Microbial remains from the Chambaghat Formation, Krol Group, Himachal Lesser Himalaya, India and their significance

The present correspondence records an assemblage of microbial remains comprising cyanobacteria, multicellular tissues of algal thalli (thallophytes) belonging to Rhodophyta, acritarchs and vase-shaped microfossils (VSMs) from the phosphatic black chert lenticles and shale partings associated with quartz arenite of Chambaghat Formation (Krol Sandstone), Krol Group[1,2] exposed about 400 m northeast of Jahar (30°45′35″: 77°13′30″) in the Southern limb of Kamlidhar Syncline, Sirmaur district, Himachal Lesser Himalaya (Figure 1 *a* and *b*). These fossils have also been recorded from the same horizon exposed about 300 m south of Sauti (30°48′25″: 77°11′35″), Sirmaur district, Himachal Lesser Himalaya.

The petrographic thin sections and macerated fraction of phosphatic chert lenticles and shale show the presence of 22 genera of brownish-yellow microbial remains. The present assemblage is divisible into four distinct microfossil communities, viz. cyanobacteria, acritarchs (medium-sized, simple and ornamented sphaeromorphs as well as few forms with well developed processes belonging to acanthomorphs), VSMs and multicellular tissues of algal thalli (thallophytes) belonging to Rhodophyta phylum (Figure 2). The slides and negatives are preserved in the museum of Birbal Sahni Institute of Palaeobotany, Lucknow (Statement No. 1118).

The recovered cyanobacterial remains are represented by a group of sphaeroidal cells and unbranched trichomes, both septate and aseptate. They belong to the orders Chroococcales, Entophysalidales, Oscillatoriales and Nostocales. They compare morphologically with the known taxa, viz. *Tetraphycus hebeinsis* Liu; *Myxococcoides minor* Schopf; *Bavlinella faveolata* (Shepeleva) Vidal; *Eoentophysalis gilensis* Zang; *Siphonophycus kestron* Schopf; *S. typicum* (Hermann) Butterfield in Butterfield *et al.*; *S. septatum* Schopf; *S. robustum* (Schopf), Knoll and Golubic, emend. Knoll *et al.*; *Obruchevella parva* Reitlinger, and chain-like aggregation of spherical cells cf. *Veteronostocale moniliforme* Xu and Gao; *Oscillatoriopsis breviconvexa* Schopf and Blacic, and *Eomicrocoleus crassus* Horodysyki and Donaldson.

The acritarchs are represented by simple and ornamented forms belonging to Sphaeromorphida and Sphaerohystrichomorphida subgroups, morphologically similar to the known genera, viz. *Margominuscula simplex* Pychova; *Leiosphaeridia holtedahlii* (Timofeev) Jankauskas; *Satka colonialica* Jankauskas; *Paracrassosphaera dedalea* Faizulina and Treshchetenkova; *Granomarginata prima* Naumova; *Lophosphaeridium* sp. Zhang *et al.*; *Micrhystridium lanceolantum* Yin; *Baltisphaeridium perrarum* Jankauskas; *Vandalosphaeridium reticulatum* (Vidal) Vidal; *Gorgonisphaeridium pindyium* Zang, and a unique form having ellipsoidal-to-ovoid chamber or testae of VSM, viz. *Melanocyrillium hexodiadema* Bloeser is also present. They are 23–40 μm long, have laevigate fractured surface and narrow neck with 5–6.0 μm broad opening.

Two genera of multicellular tissues of algal thalli (thallophytes) belong to the Rhodophyta phylum. They are circular in cross-section, and do not show reproductive structures (organs/parts); hence they may represent juvenile stage of the algal thalli (gametophyte) and measure up to 120 μm. The forms are with or without epidermal layer. The cells are polygonal to sphaeroidal, compact or sometimes loosely arranged. Three taxa, viz. *Wengania globosa* (Zhang) Zhang *et al.*; *W. minuta* Xio and *Thallophyca ramosa* (Zhang) Zhang *et al.* have been identified.

The underlying Blaini Formation has been correlated with Nantuo Formation of South China, which is considered of Terminal Neoproterozoic age[3,4]. VSMs with short neck recorded here, have also been recorded

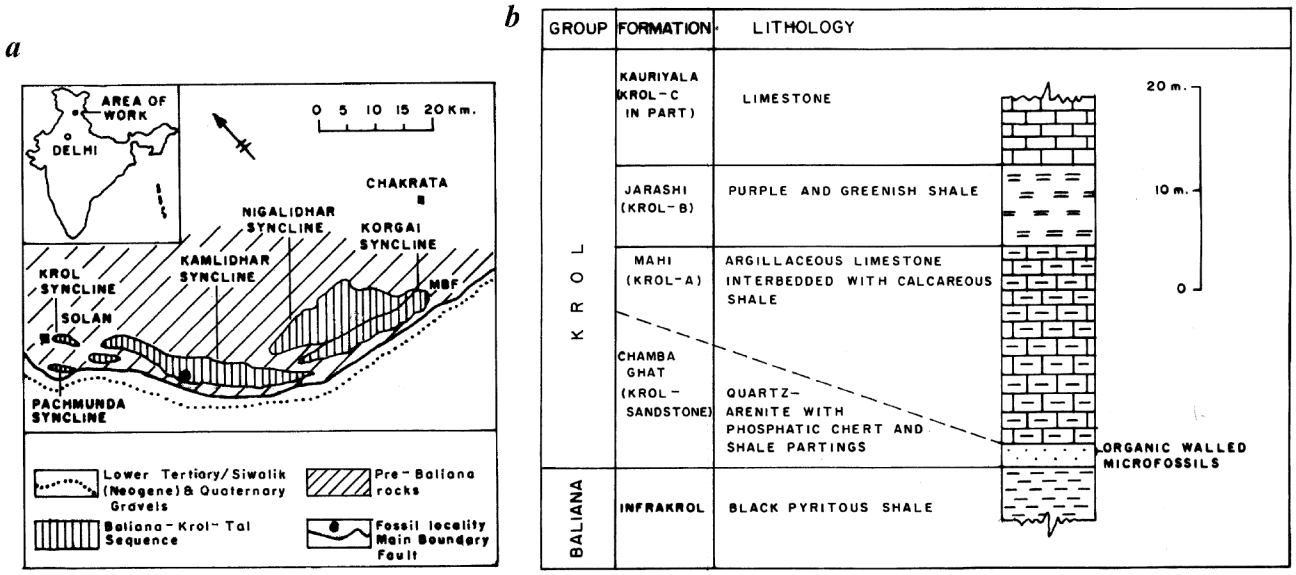

Figure 1. *a*, Geological map of Baliana–Krol–Tal succession of Krol Belt, Himachal Lesser Himalaya showing fossil locality (modified after Shanker *et al.*[1] and Auden[22]); *b*, Stratigraphy column of part of Krol Group exposed at Jahar–Phagla Section, southern limb of Kamlidhar Syncline, Sirmaur district, Himachal Pradesh showing fossiliferous horizon.

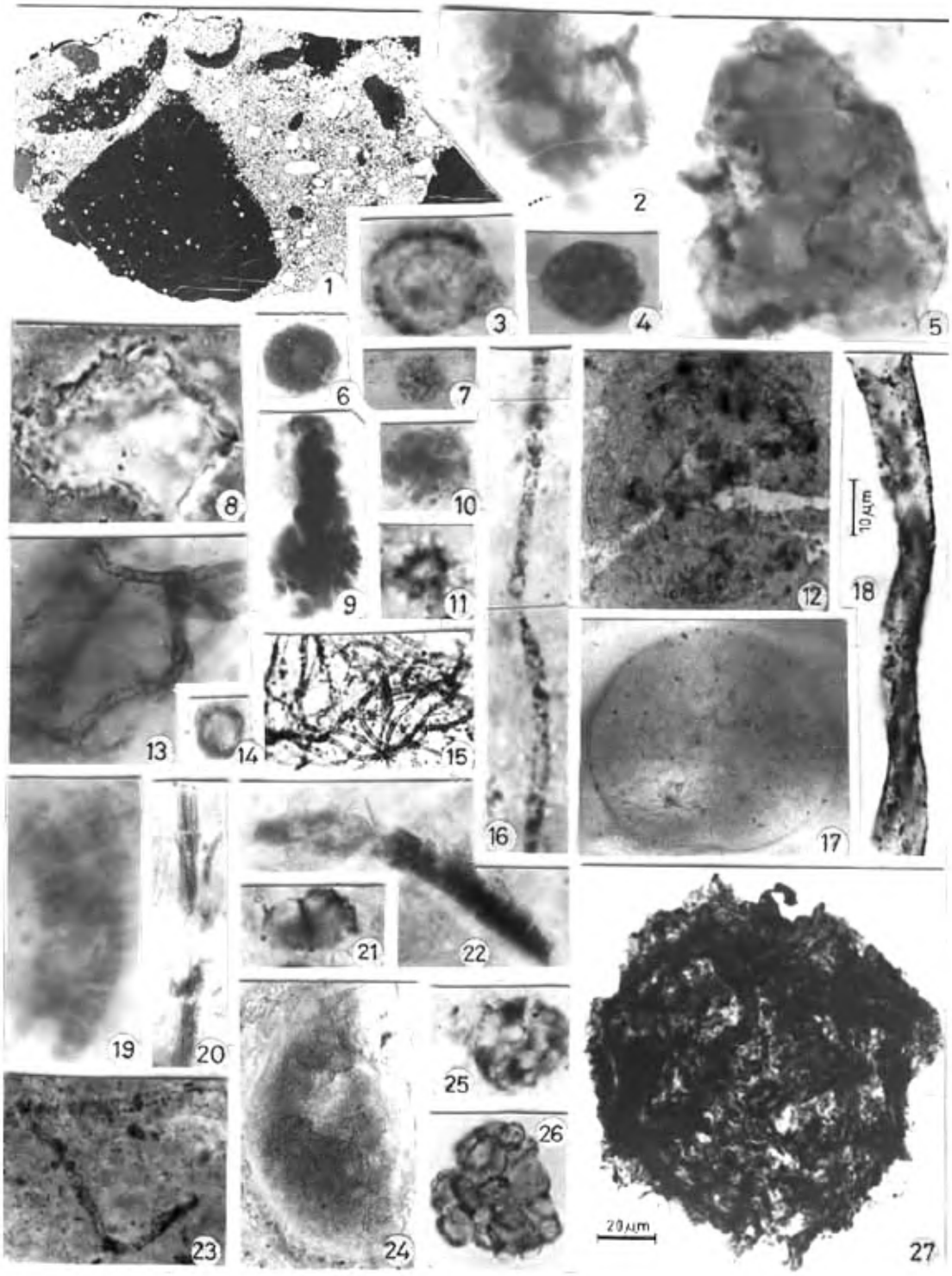

Figure 2. Twenty-two genera of microfossils, viz. cyanobacteria, multicellular tissues of algal thalli (thallophytes) belonging to Rhodophyta, acritarchs and vase-shaped microfossils. 1, Thin section of phosphatic chert and shale associated in sandstone of Chambaghat (Krol sandstone) Formation. X3.5; 2, *Vandalosphaeridium reticulatum* (Vidal) Vidal, 1981; 3, *Eoentophysalis gilensis* Zang, 1995; 4, *Myxococcoides minor* Schopf; 1968; 5, *Leiosphaeridia holtedahlii* (Timofeev) Jankauskas, 1979b; 6, *Paracrassosphaera dedalea* Faizulina and Treshchetenkova, 1979; 7, *Bavlinella faveolata* (Shepeleva) Vidal, 1976; 8, *Lophosphaeridium* sp., Zhang *et al*., 1998; 9, *Melanocyrillium hexodiadema* Bloeser, 1985; 10, *Granomarginata prima* Naumova, 1960; 11, *Micrhystridium lanceolantum* Yin, 1985; 12, *Wengania minuta* Xio, 2004; 13, *Siphonophycus typicum* (Hermann) Butterfield in Butterfield *et al*., 1994; 14, *Margominuscula simplex* Pychova, 1969; 15, *S. robustum* (Schopf) emend. Knoll and Golubic, Knoll *et al*., 1991; 16, *S. septatum* Schopf, 1968; 17, *W. globosa* (Zhang) Zhang *et al*., 1998; 18, *Siphonophycus kestron*, Schopf, 1968; 19, *Obruchevella parva* Reitlinger, 1959; 20, *Eomicrocoleus crassus* Horodyski and Donaldson, 1980; 21, *Tetraphycus hebeinsis* Liu, 1982; 22, *Oscillatoriopsis breviconvexa* Schopf and Blacic, 1971; 23, *Veteronostocale moniliforme* Xu and Gao, 1991; 24, *Thallophyca ramosa* (Zhang) Zhang *et al*., 1998; 25, *Baltisphaeridium perrarum* Jankauskas, 1990; 26, *Satka colonialica* Jankauskas, 1989; 27, *Gorgonisphaeridium pindyium* Zang, 1995. (Bar = 10 µm except figures nos 2, 13, 15, 17, 20, 22, 24, 27 where bar = 20 µm.)

from the Late Precambrian sediments of Vindhyan Supergroup[5]. The decreasing diversity of microplanktons and medium size leiosphaerids of sphaeromorphida acritarch as well as few acanthomorphs in the present assemblage favours Vendian age to these sediments[6]. The rhodophytes, viz. *Wengania* and *Thallophyca* are also known from the Terminal Proterozoic Doushantuo Formation of South China[7,8]. Thus, the recovered microfossil assemblage from the phosphatic chert lenticles and shale of Chambaghat Formation and available data from the overlying and underlying formations[9–16] indicate Terminal Neoproterozoic age to these sediments.

The presence of medium-size ornamented acritarchs, rhodophytes, viz. *Wengania* and *Thallophyca* and cyanobacterial remains with mucilaginous sheath[17] and coiling of filaments[18,19], small size of cells in coccoidal forms[20] associated with phosphatic chert lenticles and shale indicates moderate deep marine environment under stable shelf conditions. However, the dominant lithology consists of quartz arenite, which is deposited in shallow-water environment, such as tidal flat or lagoonal complexes. The present assemblage and its diversity suggest amalgamation of two environments (desiccating in the stagnant water body affected by storms) by any natural obstacle[8,21] for the deposition of phosphatic black chert lenticles and shale associated with quartz arenite of Chambaghat (Krol Sandstone) Formation, Krol Group.

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Pseudovivipary in two rupestrian endemic species (*Leiothrix spiralis* and *Leiothrix vivipara*)

Pseudovivipary is a rare phenomenon described for approximately 50 species of angiosperms[1]. It describes plants that produce asexual propagules in place of the sexual reproductive structure. Several authors[2] have argued that pseudovivipary has evolved in response to a short growing season, enabling plants to complete the cycle of offspring production, germination and establishment during the brief periods favourable to growth and reproduction in markedly seasonal environments[1].

Though pseudovivipary was known in plants belonging to many families (Alliaceae, Liliaceae, Agavaceae, Poaceae, Saxifragaceae and Polygonaceae)[1], the Eriocaulaceae family was not cited in the revision made by Elmqvist and Cox[1]. Most species in the Eriocaulaceae family occur in the rupestrian grasslands in the Espinhaço mountain chain, above 1000–1100 m, up shallow and sandy soils, and rocks mostly of quartzites and sandstones[3] (Figure 1 *a*). The genus *Leiothrix* is restricted to South America and contains 37 species with 25 in the Espinhaço mountain chain. Many Eriocaulaceae species possess the capacity for inflorescence proliferation[4]; however pseudovivipary is not always observed. This suggests that for some species pseudovivipary is an ecological phenomenon, which depends on environmental influences. However, all species of *Leiothrix* subg. *Stephanophyllum* are pseudoviviparous and some of them (*L. spiralis* and *L. vivipara*) are endemic to the state of Minas Gerais, Brazil (19°12′–19°20′S and 40°30′–43°40′W)[5]. These species occur in areas where the soils are usually shallow and sandy, with rocky outcroppings throughout[3], and inflorescence proliferation is always observed in their life cycle, indicating that pseudovivipary in these species could be genetically determined.

Individuals of *Leiothrix* are small-rosette plants whose inflorescences on flower heads are supported by scapes. The scapes in pseudoviviparous species function like stolons when the flower heads of rosettes proliferate giving rise to plantlets or ramets.

L. vivipara is a pseudoviviparous species that occurs in dry, sandy soil, sometimes densely covered by a herbaceous layer.