Neoproterozoic sponge spicules and organic-walled microfossils from the Gangolihat Dolomite, Lesser Himalaya, India

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Isolated hexactinellid and monaxon sponge spicules with cyanobacterial filaments have been discovered in the Gangolihat Dolomite. The microfossils described were recovered in the thin sections of cherty dolomite and phyllite. Comparable sponge spicules are reported so far from lower Vendian sediments; therefore an early Vendian age can be suggested for the Gangolihat Dolomite. The main purpose of this communication is to document the presence of sponge spicules and silica biomineralization during the sedimentation of Gangolihat Dolomite in the Kumaun Lesser Himalaya, India.

SPONGES had a largely undocumented history before their entry into the skeletal fossil record. It is accepted that sponges had achieved skeletal diversity by the latest Proterozoic and that siliceous biomineralization preceded calcareous biomineralization in sponges[1]. Phylogenetically, they constitute the most original group within the metazoa. Presence of sponge spicules provides an evidence of metazoan silica biomineralization in the Proterozoic fossil record. Late Proterozoic sponge spicules have been documented from Vosgas Mountain, Mongolia, China and Australia[1–4]. Recently, Neoproterozoic sponge-like fossils have been reported from the Upper Vindhyan in India[5]. Early Cambrian records of sponge spicules are also documented worldwide (ref. 6 and references therein).

The sponge spicules described in this communication have been recorded from two different localities of the Gangolihat Dolomite, which is extensively developed in the Inner sedimentary belt of the eastern Kumaun Lesser Himalaya (Figure 1). The fossiliferous samples were collected near the village of Utrora, ~ 3.5 km south-west of Kapkot (29°57′N: 79°56′E) in the Bageshwar–Kapkot road and near the village of Chhera in Chandak–Cherra road section in Pithoragarh (29°35′N: 80°15′E) (Figure 1). The discovery of a well-preserved microbiota from the Deoban limestone, Great Limestone, Krol belt of Lesser Himalaya[6–13], has given encouragement for further search of palaeobiologic records in the eastern part of Kumaun Lesser Himalaya where no authentic microbiota has been reported so far. Well-preserved sponge spicules and organic-walled microfossils from the Gangolihat Dolomite may certainly provide a nonpareil perception about the early stages of animal evolution and complexity of

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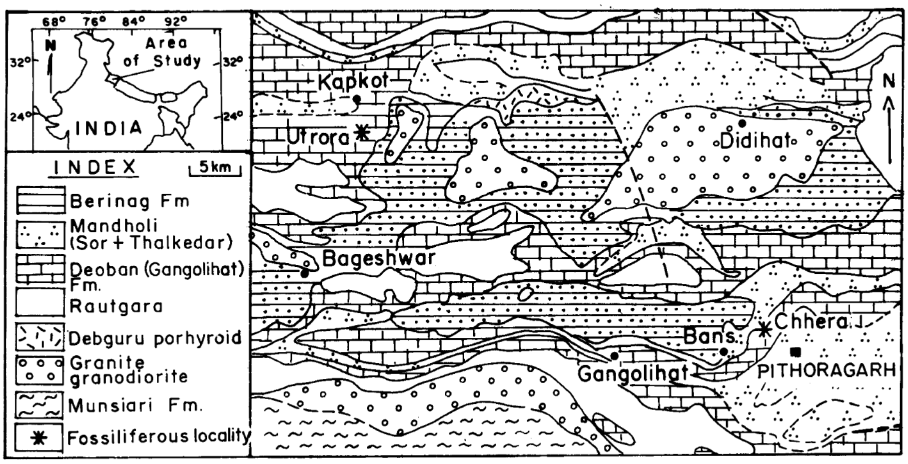

Figure 1. Geological map of the area showing fossil locality (after Valdiya[15]).

Table 1. The stratigraphic succession of the Kumaun Leser Himalaya (after Valdiya[15])

Mandhali Formation (Sor Formation)	Thalkedar limestone	Blue–grey banded limestone, often with chert laminae and nodules, and argillaceous limestone alternating with calcareous grey phyllite.
	Sor slate	Light green and grey–green sand stone.
Deoban Formation (Gangolihat, Dolomite, Kapkot Formation)	Dhari Member	Blue–grey limestone with calc–slate and marlite.
	Chandak Member	Dolomitic limestone characterized by spectacular development of stromatolites. Pockets of flat pebble intraformational conglomerate. Conspicuous chain of lentiform deposits of magnesite.
	Hiunpani Member	Fine-grained cherty dolomite of pink and white colours alternating with chert laminae.
	Chhera Member	Pink violet and maroon slate-phyllite interbedded with subordinate pink, green and white marble, often sandy.

Gangolihat Dolomite ecosystem existing at the time of sedimentation.

The stratigraphic succession of the area is shown in Table 1.

The argillocalcareous sequence of the present area was described as the Calc Zone of Tejam[14]. Valdiya[15] has divided it into two formations, the older Deoban Formation and the younger Mandhali Formation. The carbonate sequence was named the Gangolihat Dolomite. In the Bageshwar–Kapkot section, this unit was described as the Kapkot Formation[16]. Gangolihat Dolomite constitutes a total thickness of about 700 m in Pithoragarh[17] and consists predominantly of limestone, cherty limestone, stromatolitic dolomite and phyllitic units. It has been divided into four members, Chhera, Hiunpani, Chandak and Dhari, respectively, in ascending order. The Gangolihat Dolomite is overlain by the Sor Formation (with Sor slate and Thalkedar limestone Members of Valdiya[15]). In the Chhera village of Pithoragarh, grey and purple coloured phyllite (Chhera Member of Valdiya[17]) is exposed. The phyllite is highly siliceous. In the lower part of the section, thinly-bedded pink limestone alternates with purple calcareous phyllite sequence (Figure 2 *a*). The stromatolitic dolomite

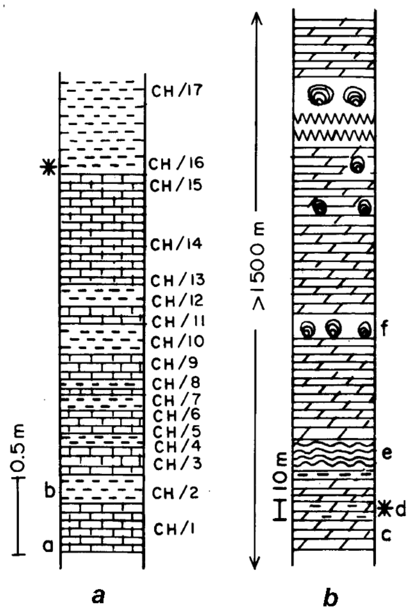

Figure 2. Stratigraphic column of ***a***, Chhera section and ***b***, Utrora section, showing the position of fossiliferous samples. a, limestone; b, phyllite; c, dolomite; d, cherty dolomite; e, cryptalgal laminates; f, stromatolitic dolomite; *, fossiliferous samples.

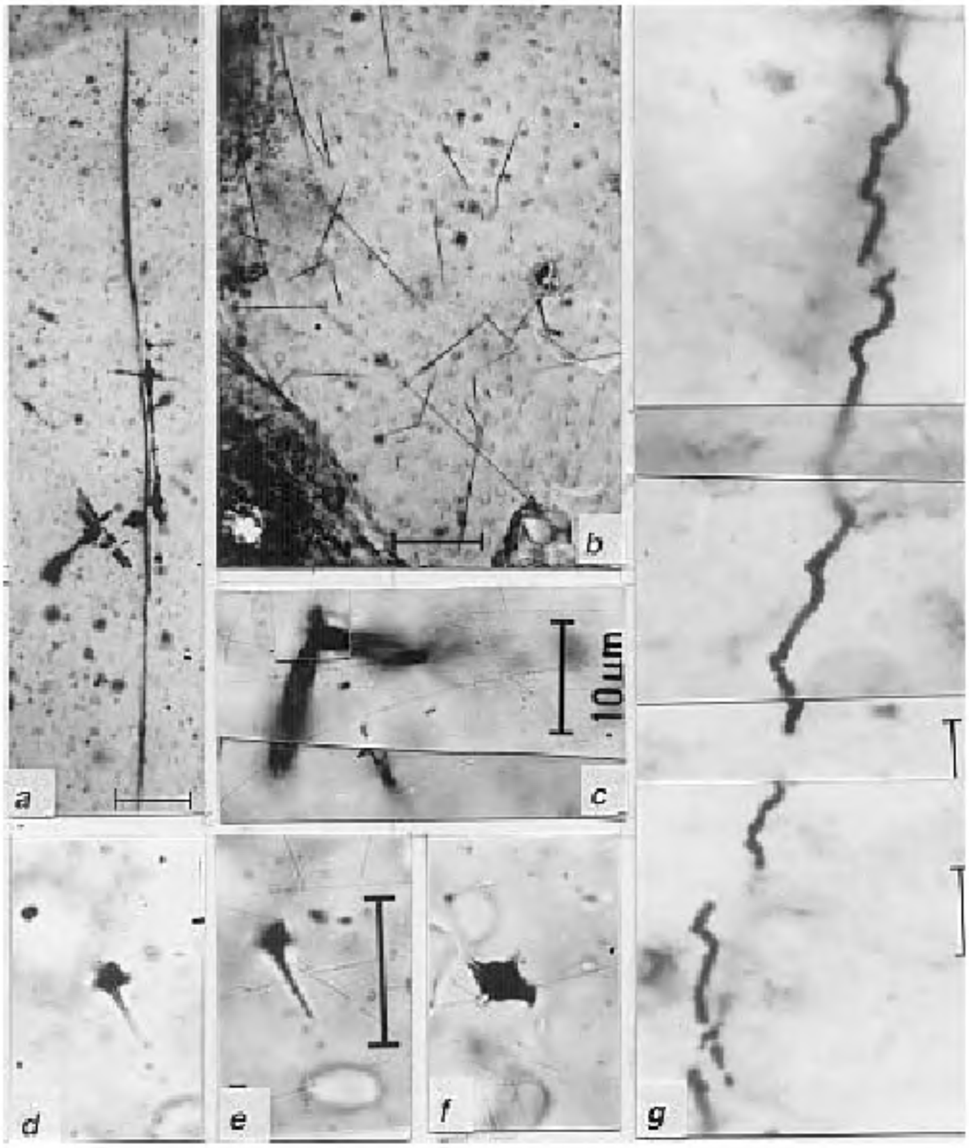

Figure 3. ***a, c***, Hexactinellid sponge spicules; Loc. Chhera; ***b***, Monaxon sponge spicules. Loc. Chhera; ***d, e***, hexactinellid sponge spicule in different focal depths. Loc. Utrora; ***f***, hexactinellid sponge spicule. Loc. Utrora; ***g***, *Nostocomorpha* sp. Loc. Utrora. Scale bar is 10 μm for ***a, b, g*** and ***e***. Scale bar in ***e*** is the same for ***d*** and ***f***.

exposed in the Bageshwar–Kapkot section is siliceous dolomite which often contains chert nodules and chert bands (Figure 2 *b*). The chert nodules range from 1 to 12 cm in diameter. The cherty bed is approximately 10 m thick. Dolomite units become thicker upward in the sequence, and are oolitic at places.

The age of the Gangolihat Dolomite was mainly deduced on the basis of stromatolites in the absence of radiometric dates. The carbonate belt shows characteristic forms of Lower Riphean stromatolites (*Kussiella kussiensis*, *Conophyton garganicus*, *Conophyton cylindricus*, *Colonella columnaris*, and *Plicatina antiqua*) at the base, Middle Riphean stromatolites (*Baicalia bacalica*) in the Middle and Upper Riphean stromatolites (*Minjaria uralica*, *Masloviella columnaris*) in the upper part. The biozonation based on stromatolites established that the Deoban, Shali and Jammu (Great) Limestone belts are correlatable and homotaxial with the Gangolihat Dolomite and indicate an Early to Middle Riphean age[18]. The microfossil assemblage comprising cyanobacteria, algae, fungi, acritarchs and possible nematodes, suggests an Early Vendian age for the Deoban Formation[9]. The microbial fossils, including cyanobacteria, sphaeromorphic and acanthomorphic acritarchs and vase-shaped microfossils reported from the Great Limestone suggest a Late Riphean to Vendian age[10]. Besides, in the eastern extension of these carbonate rocks in Nepal, Neoproterozoic to Cambrian *Palaeobasidiospores* have been recorded[19].

Neoproterozoic monaxial siliceous sponge spicules have been earlier reported from quartz phyllite of the Ville Series from the Vosges Mountain[2]. Some disk-like bodies of hexactinellid sponge spicules have been reported from the Neoproterozoic Ediacara fauna of South Australia[4]. Further, Ediacarian (~ 543 Ma) hexactinellid sponge spicules have been reported from south-western Mongolia[1]. Late Proterozoic sponges have been documented with soft tissue from phosphorite of Doushantuo, South China. These sponges are older than the Ediacara and are reported to be of Early Vendian age, ca. 580 Ma and they contained only monaxon spicules[3]. Early Cambrian sponge spicules were mainly hexactinellids and were documented worldwide (ref. 6 and references therein). It is concluded on the basis of the worldwide presence of these sponge spicules, that silica biomineralization started during Early Vendian. Therefore, a comparison of the recorded Neoproterozoic sponge spicules, especially from Mongolia[1] and China[3] to those present in the Gangolihat Dolomite suggests an Early Vendian age for the Gangolihat Dolomite. The present communication mainly deals with the discovery of well-preserved sponge spicules and cyanobacterial filament from the Gangolihat Dolomite. A detailed study of this microbial assemblage will provide new information on early stages of metazoan evolution during Neoproterozoic (Gangolihat) sedimentation. A large number of thin sections were examined and unquestioned[20] simple small monaxial oxeas and hexactinellid sponge spicules occur abundantly in the collection. Long and thin monaxons are straight or sometimes bent a little, spicules are equidimensional and smooth, ranging in diameter from 0.5 to 1 μm and 20 to 70 μm long (Figure 3 *b*). The presence of monaxon ray is confirmed by the tapering of the ray in both directions. Hexactinellid spicules are 1 to 5 μm in diameter and 10 to 300 μm in length (Figure 3 *a*, *c*, *d–f*). In a thin section, there is cross-section of a vertical ray near the intersection of other rays (Figure 3 *a*). Some thicker, short spicules with diameters ranging from 5 to 7 μm are also seen embedded in the matrix. Long and unbranched chain-like aggregates with the length up to 600 μm are seen in thin section of chert nodule-bearing dolomite (Figure 3 *g*). A chain of 8 to 10 μm diameter spheres occurs as a single filament. Such structures are known to be remains of filamentous micro-organisms whose organic matter has been completely replaced by diagenesis of iron minerals[21], and are classed under *Nostocomorpha* Sin and Liu[21,22]. No organic matter is visible in these fossils. Comparable structures were also reported from various Proterozoic successions[21].

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Organic carbon stock in Indian soils and their geographical distribution

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The first ever estimate of organic carbon (OC) stock in Indian soils was 24.3 Pg (1 Pg = 10^{15} g) based on 48 soil series taking into account of a few major soils. The present OC stock has been estimated as 63 Pg in the first 150 cm depth of soils. Soils with their geographical distribution through the country were used for computing soil organic carbon (SOC) stock in different depths in various physiographic regions. To sustain the quality and productivity of soils, the knowledge of OC in terms of its amount and quality in soils is essential. This has more relevance in soils of the tropical and subtropical parts of the globe, including the Indian sub-continent. SOC stock appears to be a single parameter that can help effectively in prioritizing the area for restoring soil health.

RESTORATION of soil quality through soil organic carbon (SOC) management has remained the major concern for tropical soils. To make this programme successful, the comprehensive knowledge on SOC stocks forms an essential prerequisite in future land resource management programmes. The contributions of SOC on physical, chemical and biological properties of soils in sustaining their productivity are being appreciated since the dawn of human civilization. Important factors controlling SOC levels include climate, hydrology, parent material, soil fertility, biological activity, vegetation patterns and land use[1]. SOC is sensitive to impact of human activities, viz. deforestation, biomass burning, land use changes and environmental pollution. To sustain the quality and productivity of soils, a knowledge of SOC in terms of its amount and quality is essential. The first comprehensive study of organic carbon (OC) status in Indian soils was conducted by Jenny and Raychaudhuri[2]. They studied 500 soil samples collected from different cultivated fields and forests with variable rainfall and temperature patterns. The study confirmed the effects of climate on carbon reserves in the soils. However, these authors did not make any estimate of the total carbon reserves in the soils. The first attempt in estimating OC stock was made by Gupta and Rao[3]. They reported OC stock of 24.3 Pg (1 Pg = 10^{15} g) for the soils ranging from surface to an average subsurface depth of 44 to 186 cm with the database of 48 soil series. However, this estimate was based on a hypothesis of enhancement of OC level judging by success stories of afforestation programmes on certain unproductive soils.

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In the recent past, the greenhouse effect has been of great concern, and has led to several studies on the quality, kind, distribution and behaviour of SOC[4–7]. Global warming and its effect on soils in terms of SOC management have led to several quantitative estimates for global C content in the soils[4–10].

The most prudent approach to study SOC, however, would be on an unit area basis for a specified depth interval which requires information on the spatial distribution of soil types, SOC and bulk density of soils. It would thus provide a better understanding of the terrestrial reservoir of SOC far beyond the general objectives of C sequestration in soils and the detrimental effects of global warming[4]. No efforts have yet been made to work out the OC stock in dominant physiographic regions of India. The present attempt is to elucidate the SOC stocks, their distribution over a range of soil depths and their relative contribution as influenced by physiography.

The size of total SOC stock is calculated following the method described by Batjes[6]. The first step involves calculation of OC, multiplying OC content (g/g), bulk density (mg/m^3) and thickness of horizon (m) for individual soil profiles with different thickness varying from 0 to 30, 0 to 50, 0 to 100 and 0 to 150 cm. During the soil survey programme of our country and also while establishing benchmark soils of India[11,12], the soils were studied and sampled up to a depth of 150 cm. Information in terms of OC and BD has been very helpful for the estimation of SOC stock in the first 30, 50, 100 and 150 cm depths. The total OC content determined by this process is multiplied by the area of the physiographic unit in the second step to work out the total SOC stock in Pg.

The Indian sub-continent comprises three major physiographic regions, namely Mountain and Hill Region of the Himalayas, Indo-Gangetic Plain and Peninsular Plateau, including the Coastal Plain, and a group of islands[13]. Based on stratigraphic and tectonic history and relief along with the erosional processes, Singh[14] earlier reported four physiographic macro regions, namely (i) the Northern Mountains, (ii) the Great Plains, (iii) the Peninsular Uplands, and (iv) the Indian Coasts and Islands. NATMO[15] has classified the physiography of India into five regions, viz. (i) the Northern Mountains, (ii) the Great Plains, (iii) Peninsular India, (iv) the Peninsular Plateau, (v) the Coastal Plains and Islands.

An attempt has been made to estimate the SOC stock in these physiographic regions[15]. This information will have relevance in terms of comparing the SOC stock in different physiographic regions.

The Northern Mountains extend all along the northern border of the country, with a length of 2500 km, an average width of 240 km and an area of 55.3 mha. Three major fold axes represent the Himadri (Greater Himalayas), Himachal (Lesser Himalayas) and the Siwaliks (Outer Himalayas) in this physiographic region. Mighty