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Organic-walled microfossils from the Neoproterozoic black phosphatic stringers in the Gangolihat Dolomite, Lesser Himalaya, India

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A well-preserved microbiotic assemblage is recorded from the Jhiroli magnesite, eastern Kumaun Lesser Himalaya. The assemblage contains cyanobacterial filaments, coccoids and acritarchs identified mainly as

Siphonophycus robustum, *S. typicum*, *S. capitaneum*, *Gunflintia minuta*, *Oscillatoropsis obtusa*, *Chlorogloeopsis contexta*, *Sphaerophycus parvum*, *Leiosphaeridia crassa*, *Trachyhystriosphera vidalii*, *Trachyhystriosphera* sp., *Micrhystridium pallidum* and *Cymatiosphaera minuta*. Presence of acanthomorphic acritarchs such as *Trachyhystriosphera*, *Cymatiosphaera* and *Micrhystridium* is important in assigning the age of the Gangolihat Dolomite. On the whole the microbiotic assemblage suggests Vendian or younger age for the Gangolihat Dolomite.

IN recent years, our understanding of early complex life has enormously improved due to worldwide interest in microscopic fossils in Neoproterozoic–Cambrian rocks. A variety of relicts of early multicellular life is found trapped within Proterozoic sediments which were earlier seen as a province of cyanobacteria only. Proterozoic microfossils as compared to Palaeozoic microfossils, exhibit a comparatively low biotic diversity and low morphological complexity. This low morphological diversity resulted in fewer characters used for assigning taxa and their correlation worldwide. The Proterozoic carbonate rocks are being studied extensively for biostratigraphy, palaeoecology and palaeoenvironmental aspects, as well as for gathering information on biotic evolution throughout the world^{1–3}. In the Lesser Himalayan succession of India, the Krol–Tal sequence^{4–6}, Deoban Formation^{7,8}, Vaishnodevi Limestone⁹ and Gangolihat Dolomite¹⁰ have proved to be significant as they have revealed well-preserved prokaryotic, eukaryotic and multicellular life forms. These formations have created immense interest among palaeobiologists for exploring the antiquity of multicellular life in the Proterozoic carbonates. The present communication reports a diverse microbiota in dark black phosphatic stringers within magnesite in the Jhiroli magnesite, ~45 km from Almora, in the eastern part of Kumaun Lesser Himalaya (Figure 1). It is the continuation of an earlier publication that first documented an early Vendian organic-walled microfossil and sponge-spicule from Gangolihat Dolomite¹⁰. Fossiliferous samples were collected from pit 1 of magnesite at Jhiroli (79°45′07.56″: 29°45′50.03″). In the Jhiroli magnesite section, Gangolihat Dolomite consists of limestone, cherty limestone, stromatolitic dolomite and phyllitic units. The magnesite horizon is conspicuous within the section (Figure 2). The individual magnesite bodies are elongate and dome-shaped and often stromatolitic.

At places, magnesite has completely replaced the stromatolites and the magnesitized stromatolites not only preserve the original stromatolitic structure but also the parts already phosphatized¹¹. Within the cherty phosphatic bands microbiotic remains of cyanobacteria and phytoplanktons were found well preserved.

The vast argillo-calcareous succession exposed in the Inner Lesser Himalaya has been described as Calc Zone of Badolisera and Calc Zone of Pithoragarh¹². The succession comprises in the ascending order the Rautgara–

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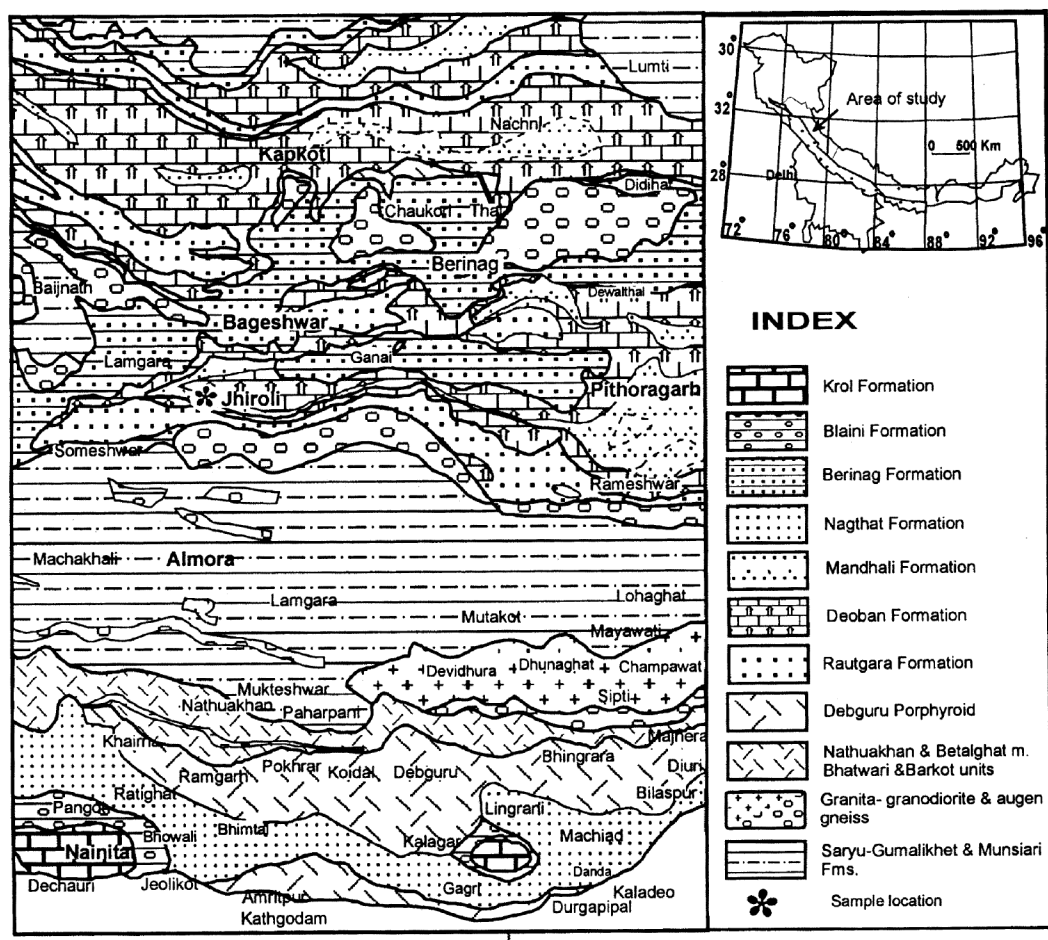


Figure 1. Geological map of the area showing fossil locality after Valdiya¹¹.

Gangolihat–Sor–Thalkedar formations¹³. It is overlain by a succession of quartzite and chlorite schist of the Berinag Formation. Valdiya has divided the carbonate rocks of the eastern Kumaun lesser Himalaya into two formations, the older Deoban Formation (= Gangolihat Dolomite) and younger Mandhali Formation containing Sor slate and Thalkedar Limestone members. In the present area Sor slate and Thalkedar Limestone members are not exposed and the Gangolihat Dolomite is bounded by Rautgara Formation below and Berinag Formation above. The generalized stratigraphic succession based on Valdiya and Pant¹⁴ is given in Table 1.

The microfossils in the present study were obtained in thin sections; maceration of samples using standard palynological techniques yields only structure-less carbonaceous matter. The fossil assemblage present in the dark black phosphatic stringers within magnesite is dominated overwhelmingly by filamentous cyanobacteria. Well-preserved microfossils have only been recovered from the black phosphorite beds comprised of calcareous and phosphatic interlaminae. The phosphatic components are generally microsparite (5 µm) and the calcareous component comprises dolospars.

Cellularly preserved cyanobacteria, acritarchs, multicellular algae and microscopic metazoans have been described from phosphorite of Doushantuo Formation, China (Xiao *et al.*¹⁵ and references therein). In India, well-preserved, organic-walled microfossils have been described from chert–phosphorite Member of Tal Formation⁴. This is another report of organic-walled microfossils from Gangolihat Dolomite, Lesser Himalaya, where microfossils are found well-preserved within phosphorite stringers. Phosphorites thus provide an excellent source for understanding the early evolution of animal life. The exact process of phosphate biomineralization is not fully known, but it has been revealed that even the soft part can become phosphatized shortly after death¹⁶. Phosphogenesis needs high concentration of phosphate added with other physical and biological processes to increase pore-water PO_4 ^{15,16}.

The population of non-septate and septate filamentous cyanobacteria, coccoids and acritarchs is identified as *Siphonophycus robustum*, *S. typicum*, *S. capitaneum*, *Gunflintia minuta*, *Oscillatoropsis obtusa*, *Chlorogloeopsis contexta*, *Sphaerophycus parvum*, *Leiosphaeridia crassa*, *Trachyhystrichosphaera vidalii*, *T. sp.*, *Michrystidium*

Table 1.

Berinag Formation	Predominantly quartzarenite, locally conglomeratic with interbedded metavolcanics. Locally mylonitized schistose and sericitic quartzite
Berinag Thrust	
Thalkedar Limestone	
Mandhali Formation	Cherty, dolomitic limestone and dolomite with calcareous grey phyllite and sporadic stromatolites
Sor slate	Olive green, brownish, grey and black slate with subordinate argillaceous and dolomitic limestone
Gangolihat Dolomite (Deoban Formation)	Stromatolitic dolomite and lenticles of magnesite and talc Thinly bedded greyish limestone and marl
Rautgara Formation	Brown, dark, purple and olive-green slate, quartzarenite, litharenite and sublitharenite
Base not seen	

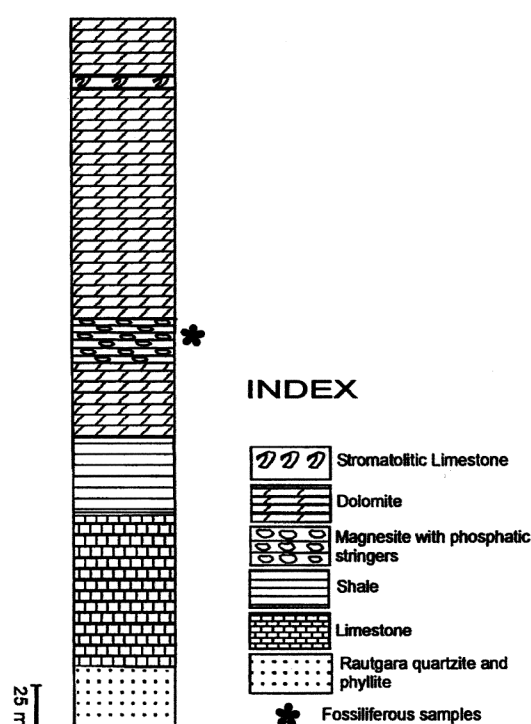


Figure 2. Stratigraphic column of the section showing position of fossiliferous samples.

pallidum and *Cymatiosphaera minuta*. Approximately 75% of the population consists of cyanobacterial filaments ranging in size from 0.5 to 40 μm in cross-sectional diameter and 25% of the population consists of coccoids and acritarchs. Both septate and non-septate filaments are well preserved. Size frequency distribution of these filaments shows that the population is dominated by *S. typicum*. Some of the smaller filaments may be fragments of larger filaments which are several micrometres long. Sometimes pyrite granules are also deposited within the cyanobacterial sheath and therefore change its original shape and diameter. Among acritarchs, the most important components are *Trachyhystrichosphaera*, *Cymatiosphaera* and *Michrhystridium*.

The microfossils are generally black, indicating moderate to high degree of organic maturation. The non-septate filaments having diameters ranging from 2 to 40 μm are considered under the genus *Siphonophycus*. The present population contains three species of *Siphonophycus*. These are *S. robustum* (with a cross-sectional diameter of 2.5–3 μm ; Figure 3 i, n); *S. typicum*, 4–8 μm (Figure 3 a–c, k, o); and *S. capitaneum*, 16–32 μm (Figure 3 e–g, l). Knoll *et al.*¹⁷ emended the genus *Siphonophycus* to include *Eomycetopsis* and *Tenuofilum* (originally recognized by Schopf¹⁸) as well as *Leiothrichoides* German. The genus comprises tubular microfossils likely to represent the preserved extracellular sheaths of oscillarian or nostocalean cyanobacteria. *Siphonophycus* species constitute the principal filamentous constituents of Proterozoic benthic mat communities.

Small septate filaments (1 to 2 μm in cross-sectional diameter) are considered here as *G. minuta* (Figure 3 d). These are uniseriate, unbranched, curved and septate filaments with variable spacing of cells. Diameter of filaments ranges between 1 and 1.7 μm . Maximum length measured is 150 μm . Well-preserved filaments show presence of septae, and are sometimes totally carbonized showing constrictions at the site of septae. Sometimes needle-like projections are also seen on the outer side of these filaments. The systematic affinity of *Gunflintia* is unclear. Barghoorn and Tyler¹⁹ regarded it as filamentous cyanobacteria. Cloud²⁰ noted the similarity of *Gunflintia* filaments to *Sphaerotilus* and *Leptothrix*-type iron bacteria. Golubic *et al.*²¹ showed differences between heterotrophic *Sphaerotilus* and chemolithotrophic *Leptothrix* that may prove *Gunflintia* is the ancestor of *Leptothrix* but not of *Sphaerotilus*.

Two specimens of *Chlorogloeaopsis contexta* are documented here. These are compressed cylindrical aggregate without envelop, 7–25 μm wide, up to 100–110 μm long, composed of two distinct rows of 10–12 μm wide cells (Figure 3 m). German²² illustrated *C. contextus* as 25 μm wide; the latter is more like *C. zairensis*. Hofmann and Jackson²³, however, considered both to be conspecific and attributed them to the genus *C. contexta*. The genus was recognized from the upper part of Bushimay Group,

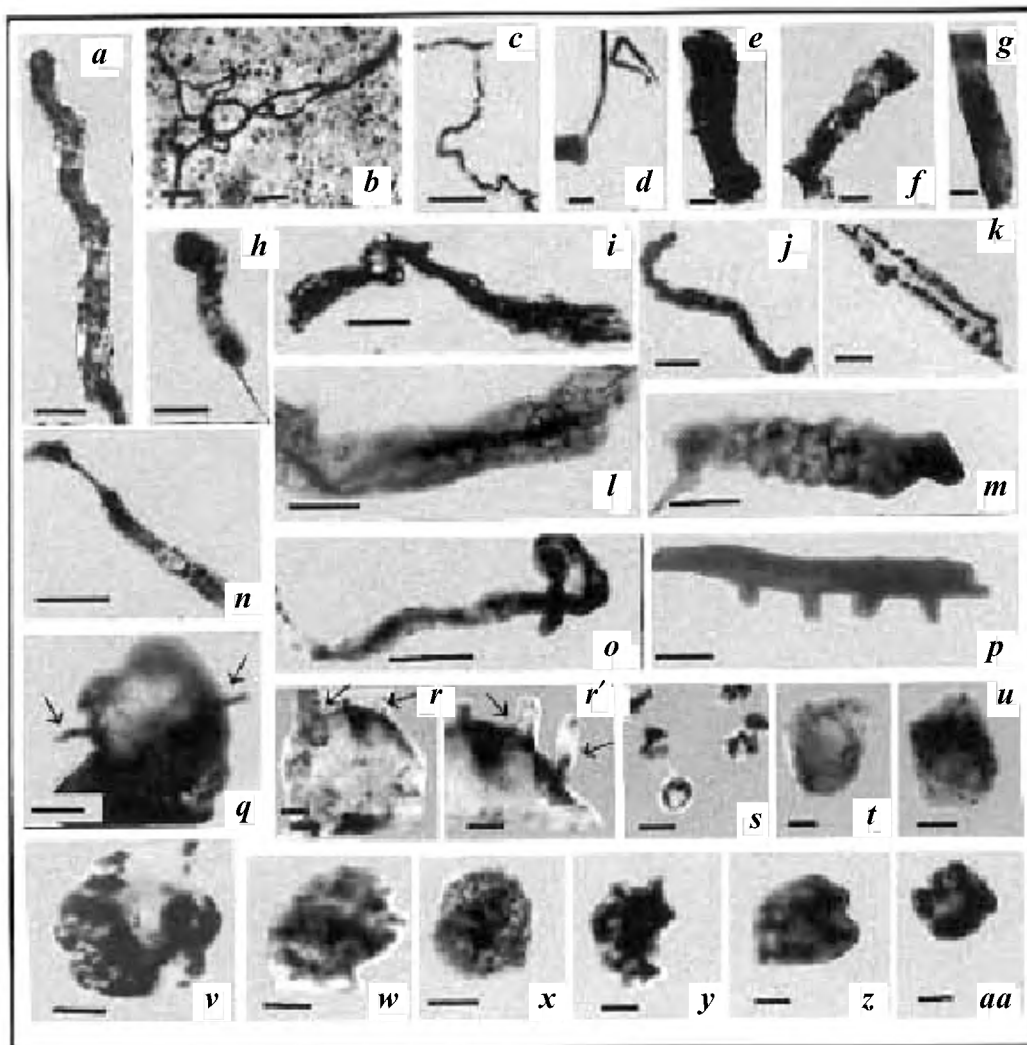


Figure 3. *a–c, k, o*, *Siphonophycus typicum*; *d*, *Gunflintia minuta*; *e–g, l*, *S. capitaneum*; *h, j*, *Oscillatoriopis obtusa*; *i*, Bunch of *S. robustum*; *m*, *Chlorogloeopsis contexta*; *n*, *Siphonophycus robustum*; *p*, Unidentified compressed acanthomorphic acritarch; *q*, *Trachyhystrichosphaera* sp. (arrow points to processes); *r, r'*, *Trachyhystrichosphaera vidalii*, *r'* is enlarged view of *r*; *s*, *Sphaerophycus parvum*; *t, u*, *Cymatiosphaera minuta*; *v*, *Leiosphaeridia crassa*; *w–z, aa*, *Micrhystridium pallidum*. Bar in *b, c, i* is 50 μ m; *l, m, o, p* 25 μ m; *a, e–h, j, k, n, q, r, r'* is 10 μ m and 5 μ m for the remaining.

1300–940 Ma in Zaire²⁴. Microfossils comparable to *C. contexta* are also reported from Vendian of Podolia²⁵.

Uniseriate trichome fragments, identified as *Oscillatoriopis obtusa* Schopf¹⁸, are multicellular, unbranched filaments, 5–7 μ m in cross-sectional diameter and >300 μ m in length. These filaments are characterized by uniform cell length with rectangular cell outline within individual filaments (Figure 3 *h, j*). Butterfield²⁶ applied the generic name *Oscillatoriopis* to all undifferentiated *Oscillatoria*-like trichomes without clearly developed extracellular sheaths, and differentiated species on the basis of size range and cell shape. The present specimens are closely comparable with *O. obtusa*²⁶ having a cross-sectional diameter of 4–8 μ m and cells being wider than longer.

Small spheroids of 1.5–4 μ m diameter with granular walls are closely comparable to *S. parvum* Schopf¹⁸ (Figure 3 *s*).

S. parvum has been reported from the Paleoproterozoic Belcher Islands, Canada²⁷. It is also known in other Palaeoproterozoic formations such as Amelia Dolomite²⁸, HYC Pyrite Shale²⁹, Balbirini Dolomite³⁰, Mesoproterozoic Dismal Lake Group of Arctic Canada³¹, the Mesoproterozoic–Lower Neoproterozoic Deoban limestone³², the Neoproterozoic Draken Conglomerate of Svalbard³³ and Neoproterozoic (Vendian) Infrakrol Formation of India^{5,6}.

Spheroidal vesicles 15–20 μ m in diameter are identified as *Leiosphaeridia* sp. (Figure 3 *v*). *Leiosphaeridia* is a common component in the Proterozoic. The biological affinities of these microfossils are uncertain.

A well-preserved specimen of acanthomorphic acritarch is identified here as the *Trachyhystrichosphaera vidalii*³⁴. The vesicle is spheroidal with 75 μ m in maximum diameter and bears characteristic hollow pipe-like processes ~12 μ m

long and 4 μm wide (Figure 3 *r*, *r'*). These processes open directly into the vesicle interior. The specimen resembles closely with the description of *T. vidalii*³⁵, in its diameter range and tubular processes. Another diagnostic acritarch is characterized by a vesicle with 10–15 long processes around the periphery. The diameter of the vesicle is 30 μm and processes are 8 μm long and 2 μm in diameter (Figure 3 *q*). In the specimen the processes are too large and scarce, which is comparable to *Trachyhystrichosphaera* sp. (Knoll, pers. commun.). The type specimen of *T. vidalii* was described from upper Riphean Hunnberg Formation and Draken Conglomerate Formation, Svalbard^{17,34}, Upper Riphean in Russia^{2,36} and Vendian Chichkan Formation of Malokaroy Group of Central Asia³⁷. Zang³⁵ suggested that the assemblage represented by *Trachyhystrichosphaera vidalii*–*T. aimica*–*Cymatiosphaera kullingii* has been used for global correlation in the early Neoproterozoic. It is observed that late Riphean forms are comparatively smaller in size. A single specimen of large (~200 μm), compressed acritarch presently kept under unidentified acritarch (Figure 3 *p*), was also observed in the present assemblage.

Small solitary vesicles with a cross-sectional diameter of 10–12 μm , possessing thick, lighter coloured, non-laminated envelopes are comparable to *Cymatiosphaera minuta* (Figure 3 *t*, *u*). The specimens are characterized by the presence of crests which divide the vesicle into polygonal fields. The specimens are abundant and associated with mats of small coccoids and filamentous prokaryotes and are comparable to forms reported by Knoll and Swett³⁸, Volkova³⁹, and Baudet *et al.*⁴⁰, but show a narrow size range. *C. minuta* is an important part of the assemblage. These forms are reported from Upper Proterozoic or younger rocks⁴¹.

Small sub-circular vesicles of 9–14 μm diameter range, covered with small (1–1.5 μm) spiny processes present in the assemblage are comparable to *Micrhystridium pallidum* (Figure 3 *w*–*z*, *aa*). Similar forms are described from uppermost Proterozoic and lowermost Cambrian formation of central Mackenzie Mountain, northwestern Canada⁴⁰.

As already mentioned, the age of the Gangolihat Dolomite is poorly constrained radiometrically. The Riphean age of the Gangolihat Dolomite was mainly deduced on the basis of stromatolites (*Kussiella kussiensis*, *Conophyton garganicum*, *Conophyton cylindricus*, *Colonella columnaris*, *Plicatina antiqua*, *Baicalia bacalica*, *Minjaria uralica* and *Maslovina columnaris*). In recent years, microbiotic assemblages, including cyanobacterial filaments, acritarchs (acanthomorphic, pterospersimorphic, and sphaeromorphic acritarchs), metazoans and metaphytes have proved to be significant especially for Proterozoic biostratigraphy and other evolutionary aspects⁴². Microbenthic assemblages typically preserved in Palaeoproterozoic and Mesoproterozoic cherts differ markedly from their Neoproterozoic counterparts⁴³. Neoproterozoic biota is more diverse in its contents of oscillatoriacean trichomes, large unicellular and multicellular eukaryotes^{26,44,45}. The acritarchs of Neoproterozoic

assemblages are characterized by moderately processed forms⁴³. The presence of cyanobacteria, algae, acritarchs and possible nematodes suggests an Early Vendian age for the Deoban Formation⁸. Further, cyanobacterial filaments, sphaeromorphic acritarchs and vase-shaped microfossils suggest a Late Riphean–Vendian age for the Great Limestone⁹. Interestingly, Neoproterozoic–Cambrian *Palaeobasidiospores* have been reported in the eastern extension of these carbonate rocks in Nepal⁴⁶. The discovery of Neoproterozoic sponge–spicules and cyanobacteria further suggested an Early to Late Vendian age for the Gangolihat Dolomite¹⁰. However, the distinctive large acritarchs described from many formations of Early Vendian (Early Neoproterozoic III) age elsewhere, e.g. the Pertatataka Formation of Australia⁴⁷, the Doushantuo Formation of China⁴⁸, the Scotia Group of Spitsbergen⁴⁹, and the Infrakrol Formation of India⁶ are missing in the Gangolihat Dolomite. Recent researches have suggested that the first appearance of acanthomorphic acritarchs of the genus *Trachyhystrichosphaera* might be used as a basis for establishing the lower boundary of the Neoproterozoic era^{26,34,49,50}. Although majority of the cyanobacterial filaments and leiosphaerids are cosmopolitan and stratigraphically long-ranging, certain distinctive fossils in the assemblage such as *Trachyhystrichosphaera*, *Cymatiosphaera*, *Micrhystridium* and the presence of hexactinellid sponge spicules¹⁰ represent elements that are known from certain formations attributed to the Vendian and younger age. By comparison with other regions, the present microbiotic assemblage of cyanobacteria, coccoids, and mainly acanthomorphic acritarchs from Jhironli Magnesite further support the concept of Neoproterozoic (Vendian) or younger age for Gangolihat Dolomite.

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Geochemical and isotopic anomalies preceding K/T boundary in the Cauvery basin, South India: Implications for end Cretaceous events

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The Upper Cretaceous–Lower Tertiary deposits of the Cauvery basin show prominent geochemical and isotopic anomalies preceding the K/T boundary. Analyses of stratigraphic variations of whole-rock elemental concentrations and stable isotopic compositions in the light of sedimentation history, petrography and mineralogy of the rocks reveal that these anomalies may be due to increased detrital influx caused by sea-level and climatic changes, Deccan volcanism and release of volatile gases from buried hydrocarbons, presumably gas hydrates. Comparison of these interpretations with that of K/T sites located in Guatemala, New Mexico and Israel revealed that these interpretations are in conformity with records on gradually increasing environmental stress during Upper Cretaceous that culminated with two major catastrophic events such as bolide impact and Deccan Trap volcanism. Thus this communication provides additional support to the growing acknowledgement of the theory that higher faunal turnover across the K/T boundary the world over might have been the result of gradual environmental deterioration rather than a sudden impact in the global scale.

THE close of the Mesozoic era marked the beginning of an eventful phase in the geologic history in terms of global climatic deterioration that left imprints on faunal and floral distribution and on sedimentary deposits¹, based on which it is established that an abrupt boundary separates the Cretaceous from the Tertiary virtually everywhere in the global stratigraphic record². Review of the scenarios for the Cretaceous/Tertiary boundary event revealed³ that the oceans were already stressed by the end of the Late Cretaceous as a result of the long-term drop in atmospheric CO₂, long-term drop in sea-level and the frequent development of oceanic anoxia. An increasing body of evidence points to the presence of abrupt $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ changes associated with the K/T boundary^{4–6}. At a number of localities, however, $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ changes have been found to precede the K/T boundary⁷. Many researchers^{7–11} recorded anomalies of the Platinum group and other geochemical elements far below the K/T boundary. The anomalies that predate the

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