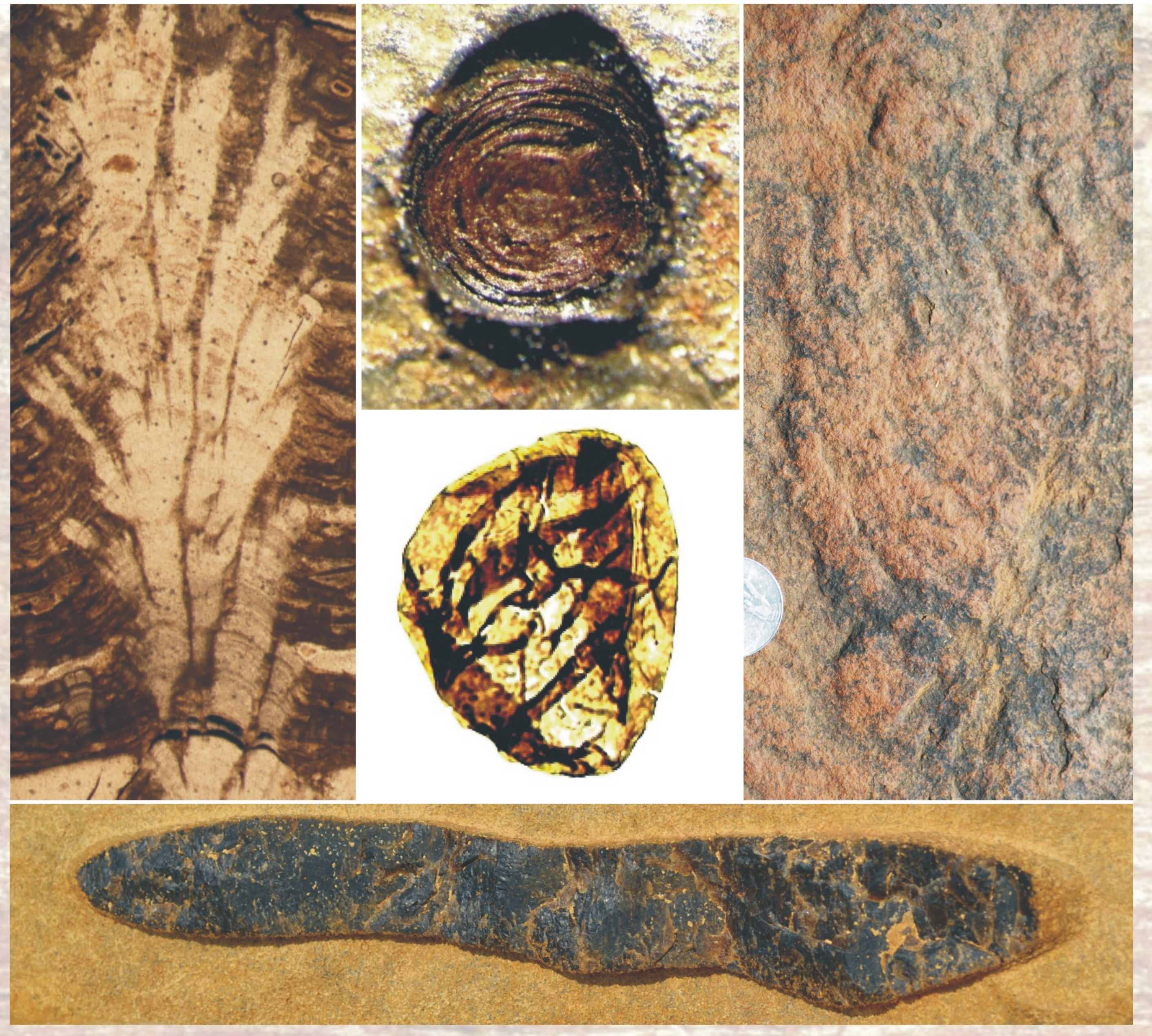
Palaeobiology, Biostratigraphy and Organic Matter Maturation of the Bhander Group sediments, Maihar area, Satna District, Madhya Pradesh



Thesis submitted to the University of Petroleum and Energy Studies for the Degree of

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By

Deepak Singh

M.Tech.

Department of Petroleum Engineering & Earth Science, UPES (2012)

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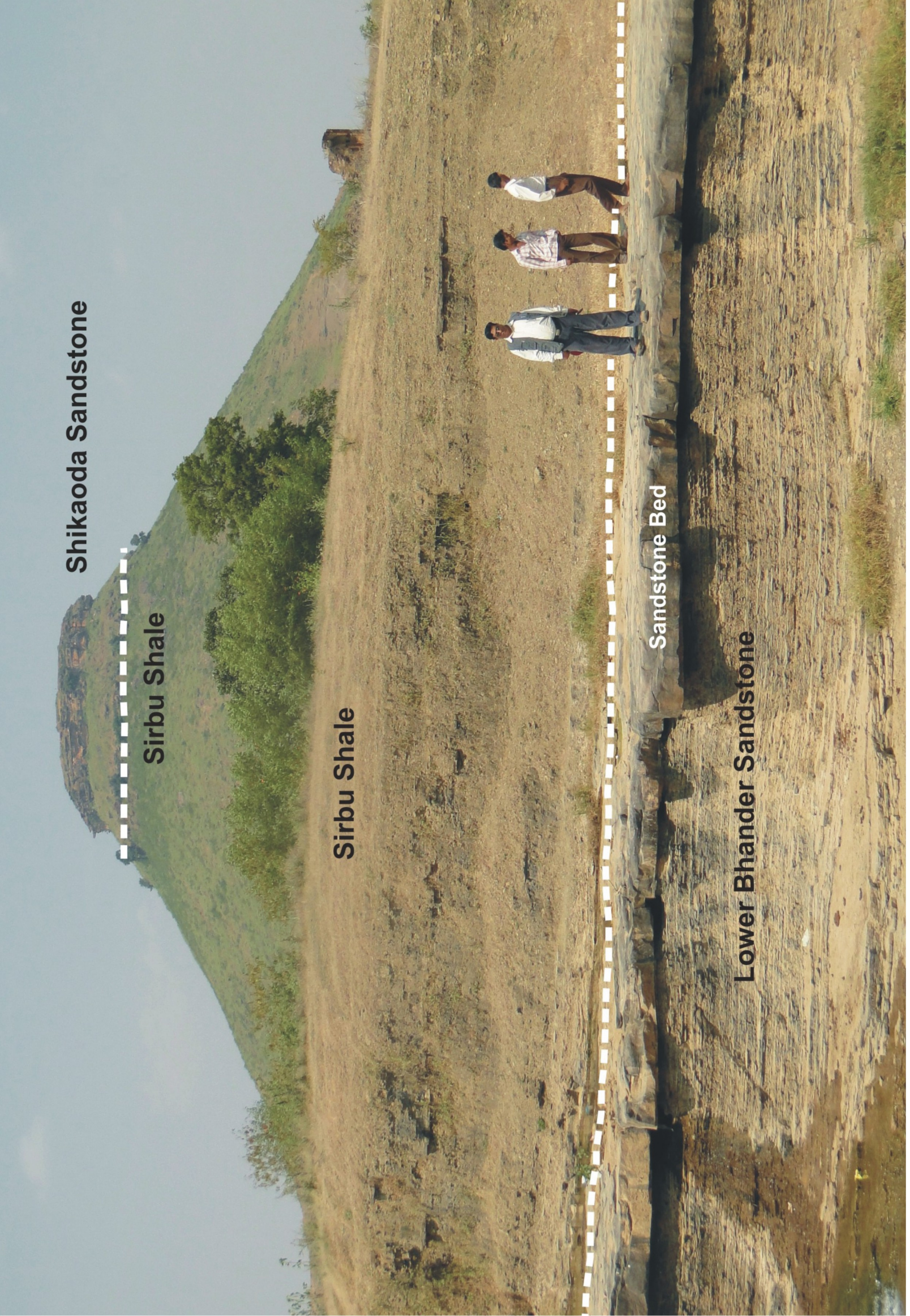

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(Deepak Singh)

CONTENTS

Chapter 1

INTRODUCTION

The Mesoproterozoic and the Neoproterozoic successions world over are the target of study to understand the changes that took place in the lithosphere and biosphere during this period. The sedimentary successions of this period on the earth are repository of evolution in the biosphere. The advent of eukaryotes, origin of sex, multicellularity, metaphyte and metazoan and biomineralization are some of important events in the biosphere. Indian sub-continent is fortunate enough to have many sedimentary successions spaning over the Archaean to Neoproterozoic. Many of these sequences are unmetamorphosed or mildly metamorphosed to have survived the evidence of biosphere.

In the Northern India, there existed a great basin known as the Vindhyan basin. In spreads over a large area from the Sasaram in the east to the Chittorgarh in the West. The pack of sedimentary succession occupying this basin is known as Vindhyan Supergroup (Krishnan and Swaminath, 1959). The study area exists in this largest Proterozoic intracratonic basin of India. This Supergroup is subdivided into two parts- The Lower Vindhyan made up of the Semri Group and Upper Vindhyans which are further divided into three groups, the Kaimur, the Rewa and the Bhander. The Bhander Group is the youngest of the Vindhyan Supergroup and is mainly exposed in Central India in two valleys, the Son Valley and the Chambal Valley.

The main problem in the Bhander is to ascertain its age. Only radiometric date available in the Bhander Group needs fortification to provide definite age bracket to this group. The palaeontological remains determination entombed in the different stratigraphic horizons of the Bhander Group are the only available tool for age.

The palaentological remains recorded so far are difficult to weave in the present state of the knowledge or the Neoproterozoic. Reports of Ediacaran fossils (De, 2003, 2006) from the Bhander Group have widely opened the challenge. Earlier workers have suggested divergent ages for different horizons of the Bhander Group. Friedman et al. (1996) reported the presence of Precambrian-Cambrian boundary between the Bhander Limestone and the Sirbu Shale on the basis of the carbon isotope data. The Pc – C boundary has also been suggested within the Rohtas Formation of the Semri Group by Azmi (1998) on the basis of the discovery of small shelly fossils and brachiopod. These two data sets contradicts each other. As there is no evidence that the Vindhyans have Cambrian deposits therefore claim of Precambrian-Cambrian boundary within the Rohtas Formation of the Semri Group by Azmi (1998) has been rejected (Kumar, 1999, 2001; Bhatt et al., 1999). Bengtson et al. (2009) tried to resolve the age controversy concerning the Rohtas Formation, but raised many questions for the correlation of early life (Kumar, 2009). In the Maihar area, Madhya Pradesh, the topmost horizon of the Vindhyan Basin has been assigned Ediacaran age (Kumar and Pandey, 2008) but there is no way to mark the beginning of the Neoproterozoic sedimentation in the Vindhyan Basin as no radiometric data is available except the age of the Sirbu Shale i.e. 741 ± 9 Ma (Rathore et. al., 1999) and no fossil is reported which could give any clue for the beginning of sedimentation at ca. 1000 Ma. Malone et al. (2008) on the basis of palaeomagnetic data and detrital geochronology have asserted that the Upper Bhander Sandstone (the Shikaoda Sandstone) should be older than 750 -771 Ma and is likely close to 1073 Ma. It means that the sedimentation in the Vindhyan Basin ended ca 1000 Ma. The palaeomagnetic data is interpreted by them in such a way that it fails to address the available radiometric and palaeontological data based on the study of microfossils, stromatolites, carbonaceous megafossils and microbial mat structures. The palaeomagnetic data has to be interpreted in the available geological framework. Hence, the interpretations of Malone et al. (2008) is ignored. Available database of the microbial mats, carbonaceous megafossils, microfossils and stromatolites have suggested the Neoproterozoic age (Upper Cryogenian - Ediacaran) for the Bhander Group. This conclusion gets support from the absence of the Cambrian fossils including trace fossils from the Bhander sediments.

The microfossils recovered from the shales of the Precambrian age by maceration technique provide a rich source of data used for palaeobiological studies; but contamination of extant material is a general problem in application of this method. On the basis of maceration technique, Prasad (2007) has reported a good assemblage of microfossils from the Bhander Group. At the same time the biota studied in petrographic thin sections of black bedded chert, though reliable, but hard to find. Therefore, stromatolites, algal mat texture, megafossils and microfossils are only available tools for palaeobiological studies. Based on these parameter a high resolution biostratigraphy can be attempted.

Stromatolites, algal mat texture, megafossil, microfossil and possible remains/trace provide the clue to solve the problem of age and arrange lithostrata of the Bhander Group in more accurate manner on the basis of biostratigraphy. Therefore, an attempt has been made for investigation of different horizons within the Bhander Group from the Son Valley Section in present study.

The deposition of the Bhander Group completed in the Late Neoproterozoic in shallow marine and lagoon environment (Bose et.al. 2001). Only algal material was present to be preserved in the sediments of the Bhander Group at that time. Algal material converted into kerogen type-I after diagenesis. This kerogen type-I is responsible for generation of oil not the gas. Hence, probability of formation of hydrocarbon exists in oil window. The generation of hydrocarbon depends upon various factors and organic matter maturation is one important factor of them. The colour of organic matter changes with increase in temperature with depth during stratification of the sediments. Thermal Alteration Index (TAI) is the tool to calculate variation in the colour of organic matter with temperature. In the present study calculation of TAI has been done from different stratigraphic horizons of the Bhander Group to find out the zone of hydrocarbon generation.

1.1 Objectives

The main objectives of the present thesis are:

(A) To document the carbonaceous macrofossils, ministromatolite, microfossils/acritarchs, permineralized microfossils and Microbially Induced Sedimentary Structures (MISS) in the different formations of the Bhander Group: attempt their taxonomy and relevance with sedimentary sequence entombing them;

(B) To attempt and provide biostratigraphy of the Bhander Group;

(C) To assess the Thermal Alteration Index (TAI) of the preserved microfossils from different horizons of the Bhander Group;

(D) To discuss the palaeobiological assemblage and their potential in hydrocarbon generation.

1.2 Organization of the Thesis

Chapter 1, the introduction provides the status of the knowledge and states the problems of the study area and main objectives of the work. Chapter 2, General Geology- provides detail description of the geology and stratigraphy of the Vindhyan Supergroup. Chapter 3, Material and Methods- describes present work for which samples of fossils and sedimentary rocks have been collected and analysed in laboratory as well as in the field. The methods used during present study to generate data for the interpretation.

Chapter 4, Palaeobiological Remains- deals with the palaeobiology of the Bhander Group, Vindhyan Supergroup. Chapter 5, Organic Matter Maturation- discusses the organic matter maturation studies. Chapter 6, Discussion- provides the discussion and result of the detailed biostratigraphy. Chapter 7, Conclusion- summarizes the primary conclusions based on this study. The last section of this work lists the references cited in the text.

Chapter 2

GENERAL GEOLOGY

2.1 Introduction

The Vindhyan basin is a classic example of Proterozoic intracontinental basin that developed in the central part of the Indian shield along with several other basins such as the Cuddapah, the Chhattisgarh, etc. (Fig. 2.1).

It is the largest Proterozoic basin in India, containing more than 5000 m thick sequence of sandstones, shales, limestones, dolostones, conglomerates and porcellanites, occupies an area of about 2, 00,000 sq km. Out of this 80,000 sq km

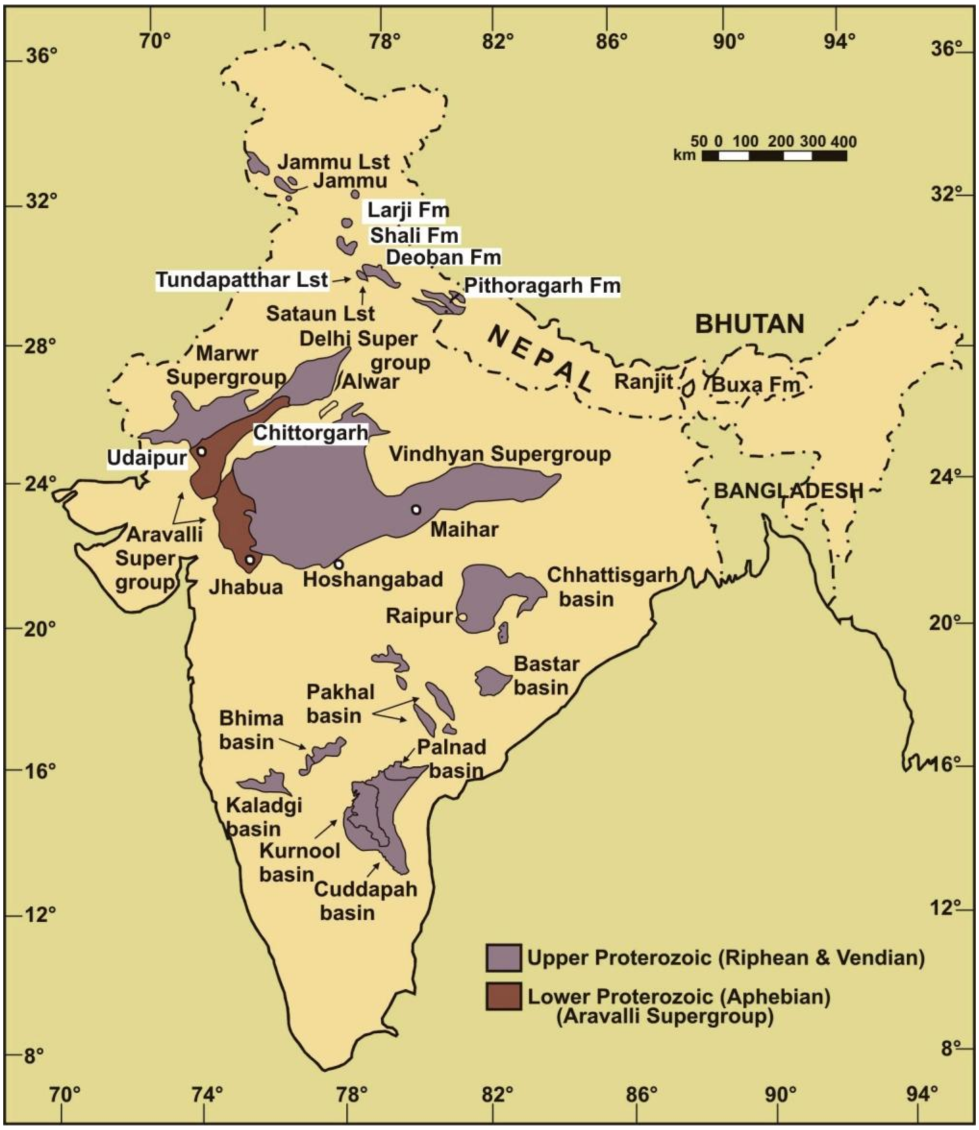


Fig. 2.1- Representative map of the different Proterozoic basins of India (Modified after Raha and Sastry, 1982)

is covered by the Deccan Trap and 10,000 sq km substantially thick rocks have also been estimated under the Gangetic alluvium (Mathur, 1965; Jokhan Ram et al., 1996). The strata are exposed in two valleys: the Son Valley and the Chambal Valley. The rocks are unmetamorphosed and undisturbed to poorly disturb with low angle dips. The tectonic disturbance and grade of metamorphism increase from east to west i.e. from the Son Valley to the Chambal Valley. The rocks of NW Vindhyan basin are tectonically more disturbed along Great Boundary Fault (GBF) (Fig. 2.2). Overall the rocks, in general, show excellent preservation of sedimentary structures, stromatolites, microbial mats, carbonaceous megafossils and microfossils (Auden, 1933; Valdiya, 1969; Singh, 1976; McMenamin et al., 1983; Prasad, 1984; Kumar, 1980, 2001; Venkatachala et al., 1996; Kumar and Srivastava, 1997, 2003; Prasad, 2007, Prasad et al., 2007; Misra and Kumar, 2005; De, 2003, 2006; Sharma, 2006 a, b, c, Kumar and Pandey 2007, 2008; Sharma and Shukla, 2009 a,b; Singh et al. 2009; Sharma et al., 2009, 2010).

Oldam (1856) was the first professional geologist to use the term 'Vindhyan' for the entire group of rocks forming a prominent feature along the northern bank of Narmada River known as *Vindhya Parvat* or *Vindhyachal*. Subsequently,

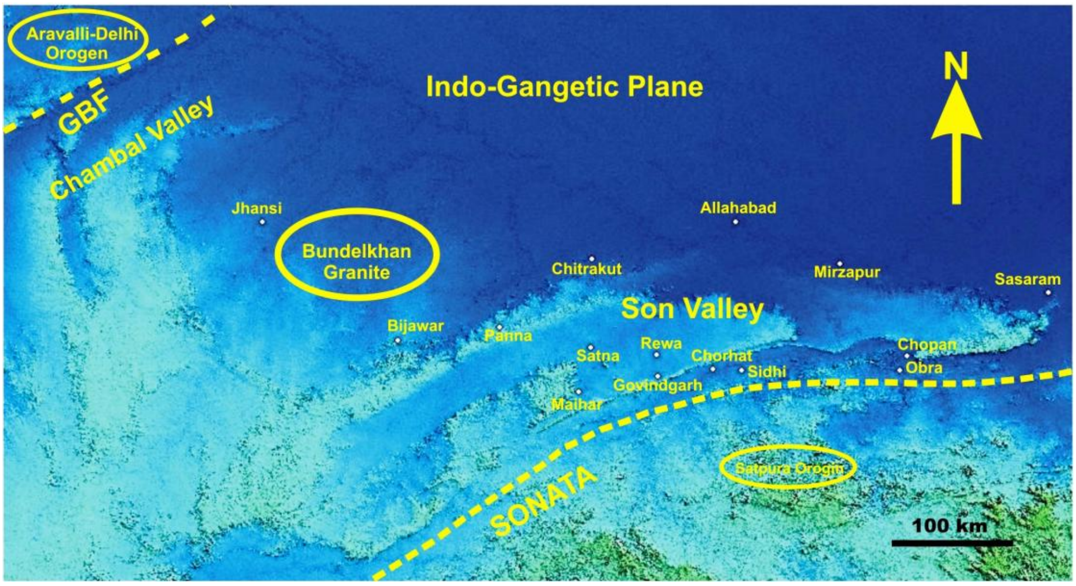


Fig. 2.2- Outcrop of the Vindhyan basin Note: (1) confinement of the basin between the Great Boundary Fault (GBF) and the Son-Narmada lineament (SONATA); (2) occurrence of the Bundelkhand Granite in the middle of the basin; (3) the Indo-Gangetic plain covering the northern part of the basin; (4) occurrence of the Vindhyan strata in two different sectors- Chambal Valley and Son Valley. (adapted after Chakraborty, 2006)

significant contributions were made on the geology of Vindhyan by Medlicott (1860). He first time used the word Lower Vindhyan and studied the Vindhyans of the Son Valley. Nonprofessional geologist like Captain Dangerfield (1823) and Jacquomot (1841) have discussed the nature of Vindhyan rocks during the course of search for diamonds in Panna area, M.P. Blandford (1869) studied the Vindhyans of Central India. Hacket (1881) studied the Vindhyans of Rajasthan. Some of the workers (Coulson, 1927; Heron, 1917, 1932, 1936; Oldham et al., 1901; Auden, 1933; Fox, 1928; Mathur, 1981; Narayan, 1980) made further contributions to the knowledge of Vindhyans. Ghosh (1981), Mathur (1970) and others have studied the Bundelkhand-Baghelkhand region. Roy et al. (1981) studied the photo-geological aspects of Bhopal- Hoshangabad inlier. Munshi and Soni (1977) and Choubey (1979) studied these sediments with particular reference to their depositional environment and tectonics. Mallet (1869), Krishnan and Swami Nath (1959), Misra (1969), Banerjee (1964, 1974), Prasad (1975), Pascoe (1973), Kumar (1977, 1980), Sastry and Moitra (1984), Prasad (1984), Mathur (1987), Soni et al., (1987) and Bhattacharyya (1993, 1996) further discussed the various aspects of the Vindhyan Basin.

The Vindhyan Supergroup has been subdivided into four groups; in stratigraphic order these are the Semri Group, the Kaimur Group, the Rewa Group and the Bhander Group, each group is further subdivided into different formations, the Semri Group is generally referred to as the Lower Vindhyan and the Kaimur, Rewa and Bhander Group have been clubbed as the Upper Vindhyan. The Bhander Group is the youngest group of the Vindhyan Supergroup and it is well exposed around the study area Maihar (in red box), Satna District, M.P (Fig. 2.3).

In recent years, a number of publications dealt with the geology of the Vindhyan Supergroup. Geological Survey of India published the proceedings of the symposium on the Vindhyans of Central India in 1981. Valdiya et al. (1982) edited a volume entitled *Geology of Vindhyachal* which incorporated papers on different aspects of the geology of the Vindhyan Basin. Bhattacharyya (1993) published a field guide book on the geology of the Maihar area, M.P. and edited *Recent advances in Vindhyan Geology* (Bhattacharyya, 1996). Ray and Chakraborty (2006) edited another volume on the Vindhyans. Kumar and Sharma (2012) gave most recent account on field geology of the Vindhyan Basin.

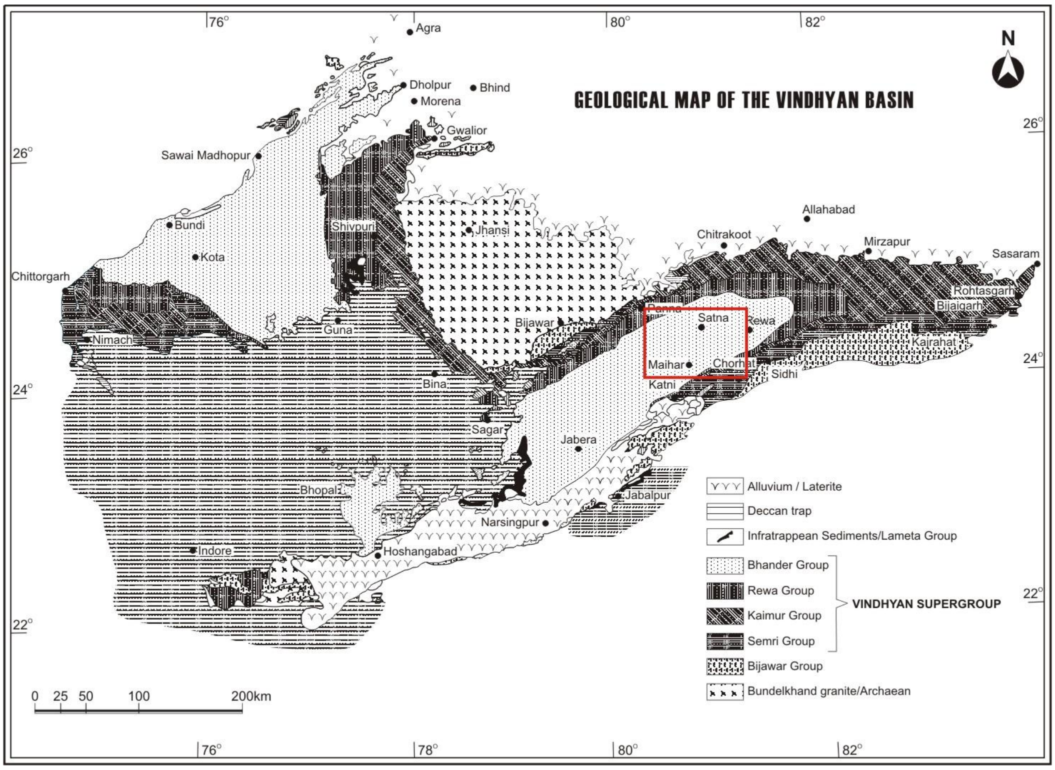


Fig. 2.3- Regional geological map of the Vindhyan Basin (Simplified after Soni et al. 1987)

2.2 Lithostratigraphy

Sedimentary successions of the basin, comprising a thick pile of sandstone, porcellanite, shales and limestone are broadly divisible into the Lower Vindhyans (the Semri Group) and Upper Vindhyans (the Kaimur, Rewa and Bhander Groups). Each group has been further divided into different formations and members (Fig. 2.4). However, the Vindhyan Basin shows different lithological succession in the eastern and western part of the Basin. Lithological succession in the eastern part is referred to as the Son Valley Section and the western part as the Chambal Valley Section (Fig. 2.2). The Vindhyan sediments show much facies variation and both horizontal and vertical gradation in lithology. The stratigraphical successions of the eastern part does not compare well with the stratigraphical succession of the western part of the basin.

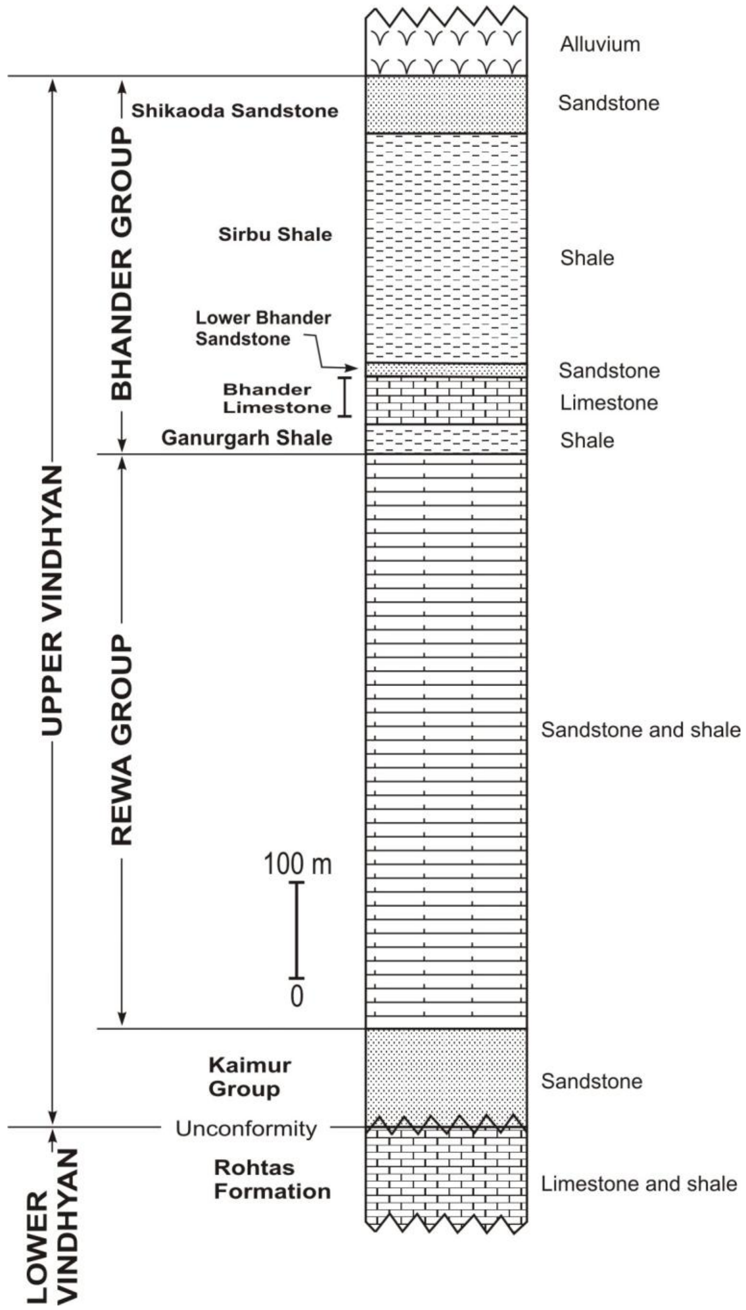


Fig. 2.4- Lithostratigraphy of the Upper Vindhyan Supergroup (Kumar and Pandey, 2008)

Oldham (1856) proposed three subdivisions within the Vindhyan and designated them as the Kaimur, Rewa and Bhander. Medlicott (1859) introduced the term Semri Series for the sediments below the Kaimur. Mallet (1869) proposed a broad two-fold classification into lower and upper. The former comprising the Semri Series and the later including Kaimur, Rewa and Bhander Series. Heron (1936) mentioned that the Suket Shale graded into the Kaimur Sandstone. Verdenburg (1906) maintained that there was a substantial difference between the Lower and Upper Vindhyan and proposed the Lower Vindhyan (Semri Series), Kaimur and

Rewa Series should be grouped as Ken Subdivision and Bhander Series as Bhander Subdivisions. Auden (1933) divided the Vindhyan Supergroup into four equal series namely the Semri, Kaimur, Rewa and Bhander Series. Auden (1933) originally referred to the Semri Group as the Semri Series. He divided the Semri Series into four stages as the Basal Stage, the Porcellanite Stage, the Kheinjua Stage and Rohtas Stage. Later worker used 'Formation' in spite of 'Stage' (Table 2.1). Sastry and Moitra (1984) named the lowermost lithounit of the Semri Group, Basal Conglomerate of Auden (1933) to Deoland Formation. Porcellanite Stage was also renamed as Deonar Formation.

Misra (1969) favored retention of the usage of Lower and Upper Vindhyans on the basis of calc- argillaceous nature of the lower Vindhyan and the existence of a disconformity between the lower and Upper Vindhyans and transgression of the red non – marine sediments over marine sediments of Lower Vindhyans. In conformity with the Code of Stratigraphic Nomenclature of India (1971) 'System' and 'Series' have been replaced by majority of the workers (Table 2.1). Mathur (1987) suggested that all the groups should be accorded equal status and 2-fold classification should be abandoned. In the existing study, the Vindhyan Supergroup has been subdivided into four groups *viz.*, the Semri Group, the Kaimur Group, the Rewa Group and the Bhander Group (see Auden, 1933, Bhattacharyya 1996) (Table 2.1).

The present dissertation is based on the palaeobiological work on the Bhander Group sediments. Specific details of the lithostratigraphic succession are given below so as the reader can appreciate the context of fossil occurrences.

2.3 The Bhander Group

The Bhander Group constitutes the youngest group of the Vindhyan Supergroup which has been subdivided into different formations. The original classification proposed by Krishnan (1968) was modified by Sastry and Moitra (1984) (Table 2.2).

In the Son Valley Section, the Bhander Group is best developed in the Satna – Maihar area, Madhya Pradesh and in the Chambal Valley Section it is exposed in the Bundi – Kota area, Rajasthan.

Table 2.1- Broad subdivision of the Vindhyan Supergroup as proposed by Auden (1933)

	After Auden (1993)	Modified
	Bhander Series	Bhander Group
Upper Vindhyan	Rewa Series	Rewa Group
	Kaimur Series	Kaimur Group
Lower Vindhyan	Semri Series	Semri Group

Lithostratigraphy of the Bhander Group

In the Son Valley Section, the study area lies in the surroundings of the Maihar, Satna District, M.P. (Fig. 2.3). The upper most horizons is best developed in Tamas (Tons) River section, Satna Cement mines at Sajjanpur, Satna District and Aber section about 27 km NE from Satna city on Satna- Semaria road. Here, the Bhander Group has been subdivided into four formations; in stratigraphic order these are the Ganurgarh Shale, the Bhander Limestone, the Sirbu Shale and the Maihar Sandstone. Sastry and Moitra (1984) have replaced the name 'Bhander Limestone' with the 'Lakheri Limestone' which is originally used by Prasad (1984) in Chambal Valley section. Bhattacharyya (1996) also following their suggestion and gave a detailed account of the Bhander Group of the Son Valley Section in the Maihar area. Few researchers place a unit of sandstone between the Bhander Limestone and the Sirbu Shale. It has been designated as the Lower Bhander Sandstone.

2.3.1 Ganurgarh Shale: It is the oldest formation of the Bhander Group. Its thickness varies between 100 m – 270 m (Bhattacharyya, 1993). It is represented by centimetre to decimetre thick alternate band of light brown to purple – coloured shale and calcareous fine sandstone/siltstone to fine grained sandstone. The Ganurgarh Shale becomes dominantly calcareous towards the top and represents a transitional facies between the Upper Rewa Sandstone and Bhander Limestone (Bhattacharyya, 1993). Best exposures can be seen at Ramnoi village, Rewa on Satna-Rewa highway.

2.3.2 Bhander Limestone: Several limestone quarries in and around Maihar expose different stratigraphic levels of the Bhander Limestone. Amongst these, the best quarry sections are found at Girgita, Emaliya, mines of Satna cement factory, the upper part of the Bhander Limestone is well exposed on the banks of Tamas river near Dulni village (Fig. 2.5). Its thickness varies between 80 – 100 m (Bhattacharyya, 1993). The good exposure of the Bhander Limestone can be seen around in Maihar township in the low lying areas. It is extensively mined for cement and metallurgical industry and for making lime. It constitutes the only calcareous horizon of the Upper Vindhyan in the Son Valley Section. It is also referred to as Nagod Limestone (Rao and Neelkantam, 1978). It is made up of grey to dark grey limestone and greyish green shale.

The lower part of the Bhander Limestone is best exposed on the Tamas (Tons) River bank opposite Emilia quarry. It shows mega ripple bedding, small scale cross bedding, parallel bedding, flaser bedding, mud cracks and various types of ripple marks. It is characterized by light brown coloured parallel laminated sandy limestone with thin mud layers. Thin intraformational conglomerate is found occasionally along with thin shaly limestone. This basal facies of alternating black and creamish coloured limestone is found to be overlain by irregular sheet of black chert. This chert is oolitic in nature and extensively

Table 2.2 Comparative lithostratigraphy of the Bhander Group in the Son Valley and Chambal Valley

	Son Valley		**Chambal Valley**
	After G.V.Rao in Awasthi, 1964	After Sastry & Moitra 1984	Prasad, 1984
Bhander Group			Dholpura Shale
			Balwan Limestone
	Maihar Sandstone	Shikoda Sandstone	Shikoda Sandstone
	Sirbu Shale	Sirbu Shale	Sirbu Shale
		Bundi Hill Sandstone	Bundi Hill Sandstone
			Samria Shale
	Bhander Limestone	Lakheri Limestone	Lakheri Limestone
	Ganurgarh Shale	Ganurgarh Shale	Ganurgarh Shale

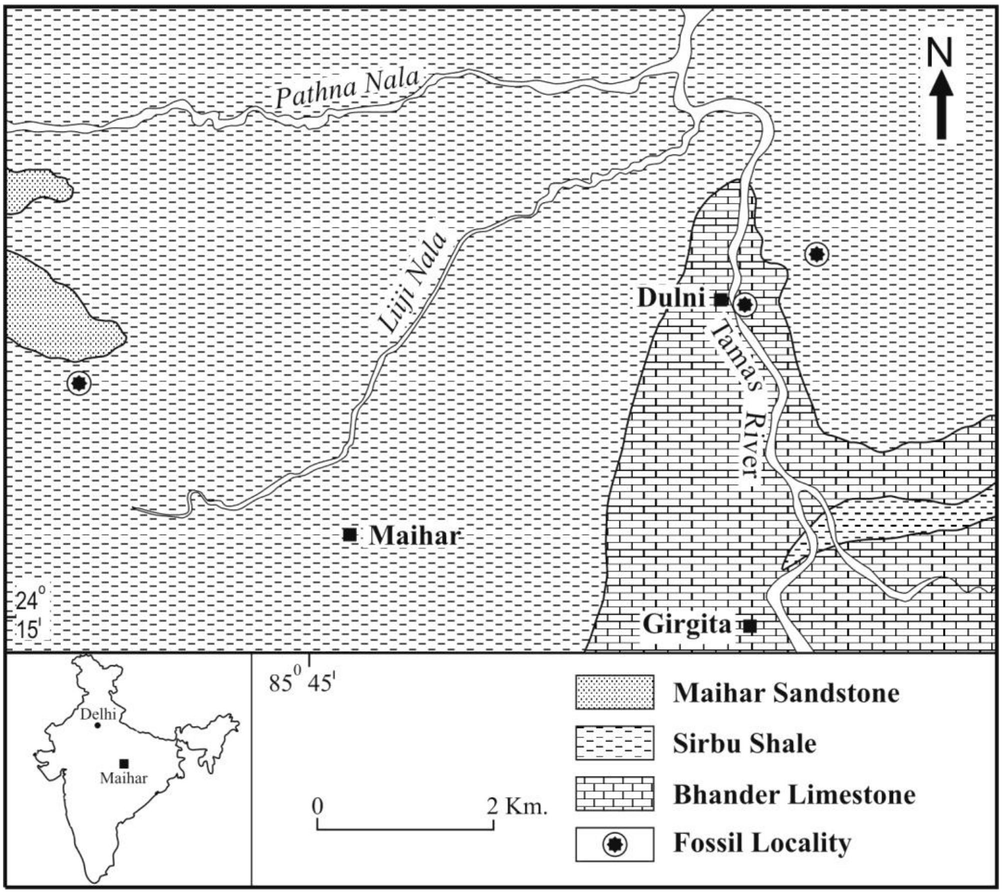


Fig. 2.5- Geological map of the Girgita, Emaliya and Dulni areas in Maihar, Satna District, M.P. (Modified after Bhattacharyya, 1993).

deformed and diagenetic origin. These certified horizons may be simple, single discontinuous sheets or lens, or may comprise superimposed lenses separated by a thin parting of unreplaced micritic limestone (Fig. 2.6).

The chertified oolites of lower part of the Bhander Limestone show pervasive deformation. Externally, however, the oolite bed itself does not exhibit any sign of structural disturbance. In thin sections study no preferred orientation of deformed ooids were discernible, the long axes lie statistically parallel to bedding plane (the pane of directions of extension) but whose short axes are normal to the bedding plane (direction of shortening).

Sarkar et al. (1982) gave the possible mechanism of deformed ooids in the lower part of the Bhander Limestone. The deformation of ooids needed to be examined at two levels: a) the behavior of individual ooids, and b) the behavior of the bulk material (ooids-matrix system). They recognized nine broadly distinctive fabrics on the basis of intensity and nature of the deformation.

Fig. 2.6- Chert bed in the Bhander Limestone at Girgita quarry, Maihar area, Satna District, M.P.

Fig. 2.7- Columnar stromatolite *Baicalia baicalica* Bhander Limestone, Tons river valley near Girgita quarry, Maihar area, Satna District, M.P.

The ooides of Girgita quarry are dominantly elliptical and suffered homogeneous deformation (Pl. 2.1). The direction of elongation is not uniform (Pl. 2.1a). Deformation of ooids into ellipsoids implies that these ooids were of more or less of uniform competence, and the bulk material was more uniform as compared to the other oolite in the upper part of the Bhander Limestone. In other words, ductility contrast between ooid and matrix, although varied in space, was lower in the case of the oolite of Girgita quarry. This chertified oolitic facies is overlain by stromatolitic limestone facies. Stromatolites are of columnar type with vertically-stacked convex upward hemispheroids having variable basal radius (Fig. 2.7).

Molar Tooth Structure (MTS) is a common feature that has been found in the Bhander Limestone. In the present study, MTS has been reported from Girgita quarry (Fig. 2.8 and 2.9) and Aber localities (Fig. 2.10). The depositional

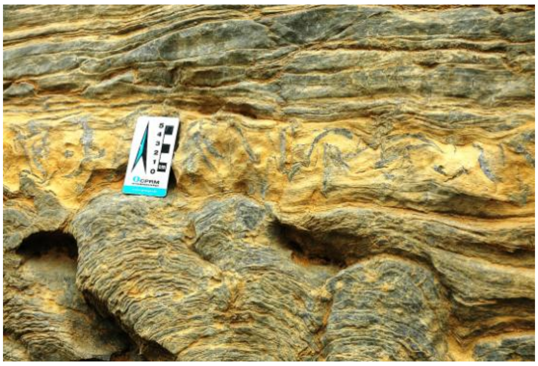


Fig. 2.8- Molar Tooth Structure recorded in the Bhander Limestone, present in the bed above stromatolite from Girgita quarry, Maihar area, Satna District, M.P.

Fig. 2.9- Molar Tooth Structures from Girgita quarry, Maihar area, Satna District, M.P.

environment of MTS has been described as the subtidal shelf (James et al., 1998), its origin is still an enigma. Several workers proposed the different methods and mechanism of origin of MTS including microbial actions (Smith, 1968; O'Connor, 1972; Furniss et al., 1998; Meng et al., 2002, 2003), evaporite replacement (Eby, 1975), subaqueous shrinkage (Knoll et al., 1990) and seismicity (Song 1988; Qiao et al., 1994, 1996, 2000; Fairchild et al., 1997; Pratt, 1998). Gellatly and Winston (1998) and Pollock et al. (2006) suggested this in combination with rapid replacement of a vaterite ($CaCO_3$) precursor by micritic calcite in an organic-rich alkaline setting. Qiao et al. (1994), Fairchild et al. (1997), Pratt (1998, 2001), Qiao and Gao (2000), and others have indicated that crack generation is directly related to seismic activity. Pratt (1998, 2001) claimed that seismic pumping may have triggered physical injection of particulate carbonate into these voids, and hence implied that Molar-Tooth carbonate is primarily a chemical sediment, not a cement. The seismic argument suggests that the cracks were generated by cyclic loading, a process which also occurs due to the passage of long period marine waves, and hence MTS could be storm-induced (Fairchild et al., 1997; Long, 2001; Bishop et al., 2006). This may explain the predominance of these structures in ramp settings above storm wave-base and their common association with hummocky cross-stratified beds (James et al., 1998; Long, 2001; Sherman et al., 2001; Bishop et al., 2006). An alternate model (Marshall and Anglin, 2004) suggested that these structures were produced by explosive CO_2 clathrate destabilization within tens of metres of the sediment/water interface, at water depths well in excess of 100 m and temperatures below 10° C. Whatever the

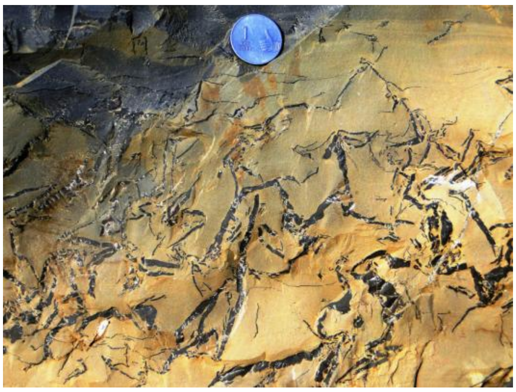


Fig. 2.10- Molar Tooth Structures recorded in Bhander Limestone from Aber locality, Satna District, M.P.

Fig. 2.11- Reddish coloured stromatolitic limestone facies in Bhander Limestone, Badi Pahadi, Maihar area, Satna District, M.P.

mechanism of formation of Molar-Tooth carbonate, both the rheology of the host strata and the void-forming process play a role in influencing the final morphology of the structure (Pollock et al., 2006). A common problem in all models is the question of interconnectedness of the initial cracks, both for passage of fluids and/or gas, and for direct connection of pores to sea-water.

The development of MTS seems to be largely restricted to the interval between 1900 and 550 Ma (Pratt, 1998; James et al., 1998; Shields, 2002), with two examples (in siliciclastic mudstone) from the Archaean (Bishop et al., 2006; Bishop and Sumner, 2006). The major decline in abundance appears to coincide with a major shift in the strontium-isotope record at ~750 Ma, well before the advent of extensive reworking of sediments by metazoans. Shields (2002) indicates that this may reflect a decrease in $CaCO_3$ concentrations in the world ocean, combined with a possible increase in the concentration of precipitation inhibitors. Jia et al. (2010) described the mechanism of Neoproterozoic MTS on the basis of compression and dewatering of carbonate veins by pressure of deposits and sea water.

The middle part of the Bhander Limestone is capped by another reddish coloured stromatolitic limestone facies which is about a meter thick as seen at Badi Pahadi Limestone quarry (Fig. 2.11). A siltstone facies separates the middle part of the Bhander Limestone from the upper part. This siltstone facies is nearly 5 m thick, is well exposed near Pahari Village, 1 km east of Emaliya limestone quarry. This siltstone facies is characterized by alternating siltstone, very fine sandstone and red-coloured shale (Fig. 2.12).

Fig. 2.12- Siltstone unit of Bhander Limestone near Pahari village, Maihar area, Satna District, M.P.

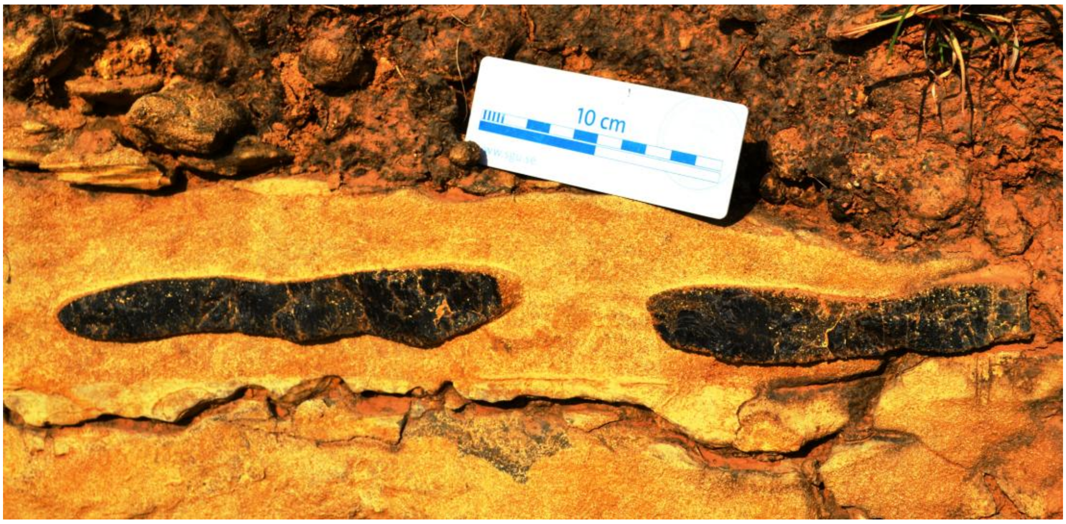


Fig. 2.13- Chert nodules lying parallel to bedding plane in the Bhander Limestone, Dulni, Maihar area, Satna District, M.P.

Dark muddy oolitic limestone facies forms the base of the upper part of the Bhander Limestone, as seen on Tamas river banks near Dulni Village. Black limestone facies, which is oolitic and is nearly 3 meter thick, is characterized by plane lamination, small scale cross bedding and ripple marks.

The limestone at Dulni is characterized by sporadic elliptical lenses of coal-black massive chert, flattened parallel to the lamination (Fig. 2.13). Generally, the

Fig .2.14- Bowing out of bedding around a chert nodule in the Bhander Limestone, Dulni, Maihar area, Satna District, M.P.

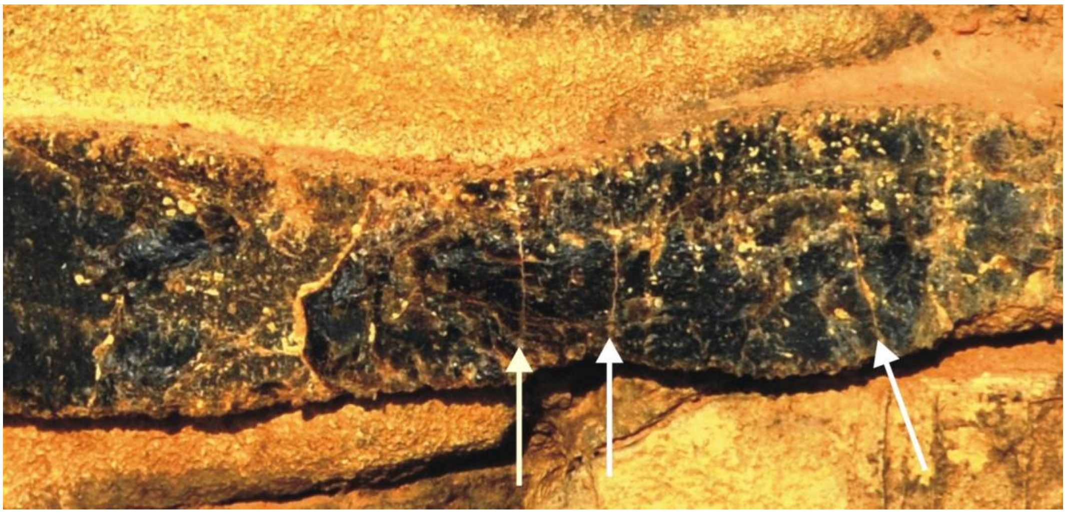


Fig. 2.15- Vertical cracks (normal to bedding) within the nodule in the Bhander Limestone, Dulni, Maihar area, Satna District, M.P.

nodules do not appear to transgress laminations; laminations rather tend to lap around the nodules (Fig. 2.14). Swerving of laminations around nodules is a definite indication of the contrast of competence between the nodules and the surrounding limestone during compaction and is evidence of precompactional origin of the nodules. Confinement of parallel, vertical cracks within the nodules (Fig. 2.15) also confirms the difference of competence between the rigid nodule and its more plastic host. Oolites near the contact with chert got readily squeezed because they were laid immediately against the rigid body of chert and those lying away from the contact in the carbonate were free from the disturbing effects of the inclusion, that is, deformation.

The ooids within the chert nodules are almost undeformed, whereas those in the immediately surrounding limestone are both deformed and undeformed. There is a sharp change in packing density of ooids across the chert-limestone contact. In the limestone, both the deformation and packing density of ooids decrease normally away from the contact with chert. (Chanda et al., 1977) made a measurement with four samples along linear traverse across the chert-limestone contact. Result of that experiment is graphically represented in (Fig. 2.16). Immediately adjacent to the contact, the number of ooids per unit length is significantly greater in limestone than in chert, and the number shows a gradual decline in the limestone with increasing distance from the contact. In contrast, the number of ooids per unit length in chert remains constant (between 3 to 4 ooids) irrespective of the distance from the contact.

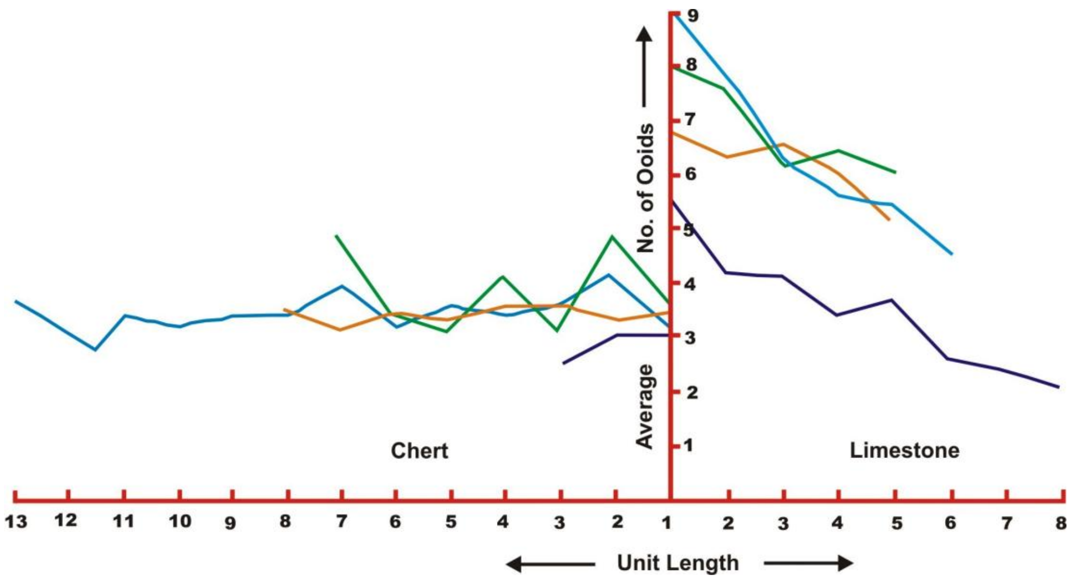


Fig. 2.16- Spatial variation in the number of ooids per unit length (1.3 mm) across chert and limestone away from their contacts in four samples (indicated by different symbols). Number of ooids per unit length is the average determined from five to six parallel traverse segments per sample (redraw after Chanda et al., 1977).

The deviation in shape of deformed ooids from perfect ellipsoids in both the upper and lower part of the Bhander Limestone appears to have been caused by ductility contrast between ooid and matrix and between ooid themselves (Sarkar et al., 1982).

Reijers and Have (1983) suggested that in an agitated shallow marine warm environment with water saturated with respect to $CaCO_3$, slow precipitation around nuclei results in the formation of the cortexes with a concentric internal structure. In the Dulni river section, ooids are found (Pl. 2.2) with concentric cortex architecture that's means the depositional environment was shallow marine. Similar environmental conclusions have been derived from several recent environments and in laboratory test by Heller et al. (1980).

The upper most part of the Bhander Limestone is characterized by greyish to yellowish micritic limestone, oolitic limestone, stromatolitic limestone with gypsum lenses, siltstone and silty shale. Horizon shows the parallel lamination, large and small scale cross bedding, flaser and lenticular cross bedding, wavy bedding, current ripples, interference ripple, mud cracks and penecontemporaneous deformational structure.

Fig. 2.17- Zone of light yellow coloured thin bedded limestone with convolute lamination in the Bhander Limestone, Dulni, Maihar area, Satna District, M.P.

The black limestone facies is overlain by a thick (3 m approximately) zone of light yellow coloured thin bedded oolitic limestone facies characterized by ripple and cross stratification, also contains chert nodules. This zone is also characterized by the presence of series of convolute lamination and load structures (Fig. 2.17).

Fig. 2.18- Convolute lamination and ball & pillow structures in the upper part of the Bhander Limestone, Dulni village section, Maihar area, Satna District, M.P.

Fig 2.19-Overturning of convolute laminations in the upper part of the Bhander Limestone, Dulni village section, Maihar area, Satna District, M.P.

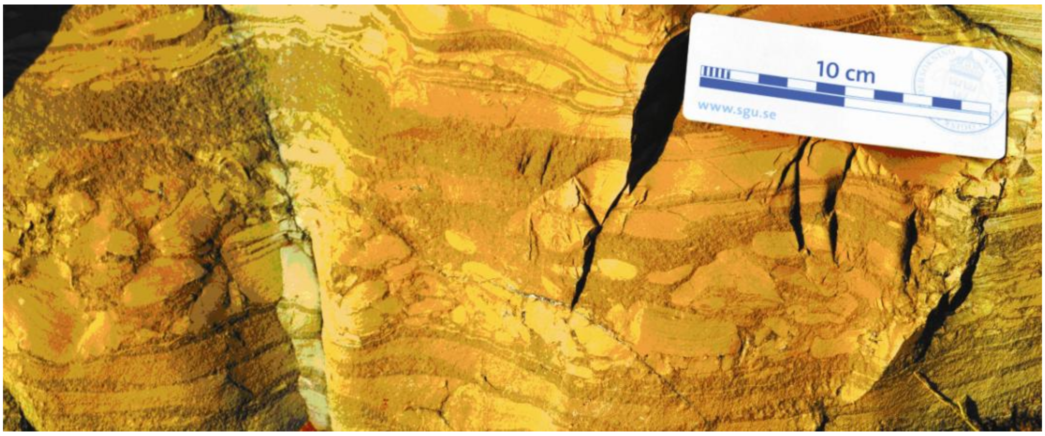


Fig 2.20 Intraclast with fining upward sequence in the upper part of the Bhander Limestone, Dulni village section, Maihar area, Satna District, M.P.

Convolute laminations are complex set of folds with broad and open synclines and tight and packed anticlines with vertical fold axes (Fig. 2.18). Overturning of the fold axis is observed (Fig. 2.19). The upper surface of this zone is sharply truncated. Convolute lamination is considered to be the result of plastic deformation of partially liquefied sediments soon after deposition and further suggests a complex system of vertical motion, rather than lateral displacement, causing internal readjustment of material in quick condition (Pettijohn, 1975). Load balls and load structures are also found in the convolute laminated zone. Intraclasts, lying parallel to the bedding plane locally show graded bedding with fining upward sequence (Fig. 2.20). When followed upward, the Bhander Limestone gradually becomes more shaly with greenish-coloured shales and impure limestone that gradually passes over to Lower Bhander Sandstone.

2.3.3 Lower Bhander Sandstone: This is poorly recorded and identified unit of the Bhander Group in the Son Valley, its maximum thickness has been

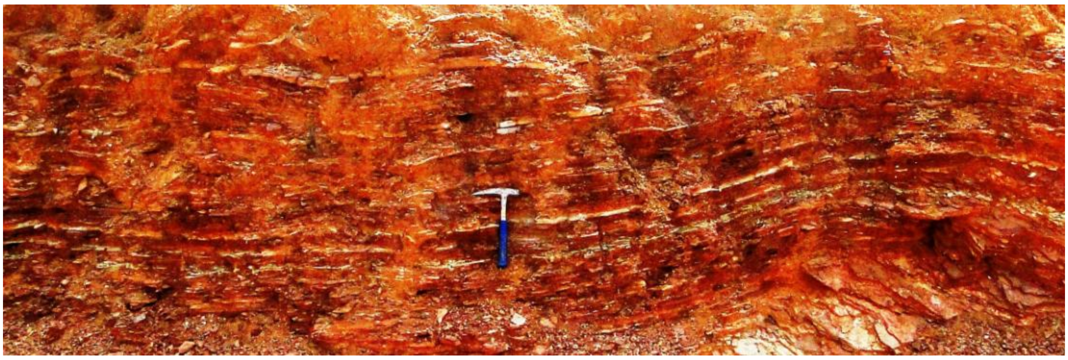


Fig. 2.21- Vertical section of the upper part of the Lower Bhander Sandstone, Lilji Nala, Maihar area, Satna District, M.P. Alteration of thin bedded fine sandstone (white bands) and thick, red to chocolate shales (darker bands).

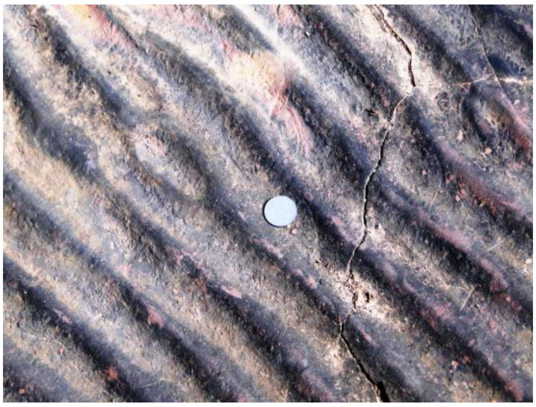


Fig. 2.22- Close view of wave ripples in the Lower Bhander Sandstone from Lilji Nala, Maihar area, Satna District, M.P.

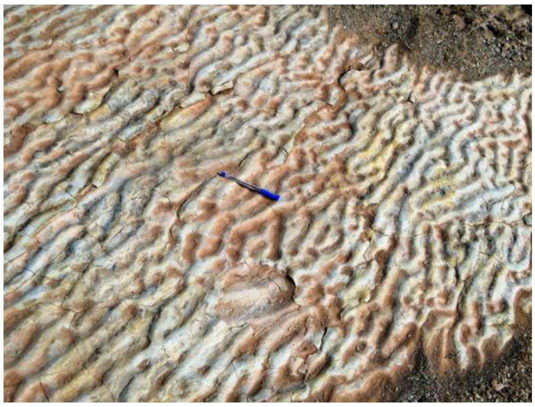


Fig. 2.23- Multi crested wave ripple in the Lower Bhander Sandstone from Lilji Nala, Maihar area, Satna District, M.P.

noted in Chambal Valley section approximately 200 m (Sastry and Moitra, 1984) and 61 m in Son Valley Section (Bhattacharyya, 1993). Lower Bhander Sandstone is heterolithic facies characterized by rhythmic alteration of shale, sandstone, and shale-pebble conglomerate (Fig. 2.21). The red to brownish red colour is a common feature of all the facies. Vertical alteration of these three facies accompanied by lateral change in their frequency from section to section is the typical signature of the Lower Bhander Sandstone.

The sandstone component varies in thickness from few millimeters to 15 cm. Ripple marks, both of wave and current types, are abundant (Fig. 2.22, 2.23 and 2.24). Ripple crest trend varies from bed to bed. Various types of modified ripple characterize the sandstone facies. The basal surface of these numerous sandstone beds are often found to be sculptured into flutes, grooves, brush marks, loadcasts and various other markings. These sole structures help in the determination of

Fig. 2.24- Over view of the ripple marks exposed in the Lower Bhander Sandstone from Lilji Nala, Maihar area, Satna District, M.P.

Fig. 2.25- Rain imprints and ripple marks combo impression recorded in the Lower Bhander Sandstone, Maihar area, Satna District, M.P.

palaeocurrent direction and indicate that sand was introduced by a sudden and swift-flowing current in pulses in an otherwise calm and mud-depositing environment.

Salt pseudomorphs (Fig. 2.26 and 2.27) occur in profusion on the top and sole of these various sandstone layers as cubic projections in wide range of sizes, in present study the observed ranges are between 0.7 cm to 1.5 cm. The occurrence of salt-pseudomorphs, in the absence of proper salt deposits, possibly indicate temporary increase in salinity of the pore water which might have caused precipitation of isolated cubes of halite.

Infilled polygonal desiccation cracks of various dimensions are also quite common in the Lower Bhander Sandstone. Besides, shallow scours, mantled with ripples, occur in places; some of them bear water recession marks along their edges. These desiccated surfaces are locally marked by rain imprints (Fig. 2.25).

Fig. 2.26 & Fig. 2.27- Salt pseudomorphs recorded in the Lower Bhander Sandstone, Lilji Nala, Maihar area, Satna District, M.P. Note the cuboidal casts of the salt on the sole surface of the Sirbu Shale. (Fig 2.26 crystal size = 0.7 cm; Fig. 2.27 crystal size = 1.5 cm)

Shale-pebble intraformational conglomerate is the third facies of the trinity of mudstone-sandstone-conglomerate facies that characterized the Lower Bhander Sandstone (Bhattacharyya, 1993). Lilji creek provides an ideal section to study vertical variation of different lithofacies of the Lower Bhander Sandstone.

2.3.4 Sirbu Shale: The changes from the Lower Bhander Sandstone to the overlying Sirbu Shale is transitional and the basal part of about four meters is well exposed along Pathna Nala and Kolua village. The maximum thickness of the Sirbu Shale is exposed at Karari Nala locality (Fig. 2.28). It is characterized by light yellow, grey to greyish green shale and siltstone interbedded with grey to brownish grey sandstone. The thickness of shale and sandstone varies considerably. It attains the thickness of 100-250 m (Bhattacharyya, 1993). The shales alternate with sandstone and vary considerably. The sandstone facies show parallel and cross bedding, various types of scour marks, tool marks, ripple lamination and various types of ripple marks dominated by wave ripples. A few horizons also show hypersaline environment inferred on the basis of presence of salt pseudomorph shales. An arenaceous facies overlying the Bhander Limestone

Fig. 2.28- Panoramic View of the different stratigraphic units of the Bhander Group as seen from the right bank of the Karari Nala on the junction of Nagod- Jasso Road.

identified by Krishnan (1968), Sastry and Moitra (1984) and Bhattacharyya (1993) as the Lower Sandstone has been included within the Sirbu Shale by a few workers (Singh, 1976 and Kumar, 1976). Several smaller stromatolite domes are found to cluster together and are bound together by still larger algal concentric rings, forming composite stromatolite dome (Fig. 2.29, 2.30 and 2.31).

The carbonate horizon shows development of domal stromatolite *Maiharia maiharensis* (Kumar, 1976). Kumar and Srivastava (2003) have reported an assemblage of carbonaceous megafossils consisting of *Chuaria circularis, Tawuia dalensis*, cf. *Lanceoforma* sp., cf. *Phascolites symmetricus* and unnamed

Fig. 2.29- Stromatolite in the limestone unit of the Sirbu Shale, Kolua Village, Satna District, M.P.

Fig. 2.30- Stromatolite developed in the limestone unit of the Sirbu Shale from Kolua Village, Satna District, M.P.

Fig. 2.31- Stromatolite in the limestone unit of the Sirbu Shale exposed in the Pathera Nala, Maihar area, Satna District, M.P.

filamentous forms. Prasad (2007) have reported *Obruchevella* spp. – *Dictytidium* sp. – *Cristallinium* sp. and suggested Ediacaran age for the Lower Bhander Sandstone and Sirbu Shale.

2.3.5 Shikaoda Sandstone: The Shikaoda or Maihar Sandstone has also been referred to as the Upper Bhander Sandstone. Sastry and Moitra (1984) have named it as the Shikaoda Sandstone. It is the youngest horizon of the Bhander Group in the Son Valley area and its thickness is 54 m (Bhattacharyya, 1993). The Sirbu Shale grades into the Shikaoda Sandstone. It is characterized by brown to red coloured sandstone and deep red coloured shales. Parallel bedding, cross

Fig. 2.32- Cross bedding lamination from top of the Shikaoda Sandstone in the premises of Ram Govind Dham temple, Maihar area, Satna District, M.P.

bedding (Fig. 2.32), wave and with a very wide variety of forms, rill marks, wrinkle marks, current crescent, load cast, deformational structures, channel structures and mud cracks are reported from the Shikaoda sandstone. In mud dominated horizons tidal bedding is seen. Singh (1976) has observed two opposite current direction with one dominating over the other. The Shikaoda Sandstone is fine grained, moderately to poorly sorted and subgraywacke in composition (Basumallick 1962).

2.4 Age of the Bhander Group

In recent years, a number of papers have been published on radiometric dates which modified the concept of the beginning of the sedimentation in the Vindhyan Basin from 1400 Ma to ca. 1800 Ma (see Misra and Kumar, 2005; Kumar and Sharma, 2012). Ray (2006) has reviewed the age of the Vindhyan Supergroup and opined that the age of the Lower Vindhyans in the Son Valley is now resolved, whereas the problems with the age of the Upper Vindhyans and their correlation remain to be answered. There is only one radiometric data available regarding to the age of Bhander, recorded by Rathore et al. (1999). The age of the Sirbu Shale of the Bhander Group has been recorded as 741 ± 9 by K-Ar analysis of gluconites. Except this Ray et al. (2002) calculated $^{87}Sr/^{86}Sr$ ratio for the Bhander Group and suggested, Neoproterozoic age. In scarcity of the radiometric dates, the age of the Bhander Group is to be assessed on the available palaeontological record and lithostratigraphic correlation. The stromatolites are recorded from the Bhander Group and the age of the Bhander Group has been suggested on the basis of these abundantly recorded stromatolites. The Bhander Group is characterized by the presence of *Baicalia, Tungussia* and *Patomia* and complete absence of coniform stromatolites (Kumar, 1982; Misra and Kumar, 2005). On the basis of stromatolites, Kumar (1982) has suggested upper Cryogenian age for the Bhander Limestone. In the Maihar area, the Shikaoda Sandstone is underlain by the Sirbu Shale, from which Kumar and Srivastava (2003) have reported *Chuaria-Tawuia* association along with other carbonaceous megafossils including *Phascolites* and they have suggested that the age of the Bhander Group is somewhere between upper Cryogenian and Ediacaran. Rai (1999) for the first time reported the occurrence of microbial mat textures from the Maihar Sandstone and suggested

Ediacaran age. No Cambrian fossil has so far been discovered from the Bhander Group. The Ediacaran fossils reported by De (2003, 2006) are not convincingly biogenic and hence ignored. Prasad (2007) has studied the microfossils recovered from the Bhander Group by maceration technique and on this basis he has suggested latest Cryogenian to Late Ediacaran age (ca. 650–544 Ma). Presence of *Arumberia* and associated fossils with typical Ediacaran body fossil *Beltanelliformis minuta* supports the Shikaoda Sandstone is Ediacaran of age (Kumar and Pandey 2008). On the contrary Malone et al. (2008) have interpreted the palaeomagnetic data and zircon dating of the Bhander Group and have suggested that the Upper Vindhyan sequence should be older than 750 – 771 Ma. They also suggested that the sedimentation in the Vindhyan Basin ended around 1000 Ma. This interpretation fails to account for the available geological and palaeontological data.

We have not reached any final conclusion regarding to the accurate time period for the deposition of the Bhander Group, hence the real age still remains a problem. Neither radiometric data are enough to achieve the goal nor palaeobiological data have unique interpretation. However, in the present study Late Cryogenian to Late Ediacaran age of the Bhander Group has been proposed.

2.5 Tectonic Framework

Vindhyan Basin is bounded by the Son-Narmada Geofracture in the South; some parts of the basin in the south and southwest are covered under 65 Ma old Deccan flood basalts. This basin is bounded towards west and northwest by NE-SW trending Great Boundary Fault of Delhi-Aravalli orogenic belt and in the south by SONATA lineament. Towards east, it is bounded by exposed folded Satpura Massif and the Bundelkhand Massif and Indo-Gangetic Plains (Fig. 2.2) in the north. Bundelkand Granitic Massif of Archaean age sits as basement in the middle of this basin, thereby dividing it into two parts - the Son Valley on the southeastern side and the Chambal Valley on the southwestern side where exposures occur from Agra (Uttar Pradesh) to Chittorgarh (Rajasthan). Two major faults, Yamuna fault and Sawai Madhopur-Damoh fault, trending NW-SE (Fig. 2.33) can be seen orthogonally transecting the regional structural trend (Jokhan Ram et al., 1996).

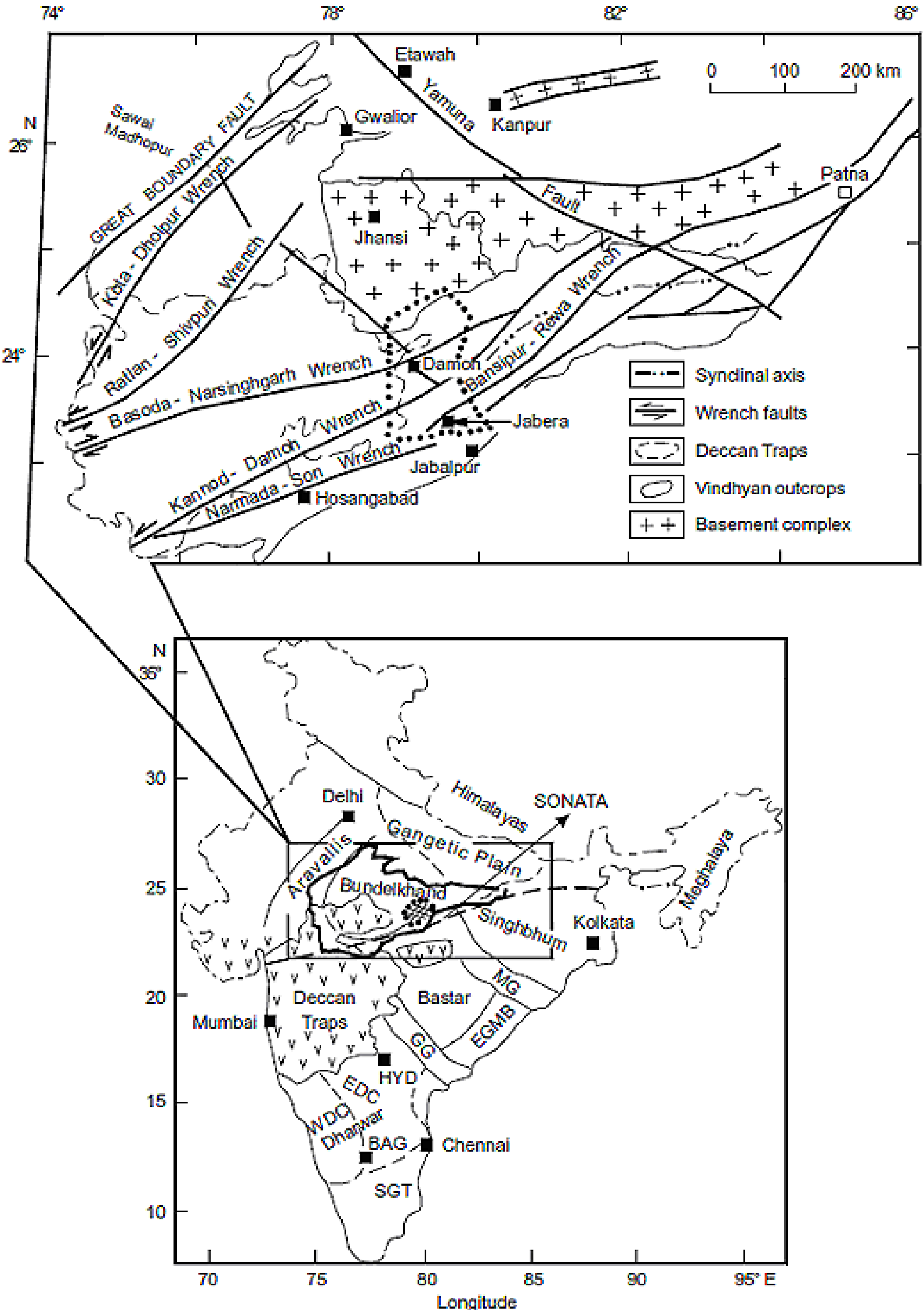


Fig. 2.33- Distribution of cratonic blocks and associated rift valleys in the Indian peninsular shield. The curved solid lines indicate Vindhyan Basin and the hatched region is the area of present study. Tectonic map of the Vindhyan Basin and its adjoining areas is shown in top figure (*after* Jokhan Ram et al., 1996), where solid dots indicate area covered by this study. GG: Godavari graben; MG: Mahanadi graben; HYD: Hyderabad: BAG: Bangalore; EDC; Eastern Dharwar Craton; WDC; Western Dharwar Craton; SGT; Southern Granulite Terrain.

The southern margin of the Vindhyan basin is marked by a major ENE–WSW trending lineament termed Narmada–Son lineament south of which occurs the Satpura orogen. The Vindhyan stratum defines a broad, regional syncline trending ENE–WSW. The axis of the syncline is slightly curved and plunges gently towards west. The average dip of the southern limb is greater than that of the northern limb rendering the axial plane to dip southerly.

Another major fault having NE-SW orientation passes through Katangi, which is situated southeast of Jabera. North of this fault lies the well known Jabera dome trending NE-SW below the Vindhyan sediments, which may either be attributed to Bijawar metasediments or the basic/ ultrabasic intrusives at the basement level. Occurrence of volcaniclastic deposits in Upper Vindhyan sequences does not conform to the widely held belief that the Upper Vindhyans are devoid of any volcanic episode, representing a quiescent tectono-sedimentary history (Chakraborty et al., 1996).

Plate 2.1

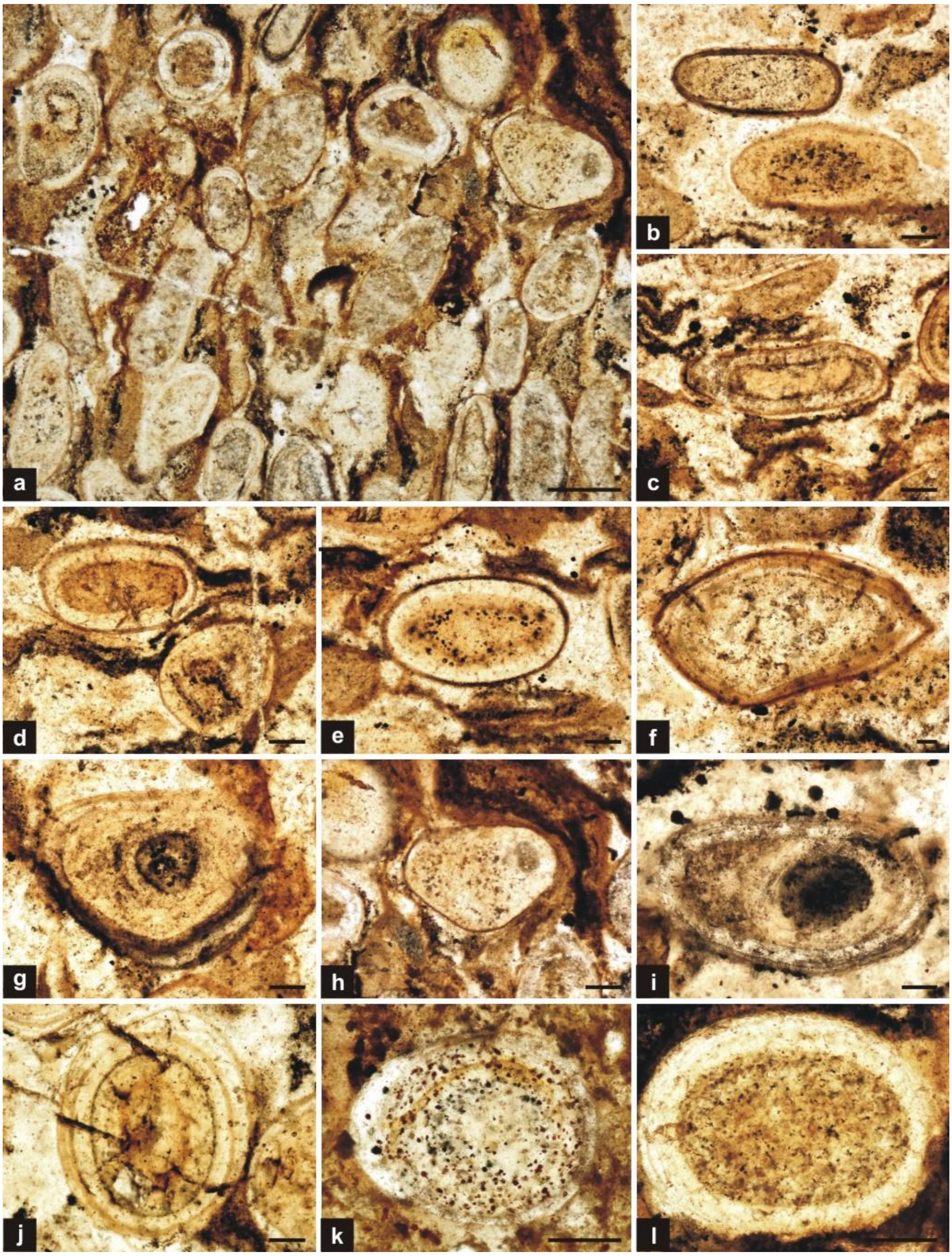


Plate-2.1- Oolites of lower part of the Bhander Limestone from Girgita quarry under thin section study. a- Section of cherified ooids cut parallel to the bedding plane. High frequency of circular section of deformed ooids. Orientation is not uniform and darkness of the stringers is owing to enrichment in organic matter. b - d: highly deformed ooids, dark concentric ooid laminae enriched in organic matter. e and h: weakly deformed ooids. f: plastically deformed, irregular ooid. g and i :dark colour organic matter act as nucleus. j – l: concentric rings represent more than one stage of deposition, dark lines in the 'j' are cracks.

Scale Bar: a = 500 µm; b – l = 100 µm.

Plate 2.2

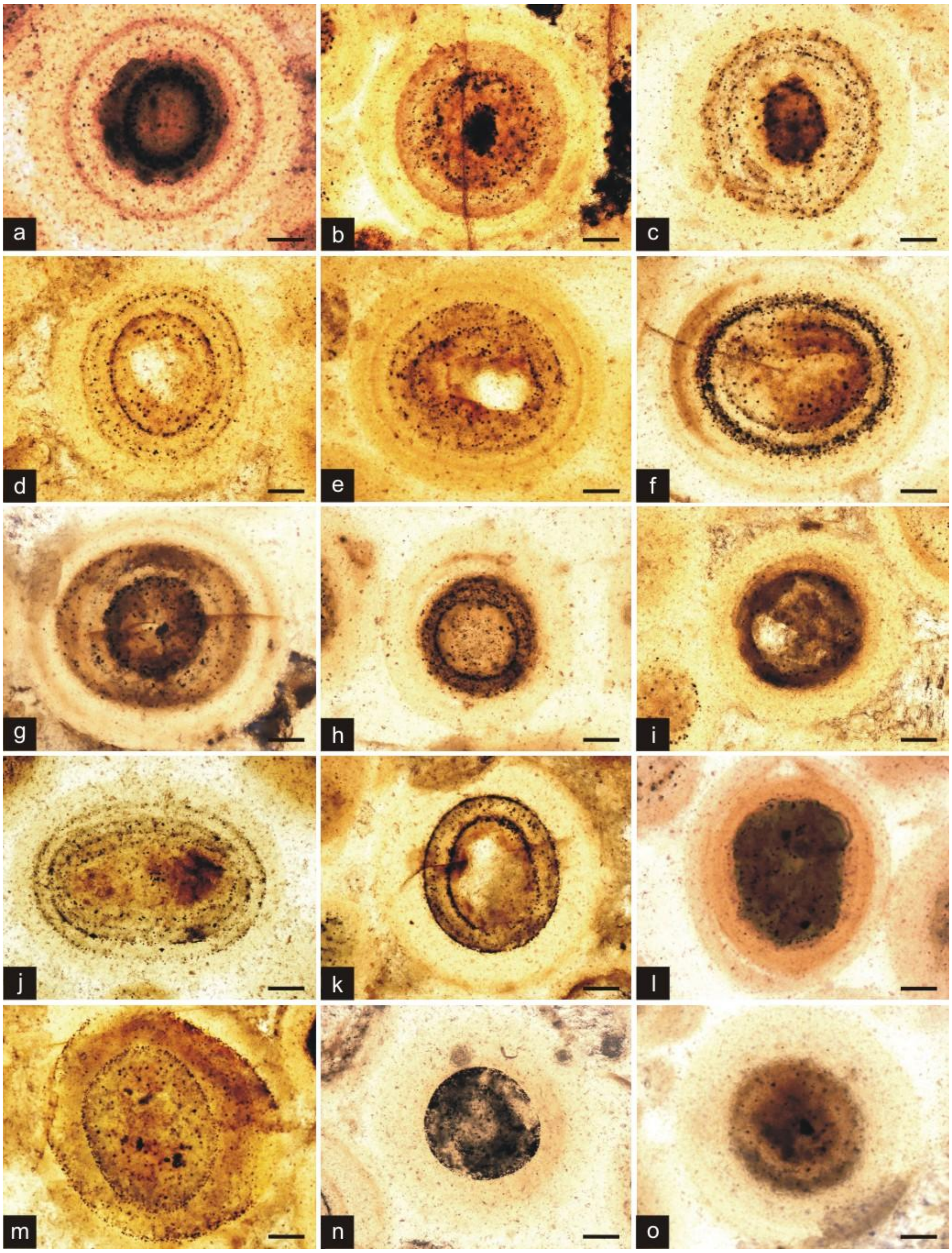


Plate-2.2 Dulni Oolites. In this plate the thin sectional view of the ooids of Dulni. a-e and g- circular concentric cortex architecture, different colour of rings represent different stages of deposition. f and j: oblong shape ooids with concentric rings. h, i and k – m: one or two concentric rings represent less differentiation in the environmental stages. n and o: big clast with only one cortex layer.

Scale Bar: a – o = 100 μm.

Chapter 3

METHODOLOGY

Methodology is the process to find out the desired results of any problem with useful combination of tools and data sets. At the present the methodology has been broadly divided into two parts to solve the present problem. The scope of the first part covers detail outcrop observations in the field to collect data to fulfill the objectives of the goal. For gather field data following equipments were used, most extensively used equipment like hammer, chisel, brunton, measuring tape, clinometer compass, Abney level, camera etc. Extensive literature consulation was carried out before performing any fieldwork. Toposheets of the Survey of India were (63 D/11, 63D/12, 63 D/14; 63 D/14, 63 D/15, 63 D/16, and 63 H/6) used for the present study. After obtaining relevant field information of the study area, locations and geological maps with detailed lithologs have been prepared.

The second part deals with the laboratory work. Petrographical analysis of thin section under microscope, acid maceration for collection of the microfossils, geochemical analysis to cover stable Isotope and TOC measurement. Megafossil were studied in the laboratory. Detailed lithologs have been prepared by combination of field data at different location. Schematic diagrams have been prepared with the help of previous available data and data generate during present work.

Thus, the work has been divided into two parts:

- Field Studies
- Laboratory Methods

Present chapter provides a detailed description of the methodologies adopted for the dissertation work.

3.1 Field studies

The field area covers the Vindhyan exposures in Son valley, surroundings of Maihar (24º 16' 12" N, 80º 45' 0"E) bounded between Satna and Katni (Fig. 2.3). Satna (24º 34' 48" N, 80 º 49' 48"E) and Katni (23º 50' 24" N, 80º 23' 24"E) are located in the Madhya Pradesh state. The Maihar station is well connected with

Fig. 3.1- Road map of the Maihar and adjacent areas showing localities from where samples were collected for present study.

the railways and roadways networks. The main attention during the field work was on the stromatolites, carbonaceous megafossils, trace fossils and microbial mats in the siliciclastic rocks. Traverses were made from the bottom to top part of the each formation to identify distinctive facies and facies associations based on lithology, texture, structure, geometry, thickness of beds and nature of bed boundaries were documented. True thicknesses of the formations and its facies constituents were measured from quarries, cliffs, river sections and road cuttings. Facies logs were constructed from the facies thickness data and were correlated laterally wherever the exposures permitted. Fresh samples were collected in field with due care for the laboratory studies. Black bedded chert, chert nodules in the carbonate successions, oolitic chert were searched and collected for the study of microfossils, microstructures and textures by petrography. All geographical locations shown in the map (Fig. 3.1), occure around Maihar town, few near to Satna and only Ramnoi locality lies in Rewa District.

3.2 Laboratory methods

3.2.1 Thin sections

Thin sections of sandstone, limestone and chert were prepared in the section preparation lab of the Birbal Sahni Institute of Palaeobotany, Lucknow and Continental Instrumentation, Lucknow. Cross sections are useful for the identification of rocks, minerals and microfossils. The samples were broken into small pieces (approximately 2 cm × 2 cm). The hardened samples were then polished over a piece of glass by using 220, 400, 800 and finally 1000 mesh carborundum powders. The polished 40 smooth surface was then mounted on a glass slide using cold-setting resin (R.I.>1.54). The other side of the sample was polished in the same way. The final thickness of the sections was reduced close to 30 micron and the sections were then covered by a transparent cover slip and numbered.

3.2.2 Photo Documentation

Photo Documentation has been done with the use of three different microscopes:

Stereoscopic microscopy – The stereo or dissecting microscope is an optical microscope variant designed for low magnification observation of a sample using incident light illumination rather than transillumination. It uses two separate optical paths with one objective and two eyepieces to provide slightly different viewing angles to the left and right eyes. In this way it produces a three-dimensional visualization of the sample being examined. During present study Stereo microscope Leica MZ12 was used for observing magafossils.

Light Microscopy – Optical or light microscopy involves passing visible light transmitted through or reflected from the sample through a single or multiple lenses to allow a magnified view of the sample. The resulting image can be detected directly by the eye, captured digitally. Nikon Eclipse 80i used for magnifying microfossils in palynological slides by passing visible light transmitted through the samples.

Scanning Electron Microscope (SEM) – A scanning electron microscope (SEM) is a type of electron microscope that images a sample by scanning it with a beam of electrons in a raster scan pattern. The electrons interact with the atoms that make up the sample producing signals that contain information about the sample's surface topography, composition, and other properties such as electrical conductivity. LEO 430 SEM used during present study at Birbal Sahni Institute of Palaeobotany, Lucknow.

Sample Preparation- All samples fit in the specimen chamber and are generally mounted rigidly on a specimen holder called a specimen stub, 13 mm radius aluminum stubs were used in the study. For conventional imaging in the SEM, specimens must be electrically conductive, at least at the surface, and electrically grounded to prevent the accumulation of electrostatic charge at the surface. Therefore, non conductive specimens usually coated with an ultrathin coating of electrically conducting material, deposited on the sample either by low-vacuum sputter coating or by high-vacuum evaporation. Conductive materials in current use for specimen coating is gold/palladium alloy, the thickness of coating is lie between 100 Aº– 300 Aº. Polaron sputter coater used for coating.

3.2.3 Maceration

Maceration or Acid digestion of rocks is a technique to extract insoluble organic microfossils from rock matrix as carbonates siliciclastic rocks and carbonaceous siltstone and shale. The following steps were used to extract acritarchs from the rocks: cleaning, disaggregation, removal of carbonates, removal of silicates, removal of fluorides, oxidation, filtration, and slide preparation, these are show in flow-chart (Fig. 3.2).

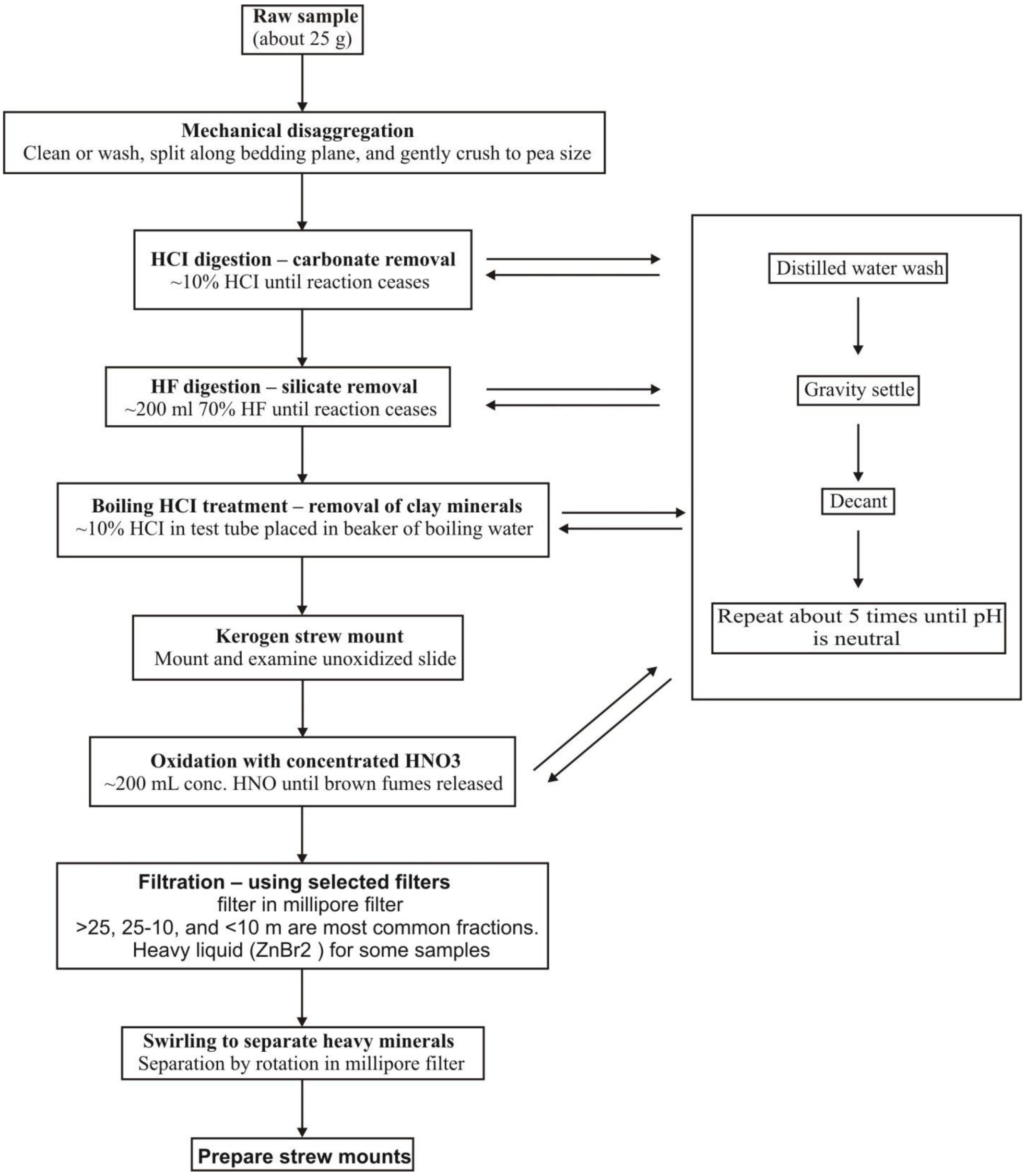


Fig. 3.2- Flow chart showing steps for extracting palynomorphs from Proterozoic samples after K.Grey (1999).

Cleaning and disaggregation- Samples were cleaned externally by scrub with a stiff brush to remove mud. After removal of mud, sample washed with hot, running tap water until the decanted water ran clear then washed two or three times using distilled water. Avoid violent crushing methods otherwise large size (> 500 µm) specimens of acritarch may be fragmented. Disaggregation is least destructive method of sample catching. Fissile shales were split along bedding surfaces using finger nails or a knife blade. Both Burzin (1990) and Butterfield et al. (1994) pointed out that bedding-parallel thin sections revealed concentrations of fossils, and concluded that much of the fragmentation resulted from extraction methods. Alternate wetting and drying could break-up even well-consolidated samples. If above techniques fail to disaggregate then the samples were crushed either in a mortar and pestle or by using a hammer and a metal plate, the samples were placed between two clean aluminum pie dishes (Phipps and Playford, 1984). The crushed samples have diameter of 5 mm, this large size reduces the risk of damaging larger acritarchs. Fragmented samples were then washed several times with distilled water.

Carbonate removal - HCl treatment removed carbonates from the sample. HCl treatment was carried out in the same plastic screw-topped container later used for HF acid digestion. A few milliliters (ml) of dilute (about 10% of the stock solution) HCl were added to the sample to test the strength of the reaction. Samples that showed little or no reaction were treated directly with about 100 ml of 32% HCl for about 24 hours, and then tested again with fresh acid to check whether the reaction had ceased. The sample was then washed to near neutrality with distilled H_2O by settling and decanting after each wash (at least four washes were usually required). The solution was left slightly acidic so that any possible carbonates, precipitated when HF dissolved the silicates, would be dissolved by the residual HCl, reducing the formation of fluorides.

Fluoride removal - HCl was used to remove any precipitates that had formed during the HF processing. The decanted sample was transferred to a 500 ml, 25 mm-diameter, plastic screw-top test tube with a conical bottom. About 250 ml of 32% hydrochloric acid was added to the sample, and the contents were raised to boiling point. Boiling was continued until the greyish, gel-like fluorides had dissolved. The sample was allowed to cool, and was then decanted, washed, and allowed to settle. The process was repeated until the pH was neutral.

Kerogen mount - A kerogen mount of the organic fraction was made at this stage as a record of the unoxidized sample and to determine thermal maturation. It was also used to estimate how much oxidation might be required.

Oxidation - About 200 ml of concentrated HNO_3 was added to the decanted sample to oxidize dark-coloured organic matter, and in some cases to remove pyrite framboids or surface encrustations. The amount of oxidation required was pre-determined from the kerogen mount or by microscopic examination of a few drops of macerate. Most samples required about 10 minutes of oxidation, but some required longer or shorter periods. Oxidation was stopped by the addition of distilled water, as soon as brown fumes were given off and the residue had changed colour from black to a honey brown. Some samples were difficult to oxidize because they contained abundant small pyritic framboids embedded in the organic matter. These pyritic particles increased the specific gravity of the organic material, causing it to settle to the bottom of the tube along with free mineral particles, and appeared to be one of the reasons why heavy-liquid separation was generally unsuccessful. The framboids also obscure details of the vesicle surface, although they could usually be dissolved as part of the oxidation process, provided the reaction was a gentle one. In some cases, specimens were held together by pyritic encrustation and complete removal of the framboids would fragment the specimen, so oxidation was not allowed to proceed for too long. For samples with abundant pyrite framboids, the reaction sometimes had to be stopped when only partially complete, and the residue spot-checked by microscopic examination to monitor the effectiveness of the procedure. The sample was then either thoroughly washed with distilled water by the usual decantation method until neutral, or subjected to further oxidation.

Separation of heavy minerals - Techniques involving the use of heavy-liquid fractionation (using ZnBr2 or ZnCl2 at specific gravities of between 2.0 and 2.2) and centrifugation to separate the organic residue from undissolved mineral particles were described in detail by Phipps and Playford (1984) and Traverse

(1988). The technique was used only for a few large process-bearing acritarch preparations that had an abundance of heavy minerals that could not be separated by swirling. In the few samples, for which heavy-liquid separation was attempted, the samples were still allowed to settle by gravity. Experiments to substitute non-toxic, non-corrosive sodium polytungstate ($3Na_2WO_4.9WO_3.H_2O$) for $ZnBr_2$ (Gregory and Johnston, 1987; Savage, 1988) proved unsuccessful because clean separations were not obtained, a factor probably related to the high viscosity of the liquid at the required specific gravity. Separation of organic residue and heavy-mineral grains were usually accomplished quickly and easily by a swirling method carried out in the filter funnel. At the end of the filtration process, the filter funnel was tilted to about 45°, and the material trapped on the filter was washed off the cloth into the body of the funnel using about 5 mL of distilled water from a squeeze bottle. Within a few seconds, the heavy-mineral fraction began to settle out into the angle in the funnel wall. Organic material remained in suspension for a few seconds longer, and could be separated from the heavy minerals by rotating the funnel a few degrees clockwise. With a little practice, the two fractions could be cleanly separated, and the organic suspension transferred to a 5 mm-diameter, conical-based glass tube using a pipette. The procedure sometimes needed to be repeated to obtain all the organic material.

Slide preparation - As for most palynological preparations, residues were mounted on microscope slides using a transparent medium. A variety of substances are available (Traverse, 1988), but for permanent mounts an epoxide-based mounting medium that has a refractive index slightly higher or lower than that of sporopollenin (1.48) was preferred. Although glycerine jelly has an appropriate refractive index (1.43), it is not really permanent; the jelly can dry up; or, if temperatures rise, the jelly melts and the specimens move around. The method outlined here is for Petropoxy 154, but other media such as Epotek 301 are also suitable, and are more appropriate if fluorescence studies are to be carried out because Petropoxy will fluoresce.

A cover slip (no. 1) was placed on a hotplate at a temperature of about 100°C. Two drops of a dispersing agent, 3% polyvinyl alcohol (PVA), were placed on the cover slip with a pipette. A few drops of residue were then added to the PVA and the mixture was gently spread over the surface of the cover slip with the pipette. A little extra distilled water was added to obtain the required dispersion and the residue was dried out slowly (at about 100°C). A drop of Petropoxy 154 was placed on a microscope slide, and the slide was warmed gently to drive off any bubbles in the resin. The coverslip was then inverted and lowered steadily onto the Petropoxy 154, allowing the resin to spread by capillary action. Excess resin and air bubbles were squeezed out from below the cover slip by gently pressing on the coverslip, and the prepared slide was placed on a hotplate at a temperature of 135° for 10–15 minutes to cure the resin. The cured slide was cleaned using a razor blade and ethanol. Surplus residue was stored in glass vials with a few drops of $CuSO_4$ added as a preservative, and the lid of the tube sealed with nail polish to prevent evaporation of the contents.

Contamination issues - A further advantage of the modified techniques was a reduction of the risk of contamination, which poses a problem in Proterozoic successions where specimens can be sparse and their taxonomy is poorly known. An indication of the extent of this problem was given in a discussion by Schopf (1992), and can be accessed from the comprehensive tables of micro-nonfossils and micro-dubiofossils reported from the Proterozoic (Mendelson and Schopf, 1992; Manoharachary et al., 1990; Shuka et al., 1992; Sharma et al., 1992). Although modern pollen and most Phanerozoic fossils can be recognized if they occur as contaminants, a variety of biogenic structures and other artefacts may be introduced during preparation procedures and can be mistaken for bonafide fossils.

Contamination risks from airborne particles of organic matter and cross-contamination of samples are considerably reduced by using a minimum number of containers for each sample.

Potential contaminants can be monitored if blanks (such as granite or other plutonic rocks) are processed at the same time as regular samples. Airborne particles can be collected by exposing cover slips with smears of mounting medium in the preparation area. Tap water and the various chemical reagents should be microscopically examined from time to time for potential contaminants. Results obtained from such studies indicate that great care is needed to ensure that only organisms of undoubted Proterozoic origin are included in systematic descriptions.

3.2.4 Measurement of Total Organic Carbon (TOC)

TOC (total organic carbon) measurements of black shale and carbonate samples were carried out at Geochemistry Department of National Geophysical Research Institute (NGRI), Hyderabad. For this purpose the inorganic carbon fraction was removed first by treating the sample with about 50 mg of homogenized 63 micron powdered samples with 3-4 drops of 50% HCl to remove its inorganic carbon content and kept in the oven overnight at 105°C. The dried, HCl treated samples were taken in the Quartz boat and loaded into the furnace of the TOC analyzer for total organic carbon measurements. The model of TOC analyzer used is Soild Module 1000°C from Elementar Analysensysteme GmbH. Procedural blank and the soil standard (Boden Soil Standard, 4.1% TOC) was also analyzed in the similar way. The TOC released due to the chemical oxidation of the organic carbon is measured by the IR detector and expressed in wt %. The % RSD is ≤ 1%. Table 3.1 gives the operating conditions of the Solid Module.

Table 3.1 Technical Specifications of TOC

Carrier Gas	Zero Air
Carrier Gas Flow	200 ml/min
Pressure	0.9 bar
External Standard	Boden Soil Standard
Max. Temperature	900°C
Run Time	18 mins

Principle & Instrumentation of TOC Analyzer – The total organic carbon content analysis is based on the oxidative combustion of rock samples in presence of platinum catalyst to form carbon dioxide and its subsequent determination with an Infrared detector. The total carbon determinations are carried out from the original sample while for TOC determination the sample is externally acidified and then dried before the analysis. (Fig. 3.3) shows the schematic diagram of Total Carbon Analyzer. The sample is combusted in a heated combustion reactor consisting of a pre and post combustion furnace. At lower temperature of 70°C, the purgable and inorganic carbon is removed with the carrier gas (zero air comprising of nitrogen and oxygen) and at higher temperature of 900°C, the non-purgable or the organic carbon is combusted in presence of oxygen and catalyst.

The carbon containing combustion gases are oxidized to CO_2 in presence of post combustion catalyst (platinum on ceramic carrier). The reaction gas flows through a drying unit and a halogen absorption tube where unwanted compounds are withheld. The CO_2 obtained is measured in the Infra Red Detector. The liquid TOC software converts the integral of the measuring signal into a respective concentration value with the help of a stored linear calibration (Elementar Soild Module 1000°C operating manual). The lower detection limit for approximately 2 μg C absolute is ~5 ppm C with 400 mg sample weight and the linear working range is up to 1.2 mg C absolute or 100%. The precision /standard deviation is ± 0.7 μg absolute or ≤ 1%, relative for the homogeneous test substances or standards.

3.2.5 GC-C- IRMS

Analytical Procedure – The $\delta^{13}C$ analyses of desorbed hydrocarbons is carried out using Gas Chromatograph-Combustion-Isotope Ratio Mass Spectrometer (GC-C-IRMS) which comprises of Agilent 6890 Gas Chromatograph coupled to a Finnigan-Delta Plus^{XP} Isotope Ratio Mass Spectrometer via a GC combustion III interface. One ml of the adsorbed soil gas is injected into the Agilent 6890 GC injection port equipped with "Pora Plot Q" capillary column of length 25 cm and diameter 0.32 mm in splitless mode with Helium as carrier gas at fixed oven temperature of 28°C. The chromatographically separated hydrocarbon gases after eluting from GC column enter a pre-oxidized Cu-Ni-Pt combustion reactor maintained at 960°C where they get converted into carbon dioxide and water. The water is removed using Nafion membrane tube prior to their entry into the mass spectrometer. The purified CO_2 after combustion goes into the mass spectrometer

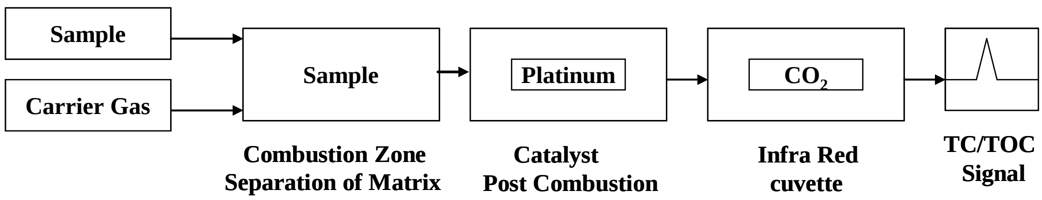


Fig. 3.3- Schematic diagram of Total Organic Carbon analyzer (after Mani, 2008).

for $^{13}C/^{12}C$ ratio measurement of the respective hydrocarbon. The GC-C-IRMS is calibrated with Natural Gas Standard (NGS-1) mixture using the ISODAT software. The $\delta^{13}C_1$ value in the sample is calculated with respect to the standard and reported relative to PeeDee Belemnite (PDB). The precision of the isotope analysis is ±0.5%.

Principle and Instrumentation of GC-C-IRMS – Stable isotope mass spectrometers are widely used to determine the ratio of ^{13}C to ^{12}C in geological samples. The basic mass spectrometer comprises of the i) ion source for fragmentation of sample molecule into ions and ii) mass analyzer for separating the ion beam according to the mass of the respective ions. The sample and reference gases are carried into the ion source of the mass spectrometer through a stream of helium as carrier gas. With the advancement of hyphenated techniques, the separation power of gas chromatograph has been coupled to the mass spectrometer along with introduction of sample combustion interface into the gas chromatograph-isotope ratio mass spectrometer. The separated products of the sample mixture in the stream of helium at the output of the gas chromatograph are passed through an oxidation/reduction reactor and then introduced into the mass spectrometer for precise concentration determination. The open split-coupling device ensures that only a part of the sample/reference gas containing carrier gas is fed into the ion source of the MS. In this way, pulse injection of sample gas can be analyzed, reducing the volume constraints and sample size. Figure 3.4 shows the schematic of GC-C-IRMS.

The Gas Chromatograph-Combustion (GC-C) device comprises of Agilent 6980 Gas Chromatograph fitted with Poraplot Q capillary column, oxidation and reduction reactor along with water separator. The oxidation reactor is a non porous alumina tube in which three wires of copper, nickel and platinum of 240 mm identical length and 0.125 mm internal diameter are braided and centered end to end within the tube. The reactor is inserted into the Al_2O_3 furnace operated at 940°C. The reduction reactor is placed between the double T-piece and water separator and is identical with oxidation furnace except for the reactor filling which is pure copper with three copper wires of 240 mm identical length and 0.125 mm internal diameter. The reduction temperature is maintained at 640°C.

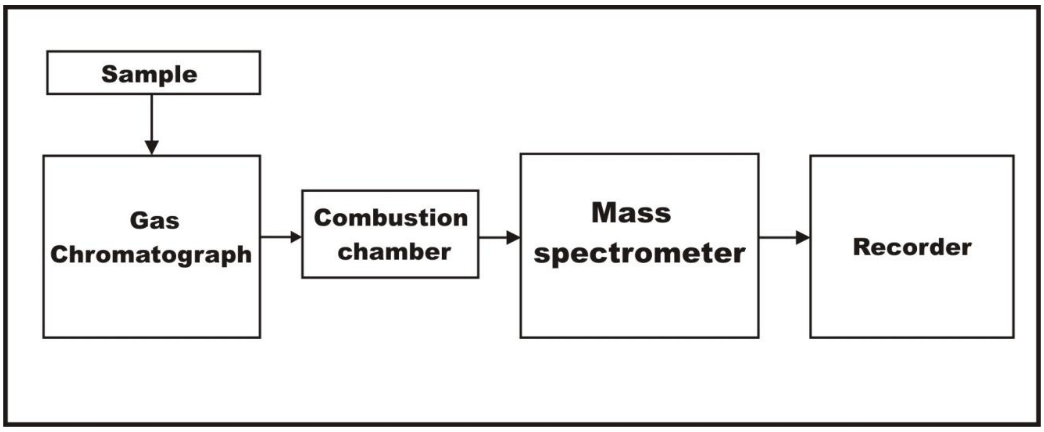


Fig. 3.4- Schematic diagram of GC-C-IRMS (after Mani, 2008).

The Delta Plus XP CF-IRMS used in the isotope ratio determination comprises of i) electron impact ion source ii) magnetic analyzer with effective magnetic deflection of radius of 180 mm and iii) self-aligning Faraday collectors. The ISODAT software is used for the data acquisition (Thermo Finnigan Delta XP Manual).

The compound specific analysis of hydrocarbon mixture for $^{13}C/^{12}C$ ratio measurement has been carried out by injecting the sample mixture consisting of C1-C5 hydrocarbons into the gas chromatograph. The individual components after chromatographic separation are converted into CO_2 and H_2O in the combustion reactor. The CO_2 gas in the analyte stream is transported into the IRMS via an open split assembly. To minimize inaccuracies in measuring the absolute amounts of ^{12}C and ^{13}C, the ratio of the two in a sample is compared with that in a standard analyzed. By definition, the standard $\delta^{m}E$ value of a standard is $0^{0}/_{00}$, so negative values of a sample indicate depletion in the heavier isotope compared with the standard and the positive values indicate enrichment in the heavier isotope (for PDB $^{13}C/^{12}C = 0.011237$).

3.2.6 Absorbed Gas Analysis

One gram of 63 µm wet, sieved black shale sample was used to extract light gaseous hydrocarbons after acid treatment in glass degasification apparatus and was subsequently analysed on Gas Chromatograph (GC) and Gas hromatograph–Combustion–Isotope Ratio Mass Spectrometer (GC–C–IRMS). During acid

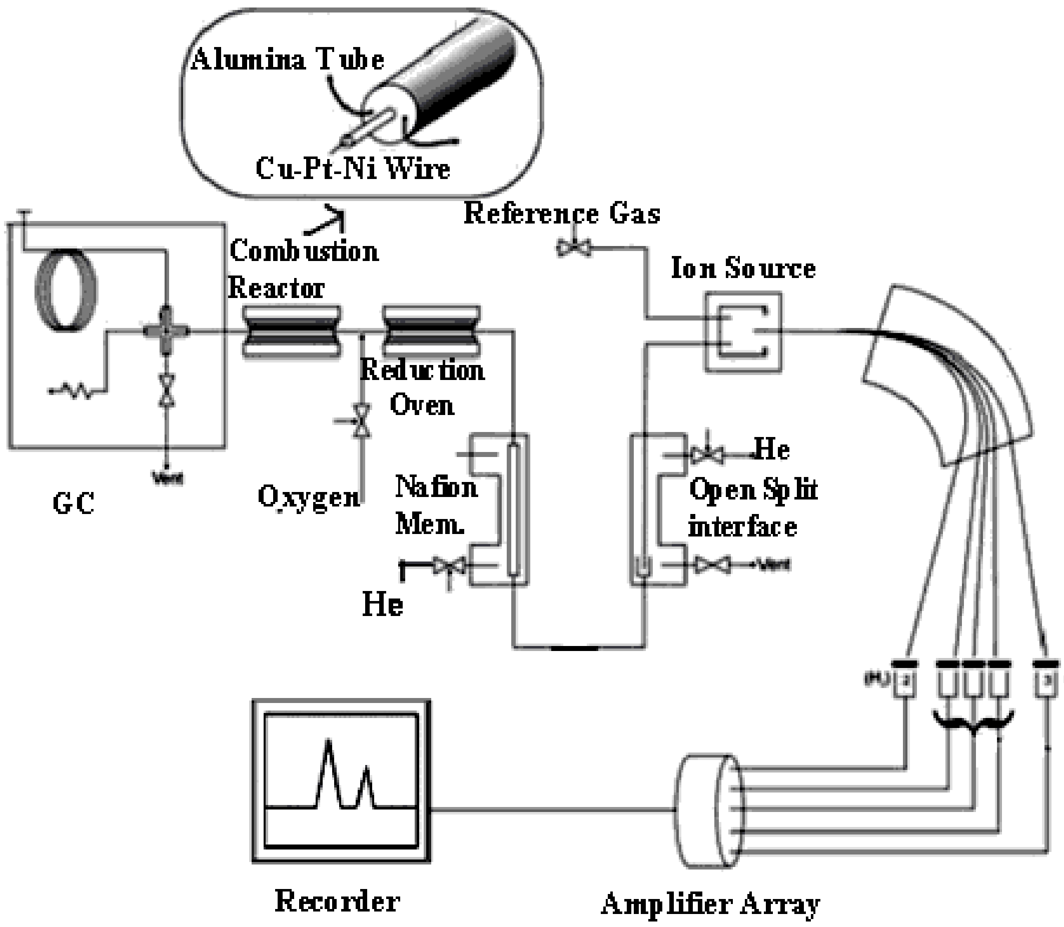


Fig. 3.5- Schematic diagram of GC-C-IRMS (after Gavin et al., 2007).

treatment, the dominant gas released was CO_2, which was trapped in KOH solution. The light gaseous hydrocarbons were collected by water displacement in a graduated tube fitted with rubber septa. The volume of desorbed gas was recorded and 500 µl of desorbed gas sample was injected into Varian CP 3380 GC fitted with Porapak Q column, equipped with flame ionization detector. GC was calibrated using external standards with known concentrations of methane, ethane, propane, *i*-butane and *n*-butane. Quantitative estimation of light gaseous hydrocarbon constituents in each sample was made using peak area measurements and correction for moisture content on wet basis was also applied. The hydrocarbon concentration values of individual hydrocarbons from methane through pentane were expressed in parts per billion (ppb) on dry-weight basis. The accuracy13 of measurement of C1–C4 components was < 1 ng/g. Carbon isotopic composition of light hydrocarbons from soil samples was determined using GC–C–IRMS, which comprises of Agilent 6890 GC coupled to a Finnigan- Delta

PlusXP IRMS via GC combustion III interface (Fig. 3.5). Next, 1 ml of desorbed gas was injected to GC in splitless mode with helium as the carrier gas at fixed oven temperature of 28°C. The light hydrocarbon gases eluting from the GC column entered the combustion reactor maintained at 960°C, where they were converted to CO_2 and water. Nafion membrane tube was used to remove water, prior to the entry of CO_2 into the mass spectrometer. Reference standards were intermixed with samples to monitor instrumental performance. The carbon isotope ratio in the sample was determined by comparing isotope ratios with those of standards, NIST RM 8560 (IAEA NGS2) using ISODAT software. The $\delta^{13}C$ was calculated using the following equation:

$$\delta^{13}C = [(^{13}C/^{12}C)_{sample} - (^{13}C/^{12}C)_{PDB}] \ / \ [(^{13}C/^{12}C)_{PDB} \times 1000]$$

The carbon isotopic composition was reported in per mil (‰) relative to the PeeDee Belemnite (PDB). The precision of the isotopic analysis14 was ± 0.5‰. In the present study, the magnitude of each of the five organic constituents (C1, C2, C3, *i*C4 and *n*C4) in black shale and siltstone samples was measured and expressed in ppb. The compositional characteristics of these hydrocarbon gases desorbed from black shale samples indicate the presence of methane (C_1), ethane (C_2), propane (C_3) *i*-butane (iC_4) and *n*-butane (nC_4).

Chapter 4

PALAEOBIOLOGY

The Ediacaran sequences (635 – 542 Ma) sediments in the world have diversified life forms preserved in and recorded from chert, sandstone and shale. Chert provides a suitable environment for well-preservation of microorganisms. It gives the information regarding evolution in the organism. Body fossils, compressions and impressions, skeletonized body fossils and trace fossils, are preserved in the sediments of this age. The scope of the word 'Palaeobiological remains' or in other words any evidence that shows existence of life is Palaeobiological remains. In the Bhander Group, the palaeobiological remains are represented by diversified form of ancient life *viz.* carbonaceous remains, microscopic fossils, stromatolites, microbially induced sedimentary structures (MISS), mat related sediments and Bizarre structures.

Abundant preservation of megascopic carbonaceous forms attributed to *Chuaria circularis* and *Tawuia dalensis* have been recorded from shale units of Bhander Limestone, microfossils from Lower Bhander Sandstone and Sirbu Shale, microstromatolites from the Bhander Limestone and MISS from Shikaoda Sandstone. Few possible remains of Ediacaran fossils are recorded from the Shikaoda Sandstone.

4.1 Microstromatolites

In stromatolite's classification, microstromatolites are divided into two categories of suprageneric rank (Raaben 1986; Raaben and Sinha, 1989; Raaben et al., 2001). Milimeter-scale (less than 1 cm across) columnar microstromatolites are placed under 'Minicolumellida' and other category of stratinodular buildups with microscopic nodules and submillimeters scale columellae are known as 'Ministromida'. The former category is constituted of most of the known microstromatolite taxon. Presently, there are more than 80 formal species belonging to 30 formal genera (Raaben, 1998). Colummar microstromatolites are also commonly known as 'asperimorph stromatolites' a term coined by Grey (1984); whereas Chinese scientists reffered them as 'pseudogymnosolenids' (Liang et al., 1984, 1985). In India, asperimorph stromatolites are recorded from the Cuddapah and Kaladgi Supergroup and from Buxa Dolomites (Sharma et al., 1998; Sharma and Shukla, 2004; Sharma and Pandey, 2012; Tiwari, 2001). Like other microstromatolites, Indian occurrences are confined to the Palaeoproterozoic or Early Mesoproterozoic successions. Kumar (1999) mentioned the presence of microstromatolite from the Girgita quarry of Maihar area in Bhander Limestone. Another reference of 'ministromatolite' has been made from the Bhander Group (Pandey, 2011) of the Vindhyan Supergroup. The Bhander Group is the youngest group of the Vindhyan Supergroup and is believed to be the Neoproterozoic in age. Our studies have demonstrated the presence of biostrome of microstromatolite in the Bhander Limestone exposed in Aber area (Fig. 4.1) of the Satna District, Madhya Pradesh. Contrary to all other known microstromatolites, the Aber occurrence is definitely Neoproterozoic in age and therefore intriguing. The Aber occurrence of microstromatolite is being formally described. Field observations and collection of samples were made between 2009 and 2011. Most of selected and described samples were collected during the field trip in 2011. Microstromatolites were studied following the methods suggested by Hofmann (1969, 1977a); Walter (1972); Preiss (1972); Grey (1989). Most of the observations have been gathered on the thin section studies of chert collected from Aber area. Linnean (binomial) nomenclature is adopted for microstromatolite naming. Hofmann and Jackson (1987) described the ministromatolites as a product of abiogenic precipitation because of the characteristic radial fabric of carbonate precipitation. Similar fabric has been noted in the *Asperia*, *Yelma* and *Pseudogymnosolen*. Hofmann and Jackson (1987, p. 964) mentioned the necessity to differentiate between the ministromatolites with and without radial fibrous – fabric and emphasized that the forms without radial fibrous – fabric as "both biophoric and biogenic" in origin. They compared it with the build-ups of the Gunflint Formation. Similar microstromatolites with smooth laminae and without radial-fibrous fabric are also documented as *Minicolumella chauhanae* Raaben, *Vetella uschbasica* Krylov. Raaben (1998) described a columnar microstromatolite *Tysseria voronovae* Raaben from the Lower Cambrian Tyusser Formation, Northern Siberia with thin fibrous laminae alternating with the thicker radial-fibrous laminae but all are after molds of cyanobacteria. A synthesis by Raaben (1998) on the microstromatolites suggests that the columnar microstromatolites were widely distributed in both the Palaeoproterozoic and the Early Riphean and

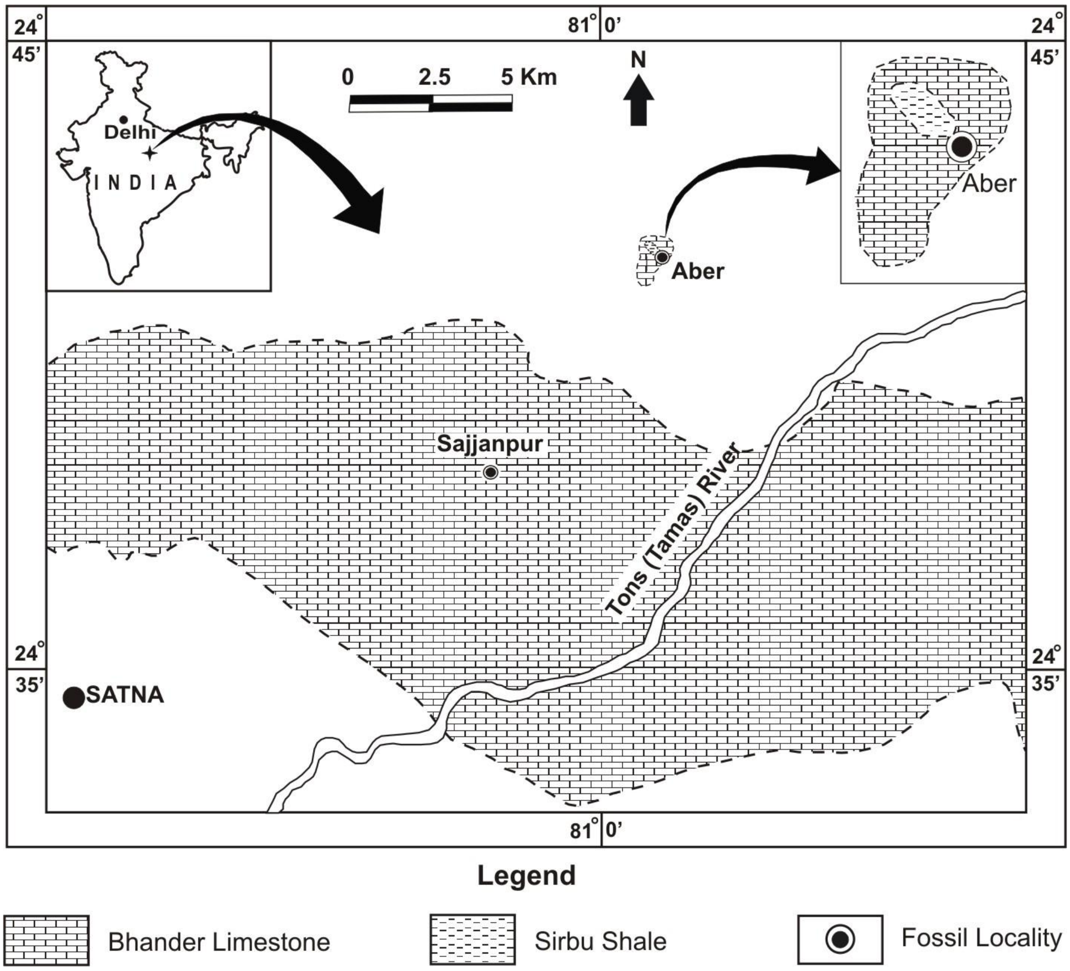


Fig. 4.1- Geological map of the *Ministromatolite* bearing locality Aber, Maihar, Satna District, M.P (Pandey, 2011).

the Cambrian. Similar microstromatolites were also reported from present day landfill leachate (Maliva et al., 2000). These stromatolites were formed in an aphotic and anoxic environment that was supersaturated with calcite and composed of branching cylindrical bundles of concentrically laminated radial fibrous crystals.

Systematic Palaeontology

Group-*Aberia* new group

Type from-*Aberia kumarii* nov form

Derivation of name- After the type locality which occurs at Aber, 27 km NE of Satna township on Satna – Semaria motor road.

Diagnosis- Columnar stromatolite, bridging absent, naked, frequent, parallel, β–style branching, thin, wispy, gently convex to flat laminae and narrow irregular interspace.

Content- *Aberia kumarii* only.

Remarks- This stromatolite cannot be easily assigned to any of the known microstromatolite taxon.

Distribution and age- The Bhander Limestone, the Bhander Group, Son Valley area, the Vindhyan Supergroup, Satna District, Madhya Pradesh, India and the age is Neoproterozoic, about ~ 700 Ma.

Aberia kumarii new from

(Plate 4.1-4.7)

Material- Well preserved specimen occur in two localities- Aber and Girgita both in Satna District. Three dimensional reconstruction is not possible owing to extreme narrowness of the columns and irregular interspaces.

Holotype- slide BH-23D; from Aber locality. Paratypes BH-23E, BH-23A, BH-23C all from Aber locality. Other material include fragments and piece collected from the Aber locality. Stromatolite from the Girgita locality were documented by Kumar (1999).

Derivation of name- After Prof. S. Kumar of the Geology Department of the University of Lucknow, Lucknow, who devoted spent his entire active research career in understanding the stromatolites of the Vindhyan Supergroup.

Diagnosis- Columnar stromatolite, brindging absent, column naked, frequent, parallel, β style branching; thin wisphy, gently convex to flat laminae, laminae traceable from interspace to column, and narrow irregular interspaces.

Description-*Outcrop details-* Stromatolites are noted in the thin sections of chert bands and large nodules occurring in two localities in Satna District, namely Girgita quarry and Aber. In Aber, the chert nodules are found in the lower part of the Bhander Limestone. These nodules are frequent and occur at irregular intervals, sometimes assuming bedded shape, because of their hardness such limestone bands are called 'Lohawat' in common parlance. There are other types of stromatolitic bioherms in the younger part of the Bhander Limestone. *Aberia kumarii* is confined in the silicified part of the carbonate bands. The thickness of such bands are ~ 30-50 cm, domical nodular bioherms are 30 cm in diameter

(Plate 4.1, a-d). Distinct colour differentiation is noted in the parts where columns occur which probably denotes silicification of original crystals of calcite or evaporites. At Girgita, the bedded cherty horizons underlie edgewise conglomerate and the other stromatolitic horizons. *Aberia kumarii* occur in the thin section of bedded cherty units.

Mode of Occurrence- Domal to bedded bioherms occur at irregular intervals. Domal bioherms are common at Aber locality whereas bedded bioherms are noted at Girgita. Bioherms begin as flat-laminated stromatolites that grades upward into columnar stromatolites.

Branching- Branching is frequent, parallel and β-style. In some regions column remains parallel and show incipient side branches (Plate 4.2a). Flat laminated regions of the stromatolites alternate with branched stromatolites, several variations in such alterations are noted (Plate 4.2, b-d).

Column Shape- Columns are 3-4 mm in length and 0.5 to 2 mm in width. Most of columns are straight, seldom sinuous or inclined, column are circular in plain view. Column margins are naked, bridging absent in almost all the cases (Plate 4.3, a-e; 4.4, i). In some parts, pseudocolumnar nature are also noted (Plate 4.4, a-h).

Lamina Shape- Most laminae are gently convex to flat, occasionally steeply convex laminae. Laminae are very fine and at the base of columnar stromatolites are flat-laminated. Laminae in the columns and in certain pseudocolumns show flexures. Laminae terminate abruptly at the column margins without forming a wall (Plate 4.5, a-c and Plate 4.6, a-d).

Microstructure- Laminae consist of alternating pairs of light and dark laminae of filmy microstructure type. Light laminae are considerably thick between 250 and 500 µm, tapering towards the margin. They are lensoid and more or less continuous across the column and are micritic. Dark laminae are very thin (10 – 25 µm), wispy, continuous, seldom discontinuous. Boundaries between light and dark laminae are poorly defined. Sometime dark laminae show composite nature and consist of several fine laminae only a few micrometer thick, represented by very fine light laminae. (Plate 4.6, e and 4.7, a-c).

Texture- The texture consist of extremely fine grained, mainly amorphous silica/quartz (Plate 4.7, a-c).

Interspace filling- Interspaces between the columns are narrow and irregular, sometime occupied by the fine laminations which continue into the adjacent columns. At some places, lensoid bulges are present filled with fine micritic material which in most cases altered by the silicification (Plate 4.2, a).

Secondary alteration- Observations on the laminae of the thin sections of the stromatolites and interspaces suggest that the distinctive visibility of prominent columnar growth is after the late diagenetic origin. Silicification may also be late diagenetic in origin. Extremely fine interspaces with alteration of micritic also denotes the late diagenetic changes. No stylolites are observed.

Comparisons- Alteration between columnar and flat laminated stromatolite, presence of thin wispy laminae distinguish *Aberia kumarii* from other forms of microstromatolites. It is similar to *Omachtenia* Nuzhnov and *Wilunella glengarrica* Grey in being columnar layered and in having naked columns but it differs because the columns in *Aberia* radiate and widen upwords, and some of the columns are more stratified and flat laminated. The laminar profile shows less variation and range from stratiform to columnar, than in *Wilunella* and *Omachtenia.*

Remarks – These stromatolites are very distinct within the assemblage of the Bhander Group which are columnar branched and large sized in comparison to *Aberia kumarii.* Though these cannot be recognized easily in the field but are abound in the cherty part of the Bhander Limestone and can be studied easily in the polished and thin section.

Distribution and age- The Bhander Limestone, the Bhander Group, the Vindhyan Supergroup, Neoproterozoic, age ~ 700 Ma.

4.2 Mat Structure

Mat formation acts as a positive catalyst for optimizing microbe survival in wide range of environments (Noffke et al., 2003b; Schieber et al., 2007). Mats are although rarely preserved but they enhance cohesiveness of sediments and resistance of erosion (Schieber et al., 2007; Sarkar et al., 2008). Ecological response of the mat forming microorganisms to various factors results into characteristic sedimentary structures formally termed as ‘Microbially Induced Sedimentary Structures’- MISS (Noffke et al., 2001a). MISS have been considered as an important biosignatures for ancient microbial communities and mats (Gerdes et al., 2000; Noffke, 2007; Noffke et al., 2001a, 2003a). MISS have drawn extensive attention in recent years (Gerdes et al., 2000; Noffke, 2007; Noffke et al., 2001a, b, 2003a, b, 2006a, b; Schieber, 1986; Schieber et al., 2007; Sarkar et al., 2005, 2008) and are a growing field of investigation.

MISS Studies - A Precis

The microbial mats show more complex sedimentary structures that may be the result of more than one depositional factors, different workers attempted to decode its mystery. Gerdes et al. (2000) studied sedimentary structures from two modern siliciclastic peritidal environments in different climatic zone. The sedimentary structures formed by interplay between microbial and physical process and their characteristics are based on the following parameters:

- Intrinsic biofactors;
- Biological response to physical disturbances of the growth base;
- Trapping/binding effects;
- Secondary physical deformation of biogenic build-ups;
- Post-burial processes;
- Bioturbation and grazing.

Pettijohn and Potter (1964) divided the sedimentary structures into four major groups:

1. Bedding external form
2. Bedding internal organization and structures
3. Bedding plane features
4. Bedding disturbed and deformed

Microbially induced sedimentary structures (MISS) classified as a fifth category in Pettijohn and Potter's (1964) classification of primary sedimentary structures by Noffke et al. (2001a, b). They had divided MISS into two class: A) structures atop bedding planes and B) internal bedding structures formed due to five main biological activities (1) leveling, (2) biostabilization, (3) imprinting, (4) microbial grain separation, and (5) baffling, trapping, and binding.

Class A: On bedding planes

1. leveled depositional surface, wrinkle structures;
2. microbial mat chips;
3. erosional remnants and pockets;
4. multidirectional/palimpsest ripples;
5. mat curls, shrinkage cracks.

Class B: Within beds

1. sponge pore fabrics, gas domes, fenestrae structures;
2. sinoidal laminae;
3. oriented grains, benthic ooids;
4. biolaminites, mat-layer-bound grain sizes.

Schieber (2004) analyzed the influence of mat on the depositional fabrics of sedimentary rocks across a broad spectrum of physical, biological and chemical processes, and provided the information regarding the features that preserved in sandstone as well as in shales. Microbial mat features in sandstone and shale incorporate:

- Mat growth
- Metabolic effect
- Physical mat destruction
- Mat decay and diagenetic effect

Later, Schieber et al. (2007) provided a detailed and more formal description which is based on the previously proposed classification scheme of Schieber (2004). They divided microbial growth features broadly into two groups. A third category *viz.* 'complex structures' has been incorporated to include complementing the range of features.

1. Microbial mat features preserved in sandstone
   a. Features formed under conditions of mat growth
   b. Features formed due to metabolic effect of growing mat
   c. Features formed by physical mat destruction
   d. Features resulting from mat decay and diagenesis

2. Microbial mat features preserved in shales

a. Features formed as a result of mat growth

b. Features formed as a consequence of mat metabolism

c. Features produced by physical mat destruction

d. Features formed under conditions of mat decay and diagenesis

3. Complex Structures

These classifications scheme of mat related structures are genetic and based on the formation of these structures. Sarkar et al. (2008) provided a classification scheme which was based on the genesis of mat induced sedimentary structure in relation to their palaeoenvironment.

(1) ML (Mat-layer) structures

(i) mid (mat-layer discoidal) structures

(ii) mlc (mat-layer crumpled) structures

(iii) mlw (mat-layer wrinkled) structures

(2) MI (mat-induced) structures

(i) misc (mat-induced surface cracks)

(ii) micr (mat-induced cracks along ripple crests)

(iii) misr (mat-induced surface ridges)

(iv) mib (mat-induced bulges)

(3) MP (mat-protected) structures

(i) mpsf (mat-protected) setulf

(ii) mppr (mat-protected patchy ripples)

(iii) mpr (mat-protected ripples)

Microbial Mat Structure in Bhander Group

The *Arumberia banksi* Glaessner and Walter, *Rameshia rampurensis* Kumar and Pandey and *Arumberia vindhyanesis* Kumar and Pandey are recorded from the Shikaoda Sandstone exposed in the upper reaches of Kudra hillock at Maihar towards the northeastern end with GPS value as N 24° 12.463’, E 80° 38.784’ (Fig. 4.2). These are reported from the fine to medium-grained sandstones from the sole and top of the beds. *Arumberia* and *Rameshia* are considered as organsedimentary structures formed by the interaction of microbial community with the siliciclastic

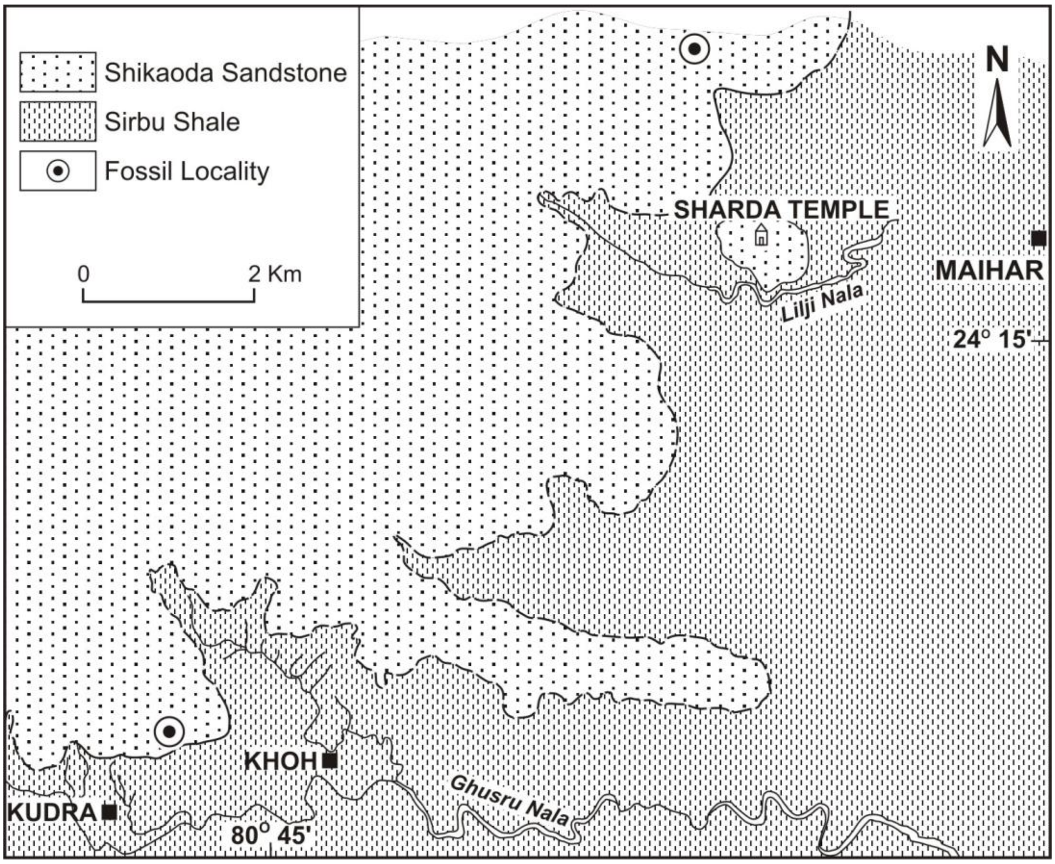


Fig. 4.2- Geological map of the *Arumberia* bearing localities Maihar, Satna District, M.P. (modified after Kumar and Pandey, 2008)

sediments. They flourished in shallow marine tidal setting. On the basis of the presence of *Arumberia*, an Ediacaran age is suggested for the Shikaoda Sandstone (Kumar and Pandey 2008). These are well preserved on both the top and sole of the sandstones.The growth of live mats on recent sediments also seen in Emaliya quarry, Maihar area, Satna District, Madhya Pradesh (Plate 4.9, g & h).

Group: *Arumberia* Glaessner & Walter, 1975

Type Form: *Arumberia banksi* Glaessner & Walter, 1975

***Arumberia banksi* Glaessner & Walter, 1975**

(Plate 4.8 a-h, Plate 4.9 e & f)

Locality: Rampur Hillock and Kudra village, Maihar, Satna District, M.P.

Stratigraphic Horizon: Shikaoda Sandstone, Bhander Group.

Lithology: Brown coloured fine-grained sandstone.

Description: It consists of array of straight to gently curved parallel to subparallel ridges about 1 mm wide and separated by flat to gently concave furrows of 1-3 mm in width. Generally the ridges are parallel, but they also bifurcate and rarely trifurcate. The ridges are parallel to current direction or more or less right angle to the crest of the ripple, but exceptions are also noted. Relief from ridge top to furrow bottom is less than 1 mm. Ridge ranges in length from 1.5 cm to 14.0 cm. Ridges are developed on plane surface as well as on the stoss side of the ripple. In some specimens bedding surface is almost flat and the ridges form a carpet. At places the grooves are criss crossed and anastomosing or scaly. They are also curved, subparallel and radiate from a pointed and twisted nose.

Remark: Originally *Arumberia banksi* was considered a cup shaped animal (Glaessner and Walter, 1975), but now it is considered a microbially bound sedimentary structure (McIlroy and Walter, 1997). The ridges of present form show smaller length of ridges compared to *Arumberia banksi,* described from the Arumbera Sandstone southwest of Alice Springs by Glaessner and Walter (1975).

Age and Distribution: Ediacaran (transitional zone between Latest Neoproterozoic and Cambrian) and worldwide occurrence.

Arumberia vindhyanensis Kumar and Pandey 2008

(Plate 4.9 a-d)

Locality: Kudra village, Maihar, Satna district, M.P.

Stratigraphic Horizon: Shikaoda Sandstone, Bhander Group.

Lithology: Dark brown coloured fine-grained sandstone.

Description: Leaf like structure is oriented broadly in palaeocurrent direction and formed by grooves. Slightly tapering at the base, where it is rounded. Sometimes they overlap with one another. With the increase in length, their relief tends to decrease. Grooves about 1 mm wide and range in length from 1-13 cm with mean value as 3 cm. Width between two grooves varies from 2- 9 mm. Relief from ridge top to furrow bottom is less than 1 mm.

Remark: Possibly a specific community of algae was responsible for the formation of this form. The form is densely populated and attached only with the crest of ripple or mounds of irregular surface. It differs from *A. banksi* in having a leaf like morphology in which a groove divides the leaf like structure in equal parts.

Age and Disrtibution: Ediacaran (transitional zone between Latest Neoproterozoic and Cambrian) and worldwide occurrence.

4.3 Carbonaceous Remains

Carbonaceous remains have been recorded only in the greenish grey shales of the Bhander Limestone and yellow and grey shales of the Sirbu Shale. The fossil-bearing horizons are marked in Fig. 4.3.

The fossils are seen on bedding surfaces of the shales. Occasionally, the fossils are also seen within the bed. The fossils in general are marked by the carbonaceous matter, but they are also preserved as impressions. Abundant well preserved, diversified macrofossils preserved as carbonaceous compressions and impressions have been recorded from the Bhander Group of the Vindhyan Basin, Central India. These fossils are found at Dulni, Aber and Rampur localities of Satna District of Madhya Pradesh and belong to the Bhander Limestone and Sirbu

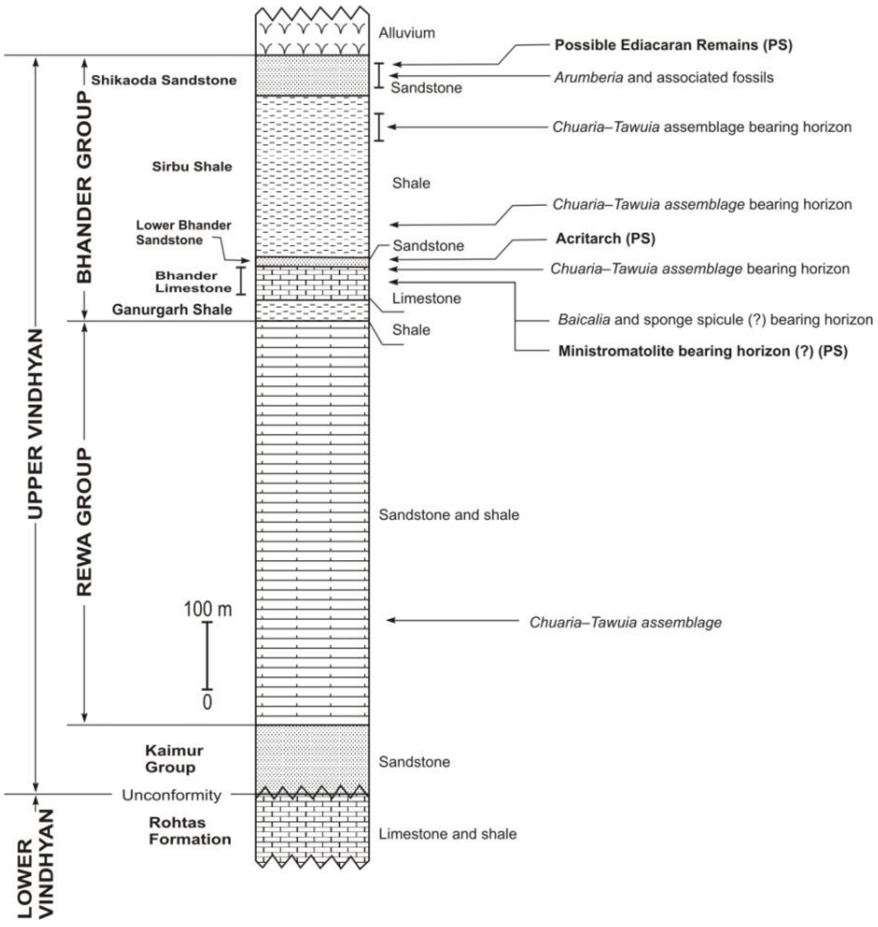


Fig. 4.3- Litostratigraphic units of the Upper Vindhyan (Kumar and Pandey, 2008) PS= Present Study.

Shale Formation of the Bhander Group. The impressions and carbonaceous compression of the Bhander Limestone and Sirbu Shale belong to *Chuaria circularis* and *Tawuia dalensis.*

Proterozoic carbonaceous macrofossils occur in the sediments as micrometer thick films, millimeter to centimeter-sized bodies with or without distinct ornamentation as well as irregular angulated fragments and ribbon like films on bedding planes (Hofmann, 1985a, 1992a). Several assemblages of carbonaceous macrofossils have been recorded from different parts of the world. Due to a lack of distinctive characteristics other than gross shape, the biological affinities and inter-relationship of these remains are to a large extent still uncertain.

The systematics of the present assemblage is given in the following section.

SYSTEMATIC DESCRIPTIONS

Group: ACRITARCHA Evitt, 1963

Genus: *Chuaria* Walcott 1899 emend. Vidal & Ford 1985.

Diagnosis: as for the type species.

Type Species: *Chuaria circularis* Walcott 1899. (Plate 4.10 a-o, Plate 4.11 a-i, k, Plate 4.13 a,b and k-s, Plate 4.14 b-n)

Synonymy:

1899 *Chuaria circularis* Walcott, pp. 234-235, pl. 27, figs. 12, 13.

1935 *Fermoria minima* Chapman, p. 115-116, pl. 1, figs. 1, 3.

1935 *Fermoria granulose* Chapman, p. 116, pl. 1, figs. 2, 4; pl. 2, fig.5.

1935 *Fermoria capsella* Chapman, p. 117, pl. 2, figs. 3-4.

1935 *Protobolella jonesi* Chapman, p. 117-118, pl. 1, figs. 5-6; pl. 2, fig. 1.

1936 *Fermoria minima* Chapman, Sahni, p. 465-466, pl. 43, figs 1-4.

1970 *Kildinella magna* Timofeev, pl. 1, figs. A, B.

1973 *Chuaria circularis* Walcott, Ford & Breed, p. 539, pl. 61, figs. 1-7; pl. 62, figs. 1-6; pl. 63, figs. 1, 2, 4.

1977 *Chuaria circularis* Walcott; Ford & Breed, p. 171-173. pl. 1, figs. 1-6.

1977 *Chuaria circularis* Walcott, Hofmann, p. 3, fig 2.

1977 *Fermoria* disc-like remains type 1-6, Maithy & Shukla, p. 183, pl. 5, figs. 35-40.

1977 *Tasmanites vindhyanensis* Maithy & Shukla, p. 182-183, pl. 4, figs. 32-33.

1979 *Nucellosphaeridium* spp. Hofmann (in Hofmann & Aitken), p. 156, figs. 12A-C.

1979 *Chuaria circularis* Walcott, Hofmann (in Hofmann & Aitken), p. 157, figs. 13 K-M.

1979 *Morania? antique* Fenton & Fenton, Hofmann (in Hofmann & Aitken), p. 160, figs. 13 J, 17 A (partim).

1982 *Chuaria circularis* Walcott, Duan Chenghua, p. 59-61, figs. 3A-J, 5A-J, O, P.

1982 *Chuaria circularis* Walcott, Knoll, pl. 2, fig. 1; pl. 4, figs. 7, 13.

1983 *Chuaria circularis* Walcott, Mathur, p. 363-364, fig. 1A.

1983 *Chuaria fermorei* Mathur, p. 363-364, fig. 1B.

1983 *Chuaria circularis* Walcott, Suresh & Sundara Raju, p. 81-82, fig. 2, 1-5.

1985b *Chuaria circularis* Walcott, Hofmann, p. 342, pl. 35, figs. 2, 4; pl. 37, fig 1 (partim); pl. 38, fig. 4 (partim); pl. 39, fig. 2 (partim); text-fig. 4 (partim).

1985 *Chuaria circularis* Walcott emend. Vidal & Ford, p. 355-359, pl. 3, fig. A

1987 *Chuaria circularis* Walcott, Sun, p. 115, pl. 1, figs. 1-8; pl. 4, figs. 1-2.

1993 *Chuaria circularis* Vidal & Ford (1985), Vidal, Moczydłowska & Rudavskaya, p. 390-393, figs. 3A-D; fig. 4B, D.

1994 *Leiosphaeridia wimanii* Brotzen (1941), Butterfield, n. comb.; Butterfield, Knoll & Swett, p. 42-43, fig. 13D-F.

1994 *Chuaria circularis* Walcott 1899, Butterfield, Knoll & Swett, p. 32-34, figs. 8G-H, 13G-I.

1994 *Chuaria circularis* Walcott, Yin & Sun, p. 99-100, pl. 4 (b).

1994 *Chuaria circularis* Walcott, Steiner, p. 95-101, pl. 1, figs.4-17; pl. 3, figs. 1-7; pl. 4, figs. 1-4; pl. 8, fig. 2; pl. 9, figs. 1-2; pl. 11, figs. 8-10; pl. 12, figs. 4-11.

1994 *Chuaria circularis* Walcott, Vidal & Ford (1985), Hofmann & Rainbird, 1994, p. 724-725, pl. 1, figs. 1-6.

1996 *Chuaria circularis* Walcott, Maithy & Babu, p. 2, pl. 1, figs. 1, 10, 11.

1997 *Chuaria pendjariensis*, Amard, p. 478, fig. 3a, b.

1997 *Chuaria circularis* Walcott, Rai, Shukla & Gautam, p. 784-786, figs. 3 c-f, h-j, l-n, p-r, t-v, x-z.

1998 *Chuaria circularis* Walcott, Haines, p. 5, figs. 5A-D.

2001 *Chuaria circularis* Walcott emend. Vidal & Ford (1985), Kumar, p. 193, figs. 6a-f, h-j; figs. 14f-h.

2001 *Chuaria vindhyanensis*, Kumar, p. 196, figs. 14f-h.

2001 *Suketea rampuraensis*, Kumar, p. 203, figs. 9g, h.

2003 *Chuaria circularis* Walcott emend. Vidal & Ford (1985), Kumar & Srivastava, p. 146-147, pl. I, figs. a-g.

2003 *Chuaria circularis* Walcott emend. Vidal & Ford (1985), Kumar & Srivastava, p. 147-148, pl. I, figs. h, i, j & k.

2003 Form A, Kumar & Srivastava, p. 150, pl. II, fig. a.

2003 *Bhanderia maiharensis*, Kumar & Srivastava, p. 149, pl. II, fig. i; pl. III, figs. b-c.

2004 *Chuaria circularis* Walcott, Srivastava, p. 644-646, figs. 2a-c, e, o-q.

2006 *Chuaria circularis* Walcott, Srivastava & Bali, p. 875, fig. 3 (1-4, 8, 10, 11, 13, 15-17).

2009 Chuaria Circularis Walcott, Sharma et al., p. 129-130, figs. 6a-o, 7n-u.

Sl. No.	Locality	Stratigraphy	Lithology
1	Aber	Bhander Limestone	Greyish green shale
2	Dulni	Bhander Limestone	Grayish green shale
3	Rampur	Sirbu Shale	Yellowish grey shale

Locality: 1. Aber, Satna District, Madhya Pradesh
2. Dulni, Satna District, Madhya Pradesh
3. Rampur, Satna District, Madhya Pradesh

Stratigraphic Formation : a. Bhander Limestone (Locality 1 and 2)
b. Sirbu Shale (Locality 3)

Lithology: Greyish green

Type Material: Algonkian, Chuar terrane, Kwagunt valley, within the Grand Canyon of the Colorado, in Arizona. No type specimen was designated by Walcott (1899). Lectotype was designated by Ford & Breed (1973), catalogued under U.S. National Museum USNM 33800.

Description: Circular to oval shape compressions on bedding surfaces. Compressions are made up of carbonaceous matter, in absence it is marked by a distinct impression. Wrinkles and three dimensional preservation are common. Diameter ranges from 0.3 mm to 5.7 mm with median 1.4 and mode 1.5 mm (N = 365) in Aber (Fig. 4.4, Plate 4.10 and 4.11) while in Dulni (Fig. 4.5, Plate 4.13) the range of diameter varies from 0.5 mm to 3 mm with median 1.4 mm and mode 1.5 mm (N = 375) and in Rampur (Fig 4.6 Plate 4.14) the specimen dimension range varies from 0.4 mm to 2.8 mm (N = 37) except from this range three specimen are much bigger in size, these big specimens are in the range of 7 mm to 9 mm. In Dulni, few specimens appear in prominent spherical form, concentric layers provided the view of cabbage (Plate- 4.13). Specimens occur isolated and rarely in contact with one another. Overlapping is also very rare. In vertical sections appear as dark lines.

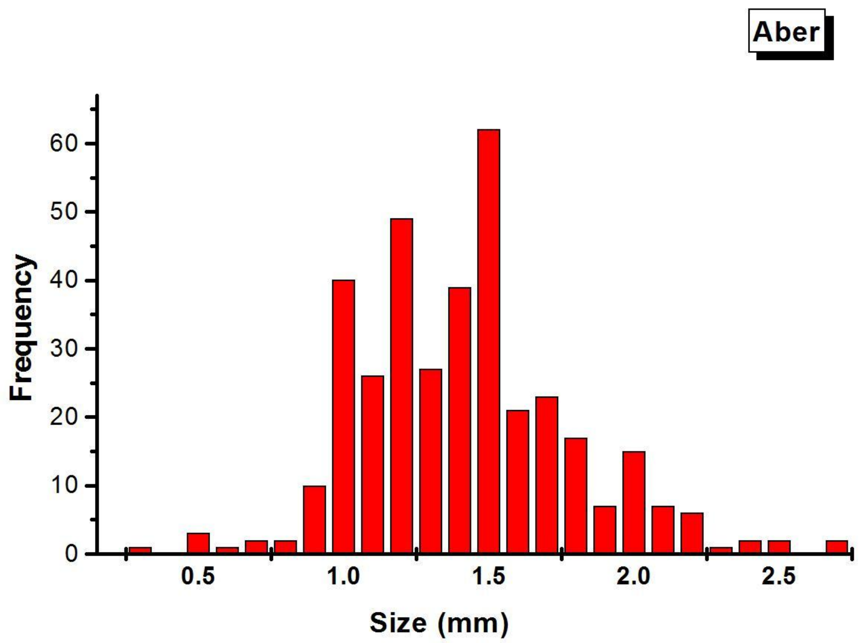


Fig. 4.4- Histogram of carbonaceous remains of Aber.

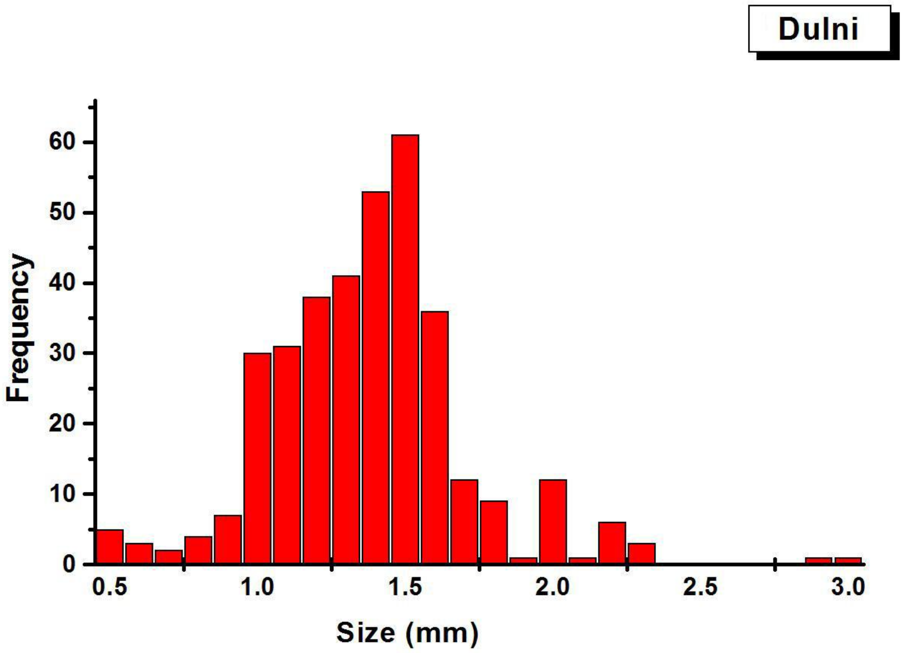


Fig. 4.5- Histogram of carbonaceous remains of Dulni

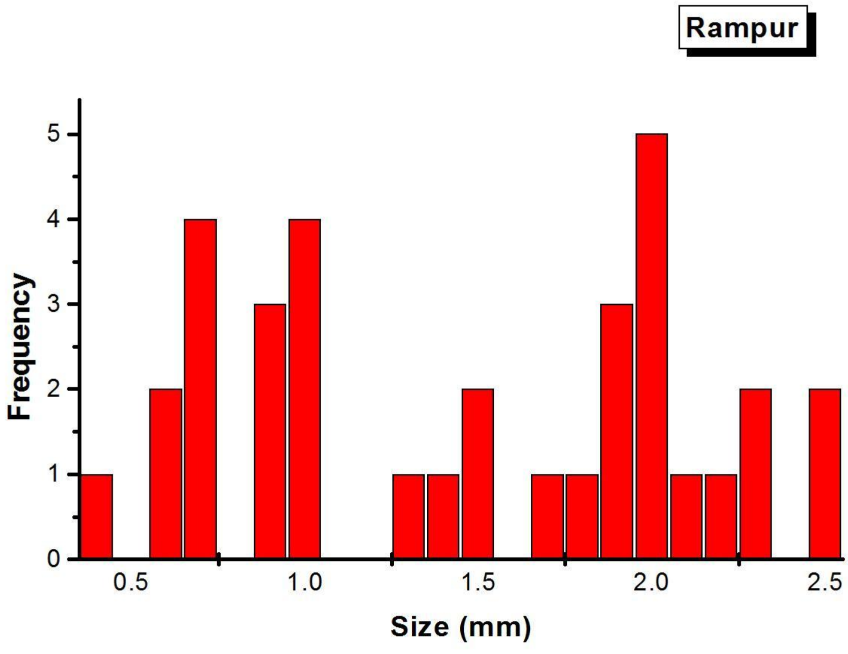


Fig. 4.6- Histogram of carbonaceous remains of Rampur

Discussion: In the Bhander Group megafossils are recovered only from the shale, that indicates preservation of megafossils controlled by sedimentary facies. Specimens *of Chuaria circularis* recorded from the Bhander Group are morphologically similar to the type material and many of the other specimens from China, Canada and other localities in the world. *Chuaria circularis* is the most abundant form and is well represented in both the Bhander Limestone as well as in the Sirbu Shale. In the Bhander Limestone it occurs in association with *Tawuia* sp. The specimens are in the forms of impressions and compressions of carbonized material and are deposited and compacted between the bedding planes or parallel to the laminations of rock. We can easily see the counter part of organic matter on each surface of broken shale along the bedding plane. Some of the specimens show wrinkles and folds on their surfaces. Wrinkles are concentric, random, radial or irregular. The surface of carbonized specimen is bright and smooth (Fig. 4.7).

No lamellar organization on the wall of the specimens of the *Chuaria circularis* recovered from the Chuar Group, were noticed by the Jux (1977) but trabecular and rarely canal like structure present. Canal like structures were also recorded by Amard (1992) but no trabeculae were observed by reinvestigation of the wall structure of *C. circularis* under the optical and scanning electron microscopes. However, Arouri *et al.* (2000) and Talyzina (2000) describe the single-layered, electron dense and homogeneous wall of *Chuaria circularis*.

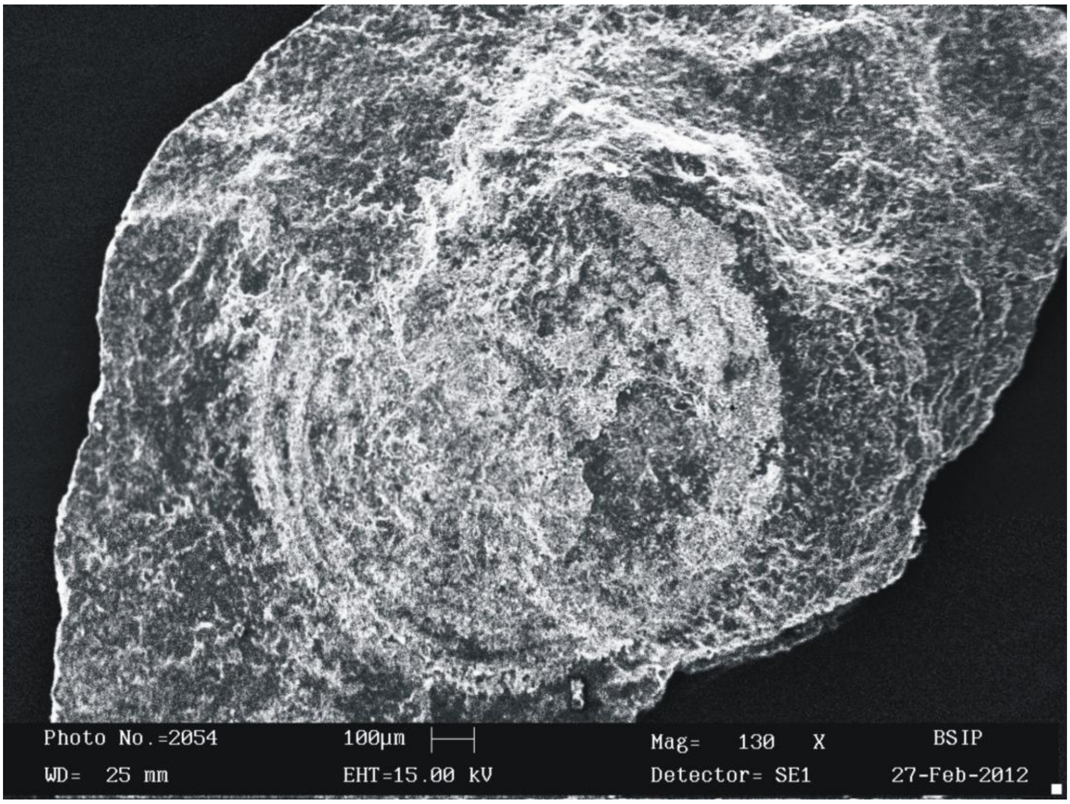


Fig. 4.7 SEM image of *Chuaria circularis.*Concentric rings of the carbonaceous material clearly visible.

Other workers suggested the presence of holes in wall and nature of wall structure

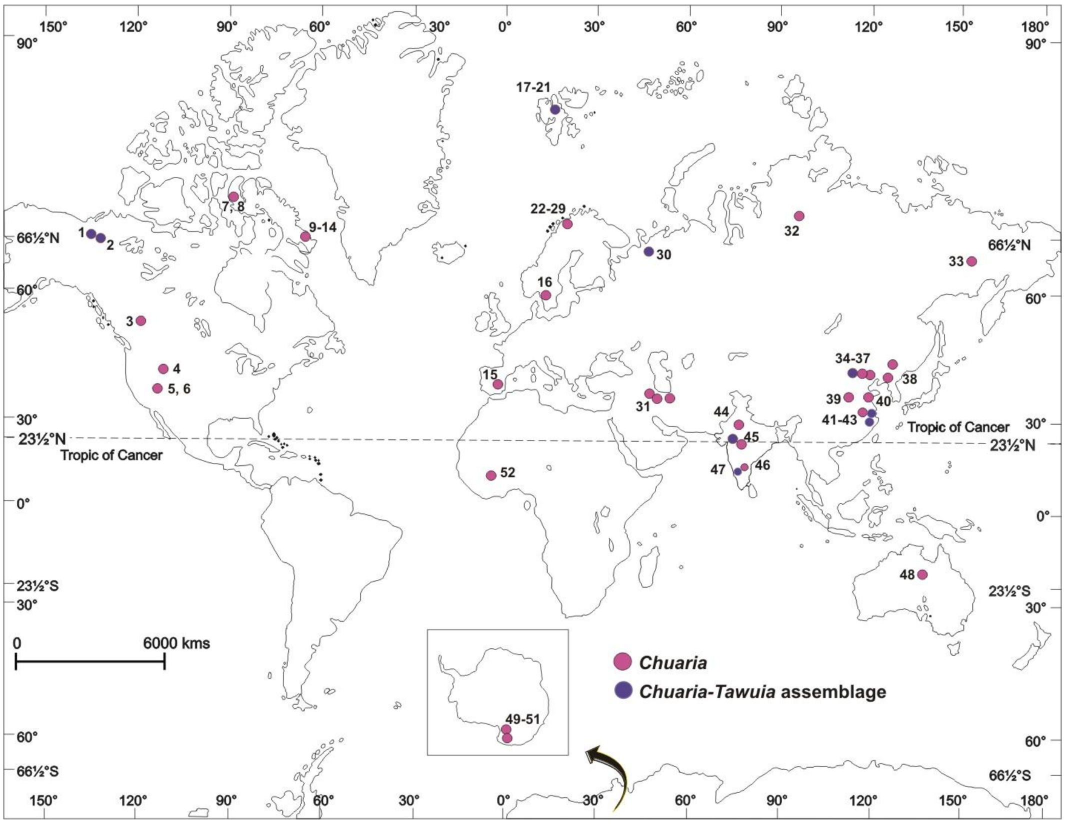


Fig. 4.8- Global distribution of *Chuaria* & *Tawuia.* Known occurrence of *Chuaria* & *Chuaria-Tawuia* assemblage modified after, Hofmann, 1985a), Shukla, 2011.

of *Chuaria circularis* (Talyzina, 2000; Javaux et al., 2004; Dutta et al., 2006; Sharma et al., 2010).

Sharma et al. (2010) suggest that the trabecular ultrastructure should be treated as additional taxonomical attributes for *C. circularis.* They also observed the presence of distinct radial canals penetrating the wall. They reported single layered cell wall structure but no radial pore were found by them. These ultrastructure studies helped in understanding the wall structure of *Chuaria* but little was understood in terms of 3D morphology and affinity of these carbonaceous discs.

Age and distribution: Mesoproterozoic to Neoproterozoic, commonly occurring between 1000 Ma to 700 Ma, global distribution (Fig. 4.8).

Type Genus: *Tawuia* Hofmann, 1979

Diagnosis: As for type species.

Type species: *Tawuia dalensis* Hofmann, 1979 (Plate 4.12: a-h; 4.13 c-j; 4.14 a)

Synonymy:

1979 *Tawuia dalensis* Hofmann, Hofmann & Aitken, p. 158, figs. 13A-I.

1982 *Tawuia dalensis* Hofmann, Duan, p. 63, figs. 5K-N.

1982 *Tawuia sinensis* Duan, p. 63, figs. 3 K-Q, fig. 5p (partim).

1982 *Tawuia dalensis* Hofmann, Knoll, pl. 3, figs. 12-14.

1983 *Tawuia suketensis* Mathur, p. 364, figs. 1D.

1983 *Tawuia rampuraensis* Mathur, p. 364, fig 1E.

1985b *Tawuia dalensis* Hofmann, pl. 35, figs. 1-3; pl. 36, figs. 1-5, 7-11; pl. 37, figs. 1, 2, 4-7; pl. 38, figs. 1-3; text-figs. 3, 4 (partim).

1987 *Tawuia dalensis* Hofmann, Sun, p. 123, pl. 4.

1993 *Tawuia dalensis* Hofmann, Vidal, Moczydłowska & Rudavskaya, p. 393, figs. 4A-C.

1994 *Tawuia dalensis* Hofmann, Butterfield, Knoll & Swett, p. 25-26, figs. 8B-E, 23H.

1994 *Tawuia dalensis* Hofmann, Steiner, p. 107-111, pl. 2, figs. 1-14; pl. 5, figs. 1-2; pl. 11, fig. 7; pl. 12, figs. 5, 6.

1996 *Tawuia dalensis* Hofmann, Maithy & Babu, p. 2, pl. 1, figs. 1, 3.

1997 *Tawuia dalensis* Hofmann (in Hofmann & Aitken), Rai, Shukla & Gautam, p. 786, figs. 3 g, k, o, s, w.

2001 *Tawuia dalensis* Hofmann, Kumar, p. 198, figs. 9a, c, d; figs. 14j, k.

2001 *Tilsoia khoripensis* Hofmann, Kumar, p. 201, figs. 9b.

2003 *Tawuia dalensis* Hofmann, Kumar & Srivastava, p. 148, pl. II, figs. d & g.

2004 *Tawuia dalensis* Hofmann, Srivastava, p. 644-646, fig. 2d.

2006 *Tawuia dalensis* Hofmann, Srivastava & Bali, p. 875, fig. 3 (5, 12, 23).

Type Material: Specimen collected by Aitken from the basinal sequence of Little Dal Group. Mackenzie Mountains, northwestern Canada, Holotype number GSC 57893.

Description: Elongated rod- and ribbon- like impressions of milimetric width, short to slender. Parallel-sided but slight pinching is also noted. Ends subrounded to flat. Tapering at both the ends also noted. Very thin film of carbonaceous matter preserved. outlines smooth and even; sides parallel to slightly tapering, ends approximately semicircular (adopted from Hofmann in Hofmann & Aitken, 1979).

Dimension of long axis varies from 0.7 mm to 4.4 mm in Bhander Limestone and 0.6 mm to 6.3 mm in Sirbu Shale. Maximum recorded length is 9 mm from Sirbu Shale (2 samples traced).

Discussion: Specimens of *Tawuia dalensis* recorded from the Bhander Limestone and Sirbu Shale of Bhander Group are smooth and no overlapping and twisting observed, similar to the type material and many of the other known specimens from other localities. Specimens of *Tawuia dalensis* occur with the *Chuaria circularis* in the same bedding plane. *Tawuia* and *Chuaria* commonly occur together in the same assemblage. Because of the distinct morphology they can be easily distinguished but there are some specimens which are intermediate between the two. This combination has been noticed at several places in the world (Hofmann, 1981, 1992a. b: Kumar, 2001). *Tawuia* specimens are reported from Canada, China, Svalbard and India. Circular and oval to short elliptical specimen described as *Chuaria* and elliptical to more elongated forms described as *Tawuia* by Sun (1987). Hofmann (in Hofmann & Aitken, 1979) considered *Tawuia* either algal (phaeophyta?) or metazoan affinity. Fu (1986) said the *Tawuia* have parabolic shape on the bases of morphometric study. Hofmann (1992a) did not find any preserved filament in *Tawuia* as mentioned by Sun (1987).

Kumar (2001) has suggested genetic link between *Chuaria* and *Tawuia* and has suggested that both are parts of a multicellular plant *Radhakrishnania*, a thallophytic plant of Chlophycean / Xanthophycean affinity, but more correct hypothesis was given by Sharma et al. (2009) in their Hybrid model of *Chuaria – Tawuia* complex. They have shown the mechanism of formation of varied geometrical shapes as thick rimmed *Chuaria*, concentric *Chuaria*, *Chuaria* with folds, elliptical *Chuaria* formed due to distortion in circular structure, a complete *Chuaria* on compression formed notch and *Chuaria* with notch and folds formed by ruptured and twisted *Tawuia*. They concluded in their 'Thin walled pressure vessel theory' as applicable to cylindrical and spherical structures indicate that *Tawuia* and *Chuaria* are closely inter-related.

Age and distribution: Neoproterozoic, commonly occurring between 900 Ma to 700 Ma in Canada, China, Svalbard, India.

4.4 Acritarchs

Acritarchs are small organic fossils, present from approximately 3,200 million years ago to the present. Their diversity reflects major ecological events such as the appearance of predation and the Cambrian explosion. Acritarchs include the remains of a wide range of quite different kinds of organisms - ranging from the egg cases of small metazoans to resting cysts of many different kinds of chlorop- hyta (green algae). It is likely that some acritarch species represent the resting stages (cysts) of algae that were ancestral to the dinoflagellates. Acritarchs may represent the remains of any of the three domains of life, the archaea, the bacteria, and the eukaryotes. Archaea and bacteria usually produce fossils of a very small size, although the sheaths of some bacteria can reach the millimetre scale. During SEM analysis no acritarchs clearly seen but few artifact (Plate 4.21 a-c), produced during stub preparation and image of spherule (Plate 4.21 d) of most likely gold palladium has been recorded. Eukaryotes can sometimes be identified by complex traits such as ornamentation or projections, although simple eukaryote acritarchs also exist (Buick, 2010). The acritarchs in this study were mainly extracted by maceration of yellow-grey to dark-grey siltsone.

SYSTEMATIC DESCRIPTION

Group- ACRITARCHA Evitt, 1963

Subgroup- SPHAEROMORPHITE Downie et al., 1963

Genus- LEIOSPHAERIDIA Eisenack 1958 emend. Downie & Sarjeant, 1963

Type species- *Leiosphaeridia jacutica* (Timofeev, 1966) Mikhailova et Yankauskas, (Yankauskas et al., 1989)

(Plate 4.16 f, h & m-o)

Locality: Dudhia Nala, Satna District, Madhya Pradesh.

Stratigraphic Horizon: Lower Bhander Sandstone.

Lithology: Dark grey-black sandstone.

Description- Vesicle spheroidal, solitary, single-walled, diameter range from 70 to 800 µm. Walls thick, chagrinate or coarse grained, about 2 µm thick, with folds; surface texture smooth.

Material examined- A few dozen specimens from Lower Bhander Sandstone.

Occurrence- Widely distributed in Proterozoic rocks.

Type species- *Leiosphaeridia crassa* (Naumova, 1949) Yankauskas et al., 1989.

(Plate 4.15 a-c; 4.19 a-i)

Locality: Rampur Hillock, Satna District, Madhya Pradesh.

Stratigraphic Horizon: Sirbu Shale.

Lithology: Yellowish-grey shale.

Description- Subspheroidal to oblong vesicles, diametric range from 60 µm – 235 µm. Walled thick, coarse grain, with folds. *L. Crassa* occurs variously as isolated individuals, large populations covering entire bedding planes, or very localized associations.

Material Examined- One hundred specimen from Sirbu Shale and Lower Bhander Sandstone

Occurrence- Distributed in Proterozoic rocks.

Type species- *Leiosphaeridia minutissima* (Naumova, 1949) emend. Yankauskas et al., 1989

(Plate 4.18 a-k; 4.20 a-i)

Locality: Rampur Hillock & Karari Nala, Satna District, Madhya Pradesh.

Stratigraphic Horizon: Sirbu Shale & Lower Bhander Sandstone.

Lithology: Yellowish-gray shale & Dark gray – black sandstone.

Description- Spheroidal, solitary, single walled vesicles 44 µm – 115 µm in diameter. Walled translucent, hyaline to fine grained, less than 1 µm thick, with folds; surface smooth.

Material examined- A few dozen specimen from Sirbu Shale and Lower Bhander Sandstone.

Occurrence- Widely distributed in Proterozoic rocks.

Type species- *Leiosphaeridia tenuissima* Eisenack, 1958.

(Plate 4.15 g & h, 4.16 a-e, g and i- l; 4.17 a-l)

Locality: Dudhia Nala, Satna District, Madhya Pradesh.

Stratigraphic Horizon: Lower Bhander Sandstone.

Lithology: Dark grey – black Sandstone.

Description- Subspheroidal to oblong, solitary vesicle, diametric range from 70 µm – 200 µm. *L. tenuissima* are distinguished from *L. jacutica* by relative transparency and flexibility of their walls.

Material Examined - Fifty specimen from Lower Bhander Sandstone.

Occurrence- Distributed in Proterozoic rocks.

Type species – *Ostiana microcystis* Hermann, in Timofeev, Hermann and Mikhailova, 1976.

(Plate 4.15 d-f)

Locality: Dudhia Nala, Satna District, Madhya Pradesh.

Stratigraphic Horizon : Lower Bhander Sandstone.

Lithology: Dark grey – black sandstone.

Genus- *Ostiana* Hermann in Timofeev, Hermann and Mikhailova, 1976.

Description – Spheroidal and ellipsoidal vesicles arranged into irregular planar colonies. Within colonies, vesicles connected to one another on two or more sides and compressed along conjuctions. Vesicle walls translucent to opaque, fine- to medium- grained. Maximum vesicle dimension of spheroids 10 – 20 µm; colony size 33 µm × 60 µm.

Material examined- three colonies from Lower Bhander Sandstone.

Occurrence – Latest Mesoproterozoic and Neoproterozoic (Tonian - Ediacaran).

4.5 Ediacaran Element

Ediacaran fossils assemblage comprise of variety of metaphytes and metazoans. Most of the recorded animal groups in the Ediacaran assemblage either belong to Coelenterata and Coelomata. Representative of Colenterata are grouped under Phylum Cnidaria and Petalonamae and Coelomata are grouped under Phylum Annelida, Arthropoda, Tribrachidia and Echinodermata. ‘Sessile’ Colonial Cnidaria are placed under two families Pteridiniidae and Charniidae. Pflug (1970) placed the Coelentrates under a new Phylum Petalonamae. The fossil members of the Petalonamae are having frond or leaf – shaped main body with median axis with transverse lateral furrows and outer flange and an attachment disc. The members of the Family Pteridiniidae belonging to Phylum Petalonamae *viz. Pteridinium* and *Phyllozoon* are rare elements in the Ediacara. It is believed that the morphology and biology (growth and functioning) of frondose fossils are not properly understood (Glaessner, 1984). There are characters common to Charniidae and Pteridiniidae (Glaessner, 1984). In Pteridiniidae, there is a complex structure on either side of the median axis but without stalk or attachment discs, where as the members of the Charniidae show foliate structure with a median rachis, a stalk and an attachment disc. The lateral structures are divided into ridges. The members of Charniidae show close resemblance to representative of the living order Pennatulacea (Class Anthozoa, Subclass Octocorallia) to which they were assigned (Glaessner and Daily 1959, p. 394). In the Maihar locality, the frondose structures are documented for the first time from the Shikaoda Sandstone of the Bhander Group. The Ediacara fossils occure in a cluster of frondose organisms in stratigraphically the youngest horizon of the massive Shikaoda Sandstone. Stratigraphically as well as geochronologically it is the most suitable unit to contain Ediacaran type fossils. Previously some putative animal fossils were reported from the Bhander Group. Verma and Prasad (1963) and Das (1987) have reported tracefossils from the Bhander Limestone. Maithy and Gupta (1983) reported Archaeocyatha- a colonial algae form the Bhander Limestone. De (2003, 2006) reported medusa from the Sirbu Shale. Later, trace fossils and Archaeocyatha were considered non-fossils (Sharma et al., 1992) and medusae like structure proved to be non convincing (Kumar and Sharma, 2010, 2012). In absence of any convincing metaphytic/metazoan entity the report of metazoan fossil, *Charniodiscus*, belonging to family Charniidae of Phylum Petalonamae assumes great significance.

Method – Study of the Maihar *Charniodiscus* specimen is restricted to the outcrop surface that allows collection of morphometric-data for diagnosis and descriptive analysis and comparison with other specimens of the world. Outcrops bearing frondose organisms are present in the compound of a temple. No attempts were made to make collections from the outcrop to avoid hurting the feelings of the people of the temple trust. At present no latex moulds or casts were prepared. The Maihar specimens were measured in detail on the outcrop itself and the 12 best preserved specimens were photographed.

SYSTEMATIC PALAENTOLOGY

Coelenterata

Phylum – Petalonamae Pflug, 1970

Family – Charniidae Glaessner, 1979

Genus – Charniodiscus Ford, 1958

Type Species – Charniodiscus concentricus Ford, 1958

CHARNIODISCUS Sp.

Plate 4.22 a-e; 4.23 a & b; 4.24 a & b.

"Leaf shaped organism" Misra, 1969 (partim) pls. 3d, 4d and 5b.

"*Charniodiscus concentricus"* Jenkin 1992, p. 138-139, fig. 4c.

"Erect elevators not yet formally described" Seilacher, 1992, fig. 1 (partim), 2 (partim), 3.

"Pennatuloid organism with stalk and holdfast" Conway Morris, 1989, p. 16, fig. 2.4e.

"*Chaniodiscus* sp." Narbonne et al., 2001, p. 26, pl. 1h (partim).

"*Charnia*/*Charniodiscus*" Peterson et al., 2003, p.129, fig. 1a.

"*Charniodiscus procerum*" LaFlamme et al. 2004, fig. 3.1 (partim), 3.2-3.4.

Diagnosis- *Charniodiscus* with less than 15 primary branches. Stem prominent, well-defined representing greatest portions of the length. Frond lanceolate bent on the one side of stem.

Description- The genus *Charniodiscus* is represented by the frond shaped structure which is either lanceolate to ovate or linear with or without stem and basal disc surrouded by outer rim, sometime exhibiting fine concentric rings and/or radial markings. Number of primary branches attached to stem. Basal attachment disc circular, 10 – 93 mm (mean 35 mm) in diameter, ornamentation absent, consisting of smooth outer region no concentric rings and central boss to which stem attached. Frond length - disc diameter ratio high (mean 8.30). Stem 19-126 mm (mean 75 mm) long and joins high relief central boss to foliate main body. Stem cylindrical and forms broad attachment region at the base. Low frond length-stem length ratio not discernable. Lanceolate frond complex and ornamented. Composed of two identical leaf shaped foliate structure, stem continues into frond, primary branches parallel to subparallel. In most of the observed specimens one half of the frond in overturned on the other. Frond form an integral sheet like structure.

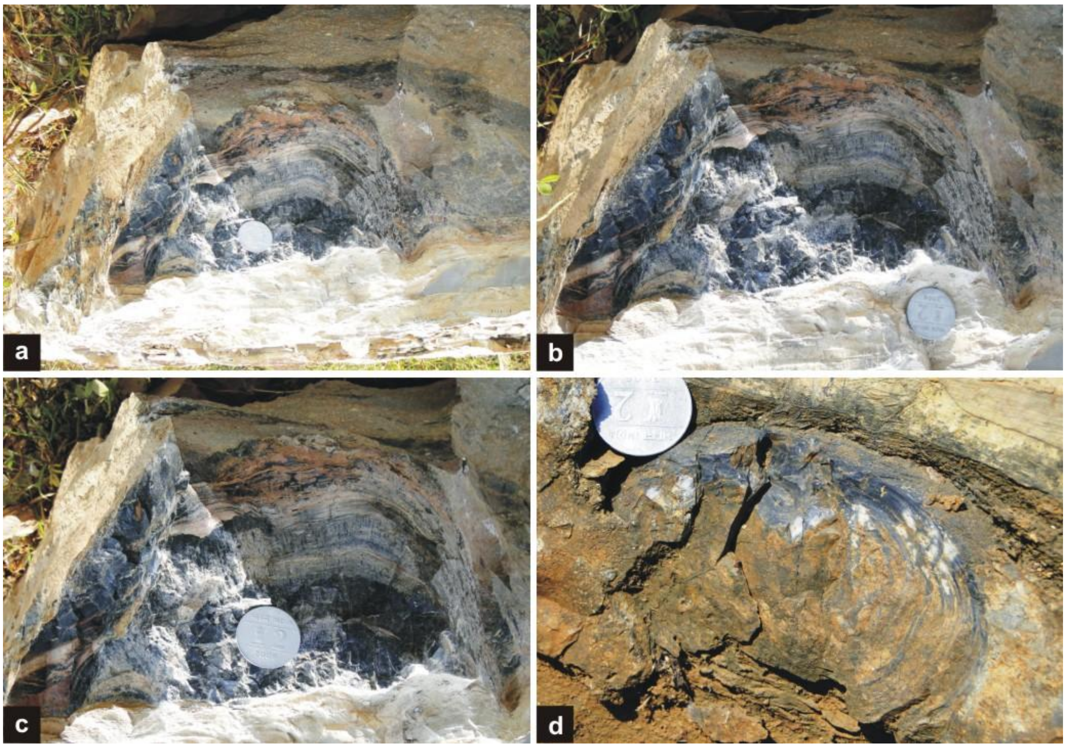
Occurrence– A closely comparable form *C. procerus* occurs in the upper part of the Mistaken Point Formation and overlying Trepassey Formation, Newfoundland, Canada (LaFlamme et al., 2004). The age of the Mistaken Point biota vary from 575-565 Ma (Benus, 1988; Bowring et al., 2003). These are considered as the oldest Ediacaran fossil known (Martin et al., 2000; Narbonne and Gehling, 2003; LaFlamme et al., 2004). Present record of *Charniodiscus* sp. is from the uppermost stratigraphic unit of the Shikaoda Sandstone, Maihar, Satna district, M. P. India.

Discussion– *Charniodiscus* is a common fossil found in terminal Neoproterozoic sediment and Ediacaran biota (575-542 Ma). Although most of the workers accepted the morphological similarity between *Charniodiscus* and modern pennatulaceans suggesting common ecology as stalked, benthic, colonial organisms but proposed varied affinities including prokaryotic colonies (Steiner and Reitner, 2001), sedantry ancestors of ctenophores (Dzik, 2002), fruitating bodies of marine fungi (Petersen et al., 2003) or as representatives of the Vendobionta, an extinct kingdom (Seilacher, 1992). *Charniodiscus* has been recorded from England, South Australia, White Sea of Russia, the Wernecke Mountains of the northwestern Canada, from the Mistaken Point Formation in Newfoundland and India (Mathur and Shanker, 1989, Shanker, 1992, Boynton and Ford, 1995; Glaessner and Daily, 1959; Fedonkin, 1985; Narbonne and Hofmann, 1987; Narbonne et al., 2001 Shanker et al.). Inspite of wide occurrence, recovery of complete specimens is rare and only two complete specimens are described outside the Newfoundland (Ford, 1962, 1963; Jenkins and Gehling, 1978; Jenkins, 1996); only Eastern Newfoundland locality has revealed thousands of complete frond specimens (Narbonne et al., 2001; Clapham et al., 2003).

At present there are five valid species of *Charniodiscus* known worldwide. These include *C. procerus*, *C. spinosus*, *C. longus*, *C. concentricus*, *C. arboreous*; besides, these two fragmentary specimens *C. oppositus* and *C. planus* are also described (LaFlamme et al., 2004; Sokolov, 1973). Jenkins and Gehling (1978) suggested that morphological structure of the foliate frond in an important feature in establishing the species to which distance ratio was also added. Number of primary branches is the primary criterion for establishing the different species of the *Charniodiscus*. Of late, on the basis of primary branches two categories are recognised (1) less than 15 primary branches and (2) greater than 20 branches.

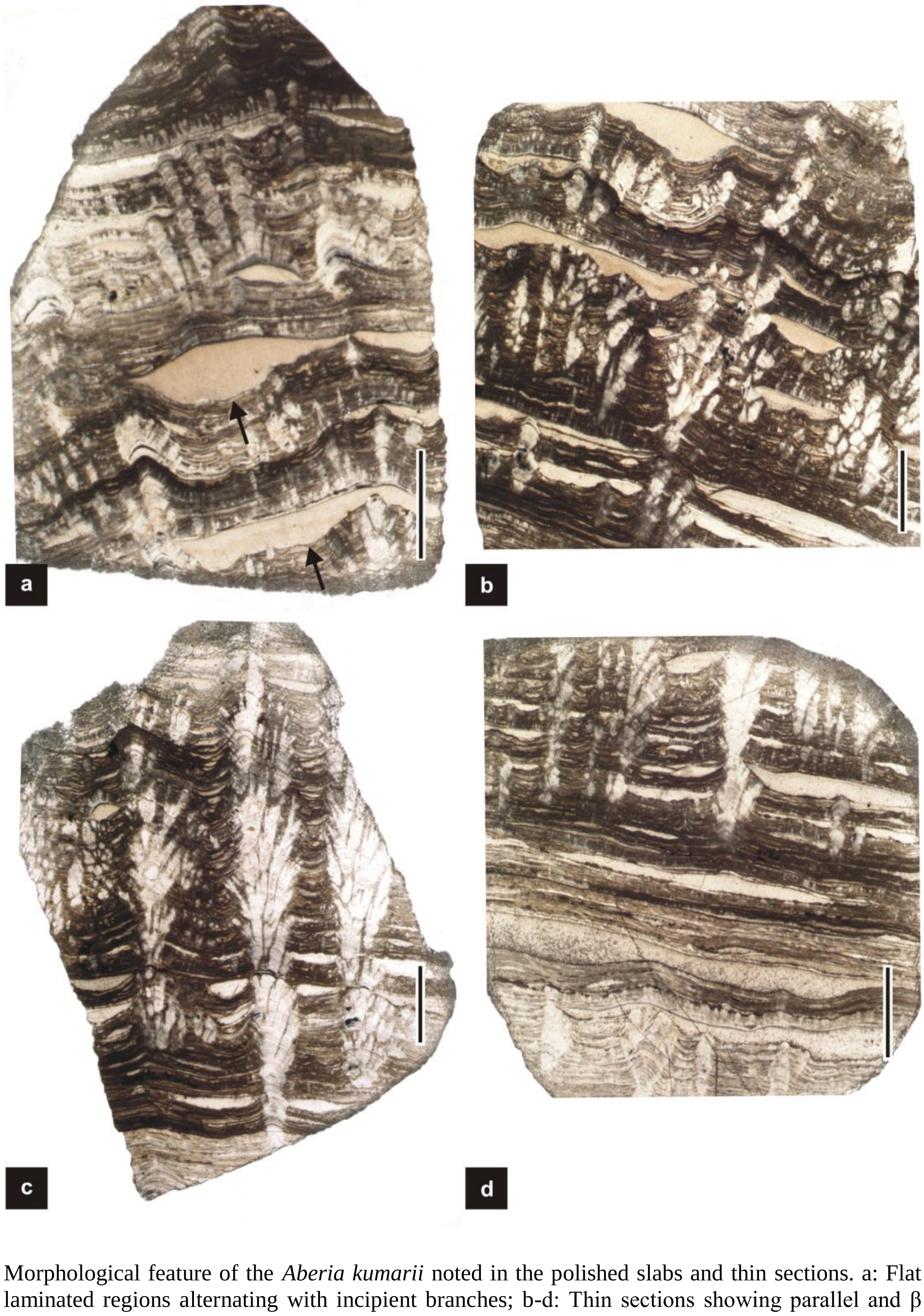
Preservation– The Shikaoda Sandstone fossil remains are preserved as low relief markings on the top of sandstone beds, which are resistant quartzite. The frondose organisms of the Maihar area lie parallel to sub parallel to the bedding plane as is the case of Nama assemblage (Dzik, 1999; McCall, 2006) but in two dimensions. A large number of *Charniodiscus* recorded from at the Mistaken Point are located in the Avalone zone of the southeastern Newfoundland, where the fossiliferous beds are covered by a thin veener of ash which allowed the preservation of high-relief fossil fronds on the upper bedding plane surfaces (Narbonne et al., 2001). Unlike the Australia and White sea of Russia, where the *Charniodiscus* specimens are preserved as positive hyporeliefs on the underside of the sandstone event beds; fossils of the Mistaken Point and the Maihar specimens are preserved as positive epireliefs on the upper surfaces of fine-grained sandstone bedding planes. In the Flinders Ranges of the South Australia, partings encompassing the fossil material are apparently oxidized and preservation is formed by the aligned grains in direct contact with the organisms (Jenkins and Nedin, 2007). The clustering of the specimens at one place and in the same direction suggests their deposition by a storm generated waxing density current, where they simply bent over and got aligned in one direction. The encompassing sediments are well sorted, fine grained sediments without any clay or silt partings.

Plate 4.1



Field occurrence of microstromatolite recorded from the Bhander Limestone at Aber, Satna District, M.P. a-c: Chert nodule encompassing microstromatolites gradual enlargement of the in transverse section; d: Semicircular outline of the chert nodule on the bedding pane. Scale Bar = size of the coin (2.7 cm)

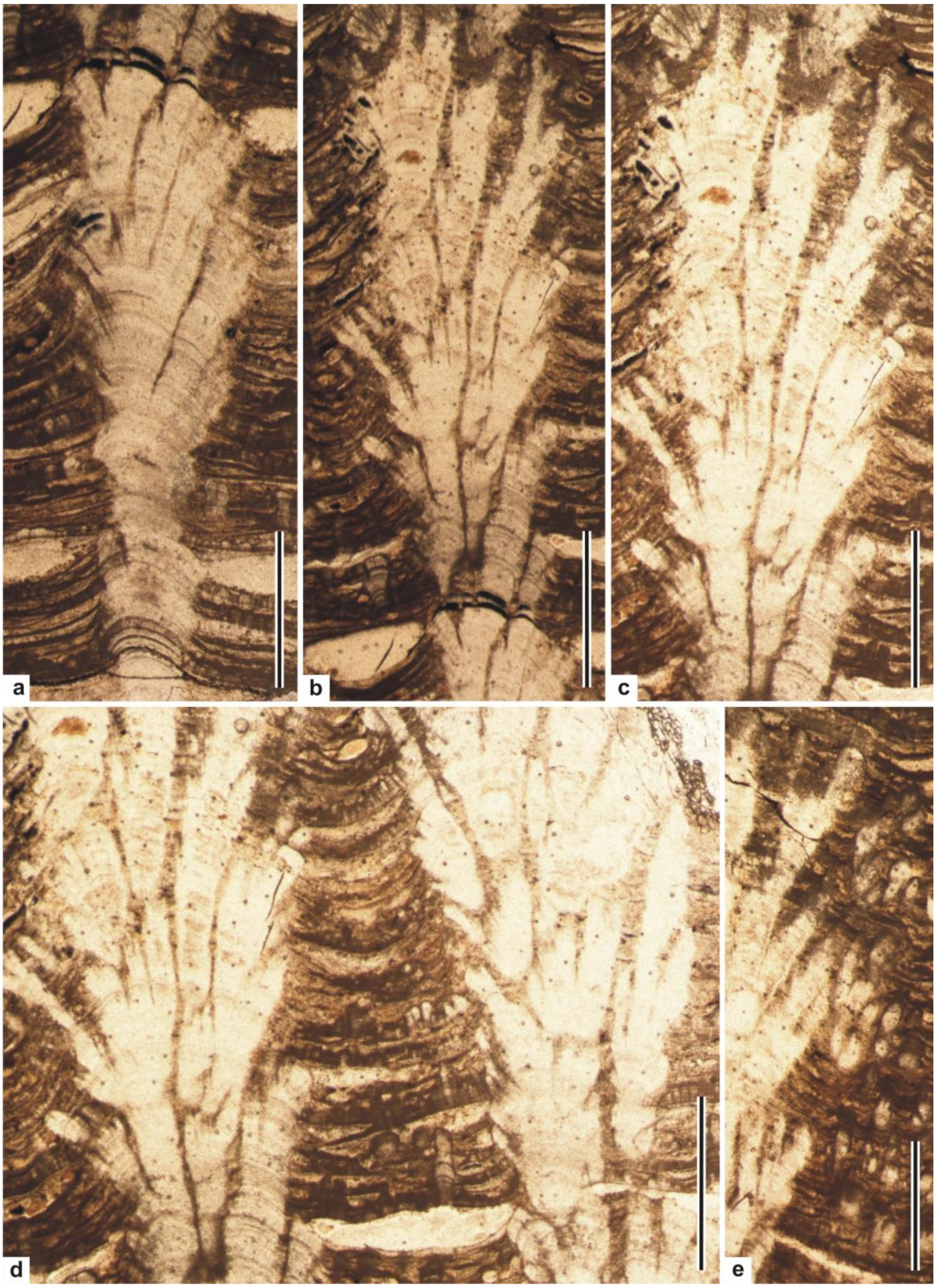
Plate 4.2



Morphological feature of the *Aberia kumarii* noted in the polished slabs and thin sections. a: Flat laminated regions alternating with incipient branches; b-d: Thin sections showing parallel and β style branching. Arrow in ‘a’ denote leusoid bulges b = Holotype; Slide No. a: BH-23E, b: BH-23D, c: BH-23A, d: BH-23C.

Scale bar = 4mm in all the figures.

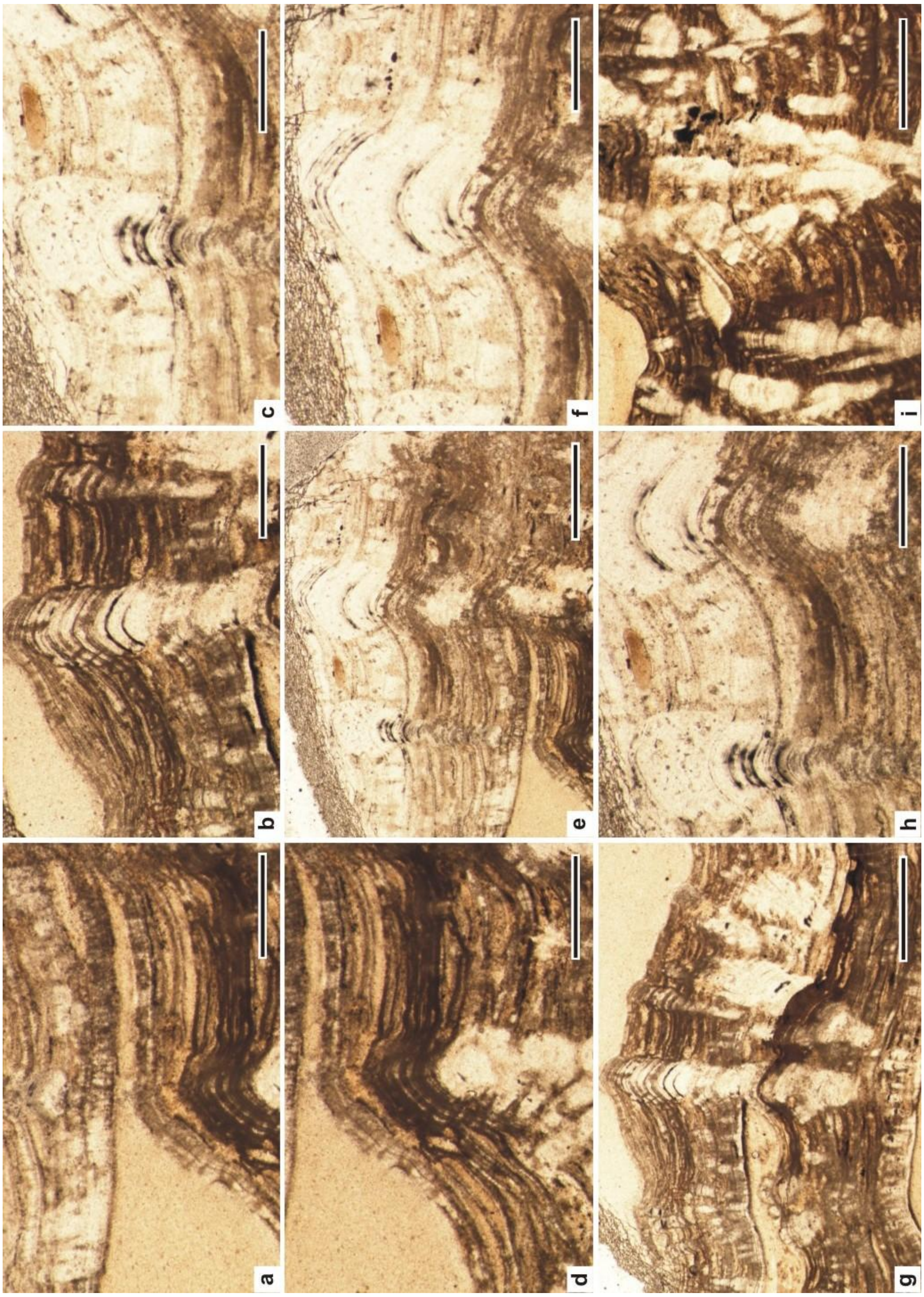
Plate 4.3



Column shape in the *Aberia kumarii* noted in the polished thin section a-e: Column margins are naked and bridging is absent in all the cases. Slide No. BH-23A.

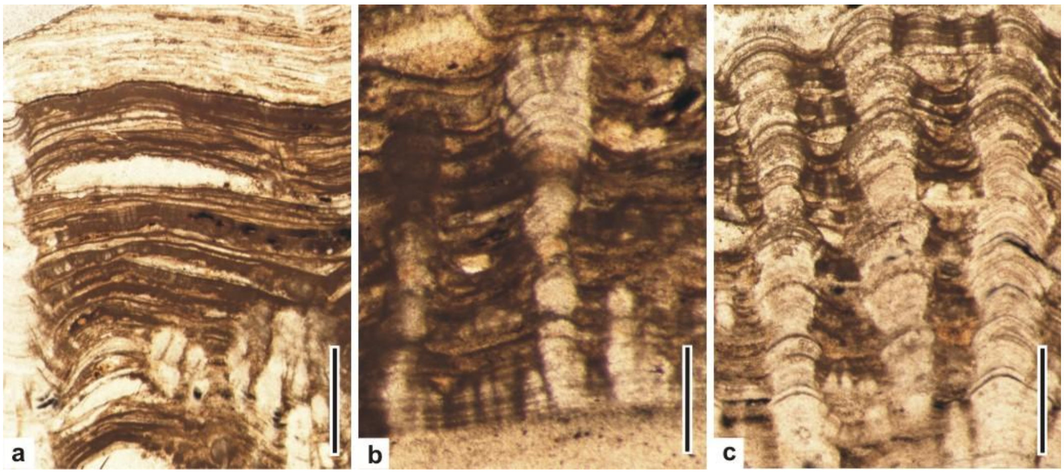
Scale Bar = 1 mm in all the figures.

Plate 4.4



Pseudocoumnar shape noted in the *Aberia kumarii*. a-h: Pseudocolumnar shape and branching pattern. Slide No. BH-23D. Scale Bar = 1 mm in all the figures.

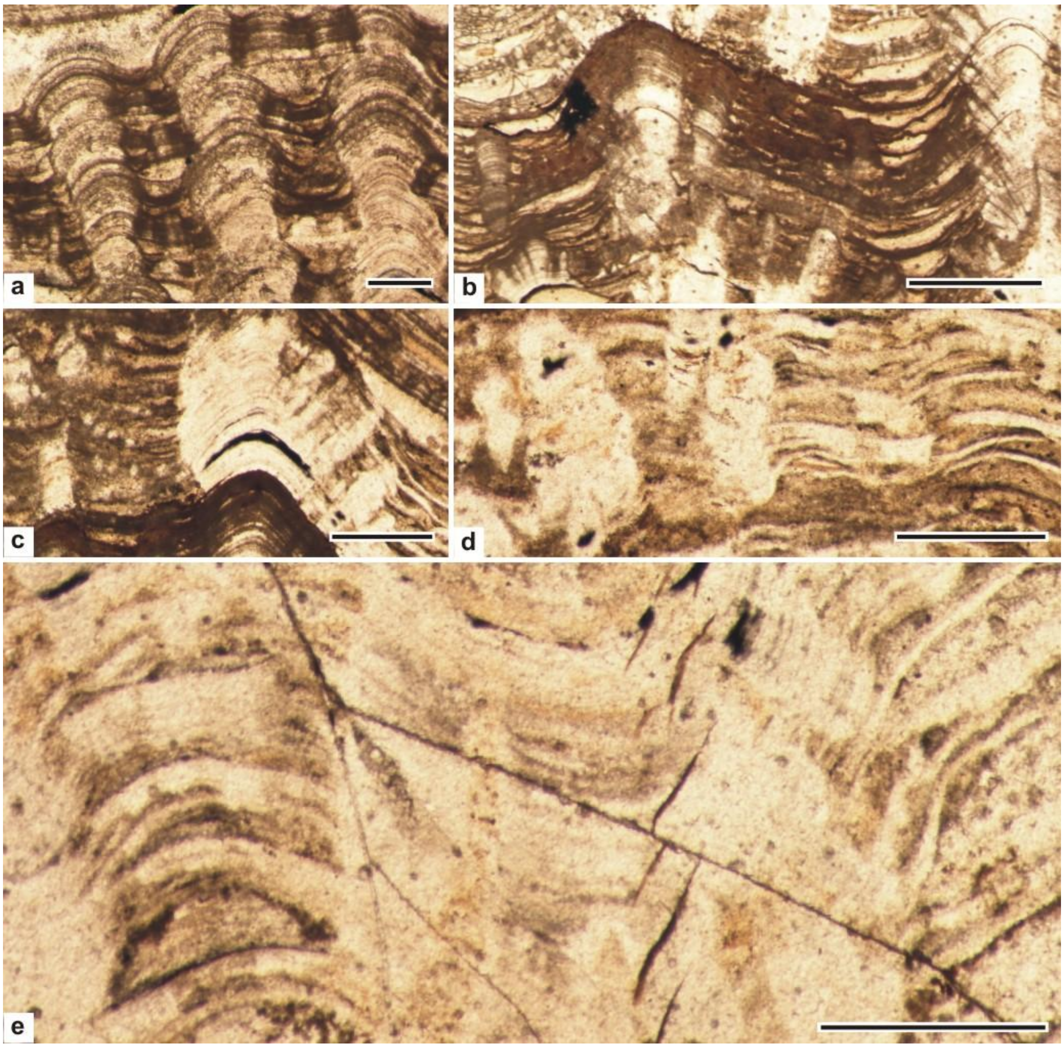
Plate 4.5



Note the lamina shape of the stromatolite *Aberia kumaraii* noted in the poished thin sections. a: flat to gently convex lamina shape; b: flat to gently convex lamina with disruptions due to columnar growth; c: note the flat to gently convex laminae pattern. Slide No. a: BH-23A; b: Bh-23D; c: BH-23E.

Scale Bar = 1 mm in all the figures.

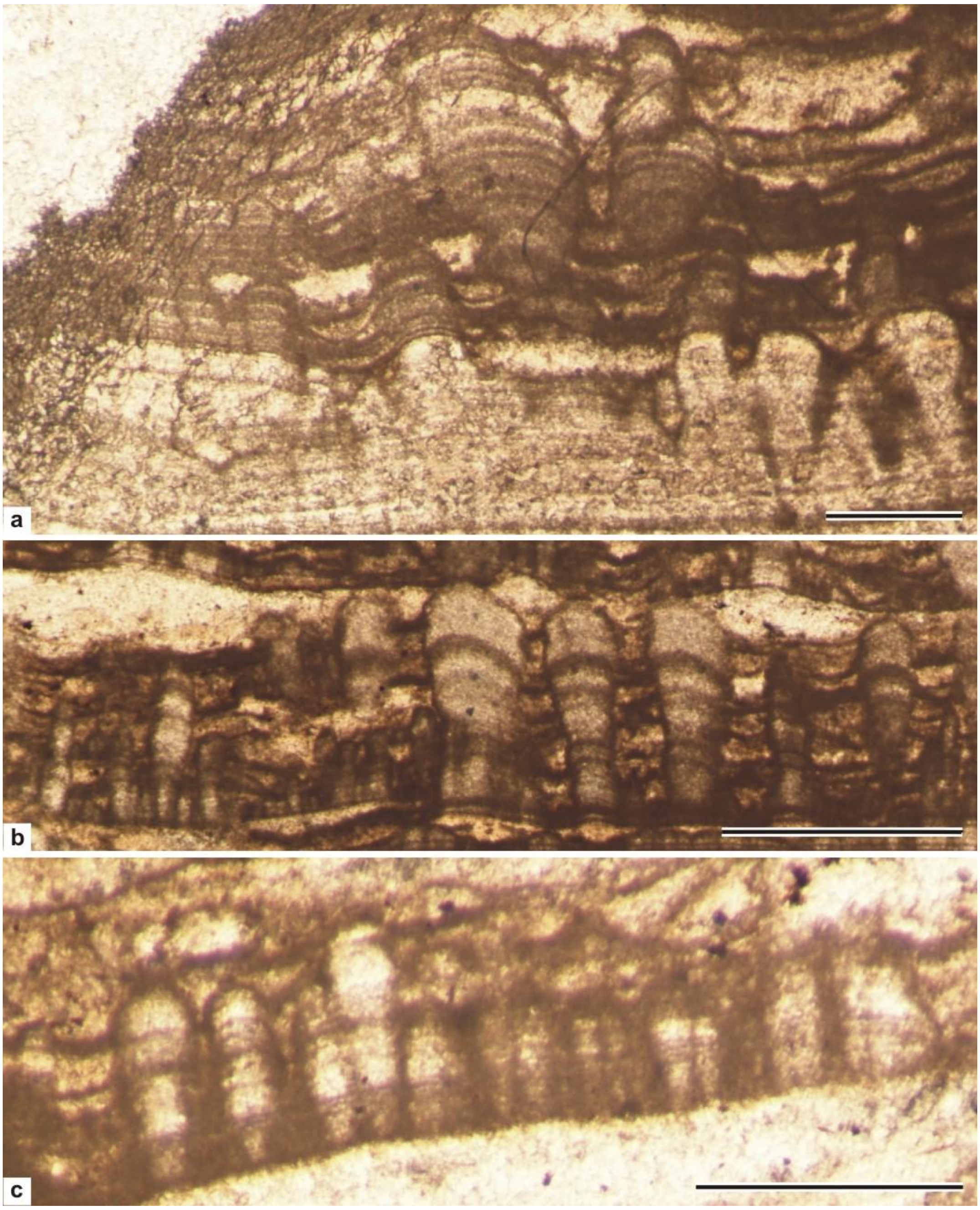
Plate 4.6



Note the lamina shape of the stromatolite *Aberia kumarii* noted in the polished thin section. a: flat to gently convex lamina shape in the columnar zone; b-c: flat to gently convex lamina shape in the pseudocolumnar zone of the stromatolite; d: flat laminated zone; e: microstructure of stromatolite. Slide No. a,c and d: BH-23E; b: BH-23A; e: BH-23C.

Scale Bar = 1 mm in all the figures.

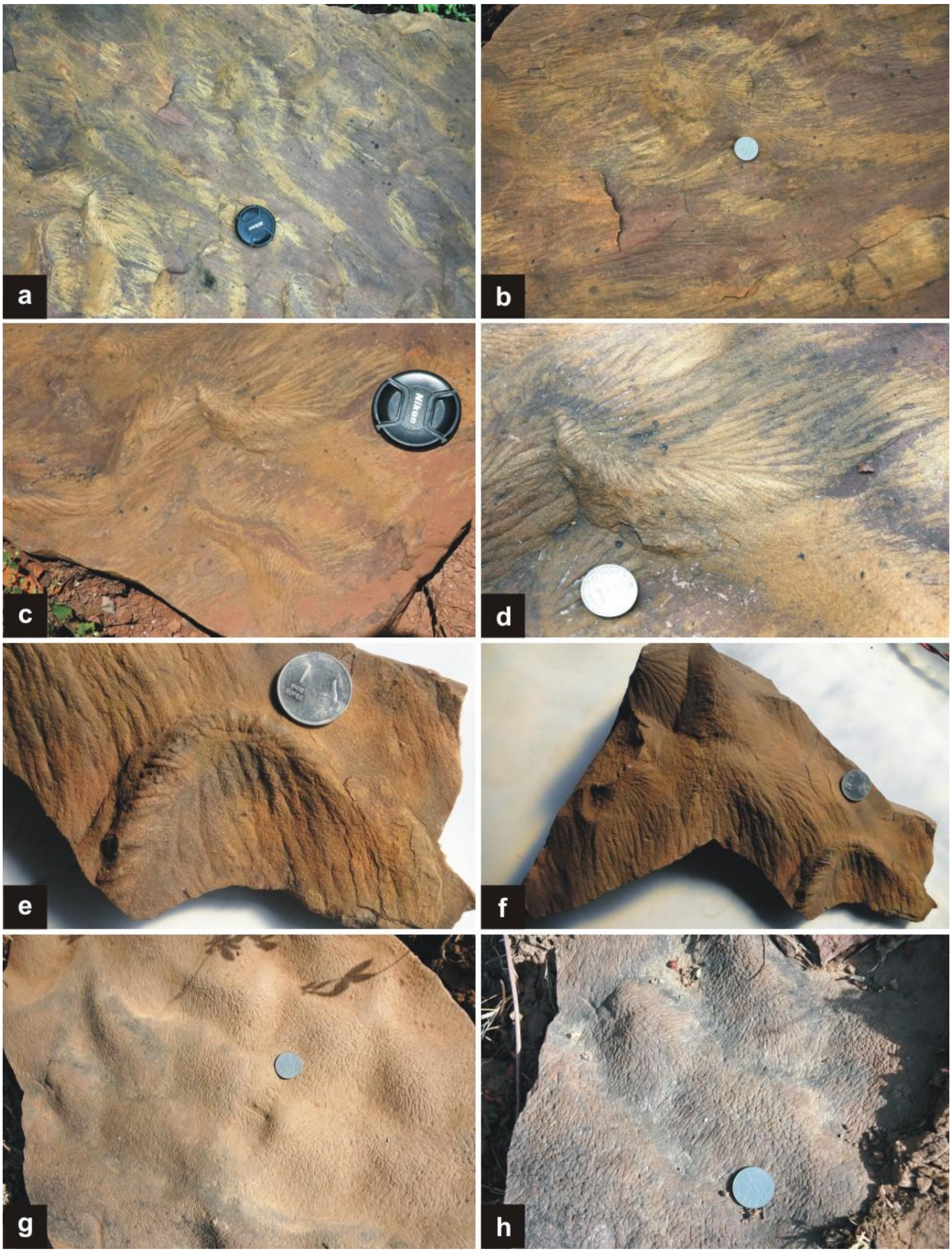
Plate 4.7



Microstructure of microstromatolite *Aberia kumarii.* Note the alternating pairs of light and dark laminae of filmy microstructure. a-c: light laminae are thicker than the dark laminae. Both the laminae maintain the same thickness throughout width. Slide No. BH-23C.

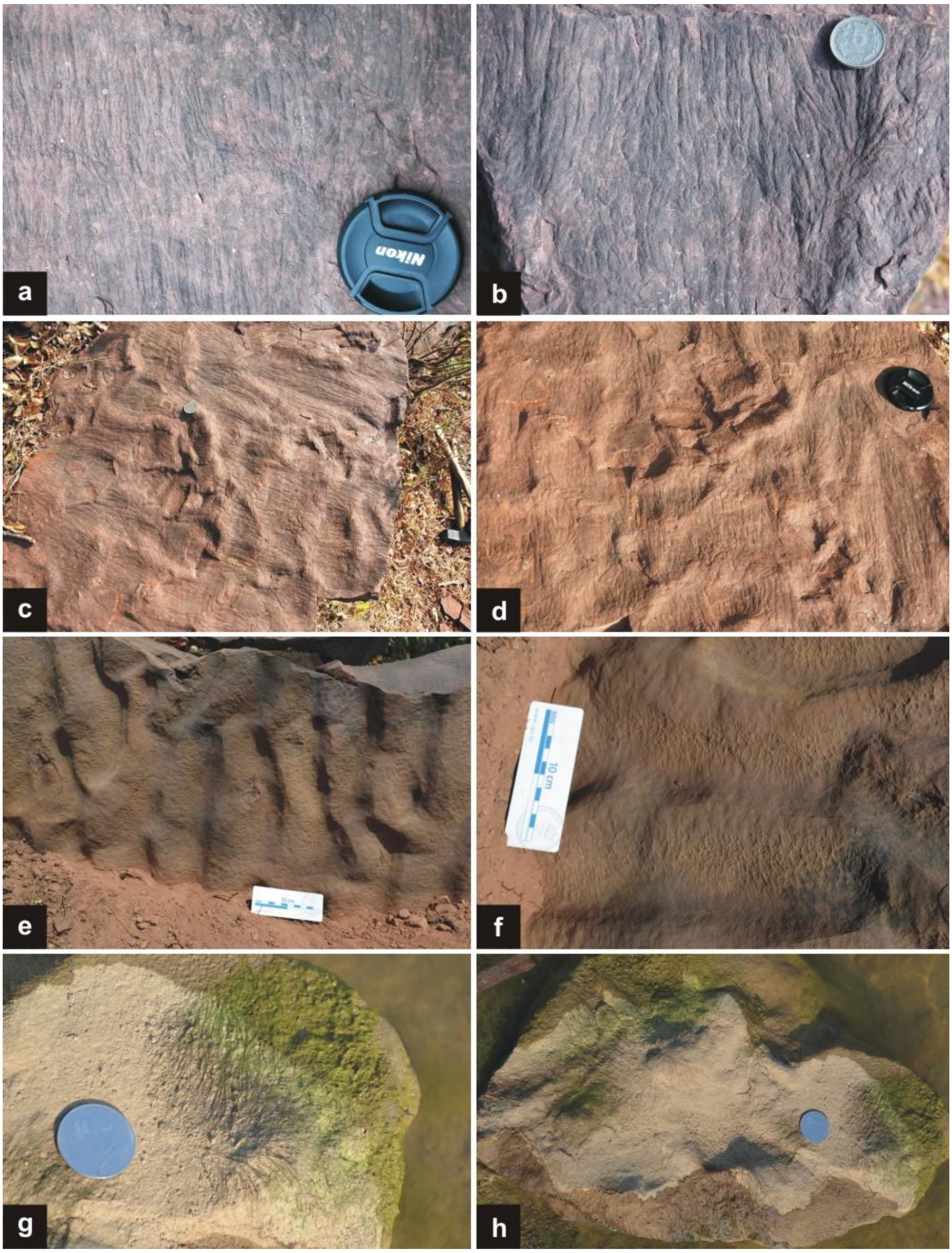
Scale Bar = 1 mm in all the figures.

Plate 4.8



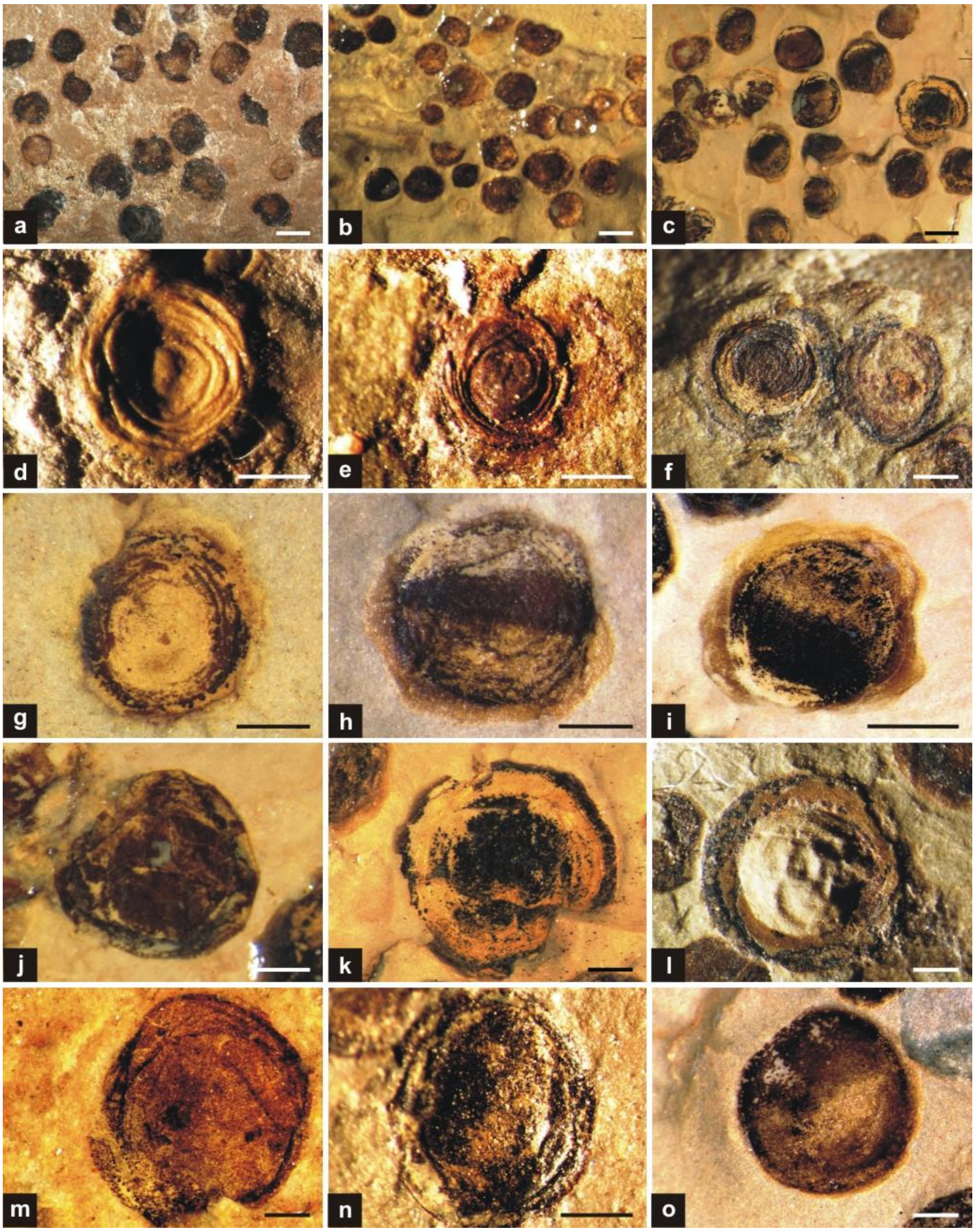
(a) and (b) *Arumberia banksi* on rippled surface of the Sikaoda Sandstone, Kudra village, Maihar area. Diameter of lens cover = 4.5 cm. (c) and (d) Close up view of *Arumberia banksi*, Kudra village, Maihar area. Scale length = 4.5 for ‘c’ and 2.5 cm for‘d’. (e) and (f) *Arumberia banksi* on rippled surface, Kudra village, Maihar area. Diameter of coin = 2.5 cm. (g) and (h) Close up view of *Arumberia banksi* showing criss-crossed nature of grooves, Kudra village, Maihar area. Diameter of coin= 2.2 cm.

Plate 4.9



(a) and (b) *Arumberia vindhyanensis* on the rippled surface, Kudra village, Maihar area. Long slender leaf-like morphology is developed on the stoss side of a ripple. At the crest it is rounded. Mid grooves divide the leaf-like structure. Scale length =4.5 cm for ‘a’ and .2.3 cm for ‘b’. (c) View of *Arumberia vindhyanensis* on irregular surface of the Maihar Sandstone, Kudra village, Maihar area. Scale length = 2.3 cm (d). Close up view of *Arumberia vindhyanensis*, Kudra village, Maihar area. Scale length = 4.5 cm. (e) *Arumberia banksi* on rippled surface of the Sikaoda Sandstone, Kudra villege, Maihar area. Scale length = 10cm. (f) Close up view of *Arumberia banksi*, Kudra villege, Maihar area. Scale length = 10 cm. (g) Close view of the growth of live mat on recent sediments, Emaliya quarry, Scale length = 2.7 cm (h) live mat on recent sediments, Scale length = 2.7 cm.

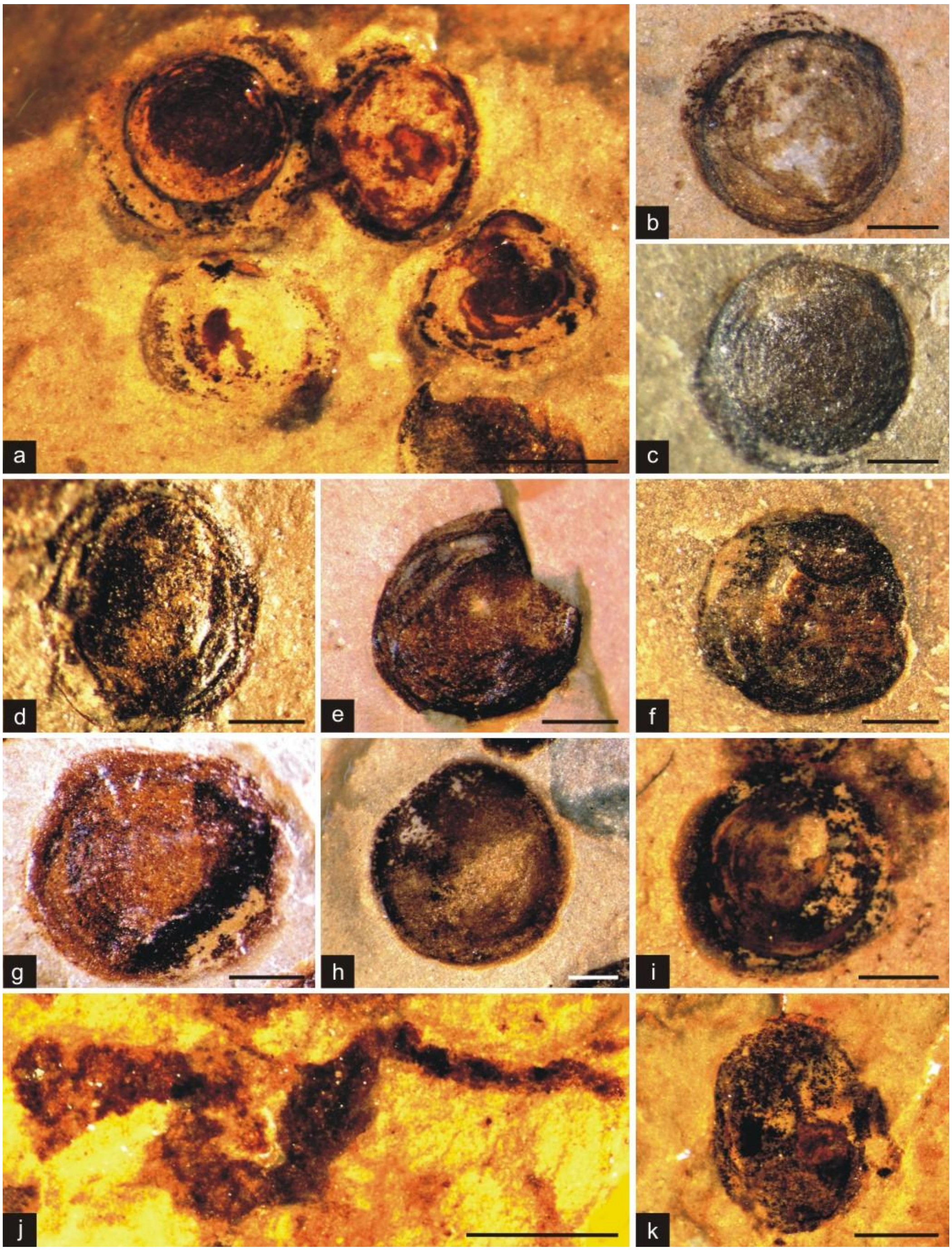
Plate 4.10



Carbonaceous megafossils recovered from the shale unit of Bhander Limestone, Bhander Group, Vindhyan Supergroup exposed in Aber area, Satna District, M.P. Details in the parenthesis denote the specimen number. a-c-General distribution of the *C. circularis* on the bedding plane of the shale with increase in magnification (a = BH-27 B 12; b = BH-27 B 3G, c = BH-72 B 15A); d-f- *C. circularis* with concentric rings with three dimension preservation (d = BH-27 22A", e = BH-27B 20E, f = BH-27B 27C); g, h & k- *C. circularis* with thin wall and concentric rings (g = BH-27B 14C, h = BH-27B 14E' and k = BH-27B 15B); i, j & o-are corbonized specimen of *C. circularis* (i = BH-27B 15E, j = BH 27B 15C & o = BH-27 33B) and m-showing impression of *C. circularis* (m = BH-27 42B); k - *C. circularis* showing thick rim of carbonized material on the periphery of the specimen (BH-27B 15B); n - three dimensional preservation with concentric rings (n = BH-27B 20D).

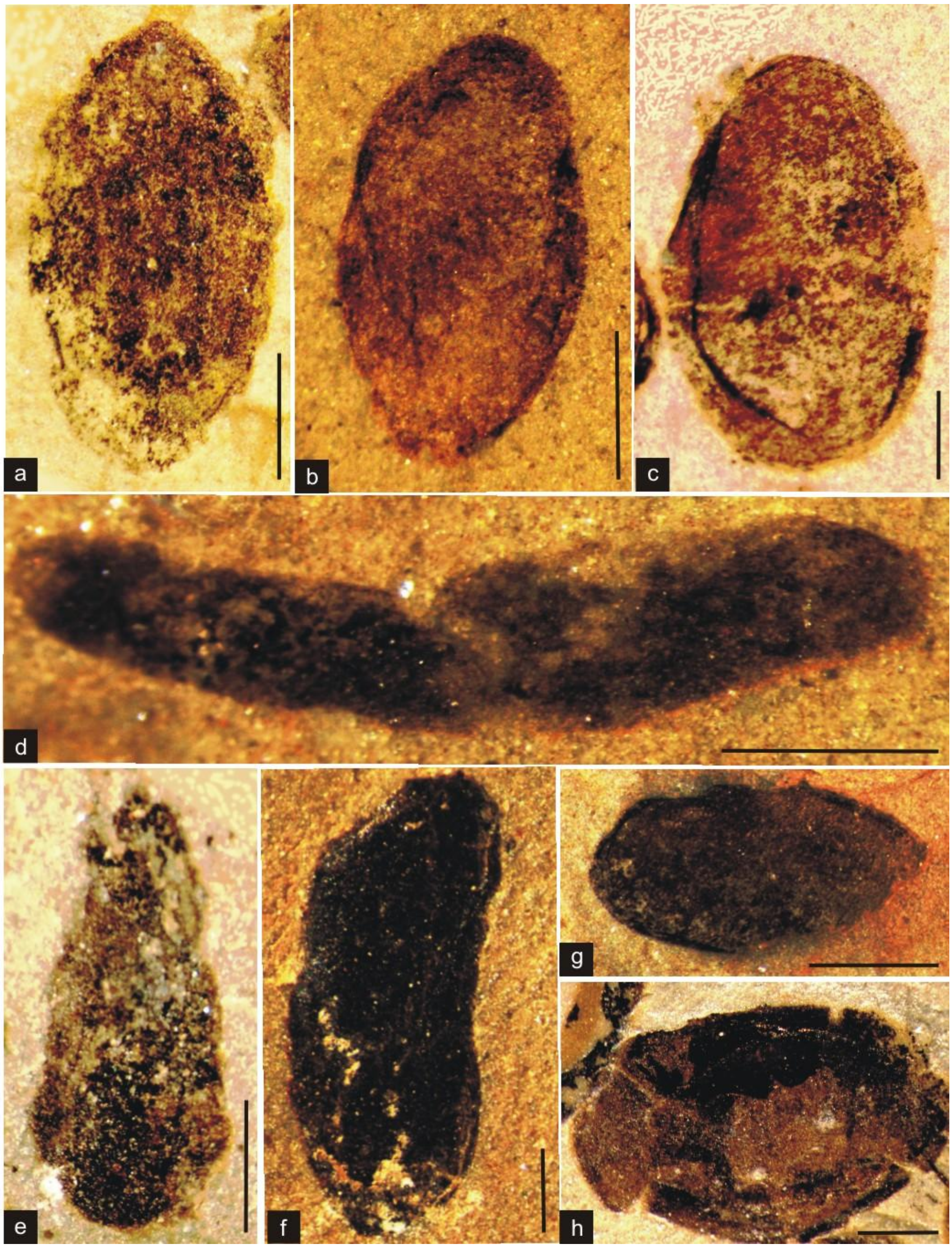
(Scale Bar- a = 0.4 mm, further remaining have a same scale of 0.5 mm)

Plate 4.11



Carbonaceous megafossils recovered from the shale unit of Bhander Limestone, Bhander Group, Vindhyan Supergroup exposed in the Aber area, Satna District, M.P. Details in the parenthesis denote the specimen number. a-bunch of *C. circularis* represent concentric rings and thick rim on the periphery of the specimen (a = BH-27B 27B); b- three dimensional convex compression of *C. circularis* with concentric ring and irregular fold (b = BH-27 32A); c- three dimensional concave compression of *C. circularis* with concentric ring (c = BH-27B 31A); d - three dimensional preservation of *C. circularis* with concentric rings (d = BH-27B 20D); e & g- *C. circularis* with concentric rings (e=BH-27B 9A, g=BH-27B 32E); f - *C. circularis* with random folding in carbonized material (f= BH-27B 21B); h - *C. circularis* showing thick rim of carbonized material on the periphery of the specimen (h = BH-27 33B); i- *C. circularis* with concentric rings (i = BH-27B 25A); j - ribbon like carbonaceous matter (j = BH-27 37B); k- *C. circularis* showing oval shape carbonaceous matter partially weathered out.
(Scale Bar - a, e, I, j and k = 1 mm, b, c, d, f, g and h = 0.5 mm)

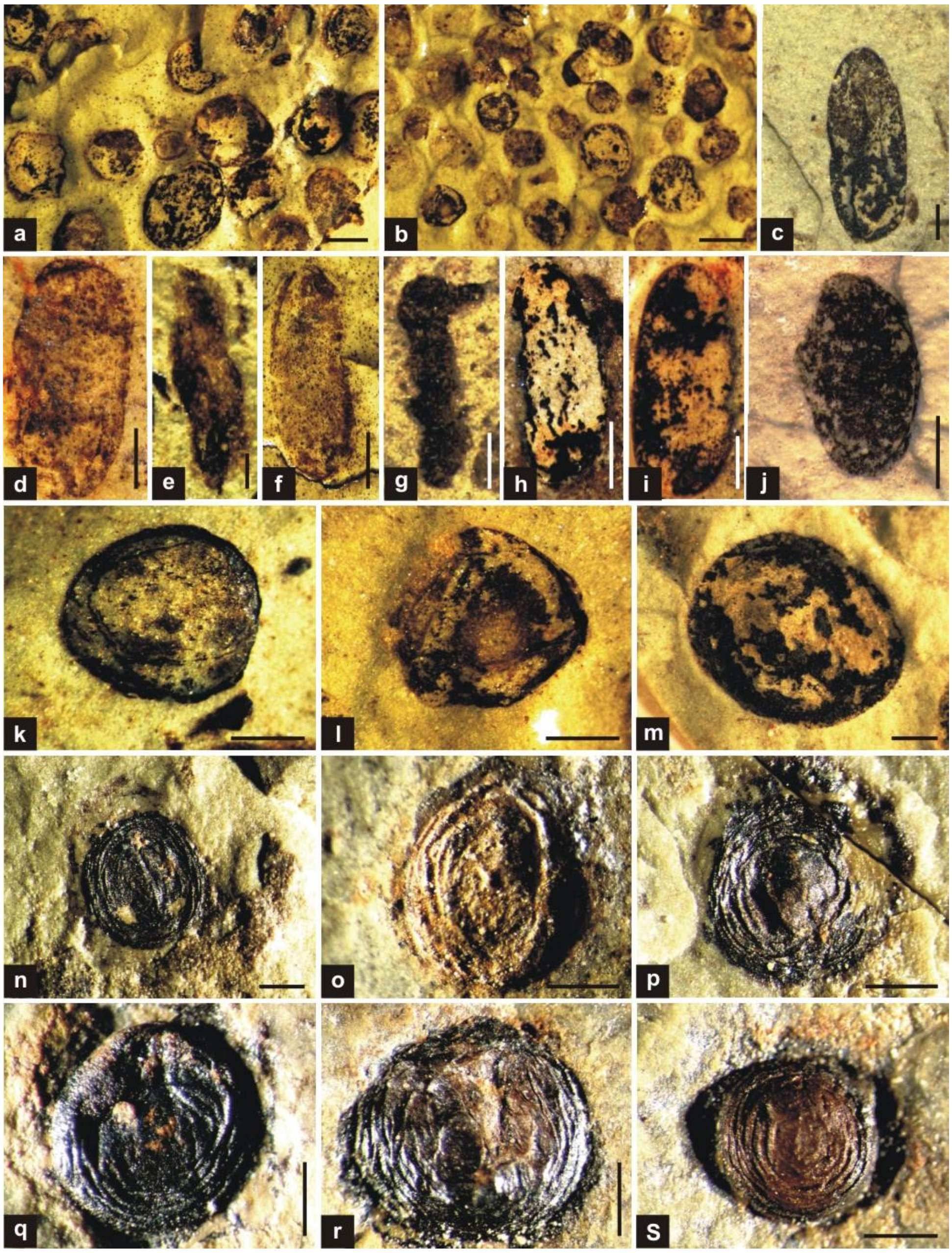
Plate 4.12



Carbonaceous megafossils recovered from the shale unit of Bhander Limestone, Bhander Group, Vindhyan Supergroup exposed in the Aber area, Satna District, M.P. Details in the parenthesis denote the specimen number. a - c- impression of *T. dalensis* (a = BH-27 15A, b = BH-27 23A, c = BH-27B 14D); d-long compression of *T.dalensis* (d = BH-27 14A); e, g & h-compression of *T.dalensis* (e = BH-27B 7A, g = BH-27B 31B, h = BH-27B 32C); f- sinuous compression of *T.dalensis* (f = BH27B 20B).

(Scale Bar – a-b and d-g = 1 mm,c and h = 0.5 mm)

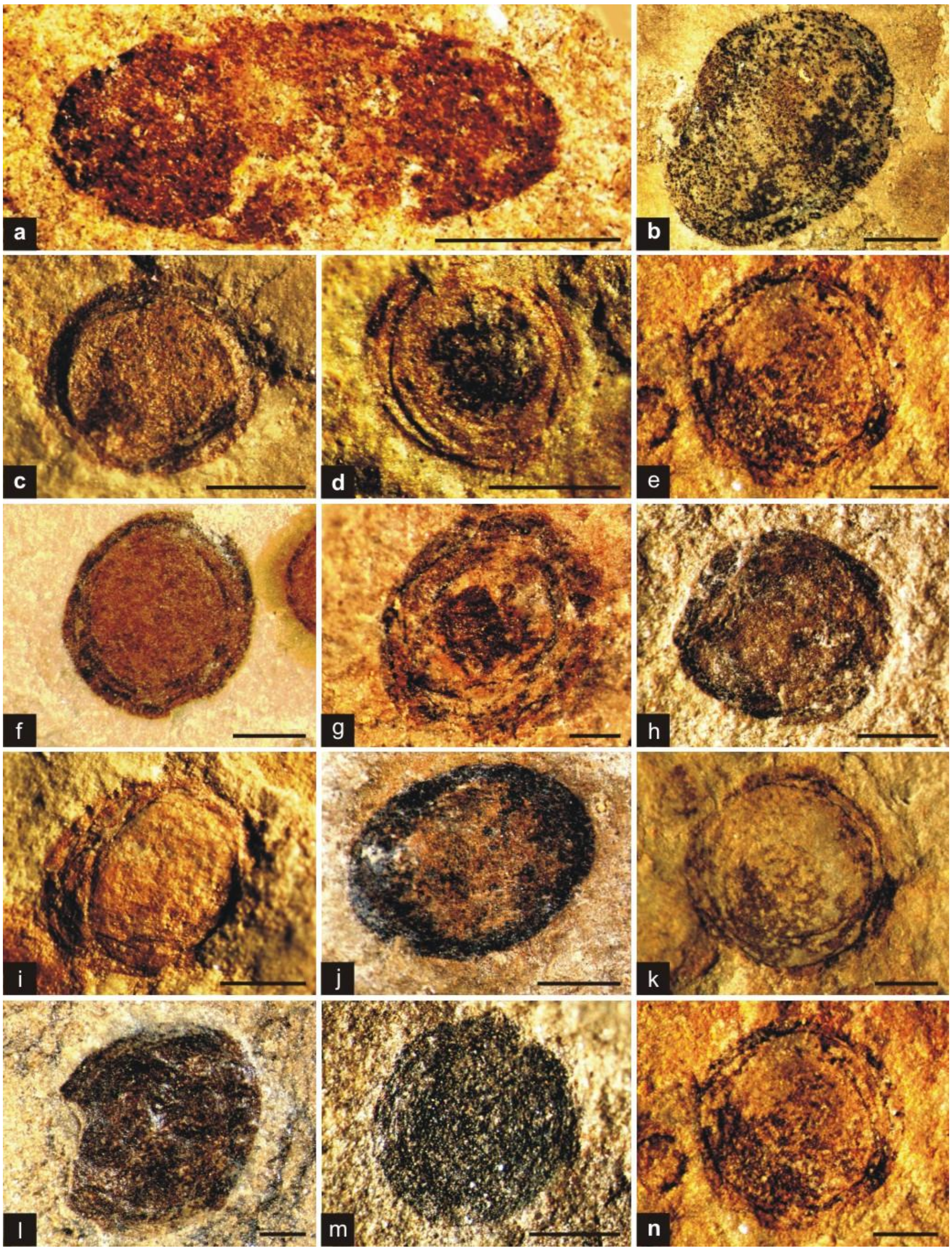
Plate 4.13



Carbonaceous megafossils recovered from the shale unit of Bhander Limestone, Bhander Group, Vindhyan Supergroup exposed in Dulni area, Satna District, M.P. Details in the paranthesis denote the specimen number. a & b - General distribution of the *C. circularis* on the bedding plane of the shale with increase in magnification (a=BH-1 33A & b=BH-1 1As); c & j - showing ribbon shape compression of *T. dalensis* (c = BH-1 14A & j = BH-1 48A); d & f- showing impression of *T. dalensis* (d = BH-1 16Gs & f = BH-1 18A); e & g - compression of *T. dalensis* (e =BH-1 14E & g = BH-1 15As); h & i – *T. dalensis* showing ribbon shape carbonaceous matter partially weathered out (h = BH-1 36Bs & i = BH-1 18Ds); k & l - *C. circularis* with thick wall of carbonaceous material and random fold (k = BH-1 14D & l = BH-1 33Cs); m – oval shape *C. circularis* with thick wall of carbonaceous material (m = BH-1 34'As); n - r- three dimensional preservation of *C. circularis* with concentric rings and random folding (n = BH-1 7c', o = BH-1 18Bs, p = BH-1 7B, q = BH-1 16F and r = BH-1 16Cs); s - three dimensional preservation of *C. circularis* with concentric rings (s = BH-1 16A).

(Scale Bar- a = 0.4 mm, b-e, i and k-s = 0.5 mm, f-h & j =1 mm).

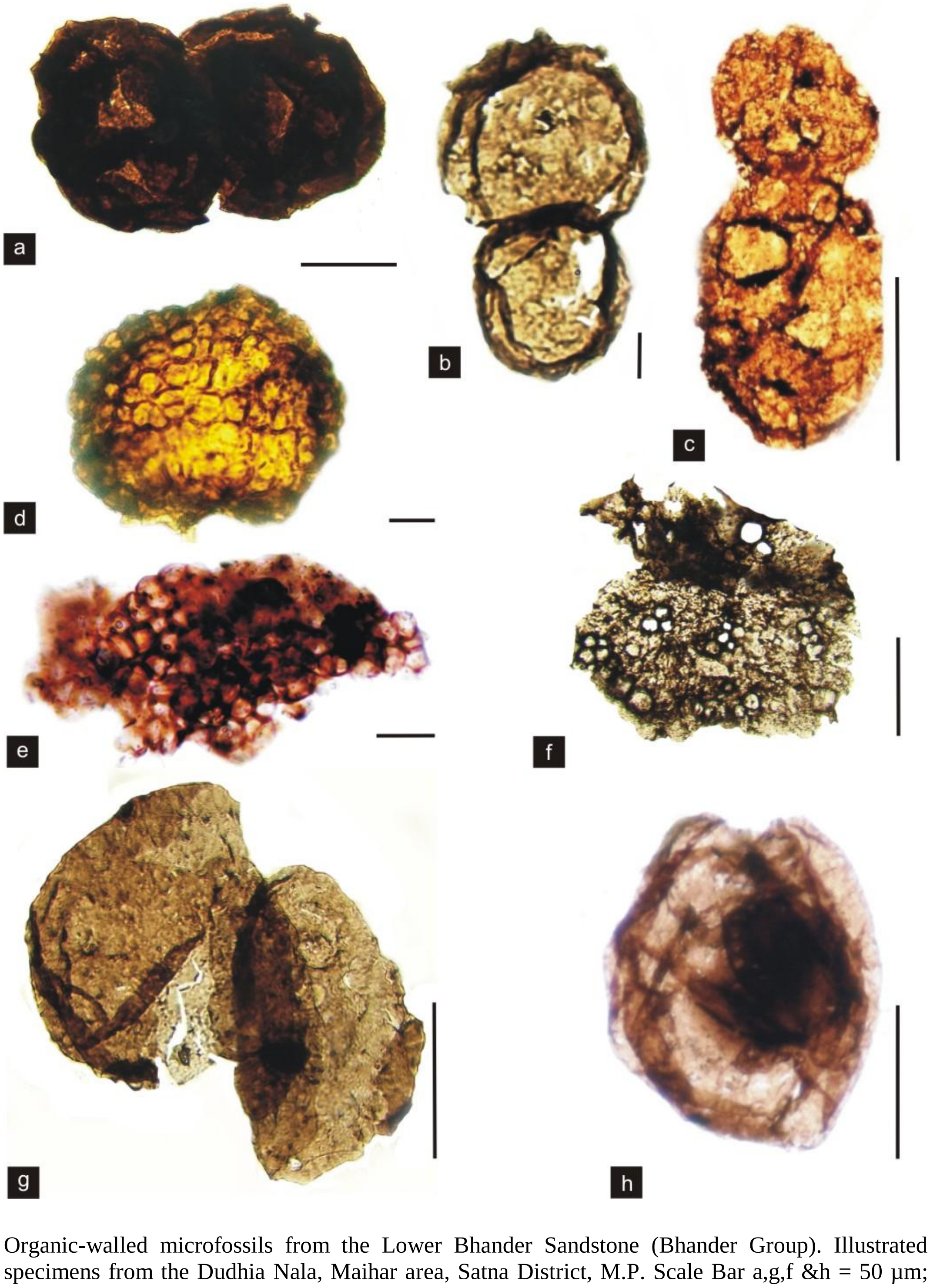
Plate 4.14



Carbonaceous megafossils recovered from the Sirbu Shale, Bhander Group, Vindhyan Supergroup exposed in Rampur Hillock area, Maihar, Satna District M.P. Details in the parenthesis denote the specimen number. a- Impression of the oval shape *Tawuia sp* .(a= BH-6 16A); b- compression of the oval shape *C. circularis* (b = BH-6 31A); c- three dimensional impression of *C. circularis* (c = BH-6 31A); d- *C. circularis* with concentric rings (d= BH-6 31B); e- three dimension impression with concentric rings of *C. circularis* (e = BH-6 43B); f - *C. circularis* showing thick rim of carbonized material on the periphery of the specimen (BH-6 47B); g - *C. circularis* with three dimensional concentric rings and showing random folding (g = BH-6 4A); h & i - *C. circularis* showing random folding (h = BH-6 16A, & i = BH-6 37A); j & l – oval shape *C. circularis* with thick wall (h = BH 6 15 & l = BH 13 9E); k & n - *C. circularis* with three dimensional concentric rings (k = BH-6 43A, n = BH-6 42A); m - *C. circularis* showing and thick wall with three dimensional concentric rings.

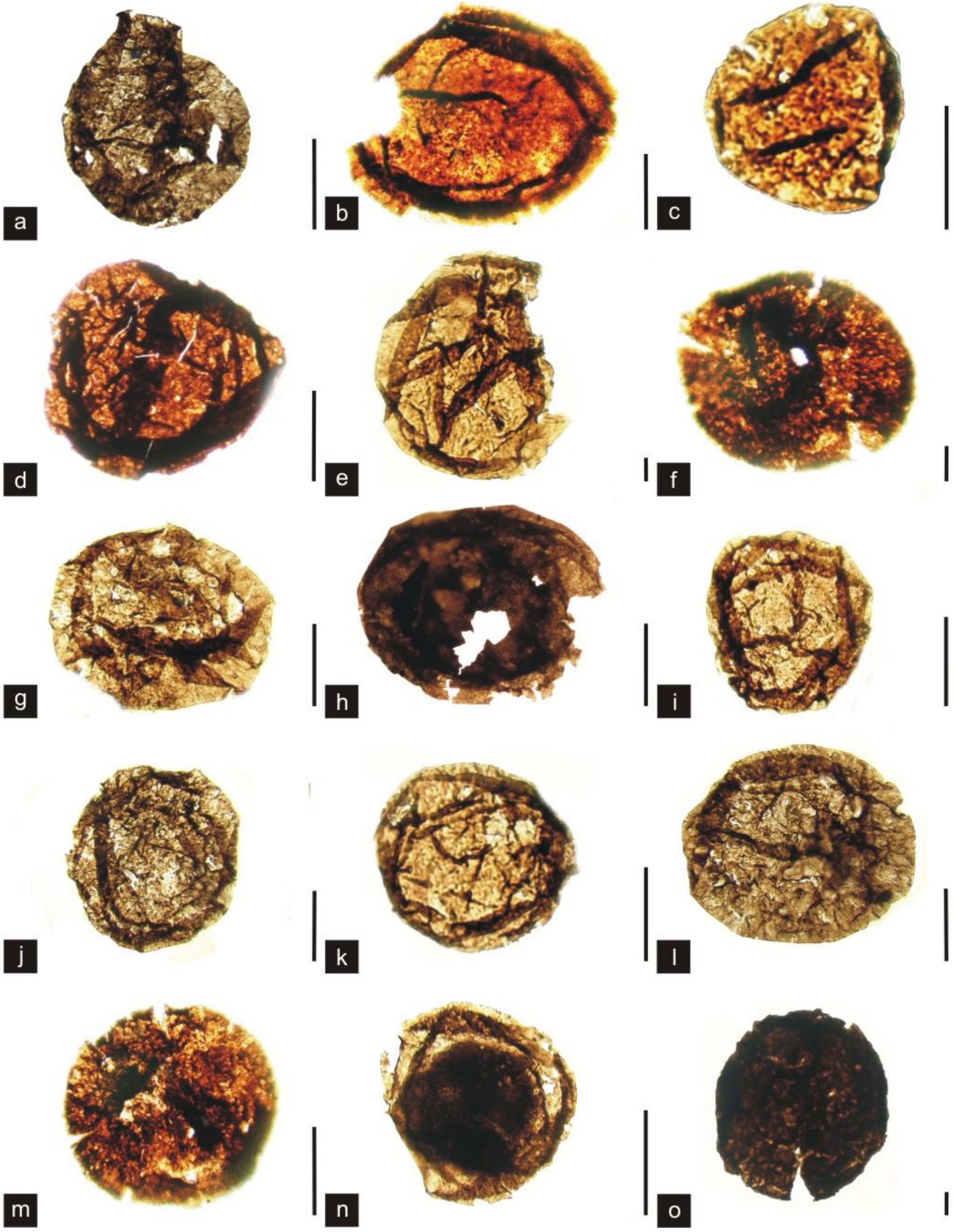
(Scale- a-d, h-j and m = 1 mm, & e-g, k, l and n = 0.5 mm)

Plate 4.15



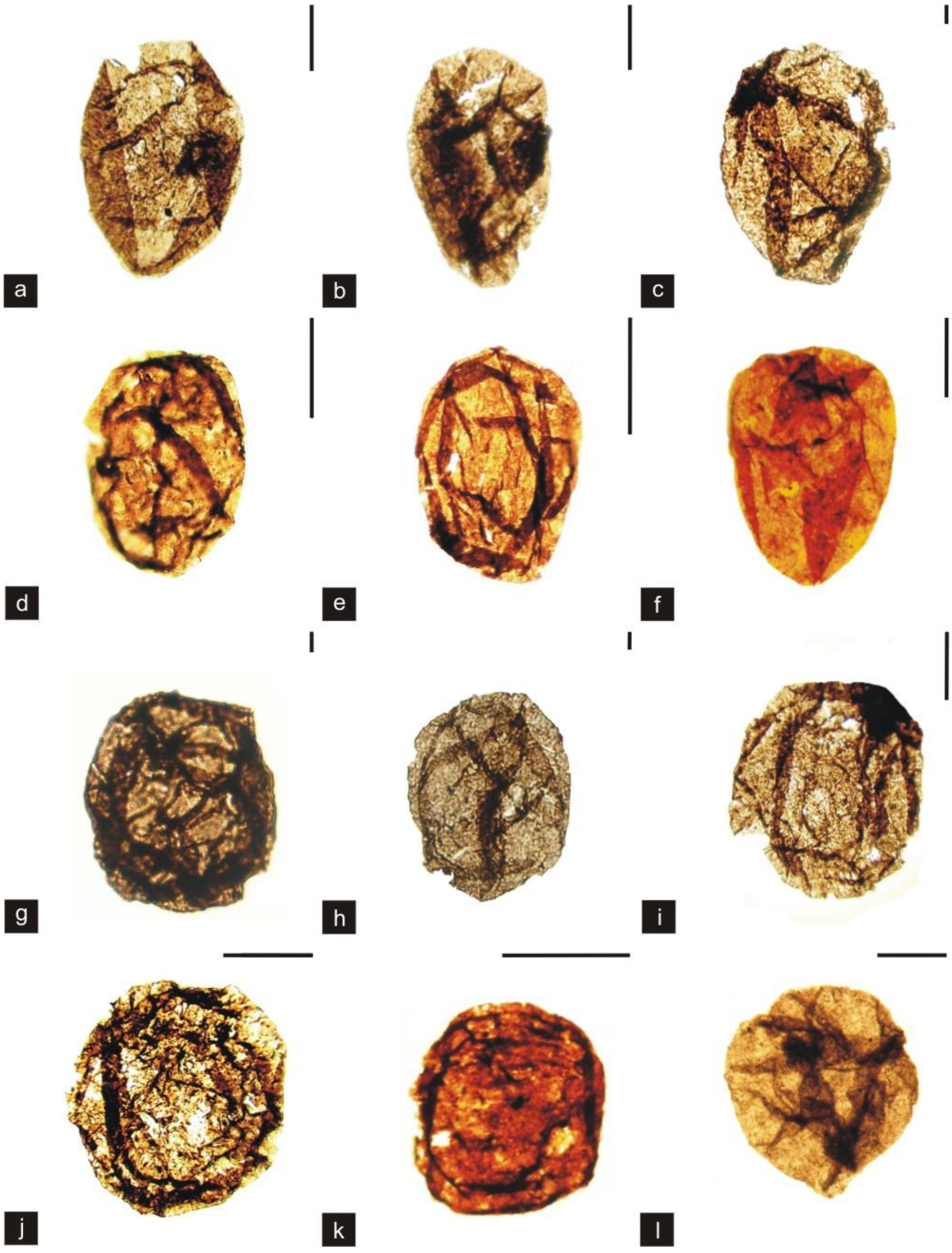
Organic-walled microfossils from the Lower Bhander Sandstone (Bhander Group). Illustrated specimens from the Dudhia Nala, Maihar area, Satna District, M.P. Scale Bar a,g,f &h = 50 µm; d,e & b = 10 µm and c = 100 µm. a – c*: Leiosphaeridia crassa* Naumova. a- BH-5I-7948-3, b- BH-5F-7948-31, c- BH-5F-7948-79. d – f:*Ostiana microcystis* Hermann. d- BH-5F-7948-67, e- BH-5A-7948-93, f- BH-5F-7948-27. g & h*: Leiosphearidia tenuissima*. g- BH-5H-7948-9 & h- BH-5A-7948-60

Plate 4.16



Organic-walled microfossils from the Lower Bhander Sandstone (Bhander Group). Illustrated specimens from the Dudhia Nala, Maihar area, Satna District, M.P. Scale Bar a, b, f, g, i, j, k, l, m & n = 50 µm; c, e & o = 10 µm, d & h = 100 µm. a-e, g and i- l: *Leiosphaeridia tenuissima* Eisenack. a- BH-5H-7948-13, b- BH-5F-7948-89, c- BH-5H-7948-21, d- BH-5F-7948-49, e- BH-5H-7948-41, g- BH-5F-7948-51, i- BH-5I-7948-3 f, h & m-o: *Leiosphaeridia jacutica* Timofeev. f- BH-5F-7948-65, h- BH-5H-7948-13, m- BH-5H-7948-55, o- BH-5I-7948-23.

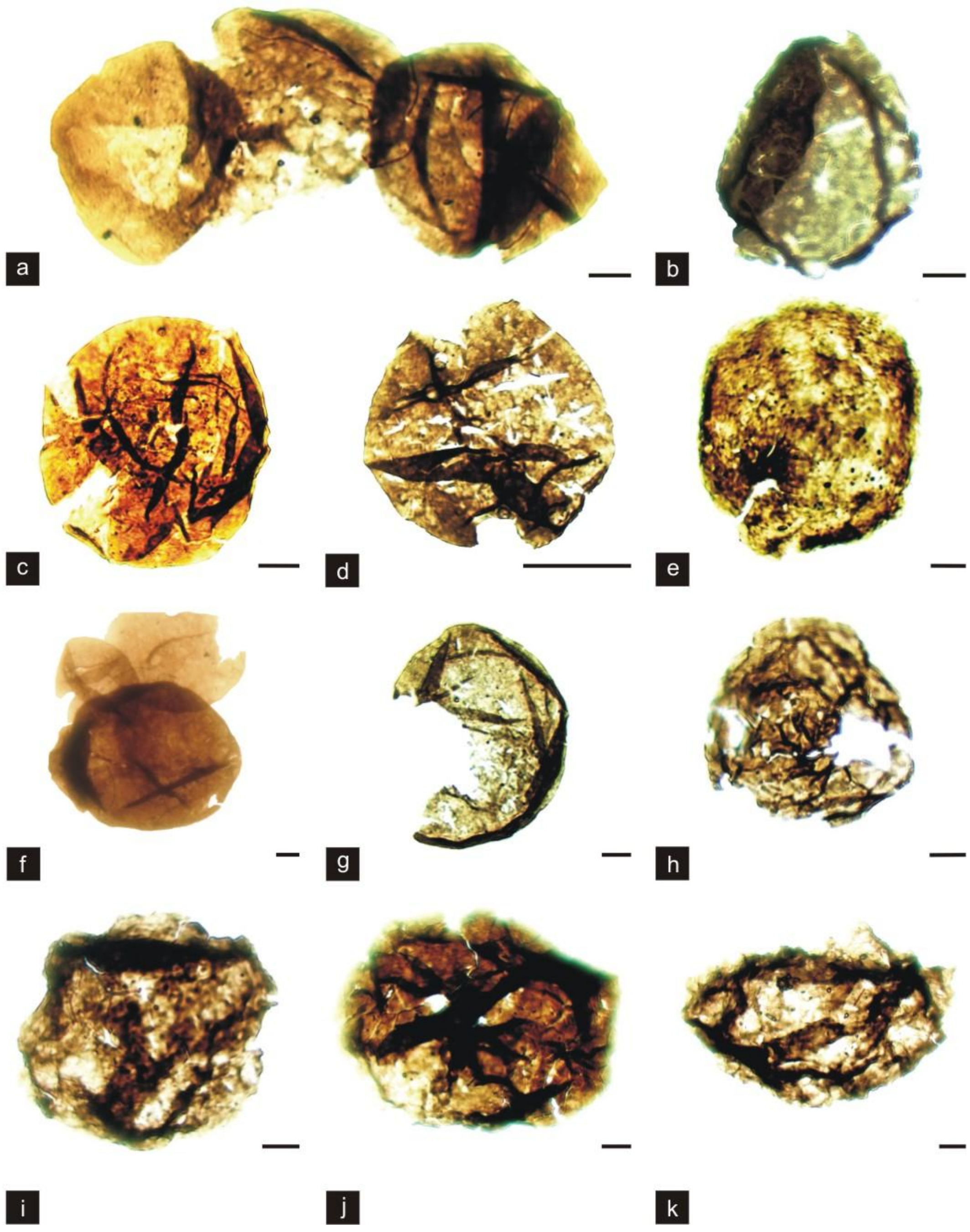
Plate 4.17



Organic-walled microfossils from the Lower Bhander Sandstone (Bhander Group). Illustrated specimens from the Dudhia Nala, Maihar area, Satna District, M.P. a-l: *Leiosphaeridia tenuissima* Eisenack. a- BH-5H-7948-29, b- BH-5F-7948-55, c- BH-5I-7948-9, d- BH-5J-7948-49, e- BH-5F-7948-85, f- BH-5B-7948-3, g- BH-5I-7948-33, h- BH-5I-7948-31, i- BH-5H-7948-33, j- BH-5H-7948-60, k- BH-5A-7948-3, l- BH-5A-7948-31

Scale Bar a,b,d,e,i,j,&l = 50 µm; c,g&h = 10 µm, f&k = 100 µm.

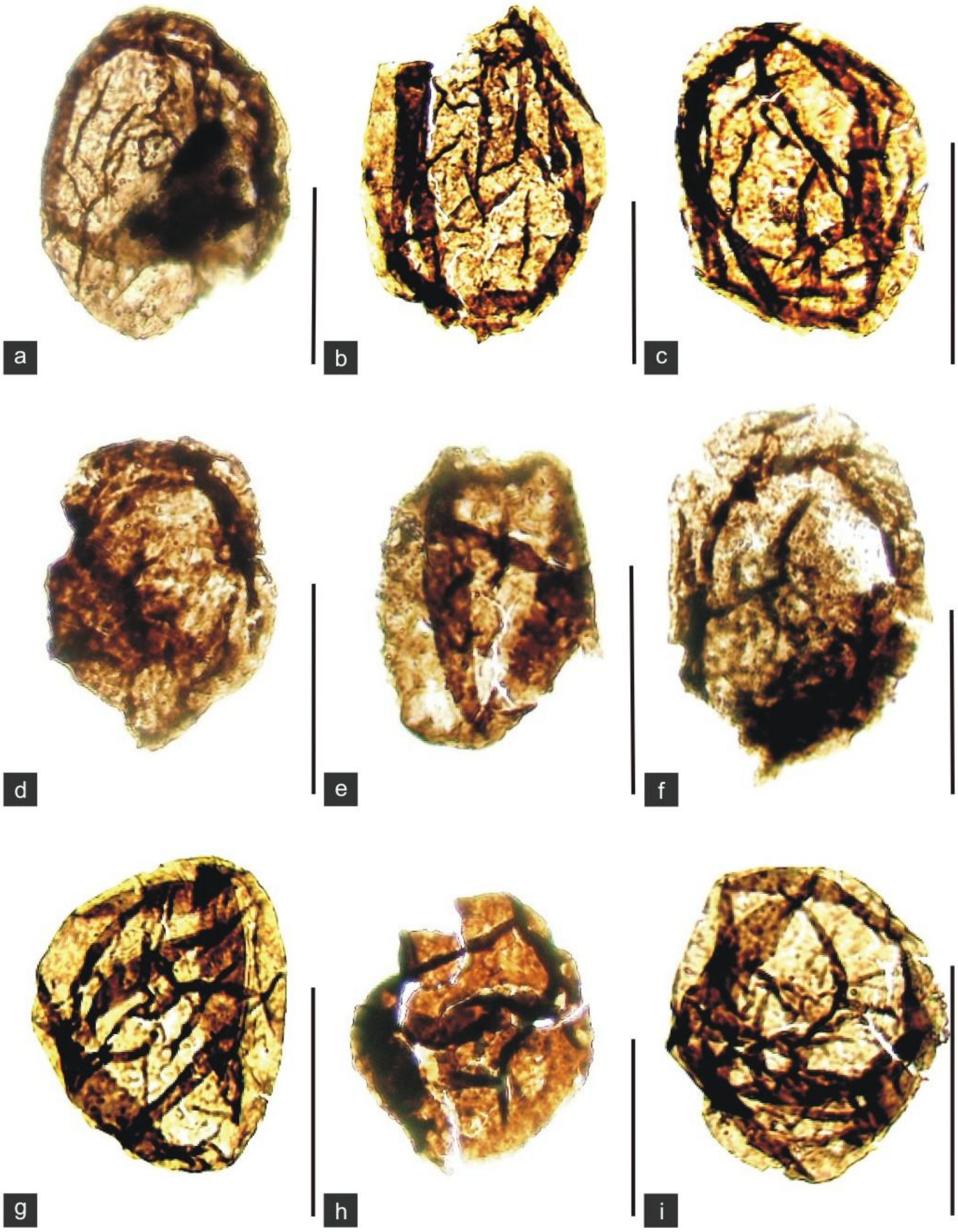
Plate 4.18



Organic-walled microfossils from the Lower Bhander Sandstone (Bhander Group). Illustrated specimens from the Karari Nala, Maihar Area, Satna District, M.P. a-k: *Leiosphaeridia minutissima* Naumova. a- BH-19C-7952-1, b- BH-19C-7952-17, c- BH-19B-7952-45, d- BH-19A-7952-21, e- BH-19B-7952-37, f- BH-19C-7952-5, g- BH-19B-7952-29, h- BH-19B-7952-19, i- BH-19A-7952-37, j- BH-19C-7952-19, k- BH-19B-7952-11.

Scale Bar a-c&e-k = 10 µm, d- 50 µm.

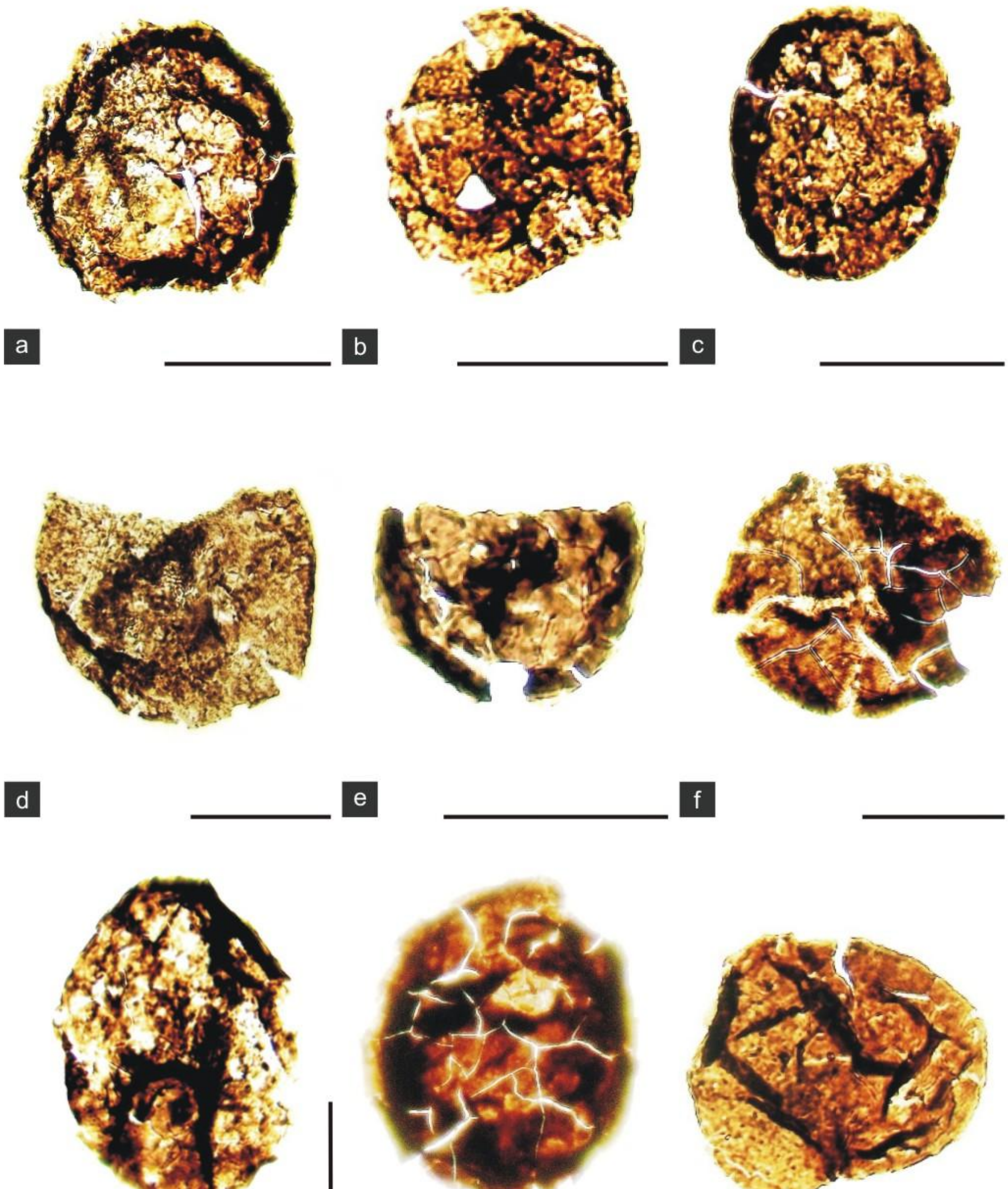
Plate 4.19



Organic-walled microfossils from the Sirbu Shale (Bhander Group). Illustrated specimens from the Rampur, Maihar Area, Satna District, M.P. a-i: *Leiosphaeridia crassa* Naumova. a- BH-13C-7947-5, b- BH-13F-7947-7, c- BH-13F-7947-25, d- BH-13B-7947-7, e- BH-13B-7947-11, f- BH-13A-7947-23, g- BH-13F-7947-17, h- BH-13C-7947-11, i- BH-13F-7947-17.

Scale Bar a-i = 50 µm.

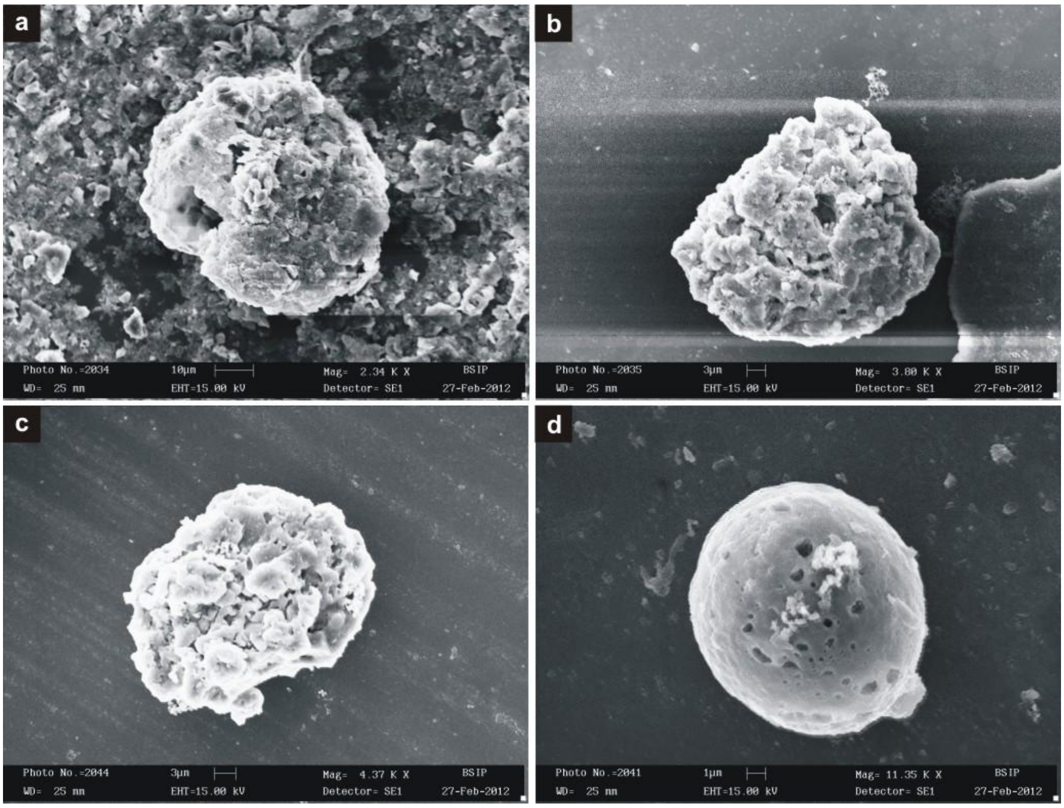
Plate 4.20



Organic-walled microfossils from the Sirbu Shale (Bhander Group). Illustrated specimens from the Rampur, Maihar Area, Satna District, M.P. a-i: *Leiosphaeridia minutissima* Naumova. a- BH-13E-7947-5, b- BH-13A-7947-19, c- BH-13F-7947-5, d- BH-13E-7947-9, e- BH-13E-7947-1, f- BH-13C-7947-9, g- BH-13F-7947-27, h- BH-13E-7947-15, i- BH-13A-7947-21.

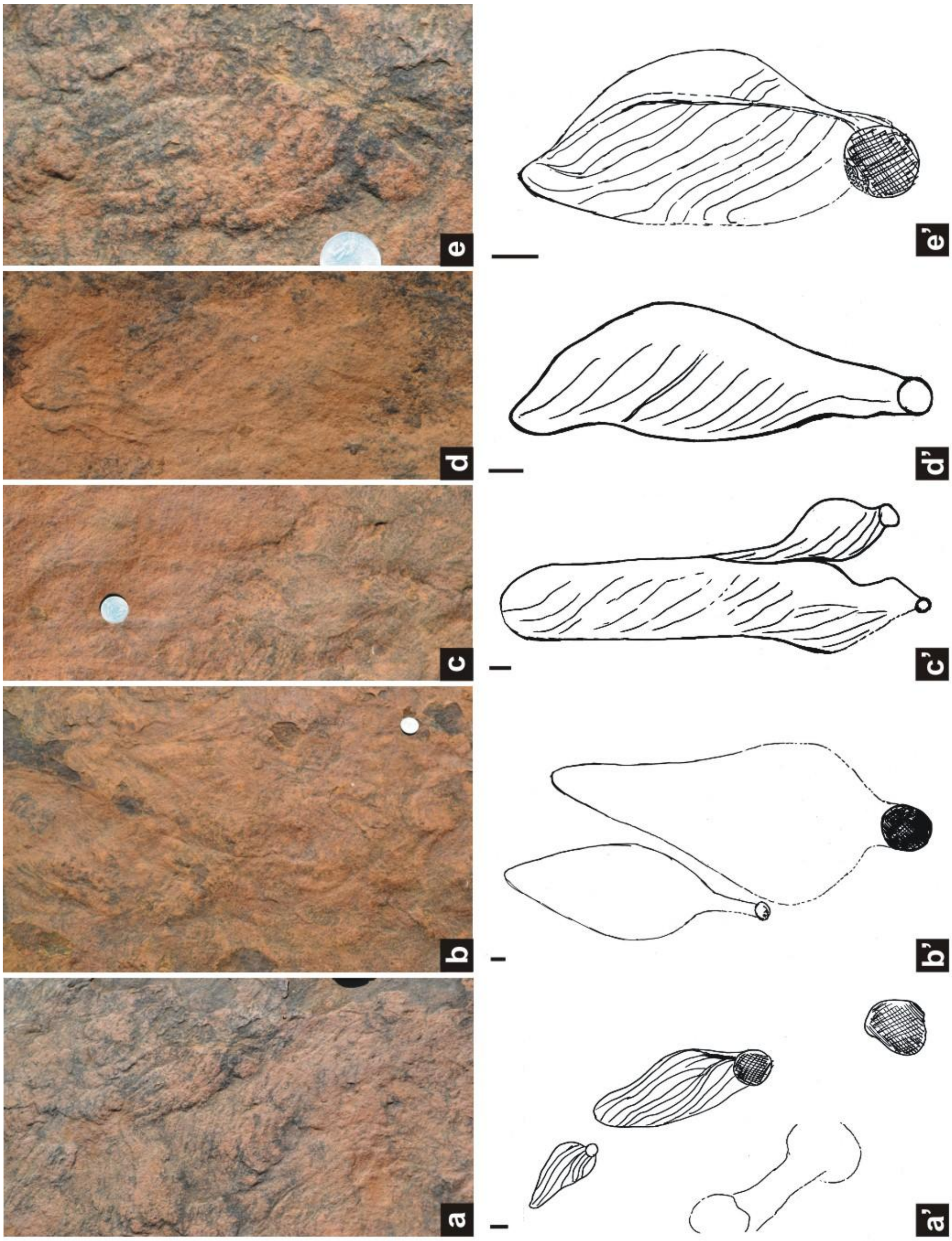
Scale Bar a-i = 50 µm.

Plate 4.21



a-c: SEM images of the artifact formed during stub preparation, d: Spherule of most likely gold palladium.

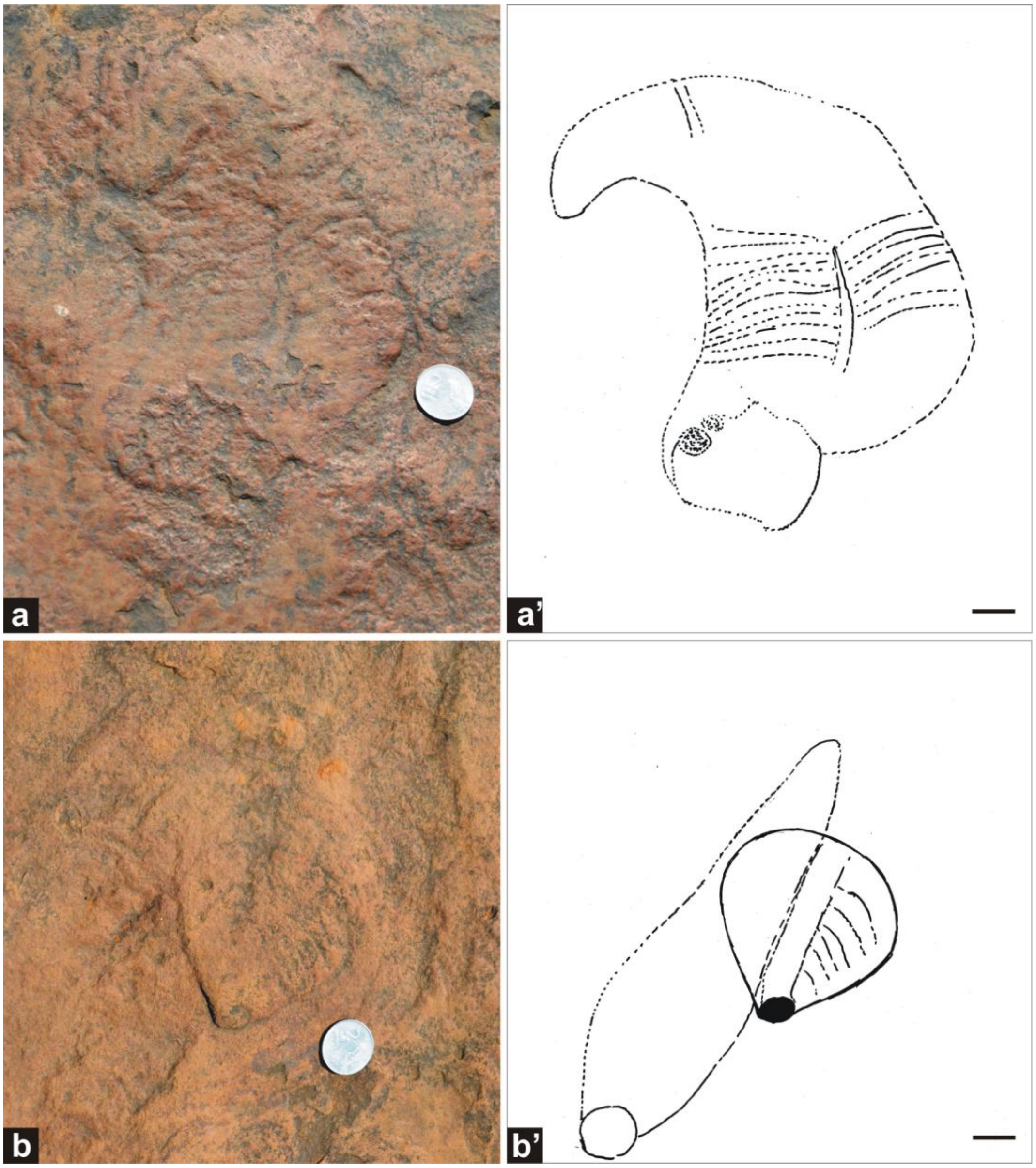
Plate 4.22



Charniodiscus sp. impression on the top of bedding surface of the Shikaoda Sandstone. a: Note the basal disc and frondose structure overlap of one half on the other; b: two specimen with prominent basal disc and other flang; c: long straight frond structure with small stem and poorly preserved ribs; d: Overlaped two specimens of *Charniodiscus* ; e: well preserved specimens of *Charniodiscus* note the folding of one half on the other, conspicuously stem is absent. On the lower side of each specimen are given the line sketches of the specimens. All the specimens are on the outcrop.

Scale bar = 4 cm in all the specimens.

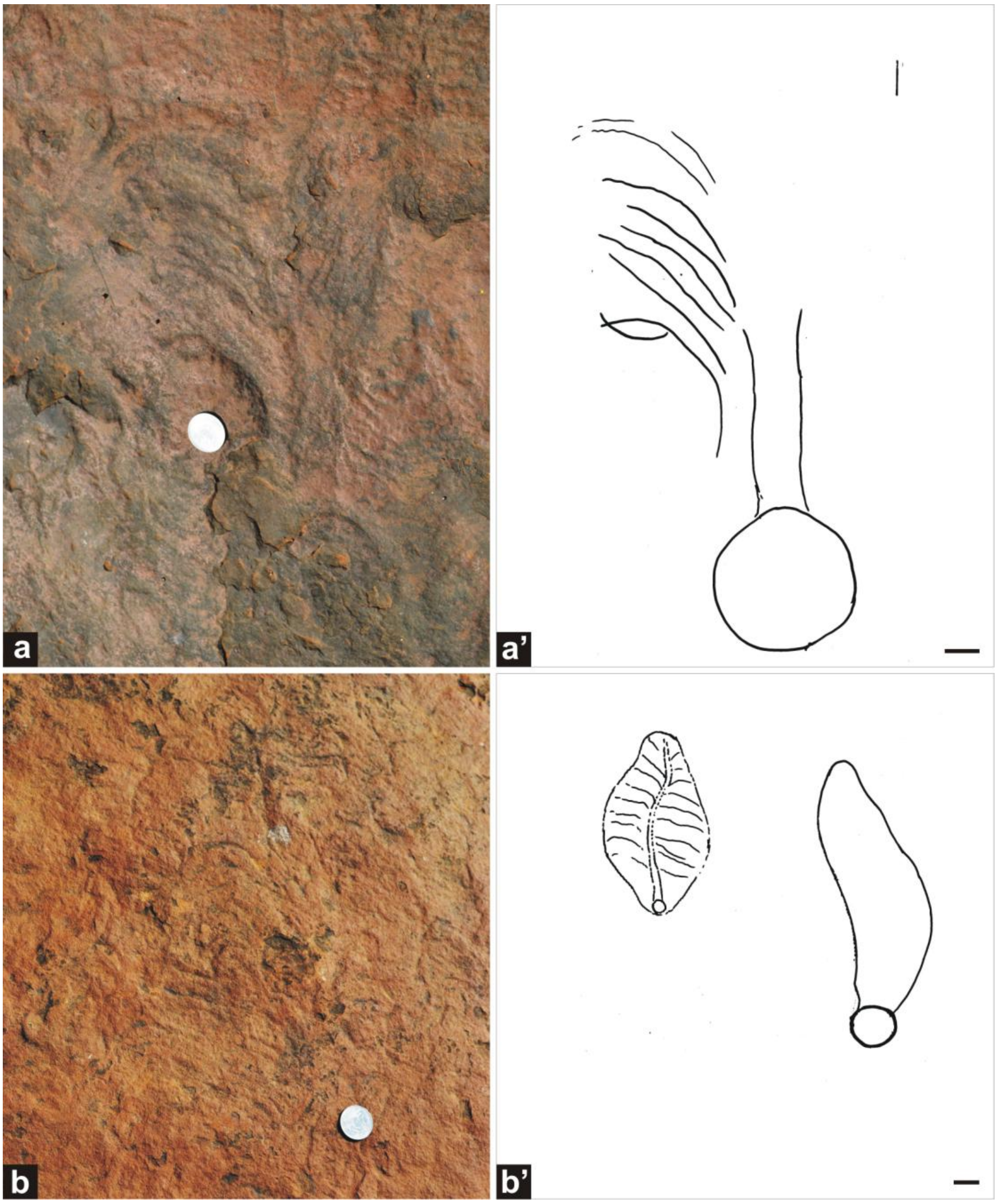
Plate 4.23



Charniodiscus sp. impressions; poorly preserved on the top of bedding surface of the Shikaoda Sandstone. a: Low Frond- disc ratio specimen. Note the circular disc and median axis with lateral branches; b: two overlapping specimens. Both the specimens are from out crop. On the right hand side are given the line sketches of the specimens.

Scale bar = 4 cm for both the specimen.

Plate 4.24



Charniodiscus sp. impressions on the top of the bedding plane of the Shikaoda Sandstone. a: Note the basal disc and stem with incomplete frond and lateral branches; b: two specimens of the frond with median axis on the right hand side are given the line sketches of each figure; Both the specimens are from the outcrop.

Scale bar = 4 cm for both the specimens.

Chapter 5

ORGANIC MATTER MATURATION

Proterozoic basins have generally been of little interest for petroleum exploration. They have been considered not to be prospective for many reasons, such as excessively metamorphosed, having very little organic content or chances of hydrocarbon pools to have destroyed during Phanerozoic tectonism. Over the last few decades, it has become more widely recognized that there are many basins of this age that have had a mild thermal history and have remained almost undisturbed throughout the Phanerozoic. In addition, palaentological research has shown that there were abundant sources of oil prone organic matter during the Proterozoic; known source rocks of this age are very rich, and there are good reasons for predicting that the best Proterozoic source are likely to be richer than their best Phanerozoic counterpart. Rich source rocks of low thermal maturity are known from basins as old as Early Proterozoic (1700 Ma in the example of the McArthur Basin of northern Australia). Proterozoic basins have a full range of reservoir types, including reefs (formed from stromatolites).

Craig et al. (2009) have suggested that the Neoproterozoic–Early Cambrian Period can be broadly divided into three distinct phases related to global tectonics and climate:

(1) Tonian–Early Cryogenian: c.1000–750 Ma – Pre-glacial;

(2) Mid-Cryogenian–Mid-Ediacaran: c. 750–600 Ma – Glacial;

(3) Late Ediacaran–Early Cambrian: c. 600–500 Ma – Post-glacial.

They concluded that the Neoproterozoic–Early Cambrian petroleum systems are widely developed globally and our knowledge of them is improving rapidly. Recent fieldworks in the Taoudenni Basin in Mauritania, the Anti-Atlas region of Morocco, the Al Kufrah Basin in Libya, the Naguar–Ganganagar Basin of Rajasthan, the Son Valley of central India and the Himalayan foothills of NW India by the members of the Maghreb Petroleum Research Group have added substantially to our understanding of Neoproterozoic–Early Cambrian reservoir, source and seal relationships. This has confirmed the widespread presence of stromatolitic carbonate units of potential reservoir facies and of black shales with potential source rock characteristics in many Neoproterozoic successions across North Africa, the Middle East and the Indian Subcontinent.

'Pre-glacial' Neoproterozoic petroleum systems on the Peri-Gondwana Margin are largely restricted to old cratonic blocks. They consist predominantly of stromatolitic carbonate reservoirs, charged from interbedded and laterally equivalent black shales containing organic matter of algal origin.

'Glacial' Neoproterozoic petroleum systems are controlled by the deposition of organic rich shale source rocks deposited during periods of post-glacial transgression. The Late Ordovician–Early Silurian Glacial–Post-glacial petroleum system provides a good analogue for reservoir, seal and source distribution in these Neoproterozoic 'Glacial' systems.

The Bhander Group of the Vindhyan basin represents Post-glacial deposition. 'Post-glacial' Neoproterozoic–Early Cambrian petroleum systems on the Peri-Gondwana Margin in the Middle East and the Indian Subcontinent are mainly associated with fault-bounded basins in East Gondwana, which are filled with mixed carbonate, evaporite and shale successions of latest Neoproterozoic and earliest Cambrian age.

Oman is the best known example of these latter systems, but very similar systems occur, or are likely to occur, in other basins in Arabia, the Indian Subcontinent and, possibly, also in some parts of North Africa.

Source rock is one of the main pillar of any petroleum system, it is represented by combination of an organic matter and a special type of fine grained, impermeable rock. Organic matter preservation happened with sediments deposition in the basin. The generation of the crude oil/gas depends upon the formation of the kerogen in the source rock, and this kerogen has a direct relationship with the ratio of organic matter preservation and sediments deposition. If sedimentation rate > organic matter deposition then dilution happened and if organic matter > sedimentation rate then there will be no preservation of organic matter, due to oxidation. In the case of studied samples from different horizons of the Bhander Group, we have got very good preservation of the organic matter that support the view of formation of good quantity of kerogen. But without maturity of these organic matters there will be no kerogene because cooking of organic matter is necessary in the kitchen of petroleum play.

Therefore in the present chapter, there is a brief discussion on the evaluation of organic matter concentration by Total Organic Carbon (TOC) analysis, its origin either biogenic or thermogenic, organic matter maturation by Thermal Alteration Index (TAI) and zone of hydrocarbon formation.

5.1 Total Organic Carbon (TOC)

Total Organic Carbon (TOC) analysis was performed with Elementar Liqui TOC Analyzer with the solid sample module. Selected samples from different black shale and silty units were chosen for TOC analysis. For this carbonates and black shales samples have been collected from two stratigraphic horizons, the Bhander Limestone and Lower Bhander Sandstone.

Total organic carbon contents vary with stratigraphic units in the Bhander Group. The shale unit of carbonates of the Bhander Limestone has 0.17% TOC. The black shales/siltstone, separated from the Lower Bhander Sandstone are showing the value of TOC, i.e. 0.32 %. These results indicate, yields of extractable TOC are low in carbonates and average in black shales for source rock and generation of Hydrocarbon.

5.2 Light Hydrocarbon Gases (C1-C5)

In this study, the magnitude of each of the seven light hydrocarbon gases that are absorbed on to the clay matrix of black shales constituents (C1, C2, C3, *i*C4 *n*C4, *i*C5 and *n*C5), are measured and expressed in ppb. The compositional characteristics of these hydrocarbon gases in black shales indicate the presence of methane (C1), ethane (C2), propane (C3), *i*-butane (*i*C4), *n*-butane (*n*C4), *i*-pentane (*i*C5) and *n*-pentane (*n*C5). Values for each analyzed shales gas constituents are summarized in Table 5.1. The distribution of C1, C2 and C3 gases in the shale/silt units showed high concentration.

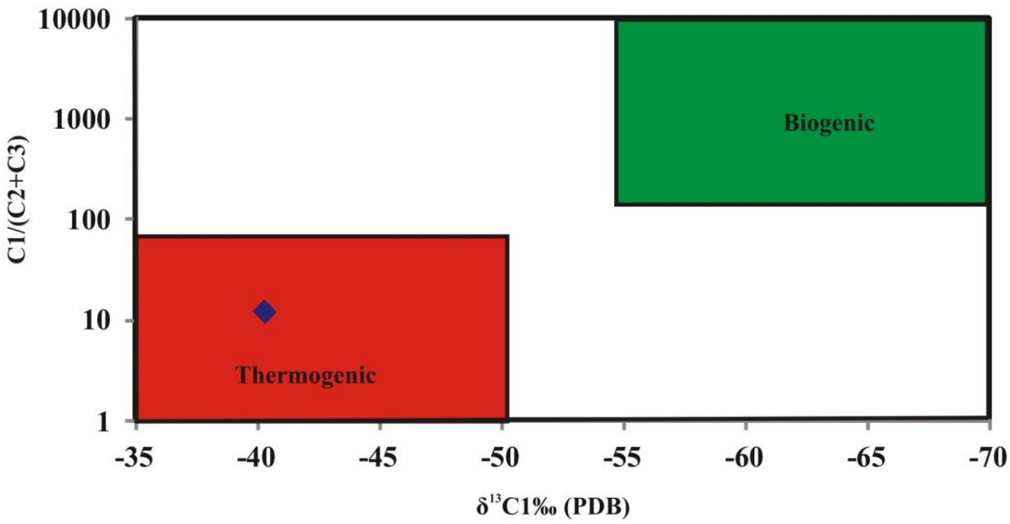


Fig 5.1- $\delta^{13}C1$ versus C1/(C2+C3) Bernard Plot showing thermogenic origin of light hydrocarbons.

Bernard plots – Stable carbon isotopes yield information on the origin of hydrocarbons from varied locations or sources (Fuex, 1977; Faber and Stahl, 1983; 1984; Schoell, 1983; Stahl, 1977; Stahl et al. 1981; Whiticar, 1996; 1999). A Bernard plot can be used to differentiate light hydrocarbon gases derived from thermogenic or bacterial sources (Bernard et al., 1978). C1/(C2+C3) ratios <100 and $\delta^{13}C1$ heavier than -60 ‰ are characteristic of thermogenic hydrocarbons; whereas C1/(C2+C3) ratios > 1000 and $\delta^{13}C1$ lighter than -60 ‰ indicate an origin from biogenic sources (Bernard et al., 1978). A Bernard plot showing the relationship between methane $\delta^{13}C1$ and C1/(C2+C3) from the black shales/silt stone samples of the Bhander Group, Upper Vindhyan is shown in Figure 5.1.

The carbon isotopic composition of $\delta^{13}C_1$ is – 40.76 ‰ (PDB). Which indicate that these gases are of thermogenic origin and in all likelihood of a thermogenic source for the light hydrocarbons. Gases of thermogenic origin generally show a trend of decrease in concentration from methane to pentane i.e. C1>C2>C3>C4>C5 (Klusman, 1993; Tedesco, 1995; Sanez, 1984). The light hydrocarbon gases from the Lower Bhander Sandstone and Bhander Limestone's black samples are following a similar pattern. (Table 5.1).

Table 5.1 Light hydrocarbon (C1-C5 ppb) distribution in the black shale/silt unit of given formation, Bhander Group, Satna District, M.P.

Sample ID	BH-5 (Lower Bhander Sandstone)	BH-34 (Bhander Limestone)
C1 ppb	71	55587
C2 ppb	4	4595
C3 ppb	0	929
IC4 ppb	0	168
nC4 ppb	0	163
iC5 ppb	0	103
nC5 ppb	0	88

Haworth, Sellens, and Whitaker (1985), had given the interpretation of light hydrocarbon gases (C1-C5), using mud log data. They used some parameters and given the mathematical formula to calculate these ratios. The ratios were calculated as provided below:

Wetness (Wh) = ((C2 + C3 + iC4 + nC4 + iC5 + nC5)/ (C1 + C2 + C3 + iC4 + nC4 + iC5 + nC5)) × 100

Balance (Bh) = (C1 + C2) / (C3 + iC4 + nC4 + iC5 + nC5)

Character (Ch) = (iC4 + nC4 + iC5 + nC5) / C3

Set points used for the Wh ratio were as follows:

< 0.5 = very dry gas.

0.5 - 17.5 = gas, density increases as Wh increases.

17.5 - 40 = oil, density increases as Wh increases.

> 40 = residual oil.

When plotted together, Wh and Bh give an interpretation of fluid character as follows:

- If Bh is greater than 100, the zone has very dry gas.
- If Wh indicates a gas phase and Bh is greater than Wh, gas is indicated,
- If Wh indicates a gas phase and Bh is less that Wh, gas/oil or gas/condensate is indicated.
- If Wh is in the oil phase and Bh is less than Wh, oil is indicated.
- When Wh is greater than 40, Bh will be much less than Wh, indicating residual oil.
- The Ch ratio was chosen to interpret shows where, in certain circumstances, high

- Methane readings indicated a lighter hydrocarbon fluid character, using only Wh and Bh, Ch is used only to clarify the interpretation of Wh and Bh when they indicate gas. The resultant Ch is interpreted as follows:
- If Ch is less than 0.5, the Wh and Bh interpretation of gas is correct.
- If Ch is greater than 0.5, the gas character by the Wh and Bh ratios in associated with oil.
- The maximum Wetness (Wh) ratios, values of present study, ranges between 5.13 and 9.54 which indicate gas bearing. These values are showing gas with high density. All the samples are showing Wetness (Wh) ratios < Balance (Bh) ratios, but the value of Bh (41.5) is smaller than 100 which indicates gas phase. The value of Character (Ch) ratios is greater than 0.5 which are supporting the Wh and Bh interpretation of gas is correct. Rest values of Character (Ch) ratios, which are greater than 0.5, this indicate the gas character by the Wh and Bh ratios in associated with oil.

5.3 Palynofacies Analysis

For the palynofacies analysis rock samples were collected from the different formation of the Bhander Group section exposed near Rampur Hillock, Dudhia Nala, Karari Nala, Shahpur and Girgita quarry all in the Satna District, M.P.

Petroleum geologists are well aware of the fact that the dispersed organic matter derived either from marine or non-marine sediments on reaching its maturation level over extended period of time contributes as source material for the production of hydrocarbons. For the study of this dispersed organic matter, many researchers all over the world have proposed different classifications. The important contributions on such classifications are those of Burgess (1974); Tissot et al. (1974); Bujak et al. (1977); Masron and Pocock (1981); Venkatachala (1981, 1984); Batten (1983,1996); Hart (1986); Pocock et al. (1987); Tyson (1994) and Boussafir et al. (1995). Further, various laboratories engaged in the task of petroleum exploration use their own classification of organic matter. In the present study, the classification of dispersed organic matter proposed by Venkatachala (1988) has been adopted with minor modifications. For determining thermal alteration of sediments, many approaches are being used today, most of which require advanced equipments and relatively expensive analytical techniques. We have here applied less costly, relatively simple, effective and globally accepted approach of visually assessing palynomorphs colour to determine TAI (1 – 5 scale as proposed by Staplin 1969, 1977).

The hydrocarbon source rock potential of the Sirbu Shale exposed in the Dudhia Nala, Karari Nala and Rampur Hillock areas has been evaluated on the basis of dispersed organic matter and TAI. The dispersed organic matter in the rock samples is isolated by standard maceration technique (Grey, K. 1999), which involves digestion with hydrochloric acid and hydrofluoric acid. The nitric acid treatment is avoided to get unoxidised residue. The macerate is thoroughly washed and smeared on zero cover glass and mounted on slides using polyvinyl alcohol and Canada-balsam. The quantitative estimation of the organic matter is made by visual estimation following the classification described by Venkatachala (1981, 1984, and 1988) is adopted here. TAI values are assessed on the 1–5 scale of Staplin (1969, 1977).

5.3.1 Hydrocarbon source rock evaluation

Sediments that have been able to generate petroleum or which may have the potential to do so are called ‘source rocks’. Organic rich shales, mudstones and certain very fine-grained carbonates deposited under suitable conditions and oxygen deficient waters are considered excellent source sediments. Both autochthonous and allochthonous organic debris contribute to the total organic matter (TOM) of a litho-unit. Type of organic matter and its facies are considered very important while evaluating source rock potential. These types of organic matter must be identified and distinguished, for different types of organic matter, and have different hydrocarbon potentials and products. The organic matter that occurs in sediments is either from terrestrial or marine sources Table-5.2.

Now a days the term Kerogen is used by various workers in state of total organic matter. The term was originally defined by Crum Brown (1912) as solid bituminous, mineraloid substances in oil shales. Kerogen is the end product of mechanical, chemical and biological alteration of accumulated plant material. The formation of kerogen depends upon the density of organic matter preserved in the sediments. Organic matter occurs sometime faster than the rate of breakdown, then, it is preserved and incorporated in the sediments. Terrestrially sourced

Table 5.2 Different source of organic matters occur in sediments (Venkatachala, 1988)

Primary Material

Terrestrial Source

Plant leaf and stem
Plant spores and pollen
Lignified wood fragments – partially fusinised
Mineral charcoal – fusain, micrinite
Resin
Planktonic fresh water algae

Marine Source

Phytoplankton
Benthos – Bacteria, Algae and Fungi

Modified Products

Sapropel
Fluffy to semi coherent masses
Finely dispersed organic matter
Platy, translucent, brittle, amber marterial
Resistent, inert, platy modified cuticular remains

material is also deposited in a marine environment, and gets mixed up with marine plant products resulting into a potential source rock.

The following type of organic matter can be recognized in sediments;

Structured terrestrial material (wood/cuticle): This organic matter comprises unaltered cellular remains of leaf, root and stem tissues. Terrestrial plants were absent in the Ediacaran time, hence present samples represent absence of structural terrestrial material. This type is easily recognizable when fresh and has no significant hydrocarbon potential, but contributes for gaseous hydrocarbons.

Spores and pollen: These are resistive material and commonly preserved in sediments. Their content in sediments adds to the liquid hydrocarbon potential. The spore and pollen are completely absent in the studied sediments.

Charcoal (fusinite): This is formed due to oxidation of structured terrestrial woody organic matter, which is extremely resistant to decay. It has no/negligible hydrocarbon source rock potential except for dry gas. Black colour suggest oxidation environment during deposition. Absent in the studied formations.

Biodegraded terrestrial organic matter: This is terrestrial organic matter. In the first stage it is made up from hard and soft parts of plants (angiosperms, gymnosperms, pteridophytes and bryophytes). This type of material which is partly or completely biodegraded is subject to easy conversion or thermal alteration to produce hydrocarbons. Such organic matter is absent in the Bhander Group.

Biodegraded aqueous organic matter: Mostly algal remains formed this organic matter. The frequency of biodegraded aqueous organic matter in the investigated area is quite high 75%. This organic matter is considered to possess enhanced hydrocarbon source potential than structured terrestrial organic matter. The remains in this group are-

Phytoplankton: This is indicative of marine environment. Grey amorphous organic matter or greenish yellow amorphous granular organic matter are indicative of marine origin source and generally associate with phytoplankton. Grey amorphous matter is formed in sealed basins and reducing environments while the greenish yellow amorphous matter indicate oxidizing environments.

Thalloid algal matter: It is preserved as dark brown and mostly structureless pieces under the light microscope; however they appear spongy under SEM. This is easily converted into amorphous organic matter and is sourced by mostly red and brown algae. Greenish yellow amorphous granular organic matter is also result of biodegradation of algal matter, possibly large sea weeds. Marine grasses also possibly give rise to this type of organic matter.

Filamentous algae: These are remains of blue green algae and mostly associated with reducing environments. They formed algal mats which entrap sediments. Algal mat formed MISS, which have been recorded from the Kudra village, Bhander Group in the present study. Biodegradation of filamentous algae forms amorphous flanky or granular organic matter.

Amorphous organic matter: Amorphous organic matter is completely transformed material into structureless matter where all recognizable cellular structure has been lost. It is very hard to distinguish the source of this matter as terrestrial or aquatic. The frequency of this organic matter is 4% approximately in the studied sediments. Such matter is spongy and appears porous and is generally yellowish – brown or orange in colour. During thermal alteration process this type is converted from yellowish brown to dark brown in colour. Amorphous organic matter formed by diagenesis of organic matter at aerobic environments with limited supply of oxygen.

Organic matter of Bacterial Origin: This type of organic matter forms from the conversion of both terrestrial and algal organic matter by fungal and bacterial attack. Sometime whole organic matter is destroyed by the activity of fungus and bacteria, and the resultant product is called bacterial mush. The colour of this organic material is yellowish green – brown and an excellent hydrocarbon source.

Grey amorphous organic matter: This matter is granular and flaky and commonly associated with phytoplankton remains which are indicative of marine source. Pyrite associated with it commonly, that's indicating reducing environment of deposition. This represents very low frequency (0-1%). It converts into greyish – black or black matter after thermal alteration of organic matter.

Structured marine organic matter: Algae such as dinoflagellates, acritarchs, diatoms, radiolarian, as well as remains of larger brown and red algae constitute this type. These are particulate and good source of hydrocarbons. Amorphous and semi-amorphous matter forms by the biodegradation and alteration of this matter. The overall dominance/trend of different types of organic matter in the different localities describe in Table 5.3. Biodegraded marine organic matter > Structural marine organic matter > Amorphous organic matter> black debris and rest are negligible or absent in the studied sediments. The dominance of biodegraded marine organic matter, structural marine organic matter and amorphous organic matter in the Sirbu Shale, Lower Bhander Sandstone, and Bhander Limestone of the area indicates good source-rock potential for hydrocarbons.

Table 5.3- Thermal Alteration Index of different horizons of the Bhander Group.

S. No.	Locality	Stratigraphy	Lithology	Dominant Organic Matter	TAI	Remarks (Plate)
1	Rampur	Sirbu Shale	Yellowish grey shale	Biodegraded Marine	3.0	5.1
2	Dudhia Nala	Lower Bhander Sandstone	Dark grey shale	Structural Marine	3.1	5.2
3	Karari Nala	Lower Bhander Sandstone	Yellowish grey shale	Biodegraded Marine	2.9	5.3
4	Shahpur	Bhander Limestone	Greyish green shale	Biodegraded Marine	3.0	5.4
5	Girgita Quarry	Bhander Limestone	Greyish green shale	Black Debris	3.4	5.5

5.3.2 Thermal Alteration Index (TAI)

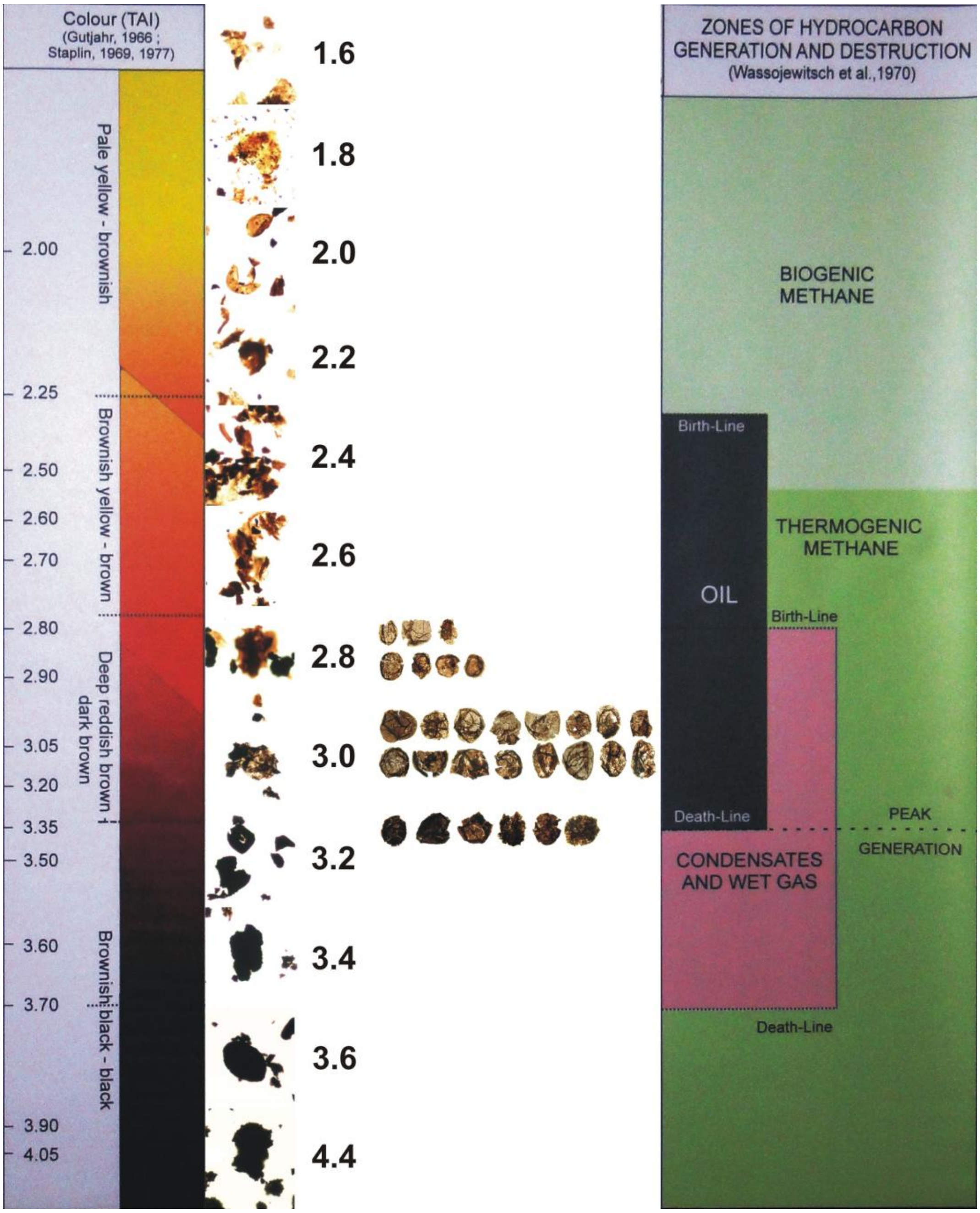
For evaluating organic maturation level of the sediments *vis-a-vis* hydrocarbon potential, TAI to the 1–5 scale as proposed by Staplin (1969, 1977); has been used for the present study. The TAI is based upon the maturation colour of organic matter. The TAI values worked out for the Bhander Group sediments are measured as in Table 5.2. Lower Bhander Limestone (Girgita) shows maximum value of TAI, i.e. 3.4 in whole Bhander Group, while Lower Bhander Sandstone (Karari Nala) indicate minimum value i.e. 2.9, this range represent is an optimum maturation level of a very good hydrocarbon source rock potential.

5.4 Conclusion

The occurrence and relative abundance of dispersed organic matter types, the thermal maturation levels as evaluated by TAI values and the dominance of organic facies have been worked out to interpret the hydrocarbon source potential of the Bhander Group of the Maihar area. The palynofacies data generated during the analysis is quite significant in understanding hydrocarbon generation potential of these sediments. The present study reveals a moderate to fairly rich organic matter in the sequence. The Bernard Plot shows thermal origin of light hydrocarbon. TAI values of these sediments are measured in the range of 2.9 to as 3.4, which indicate well-matured facies.

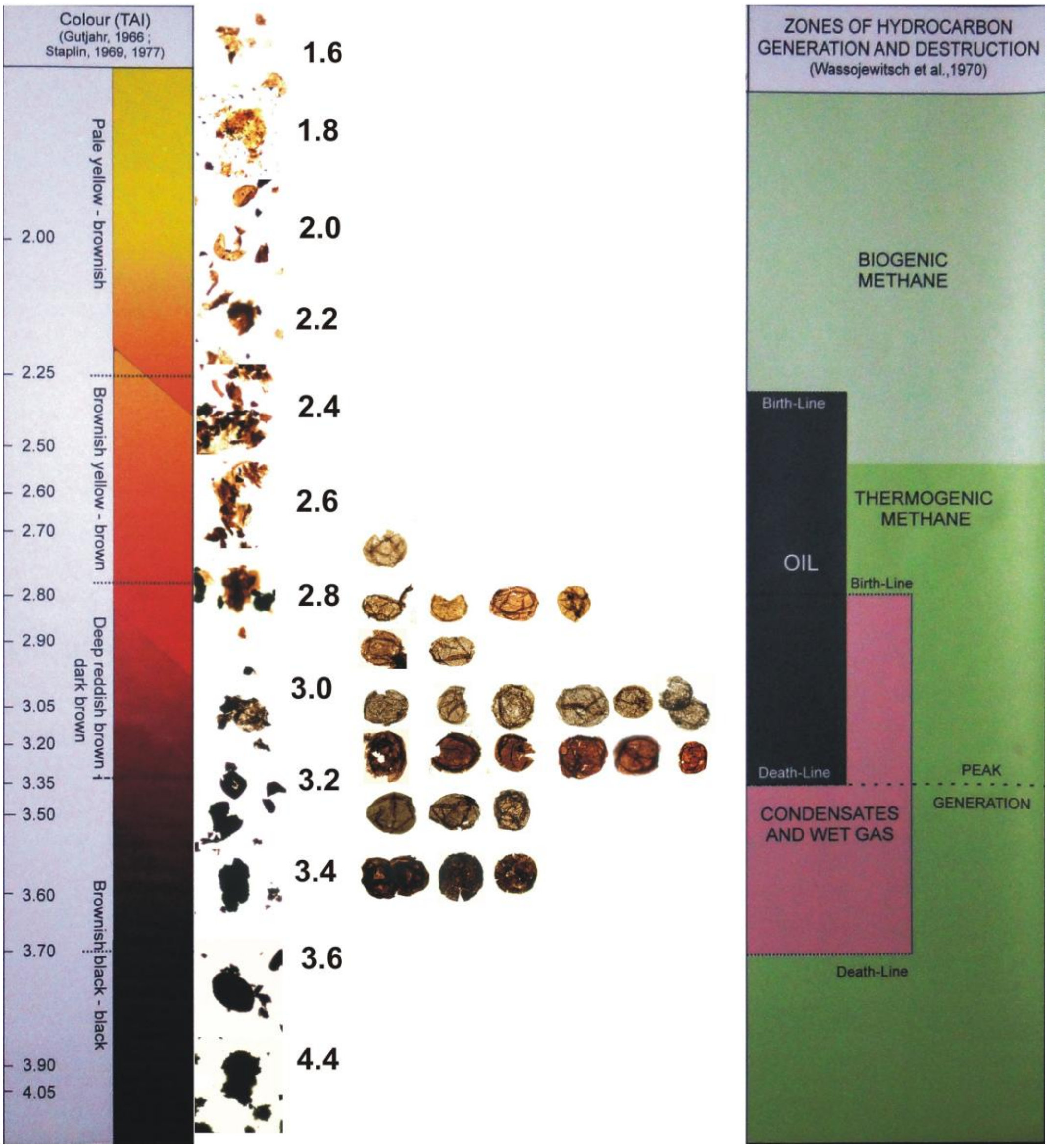
The Bhander limestone shows the TAI value from 3 – 3.4, this range comes in the oil to condensate gas zone of hydrocarbon generation and sediments of Lower Bhander Sandstone comes in the range of TAI value from 2.9 to 3.1, that represents oil window in the zone of hydrocarbon generation while the sediments of the Sirbu Shale shows value 3 of TAI that's indicate oil window in the zone of hydrocarbon. The studied sediments of the Bhander Group have sapropelic organic matter facies with adequate maturity ($2.9 < TAI < 3.1$) to generate liquid hydrocarbon while the studied sediments of the Bhander Limestone at Girgita quarry also has sapropelic facies with TAI 3.4, which consider to be good for condensates and wet gas generation and the value of Character (Ch) ratios, which are greater than 0.5, this indicate the gas character by the Wh and Bh ratios in associated with oil.

Plate 5.1



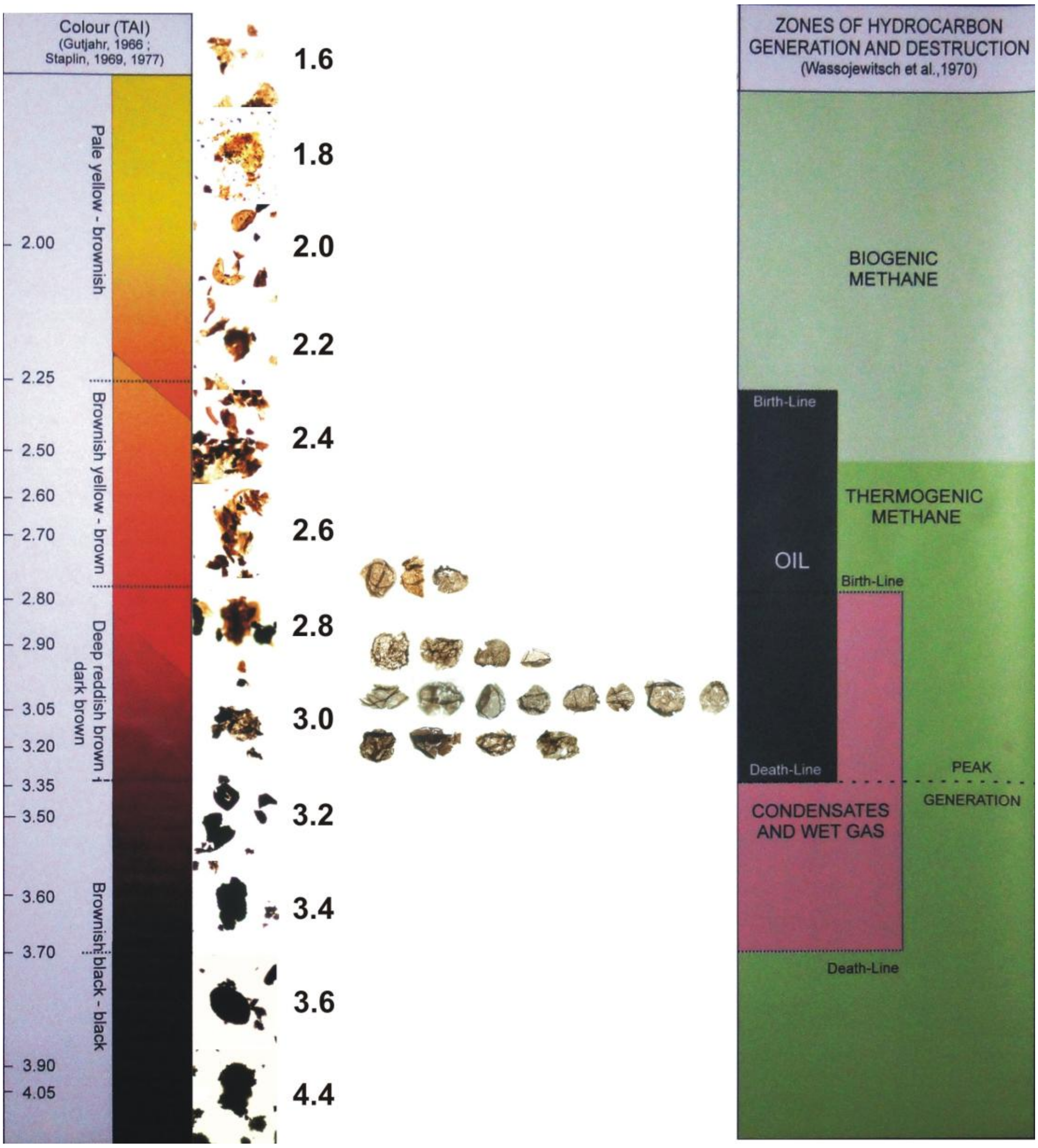
Thermal Alteration Index of the organic matter collected from the Rampur Hillock, Sirbu Shale, Bhander Group, Maihar area, Satna District, M.P.

Plate 5.2



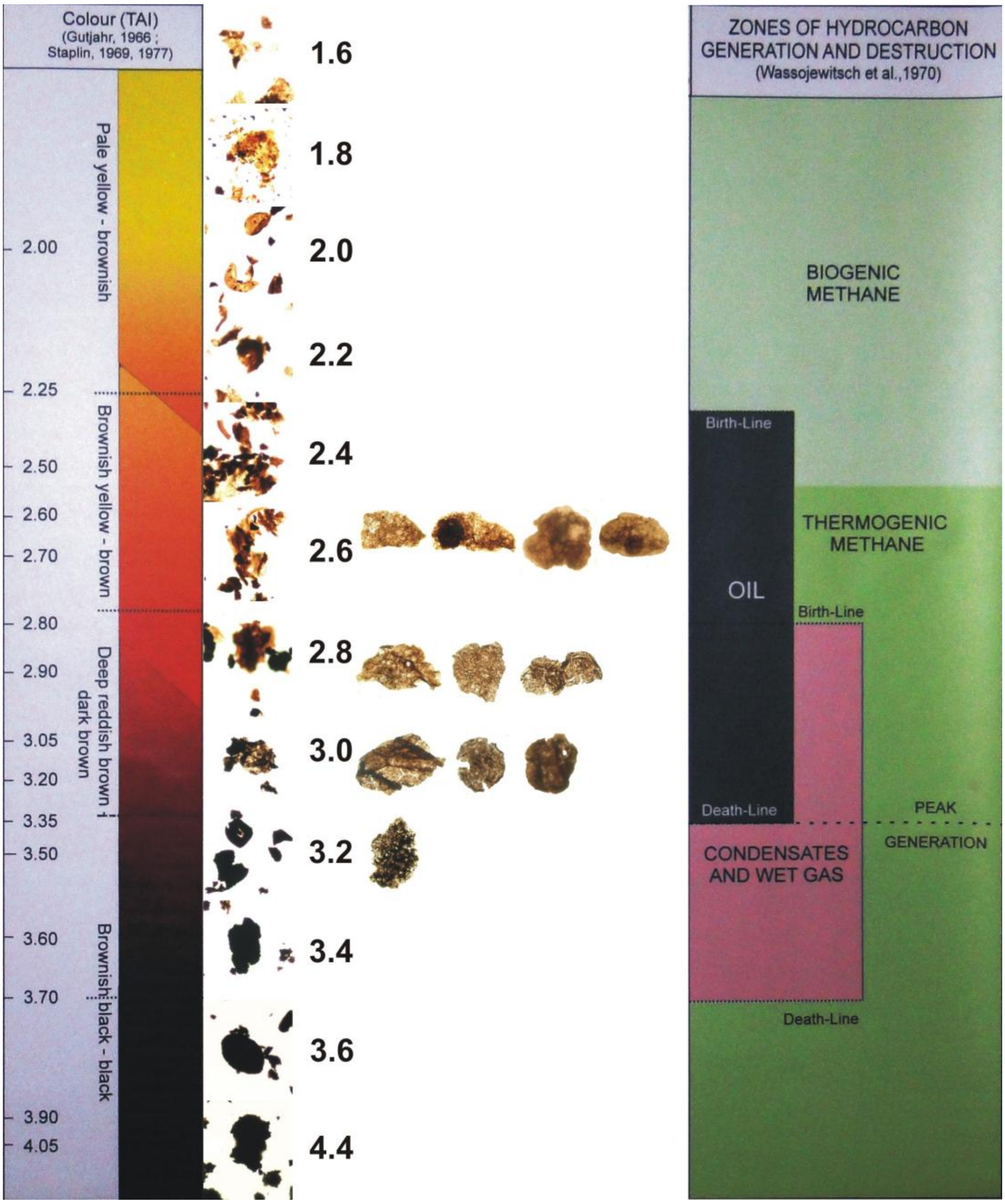
Thermal Alteration Index of the organic matter collected from the Dudhia Nala, Lower Bhander Sandstone, Bhander Group, Maihar area, Satna District, M.P.

Plate 5.3



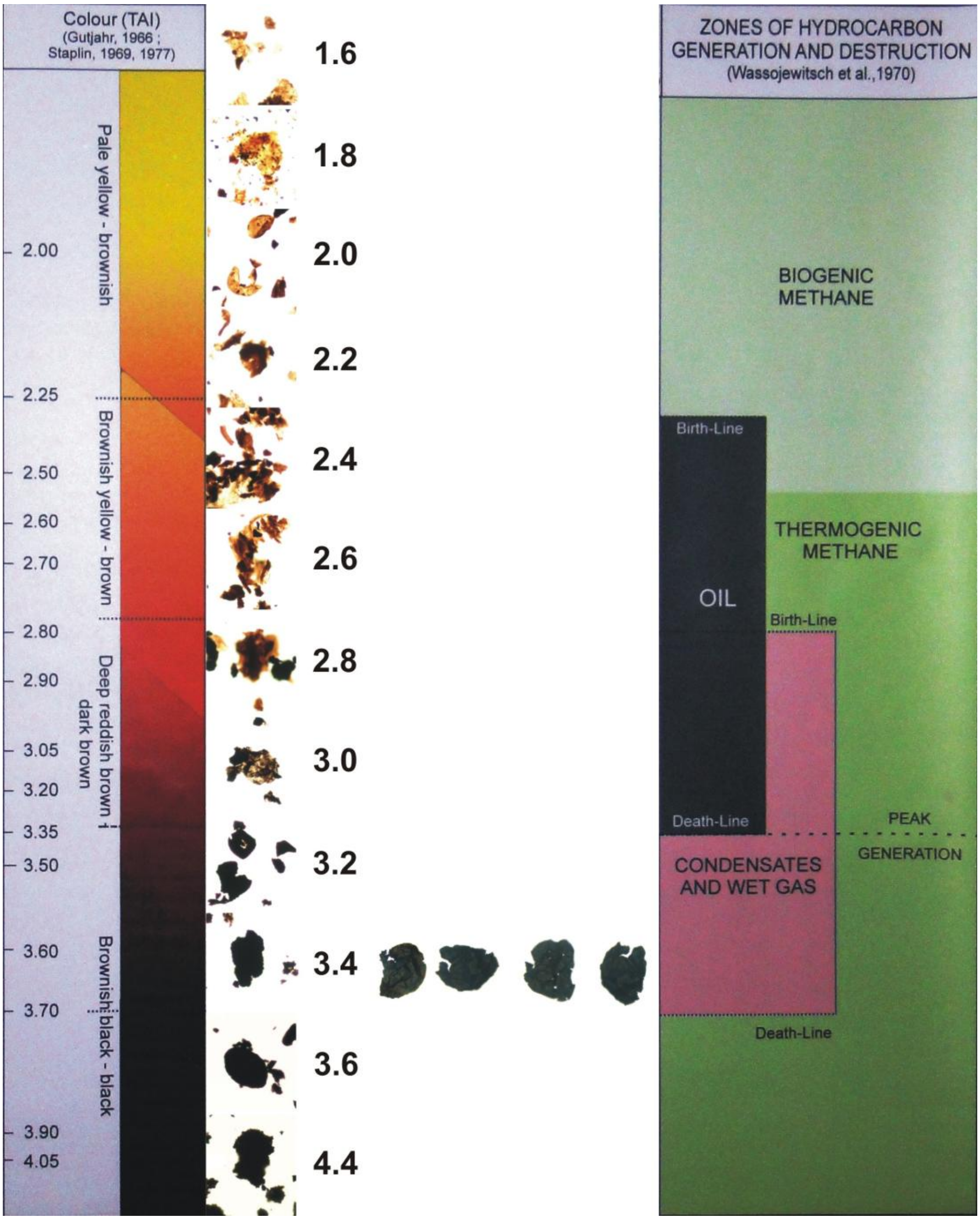
Thermal Alteration Index of the organic matter collected from the Karari Nala, Lower Bhander Sandstone, Bhander Group, Maihar area, Satna District, M.P.

Plate 5.4



Thermal Alteration Index of the organic matter collected from the Shahpur, Bhander Limestone, Bhander Group, Maihar area, Satna District, M.P.

Plate 5.5



Thermal Alteration Index of the organic matter collected from the Girgita quarry, Bhander Limestone, Bhander Group, Maihar area, Satna District, M.P.

Chapter 6

DISCUSSION AND CONCLUSION

6.1 Discussion

The Bhander Limestone and the Sirbu Shale of the Bhander Group have yielded carbonaceous megafossils attributed to *Chuaria circularis*, *Tawuia* and acritarchs from approximately all horizons except the Ganurgarh Shale. Ministromatolite from the Bhander Limestone, MISS and possible Ediacaran remains are recorded from the upper part of the Shikaoda Sandstone. The preservation, biostratigraphic and evolutionary significance of these fossils of the Bhander Group have been discussed in the following sections.

Megafossils Biostratigraphy – The discovery of circular carbonaceous disc from the Chuar Group, USA was later established as *Chuaria circularis* (Walcott, 1899, pp. 234-5; pl. 27, fig.12 and 13). *Chuaria* is widely distributed in Meso-Neoproterozoic sediments from all over the world (Krischvink, 1992; Dutta et al., 2006), as an exception it is also recorded from Palaeoproterozoic rocks (Hofmann and Chen, 1981). The origin, affinity and morphology of the taxon continue to be a big question even after a century of its discovery. Various workers established its relationship with gastropods, brachiopods, hyolithids, chitinous foraminifera, medusoides and trilobite eggs, or even considered it as inorganic (Spamer, 1988). Even today there is no general agreement regarding its position to which higher group kingdom or phylum- *Chuaria* belongs to, though most workers place it in the Plant Kingdom (Ford and Breed, 1973; Duan, 1982; Suresh and Sundara Raju, 1983; Sun, 1987; Hofmann, 1992a; Vidal et al., 1993). White (1928) first attempted to understand the affinity of the *Chuaria*; he suggested *C. circularis* was an alga, but his views were not accepted by later workers, *viz.* Hofmann (1971), Vidal (1974, 1976) and Jux (1977). Ford and Breed (1973) suggested that *Chuaria* was algal in origin, most likely a large size leiosperid. Duan (1982) suggested its proximity to the multicellular brown algae. Suresh and Sundara Raju (1983) described it as colonial alga similar to *Volvox* whereas according to Sun (1987) *Chuaria* was a colonial form constituted of filamentous cynobacteria comparable to the modern species *Nostoc microscopium*. The ideas of Sun were later supported by Steiner (1997), who proposed that *Chuaria* may have had various biological affinities ranging between prokaryotic colonies to eukaryotic algae, a view similar to Hofmann (1977b) who earlier suggested that *Chuaria*, as a fossil remanant, represents different biological groups. Kumar (2001) believed that there was a certain relationship among *C. circularis*, *Tawuia* and *Tilsoia*, three taxa of carbonaceous megafossils recorded from the Suket Shale of the Vindhyan basin, and these forms represent three different parts of the muticellular Chlorophycean/Xanthophycean plant; *C. circularis* representing a compressed cyst-like spherical body attached to *Tawuia* a filamentous thallus, of which *Tilsoia* acted as a holdfast and *C. vindhyanensis* was a new species, that represented spores of *C. circularis*. Kumar and Srivastava (2003) proposed a relationship among ring like body named *Bhanderia*, *C. circularis* and *C. dulniensis* and believed to have been produced by *Chuaria.* Maithy (2003) suggested that the *Chuaria-Tawuia* complex represented different generations of the same plant. Maithy and Babu (2004) proposed a model, that incorporated *Chuaria*, *Rohtasea*, *Amjohrea*, *Rampuraea*, *Nostoc*, and an imagined globose colony as constituents of vegetative cycle – 'Chuarid cycle'. *Tawuia, Sinosabellidites*, *Protoarenicola* and algal filaments with *Chuaria* were considered as reproductive endosporulating life cycle – 'Tawuid cycle'. Sharma et al. (2009) gave another model known as 'Hybrid Model'. This latest model, based on multidisciplinary study, assessing cylindrical and spherical shapes suggests variable cell wall strength and algal affinity for the *Chuaria*. This model discusses and demonstrates varied geometrical morphologies assumed by *Chuaria* and *Tawuia*, and also shows the inter-relationship of *Chuaria–Tawuia* complex. Different workers have tried to decode and explain its life cycle (Sun, 1987; Kumar, 2001; Kumar and Srivastava, 2003; Maithy, 2003; Maithy and Babu, 2004) but without universal acceptance. The Hybrid Model of Sharma et al. (2009) gives the clue to solve the puzzle of *Chuaria* and *Tawuia* relationship.

Hofmann and Aitken (1979) described a taxon that is characterized by straight and curved roundly terminated tomaculate-shape and named it as *Tawuia dalensis* Hofmann. This form is often found in association with *Chuaria* and hence has been considered to constitute the *Chuaria-Tawuia* complex. Knoll, (1982); Hofmann, (1985b) further supported allometric growth curves for *Tawuia*.

Worldwide data on carbonaceous megafossils of Proterozoic show that *Chuaria* represents a form taxon (where lower size limit is opened) with various probable biologic affinities to which mainly prokaryotic colonies and their outer envelopes contributed. Its occurrence ranges from Palaeoproterozoic into the Lower Cambrian, but main distribution lies within Neoproterozoic (Steiner, 1997). A different type of spirally coiled carbonaceous megafossil assemblage, known as *Grypania spiralis*, reported from the Early Proterozoic (2 Ga old) Negaunee Iron Formation, Lake Superior region, Michigan (Han and Runnegar, 1992) is considered as the oldest carbonaceous remains. Another occurrence in the Jixian Group China (Hofmann and Chen, 1981) is 1800 Ma old. Sharma (2006b) reported different varieties of the carbonaceous remains from the Koldaha Shale of the Semri Group which is considered as the 1700 Ma old assemblage. Srivastava and Bali, (2006) have reported another (~ 1600 Ma old) carbonaceous fossil assemblage from the Chorhat in the Vindhyan Supergroup and suggested that the smaller size of the Chorhat fossil either indicate low oxygen level or consistency in morphology from micro to megascopic level may represent a transitional phase of evolution from micro to megascopic life.

Due to its large geological range *Chuaria* alone is not a good indicator of age but it can be of some use if it is considered with *Tawuia. Tawuia, Longfengshania, Chuaria* and other taxa characterized 950 – 700 Ma old sequence and series to define a *Tawuia* assemblage zone (Hofmann, 1992c). *Tawuia* is reported from the five main areas of three continents (Hofmann, 1987). Vidal et al. (1993) reported *Chuaria* – *Tawuia* assemblage from Khastakh – 930 boreholes in the Lena Anabar depression, Northern Yakutia. They suggested the age for the carbonaceous remain was Late Riphean (~ Tonian). Maithy and Babu (1996) have given the age of the Bhander Group as the Late Proterozoic on the basis of assemblage of *Sphaerocongregus, Polytrichoides* and *Obruchevella* and the assemblage of *Chuaria* – *Tawuia* represent older than Sturtian glaciations (710 – 658 Ma) in Cryogenian Period.

Therefore, on the basis of the carbonaceous remains of *Chuaria* – *Tawuia* assemblage, we can consider the age of the Bhander Group as the Neoproterozoic.

Microbial Mat Biostratigraphy - The *Arumberia*-bearing Shikaoda Sandstone were deposited in a tidal influenced shallow water environment and can be suggested belonging to an Ediacaran age on the basis of worldwide occurrence of *Arumberia* near transition zone between latest Neoproterozoic and Cambrian. The suggestion of the proximity of the Cambrian gets diluted from the fact that there is no typical Cambrian fossil so far been reported from the Vindhyan rocks (Kumar and Pandey 2008). The reported Small Shelly Fauna and brachiopod by Azmi (1998) and specimen of *Spriggina* by Kathal et al. (2000) from the Rohtas Formation are untenable (see Kumar, 2001). The association of *Beltanelliformis* with *Arumberia* considered as a typical Ediacaran form gives credence to for the Ediacaran age to the Shikaoda Sandstone (Kumar and Pandey 2008). There are 16 reported occurrences of *Arumberia* from all over the world (Table 6.1). Three reports are from the Late Precambrian to Lower Cambrian (Walter, 1980; Kirschvink, 1978; Bland, 1984), three reports from the Ediacaran (Kumar and Pandey, 2009; Bogolepova et al., 2010), one reports from Early Neoproterozoic (Callow et al., 2011) and rests are from the Late Precambrian (Bland, 1984; Glaessner and Walter, 1975; Liu Xiaoliang, 1981). Bland (1984) opined that all the sequences in which *Arumberia* have been found, appear to be latest Precambrian to Lower Cambrian while McIlroy and Walter (1997) have said that it is present in the latest Neoproterozoic and has not been recorded from the pre-Ediacaran Proterozoic rocks. It appears that *Arumberia* flourished in the Ediacaran time frame.

In the light of the suggested Ediacaran age to the Shikaoda Sandstone, it is necessary to review the record of Ediacaran forms by De (2003, 2006) from the Bhander Group of the Maihar area, M.P. In 2003, he had described two medusoid genera resembling *Ediacaria* (Sprigg 1947) and *Hiemalora* (Fedonkin, 1982) from a shale horizon occurring at the base of the Bhander Group (Ganurgarh Shale), Maihar area, M.P. However, nothing can be made out from the photographs concerning the morphology and description provided by him. Much of the inferences are drawn on the basis of reconstruction based on the poorly reproduced photographs. It appears that these are not biogenic in nature and hence the identification is unacceptable. De (2006) further described 9 coelenterate genera, one arthropod genus and a few unnamed possibly new forms belonging to sponge and coelenterate from the two horizons belonging to Bhander Limestone and the Sirbu Shale respectively. None of the forms look convincingly biogenic. Like previous publications much of the inferences concerning the morphology of the

S. no.	Occurrences	Stratigraphic Horizon	Age	Country	Reference
1	*Arumberia*	Bonney Sandstone (Lowest Member of Pound Subgroup) in Flinders Ranges, South Australia.	Latest Precambrian	South Australia	Bland, 1984
2	*Arumberia*	Erudina Siltstone Member of the Billy Creek Formation.	Lower Cambrian	South Australia	Bland, 1984.
3	*Arumberia*	Arumbera Sandstone in Amadeus Basin, Central Australia.	Latest Precambrian (?)	Central Australia	Discovered by Banks in 1966 and described, named and illustrated by Glaessner & Walter, 1975.
4	*Arumberia*	The Central Mount Stuart Formation, Georgina Basin, Central Australia.	Sub-Cambrian to early Cambrian.	Central Australia	Noted by Kirschvink, 1978 & Walter, 1980.
5	*Arumberia*	The Longmyndian of England & Wales	Latest Precambrian (?)	England & Wales	Salter (1856 a, b, 1857),in Bland, 1984.
6	*Arumberia*	The Sylvitsa Series, Urals, U.S.S.R	Late Precambrian (?)	Erstwhile U.S.S.R.	Bekker, 1980 in Bland, 1984.
7	*Arumberia*	The Séries Rouges du golfe normanno-breton in Northern France & Channel Islands.	Low lower Cambrian (Slightly younger or older ages possible)	France & Channel Islands	In Bland, 1984.
8	*Arumberia*	Erquy and Bréhec Seqences.	Late Precambrian	France	Bland, 1984.
9	*Arumberia*	The Signal Hill & Musgravetown Groups, Avelon Peninsula, Newfoundland.	Latest Precambrian	Canada	In Bland, 1984.
10	cf. *Arumberia*	Auborus Formation, Nama System, South-West Africa.	Late Precambrian	South-West Africa	Miller, 1975, in Bland, 1984.
11	cf. *Arumberia*	Visigsö Formation	Late Precambrian	Southern Sweden	Kaudern, 1932 in Bland, 1984.
12	*Arumberia*	Mashan Group, Heilongjiang, North China.	Ediacaran affinity	Northern China	Liu Xiaoliang, 1981
13	*Arumberia*	Maihar Sandstone, Bhander Group	Ediacaran	Central India	Kumar & Pandey, 2008
14	*Arumberia*	Jodhpur Sandstone, Marwar Supergroup	Ediacaran	Western Rajasthan, India	Kumar and Pandey, 2009
15	*Arumberia*	Oatrov Formation	Ediacaran	East Siberia	Bogolepova et.al.,2010
16	*Arumberia*	Diabaig Formation,Torridon Supergroup	Early Neoproterozoic	Scotland	Callow et. al.,2011

Table 6.1- Occurrences of *Arumberia* from the different stratigraphic horizons. (modified after Kumar and Pandey, 2009).

forms are based on the reconstructions. With very poor quality material, it is difficult to make important and significant conclusions. In the Ganurgarh Shale at the base of the Bhander Limestone and in the overlying Sirbu Shale horizon *Arumberia* has not been recorded. Only in the Maihar Sandstone, the youngest horizon of the Bhander Group, *Arumberia* is abundantly seen (Kumar and Pandey 2008). In the light of the above facts the chances of the discovery of Ediacaran assemblage is possible only in the Maihar Sandstone horizon and to a certain extant in the Bhander Limestone and any Ediacaran fossil reported underlying this horizon needs a careful scrutiny.

Acritarch Biostraigaphy- It is hard to define what an acritarch is. The typical statement in the literature is: "Acritarch is a group of decay-resistant organic-walled vesicular microfossils.... Most acritarchs from the Proterozoic and Palaeozoic are interpreted as unicelled photosynthetic protists...." Huntley et al. (2006). Except this Buick (2010) suggested organic-walled microfossils of large size (50 micrometres or more) and of uncertain biological affinities are known as acritarchs, but in a simple way acritarchs are small organic fossils, present from approximately 3,200 million years ago to the present.

The Proterozoic includes over half the history of life on this planet, but the available data about Proterozoic organisms are exceedingly sparse. Acritarchs are like sharks' teeth from the Phanerozoic or cigarette butts from the 1960's. That is, they are found everywhere, are practically indestructible, and come in a variety of interesting shapes and sizes. They look informative, but ultimately tell us rather little about the organisms or ecosystem which produced them – other than the fact that it contained sharks or smokers, as the case may be. Acritarchs tell us even less because we don't know what produced them. Although acritarchs have been probed and prodded with almost every sort of device known to man, they have yielded relatively little detailed structural information. They are unmineralized, organic-walled structures. After sitting around for one or two billion years, almost all nano-scale molecular organization has been lost. What is left is kerogen, amorphous platelets of polycyclic aromatic hydrocarbons with no obvious resemblance to any familiar cell wall material. (Kempe et al., 2002).

Fossils from the Neoproterozoic (Tonian) include forms commonly identified as fungi and recognizable modern orders of green algae (Falkowski et al., 2004; Golubkova and Raevskaya, 2005). Huntley et al. (2006) have given new morphological features of the Neoproterozoic acritarchs that include "polyhedral vesicles, bulb-shaped vesicles, barrel-shaped vesicles, triangular and hair-like processes, funnel-tipped processes, processes that fuse at the tips, and flange ornamentation about the vesicle equator."

Generally speaking, the data from the Cryogenian is poor, but suggests continuity with the Tonian forms without dramatic changes in morphology or even diversity. Porter (2004) discovered, the first fossil remains of testate amoebae appear late in the Cryogenian – the first good evidence of heterotrophic Eukarya. He suggested Ediacaran life into two new communities, one associated with the Ediacaran animals (or whatever they may have been), followed by one associated with the transitional metazoans of the Doushantuo type. The latter include recognizable modern orders of red algae (Xiao et al. 2004). Many acritarchs from this period bore regular processes and surface ornamentation, e.g. *Appendisphaera*, *Ericiasphaera* (Golubkova and Raevskaya, 2005).

In the present study, acritarch genus *Leiosphaeridia* and *Ostiana* genus have been reported from the different formations of the Bhander Group, Vindhyan basin. *Leiosphaeridia* (Eisenack, 1958) comprises acid resistant, spherical to ovoidal microfossils without processes, without divisions into fields, and without traverse and longitudinal furrows or girdles. The cell wall is thin and without tubes, the surface is smooth or with slight ornamentation. An aperture (pylome) may be present, and has been considered as an excystment mechanism. Other methods of dehiscence are also recorded, e.g. by a split.

The original diagnosis by Eisenack in 1958 was slightly emended by Downie and Sarjeant in 1963 to include slight ornamentation and to exclude reference to colour. However, the view on color was taken earlier, and published by Eisenack in 1962. In the present study, acritarchs *Leiosphaeridia jacutica*, *Leiosphaeridia crassa*, *Leiosphaeridia minutissima*, *Leiosphaeridia tenuissima* and *Ostiana microcystis* have been found. All acritarchs belonging to *Leiosphaeridia* genus are reported from Mid-Proterozoic to Neoproterozoic. The number of reported occurrences of *Leiosphaeridia* significantly decreases between the Devonian and Jurassic. Species described from the Mesozoic and Tertiary is not recorded from the Proterozoic and Palaeozoic, and vice versa Lindgren (1982).

A number of efforts have been made to quantify the pattern of acritarch diversity across the Proterozoic, Knoll (1994); Porter (2004); Huntley et al.

(2006). In general they verify that after an initial burst of diversification in the later Palaeoproterozoic, development was gradual or even static until the Neoproterozoic. Surprisingly, evidence for a diversity or even abundance bottleneck as a result of the Cryogenian "snowball earth" episodes is weak to almost non-existent (Olcott et al., 2005). It might be fairer to say that the diversity curve began to take off in the Tonian and was, at most, slowed down in the Cryogenian.

The second acritarch genus *Ostiana* occurred in the Lower Bhander Sandstone, Bhander Group, Maihar area, Satna District. Generally *Ostiana* is constituted of spheroidal and ellipsoidal vesicles. These vesicles arrange into irregular planar colonies. Within colonies, vesicles connected to one another on two or more sides and compressed along conjuctions. The *Ostiana* occurre in the rocks of Mesoproterozoic to Neoproterozoic (Tonian - Ediacaran) age (Vorob'eva, et. al., 2009). This genus is reported mainly from Russia and East Europe. From Russia, the geological formations that have yielded *Ostiana* are the Burovaya and Miroedikha Formations, Turukhansk Uplift; the Nureyen Formation, Uchuro – Maya Uplift, Siberia; the Sabergfjellet Formation, Spitsbegen, and the Vychegda Formation, Timan Uplift, East European Platform.

As we know, the genus *Leiosphaeridia* has a very vast geological range and it was widely distributed in the Proterozoic rocks (Vorob'eva et al., 2009). The oldest well preserved examples come from mid-Proterozoic rocks that are about 1.8 billion years old (Knoll et al., 2006). Recently, Javaux et al. (2010) described large, well preserved acritarchs from rocks of Moodies Group of South Africa that date to about 3.2 billion year ago. Therefore, *Leiosphaeridia* cannot be used as index acritarchs for age determination, while the *Ostiana* occurring in the Lower Bhander Sandstone, Bhander Group, represents the age between Tonian to Ediacaran Period.

Molar Tooth Structure Biostratigraphy - Molar Tooth Structures (MTS) are unusual and enigmatic, temporally restricted, calcite bleb- and sheet-like structures hosted almost exclusively in Mesoproterozoic and Neoproterozoic continental ramp and shelf carbonates. Characteristically, MTS are sharply bounded, interconnected, often ptygmatically folded or broken structures filled with uniform fine blocky calcite, but with a distinct lack of detrital infill.

Collectively, their sedimentological characteristics indicate that the calcite-filled "channels" were not open to the sediment–water interface, and that they were an early, possibly pre-diagenetic, feature. Several models have been proposed for their formation, involving various physical, chemical and biological processes.

Several models have been proposed for the formation of MTS, including seismic activity, organic or microbial structures of some sort, gas-bubble expansion cracks, nodular and void-filling evaporites, subaerial dessication cracks, intrastratal syneresis cracks, changes in ocean chemistry (Sheilds, 2002) and dewatering caused by overburden pressure (see Pratt, 1998 and references therein, for a more detailed and well-considered discussion of many of the models proposed for MTS).

Presently two models for the formation of MTS dominate the literature: a gas-bubble expansion model and a seismic shaking model. Several studies (Furniss et al., 1998; Frank and Lyons, 1998; Winston et al., 1999) have shown that crack generation by gas-bubble expansion accompanying upward movement through a sedimentary sequence prior to lithification, is a viable explanation for the form and shape of these structures. In reference to the gas-bubble model, James et al. (1998) note the scarcity or absence of sediment-filled diastasis cracks in coeval rocks, and suggest that this implies some sort of seal at the top of the sediment column in which MTS formed. They reason that if the cracks were open to the surface, they would be filled with sediment, but note that there is minimal evidence of detritus with the sparry fill. In this regard they comment that it is instructive that the experiments of Furniss et al. (1998) produced molar tooth-like cracks only when the surface was sealed. James et al. (1998) then suggest that "the most parsimonious explanation is that the muds were covered by microbial mats". Research by Pratt (1998, 1999) suggests that MT formed via a larger scale "seismic event" in which the seismicity caused shrinkage, dewatering and fissuring of the unlithified seafloor clay and lime mud, followed by expulsion of a slurry of particles of lime mud into the newly created voids. This syndepositional earthquake-induced dewatering and shrinkage of the host clay-lime mud leading to MTS formation is suggested to be absent in Phanerozoic rocks because of changes in sediment rheology due to increased organic binding related to greater diversification of microbiota in the Phanerozoic (Pratt, 1998).

Besides these two important models, another theory has been given by Marshall and Anglin (2004) for the origin of deeper water MT that invokes the decomposition of CO_2-clathrates in the ramp carbonate sediment column. They suggest that the higher CO_2 partial pressures thought to be prevalent in the Proterozoic atmosphere allow for the stabilization of CO_2-clathrates in the sediment column not unlike the methane clathrates observed in the seafloor environment today. It is further postulated that the dramatic increase in molar volume associated with clathrate breakdown opens cracks and voids in the host sediment, and the precipitation of calcite associated with the breakdown of the CO_2-clathrates results in rapid (but not instantaneous) infill, and therefore, subsequent preservation of MTS. In this model the decomposition of the CO_2-clathrates may have been triggered by, or in turn have triggered, seismic shock waves. The collapse of the CO_2-clathrates could have expelled CO_2 gas forming pressurized voids in the sediment, which minimized clastic infill. The released CO_2 could have combined with seawater to precipitate $CaCO_3$. Thus, this model complements both the gas-bubble expansion and seismic shaking models, and can explain some, but not all, of the many diagnostic characteristics and occurrences of these intensely studied and oft-debated structures, especially those formed in deeper cooler waters.

The MTS investigated in this study were sampled from the Bhander Limestone of the Bhander Group, Vindhyan Basin from two different localities – Girgita quarry and Aber. As we know the formation of MTS reported exclusively in Mesoproterozoic and Neoproterozoic continental ramp and shelf carbonates. Hence, on the basis of the presence of the MTS, two age period either Mesoproterozoic or Neoproterozoic can be suggested. But in the case of studied MTS the age of sediments should belong to Neoproterozoic because the lower strata of the Bhander Group i.e. Kaimur Group deposited in the Mesoproterozoic (Bijaigarh Shale, Kaimur Group represent age 1670±60 Ma by Singh et al. (2002) on the basis of Re-Os method, Kimberite pipe, intruding Kaimur represent age 1140±12 Ma by Crawford and Compston, 1970 on the basis of Pb-Pb, isochron method and Sandstone of the Kaimur Group represent age 1150 Ma by Paul et al. 1975 on the basis of K-Ar method). Therefore, the age of the Bhander Limestone, Bhander Group should be Neoproterozoic.

Microstromatolite Biostratigraphy- Worldwide occurrences of microstromatolite are found in Palaeoproterozoic or Early Mesoproterozoic successions. In India same pattern has been noted in the microstromatolite in the Cuddapah and Kaladgi Supergroup and from Buxa dolomites (Sharma et al. 1998; Tewari, 2001; Sharma and Shukla, 2004; Sharma and Pandey, 2012). The studied microstromatolite has been reported from the Bhander Limestone, Bhander Group and the locality is Aber, Satna District, M.P. The age of this microstromatolite create contradiction with previously reported other microstromatolites world over. Only two occurrences of mini and microstromtolites are now known from Neoproterozoic deposits of India; one is from the same horizon by Kumar (1999) and second by Tewari (2001) from Menga Limestone, upper Subansiri District, Arunachal Pradesh. With limited known occurrences of mini and microstromatolites, their biostratigraphic significance could not be evaluated. In the field microstromatolite situated above MTS. As we discussed above the age of MTS is Neoproterozoic. Hence these microstromatolites should be younger then MTS and strictly lies in Neoproterozoic.

Organic Matter Maturation- The present study deals with the hydrocarbon source rock evaluation of the Bhander Group exposed around Maihar area, Satna District, M.P. Hydrocarbon potential of these sediments is estimated on the basis of palynofacies analysis and thermal alteration index (TAI) values based on the organic matter/acritarchs colouration. The palynofacies analysis of the Bhander Group in the area reveal moderate to rich organic matter, with marine organic matter constituting the bulk of the total organic matter, followed by structural marine organic matter, amorphous organic matter and black debris. The Bhander Group that has been divided into five different formations shows different level of maturation. The range of TAI for the Bhander Group lies in the 2.9 – 3.4. Thus the generated hydrocarbon will be of thermogenic. According to this range of TAI maturity of organic matter that would have generated hydrocarbon should lie in oil window to condensate gas window.

6.2 Conclusions

Different palaeobiological evidence suggests that the Bhander Group is the Neoproterozoic succession and not older than 1000 Ma.

The present work leads to the following salient conclusions:

- The Palaeobiological assemblage in the Bhander Group, Vindhyan Basin is represented by diversified remains *viz.* microstromatolite, macroscopic carbonaceous fossils, microbially induced sedimentary structures, mat related sediments and possible Ediacaran remains.
- Abundant preservation of carbonaceous forms attributed to *Chuaria circularis, Tawuia dalensis* have been recorded from the shales and siltstone of the Bhander Limestone and the Sirbu Shale.
- Presence of *Chuaria-Tawuia* assemblage in the Bhander Limestone and Sirbu Shale of the Bhander Group indicative of the age of these formation closer to Hofmann's (1992c) upper subzone of *Tawuia* assemblage zone (900-700 Ma old).
- Rich quantity of acritarchs *Leiosphaeridia jacutica*, *Leiosphaeridia crassa*, *Leiosphaeridia minutissima*, *Leiosphaeridia tenuissima* and *Ostiana microcystis* extracted from the shale and siltstone units of the Lower Bhander Sandstone and the Sirbu Shale of the Bhander Group.
- Genus *Leiosphaeridia* cannot be used as index acritarchs for age determination, while the *Ostiana* occurring with the Lower Bhander Sandstone, Bhander Group, represents the age between Tonian to Ediacaran Period.
- Well preserved microbial mats and microbial mat meditated structures, *Arumberia Banksi* and *Arumberia vindyanensis* have been recorded from the upper middle part of the Shikaoda Sandstone.
- *Arumberia*-bearing Shikaoda Sandstone was deposited in a tidal influenced shallow water environment. An Ediacaran age on the basis of worldwide occurrence of *Arumberia* near transition zone between latest Neoproterozoic and Cambrian can be suggested.
- The Molar Tooth Structure (MTS) investigated in this study indicate the age of the Bhander Limestone, Bhander Group should be Neoproterozoic.

- Microstromatolite exposed above MTS, located at Aber area of Satna District. M.P is younger than the MTS and were also formed in Neoproterozoic.
- Possible Ediacaran element *Charniodiscus* sp. first time reported from the upper part of the Shikaoda Sandstone suggested upper most part of the unit close to oldest occurrence of the petalonamae (575-565 Ma).
- Organic matter collected from the Bhander Limestone, Lower Bhander Sandstone and Sirbu Shale of the Bhander Group studied for Thermal Alteration Index (TAI) aspect. The range of TAI for the Bhander Groups lies in the 2.9 – 3.4, that represent oil window in the Zone of Hydrocarbon Generation.
- Bernard plot represent thermogenic origin of light hydrocarbons.
- Character (Ch) ratios, which are greater than 0.5, indicate the gas character by the Wh and Bh ratios in associated with oil.

Therefore the main contribution of the thesis is the documentation of palaeobiological remains of the Bhander Group. On the basis of these remains, it is concluded that youngest stratigraphic unit of the Bhander Group exposed in the Maihar area belongs to the Ediacaran Period (635 Ma – 542 Ma). The other evidence also points out its Neoproterozoic affinity. Collectively all the palaeobiological evidence suggests that the Bhander Group is Neoproterozoic succession and not older than 1000 Ma, as suggested by some other workers based on palaeomagnetic studies. Further studies in the Bhander Group hold promise for the discovery of many other younger palaeobiological remains. It also records how thermal maturation of the organic matter changes the colour of acritarchs and provides an important tool for the identification maturity of organic matter and zone of hydrocarbon generation.

SUMMARY

The present thesis incorporates the results of a detailed study which has been carried out regarding the palaeobiology, and biostratigraphy of the Bhander Group of the Vindhyan Supergroup. Microbial mats, microstromatolites, megafossils, microfossils and possible Ediacaran remains have been recorded for suggesting the age of the different biozones within the Bhander Group. Organic matter maturity is made on the basis of Thermal Alteration Index determination. Specimen recovered from different formations of the Bhander Group help established the zones of hydrocarbon generation and destruction. The important conclusions of the work are summarised chapter wise.

Chapter – 1 introduces the problem of the Bhander Group. It is the youngest horizon of the Vindhyan Supergroup. The main problem in the Bhander is to ascertain its age. Only radiometric date available in the Bhander Group needs fortification to provide definite age bracket to this group. Therefore, only alternative available tool for correlation is palaeobiological remains from the different stratigraphic horizons of the Bhander Group. Some of the specific problems are discussed below:

The stratigraphy of this basin has become more complicated when different ages have been assigned to the same horizon by different workers. For an example regarding age of the horizon, Friedman et al. (1996) report the presence of Precambrian-Cambrian boundary between the Bhander Limestone and the Sirbu Shale on the basis of the carbon isotope data and the same boundary when suggested within the Rohtas Formation by Azmi (1998) on the basis of the discovery of small shelly fossils and brachiopod contradicts each other. Bengtson (2009) has resolved the age controversy concerning the Rohtas Formation of the Semri Group, but raised many questions for the correlation of early life (Kumar, 2009).

Malone et al. (2008) have asserted that the Upper Bhander Sandstone (the Maihar Sandstone) should be older than 750 -771 Ma and is likely close to 1073 Ma on the basis of palaeomagnetic data and detrital geochronology. It means that the sedimentation in the Vindhyan Basin ended ca 1000 Ma. This data fails to

address the available radiometric and palaeontological data. At the same time the microbiota study in petrographic thin sections of black bedded chert, though reliable but hard to find. Therefore, it narrows down to only stromatolites, algal mat texture, megafossils and microfossils as only available tools for correlation. Based on these parameters biostratigraphic age solution can be attempted. However it is really difficult to recognize the Neoproterozoic deposits in absence of radiometric data and index fossils.

Thermal maturity played a great role in the generation of hydrocarbon, on the basis of it organic matter convert into oil, gas or in graphite due to high temperature and pressure. In the present study, maturity of organic matter from different formations of Bhander Group determined by Thermal Alteration Index (TAI). Objectives of the proposed study and implications of work are also discussed.

Chapter – 2 deals with the geology and stratigraphy of the Vindhyan Supergroup. The Vindhyan sediments spread over an area of more than 2,00,000 sq km constitutes the largest Proterozoic basin in India. Out of which about 80,000 sq km is covered by the Deccan Trap and possibly 10,000 sq km lies hidden under the Gangetic alluvium (Mathur, 1965; Jokhan Ram et al., 1996). Representing deposits of an intracratonic basin, the Vindhyan Supergroup attains a huge thickness of more than 5 km. The rocks are represented by sandstones, shales, limestones, dolostones, conglomerates and porcellanites. The rocks are unmetamorphosed and least disturbed. The rocks, in general, show excellent preservation of sedimentary structures and many fossil assemblages (Auden, 1933; Valdiya, 1969; Singh, 1976; Kumar, 1980, 2001; McMenamin et al., 1983; Prasad, B., 1984; Shukla and Sharma, 1990; Sharma 1996; Venketachala et al., 1996; Kumar and Srivastava, 1997a, b, 2003; Misra and Kumar, 2005; Sharma 2003; De, 2003, 2006; Sharma, 2006a,b,c; Prasad, 2007; Prasad et al., 2007; Kumar and Pandey 2007, 2008; Sharma et al., 2009; Sharma and Shukla, 2009a,b). Oldham (1856) and Mallet et al. (1869) gave the original classification of the Vindhyan Supergroup which is based on the nature of Vindhyan rocks of central India and Rajasthan. Later on many eminent workers have given significant contribution to the knowledge of the Vindhyans, which have been discussed in detail. All the research workers are unanimous in dividing the rock sequences of the Vindhyan

Supergroup in four groups. The Vindhyan Supergroup has been subdivided into four groups; in stratigraphic order these are the Semri Group, the Kaimur Group, the Rewa Group and the Bhander Group. Each group is further subdivided into different formations. The Semri Group is generally referred to as the Lower Vindhyan and the Kaimur, Rewa and Bhander Group have been clubbed as the Upper Vindhyan. The Bhander Group is the youngest group of the Vindhyan Supergroup. However, the Vindhyan Basin shows different lithological succession in the eastern and western part of the Basin. Lithological succession in the eastern part is referred to as the Son Valley Section and the western part of the Vindhyan Basin referred to as the Chambal Valley Section.

Geology of the Bhander Group of the Son Valley Sections has been discussed in detail. In the Son Valley Section, the field work for the present thesis has been done in the Maihar area, Satna District, M.P. The Bhander Group has been subdivided into five formations; in stratigraphic order these are the Ganurgarh Shale, the Bhander Limestone, the Lower Bhander Sandstone, the Sirbu Shale and the Sikaoda Sandstone. The age assessment has been discussed for the Bhander Group. Main problem of the Bhander Group is poor radiometric dates and any index fossil. Reported Ediacaran fossils are convincingly biogenic, thus in absence of any typical Cambrian fossil the Bhander Group is considered Neoproterozoic in age.

Chapter – 3 gives the brief information of materials and methods used during the present study. Outcrop investigations and sample collection in the field are the main bases of geological studies. The study area lies around Maihar, Satna District, M.P. The Bhander Group is best exposed here. Microbial Mat and stromatolite are reported from different formations of Bhander Group. The collected field specimens were prepared in the labs for data generation. Insoluble organic microfossils were extracted from surrounding rock matrix by maceration method. Thin sections were prepared for petrographical analysis, photo documentation was done with help of light microscope for megafossil, high power microscope was used for microfossil and Scanning Electron Microscope (SEM) was used for microfossil surface topography studies.

Palynological slide preparation and Total Alteration Index (TAI) analyses were conducted to find out maturation of organic matter. Geochemical analysis were carried out in Geochemistry Department , NGRI, Hyderabad that include Total Organic Carbon (TOC), measurements of black shale and carbonate samples, Gas Chromatograph-Combustion-Isotope Ratio Mass Spectrometer (GC-C-IRMS). All these geochemical tools were used to find out organic maturity and presence of organic matter for hydrocarbon generation.

Chapter – 4 incorporates the detailed palaeobiological studies which have been carried out on the the samples of Bhander Group of the Son Valley Sections. The Bhander Group of the Son Valley Sections has yielded microbial mats, microfossils and microstructures, stromatolites and megafossils. Most significant proxy is Possible Ediacaran Remains, which has been studied for the first time in the Bhander Group from Uppermost part of the Maihar Sandstone. Besides, for the first time Acritarchs *Leiosphaeridia jacutica, Leiosphaeridia Minutissima, Leiosphaeridia crassa, Leiosphaeridia tenuissima* and *Ostiana Hermann* are reported from the Lower Bhander Sandstone.

The Bhander rocks have now yielded well preserved microbial mats and microbial mat mediated structures. *Arumberia banksi* is one of the examples which are well flourished in the upper middle part of the Maihar Sandstone, therefore the Shikaoda Sandstone can be suggested of an Ediacaran age on the basis of worldwide occurrence of *Arumberia* near transition zone between latest Neoproterozoic and Cambrian (Kumar and Pandey, 2008). *Arumberia* is considered as organosedimentary structure formed by the interaction of microbial community with the siliciclastic sediments. They flourished in shallow marine tidal setting. *Arumberia* which is considered as a typical Ediacaran form gives additional support for the Ediacaran age to the Shikaoda Sandstone.

Chuaria circularis and *Tawuia dalensis* have been reported from the Bhander Limestone and the Sirbu Shale, Son Valley Section. In the present study maximum length of *Tawuia dalensis* recorded from the Bhander Group i.e. 9 mm. Megafossils which can be confidently accepted as true fossil are the carbonaceous megafossils and all have algal affinity. Thus, in absence of any typical Cambrian fossils, the carbonaceous megafossils point to a Precambrian age, except *Chuaria-Tawuia* assemblages which can be bracketed between 950 – 700 Ma.

Chapter – 5 concerns with maturity of Organic Matter from the Bhander Group. In this method we determine the Thermal Alteration Index (TAI) from the colour of organic matter. The change in color of organic particulate debris with increasing thermal increments is an easily observable feature that requires only routine palynological preparations for its use. With proper standardization of techniques, arbitrary numerical values may be applied to the color change sequence, and related with other, more sophisticated means of determining the level of maturation. The Bhander Group that has been divided into five different formations shows different level of maturation. The range of TAI for the Bhander Group lies in the 2.9 – 3.4. The methane will be thermogenic. According to this range of TAI maturity of organic matter that would have generated hydrocarbon should lie in oil window to condensate gas window.

Chapter – 6 gives an account of overall view of Palaeobiological evidences and hydrocarbon maturation in the Neoproterozoic Bhander Group**.** This portion of thesis deals with the comparable discussion of the present work with its counterpart worldwide, what is the scope of palaeobiological remains, formation of Molar Tooth Structure (MTS) and its application to shortlist the age of the formation.

The Bhander Group of the Son Valley Sections has yielded microbial mats, microfossils and microstructures, stromatolites, and megafossils. Most significant proxy is microbial mat, which has been thoroughly studied in the Bhander Group. The Bhander rocks have now yielded well preserved microbial mats and microbial mat mediated structures. *Arumberia banksi* is one of the examples which are well flourished in the upper middle part of the Shikahoda Sandstone, therefore Shikaoha Sandstone can be suggested an Ediacaran age on the basis of worldwide occurrence of *Arumberia* near transition zone between latest Neoproterozoic and Cambrian (Kumar and Pandey, 2008). They flourished in shallow marine tidal setting. The association of *Beltanelliformis* with *Arumberia* which is considered as a typical Ediacaran form gives additional support for the Ediacaran age to the Maihar Sandstone. Most significant proxy is Possible Ediacaran Remains, which has been studied for the first time in the Bhander Group from Upper part of the Maihar Sandstone

Chuaria circularis and *Tawuia dalensis* have been reported from the Bhander Limestone and the Sirbu Shale, Son Valley Section. Megafossils which can be confidentially accepted as true fossil are the carbonaceous megafossils and all have algal affinity. Microfossils are extracted from the different formation of the Bhander Group by maceration technique.

Maturation of the Bhander Group has been tested by Thermal Alteration Index (TAI) and found that the maturity of the organic matter increases in respect of lithostratigraphy (BLSt > LBSt > SS) Shahpur locality of the Bhander Limestone is a exception here and lie in the range of oil to wet gas condensate window. Apart from this Total Organic Carbon (TOC) study has incorporated in the present study of the Bhander Group and found that its lie in the range of 0.17 to 0.32 %.

Therefore the main contribution of the thesis is the documentation of palaeobiological remains of the Bhander Group. On the basis of these remains, it is concluded that youngest stratigraphic unit of the Bhander Group exposed in the Maihar area belong to the Ediacaran Period (635 Ma-542 Ma). The other evidence also points out its Neoproterozoic affinity. Collectively all the palaeobiological evidence suggests that the Bhander Group is Neoproterozoic succession and not older than 1000 Ma, as suggested by some other workers based on palaeomagnetic studies. Further studies in the Bhander Group hold promise for the discovery of many other younger palaeobiological remains. It also records how thermal maturation of the organic matter changes the colour of acritarchs and provides an important tool for the identification maturity of organic matter and zone of hydrocarbon generation.

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