. I. The Myxophyceae of North America and adjacent regions including Central America, Greenland, Bermuda, West Indies and Hawaii*. The University of Minnesota, Minneapolis, Minnesota, USA, 328 pp.
- Tomaselli L., Lamenti G., Bosco M. and Tiano P. 2000. Biodiversity of photosynthetic micro - organisms dwelling on stone monuments. *Int. Biodeterior. Biodegrad.* **46**: 251-258.
- Tripathi S.N. 1984. Observation on subaerial blue-green algae from the campus of the Banaras Hindu University, Varanasi - I. *J. Sci. Res.* **34**: 179-185.
- Tripathi S.N., Tiwari B.S. and Talpasayi E.R.S. 1991. Growth of

- cyanobacteria (blue green algae) on urban buildings. *Energy Build.* **15-16**: 499-505.
- Tripathy P., Roy A., Anand N. and Adhikary S.P. 1999. Blue green algal flora from the temples and monuments of India. *Feddes Repertor.* **110**: 133-144.
- Uher B., Aboal M. and Kovácik L. 2005. Epilithic and chasmoendolithic phycoflora of monuments and buildings in south-eastern Spain. *Cryptogamie Algologie* **26**: 275-358.
- Videla H.A., Guiamet P.S. and Gomez de Saravia S.G. 2000. Bioteriation of Mayan archaeological sites in the Yucatan Peninsula, Mexico. *Int. Biodeterior. Biodegrad.* **46**: 335-341.
- West W. and West G.S. 1905. *A Monograph of the British Desmidiaceae*. The Ray Society, London, 204 pp.
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Received 4 April 2008

Accepted 3 May 2008