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A new Archaean stromatolite from the Chitradurga Group, Dharwar Craton, India and its significance

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ABSTRACT

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The present paper deals with the systematics, morphogenesis and depositional environment of a new stromatolite morphotype *Batiola indica* from the ~ 2.6 Ga old Archaean sediments of the Chitradurga Group, Dharwar Craton, India. It has been grouped under family Cryptophytonidae. Its morphological features are attributed to both biotic and environmental factors and considered to have been formed in a tidal regime.

Key-words—Stromatolite, Archaean, Chitradurga, Dharwar, India.

भारत के धारवाड़ क्रेटान की चित्रदुर्ग वर्ग से प्राप्त एक नवीन आर्कियन युगीन स्ट्रोमेटोलाइटी संरचना एवं इसका महत्व

मुकुंद शर्मा एवं मनोज शुक्ल

सारांश

प्रस्तुत शोध पत्र में लगभग 2.6 अरब वर्ष पुरानी आर्कियन युगीन धारवाड़ क्रेटान के चित्रदुर्ग वर्ग से प्राप्त *बेटियोला इंडिका* नामक नवीन स्ट्रोमेटालाइट चित्रप्ररूप के वर्गीकरण, संरचना विकास एवं निक्षेपण वातावरण की चर्चा की गई है। इसे क्रिप्टोफाइटोनिडी कुल के अन्तर्गत रखा गया हैं। इसकी संरचना के लिये जैविक तथा निक्षेपण कारकों को उत्तरदायी माना गया है और इसका निर्माण समुद्र के ज्वारीय वातावरण में माना गया है।

संकेत शब्द – स्ट्रोमेटोलाइट, आर्कियन, चित्रदुर्ग, धारवाड़, भारत।

INTRODUCTION

ARCHAEAN stromatolites are yet not completely understood starting pages of the early biosphere. These are testimony of interaction of biosphere, hydrosphere and lithosphere existent at that time. Generally, stromatolites are considered to be the biogenic sedimentary structures formed by trapping, binding and or precipitation activity of phototrophic microbes (Awramik, 1992). There are however possibilities that some of these layered structures may not be biogenic (Grotzinger & Rothman, 1996). In the Archaean sediments, they are found in thin localised sedimentary carbonate rocks mostly associated with volcanic sequences (Hofmann, 2000). Reviewing the Archaean stromatolite occurrences, Walter (1983) listed 11 localities (counted by major stratigraphic units) that increased to 32 occurrences

	LOCALITY AND COUNTRY	GEOLOGICAL STAGE AND AGE	STROMATOLITE TYPE	SEDIMENTARY ENVIRONMENT	REFERENCES
AUSTRALIA	Pilbara Block, Australia	Warrawoona Group, 3.5 Ga	Pseudocolumnar stromatolites, *Conophyton* type, stratiform, nodular	Shallow, hypersaline marine, peritidal environment	Lowe, 1980; Walter *et al.*, 1980; Walter, 1978; Hickman, 1973
	Hamersley Basin, Knoss locality, Australia	Tumbiana Formation, Fortesque Group, 2.768 ± 0.024 Ga	Nodular stratiform stromatolites forming domical biostromes	Intermontane basins in a basin range environment	Walter, 1972; Grey, 1979
	Hamersley Basin, Australia	Carawine Dolomite, Hamersley Group, 2.5 Ga	Decimeter to meter sized bulbous and nodular stromatolites stratiform and erect centimeter pseudocolumnar forms	Shallow marine	Grey, 1979
	Hamersley Basin, Australia	Turee Creek Group, 2.4 Ga	Pseudocolumnar stromatolites	Not available	Walter, 1983
AFRICA	Barberton Mountainland, Kaapvaal Craton, Transval, South Africa	Onverwacht Group, 3.504 ± 0.03 Ga	Stratiform stromatolites	Low energy shallow Water environment on a platform type	Lowe & Knauth, 1977; Lowe, 1980
	Wit Mfolozi Inlier, Kaapvaal Craton, South Africa	Insuzi Group, 3 Ga	Isolated and bulbous stratiform stromatolites together with variously contiguous to widely divergent	Intertidal and shallow tidal conditions at the margin of an epieric sea	Mason & von Brunn, 1977; von Brunn & Mason, 1977
	Huntsman quarry, Zimbabwe	Bulawayo Group, Bulawayo Greenstone Belt, 2.7-2.6 Ga	Linked nodular forms with a growth relief of 20 to 40 cm and oncolitic	Marginal marine environment in a water of unknown depth but probably subtidal as indicated by the stromatolite morphology	Walter, 1983, MacGregor, 1941, Cloud & Semikhatov 1969; Schopf *et al.*, 1971
	Barberton Mountainland, South Africa	Fig Tree Group, 3.3 Ga	Laterally linked domes, small domes have developed into larger domes, compound domes, or pseudocolumns, stratiform with fine crinkly laminae, columnar	Shallow water settings associated with near evaporitic or evaporitic environments	Byrely *et al.*, 1986
	Mushandike Sanctuary near Masvingo (Fort Victoria), Zimbabwe	Mushandike Formation, Zimbabwe, 3.445 ±0.60 Ga	Stratiform	Not available	Orpen & Wilson, 1981; Abell *et al.*, 1985

	LOCALITY AND COUNTRY	GEOLOGICAL STAGE AND AGE	STROMATOLITE TYPE	SEDIMENTARY ENVIRONMENT	REFERENCES
AFRICA	Belingwe Greenstone Belt, Zimbabwe	Ngesi Group, Chesire and Manjeri Formations, Zimbabwe 2.6 Ga	Stromatolitic forms are similar to *Baicalia*, *Conophyton*, *Irregularia* and *Stratifera*	Shallow water environment and display well developed dessication features	Martin *et al.*, 1980
AFRICA	T'kuio hill and Welkom Gold field area	Ventersdorp Supergroup 2.6 Ga	*Stratiform*, pseudocolumnar and low linked nodular forms	Non marine, fluvial environment	Grobler & Emslie, 1976; Buck, 1980; Winter, 1963
NORTH AMERICA	Uchi Greenstone Belt, Red Lake area and Woman Lake area	Woman Lake marble sequence, 2.83 Ga	*Collonella, Stratifera* and *Collumnaefacta* and pseudofossil *Atikokania, Stratifera*, small mounded structures, problematic columnar structures	These stromatolites are found in much deep water	Hofmann *et al.*, 1985; Thurston & Jackson, 1978
NORTH AMERICA	Slave Province Canada	Yellowknife Supergroup, Canada, 2.7 Ga	Stratiform, Pseudocolumnar layered forms 1 to 15 mm wide, with α-β parallel branching	Very shallow intermittently exposed turbulent environment	Henderson, 1975
NORTH AMERICA	Quebec Belt Superior Province, Canada	Steep Rock Group, 2.7 Ga	Elongate large nodular from, nodular stromatolites, linked nodular pseudocolumnar to columnar layered	Shallow marine environment	Hofmann, 1971; Joliffe, 1955
INDIAN PENINSULA	Yeshwanthanagar Sandur, Karnataka, India	Deogiri Formation, Sandur Schist Belt, >2.6 Ga	Columnar, elleptical in outline	Shallow marine environment	Baral, 1986
INDIAN PENINSULA	Dodguni, Marikanve, Bhimsamudra and Kalche localities of Chitradurga District, India	Vanivilas Formation Chitradurga Schist Belt, > 2.6 Ga	Cylindrical and terete columns, pseudocolumnar domal, naked strumatolite α, β&γ type branching to markedly divergent branching	Intertidal and subtidal environment	Baral, 1986; Mallikarjuna *et al.*, 1987; Srinivasan *et al.*, 1989, 1990
INDIAN PENINSULA	Kumsi, Shimoga District, Karnataka, India	Joldhal Formation, Shimoga Schist Belt, >2.6 Ga	Stratiform, domal, pseudocolumnar, cylindrical & elleptical stromatolites	Shallow intertidal environment	Vasudev *et al.* 1989
INDIAN PENINSULA	Bonai-Keonjhar District, Orissa, India	Iron Ore Formation 3 Ga	Laterally linked hemispheroid, domal shaped oncolites	Marine intertidal mud flat environment	Avasthi, 1980

Fig. 1—World-wide distribution of Archaean stromatolites and their depositional environment.

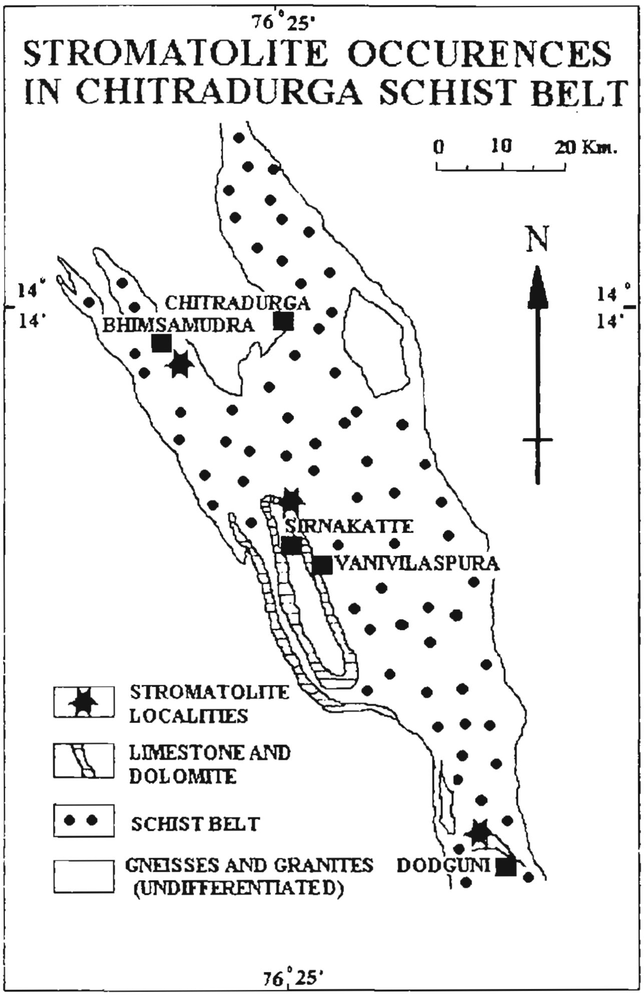

Fig. 2—Map showing Bhimasamudra Locality of the stromatolite, *B. indica* in the Chitradurga Schist Belt (after Srinivasan *et al.*, 1989).

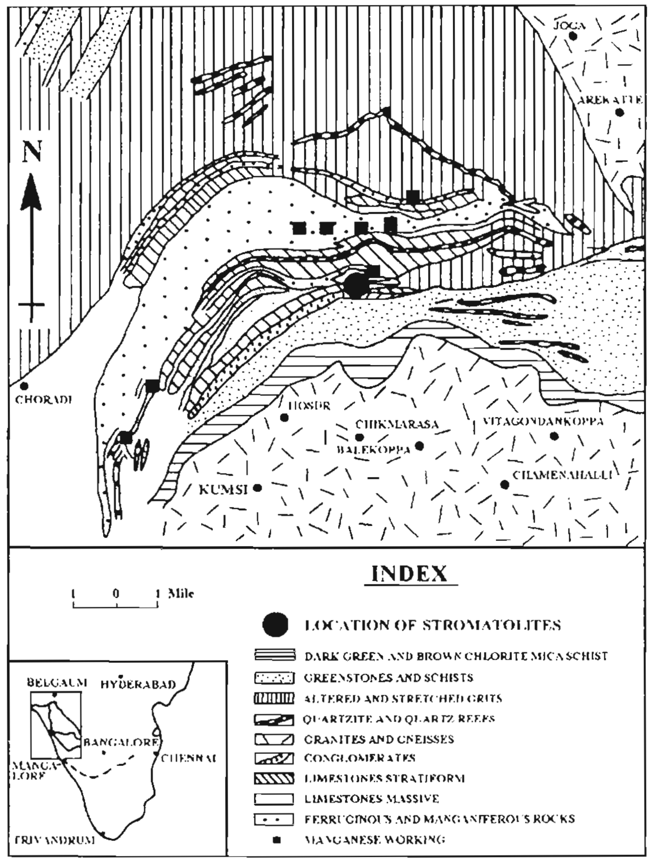

Fig. 3—Map showing the stromatolite locality in the Shimoga Schist Belt (after Jayaram, 1917).

reported from 11 small regions preserved in Archaean cratons by the close of twentieth century (Hofmann, 2000). In this global list are included three occurrences from Dharwar Craton (Murthy & Reddy, 1984; Baral, 1986; Mallikarjuna *et al.*, 1987; Srinivasan *et al.*, 1989, 1990; Vasudev *et al.*, 1989) and one from the Singhbhumi Craton (Avasthi, 1980) reported from India. Earlier reviews of Archaean stromatolites are those of Walter (1983, 1994), Nisbet (1987), Awramik (1991, 1992), Schopf, (1994) and Hofmann (2000). A summary based on earlier reported occurrences of stromatolites is tabulated in Fig. 1 for better appreciation of the newly described stromatolites in the present paper.

Morphological types of the Archaean stromatolites include convex-up, concave-up and; stacking patterns producing nodular, columnar – both unbranched and branched and oncoidal forms (Hofmann, 2000). Considering the rarity of Archaean stromatolites, it is therefore essential to report and document new occurrences, their characteristics and variations. Previously Srinivasan *et al.* (1990) reported pseudo-columnar stromatolites with concave top and long wrinkled or wavy base found associated with terete-shaped stromatolite from Bhimsamudra area of the Chitradurga Schist Belt. Similar stromatolites also occur in the cherty dolomite member of Joldhal Formation in the 12th sector of Krishna Block in Kumsi Dolomite Mine. The present paper deals with the taxonomy, textural study and morphogenesis of a new stromatolite-morphotype reported from the Archaean sediments of the Chitradurga Group with comments on its depositional environment.

GEOLOGICAL SETTING

Archaean schist belts of the Dharwar Craton are broadly divided into older and younger schist belts (Radhakrishna, 1976; Naqvi, 1981). The Chitradurga and Shimoga schist belts belong to younger schist belts and range in age from 3000-2500 Ma (Taylor *et al.*, 1988; Jayananda *et al.*, 2000; Chadwick *et al.*, 2000). Lithostratigraphic details of the Chitradurga Schist Belt has been worked out by Sheshadri *et al.* (1981) and that of the Shimoga Schist Belt by Harinadha Babu *et al.* (1981) (Figs 2, 3). The Vanivilas Formation (Chitradurga Schist Belt) and the Joldhal Formation (Shimoga Schist Belt) belong to the Chitradurga Group of the Dharwar Supergroup. Stromatolites occur in the cherty dolomite member of the Vanivilas and Joldhal formations of the Chitradurga Group. The stromatolite bearing cherty dolomite is underlain by current bedded, ripple marked quartzite, phyllite, basic and intermediate volcanic rocks and overlain by chemogenic BMF and/or BIF (Fig. 4). Earlier accounts of stromatolite occurrences in different schist belts of the Dharwar Supergroup have been given by Venkatachala *et al.* (1989), Vasudev *et al.* (1989) and Srinivasan *et al.* (1990).

SYSTEMATICS

Stromatolite has been described along the format suggested by Preiss (1972), Walter (1972), Krylov (1975, 1976) and Grey (1984), requiring studies in outcrop, three-dimensional reconstruction through serial longitudinal sectioning and characteristics of the microstructure. A plan has been devised for morphometeric analysis and data collection of new stromatolite type. Three hypothetical axes A, B and C have been assumed for taking different measurements (see Fig. 5).

Subtype—COMPACTITHI

Class—PICNOSTROMA

Order—CRYPTIIDA

Family—CRYPTOPHYTONIDAE

Morphotype—BATIOLA Gr. nov.

BATIOLA Gr. nov.

Type form—Batiola indica Gr. et f. nov.

Derivation of name—The name has been derived from cup-shaped appearance of stromatolites.

Diagnosis—Stromatolites solitary or in-groups; mostly cup-shaped also occur as discrete heads, club and wash bowl to saucer-like structure attached to substrate at a single point (Fig. 6a & b).

Content—Batiola indica only.

Comparision—Cryptophyton convolutum Raaben and Komar - the only other member of the family Cryptophytonidae has nodular shape and convolute lamination. The general shape of the build-up of *C. convolutum* is inverted pear-like with a narrow pointed base. Height of the structure equals or exceeds the diameter. Whereas in the case of *Batiola,* the build-ups are cup to bowl-shaped. There is a depression in the centre, probably, due to collapse of the mat. Both concave and convex laminae are found in the stromatolites. Central

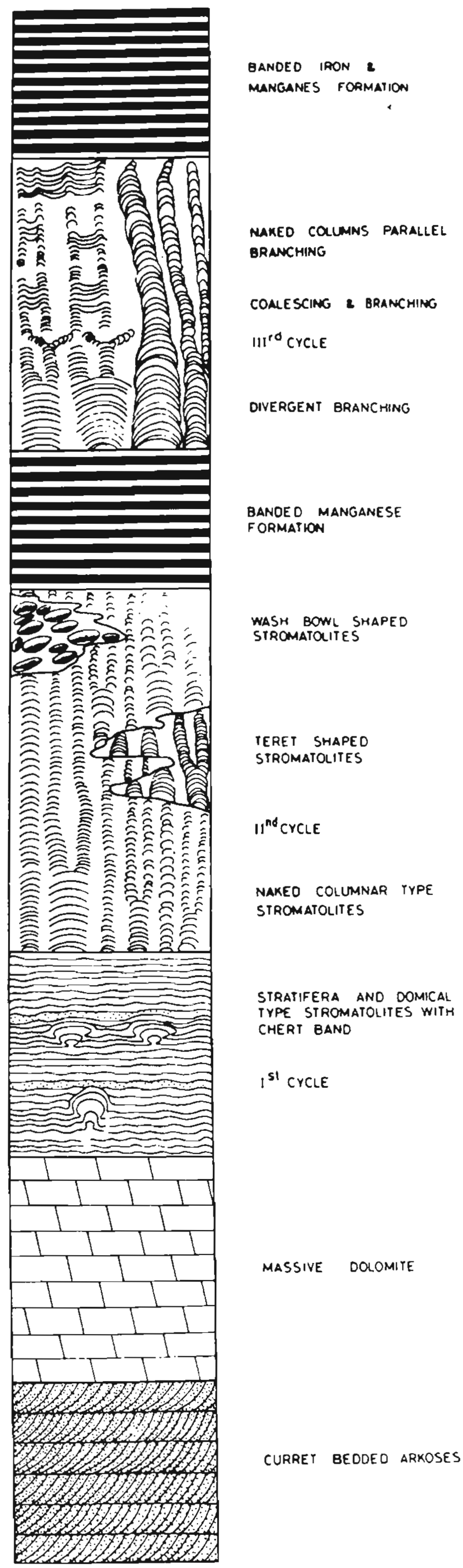

Fig. 4—Generalised succession of stromatolites and lithology as observed near Bhimsamudra Tank, Chitradurga Schist Belt (not to scale).

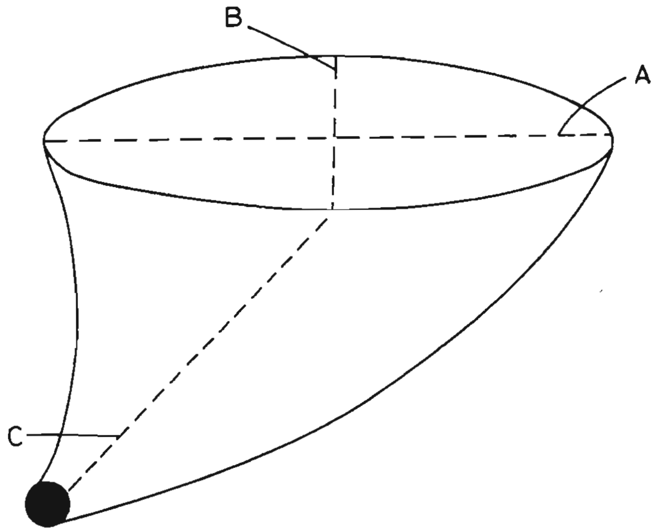

Fig. 5—Line diagram of *B.indica* and different hypothetical axes on which it was measured in the field.

depression and the occurrence of both convex/concave laminae make this group distinct from *Cryptophyton*.

Distribution—Known from the Vanivilas and Joldhal formations of the Chitradurga Group in Bhimsamudra area and 12th sector of Krishna Block in Kumsi Dolomite Mine.

Age—Late Archaean, ~2600 Ma (primary age of deposition of stromatolite is not known).

BATIOLA INDICA Gr. et. f. nov.

(Figs 6a, b, 7 & 8)

Material—12 specimens.

Holotype—Specimen Number BSIP 36718 from the Kumsi Mine, Joldhal Formation, Shimoga Schist Belt.

Name—The name "indica" is to denote the geographical location.

Diagnosis—Stromatolites generally occur in group, occasionally solitary; cup-shaped, bowl to saucer like; size vary from centimeter to decimeter; mostly attached at the bottom rarely on the sidewalls. In some cases the central part is collapsed.

Description—No sediment support has been observed between the cups, or bowl but most of them are attached at a single point at the bottom. They are circular to oblong in transverse sections and show irregular, convex and concave lamination in longitudinal sections. The observed size range along axis A is 2-90 cm, along B 1-40 cm and along C 1-70 cm. Fine laminae show admixture of carbonate and silica. Lamina profiles are irregular, convex and concave. Convex laminae are tightly joined. The cross section of stromatolites may appear oval, oblong or trapezoidal. The original morphology has changed considerably due to compression. The stromatolites have been noticed in isolated blocks in one locality and have

Fig. 6a—Field photograph showing one of the isolated blocks near Bhimsamudra Tank, see hammer for the scale.

Fig. 6b—Holotype of *B. indica*. Specimen Number BSIP 36718 (Kumsi Mine Shimoga Schist Belt).

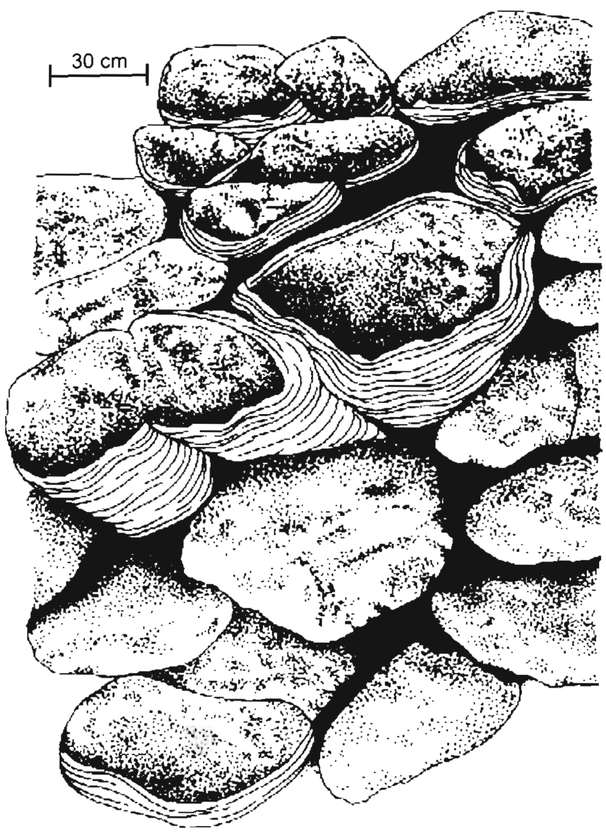

Fig. 7—Line sketch of *B. indica*.

limited lateral extension in the other. Therefore, it is difficult to infer the feature of the biostrom/ bioherm.

Mode of Occurrence

Outcrop— Stromatolites occur in pockets in both Chitradurga and Shimoga schist belts of the Dharwar Supergroup. These stromatolites have been observed at 2 km south of Bhimsamudra (North lat. 14°10'15", E log.76°15'15") locality in four isolated blocks in the Vanivilas Formation of Chitradurga Group (Fig. 2).

Extensive dolomite/limestone beds are present in the Joldhal Formation of the Kumsi area (Fig. 3). They show intercalation of Banded Manganese Formation. In the 12th sector of Krishna Block in the Kumsi dolomite mines, these bowl-shaped stromatolites have been observed at three levels. The stromatolitic horizon is both overlain and underlain by cherty dolomites.

Fascicle morphology—No true fascicles are noted.

Branching— Branching absent.

Column shape and margin structure—Genesis of bowl-shaped morphology do not allow formation of columns. It seems that these structures develop due to sun cracking of microbial mats. This pattern inhibits unidirectional growth which is essential to form columns. Margins are not prominent but are continuous, oval or oblong in outline. Laminae do not continue from one wash bowl structure to the other.

Lamina shape—Laminae are continuous, wavy, irregular, convex and concave. The profile of the top lamina is concave. The lower laminae are convex and irregular. The stromatolite is marked by alternating light and dark laminae which are composed of dolomite and a ferruginous mineral. Secondary alteration processes have partially changed the fabric.

Microstructure and texture—The light colored laminae are thicker in comparison to the dark ones. However, in the concave part of a laminae the thickness of dark and light laminae are almost equal. The microstructure of the stromatolite is complex, predominant micritic laminae are visible as light grey areas. The lighter coloured laminae are 400-500 µm thick. These laminae are smooth to slightly crinkled; clots occur subordinately. Interlaminar boundaries are indistinct. They are marked by slight change in grain size, which is either gradational or sharp. Occasionally crinkled films of black material mark the boundaries (? Organic matter). The dark grey areas are always sharply outlined by (?) organic film. These laminae are 15-20 µm thick. The darker areas are analogous in shape and texture to those that appear between micritic laminae. The main constituents of these laminae are dolomites and ferruginous mineral. The stromatolitic laminae are made up of carbonates. The presence of relict rhombs of carbonate in silicified parts indicates partial secondary replacement of carbonate. Similarly, the presence of fine rounded argillaceous/ arenaceous grains indicate the continuous inflow of detrital elements on the wet microbial mats which got deposited on them. The lighter grey laminae consist of polygonal quartz grains that have resulted from the recrystallisation of chert.

Interspace filling—The material that was present, as inter bowl filling, is no longer preserved. It might have been eroded, most probably, after consolidation of bowl-shaped stromatolites leaving solitary club-shaped structure attached to the bottom. This weathering must have occurred because of difference in constituent elements of bowl-shaped stromatolites and inter spaces.

Secondary alteration—Stromatolites in the Chitradurga Group are mostly present in dolomites, some of them are also noted in chert layers. Recrystalisation of stromatolites was not strong enough to obliterate the laminations. The beds containing them, however, are folded and tilted to vertical position, and the stromatolites are compressed.

MORPHOGENESIS OF *BATIOLA INDICA*

Similar bowl-shaped stromatolites have been reported from the Late Precambrian Annijokka Member of the Batsfjord Formation on the Varanger peninsula, North Norway (Sidlecka, 1982), from the Pleistocene sediments of Lake Lisan, a precursor

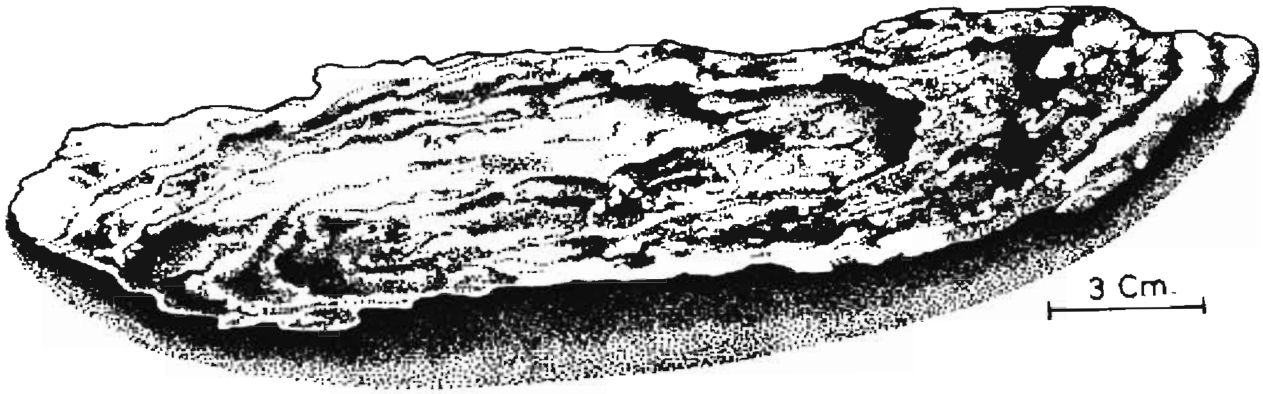

Fig. 8—Reconstruction of individual member of *B. indica*. Note the central depression.

of the modern Dead Sea (Buchbinder, 1981) and from Hamelin Pool in Western Australia (Logan *et al.*, 1974). Algal head of type "C" stromatolites from Andros Island have similar central depression (Black, 1933). Hoffman (1976) has also figured similar forms from the upper intertidal of the rocky Headlands in Hamelin Pool. These stromatolites have been variously described and not formally named by these authors. The depositional environment of these forms varies from upper intertidal to supratidal/ponded regimes. The large variation in size that is observed in Dharwar stromatolites has also been reported in the Batsfjord Formation (Sidlecka, 1982) and Lake Lisan (Buchbinder, 1981). The reported size range in Batsfjord Formation is 0.30-0.40 m across and in Lake Lisan 0.3-10 m in diameter and 0.3 to 3 m in height.

The most plausible mode of the formation of such wash-bowl-shaped structures of the Chitradurga Group has been explained through frequent exposure of algal mats and resultant sun cracking. These cracks are apparently responsible for the collapse of the top layers of mats resulting in ultimate concave shape of the upper laminae (see Fig. 9). The sandy or the arenaceous admixture, present on fascicles represents passive trapping of fine detrital grains when the mats were exposed. Repetition of similar process would give rise to bowl-shaped structures (Sidlecka, 1982). The large variation in size of these structures may be due to their development near the margin (smaller size) and in deeper zones (bigger size) of the tidal pools. Optimum level of water in deeper zones would permit growth of large "fascicles" compared to marginal areas in some of the larger pools. Deeper regions of the pools when exposed during neap tide were responsible for the larger cracks giving rise to large specimen of *B. indica*.

Mud cracks, fenestrae or bird eye structures, and film & blister algal mats are typical supratidal features. The preservation of these structures depends upon the "exposure index" (Ginsburg *et al.*, 1977). Stratified and irregular algal mats are present in both Joldhal and Vanivilas formations. Petrological thin section of bowl-shaped stromatolites shows tufted feature of laminae presumably after the mats and presence of fenestral feature. Though, the fenestrae in association with sun cracked laminae (formed possibly after tufted mats) indicate the possibility of formation in the supratidal region. However, the tufted nature of mat is generally present in upper intertidal region (Golubic, 1976; Hofmann, 1976; Golubic & Hofmann, 1976; Knoll & Golubic, 1979; Sergeev, 1994; Sergeev *et al.*, 1995). Srinivasan *et al.* (1989) have opined that these stromatolites were formed in local depressions of upper intertidal regions where prolonged dry conditions could prevail. Morphologically similar forms are also known from the Haemlin pool (Hoffmann, 1974) in the upper intertidal settings. Therefore, *Batiola indica* apparently formed in the water-logged depressions and tidal pools covered by flat low mat which can occur both above the Mean High Tide (MHT) and between the Mean Low Tide (MLT) and MHT (see figs 1 & 2 of Golubic, 1976).

CONCLUDING REMARKS

The Archaean stromatolites are not markedly different from the Proterozoic forms. Lateral variation in morphology of stromatolites related to changing environments (subtidal-intertidal and supratidal) are well-documented in areas where they are growing at present (Playford & Cockbain, 1969; Logan *et al., 1974;* Hoffman, 1976). By analogy with modern stromatolites builders (Golubic & Hofmann, 1976; Knoll & Golubic, 1979) it may be inferred that the biota which could withstand high salinity and exposure to desiccation had already evolved by the Late Archaean. Since atromatolite morphology is a product of both biotic and environmental factors, it can be inferred that sufficient diversity of both biota

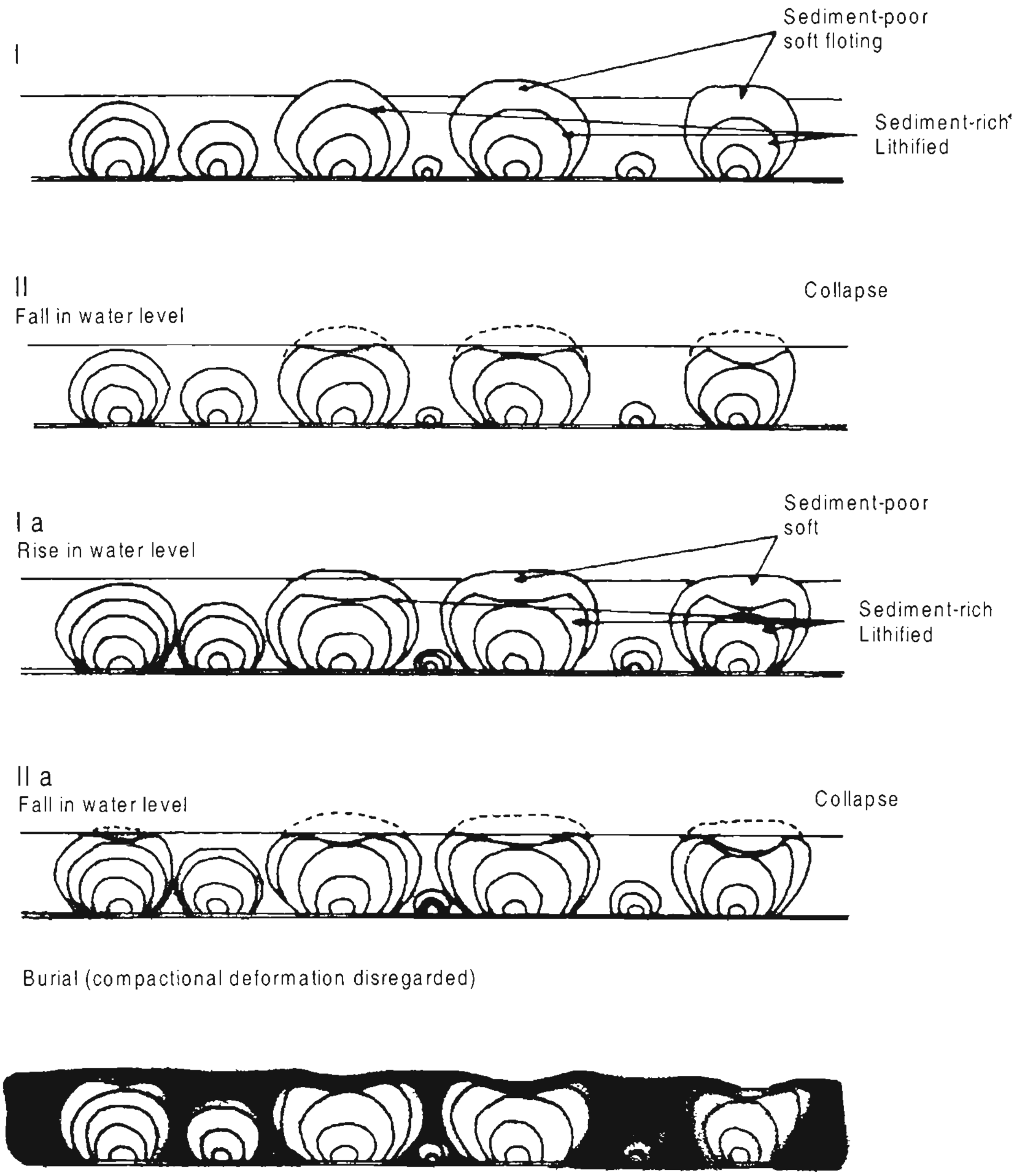

Fig. 9—Probable mode of origin of *B. indica*, the bowl-shaped stromatolites (after Sidlecka, 1982).

and environmental regimes conductive to microbial development existed during the Late Archaean.

Nodular or mound like forms that can be assigned to family Cryptophytonidae have been reported from the different stratigraphic levels in geological history belonging to different environments ranging from upper intertidal-supratidal and even ponds (Black, 1933, Logan *et al.*, 1974; Hoffman, 1976; Sidlecka, 1982) (see also Fig. 1 for the Archaean stromatolites). Simple type of Archaean stromatolites occur in two units of the Whalen Group (> 2.58 Ga) in eastern Wyoming attributable to the long ranging group *Stratifera, Columnaefacta* and *Gruneria* (Hofmann & Synder, 1985). *Stratifera, Colleniella* and *Collumnaefacta?* type of stromatolites are known from the Red Lake and Woman Lake areas of the Uchi Greenstone Belt in North Western Ontario (~ 2.92 to 2.94 Ga old), Canada (Hofmann *et al.*, 1985). Simple type of stromatolites have been recorded from Michipicoten Group (2.75-2.7 Ga.) of Canada by Hofmann *et al.* (1991).

Our present knowledge of Indian stromatolite and their depositional environments is based on the study of restricted outcrop representing specific environmental settings and may not depict the true picture of the stromatolitic bioherm distribution during the Archaean. The earlier report of Srinivasan *et al.* (1989) indicates that considerable morphological diversity in stromatolites was prevalent during the deposition of sediments of the Dharwar Supergroup of Late Archaean. Present report of *B. indica* adds a new dimension to the understanding of depositional environment of Archaean stromatolites. Stromatolites in such highly specialised niches of the Archaean are very few in the world and this is the first such report from Indian Archaean sediments.

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