Journal of the Palaeontological Society of India
Volume 61(1), June 30, 2016: 75-84
ISSN 0522-9630

MESOPROTEROZOIC ORGANIC-WALLED MICROFOSSILS FROM THE CHAPORADIH FORMATION, CHANDARPUR GROUP, CHHATTISGARH SUPERGROUP, ODISHA, INDIA

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ABSTRACT

The Chhattisgarh Supergroup is considered as the Palaeo-Meso-proterozoic sedimentary succession. In the present study, well-preserved organic-walled microfossils are recorded from the Mesoproterozoic Chaporadih Formation of the Chandarpur Group, Chhattisgarh Supergroup. The *Leiosphaeridia*-dominated assemblage is constituted of *Jacutianema solubila, Leiosphaeridia jacutica, Leiosphaeridia ternata, Leiosphaeridia exsculpta, Leisophaeridia tenuissima* and *Trachysphaeridium levis*. *T. levis* and *J. solubila* transgress into Neoproterozoic. Biostratigraphic implication of the fossil assemblage challenges the claim that the sedimentation in different Proterozoic basins of India, including Chhattisgarh Supergroup of central India, closed after Mesoproterozoic age and sedimentation did not continue into Neoproterozoic Era. This study demonstrates that the Chaporadih Formation of the Chandarpur Group entombs a few palaeobiological entities which cross over into Neoproterozoic. The present assemblage provides a new perspective to the lithostratigraphy and age of the Chhattisgarh basin.

Keywords: *Jacutianema solubila*, Chaporadih Formation, Chhattisgarh Supergroup, Neoproterozoic, Eukaryotes, Microfossils.

INTRODUCTION

Over the Archean/Palaeoproterozoic cratons, peninsular India hosts undeformed/mildly deformed and unmetamorphosed mixed sequence of siliciclastic and carbonate rocks of the Proterozoic Chhattisgarh Supergroup in the southern part of the Central Indian Tectonic Zone (CITZ) that has received poor attention in comparison to other sedimentary basins viz. the Vindhyan, Indravati, Cuddapah, and Mallampali (Chakraborty *et al.*, 2015). It is considered to be the Palaeo-Meso-proterozoic sedimentary succession. During the last decade, studies on the Chhattisgarh Supergroup provided a paradigm shift in our understanding of the lithostratigraphy, chronostratigraphy, evolution and age of this prominent Proterozoic sedimentary basin of India (Patranabis-Deb *et al.*, 2007; Patranabis-Deb and Chaudhuri, 2008; Chakraborty *et al.*, 2010; Bickford *et al.*, 2011a; Dhang and Patranabis-Deb, 2011). Except a few reports of stromatolites from the basin (Schnitzer, 1969; Moitra, 1998, 2003; Gupta, 2004), fossil contents are poorly documented from the Chhattisgarh Supergroup (Babu and Singh, 2013; Singh and Babu, 2013). Different lithounits of the Chhattisgarh Supergroup were analyzed for documenting the palaeobiological remains of the basin. In the present communication, we report the fossil contents recovered from the middle part of the Chaporadih Formation of the Chandarpur Group, Chhattisgarh Supergroup and assess the biostratigraphic potential of the recorded remains. Occurrence of *Jacutianema solubila* and *Trachysphaeridium levis* in the Chandarpur Group changes the perception about the age of basin.

GENERAL GEOLOGY AND AGE

A 2300 m thick sequence of the Proterozoic Chhattisgarh Supergroup unconformably overlies the Bastar Craton. Sedimentary succession of the Chhattisgarh Basin is exposed over 33000 km^2. Due to the incompatibility in lithological features between the eastern and western parts, the basin is divided into two sub-basins: (i). the Hirri Sub-basin to the west, (ii). the Baradwar Sub-basin to the east, respectively. Lithostratigraphically, it is divided into three groups *viz.*, the Singhora, the Chandarpur and the Raipur in ascending order (Das *et al.*, 1992) (Fig. 1). In the Hirri sub-basin, only two groups *viz*., the Chandarpur and Raipur Groups are exposed, whereas in the Baradwar sub-basin all the three groups are exposed. Based on further studies, a new 'Kharsia Group' was designated above the Raipur Group (Patranabis-Deb and Chaudhuri, 2008) (Fig. 2) (Table-1). Later, within the Chhattishgarh Supergroup, the status of the Singhora Group as an independent identity was questioned (Dhang and Patranabis-Deb, 2011) and it was considered as an extension of the Chandarpur Group. A debate on the inconsistencies in the lithostratigraphic succession of the Chhattisgarh Basin is well documented (Basu *et al.*, 2013). Recently, a new lithostratigraphic column, based on a detailed sub-surface data obtained from 350 drill holes, has been proposed, wherein the inception and development of the entire Chhattisgarh Basin is presented (Mukherjee *et al.*, 2014). In this scheme of lithostratigraphy, all the four designated groups have been retained with minor modifications in their respective formations (Table 1).

In the easternmost part of the Chhattisgarh Basin, ~1000 m thick succession of mixed siliciclastic–carbonate rocks association unconformably overlies the basement constituted by the Sambalpur granite (Pascoe, 1973). The Chandarpur Group, middle part of the Chhattishgarh Supergroup, is well exposed in and around the Amabhona area, which is about 32 km NNW of Bargarh city in the Odisha State. Conglomerate, sandstone and shale are considered to have deposited in an array of alluvial, coastal and shallow marine environments representing multiple cycles of transgression and regression (Patranabis-Deb and Chaudhuri, 2008). The Chandarpur Group

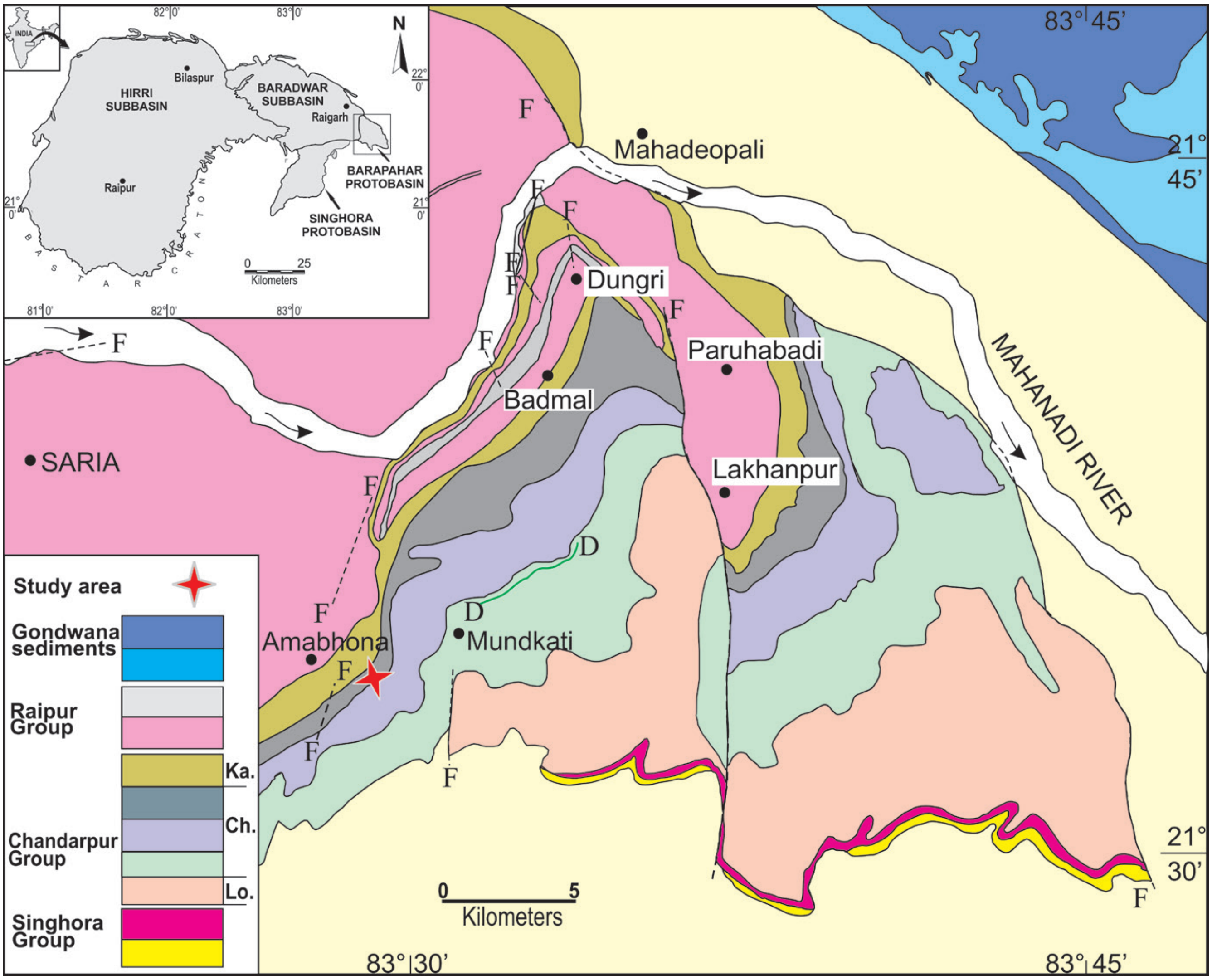

Fig. 1. Generalized geological map of the Barapahar Protobasin (redrawn after G.S.I., 1979) showing the location of the study area. . Abbreviation: *Lo.* – Lohardh Formation; *Ch.* - Chaporadih Formation; *Ka*.- Kansapathar Formation).

Table 1. Generalized lithostratigraphic succession of the Chhattisgarh Supergroup in Baradwar sub-basin (Das *et al.*, 1992; Patranabis-Deb and Chaudhuri, 2008; Mukherjee and Ray, 2010; Mukherjee *et al.*, 2014). Age data source: 1. Bickford *et al.,* (2011), 2. Pandey *et al.,* (2012), 3. Das *et al.*, (2009). * Fossiliferous unit.

	GROUP	FORMATION	LITHOLOGY	AGE
CHHATTISGARH SUPERGROUP	**Kharsia**	Nandeli Shale	Gypsiferous purple shale and dolomite	
		Sarnadih Sandstone	Sandstone and conglomerate	
	~~	~~~~~~	~~~~~~Unconformity~~~~~~	~~~~~~
		Churtela Shale	Purple shale and Tuff	1000 Ma (Tuff)[1]
		Saradih Limestone	Dolomite/Stromatolitic Limestone	
	Raipur	Gunderdehi Shale	Calcareous shale with stromatolitic limestone	
		Sarangarh Limestone	Flaggy limestone and shale	
		Kansapathar Formation	Quartz arenite	
	Chandarpur	Chaporadih Formation*	Glauconitic sandstone/siltstone, black shale	1641 ±120 Ma (Dolerite Intrusive)[2]
		Lohardih Formation	Subarkose with basal conglomerate	
	~~	~~~~~~	~~~~~~Unconformity~~~~~~	~~~~~~
		Chhuipali Formation	Stromatolitic limestone and Variegated shale	
		Bhalukona Formation	Quartz arenite and minor shale	
	Singhora	Saraipali Formation	Variegated shale/siltstone, tuff/porcellanite	c.1500 Ma (Tuff)[3]
		Rehatikhol Formation	Sandstone with conglomerate at the base	
			Archean Basement (Sonakhan & Sambalpur Granites)	

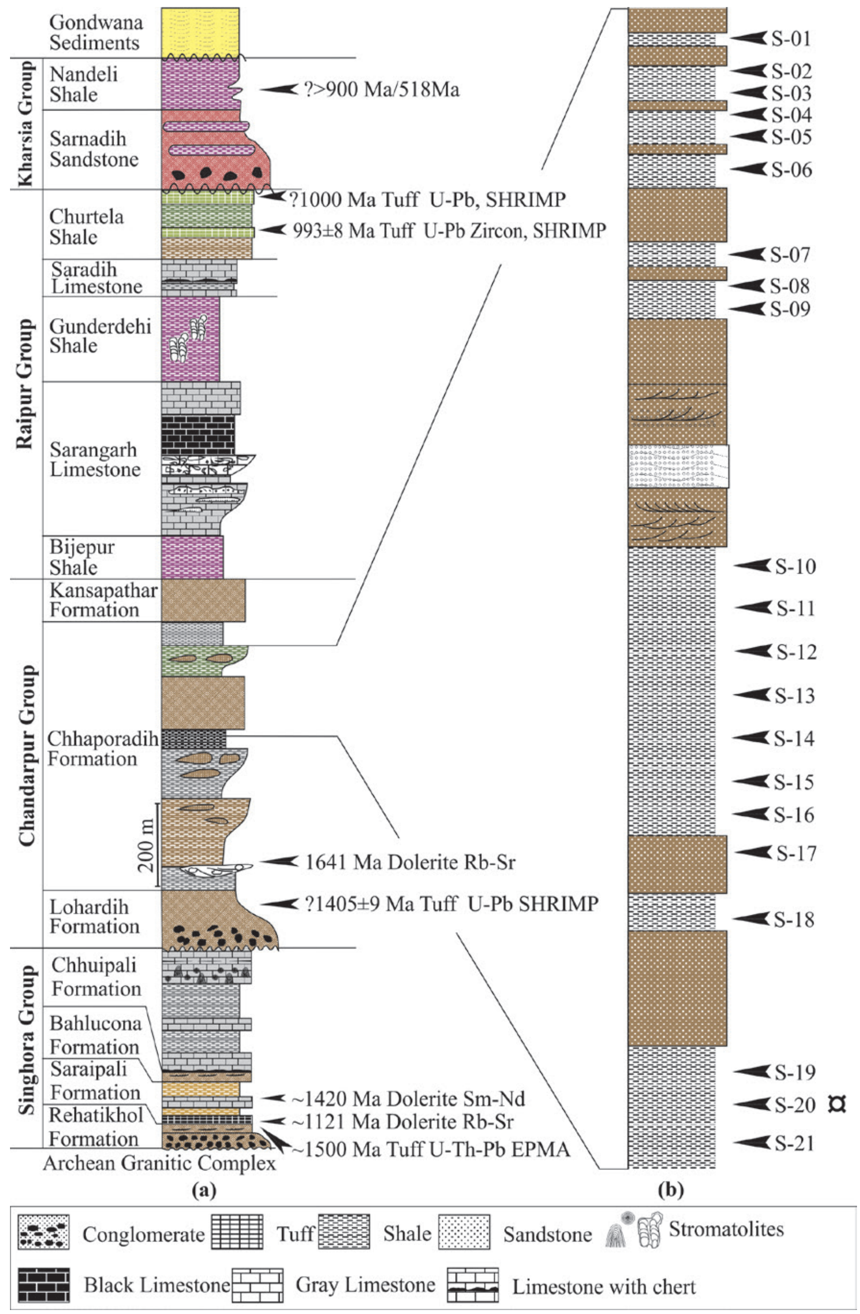

Fig. 2. Generalized lithostratigraphic column: **a.** Chhattisgarh Supergroup (after Patranabis-Deb and Chaudhuri, 2008) and **b.** Amabhona Ghat Section showing the sample locations.

is sub-divided into three distinct formations, i.e. Lohardih, Chaporadih and Kansapathar in ascending order (Table-1). The Lohardih Formation unconformably overlies on the erosional surface of the Singhora Group of rocks (Das *et al.*, 2001) which is represented by matrix- supported polymictic conglomerate, thinly bedded arkose, sub-arkose and wack arenite showing fining upward sedimentation pattern. The overlying Chaporadih Formation is characterized by extreme lithologic heterogeneity and constituted of three major lithological components namely the green mudstone, green and black shale, sandstone – mudstone and sub-arkosic sandstone. The sandstone – mudstone are the dominant constituents of the formation, and occupy almost 65% of its thickness. The green mudstone and shale with small isolated lenses of sandstone are well developed in the basal part over the Lohardih Sandstone that shows a cyclic representation of sand-mud heterolithic. The sequence is overlain by black shale (> 20 meter thick) in the upper part with a thick sheet of arkosic sandstone. The Kansapathar Formation overlies the mud dominated Chaporadih Formation, consisting mainly of well-sorted scarp forming sandstone. To date, no palaeontological remains are recovered from the Chandarpur Group of rocks. The sediments of the Chandrapur Group are folded, faulted and shows rapid facies changes (Patranabis-Deb, 2004).

Available geochronological data on the Chhattisgarh Basin are inconsistent. Distinct tuff bands are found in the Rehatikhol Formation, a part of the Shingora Group, and in the Khariar basin that is exposed south of the Chhattisgarh basin. These tuff bands are considered equvivalent (Das *et al.*, 2009). EPMA dating of monazite and SHRIMP dating of zircon of the Khariar and Shingora tuffs show a concentration of ages around ~1500 Ma (Das *et al.*, 2009; Bickford *et al.*, 2011b). The basic dyke intruding the overlying Chandarpur sediments at Damdama area, Raigarh district has yielded 1641 ± 120 Ma Rb – Sr isochron date (Pandey *et al.*, 2012). The SHRIMP, U–Pb analysis of zircon from rhyolitic tuffs (Sukhda and Dhamda tuffs) found at the top of the Raipur Group yielded an age of ca. 1000 Ma (Patranabis-Deb *et al.*, 2007; Bickford *et al.*, 2011a). These rhyolitic tuffs are considered as representing a major thermal event denoting the closer of sedimentation in the Chhattisgarh Basin (Patranabis-Deb and Chaudhuri, 2008) similar to the Vindhyan Basin (Malone *et al.*, 2008). Later, tuffs have been recorded at various other levels in the underlying formations making the stratigraphic positions of dated tuffs questionable (Mukherjee and Ray, 2010). Thus, the geochronological data suggest that the Chhattisgarh Supergroup is Palaeoproterozoic-Mesoproterozoic in age.

Previously recorded palaeobiological evidence from the entire Chhattisgarh succession are meagre and restricted to the reporting of stromatolites (Schnitzer, 1969; Moitra, 1998, 2003; Gupta, 2004). Microfossils recovered from the chert found in the Saradih Dolomite (unit below the Sukhda Tuff) indicate Neoproterozoic Cryogenian age (Singh and Babu, 2013). These studies suggested Riphean-Neoproterozoic age for the entire succession contrary to the recent geochronological data that support Mesoproterozoic age for the Chhattisgarh Basin. Acritarchs and other organic-walled microfossils are useful in establishing the biostratigraphy and determining the age and environment of sedimentary succession. The palaeobiological assemblage consists of long-ranging forms that occur across the Mesoproterozoic-Neoproterozoic age and thus it also brings out the dichotomy in the biostratigraphic and geochronological data of the Chaporadih Formation; this needs critical assessment and suitable explanation.

MATERIAL AND METHODS

For palaeobiological studies, samples were collected from the upper heterolithic unit of the Chaporadih Formation exposed in a nala cutting at the Amabhona Ghat section (2.64 Km ESE of Amabhona Village) (Long: 21°33'59.33"N; Lat: 83°29'47.62"E) in the Bargarh district, Odisha. The dominant lithology at this section is the gentle dipping mud-sand heterolotihics. Organic-walled microfossils are recovered from the lower part of this section as depicted in Fig. 2. Standard and modified palynological protocols (Phipps and Playford, 1984; Grey, 1999) were applied in the chemical digestion of the rocks (maceration), using 40% hydrofluoric acid for the recovery of microfossils and organic residue. Organic remains were mounted on the slides with the help of Canada Balsam (R.I. = 1.5). Light Microscopic (LM) studies were conducted on the fossils recovered from the carbonaceous shale. About 84 palynological slides were examined under Olympus BH2 transmitted light microscope at 40X and 100X (under oil immersion lens) magnifications for documenting the finer morphological details of micro-organisms. Size measurements were made through eyepiece micrometer; recorded specimens were photographed on software supported Olympus DP 26 digital camera. Studied petrographic thin sections, palynological slides, associated samples and photomicrographs are deposited in the repository of the Birbal Sahni Institute of Palaeobotany, Lucknow (BSIP). These can be retrieved vide statement no. BSIP-1376. England Finder co-ordinates are given for each specimen with the arrow on the slide oriented away from the observer. Statistical data are given in the taxonomic distribution and indicated by mean (x), standard deviation (SD), average deviation (AD), number of specimens measured (n), length of vesicle (L) and width of the vesicle (W).

MICROPALAEONTOLOGY

The carbonaceous shales from the Chaporadih Formation have yielded the majority of exceptionally well-preserved Organic Walled Microfossils (OWMs). These are constituted of subsphaeroidal – spheroidal vesicles of the acritarch forms belonging to Sphaeromorphida subgroup (Fensome *et al.*, 1990) followed by mono-specific vaucheriacean xanthophyte alga (Butterfield, 2004). In taxonomic composition, the organic-walled microfossils are excellent/good, three-dimensionally preserved, slightly compressed due to mutual compressions and display bark brown coloration of organic matter. On the size parameters, vesicles vary in size (60-320 µm), ornamented/unornamented, thick to thin walled and single layered. Cell division, compression and compaction folds on the vesicle wall as well as deformation in specimens are common characteristics in microfossils. Following forms have been identified: *Jacutianema solubila, Leiosphaeridia exculpta, Leiosphaeridia jacutica, Leiosphaeridia, tenuissima, Leiosphaeridia ternata* and *Trachysphaeridium levis* (Plate - I). Relatively simple morphology of smooth-walled sphaeromorph genus *Leiosphaeridia* makes it difficult to infer their biological affinities. We used the scheme of Butterfield *et al.* (1994) to identify the morphospecies of *Leiosphaeridia* on the basis of wall thickness and vesicle dimension. The taxonomic details and geographic distributions of the identified OWMs are provided below.

Division **Chrysophyta**
Class **Xanthophyceae**
Order **Vaucheriales**
Family **Vaucheriaceae**
Genus ***Jacutianema*** Timofeev and Hermann, 1979 emend. Butterfield, 2004
(*Type species : Jacutianema solubila* Timofeev and Hermann, 1979, emend. Butterfield, 2004)

EXPLANATION OF PLATE I

Organic-walled microfossils from the Chaporadih Formation: 1 – 8. ***Jacutianema solubila*** Timofeev and Hermann (a. Slide no. BSIP 14190, England Finder No. U35/2; b, f - h. Slide No. BSIP 14192, England Finder No. U37; O41/4; C59; R38/3; c. Slide No. BSIP 14191, England Finder No. J34; d - e. Slide No. BSIP 14193, England Finder No. G23/4; L53/4); 9, 10. ***Leiosphaeridia jacutica*** Timofeev (Slide No. BSIP 14190, England Finder No. J55/3; O56/1); 11. ***Leiosphaeridia ternata*** Timofeev (Slide No. BSIP 14191, England Finder No. W49/2); 12, 15. ***Leiosphaeridia tenuissima*** Eisenack (Slide No. BSIP 14190, England Finder No. R28/1; Slide No. BSIP 14192, England Finder No. S42/1); 13. ***Leiosphaeridia exculpta*** Timofeev (Slide No. BSIP 14190, England Finder No. O38/2); 14. ***Trachysphaeridium levis*** Vidal (Slide No. BSIP 14190, England Finder No. P25/1). Scale bar for each specimen = 25 µm.

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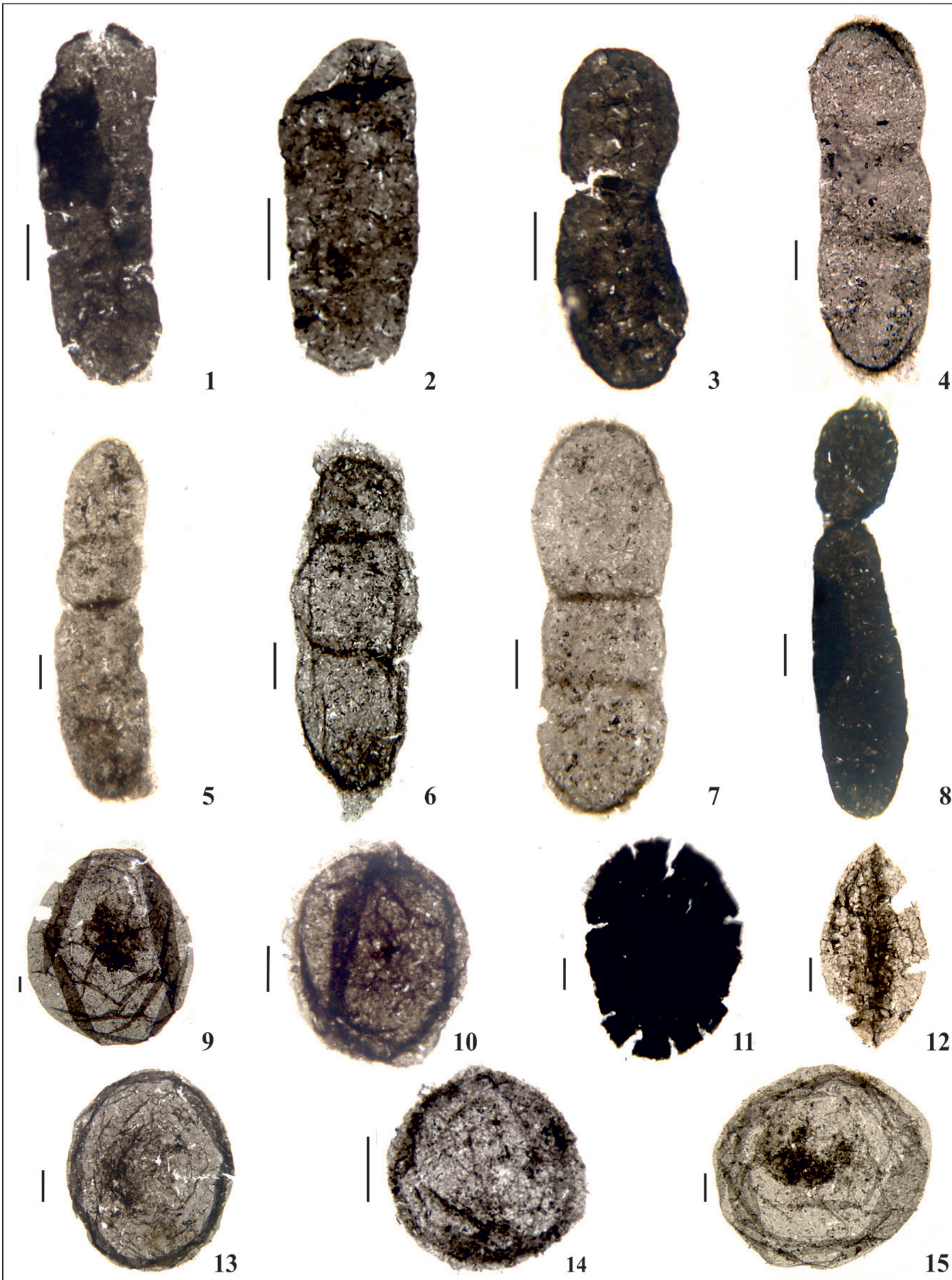
Plate I



Jacutianema solubila Timofeev and Hermann, 1979, emend. Butterfield, 2004
(Pl. I, figs. 1 - 8)

Description: Unbranched, ellipsoidal to botuliform or elongated vesicles, occurs as isolated cells or in short linear groups. Vesicles occur in pairs and triads of cells. Each cell is joined to the adjoining cell showing cytoplasmic continuity, sometimes by outer filamentous envelops. Vesicle sometimes shows incomplete cell division. Vesicle wall are translucent and hyaline. Diameter/width of the ellipsoids ranges from 40 - 72 µm, length of the ellipsoids 100 - 272 µm, (xL= 158.846 µm, xW = 51.25 µm; LSD = 58.42 µm; LAD = 50.68 µm; WSD = 14.719 µm; WAD = 12.0 µm; n = 21).

Occurrence: Widely distributed in Meso - Neoproterozoic (1030 Ma – 635 Ma) sediments: the Nureyen Formation, Lakhanda Group, Siberia (Timofeev and Hermann, 1979; Sergeev *et al.*, 2010); the Svanbergfjellet Formation, Spitsbergen (Butterfield, 2004); the Vychegda Formation, Timan Uplift, East European platform (Vorob'eva *et al.*, 2009a); Chichkan Formation, South Kazakhstan (Sergeev and Schopf, 2010). The filamentous microfossil *Palaeovaucheria clavata,* similar to the extant *Vaucheria* are known from the >1005 ± 4 Ma old Lakhanda Formation, Siberia, was tentatively identified as vegetative phase of xanthophyte alga (Hermann, 1990).

Discussion: Specimens recorded from the Chaporadih Formation are comparatively smaller, and in none of the specimens is noted the darker axial structure or branching as in the case of Svanbergfjellet Formation specimens. However, the Chaporadih specimens are laterally oriented and show cell division similar to Spitsbergen specimens (see Butterfield, 2004, Fig. 4 and Fig. 5). Spitsbergen specimens have well-defined, robust wall structure. In the absence of phylogenetically diagnostic features, the specimens reported from the Vychegda Formation are placed under acritarch (Vorob'eva *et al.*, 2009a). For lack of diagnostic characters, the only specimen reported from the Chichkan Formation has been placed under *incertae sedis*-Protista (Sergeev and Schopf, 2010). Botuliform microfossil *Jacutianema solubila* has been compared to the Gongrosira-stage-resting cells-of Vaucheriacean xanthophyte alga (Butterfield, 2004); we agree with this interpretation and consider the Chaporadih specimens as remnants of xanthophyte alga. Depending on size and characteristic ratio, *Jacutianema solubila* is distinguished from other globally known isolated botuliform taxa viz. *Archaeoellipsoides*, *Navifusa* and *Pololeptus* (Tang *et al.*, 2013) assigned as acritarchs.

Group **Acritarcha**
Genus ***Leiosphaeridia*** (Eisenack, 1958) emend. Downie and Sarjeant, 1963
(Type species : *Leiosphaeridia baltica* Eisenack 1958)

Leiosphaeridia exsculpta (Timofeev, 1969) emend. Mikhailova, 1989 (in Yankauskas *et al.,* 1989)
(Pl. I, fig. 13)

Description: Vesicle flattened, originally spheroidal, subcircular in outline, vesicle wall moderately thin. Vesicle surface covered with a net of thin wrinkles and ridges. Commonly folded on vesicle margins. Wall thickness > 1.0 µm. Diameter of the vesicle ranges from 78 – 160 µm (x = 102.45 µm; SD = 28.95 µm; AD = 23.16 µm; n = 8).

Occurrence: Although numerous other species of *Leiosphaeridia* are widely recorded from the Palaeoproterozoic sediments (Sergeev, 2009), *Leiosphaeridia exsculpta* is mostly recorded from the Neoproterozoic (850 – 700 Ma) sediments; ~800 Ma Officers Basin, Western Australia (Cotter, 1999); Dockembria, SSSR, Russia (Yankauskas *et al.*, 1989).

Discussion: *Leiosphaeridia exsculpta* recorded from Supersequence 1 of the Officer Basin, Western Australia range in diameter from 60-320 µm with a mean 147.9 µm with fine network of wrinkles (Cotter, 1999). It is also proposed that some of the larger specimens may be variants of *Cerebrosphaera buickii*. However, the surface pattern of wrinkles is different in *Cerebrosphaera buickii* (sinuous anastomosing, inter-fingering) and *Leiosphaeridia exsculpta* (parallel/sub parallel) and therefore these two forms are considered as separate entities.

Leiosphaeridia jacutica (Timofeev, 1966) emend. Mikhailova and Yankauskas, 1989 (in Yankauskas *et al.*, 1989)
(Pl. I, figs. 9, 10)

Description: Originally spheroidal but subcircular in outline, simple, solitary, compressed vesicle. Vesicle wall moderately thick, vesicle diameter ranges from 60 - 320 µm in diameter (x = 150.11 µm; SD = 93.4 µm; AD = 70.88 µm; n = 10). Surface smooth with rectilinear or curvilinear folds. Wall thickness ≥ 2 µm.

Occurrence: This cosmopolitan and long-ranging species is widely distributed in compression-preserved and chert permineralized Neoproterozoic microfossil assemblages (Butterfield *et al.*, 1994; Tang *et al.*, 2013) and moderately in Mesoproterozoic (Hofmann and Jackson, 1994; Javaux and Marshal, 2006; Vorob'eva *et al.*, 2015).

Discussion: *Leiosphaeridia jacutica* has a characteristic surface texture that ranges from psilate to granular. Such feature has been noted in a single specimen recorded from Supersequence 1 of the Officers Basin of the Western Australia (Cotter, 1999). This species is easily differentiated from other species by its thicker wall and folds.

Leiosphaeridia ternata (Timofeev, 1966) emend. Mikhailova and Yankauskas, 1989 (in Yankauskas *et al.,* 1989)
(Pl. I, fig. 11)

Description: Vesicle compressed, originally spheroidal, subcircular in outline, opaque, thick walled, usually split around the border. Excystment structures not present. The diameter of the vesicles ranges between 90 µm - 152 µm (x = 115.33 µm; SD = 32.0 µm; AD = 24.44 µm; n = 3). Wall thickness > 2 µm.

Occurrence: Widely reported from the Late Mesoproterozoic and Neoproterozoic (1200 Ma – 750 Ma) sediments (Hofmann and Jackson, 1994); Upper Sinian Liulaobei, Shijia, Zhaowei and Jiayuan Formations, and Lower Cambrian Jingshanzhai and Gouhou Formations, China (Zang and Walter, 1992b); Neoproterozoic Bitter Springs Formation, Ediacarian Pertatataka Formation and Middle Cambrian Tempe Formation in the Amadeus Basin, central Australia (Zang and Walter, 1992a) and Neoproterozoic sediments of Russia (Yankauskas *et al.*, 1989).

Discussion: Specimens of *Leiosphaeridia ternata* are profusely found in the Late Mesoproterozoic and Neoproterozoic successions of the world. Opaque structure and splitting around the periphery are considered the characteristics of this form but cleft or split cannot be considered as primary and biogenic feature because in none of the specimens the degree of inheritance is common. Therefore, it is most likely that these clefts are taphonomic or preservational features.

Leiosphaeridia tenuissima Eisenack, 1958
(Pl. I, figs. 12, 15)

Description: Simple, originally spheroidal, thin walled, compressed vesicle with smooth surface and contains rectilinear or curvilinear folds. Occasionally in the vesicle, dense organic matter is also seen. The diameter of the vesicles ranges between 98 µm – 195 µm (x = 147.66 µm; SD = 48.54 µm; AD = 33.11 µm; n= 3). Wall thickness 0.5 – 0.6 µm.

Occurrence: Commonly occurring in the Early Meso-Neoproterozoic (1500-541 Ma) deposits: 1263 – 750 Ma old Bylot Supergroup, Baffin Island, Canada (Hofmann and Jackson, 1994); Neoproterozoic of Russia (Yankauskas *et al.*, 1989) and also noted from the Early Mesoproterozoic (~1500 Ma) Kotuikan Formation, Siberia (Vorob'eva *et al.*, 2015).

Discussion: The type specimen is recorded from the Lower Ordovician of the St. Petersburg region of Russia (Eisenack, 1958). This is a long ranging cosmopolitan species which has been recorded from several Meso-Neoproterozoic successions.

Genus ***Trachysphaeridium*** Timofeev (1966) 1969
(Type species: *Trachysphaeridium levis* (Lopukhin, 1971) Vidal, 1974)
Trachysphaeridium levis (Lopukhin, 1971) Vidal, 1974
(Pl. I, fig. 14)

Description: Vesicle originally spheroidal, circular to subcircular in outline, a thin spongy vesicle wall having densely granulated ornamentations. Narrow wrinkles present on the vesicle margin. The diameter of the vesicle ranges from 78 µm – 144 µm (x = 98.862 µm; SD = 20.96 µm; AD = 23.16 µm; n = 8).

Occurrence: *Trachysphaeridium levis* is a common constituent of Neoproterozoic (800-650 Ma) sediments: Visingsö beds, Sweden (Vidal, 1976); Hunnberg and Nordustlandet Formations, Svalbard (Knoll and Calder, 1983; Knoll, 1984); Saradih Formation, Chhattisgarh Supergroup, India (Singh and Babu, 2013) and also noted in the Late Palaeoproterozoic sediments: Chitrakut Formation, India (Singh and Sharma, 2014).

Discussion: It is found in plenty in the Neoproterozoic successions. Due to its spongy wall structure, they are easily identifiable in any assemblage.

BIOSTRATIGRAPHIC IMPLICATIONS

In taxonomic composition, the organic-walled microfossil assemblage from the Chaporadih Formation is characterized by abundant smooth-walled sphaeromorphs and botuliform microfossils. The assemblage contains mainly eukaryotic protists *Leiosphaeridia*, *Trachysphaeridium* and remnants of *Jacutianema* comparable to extant vaucheria. The global age distribution of the six exceptionally well-preserved Organic-Walled Microfossils from the present study is summarized in Fig. 3. Generally, the Chaporadih assemblage is distinct from the Ediacaran acritarch assemblages which are characterized by diverse taxa of large acanthomorphs (Vorob'eva *et al.*, 2009b; Liu *et al.*, 2013; Liu *et al.*, 2014; Xiao *et al.*, 2014), but similar to the Staenian – Cryogenian (1200-635 Ma) microfossil assemblages of other parts of the world. Taxa revealed in the Chaporadih Formation have important biostratigraphic significance and are consistent with a Staenian age (1200-1000 Ma). Stratigraphically,

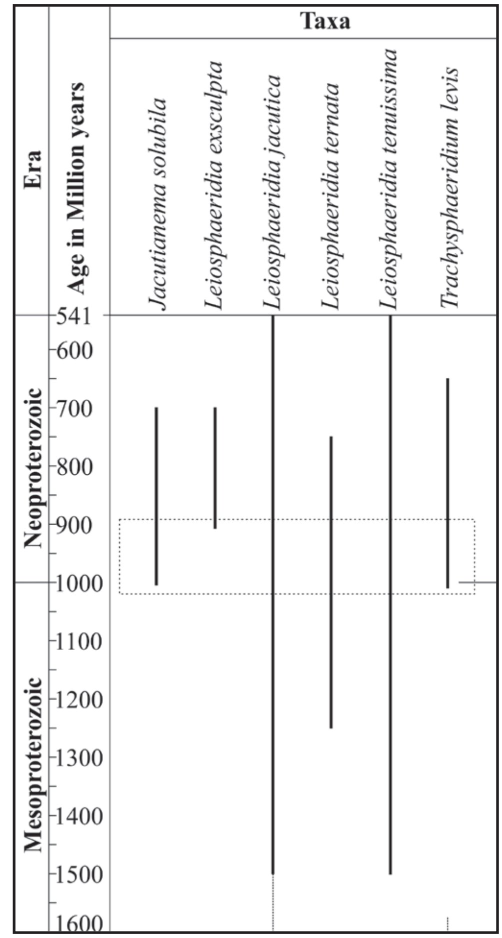


Fig. 3. Global age distribution of the recovered Organic-walled microfossils from the Chaporadih Formation, Chandarpur Group.

the most important form in the present finding is bolutiliform microfossil *Jacutianema solubila* Timofeev and Hermann (1979). *Jacutianema Solubila* is a potential taxon which is mostly recorded from the Tonian to Ediacaran sequences (1000-635 Ma) (Butterfield, 2004; Vorob'eva *et al.*, 2009a; Sergeev and Schopf, 2010); however; it was originally erected from the Lakhanda Formation in eastern Siberia as an unbranched elongated, rod-shaped, isolated filamentous microfossil with rounded ends. The Lakhanda Group has been directly dated at 1025 ± 40 Ma using Pb–Pb isochron method (Semikhatov *et al.*, 2000) and constrained to be >1005 ± 4 Ma (Rainbird *et al.*, 1998). It is widely noted that the Tonian (1000-820 Ma) assembalges are characterized by an acanthomorphic acritarch *Trachyhystrichosphaera aimika* known as a potential index fossil (Butterfield *et al.*, 1994; Tang *et al.*, 2013). However, Tonian index fossil *Trachyhystrichosphaera aimika* is absent in the Chaporadih biota.

The other interesting and stratigraphically important eukaryotic fossil contents in the Chaporadih biota are large sphaeromorphic acritarch taxa such as *Leiosphaeridia* and *Trachysphaeridium*. Both the taxa are reported in association from numerous other Meso – Neoproterozoic shale facies biotas of China (Zang and Walter, 1992b); Australia (Zang and Walter, 1992a); Russia (Yankauskas *et al.*, 1989); Siberia (Vorob'eva *et al.*, 2009a; Vorob'eva *et al.*, 2015); Sweden (Vidal, 1976); Svalbard (Knoll and Calder, 1983; Knoll, 1984) and

India (Prasad *et al.*, 2005; Singh and Babu, 2013). Recently, *Leiosphaeridia* - an unornamented spheroidal acritarch, of broad stratigraphic range occurring in Meso – as well as Neoproterozoic microbiota, has been tentatively identified as showing affinity to chlorophycean green algae based on the Trilamillar Sheath Structure (TLS) and wall ultrastructures in vesicle (Javaux and Marshal, 2006; Vorob'eva *et al.*, 2015). It is noted that the ornamented spheroidal acritarch *Trachysphaeridium* is a common constituent of Neoproterozoic microbiota and has very few occurrences in Mesoproterozoic microbiota (Vidal, 1976).

In summary, on the basis of global occurrences as well as the absence of Tonian index fossils particularly *Trachyhystrichosphaera aimika* in the recovered microfossils assemblage, we propose latest Mesoproterozoic (Staenian) age for the *Jacutianema solubila* constituting the Chaporadih biota of the Chandarpur Group.

CONCLUDING REMARKS

The comprehensive analysis of the recovered organic-walled microfossils shows the dominance of Mesoproterozoic (Staenian) microfossil assemblage in the heterolithic unit of the Chandarpur Group (Fig. 3). In general, the global correlation with known well- dated assemblages (Timofeev and Hermann, 1979; Butterfield *et al.*, 1994; Butterfield, 2004; Vorob'eva *et al.*, 2009a) also indicates Meso-Neoproterozoic affinity for the assemblage. It is due to presence of such typical Neoproterozoic dominating microfossils, i.e. *Jacutianema* and *Trachysphaeridium* (Vidal, 1976; Butterfield, 2004), we are inclined to consider the present assemblage as Meso-Neoproterozoic in age. *Jacutianema* shows affinity with as a vaucheriacean xanthophyte alga (Butterfield, 2004). Independent molecular phylogenetic analyses conclude that Xanthophytes appeared 1000 Million years ago (Brown and Sorhannus, 2010; McFadden, 2014). Complex morphology *viz*. cell division, wall structures and size parameter show eukaryotic affinities for the Chaporadih microfossils. The various species of *Leiosphaeridia* have commonly been reported from the Meso-Neoproterozoic sediments of Canada, Australia, east European platform (Hofmann and Jackson, 1994; Vorob'eva *et al.*, 2009a).The Meso-Neoproterozoic (1500 – 1000 Ma) age has been suggested for the entire Chhattisgarh succession based on various dating techniques (Das *et al.*, 2009; Bickford *et al.*, 2011a). At present, except the geochronological date of the basic dyke (1641 ± 120 Ma), position of which is not an unambiguous, no direct radiometric dates and palaeobiological evidence are available for the Chandarpur Group. Present report of the microfossil assemblage from the Chandarpur Group suggests the latest Mesoproterozoic age – equivalent to Lakhanda biota (~1025 Ma) - for these sediments and improves our understanding on the age and evolution of the Chhattisgarh Basin. Further study in this basin will certainly help resolve the geochronological controversy.

ACKNOWLEDGEMENTS

Authors are grateful to Prof. Sunil Bajpai, Director, Birbal Sahni Institute of Palaeobotany, Lucknow for providing the necessary laboratory facilities and logistic support during the progress of this work. Authors are also grateful to Prof. V.N. Sergeev and an anonymous reviewer for their comments on an earlier version of this paper and their helpful suggestions for its subsequent improvement. Permision to publish this work is thankfully acknowldged (BSIP/RDCC/15/2014-15). The reference no. of this contribution is BSIP/RDCC/15/2014-15.

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Manuscript Accepted November 2015