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MICROFACIES ANALYSIS, DEPOSITIONAL ENVIRONMENT AND ECOLOGY OF NEOPROTEROZOIC LIMESTONE OF SINCHA FORMATION, KATHUA DISTRICT, JAMMU

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Abstract: This paper presents the results of microfacies analysis and depositional environment of Sincha Formation exposed at Siara in Kathua District of Jammu region. The Sincha Formation comprises of stromatolite bearing dolomitic limestones with interbedded thin beds of chert and stand out as ribs amidst the phyllites, shales and sandstones. The characteristic feature of these limestones is alternation of white and grey colour bands of limestone giving the rocks a zebra strip appearance. We studied these rocks for sedimentological and palaeontological signatures under the microscope and distinguished five microfacies types and various types of primitive microflora (Cyanobacteria - A*rchaeoellipsoides*). The observed microfacies associations and microflora were used to infer depositional environments and standard facies zones, and environmental and ecological conditions during the deposition of the limestones of Sincha Formation.

Keywords: Proterozoic, Limestone; Sincha Formation; Microfacies; A*rchaeoellipsoides,* Ecology and Environment

Introduction

The youngest formation of the para-autochthon namely the Sincha Formation succeeds Ramban Formation disconformably and most of this formation is occupied by Sewa (= Punara) Granite thereby reducing it to a narrow zone exposed along the southern limit of this granite body. The Sincha Formation is exposed in the area around Sincha village north of Ramban where it is limited in the north by the Panjal Thrust. It is also exposed in the area around Siara along the Bani-Basholi road section. Lithologically it is composed of dark-grey to bluish-grey and light grey sandy dolomite occasionally phosphatic and pinkish limestone. Bluish-grey dolomites are interbedded with grey limestone with zebra type banding. In the grey to bluish grey limestones lenticles of chert contain primitive microflora. These limestones are hard, sheared and heavily fractured and shattered. They are frequently intercalated with slates and phyllites. Locally bands of grey shales are present in the succession. The formation was earlier grouped with Dogra Slates, Ramsu Formation and Agglomeratic Slates. Jangpangi et al. (1986) reported *sphaeromorphs* microflora of Precambrian age in the lenticles of black chert present in the basal part of the succession but no details are given on the location, stratigraphic level and description of the reported microflora.

The Sincha Formation comprises mainly of limestone and dolomite with intercalations of shale and sandstone. The area presents a fascinating geological setup with rocks varying in age from Proterozoic to Tertiary. However, these rocks have not been hitherto investigated for facies investigations to decipher their depositional and ecological conditions. The present study is an attempt to investigate this limestone dominating Sincha Formation exposed around Siara for microfacies investigation in order to decipher depositional and ecological conditions during its deposition.

Geology of the area

The present study area falls within Survey of India toposheet nos 43P/13 NE, P/14 NW. The area of study is linked by Jammu-Pathankot national highway and easily accessible from Jammu and Basholi. Siara village is 236 km from Jammu via Basholi and Bhund. Some of the best sections are exposed along the Basholi-Bani road section in the area around Siara.

Earliest geological references to the parts of the Bani-Basohli area are by Medlicot (1876) and Mc Mohan (1885). Sharma et al. (1970-71, 1976) have carried out systematic geological mapping of Bhaderwah- Bhallesh- Bani and Thatri-Khaleni- Dudu areas. Karunakaran and Ranga Rao (1979) recognized Panjal trap and Agglomeratic Group of rocks of Permo-Carboniferous age in the para-autochthonous zone in the west of Ravi River. Jangpangi et al. (1986) recognized Lower Permian Panjal volcanic and Precambrian Gamir, Baila and Ramban formations in the para-autochthonous zone in the section west of Ravi River. Detailed geological mapping of the Lesser Himalayan belt between Chenab and Ravi rivers on a scale of 1:25000 in Basantgarh, Bani and Himachal Pradesh border areas has been carried out by Raina and Sharma (1988-89). The generalised tectonostratigraphic succession in the study area from north to south is described in Table 1. Geological map of the area is given

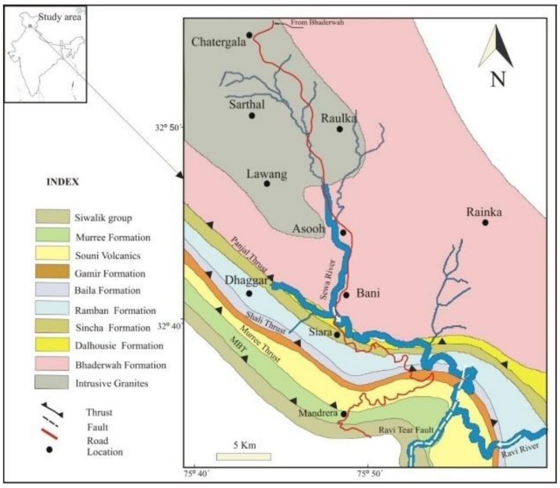

Fig. 1: Geological map of the study area (after Choudhary, 2006**)**

as Figure 1. The para-autochthonous zone in the study area is bounded by Murree Thrust in the south and Panjal Thrust in the north and displays younging of its constituent formations due north.

Subgroup/Formation	Lithology	Age
Bhadarwah	Phyllites, schists and slate	Precambrian
Dalhousie	Augen gneisses and granites (granodiorite to quartz diorites)	
------------ Panjal Thrust (= Jutogh Thrust)-------------		
Sincha	Sandy dolomites occasionally phosphatic, pinkis , grey Limestone having zebra type banding	Precambrian
Ramban	Grey to dark grey shales/slates with bands of grey quartzites, bluish grey phyllitic slates	Precambrian
Baila	Calcareous shale, nodular and lenticles of limestc black to carbonaceous slates	?Neoproterozoic
------------Shali Thrust (=Sudh Mahadev Thrust)-----------		
Gamir	Quartzite, bands of conglomerate and cherty shales and bands of limestone and purple shale	Mesoproterozoic
Souni Volcanics	Basaltic lava, greenish and greyish green in Colour	Palaeoproterozoic
------------------Murree Thrust---------------------		
Murree	Sandstones, mudstones and shales	Miocene
-------------Main Boundary Thrust-----------------------		
Upper Siwalik	Sandstone and conglomerate	M. Pleistocene

Table 1 : Generalised tectostratigraphic succession from north to south in the study area (after Raina and Sharma, 1988-89)

Methodology

Field work

Field work included the geological mapping and measurement of different lithounits. Systematic geological mapping of the outcrops demarcating formation boundaries, erosion surfaces and section measurement was carried out and collection of stratigraphic samples from different stratigraphic levels was done for sedimentological studies. Stratigraphic sections were measured bed by bed. Both vertical and lateral facies variations were recorded. The bed contacts, variations in texture, sedimentary structures, colour of the rocks, etc. were also recorded. For microfacies analysis, geological field studies in systematic manner and profiles with special consideration of facies criteria (lithology, sedimentary structure, fossil content, stratigraphic relationships and geometry of the rock bodies) were followed.

Detailed fieldwork at and around Siara was carried out. In this area Sincha Formation is exposed along the newly cut road section for widening of the existing Basholi-Bani road. The formational boundaries of the Sincha Formation were demarcated in the area based on the map prepared by Choudhary (2006) which are thrusted against the Dalhousie Formation (along the Panjal Thrust) and conformable with the overlying Ramban Formation. The exposed section was measured along the road and bed by bed measurements were taken. The litholog of the measured section was prepared and is presented as Figure 2. The Sincha Formation of the Proterozoic age has a well developed sequence of carbonate rocks, which are interbedded with shales and chert. The stromatolitic carbonates are conspicuous at many places. All the carbonates are pervasively dolomitized. Petrographic examination of these carbonates revealed that they are predominantly made up of fine grained micrite with patchy development of sparite and chert/quartz. The stromatolitic carbonates show distinct banding of alternate carbonate and cherty layers. The latter are rich in organic matter indicating prevalence of profuse algal activity.

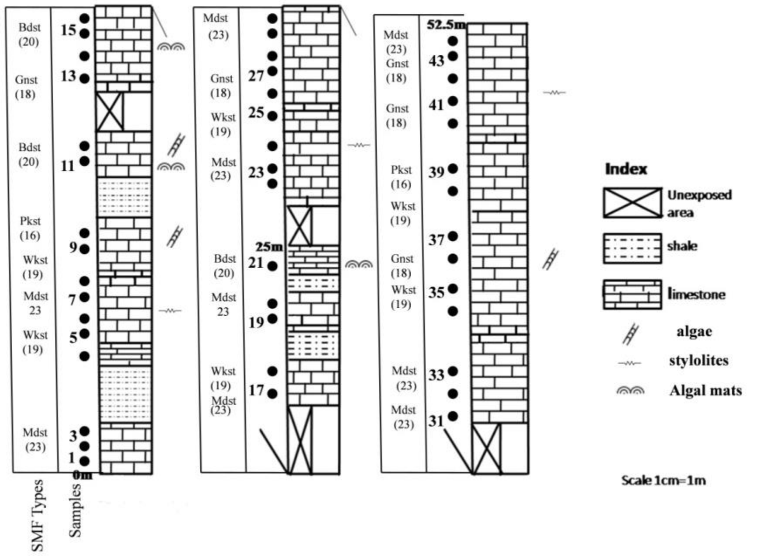

Fig. 2: Litholog of the measured section, temporal distribution of sample locations and standard microfacies. Mdst= mudstone facies, Wkst= wackestone facies, Pkst= packstone facies, Gnst= grainstone facies and Bdst= boundstone facies

Lithologically Sincha Formation is composed of greenish grey, laminated and jointed calcareous shale with lenticles of limestone. The limestone beds occur in the lower part of the formation comprising of grey, bluish grey, thinly bedded light yellowish limestones with grey argillite intercalations (Pl. 1a). The slates vary in colour from bluish grey to light grey. Outcrop-scale folds (Pl. 1b) are observed at many places. Bleached argillite is also commonly met with carbonaceous and ferruginous argillite unit which is exposed within the slate suite along the main *nala* south of Kurro and continues west of Charmur. Green, greenish grey calc-argillite is noticed along the road at Siara where these limestones form more massive beds.

At different stratigraphic levels in the lower part of the section, these rocks exhibit very thickly bedded coarse grained grey limestone beds (Pl. 1c). These beds exhibit oscillation ripples on the bedding planes. Also at some levels within the same units alternation of laminated beds of white and gray colours (zebra type bands) occurs. Dark bands are wavy in nature and represent algal laminated units. The dark cross-laminated units are followed by

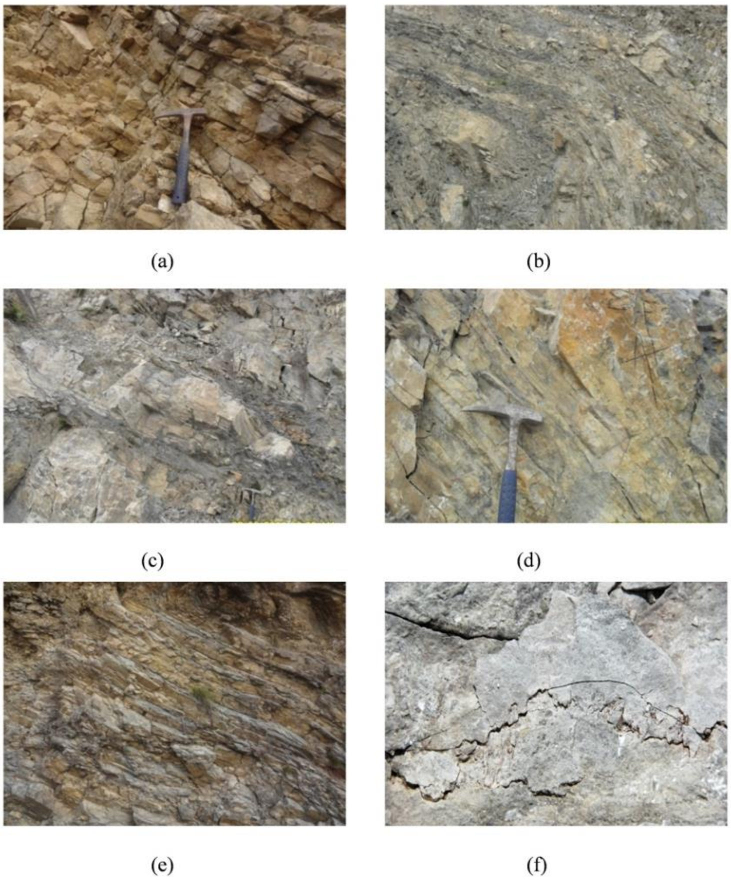

Plate 1: Field photographs showing greenish grey, laminated and jointed calcareous shale with lenticles of limestone and microstructures and small-scale folding.

convolute laminated units at their tops. Chert beds are observed at number of stratigraphic levels in the measured section (Pl. 1d). In thickly bedded units sedimentary structures, both organic and inorganic, are also observed in this section. These beds laterally pich out within few tens of meters. Very thinly bedded lithounits are internally laminated (Pl. 1e). Algal structures were observed throughout the measured section. These rocks show many microstructures like macro-vugs, stylolites (PL. 1f) and macro-veins of different generations.

The tops of the limestone beds are marked by horizontal burrows and trails of organisms. The nature of bedding is almost uniform pinching out along the strike and is laterally continuous for several meters. The well developed structures include both organic structures (algal structures) and dissolution structures. The algal structures are blue green algal mats which under different depositional conditions assume different forms. The laminae are thin, fraction of a millimeter thick forming beds which are marked by sharp contacts with the underlying and overlying beds. These beds are also marked by concentration of carbonate and fine grained clastic materials within them.

The upper part of Sincha Formation is also limestone dominated and is exposed on the slopes of Kurro village in the east and northwest and east to northeast of Chamur further east. Towards west and beyond Chala this limestone formation decreases in thickness and occurs as lenticular beds. Light grey to dark grey nodular limestone, greenish grey to ash grey, black carbonaceous phyllite/slate at places in lower part and calcareous beds with lenticles of limestone in the upper part are also present. The calcareous phyllite and slate is black in colour giving appearance of burnt coal. These phyllites are highly foliated, soft and crumbly. At the surface they are often highly weathered.

Stromatolites are organo-sedimentary structures produced by the carbonate- precipitating and sediment binding activities of the successive mats of algae, predominately the blue-green algae (*cyanobacteria*). It has been noted that during the periods of non-deposition a thin algal mat is formed and as the sediments are deposited the algae permeate them and bind them together. Lamination due to deposition of carbonate precipitates is accentuated by the alternation of these organic layers (e. g., Black, 1933; Monty, 1965; Gebelein, 1969). The term 'Stromatolith' was originally used by Kalkowsky (1908) as a purely descriptive term to cover a variety of attached laminated structures in carbonate rocks, whether or not of biogenic origin. The individual limestone bands are not more than 15-20 m thick. These limestones are grey, bluish grey, thinly bedded with argillite intercalation or partings. The limestone is frequently boudinaged imparting a pseudo-nodular look to this lithounit. The limestone is intensely deformed into small-scale folds at many places. Near Siara at Tipri mostly brecciated limestone containing clasts of pebble to cobble size are exposed. Quartzite bands are interbedded with these limestones. In addition, folded slates and phyllites characterized by cross cutting quartz veins are also exposed here.

Laboratory work

The microfacies study is based on 44 oriented thin sections prepared from samples collected at Siara. Staining of thin sections was done following the procedure after Dickinson (1965). Microfacies studies include all the sedimentologic and palaeontologic criteria in thin sections and polished slabs (Flugel, 1982). Various types of allochems and orthochems were identified and textural features noted in thin sections. The classification of microfacies types followed in this study is based on Dunham (1962) limestone classification scheme. For the identification of facies and interpretation of depositional environments, thin sections were analysed. The recognition of the "standard microfacies (SMF) types" and the "facies zones" have been defined based on Wilson (1975).

Microfacies Analysis

Microscopic studies of carbonates were given substantial impetus by Sander (1936) who presented one of the first comprehensive general surveys of the recent carbonates. According to Flugel

(1982) microfacies is the sum of all the palaeontological and sedimentological results, which can be classified in thin sections. Wilson (1975) applied the criteria to the Late Triassic reef carbonates and was latter on expanded by Flugel (1982) for numerous Palaeozoic and Mesozoic carbonate sequences in Europe. The microfacies investigation of the carbonate rocks helps in the interpretation of depositional environments and ecological conditions.

Textural Facies Types

Microfacies analysis based on thin section studies subdivide the different facies into units of similar compositional aspect that reflect specific depositional environment. Basic prerequisites for defining microfacies types (MFT) are based on discrimination of grain categories, limestone classifications based on textural criteria, the recognition of depositional fabrics and the ability to attribute fossils in thin sections to major systematic groups and taxonomic units (Flugel, 2010). Facies zones (FZ) are limestone belts differentiated according to the changes of their sedimentological and biological criteria across shelf-slope basin transects. These Facies Zones describe idealized facies belts. Carbonates formed within these Facies Zones often exhibit specific Standard Microfacies Types (SMF) assemblages that are used as additional criteria in recognizing the major facies belts.

Microfacies Types

The petrographic thin section analysis revealed five different types of microfacies viz., mudstone, wackestone. packstone, grainstone and boundstone in the current study. These are described as follows:

Mudstone Facies

This microfacies is common within the Siara limestones and found in all the studied thin sections. This microfacies consist of lime mud matrix (micrite) with little allochems (Pl. 2a). It shows high percentage of micrite (97.94%) in Siara section. According to Dunham (1962), mudstone facies are deposited in low energy environment either in protected seas or below fair weather wave base (calm water). This facies is similar to the SMF-23, massive unfossiliferous mudstone (Flugel, 2010), which corresponds to the Facies Zone 8 of restricted platform (Wilson, 1975; Flugel, 2010). Moreover, this facies type also indicates low maturity of the limestone, as the rocks of low maturity are characterized by a high proportion of micrite and low proportion of allochems. High percentage of micrite reflects deposition in a settings where current or wave energy was insufficient to winnow away the fine matrix (Folk, 1962).

Wackestone Facies

It is dominated by algal bioclasts at various levels within the succession. The microfacies is characteristic of shallow, open-marine environments (Flugel, 1982). It is mud supported microfacies; the allochems range between 10% – 50% and consists of algal fragments and *Archaeoellipsoides* (Fig. 2b,c,d). The bioclasts constitute about 40% comprising of algal fragments, heterocysts and akinetes while allochems constitutes 60% of the rock. Micritization of the algal fragment (micrite envelop) and filling of the inter-laminar spaces with micrite are identified and in some cases sparry calcite fills these spaces. The presence and diversity of the carbonate grains together with the presence of algal debris reflect deposition under high marine salinity, moderately to quite agitated conditions. According to Wilson (1975) scheme it is comparable with the SMF type 19 which were deposited within the facies zone 8 - shelf and tidal flats with restricted circulated.

Packstone Facies

This facies is not common in all the studied sections. Exceptionally, only very few samples show this facies (Pl. 2e). In this facies the allochems percentage is more than orthochems, where some of the sparite calcite crystals are of neomorphic origin. This facies consists of approximately 72% allochems and 28% orthochems (both micrite and sparite). Allochems include algal bioclasts and peloids. Peloids are dominant presenting a fenestral fabric; orthochems include both micrite and sparite. This facies is comparable with the SMF type 16 characteristic of highly agitated depositional environment of the marginal facies zone - 6 (margin of the Winnowed Edge Sands towards facies belt-7).

Grainstone Facies

The grainstone facies comprises of algal fragments dominated by heterocysts (Pl. 2f) and akinetes with occasional quartz grains. The facies is constituted of about 90% allochems and 10% orthochems mostly micrite. Well-preserved cyanobacterial remains in the form of microfossils in the limestone samples of the Siara Formation were recorded. These include: (i) heterocysts, which help fix atmospheric nitrogen and (ii) akinetes are dormant cells which form under adverse conditions (Tomitani et al., 2006). Akinetes are double thick walled resting stage cyanobacteria. This facies is also rarely seen in the analysed samples of this study and can be categorised as the SMF type 18 related to facies zone 7. However, in both the wackestone and grainstone facies, heterocysts are predominant. This microfacies may be related to facies zone-7 (Shelf Lagoon with open circulation).

Boundstone Facies

The boundstone facies is dominated by the presence of algal mats alternating with mixed clastic and carbonate layers (Pl.

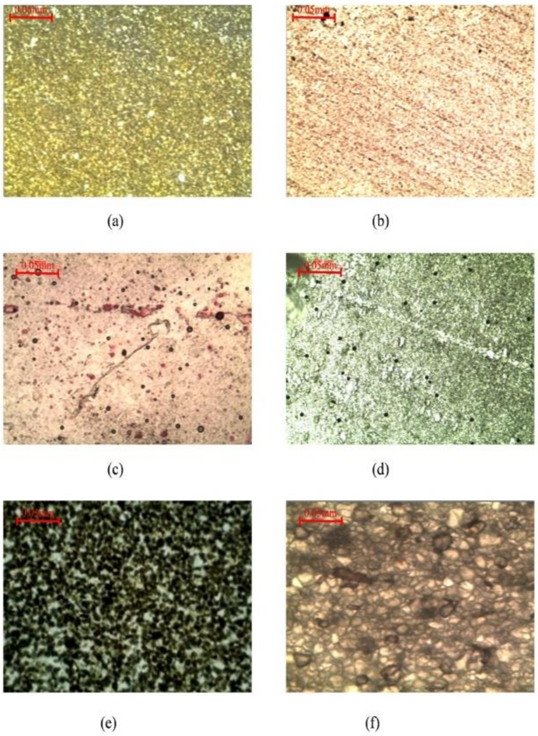

Plate 2: Distribution pattern of small-sized akinetes observed in petrographic thin sections of limestone of Sincha Formation.

3). Alternation of algal laminae and sediment layers represent interplay of algal growth laminae and influx of clastic sediments to the basin of deposition. Some microbial laminites show silicified cyanobacterial filaments and coccoid cells. The thin algal laminites are intervened by the accumulation of imbricated and cross-laminated clastic layers. This facies is comparable with the SMF type 20 and is related to facies zone-8 (Algal Mat Belt of Restricted Shelf and Tidal Flat)

Assemblage showing the cluster and random distribution of *Archaeoellipsoides.* (a) Mudstone facies dominated by micrite with few minute allochem; (b,c, d) Heterocyst and akinetes bearing wackestone. (e) Packstone facies with densely packed, horizontally layered, clotted pelolds and fine fenestral texture. (f) Grainstone facies with dominant heterocysts and subordinate akinetes.

Energy Index

Energy index classification proposed by Plumley et al. (1962) and Catalov (1972) was adopted for the energy index analysis in this study. From the energy index classification it can be interpreted that limestone genesis is based primarily upon the energy level of depositional environment, which is a function of wave and current action reflecting a fundamental concern with environmental interpretation. These genetic classifications constitute a grading spectrum between quiet water and strongly agitated water. Plumley et al. (1962) distinguished five major limestone categories as Type I (quiet water), Type II (intermittently agitated water), Type III (slightly agitated water), Type IV (moderately agitated water) and Type-V (strongly agitated water). Our study reveals that microcrystalline calcite matrix ranges from 97.94- 42.11% (Table-2) and the presence of microfossils assemblages represent the influence of both quiet and slightly agitated water condition, which fall in subtype II_1 of Type II i.e., mixed types occurring in the wide transition zone between deep water and very shallow water with restricted circulation probably with slightly high salinity between facies zones 6 and 8 (e. g., Plumley et al., 1962).

Depositional environment

The cryptalgal sediments (boundstones and laminites) form dominant facies in the

S.No	Algal bioclast	Sparite	Micrite	Fe calcite	Organic matter	Pellets	Ouartz
1	0.00	15.31	48.98	10.20	20.41	0.00	5.10
2	0.00	5.26	63.16	10.53	15.79	0.00	5.26
3	0.00	10.53	78.95	5.26	5.26	0.00	0.00
4	0.00	5.26	68.42	5.26	21.05	0.00	0.00
5	0.00	73.68	21.05	0.00	0.00	0.00	5.26
6	5.26	84.21	10.53	0.00	0.00	0.00	0.00
7	0.00	10.53	52.63	10.53	26.32	0.00	0.00
8	0.00	15.79	58.06	10.53	10.53	5.10	0.00
9	5.10	10.20	54.08	15.31	15.31	0.00	0.00
10	0.00	10.20	61.22	10.20	18.37	0.00	0.00
11	0.00	8.16	76.53	10.20	0.00	0.00	5.10
12	3.60	0.00	91.30	5.10	0.00	0.00	0.00
13	0.00	10.64	79.79	5.32	0.00	0.00	4.26
14	0.00	5.10	45.92	15.31	15.31	0.00	18.37
15	0.00	15.79	63.16	10.53	10.53	0.00	0.00
16	0.00	10.53	63.16	10.53	15.79	0.00	0.00
17	0.00	18.37	61.02	15.31	0.00	5.31	0.00
18	5.26	10.53	52.63	10.53	21.05	0.00	0.00
19	10.53	21.05	57.89	0.00	5.26	0.00	5.26
20	0.00	5.26	84.21	0.00	5.26	0.00	5.26
21	0.00	5.15	74.23	5.15	10.31	0.00	5.15
22	0.00	5.26	73.68	5.26	15.79	0.00	0.00
23	0.00	15.79	63.16	5.26	5.26	0.00	10.53
24	10.20	8.16	51.02	5.10	10.20	5.10	10.20
25	0.00	21.05	52.63	5.26	5.26	5.26	10.53
26	0.00	17.65	47.06	17.65	11.76	0.00	5.88
27	0.00	5.26	73.68	0.00	0.00	0.00	21.05
28	0.00	21.05	42.11	10.53	10.53	0.00	15.79
29	0.00	10.53	42.11	15.79	10.53	0.00	21.05
30	0.00	15.79	63.16	5.26	5.26	0.00	10.53
31	0.00	5.26	84.21	0.00	5.26	0.00	5.26
32	0.00	0.00	74.49	10.20	15.31	0.00	0.00
33	0.00	36.84	56.32	10.79	5.53	0.00	10.53
34	0.00	5.26	73.68	0.00	10.53	0.00	10.53
35	0.00	31.58	42.11	0.00	5.26	0.00	21.05
36	2.90	21.05	44.47	10.53	0.00	0.00	21.05
37	0.00	0.00	89.47	5.26	0.00	0.00	5.26
38	0.00	2.06	97.94	0.00	0.00	0.00	0.00
39	0.00	21.05	73.68	5.26	0.00	0.00	0.00
40	0.00	5.05	94.95	0.00	0.00	0.00	0.00
41	0.00	21.05	78.94	0.00	0.00	0.00	0.00

42	0.00	15.79	57.89	10.53	10.53	5.26	0.00
43	0.00	20.79	63.42	0.00	5.26	5.00	5.53
44	0.00	15.79	63.16	10.53	0.00	0.00	10.53

Table 2: Percentage of allochemical, orthochemical and detrital quartz constituents in the Sincha Formation

present study. Rare allochemical carbonate sediments are reworked cryptalgal sediments representing brief intermittent higher energy episodes in a shallow subtidal environment. The present day analogues of the cryptalgal mats include Shark Bay and the Persian Gulf (Eriksson et al., 2006 and references therein). Deposition of the carbonate sediments of Sincha Formation took place predominantly in a protected intertidal to supratidal realm. The restricted facies is represented by laminoid cryptalgal bounddstone, which is correlated with present day blister algal mats from upper intertidal and supratidal zones.

The facies associations observed in the present study indicates a lagoonal and intermittently starved basin conditions. This was followed by a quiet subtidal condition resulting in the deposition of the thick massive micrite horizon in general. The algal laminites (Fig. 3) laterally grade to algal flats of supratidal to intertidal environments suggesting local reef forming conditions. A high proportion of sparry cement and abundance of the intraclasts in the intrasparite suggests diagenetic alteration of original micrite and calcite cement. The well-rounded nature of the allochems (peloids) indicates high-energy environment causing penecontemporaneous breakdown and abrasion of the freshly laid sediments and simultaneous removal of fine grained sediments. Presence of small-scale wave-ripples suggests quite and shallow water conditions of deposition.

The finely laminated facies, intervened by algal mats are suggestive of periodic flooding of the carbonate mud flats by 'spring and storm tides' a common feature of modern supratidal environments (Laporte, 1967; Shinn et al, 1965). Similar

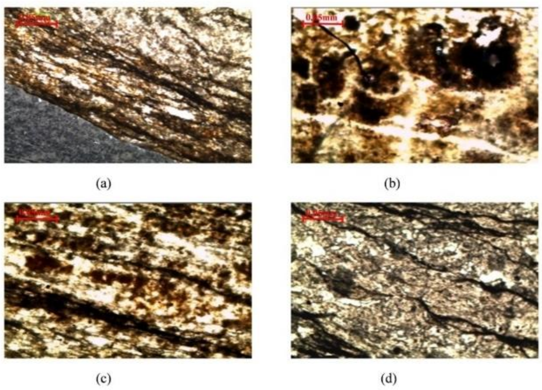

Plate 3: Algal Boundstone: (a) Alternation of algal laminae and clastic-carbonate layers: (b) A chert nodule from a supratidal microbial laminite showing silicified cyanobacterial filaments and coccoid cells; (c) growth of algal laminae and accumulation of mixed organic and clastic layers; (d) thin algal laminites intervened by the accumulation of imbricated and cross-laminated clastic layers

features are observed in the supratidal mud flats of Florida Bay and Bahamas (Shinn et al., 1965; Adams & Rhodes, 1960) and also in the ancient analogues of supratidal deposits of the Manlius Formation, New York (Laporte, 1967).

The microfacies dominated by the presence of micrite in the inter-columnar spaces reflect their deposition and growth in the low intertidal or subtidal conditions with barriers preventing strong wave splashes. The microscopic or mesoscopic rhythmic layering in the microfacies indicates a quiet subtidal/lagoonal environment. Alternations of calcite - organic matter in the dark calcitic layers indicate alternate precipitation of calcite and growth of algal layers through rhythmic transgression and regression in the basin.

Ecology and Environment

The algal laminites and mat builders which colonize both hard and loose substrates of benthic environments for stromatolite construction. The microorganisms either contribute to the construction of stromatolite structure or to its destruction (Hofmann, 1973). Both organic and inorganic components of stromatolite as well as the micro-chemical conditions within it are potentially subject to microbial influence. Only dominant or very abundant organisms can be expected to play any significant role influencing the microenvironment or the structure of stromatolites. The presence of rare species, however, contributes to the species diversity of a microbial community, which in turn may reflect the ecological conditions of the habitat (Hofmann, 1973). Generally species diversity is inversely proportional to the harshness of environment conditions. Highly fluctuating intertidal environments, for example, are dominated by few, exclusively prokaryotic species. Under more favorable conditions in permanently submerged environment, the species diversity increases and both prokaryotic and eukaryotic organisms are present. Proterozoic microflora from the sedimentary sequences of Himalaya is not well known. Records of well preserved assemblages are only known from the Krol belt of the Lesser Himalaya (Venkatachala et al., 1989; Kumar and Rai, 1992; Tiwari and Azmi, 1992; Tiwari, 1996) and Deoban Formation (Shukla et al., 1987; Kumar and Srivastiva, 1992; Srivastava and Kumar, 1997). Raha (1980b) found a scanty biota consisting of filamentous and coccoid Cyanobacteria (*Gunflintia grandis, G. minuta* and *Huroniospora* sp.) from a thinly laminated black chert alternating with dolomite layers forming domal stromatolites in the Sirban Limestone of Jammu. The discovery of the microflora reported from the Sirban Limestone of Jammu by Bhat et al. (2009) is a significant advance in this direction. The present assemblage is mainly dominated by

Cyanobacteria. Record of silicified microfossils recovered from Pecambrian successions are conspicuously dominated by filamentous and coccoid microfossils, most of which are comparable with the modern cyanobacteria (Barghoorn and Tyler, 1965; Schopf, 1968; Schopf and Blacic, 1971; Knoll, 1984, Golubic et al., 1995; Sergeev et al., 2012 and others). Paleoenvironmental interpretations based on these microfossil assemblages have also been recorded (Golubic and Campbell, 1979; Knoll, 1985a; Green et al., 1989; Knoll and Golubic, 1992; Golubic and Seong-Joo, 1999; Sharma and Sergeev, 2004; Sharma, 2006a). It is generally believed that heterocystous cyanobacteria usually form akinetes under harsh climatic and depositional conditions whose signatures are noted in the modern analogues in terms of light, temperature, nutrient availability, and salinity. All these factors play an important role for the formation of Akinetes (Fay et al., 1984, Moore et al., 2005, Sukenik et al., 2007).

The heterocysts and akinetes from the Sincha Formation probably belong to A*rchaeoellipsoides* (e. g., Horodyski and Donaldson, 1980). The occurrence of *Archeaoellipsoides* suggests extreme stress in the depositional environment like desiccation and high temperature, leading to akinete production in filamentous cyanobacteria. Akinetes do not survive in long exposures to high temperature (Oren, 2014). These are isolated spherical and rod-shaped and large ellipsoidal vesicles. A similar type of assemblage has been reported in the chert samples of the Mesoproterozoic Billyakh Group of the Western Anabar region, Northern Siberia (Golovenok and Belova, 1981, 1984). Heterocysts and akinetes are also reported from Paleoproterozoic rocks of Franceville Group, Canada (Amard and Bertrand-Sarfati, 1997), Odjick and Rocknest Formations, and Epworth Group, northwestern Canada (Hofmann and Grotzinger, 1985).

Diversity of life forms in Salkhan Limestone of the Semri Group has been used to demonstrated environmental conditions prevailing during the late Paleoproterozoic period (McMenamin et al., 1983; Venkatachala et al., 1990; Kumar and Srivastava, 1995; Sharma and Sergeev, 2004; Prasad et al., 2005; Srivastava, 2005; Sharma, 2006a; Sergeev et al., 2008; Srivastava and Tewari, 2011). Akinete populations have also been reported from many peritidal carbonates of Mesoproterozoic age, including the Gaoyuzhang and Wumishan Formations, China (Zhang, 1985; Zhang, 1982; Zhang and Li, 1985; Cao, 1992; Seong-Joo and Golubic, 1999), the Uluksan Group of Baffin Island, Canada (Hofmann and Jackson, 1991), the Kheinjua Formation, India (McMenamin et al., 1983; Kumar and Srivastava, 1995; Srivastava, 2005; Sharma, 2006b), the Deoban Limestone Formation, Garhwal Lesser Himalaya (Srivastava and Kumar, 2003), the Sukhaya Tunguska Formation, Turukhansk Uplift, Siberia (Sergeev et al., 1997; Sergeev, 1997, 1999), the Kotuikan and Yusmastakh Formations, Anabar Uplift, north-eastern Siberia (Golubic et al., 1995; Sergeev et al., 1995), and the Debengda Formation, northern Siberia (Sergeev et al., 1994).

However, most of the Cyanobacteria have limited biostratigraphic usefulness because they represent hypobradytelic evolution that is a slowest of slow rate of evolution (Bengtson et al., 1992).

Conclusion

In thin sections the dominance of mud supported microfacies indicates the limestone of Sincha Formation was generally deposited in low energy protected shallow water environment. Though high amount of micrite reflects a relatively low turbulent environment, however, taphonic features of fossils suggest gentle disturbance due to intrabasinal transport. It is also supported by energy index classification of the reported facies. Microcrystalline calcite matrix comprises more than 97.94% of the rock and presence of complex fossil assemblages representing alternate deposition in agitated and quiet shallow water. The microfacies types identified in this study are similar to SMF Type 16, 18, 19, 20 and 23, which fall in Standard Facies Zones 7 and 8 - restricted wide platforms. The present assemblage is mainly dominated by Cyanobacteria (A*rchaeoellipsoides).* Most of the Cyanobacteria have limited biostratigraphic usefulness because they represent hypobradytelic evolution that is a slowest of slow rate of evolution. Associations of MFT occurring within the same lithofacies and deposited in the same general environment suggest local sedimentary sub-environments or intrabasinal controlled processes. The paleoecological set up of the microfacies and microfossils observed in the limestone of Sincha Formation indicates that the sedimentation took place under marine shelf conditions with restricted to intermittent fresh water circulation within an interior platform.

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References

Adams,J.E.,& Rhodes, M.L. (1960) Dolomitization by seepage refluxion. Am. Assoc.Petroleum Geologists, Bull. 44, 1913-1920.

Amard B.,& Bertrand-Sarfati J. (1997) Microfossils in 2000 ma old cherty stromatolites of the Franceville group, Gabon. Precambr. Res., v. 81, pp.197–221.

Barghoorn E. S.,& Tyler S. A. (1965) Microorganisms from the gunflint chert. Science, v. 147 , pp.563–577.

Bengtson, S., Fedonkin, M. A. & Lipps, J. H.(1992) The major biotas of Proterozoic to Early Cambrian multicellular organisms. In . Schopf, J. W and Klein, C. (eds.). The Proterozoic biosphere. Cafmbridge University press, pp. 433 – 436.

Bhat, G. M., Ram, G.,& Koul, S. (2009) Potential for oil and gas in the Proterozoic carbonates (Sirban Limestone) of Jammu, northern India. Geol. Soc., London, Special Publications. Vol. 326, pp. 245 - 254.

Black, M. (1933) Algal sediment of Andros Island Bahamas. Phil Trans. Roy. Soc. Lond., Ser B, vol. 222, pp. 165 – 192.

Cao, F. (1992) Algal microfossils of the middle proterozoic gaoyuzhuang formation in Pinggu County, Beijing. Geol. Rev., v.38, pp. 382–387.

Catalov, G. A. (1972) An attempt at energy index (EI) analysis of the Upper Anisian, Ladinian and Carnian carbonate rocks in the Teteven Anticlinorium (Bulgaria). Sedimentary Geology, 8, 159-175.

Choudhary, J.B. (2006) Geotechnical and Structural evaluation of Tectonostratigraphic Units along Head Race Tunnel, Sewa Hydroelectric Project.Stage-II,Kathua District.Unpublished Ph.d thesis.University of Jammu,Jammu.

Dickson, J. A. D. (1965) A modified staining technique for carbonates in the thin-sections. Nature, pp. 205 – 587.

Dunham, R. J.(1962) Classification of carbonate rocks according to depositional texture. Mem. Amer. Ass. Petrol. Geol., vol. 1, pp. 108 – 121.

Eriksson, K. A., & Truswell, J. F. (2006) Tidal flat associations from a Lower Proterozoic carbonate sequence in South Africa, Sedimentology, 21(2): pp. 293 – 309.

Fay P., Lynn J. A.,& Majer S. C. (1984) Akinete development in the planktonic blue-green alga Anabaena circinalis. Br. Phycol. J. 19, pp.163–173.

Flugel, E. (1982) Microfacies analysis of limestone New York, Springer-Verlag Berlin Heideliberg.

Flügel, E. (2010) Microfacies of Cabonate rocks, Analysis Interpretation and Application. Springer-Verlag, Berlin, 662 p.

Folk, R. L. (1962) Spectral subdivison of carbonate of limestone types: In Ham. W. Edition, Classification of Carbonate rocks. Mem. Amer. Assoc. Pet. Geol., Oklahoma, vol. 1, pp. 62-84.

Gebelein, C. D. (1969) Distribution, morphology and accretion rate of recent sub–tidal algal stromatolites in Bermuda. Jour. Sed. Pet., vol.39, pp. 49 - 69.

Golovenok, V. K., & Belova M. Y. (1984) Riphean microbiotas in cherts of the Billyakh Group on the Anabar Uplift. Paleontologicheskyi Zhurnal. 4:20–30 (English version).

Golovenok, V. K.,& Belova, M. Y. (1981) Precambrian microfossils in cherts from the Anabar Uplift. Doklady Akademii Nauk SSSR, 261, pp. 713–715.

Golubic S., Sergeev V. N., & Knoll A. H. (1995) Mesoproterozoic Archaeoellipsoides: akinetes of heterocystous cyanobacteria. Lethaia. v. 28, pp.285–298.

Golubic, S., & Seong-Joo L.(1999)Early cyanobacterial fossil record: preservation, palaeoenvironments and interpretation. Eur. J. Phycol., v. 34, pp.339–348.

Golubic, S.,& Campbell S. E. (1979) Analogous microbial forms in recent subaerial habitats and in Precambrian cherts: Gloeothece coerulea geitler and Eosynechococcus moorei Hofmann. Precambr. Res., 8: 201–217.

Green, J. W., Knoll A. H., & Swett K. (1989) Microfossils from silicified stromatolitic carbonates of the upper proterozoic limestones-dolomite ‘Series’, central east greenland. geol. mag., v. 126, pp. 567–585.

Hofmann ,H. J., & Grotzinger J. P. (1985) Shelf facies microbiotas from the odjick and rocknest formations (Epworth Group; 1.89 Ga), north-western Canada. Can. J. Earth Sci. 22 (12) :1781–1792.

Hofmann, H. J., & Jackson G. D. (1991) Shelf facies microfossilsfrom the Uluksan Group (Late Proterozoic) Bylot Supergroup, Baffin Island, Canada. J. Palaeontol.,v. 65, pp. 361–382.

Hofmann,H.J.(1973) Stromatolites: Characteristics and utility. Earth Science reviews, v.9, pp.339-373.

Horodyski, R.J., & Donaldson, J.A.(1980) Microfossils from the Middle Proterozoic Dismal Lakes Groups, Arctic Canada. Precambrian research, v.11, pp.125-159.

Jangpangi, G., Kumar, G., Rathore, D.R., & Datta, S. (1986) Geology of The Autoctconous folded belt, Jammu and Kashmir Himalaya with special references to the Panjal Thrust. Jour. Pal. Soc. Ind.,v.31, 39-51p.

Kalkowsky, E. (1908) Oolites and Stromatolites in Norddleutschen Buntsandstone. Z. Deut. Geol. Ges., vol. 60, pp. 68 – 125.

Karunakaran, C. and Ranga rao, A. (1979). Status of exploration for hydrocarbon in the Himalayan region. Himalayan Geol.

Seminar. New Delhi 1976, Jour. Geol. Surv. India, Misc. Publ., 41:1-66p.

Knoll, A. H. (1984) Microbiotas of the late precambrian hunnberg formation, nordaustlandet, svalbard. J. Paleontol., v. 58, pp. 131–162.

Knoll, A. H. (1985a) "A paleobiological perspective on sabkhas," in ecological studies: hypersaline ecosystems v.53 eds Friedman G. M., Krumbein W. E. (Berlin: Springer;), pp. 407–425.

Knoll, A. H., & Golubic S. (1992) "Living and Proterozoic cyanobacteria," in Early Organic Evolution: Implication for Mineral and Energy Resources, eds Schidlowski M., Golubic S., Kimberley M. M. (Berlin: Springer-Verlag;), pp.450–462.

Kumar , S., & Rai, V. (1992) Organic walledmicrofossels from the bedded chert of the Krol Formation (Vendian), Solan area, Himanchal Pardesh. Jour. Geol. Ind., vol. 39, pp. 229 – 234.

Kumar S., & Srivastava P. (1995) Microfossils from the kheinjua formation, mesoproterozoic semri group, Newari area, Central India. Precambr. Res., v.74, pp. 91–117.

Kumar,S.,& Srivastava, P. (1992) Microfossils from the black chert of Bhagwanpura limestone (Middle Proterozoic), Vindhayan supergroup, chittorgarh area, Rajasthan, West India. Curr. Sci., vol. 62, pp. 371-374.

Laporte, Leo F.(1967) Carbonate deposition near mean sea-level and resultant facies mosaic; Manlius Formation (Lower Devonian) of New York State: Am. Assoc. Petroleum Geologists Bull., v. 51, p. 73-101.

Mc Mohan, C. A. (1885) Some Further notes on the Geology of Parts of Chamba Rec. Geol. Surv. India, v. 18(1) 37-78p.

McMenamin, D. S., Kumar S.,& Awramik S. M. (1983) Microbial fossils from the kheinjua formation. Middle Proterozoic, Semri Group (Lower Vindhyan), Son Valley area, Central India. Precambr. Res. 21: 247–271.

Monty, C. L. V. (1965) Recent stromatolites in the windward lagoon, Andras Island Bahamas, Soc. Geol. Belgique Annales, vol. 88, pp. 269 - 276.

Moore D., O'Donohue M., Garnett C., Critchley C.,& Shaw G. (2005) Factors affecting akinete differentiation in Cylindrospermopsis raciborskii (Nostocales, Cyanobacteria). Freshw. Biol. 50: 345–352.

of cyanobacteria: molecular-phylogenetic and paleontological perspectives. *Proc. Natl. Acad. Sci. U.S.A.* 103 5442–5447. 10.1073/pnas.0600999103

Oren ,A.(2014) "Cyanobacteria: biology, ecology and evolution," in Stress Biology of Cyanobacteria: Molecular Mechanisms to Cellular Responses, eds Sharma N. K., Rai A. K., Stal L. (New York, NY: Wiley;), 3–20.

Plumley, W. J., Risley, G. A., Graver Jr, R.W., & Kaley, M. E. (1962) Energy index for limestone interpretation and classification. American Association of Petroleum Geologist, Memoirs No. 1. pp. 85-107.

Prasad B., Uniyal S. N., & Asher R. (2005) Organic walled microfossils from the proterozoic, vindhyan supergroup of son valley, Madhya Pradesh, India. Palaeobotanist, v. 54, pp. 13–60.

Raha, P. K. (1980b) Determination of paliocurrents and rate of sedimentationfrom stromatolites in Jammu Limestone, Udhampur District, Jammu. Proc. Workshop on stromatolites. G.S.I. Misc. Pub., vol. 44, pp. 267 – 274.

Raina, B.K., & Sharma,B.L. (1988-89) Geology of Sarthal-Bani-Siara Belt Sewa River Valley Basohli Tehsil Kathua District; Jammu and Kashmir, Progress Report.

Sander, B. (1936) Beitrage zur Kenntnis der Anlagerungsgefuge(Rhythmische Kalke and Dolomite aus der Trias). Tschermaks Min. Petrograph. Mitt.48, 27-139, Leipzig Classic work about mechanical and chemical depositional textures in thin-sections.

Schopf, J. W. (1968) Microflora of the bitter springs formation, late precambrian, Central Australia. J. Paleontol., v. 42, pp. 651–688.

Schopf, J. W., & Blacic J. M. (1971) New microorganisms from the bitter springs formation (late precambrian) of the North-Central Amadeus basin, Australia. J. Paleontol., v. 45,pp. 925–960.

Seong-Joo L., & Golubic S. (1999) Microfossils population in the context of synsedimentary micritic deposition and acicular carbonate precipitation: mesoproterozoic Gaoyuzhuang Formation, China. Precambr. Res., v. 96, pp. 183–208.

Sergeev ,V. N., Knoll A. H., Kolosova S. P.,& Kolosov P. N. (1994) Microfossils in cherts from the mesoproterozoic debengda formation, olenek Uplift, Northeastern Siberia. Stratigr. Geol. Correl., 2: 23–38.

Sergeev, V. N. (1997) "Mesoproterozoic microbiotas of the northern hemisphere and the meso-neoproterozoic transition," in Proceedings of the 30th International Geological Congress, Beijing, v. 1,pp. 177–185.

Sergeev, V. N. (1999) Silicified microfossils from transitional Meso- Neoproterozoic deposits of the Turukhansk Uplift, Siberia. Bolletinodella Soc. Paleontol. Ital., v. 38 , pp.287–295.

Sergeev, V. N., Knoll A. H., & Grotzinger J. P. (1995) Paleobiology of the mesoproterozoic billyakh group, Anabar Uplift, Northeastern Siberia. Paleontol. Soc. Memoir., v. 69, pp,1-37.

Sergeev, V. N., Knoll A. H., & Petrov P. Y. (1997) Paleobiology of the mesoproterozoic-neoproterozoic transition: the sukhaya tunguska formation, Turukhansk Uplift, Siberia. Precambr. Res.,v. 85, pp. 201–239.

Sergeev, V. N., Sharma M., & Shukla Y. (2008) Mesoproterozoic silicified microbiotas of Russia and India characteristics and contrasts. Palaeobotanist, v. 57, pp. 323–358.

Sergeev, V. N., Sharma M., & Shukla Y. (2012) Proterozoic fossil cyanobacteria. Palaeobotanist, v. 61, pp.189–358.

Sharma, M. (2006a) Palaeobiology of mesoproterozoic salkhan limestone, semri group, Rohtas, India; Systematic and significance. J. Earth Syst. Sci. 115: 67–98.

Sharma, M. (2006b) Small-sized akinetes from the mesoproterozoic salkhan limestone, Semri Group, Bihar, India. J. Palaeontol. Soc. India , v.51, pp. 109–118. [Google Scholar]

Sharma, M., & Sergeev V. N. (2004) Genesis of carbonate precipitates patterns and associated microfossils in Mesoproterozoic formations of India and Russia- a comparative study. Precambr. Res., v. 134, pp. 317–347.

Sharma, V. P., Chaturvedi R.K. & Sundaram (1970-71) Systematic mapping Bhadarwah Bhallesh Bani area. Doda and Kathua districts J&K state Unpub. GSI report.

Shinn, E.A., Ginsburg, R.N., & Lloyd, R.M. (1965) Recent supratidal dolomite from Andros Island, Bahamas, in Pray, L.C., and Murray, R.C., eds., Dolomitization and limestone diagenesis: A symposium: Society of Economic Paleontologists and Mineralogists Special Publication 13, p. 112-123.

Shukla, M., Tiwari, V. C., & Yadav, V. K (1987) Late Pracambrian microfossils from Deoban Limestone Formation, Leser Himalaya, India. Palaeobot., vol. 35, pp. 247 - 256.

Srivastava, P. (2005) Vindhyan akinetes: an indicator of mesoproterozoic biospheric evolution. Orig. Life Evol. Biosphs., v. 35, pp. 175–185.

Srivastava, P.& Kumar, S. (1997) Possible evidence of animal life in Neoproterzoic Deoban microfossil assemblage, Garhwal Leser Himalaya, Utter Pradesh, Curr. Sci., vol. 72 pp. 145 - 149.

Srivastava, P., & Kumar S. (2003) New microfossils from the Meso-Neoproterozoic Deoban Limestone, Garhwal Lesser Himalaya India. Palaeobotanist, v. 52, pp. 13–47.

Srivastava, P.,& Tewari V. C. (2011) “Morphological changes in microscopic-megascopic life and stromatolites, recorded during Late Palaeoproterozoic-Neoproterozoic transition: the Vindhyan Supergroup,” in Stromatolites: Interaction of Microbes with Sediments. Cellular

Origin, Life in Extreme Habitats and Astrobiology, eds Tewari V. C., Seckback J. (Dordrecht: Springer;), v.18, pp. 87–114.

Sukenik, A., Beardall J., & Hadas O. (2007) Photosynthetic characterization of developing and mature akinetes of Aphanizomenon ovalisporum (Cyanoprokaryota). J. Phycol., v. 43 pp. 780–788.

Tiwari, M & Azmi, R. J. (1992) Late Proterozoic organic-walled microfossils from the infra Krol of Solan, Himachal Lesser Himalaya: An additional age constraint in the Lrol belt succession. Palaeobot., vol. 39, pp. 387 - 394.

Tiwari, M .(1996) Precambrian boundary microbiota from the chert phosphorite member of Tal Formation in the Korgai Syncline, Lesser Himalaya, India. Curr. Sci., vol. 71, pp. 718 - 119.

Tomitani A., Knoll A. H., Cavanaugh C. M., Ohno T. (2006). The evolutionary diversification

Venkatachala, B. S., Shukla, M., Bansal, R & Acharyya, S. K (1989) Upper Proterozoic microfossils from Infra Krol Formation, National Synform, Kumaon Himalayaa, India. Palaeobot., vol. 38, pp. 29 - 38.

Venkatachala, B. S., Yadav V. K., & Shukla M. (1990) “Middle proterozoic microbiota from nauhatta limestone (Vindhyan Supergroup) Rohatasgarh India. Development in Precambrian Geology,” in Precambrian Continental Crust and Economic Resources, ed. Naqvi S. M. (Amsterdam: Elsevier;), v.8, pp. 471–485.

Wilson, J. L (1975) Carbonate facies in geological history: Springer Verlag Berlin., pp. 470.

Zhang ,Z., Li S. (1985) Microflora of the gaoyuzhuang formation (Changchengian System) of the western Yanshan Range, North China. Acta Micropalaeontol. Sin. 2: 219–230.

Zhang, P. (1982) Microfossils from the Wumishan Formation of Jixian County. Acta Geol. Sin., v. 53, pp.87–90.

Zhang, Y. (1985) Stromatolitic microbiota from the Middle Proterozoic Wumishan Formation (Jixian Group) of the Ming Tombs, Beijing, China. Precambr. Res. v. 30, pp 277–302.