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A note on the Fan-Fabric Structures in the late Palaeoproterozoic Kajrahat Limestone, Katni, M.P., India

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Present study records the Fan-Fabric Structures from the late Palaeoproterozoic Kajrahat Limestone of the Vindhyan Supergroup, India exposed in Katni district, M. P. Centimeter (cm) size carbonate fans (1 to 10 cm in length) radiating in upward direction are part of a stromatolite dominated Kajrahat Limestone in the area. The Kajrahat FFS represent their wide-spread occurrence in the Proterozoic successions of India. Our study establishes that these fans were originally precipitated and not the result of a late diagenesis or any other post sedimentation process. These fan-fabric structures were deposited in intertidal to sub-tidal environments. Globally, fan-fabrics structures are considered a common feature of the Archaean to early Mesoproterozoic carbonate platforms.

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INTRODUCTION

The Precambrian rocks entombs about 88% of Earth's history and are essential for investigating long term changes in the lithosphere, biosphere and atmosphere (Schopf, 1983; Schopf and Klein, 1992). The Mesoproterozoic Era, otherwise considered as 'Boring Billion' (Buick *et al.,* 1995; Brasier, 2012), witnessed the development of intra-cratonic basins on the continental shields all over the world (Windley, 1977; Condie, 1989). The Vindhyan Supergroup has revealed some of the important biospheric evolutionary evidence (Kumar, 1995, 2001; Srivastava, 2005; Sharma, 2006a-b; Sharma *et al.,* 2009; Shukla and Sharma, 2016; Bengtson *et al.,* 2017; Sallstedt *et al.,* 2018; Sharma and Shukla, 2019). The present note documents the Fan Fabric Structures (FFS) recorded from the late Palaeoproterozoic Kajrahat Limestone of the Semri Group. Kumar and Sharma (2012) mentioned their occurrence in the same area but their report, however, lacks the details about their formation and this paper fills that gap. The investigated FFS are from 1-10 cm in length, radiating in upward direction preserved in carbonate horizons. FFS help understand the changes occurring in the atmosphere and their influence on the biosphere, hydrosphere including depositional realm.

GENERAL GEOLOGY, AGE AND DEPOSITIONAL ENVIRONMENT

Among the several Precambrian sedimentary basins on the Indian subcontinent, the Vindhyan basin is a repository of late Palaeoproterozoic to late Neoproterozoic age litho-successions. It is a sickle-shaped basin outcropping between the Archaean Aravalli-Bundelkhand province to the North-East and the Cretaceous Deccan Traps to the south and by the Great Boundary Fault to the west (Mazumdar *et al.,* 2000). The Vindhyan Supergroup (VSG) is one of the largest Proterozoic intracratonic sedimentary basins of the world and comprises approximately 5000 meters (m) thick sequence of sandstone, shale, limestone, dolostone with minor conglomerate and volcaniclastic rocks (Bhattacharyya, 1996). It is one of the best preserved basins and spread over a large area extending in central Indian states from Bihar, Uttar Pradesh, Madhya Pradesh to Rajasthan. This basin occupies an area of 1,20,000 square kilometers (sq. km.). An additional 80,000 sq. km. is covered by the Deccan Traps and possibly 10,000 sq. km. lies hidden under the Gangetic alluvium (Mathur, 1965, 1987; Jokhan Ram *et al.,* 1996; Kumar and Sharma, 2012). The sedimentary sequences in the basin are largely unmetamorphosed and undeformed (Soni *et*

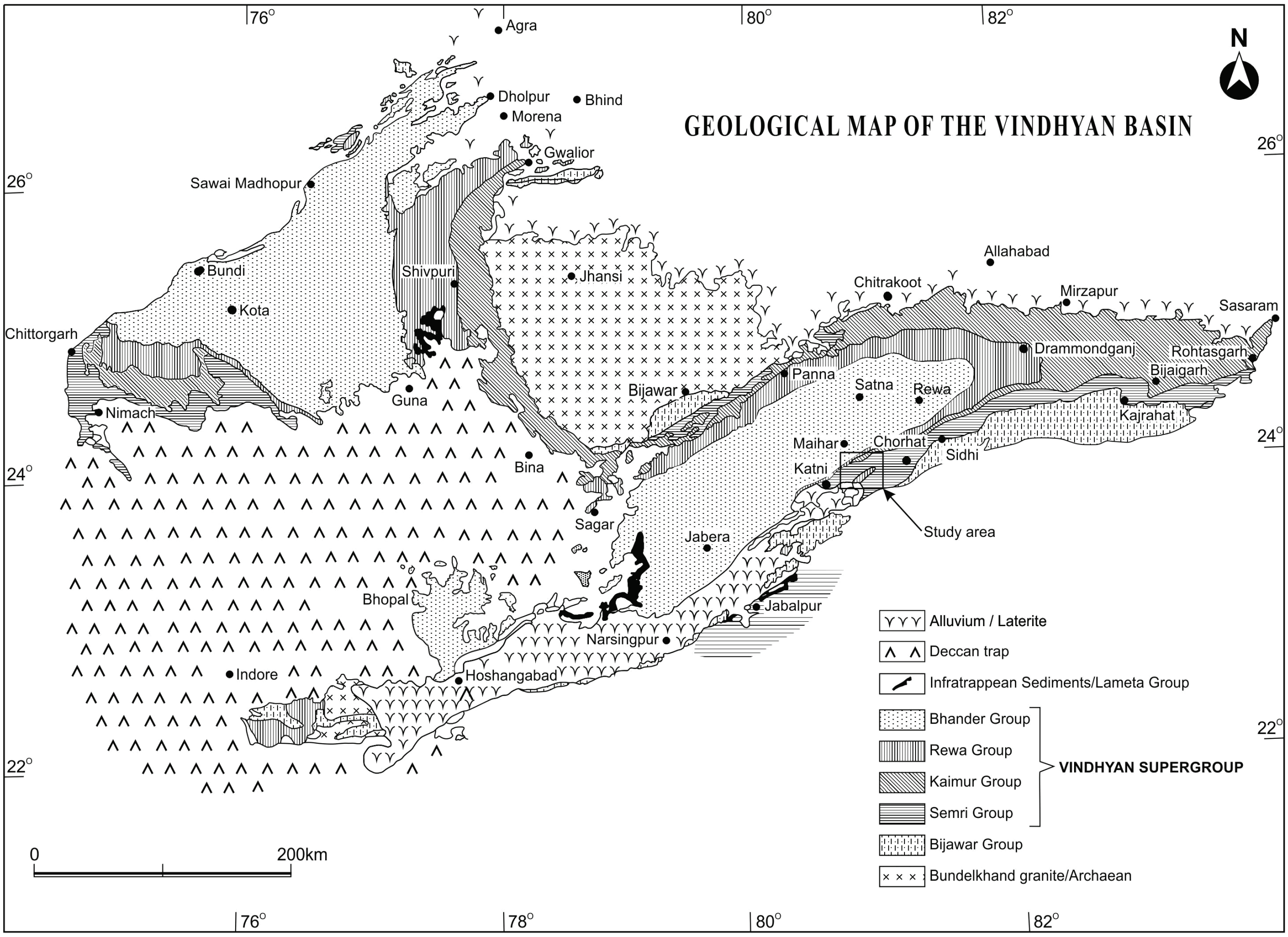

Fig. 1. Geological map of the Vindhyan Basin (simplified after Soni *et al.,* 1987).

al., 1987). It is drained by the two major rivers, the Son and the Chambal. After these two rivers, the entire succession of the VSG is divided into the Son Valley and the Chambal Valley successions.

VSG is divided into four groups *viz*., the Semri, the Kaimur, the Rewa and the Bhander, in ascending order (Soni *et al.,* 1987). A complete succession of the VSG outcrops in the Son Valley in the Satna district, Madhya Pradesh, India. In the Maihar area, the Semri (Lower Vindhyan), Kaimur, Rewa and Bhander (Upper Vindhyan) are part of the VSG Son Valley succession. Auden (1933) divided the Vindhyan succession into four stratigraphic units (Fig. 1; Table 1). The Semri Group, divided into three subgroups and nine formations, is constituted of typically alternating shale, carbonate, sandstone and volcaniclastic units (Fig. 2). These divisions are the Deoland Formation, Arangi Formation, Kajrahat Formation, Deonar Formation belonging to Mirzapur Subgroup; Koldaha Shale, Salkhan Limestone, Rampur Formation belonging to Kheinjua Subgroup and Rohtasgarh Limestone and Bhagwar Shale belonging to Rohtas Subgroup. Sedimentary units in the Vindhyan basin are primarily represented by shallow marine facies along with distal shelf to deep-water sediments.

The Kajrahat Limestone is overlain by the Deonar Formation (Porcellanite Formation) of the Semri Group in Son Valley. The Porcellanitic unit is differentiated into rhyolite, banded, massive, greenish/opaline tuffs. Ray *et al.* (2002) have dated the zircons obtained from two samples of the silicified volcanic rock of the Deonar Formation by U – Pb method which yielded an age of 1632 Ma. Bickford *et al.* (2017) dated the magmatic zircon of rhyolite by $^{207}Pb/^{206}Pb$ method with an average age 1642 ± 7 Ma. Mishra *et al.* (2018) dated magmatic zircons extracted from very fine-grained felsic ash beds found as greenish/opaline tuff in the type area of the Deonar Formation with an age of 1647 ± 18 Ma. These dates firmly establish the age of the Deonar Formation between ~ 1640 and 1632 Ma and hence the underlying Kajrahat Formation is considered as late Palaeoproterozoic in age.

The views of Singh (1973), Banerjee (1974) and Bose *et al.* (2001) on the depositional environment of various other litho-units of VSG are summarized in Table 2.

Fan fabric bearing Kajrahat Limestone is a part of the Semri Group of VSG. The Kajrahat Limestone consists of limestone, dolostone and shales with widespread development of stromatolites in this unit (Kumar, 1982; Prakash and Dalela 1982; Singh *et al.,* 2001; Banerjee *et al.,* 2007; Jeevankumar and Banerjee, 2008). The Kajrahat Limestone exposed around Kuteshwar mines in Katni district is also designated as 'Kuteshwar Limestone Formation'

Table 1: Stratigraphic succession of the Semri Group proposed by various workers.

Auden (1933)/ Prakash and Dalela(1982)		Bhattacharyya (1996)		Bose et al. (2001)	
Rohtas Stage	Limestone and Shale	**Rohtas Subgroup**	Bhagwar Shale Rohtasgarh Limestone	**Rohtas Formation**	Rohtas Limestone Rampur Shale
Kheinjua Stage	Glauconitic Sandstone Fawn Limestone Olive Shale	**Kheinjua Subgroup**	Rampur Formation Salkhan Limestone Koldaha Shale	**Kheinjua Formation**	Chorhat Sandstone Koldaha Shale
Porcellanite Stage	Porcellanite		Deonar Formation	**Porcellanite Formation**	
Basal Stage	Kajrahat Limestone Basal Conglomerate	**Mirzapur Subgroup**	Kajrahat Limestone Arangi Shale	**Kajrahat Formation**	Kajrahat Limestone Arangi Shale
			Deoland Formation	**Deoland Formation**	

(Rao *et al.,* 1979). Here the limestone is compact and thick bedded dark grey in colour. Certain parts of the lower flat bedded limestone contain nodules or specks of pyrite. It has been divided into three distinct units: the lower flat bedded limestone, the middle biohermal limestone and the upper flat bedded limestone. The measured thickness of the Kajrahat Limestone in this area is ~300 m (Mishra *et al.,* 1990). Good exposures of the middle part of the Kajrahat Limestone are biohermal. Monomember and multimember colonies of stromatolites are frequently noted in the Katni area (Banerjee *et al.,* 2007).There are repeated cycles of *Conophyton* in the middle part of the Kajrahat Limestone. Many morphospecies of *Conophyton* along with *Colonnela*, *Calypso* and *Thyassagates* have been reported (Fig. 3 [1-3]) from this place (Misra and Kumar, 2005). In the longitudinal sections, their laminae are laterally linked with each other with prominent concavity and convexity in the axial zone. In the transverse sections, the columns are oval to elliptical in shape with outer laminae encircling the other columns. At the base, the columns are about 50 cm in height and 10-25 cm in diameter.

MATERIALS AND METHODS

For the study of Fan-Fabric structures, samples of the Kajrahat Limestone were collected from Katni district, Madhya Pradesh, India. Morphological attributes of the fan-fabric structures are subject matter of this paper. In this area, the Kajrahat Limestone crops out in two localities, *i.e.,* Kuteshwar mine (N 23º58'29.9", E 80º48'32") and on the right bank of the Chhoti Mahanadi River (N 23º58'39.9", E 80º49'48.5") from where the samples were collected by MS in 2007 and UB in 2010 for the present study. The microscopic observations were undertaken in BSIP, Precambrian Palaeobiology Laboratory. To determine the nature of carbonate rocks, petrographic thin sections were stained following Dickson (1965) method for identification of calcite and ferroan calcite, dolomite and ferroan dolomite.

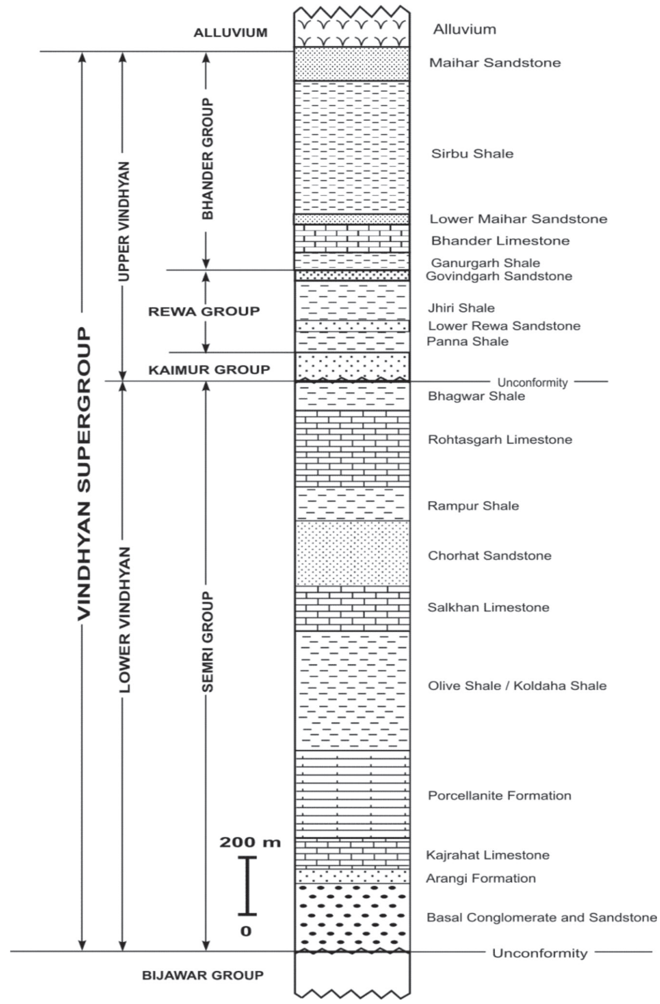

Fig. 2. General Lithocolumn of the Vindhyan Supergroup exposed in Son Valley (modified after Kumar and Pandey, 2008).

Petrographic thin sections of 23 samples (from bottom to top) of the Kajrahat Limestone collected from the Kuteshwar mines were stained with Alizarin Red S (ARS) & Potassium Ferrocyanide (PF). One half of each thin section was treated by the ARS and the other half part was treated by PF. Stereomicroscope Leica MZ12 was used to observe morphological features on hand specimens. Figured slides (16653 and 16654) are deposited in the Repository of Birbal Sahni Institute of Palaeosciences and can be retrieved vide statement no. BSIP 1544.

ATTRIBUTES OF KUTESHWAR FAN-FABRIC STRUCTURES

In present study, reported carbonate fans are part of cm to half a meter thick beds of the Kajrahat Limestone exposed in the Katni area. FFS are well preserved on the cross sections of thick and compact beds of the Kajrahat Limestone. The radial-fibrous texture is composed of radiating to sub-parallel

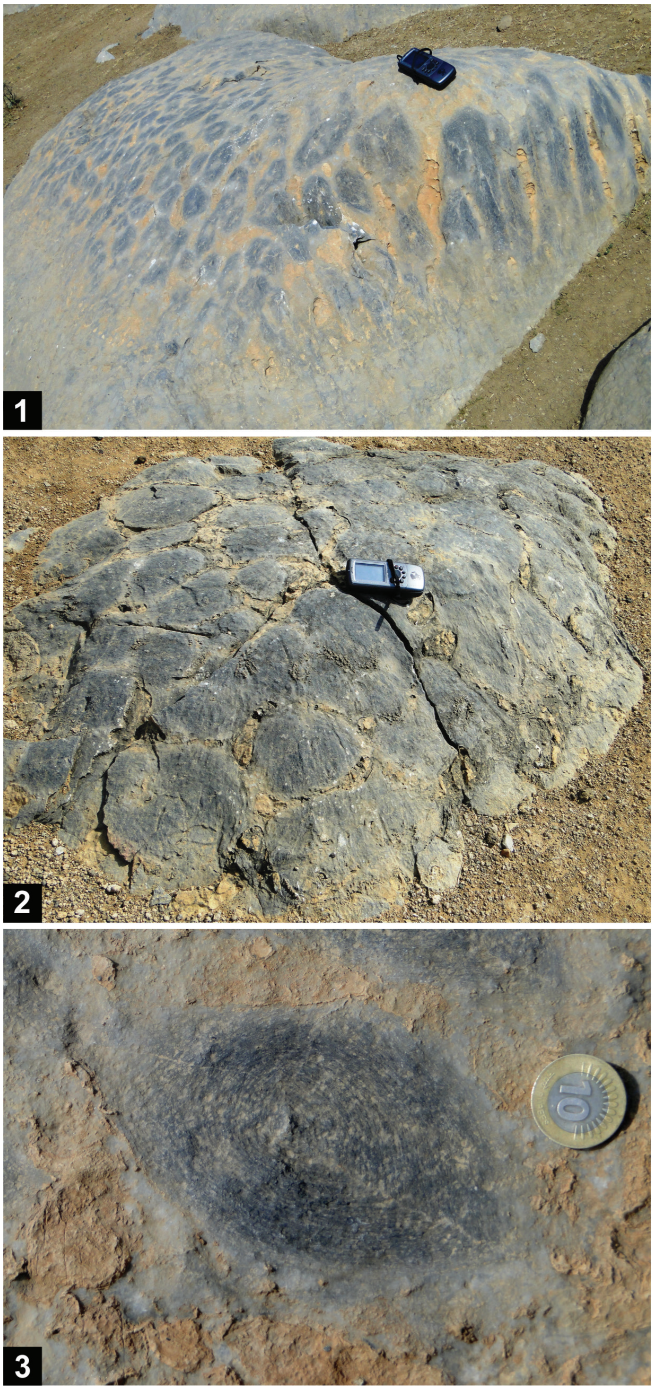

Fig. 3. (1, 2 and 3) - Stromatolites in the Kajrahat Limestone, Chhoti Mahanadi River section, Kuteshwar, M.P. (1) Longitudinal and plan view of the stromatolites in Chhoti Mahanadi sections; (2) Plan view showing oblong section of the stromatolite column; (3) Plan view of the stromatolites showing circular to oval cross sections.

blades of fibrous crystals. Basal portions of these fans are aligned with the bedding pattern and grew as upward-oriented crystals (fans). The recorded fan-fabric crystal units occur both in clusters, dense patches, sparsely to evenly spaced units across the bedding plane (Figs. 4 [1-6]). Growth pattern of the fans vary across bedding planes. In longitudinal cross-section, the crystals sizes vary from 1 to 10 cm. In the transverse cross section, crystals display square terminations. Similar to large size fan-fabrics noted on the outcrops, micron size fan fabric structures are noted in the petrographic thin sections. The inter-relationship of fan-fabric features between outcrop and thin sections are evidence for their growth as precipitates, initially as individual crystals on the seafloor.

Thin section containing fan fabrics show pinkish orange in colour, whereas those without fan remained colourless. It clearly indicates that fan fabric needle like features are majorly made up of calcium carbonate. 21 samples are constituted of calcite and two samples are ferroan calcite. Two thin sections (7957-B, S-1-E) were examined for determination of mineral composition. Presence of aragonite is rare in the geological record due to diagenetic instability and almost non-existent in pre-carboniferous sedimentary rocks. The presence of this mineral in older deposits (Precambrian) has to be inferred from petrographic, chemical or isotopic proxies (Lee and Lindgren, 2015). Thin section observations of the Kajrahat fan fabric indicate the outer boundaries of every needle shaped fan fabric are light to dark brown in color owing to presence of Manganese oxide (MnO). Needle like fan fabrics are composed of acicular aragonite crystals elongated along their C axis with pointed terminations. In some cases larger and longer aragonitic crystals show prismatic morphology. These acicular crystals are packed densely in bundles forming fans of radiating crystals having very different and divergent orientations. Under Cross Nicols (XPL) high birefringence colors may look pastel with high relief with parallel extinction, whereas under the Plane Polarized Light (PPL) it turns colorless. Total Organic Carbon (TOC) determined on these samples is in the range of 0.1% to as high as 4.1%. Similar precipitation patterns of aragonite and calcite have been noted in modern speleothems (Perrin *et al.,* 2014).

DISCUSSION

Calcium carbonate seafloor fans are common in early Precambrian (Archaean and Palaeoproterozoic) marine sequences (Kah and Knoll, 1996; Sumner and Grotzinger, 1996) but became environmentally restricted through the intertidal settings of the Mesoproterozoic (Bartley *et al.,* 2000) and occasionally found in the carbonate successions that cap low-latitude glacial deposits of the Neoproterozoic (Kennedy, 1996; Hoffman *et al.,* 1998; James *et al.,* 2001; Hoffman and Schrag, 2002). The stratigraphic distribution of carbonate and carbonate fans precipitation suggests that certain environmental conditions were instrumental in their development and preservation and thereby imply that the nature of carbonate sedimentation and ocean carbonate chemistry must have been fundamentally different from modern conditions (Kempe and Degens 1985; Grotzinger 1989; Kempe and Kazmierczak 1990, 1994; Grotzinger and Kasting 1993; Bartley *et al.,* 2000). Studies during the past two decades on the numerous Archaean and pre-Neoproterozoic radial-fibrous and laminated textures have revealed the diversity and complexity of the sedimentary precipitates into sharper focus (Seong-Joo and Golubic, 1999, 2000; Bartley *et al.,* 2000). Aragonite fan pseudomorphs deposited in cap carbonates of the Mackenzie Mountains also formed in

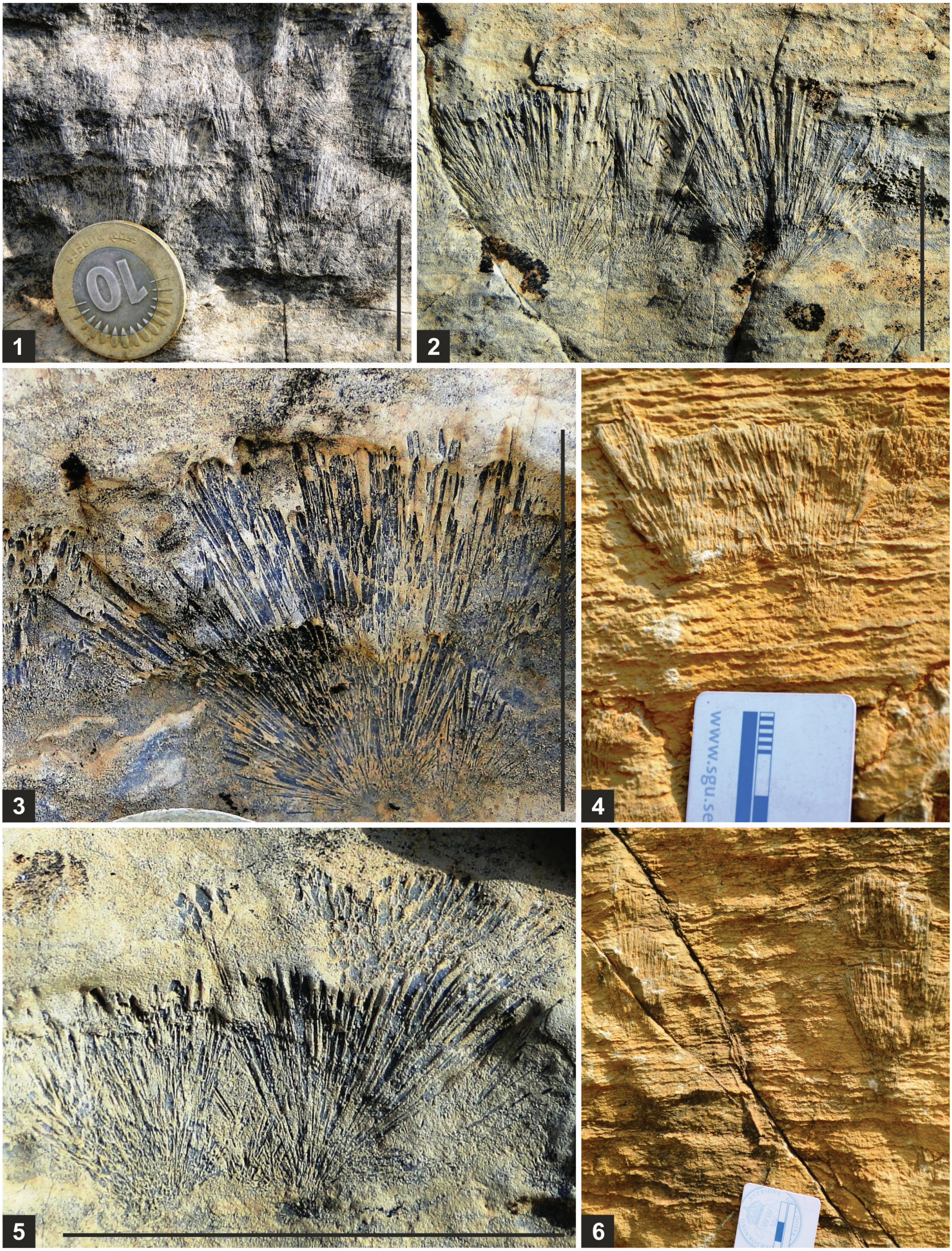

Fig. 4. Field photographs showing fan-fabric structures in the Kajrahat Limestone, exposed in the Kuteshwar area, Katni district, M.P. (1) densely packed fan-fabric structures noted on a longitudinal section of the outcrop; (2, 3, 4) enlargement of different parts of the photograph (1), note radiating nature of these fan-fabric; (5, 6) fan–fabric on partially weathered outcrop surface, fans seen in (6) are vertically parallel. Scale bar = 2.7 cm for all photographs.

limestone beds within siliciclastic-dominated settings (James *et al.,* 2001). Similar sized extant carbonate fans are now restricted to diagenetic environments (James *et al.,* 1988) and are not known to occur in open marine conditions on the seafloor.

The stratigraphic distribution of carbonate fans, their overall rarity in post-Proterozoic sections, and their occurrence in otherwise enigmatic carbonates (i.e. Snowball Earth and Lower Triassic carbonates) suggests that rare environmental factors are required for their formation (Kempe and Kazmierczak 1990 1994; Grotzinger 1989; Grotzinger and Kasting 1993). Exceptionally, sea floor-precipitated carbonate fans of cm-sized preserved and recorded in the Neoproterozoic, Rainstorm Member of the Ediacaran Johnnie Formation, Death Valley region, eastern California (Pruss *et al.,* 2008). The well preserved silicified microfossil assemblages are, in almost all cases, closely related to these sedimentary textures (Knoll *et al.,* 1993; Knoll and Sergeev, 1995; Sergeev *et al.,* 1994, 1995; Sharma and Sergeev, 2004). Analyses of fan occurrences, like those in the Kajrahat Limestone, in other geologic records may provide insight into their formations. Therefore, investigation of the Palaeo-Mesoproterozoic carbonate precipitates and associated microbiotas are very important and documented both to understand the carbonate precipitation patterns and the role of evolving ancient microorganisms in evolution.

Laminated or radial-fibrous microbialites with fine, extremely even and uniformly thick lamination, regardless of depositional orientation are considered as "precipitates" (Grotzinger and Read, 1983; Hofmann and Jackson, 1987). These precipitates formed almost exclusively by inorganic deposition of calcium carbonate, with little evidence of involvement of cyanobacteria. Unambiguous remnants of cyanobacterial communities, that could be responsible for accretion of precipitates by deposition, trapping or binding of sediments, have not been observed within these textures. The cyanobacteria or heterotrophic bacteria, as a result of their metabolic activity, probably changed the environments and indirectly facilitated the carbonate precipitation (Chafetz and Buczynski, 1992; Grotzinger and Knoll, 1995; Sharma and Shukla, 1998; Riding and Sharma, 1998; Seong-Joo and Golubic, 1999, 2000; Bartley *et al.,* 2000). Bartley *et al.* (2000) suggested that morphologically identical radial-fibrous fans are located near the intertidal and supratidal facies of an arid tidal flat, where evaporation of seawater resulted in significant carbonate oversaturation. The prolific growth of radial-fibrous structures is a result of a change in water chemistry, flooding, reduced concentration of inorganic carbon or overgrowth of cyanobacterial mats. The decomposed mats probably induce carbonate precipitation because organic molecules that inhibited this process were consumed heterotrophically and developed favorable microenvironments for carbonate precipitation. In some cases, nucleation occurred directly at the sediment–water interface and the fans grew rapidly, penetrating the mats and entombing allochthonous microorganisms. Patchy development of radial fans suggests that the growth of radial-fibrous textures was intermittent, with periods of low precipitation punctuated by rapid growth of the radial-fibrous fabric. When the nucleation occurred slightly below the sediment–water interface, the radial fan-like structures were formed (Bartley *et al.,* 2000). The size and shape of fibrous crystals resembles the fibers that constitute botryoidal aragonite (Ginsburg and James, 1976; Folk and Assereto, 1976; Grotzinger and Read, 1983; Hofmann and Jackson, 1987; Perrin *et al.,* 2014; Lee and Lindgren, 2015), although this growth habit may also occur in calcite (Bartley *et al.,* 2000). Occurrence of laminites, stromatolites, microbial features in the Kajrahat Limestone suggest that suitable physical and chemical environment was available for the formation of fan fabric found in limestone.

CONCLUSIONS

The Kajrahat Limestone noted in Kuteshwar area has well preserved carbonate FFS made up to 10 cm long radiating aragonitic crystals. These structures are preserved throughout the carbonate beds and diverging up to stromatolitic structure. Globally recorded carbonate FFS are suggestive of their being a common feature of Archaean and Palaeoproterozoic carbonate platforms which occur mostly in intertidal settings. The present record of the late Palaeoproterozoic age Kajrahat Limestone FFS was formed in a shallow subtidal storm-dominated setting. The Kajrahat Limestone currently contains the youngest known occurrence of calcium carbonate fans in the Proterozoic successions of India. Understanding of such unusual carbonate facies provides insights into the formation of carbonate fans during Palaeoproterozoic in the Earth history.

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