parts of the annual cycle species. According to Saino *et al.*[29], failure to adjust phenological events to rapidly changing climatic conditions may be an important factor causing negative demographic and conservation effects among birds breeding in Europe. According to Sokolov *et al.*[30], the prognosis of future trends in the timing of spring migration in Europe and in other regions depends on the forecast for future climate change. Understanding how the strength and magnitude of such responses vary across species and with ecological context is critical to predict the consequences of ongoing and future climate change and to identify species most at risk[31].


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# Early Ediacaran (Terminal Neoproterozoic) sponges and additional associated microbiota from Chambaghat Formation, Krol Group, Himachal Lesser Himalaya

We report here the Early Ediacaran sponges as seen in the petrographic sections of phosphatic black chert lenticles associated with quartz arenite of Chambaghat Formation (Krol Sandstone), Krol Group belonging to Kamlidhar Syncline[1,2]. Associated microbiota comprising animal embryos, acritarchs, cyanobacteria and vase-shaped microfossils (VSMs) are also recorded. The rocks of Chambaghat Formation yielding the above microbiota are exposed near Jahar (30°45.778″N : 77°13.306″E), Sauti (30°48.216″N : 77°11.673″E), Khangugh (30°49.152″N : 77°11.856″E) and Ochhghat (30°52.013″N : 77°09.224″E) in Sirmaur and Solan districts of Himachal Pradesh (Figures 1 and 2). Geological studies of the area and sample collection were undertaken by a team of geologists from the Geological Survey of India (GSI), Northern Region, Lucknow. Micropalaeontological studies were carried out by scientists from the Birbal Sahni Institute of Palaeobotany (BSIP), Lucknow under a collaborative programme with GSI.

Twenty-two genera of brownish-yellow microbial remains represented by acritarchs, algae (cyanobacteria, rhodophytes) and VSMs have been earlier recorded in petrographic thin sections and macerated fractions of phosphatic chert lenticles of Chambaghat Formation, Krol Group, Himachal Lesser Himalaya[3]. Animal eggs and embryos have also been recorded from the same horizon[4].

The present study reveals 11 taxa of biological remains comprising micro-invertebrate: sponges (two taxa) and animal embryo, acritarchs (four taxa), cyanobacteria (four taxa) of coccoidal and filamentous forms and single taxon of VSM. The slides are preserved in the museum of BSIP (statement no. 1316).

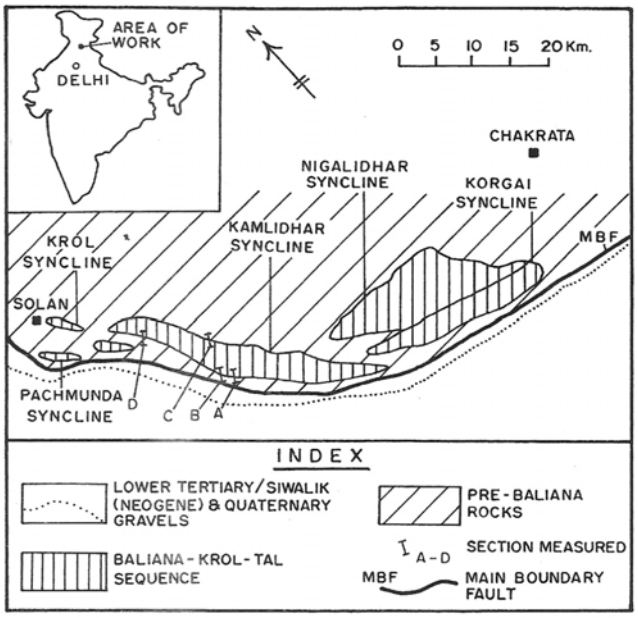


**Figure 1.** Geological map of Baliana–Krol-Tal succession of Krol Belt, Himachal Lesser Himalayas showing measured sections of Chambaghat Formation (modified after Shanker *et al.*[1]).

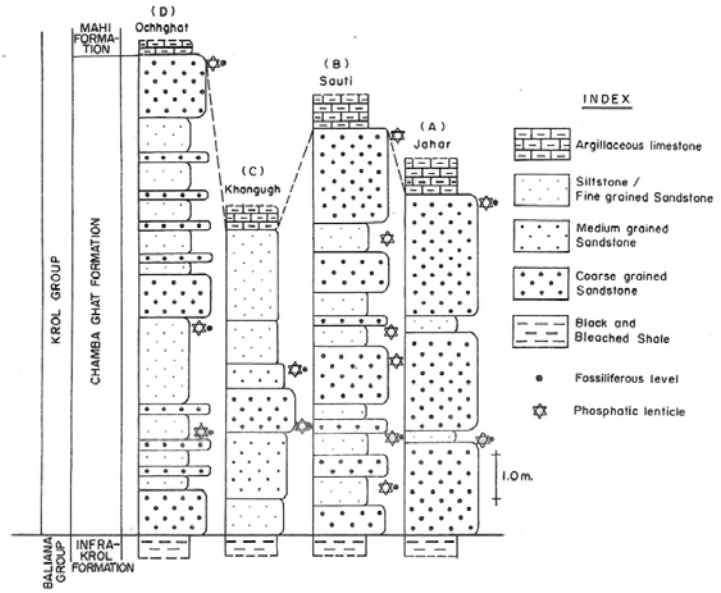


**Figure 2.** Lithocolumns of Chambaghat Formation, Krol Group exposed at different sections in Kamlidhar syncline, Sirmaur and Solan districts, Himachal Pradesh showing fossil-bearing horizons.

The immobile (sessile) bodies of microsuspension feeders (sponges) are flattened (Figure 3 *a–g*), radial symmetrical bodies having premier characters, viz. perforated two layers (pinacoderm and choanoderm) filled by non-cellular mesenchyme present in gel form (Mesogloea). This is a cylindrical/tubular multicellular body formed by interlacing threads (siliceous/spongin fibres), measuring 62 µm in length and 22 µm in width. The finger-like projections representing branches are present at the apex. Each finger-like structure is characterized by two types of pores, viz. less number of oscula and more number of ostia and a central cavity (spongocael = paragastric). The specimens shown in Figure 3 *a*, *d* and *g* are comparable to extant *Chalina* sp. whereas those shown in Figure 3 *b* and *e* are comparable to extinct *Otavia*[5] of demosponge. The isolated spicules or protecting structure representing varied nature of preservation, are monaxonal in shape and vary in size (24–60 µm in length and 9–19 µm width at base). These are celluloid and permineralized/biomineralized in nature (Figure 3 *c* and *f*). These spicules may belong to the above taxa. The other demosponge is articulated, 235 µm in length and 74 µm in width; its upper part is celluloid in nature. It has numerous monaxonal spicules which are 20 µm in length and 2 µm in width at the base (Figure 3 *h* and *i*). The spicules are dark brown-blackish, elongated, needle-like structures; one end of spicule each is sharp-tipped and the other end is not clearly defined due to angle of the cutting of sample. The spicules are confined to the extension of active body wall units (scleroblasts) of mesoderm and are proteineous in nature.

Animal embryos (Figure 4 *a–h*) are spherical to subspherical in shape; they vary in size from 75 to 200 µm in diameter. These have two-layered wall (Figure 4 *c*) with cellular structure in upper part; cell size varies from 2 to 3 µm in diameter, showing gastrulating stage (Figure 4 *a*, *b*, *f* and *h*). Other embryos are ovoidal in shape with varying size ranging from 135 to 240 µm in length and 78 to 137 µm in width, showing an early stage of development (?blastula) infilling homogenous organic matter (?proteineous in nature) with presence of cleavages (Figure 4 *d* and *e*). Interior part is comprised of irregular, brightened spindle and irregular-shaped structures of organic substance, probably of condensed cytoplasm due to warm conditions (Figure 4 *g*).

The VSM is represented by *Melanocyrillium* sp., measuring 135 µm in length and 98 µm in width at the base (Figure 4 *i*).

Acritarchs are represented by both simple sphaeromorphs and acanthomorphs, spherical to subspherical in shape with size ranging from 80 to 175 µm in diameter. These are represented by *Micrhystridium* sp. in association with demosponge (Figure 3 *g*) and *Meghystrichosphaeridium* sp., *Trachysphaeridium* sp., *Leiosphaeridia kulgunica* and *Eotylotopalla* sp. (Figure 4 *j*, *k*, *l* and *m* respectively).

Cyanobacterial remains are represented by Chroococaceae and Oscillatoriaceae comparable to *Paratetraphycus* sp., *Palaeolyngbya* sp., *Oscillatoriopsis* sp. and moulded trichome cf. *Siphonophycus* sp. (Figure 4 *n*, *o*, *p* and *q* respectively).

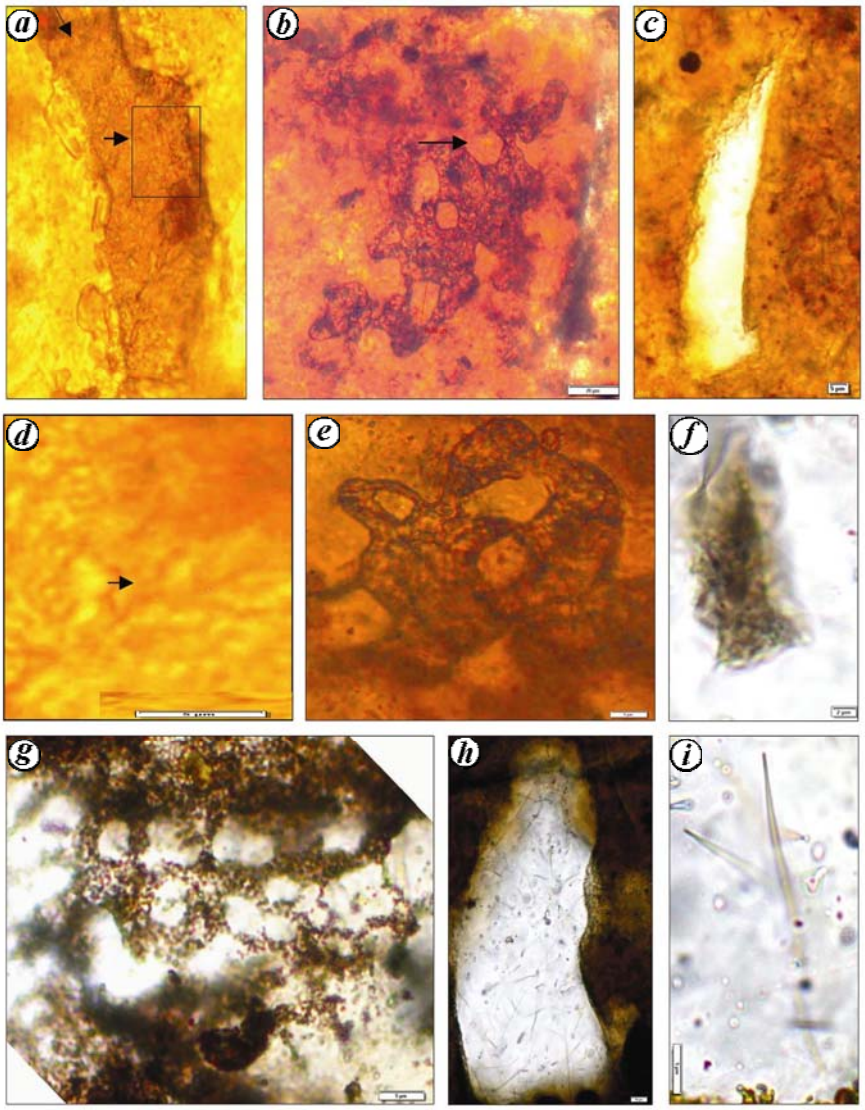


**Figure 3.** Microfossils, viz. demosponge in thin sections of phosphatic chert-bearing arenite of Chambaghat Formation, Solan and Sirmaur districts, Himachal Lesser Himalaya. Scale bar = 5 μm except 20 μm in (***b***) and 2 μm in (***f***). ***a***, Body of demosponge cf. *Chalina* sp., upper arrow showing ostium, lower arrow showing osculum; BSIP slide no. 1438. ***b***, Fragmented body of demosponge cf. extinct *Otavia*, arrow showing detachment point of spicule; BSIP slide no. 1438. ***c***, Monaxonal spicule of demosponge; BSIP slide no. 1438. ***d***, Enlarged view of block in (***a***) arrow showing probable amoeboid cell; BSIP slide no. 1438. ***e***, Southwestern enlarged part of (***b***); BSIP slide no. 1438. ***f***, Monaxonal spicule of demosponge showing celluloid nature; BSIP slide no. 1438. ***g***, Fragmented body of demosponge with *Micrhystridium* sp.; BSIP slide no. 1440. ***h***, Articulated demosponge having monaxonal spicules and its upper part is celluloid in nature; BSIP slide no. 1438. ***i***, Enlarged monaxonal spicule of (***h***) BSIP slide no. 1438.

All the above recovered microfossils are known from the equivalent Neoproterozoic Doushantuo Formation of China and Namibia[5–8].

The Baliana and Krol Groups cover the time interval of Early Neoproterozoic to Ediacaran (Terminal Proterozoic) period. The Chambaghat Formation is the lowermost unit of the Krol Group resting over the Baliana Group. The Blaini Formation of the Baliana Group is correlatable with the Terminal Neoproterozoic Nantuo Formation of South China[9–12]. The Pink Limestone (cap carbonate) of Blaini Formation is considered to be the base of the Ediacaran period[9,11]. The upper part of the Krol Group has yielded Ediacaran metazoans[13]. Thus the Chambaghat Formation is definitely of Early Ediacaran (Terminal Neoproterozoic) age and faunistically correlated with the uppermost Neoproterozoic Doushantuo Formation of South China[8,13]. The signatures of demosponges were recorded as clusters of sponge spicules from the Ediacaran rocks in Mongolia[14], molecular biomarkers (steroids) of marine demosponges from the latest Cryogenian carbonate rocks of Huqf Supergroup in South Oman[15] and mesoscopic biomineralized sponges from Australia[16]. The presence of these microbial remains associated with phosphatic chert lenticles indicates moderate deep marine environment under stable shelf conditions. However, quartz arenite

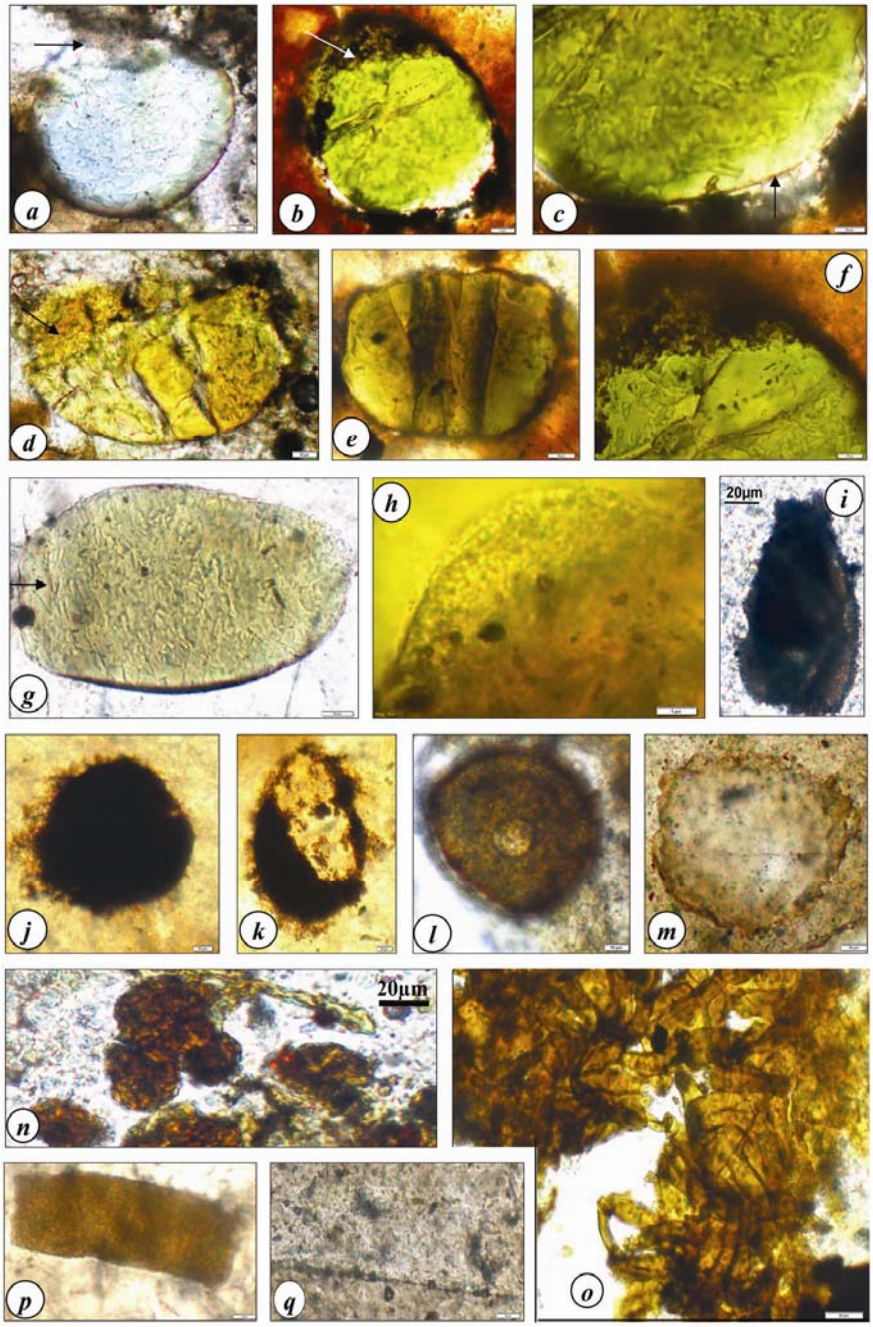


**Figure 4.** Microfossils, viz. embryos, acritarchs, cyanobacteria and vase-shaped microfossil (VSM) from thin sections of phosphatic chert-bearing arenite of Chambaghat Formation, Solan and Sirmaur districts Himachal Lesser Himalaya: Scale bar = 5 µm in (***b***), (***h***) and (***p***); 10 µm in (***j***), (***k***) and (***l***); 20 µm in (***a***), (***c***), (***d***), (***e***), (***f***), (***g***), (***i***), (***m***), (***n***), (***o***) and (***q***). ***a***, Embryo showing cytoplasm, arrow showing air chamber; BSIP slide no. 1440. ***b***, Embryo showing developmental stage comparable to gastrula, arrow showing multicelled structure; BSIP slide no. 1440. ***c***, Lower enlarged part of (***b***) (embryo), arrow showing two-layered wall (epidermis and endodermis); BSIP slide no. 1440. ***d***, Embryo, arrow showing cleavages of blastula stage infilling homogenous organic matter (? proteineous in nature); BSIP slide no. 1440. ***e***, Embryo showing cleavages; BSIP slide no. 1439. ***f***, Upper enlarged part of (***b***) showing multicelled structure; BSIP slide no. 1440. ***g***, Primitive stage of embryo showing irregular and spindle-shaped structures of probable condensed cytoplasm; BSIP slide no. 1438. ***h***, Embryo showing gastrula stage having multicelled structure; BSIP slide no. 1438. ***i***, VSM cf. *Melanocyrillium* sp.; BSIP slide no. 1442. ***j***, *Meghystrichosphaeridium* sp.; BSIP slide no. 1440. ***k***, *Trachysphaeridium* sp.; BSIP slide no. 1440. ***l***, *Leiosphaeridia kulgunica*; BSIP slide no. 1439. ***m***, *Eotylotopalla* sp.; BSIP slide no. 1443. ***n***, *Paratetraphycus* sp.; BSIP slide no. 1438. ***o***, *Palaeolyngbya* sp.; BSIP slide no.1440. ***p***, *Oscillatoriopsis* sp.; BSIP slide no. 1441. ***q***, Biomineralized algal tube cf. *Siphonophycus* sp.; BSIP slide no. 1440.

having phosphatic chert lenticles was deposited in shallow water environment, such as tidal flat or lagoonal complexes. The presence of microbial assemblage in phosphatic chert lenticles bearing quartz arenite suggests a mixed depositional environment of deep and shallow marine conditions respectively[3]. The present flora, particularly cyanobacteria, may be responsible for the existence of sponges and new offspring by embryogenesis.


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