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THE PALAEOBIOLOGICAL REMAINS OF THE OWK SHALE, KURNOOL BASIN: A DISCUSSION ON THE AGE OF THE BASIN

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ABSTRACT

Proterozoic microfossils emerge as a powerful tool of Precambrian biostratigraphy in determining age of encompassing rocks and correlation of the distant sedimentary successions. In the absence of any direct radiometric dating, the age of Kurnool Group is poorly constrained. In the Owk Shale assemblage, four species of *Obruchevella,* viz. *O. delicata*, *O. minor*, *O. parva* and *O. valdaica* were recorded as an organic walled microfossil. In addition, sphaeromorphic acritrach *Leiosphaeridia* and probable Vaucherian algae *Jacutianema* also make their appearance in the present assemblage. Documented species of *Obruchevella* are reported mostly from close to the Precambrian-Cambrian boundary successions thereby implying the younger age of the Kurnool basin. The present study discounts the possibility of recently assigned Mesoproterozoic age of the basin and supports the Neoproterozoic age for the Kurnool basin.

Keywords: Acritarchs, *Obruchevella*, Kurnool Group, Neoproterozoic, Palaeobiology, India

INTRODUCTION

In Precambrian, the occurrence of certain assemblages and microfossils clearly demarcates the age of the fossil-bearing sediments. In absence of radiometric dates, the age of many Precambrian successions are indirectly deduced with the help of the fossil assemblages occurring in the sediments. A number of Proterozoic basins of India entomb signatures of early life in peninsular as well as in the extra-peninsular region. Purana basins constitute a group of less disturbed and unmetamorphosed ‘Proterozoic’ platformal sediment packages, resting on the deformed and metamorphosed Archaean to Palaeoproterozoic basement, with a profound unconformity (eparchaean) in several parts of Peninsular India (Holland 1906). These basins, though widely separated, bear similarities in their lithologies and depositional settings and are supposed to be coeval (Chaudhuri *et al*., 1999). These Precambrian successions are poorly dated. In the absence of adequate radiometric dating and paucity of the biostratigraphic data, it is difficult to ascertain their precise age.

The Kurnool Group, exposed in the Kurnool and Palnad sub-basins, is a mildly deformed and feebly metamorphosed sedimentary sequence in south India. Absence of any volcanic components in the basin is the main reason for paucity of the geochronological data and therefore the available age connotations are primarily indirect (Kale and Phansalkar, 1991). Dongre *et al.* (2008) discovered limestone xenolith in the vicinity of the Kurnool and Bhima basins which evoked a new debate on the age of these basins. The limestone xenolith has been considered to be the part of the sedimentary rocks which were available in the vicinity of the kimberlite emplacement. The Bhima and the Kurnool basins were inferred to be inter-connected at the time of kimberlite intrusion and the closest sedimentary rocks. On the basis of the age of the kimberlite, they suggested Late Mesoproterozoic age (older than 1090 Ma) to the Kurnool and Bhima basins. The new proposition challenges the age of the Kurnool basin. Contrary to this suggestion, previously on the basis of fossil evidence and lithostratigraphic correlation, the Kurnool Group has been assigned the Neoproterozoic age (Vijyam, 1967; Salujha *et al.,* 1972; Arya and Rao, 1979; Kale and Phansalkar, 1991; Sharma and Shukla, 1999; Sharma, 2008). The new proposition by Dongre *et al.* (2008) challenges the age of the Kurnool Basin.

The present paper discusses the problem of the age of the Kurnool Group and presents the new data on the palaeobiological remains.

The newly discovered occurrence of helically coiled microfossil *Obruchevella* from the Owk Shale, together with the burrow structures in the Narji Limestone suggest Ediacaran age for the Kurnool Basin and even closer to the Cambrian (Sharma and Shukla, 2012a). In the backdrop of poor age constraints, fresh biostratigraphic investigation has been undertaken on the Kurnool Group. The present study discusses the relevance of newly recorded microfossils from these shales; discusses the problem of the age of the Kurnool Group on a wider perspective and challenges the recently assigned Mesoproterozoic age of the basin; and supports the Neoproterozoic age for the Kurnool Basin based on the occurrence of microfossil *Obruchevella* and other previously reported biota.

GENERAL GEOLOGY

An approximately 500 m thick succession composed of two repetitive cycles of quartzite, limestone and shale overlies the Cuddapah sediments. The Kurnool rocks are confined in two areas, one in the western part of the basin, in the Kundair valley, and the other in the northeast part in the Palnad basin (Fig. 1). The lithostratigraphic succession of the Kurnool Group is given in Table 1. In the stratigraphic order, these are Banganpalle Formation, Narji Limestone, Owk Shale, Panium Quartzite, Koilkuntla Limestone and Nandyal Shale.

The Banganpalli Quartzite, a basal formation of the Kurnool Group, consists of coarse-grained dark red, grey or brown

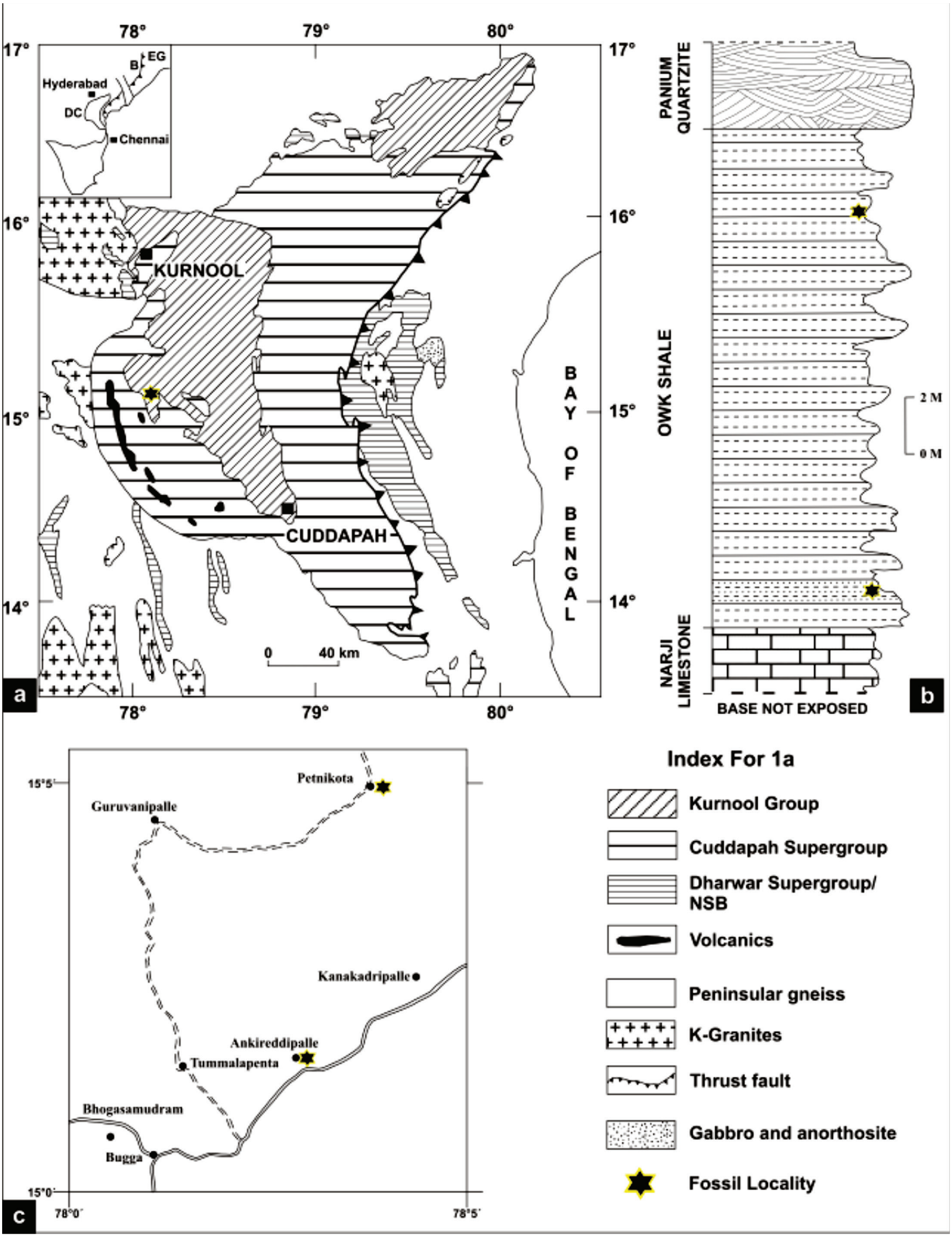

Fig. 1. (A) Generalized geological map of the Kurnool basin (after Misra, 2011). (B) Lithostratigraphic succession exposed at Ankireddipalle village, Kurnool district, Telangana showing the Narji Limestone, Owk Shale and Panium Quartzite. Circles indicate the level of the occurrence of carbonaceous fossils. (C) Locality map of the fossil-yielding areas in Ankireddipalle village, Kurnool district of Telagana.

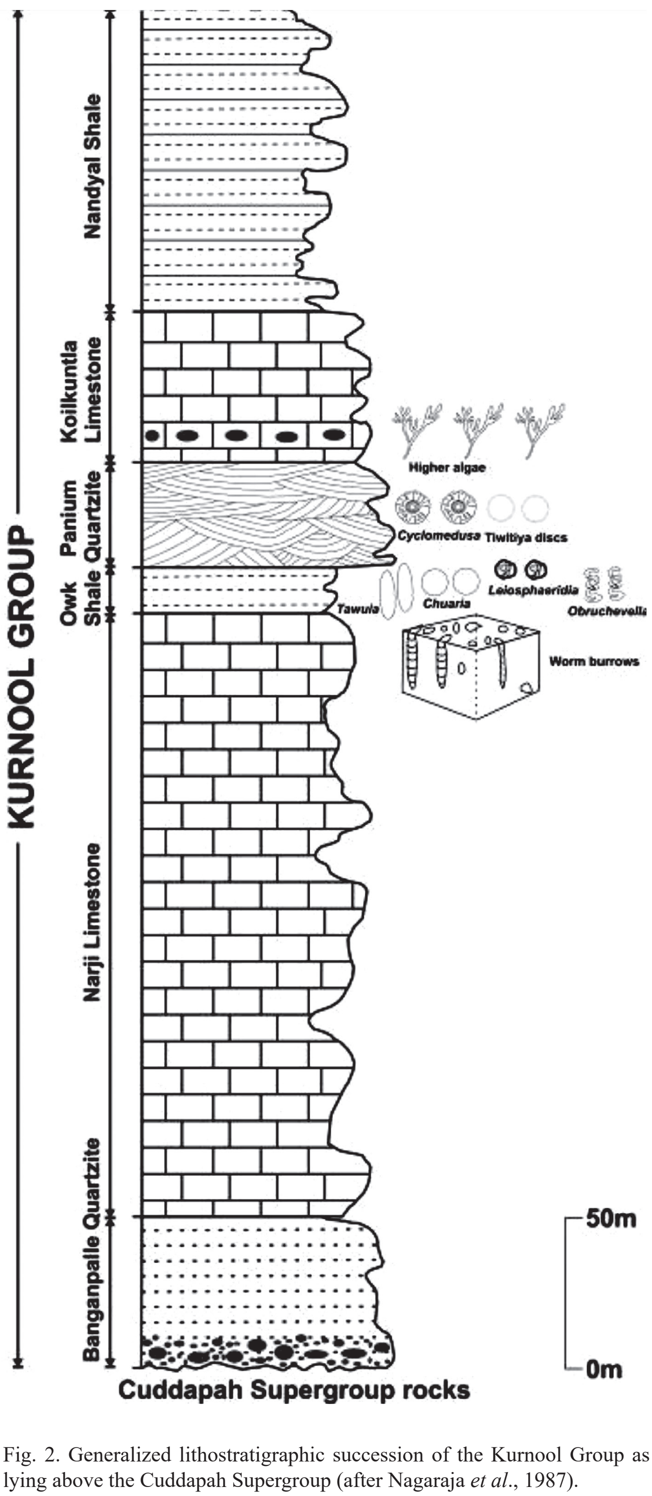

Fig. 2. Generalized lithostratigraphic succession of the Kurnool Group as lying above the Cuddapah Supergroup (after Nagaraja *et al*., 1987).

sandstone. An impersistent zone of conglomerate is also found overlapping onto several units of the Cuddapah Supergroup. Well developed and extensively distributed Narji Limestone overlies the Banganpalli Quartzite which is black and grey in colour. This limestone grades into bluish-grey high grade limestone in the middle portion and further into calcareous flags. The Narji Limestone, in turn, is overlain by buff, white or purple coloured shales - the Owk Shale. The Owk Shale is a well-laminated, thin-bedded unit with shales, siltstones, and silty-clay stones. These shales intercalate with thin-bedded silty claystone in the lower part and siltstone in the upper part. Microfossil assemblage reported in the paper was recovered in the Owk Shale. The Owk Shale grades upwards into the massive Panium Quartzite which, in turn, is overlain by the Nandyal Shale (See Fig. 2).

There is no record of suitable rock unit or any igneous intrusion known from the Kurnool Group, therefore the absolute age of the Owk Shale as well as the entire Kurnool Group cannot be determined by the direct radiometric dating. Saha and Tripathy (2012) have recorded tuff beds above the Owk Shale that can provide a definite age in near future.

AGE

Crawford and Compston (1973) concluded that the base of the Kurnool Group, not intruded by any igneous rock, is not older than 1090 Ma and could be younger than 870 Ma (Rb/Sr ages for dolerite). The Banganpalli Quartzite forming the basal unit of the Kurnool Group is diamond bearing. Source of these diamonds is considered to be the Vajrakarur Kimberlite which has been dated as 1140 Ma (Crawford and Compston, 1973). Kumar *et al.* (1993) dated the Kimberlite pipes which provided the detritus to the diamond-bearing conglomerate of the Banganpalle Quartzite as ~ 1090 Ma. If it is correct, then the Kurnool sedimentation is younger than 1090 Ma. Ramam and Murthy (1997) proposed the maximum age of 980 Ma (Rb/Sr) and minimum age of 500 Ma (K/Ar) for the shales of the Kurnool Group. The occurrence of limestone xenolith in the Siddanpalli Kimberlite is considered to have been assimilated from the closest sedimentary rocks of the Bhima or the Kurnool basins which were available in the vicinity of kimberlite emplacement. Assuming these conditions to be correct, Dongre *et al.* (2008) suggested Late Mesoproterozoic age (older than 1090 Ma) to the Kurnool basin. Chalapathi Rao *et al* (2010a) inferred the upper age limit of the Kurnool Group to be > 1.1 Ga. These varying dates of the Kurnool Group keep the debate open on the age of the basin and at present it is believed to be Neoproterozoic in age (Ramakrishna and Vaidyanadhan, 2008; Valdiya, 2010). Based on palaeomagnetic data, Goutham *et al.* (2006) suggested that the Banganpalli Quartzite and the Narji Limestone of the Kurnool Group are correlatable with the upper part of the Kaimur Group of the Vindhyan Supergroup which is considered as ~ 1.0 Ga old.

PREVIOUS STUDIES

Certain dark spotted circular structures mentioned by King (1872 p. 69) as the cycloid scales of fish were restudied by Rajurkar (1963) who compared these structures with *Fermoria,* now considered, as a junior synonym of *Chuaria*. Various carbonaceous remains of compressions and impressions, belonging to Chuarid, Tawuid, Ellypsophysid, Moranid and Beltinid groups were reported by Sharma and Shukla (1999). On the basis of the recovered fossils, the Owk Shale was correlated with the Bhander Group of the Vindhyan Supergroup and the Hulkal Formation of the Bhima Basin of the peninsular region. Salujha *et al.* (1972) reported microplankton assemblage of the genera *Leiosphaeridia*, *Lophosphaeridium*, *Granomarginata*, *Archaeofavosina*, *Protoleiosphaeridium*, *Dictyotidium*, *Leiovalia*, *Micrhystridium* and *Priscogalea*. These long-ranging genera were compared with the assemblage of the Bhima Basin.

Table 1: Lithostratigraphy of the Kurnool Group of the Cuddapah basin (after Nagaraja Rao *et al*., 1987).

	Nandyal Shale	(50-100 m)
	Koilkuntla Limestone	(15-50 m)
Kurnool Group	Paniam Quartzite	(10-35 m)
	Owk Shale (Auk Shale)	(10-15 m)
	Narji Limestone	(100-200m)
	Banganpalle Formation	(10-50 m)
	Unconformity	
	Cuddapah: Srisailam Quartzite	

Additionally, worm burrows reported by Vijyam (1967) from the Narji Limestone were subsequently elaborated by Arya and Rao (1979) as *Skolithos* and *Glossifungites* assemblage. Forms like Twitiya discs and *Cyclomedusa* sp. reported from the Panium Quartzite, are elements of Ediacaran assemblage (Sharma, 2008).

MATERIAL AND METHODS

The paper is based on the study of the Owk Shale of the Kurnool Group exposed in southern India. The shale samples were collected from the Ankireddipalle (15°07′; 78°03′) and the Petnikota areas of Kurnool district of Telengana. The thickness of the shale is 15m in this area and it is exposed on the eastern part of the hillock Δ1445. Morphological details of the *Chuaria* were studied under reflected light on Wild Heerbrugg Microscope. All the measurements were made under the microscope and photographs were taken with the microscope mounted with digital camera Nikon DS-Fi1. Standard palynological maceration techniques have been applied for the isolation of microfossils. Permanent glass slide-mounted palynological preparations were made using Canada Balsam as the embedding medium. All the illustrated microfossils in the paper were studied and photographed under transmitted light on Nikon Eclipse 80*i* Microscope. For all the illustrated microfossils specimens, England Finder coordinates and slide numbers are provided. Illustrated specimens are deposited in the repository of the Birbal Sahni Institute of Palaeosciences, Lucknow, India under the statement no. 1301 and 1324.

OWK PALAEOBIOLOGICAL ASSEMBLAGE

The study of the Owk Shale has revealed a rich assemblage of microfossils including cyanobacteria, acritarchs and higher vaucheriacean algae. The most important constituent of the Owk Shale assemblage is the Ediacaran species of the *Obruchevella* viz. *O. delicata*, *O. minor*, *O. parva* along with *O. valdaica* (Fig. 3). In addition, *Jacutianema* sp., *Leiosphaeridia crassa* and other species of *Leiosphaeridia* also recovered in the assemblage (Fig. 4). *Chuaria-Tawuia* assemblage and other carbonaceous macrofossils are also recorded from the Owk Shale (Fig. 5).

The bedding plane surface observations of the Owk Shale reveal variety of carbonaceous macrofossils which occur as bedding plane imprints and compressions. Among them *Chuaria circularis* is the abundant form with characteristic thick wall, well defined concentric to irregular folding patterns on the periphery. The walls of the *C. circularis* are opaque to the transmitted light. Most of the specimens are less than 5 mm in diameter (Fig. 6). Diameter range from 1.0 mm to 6.0 mm with median 3.2 and mode 3.3 mm (N=263). Lower limit is debatable. Concentric rings leave profound imprints on the bedding plane. Surfaces are smooth to psilate. Notch and fractures are tangential. No outer envelope noticed. Some of the specimens retain varied level of carbonaceous material. Concentric folding, a characteristic feature of the type material, is prominent in the Owk Shale assemblage which helps establishing the specimens as *C. circularis*. A relatively small number of thick walled, tomaculate shaped carbonaceous macrofossil occur in the Owk Shale assemblage along with *C. circularis*. These macrofossils are assigned to the form genus *Tawuia*. Sometimes it is difficult to differentiate between the distorted circular macrofossils assuming the shape of ellipsoids as with some of the specimens in Owk Shale. Hofmann (1985a, b and 1992) considered such specimens as short forms of *Tawuia*. It has been demonstrated that distorted circular specimens under compression leads to ellipsoidal shape but have constant length : width ratio of Ca 1.5 (Harris, 1974). Most of the *Tawuia* specimens of the Owk Shale have length : width ratio in the range of 1.5 and therefore, they are likely to be the *C. circularis*. However, distinct *Tawuia dalensis* specimens in the assemblage are few with rounded end, smooth outer wall, dark, opaque, sometimes with transverse wrinkles. In the Owk Shale assemblage, specimens of *T. dalensis* lack carbonaceous material but the imprints suggests they were made up of translucent layer. These features cannot be considered as diagnostic rather there are chances of being taphonomic characters.

The organic residue recovered after the traditional acid maceration of Owk Shale is constituted of solitary organic-walled vesicles generally assigned to acritarch genus *Leiosphaerida*. Leiosphaerids are most commonly occurring sphaeromorphic acritarchs that are known from the Precambrian sediments. The Owk Shale acritarchs are represented by simple spheromorphic forms identified as *Leiosphaeridia crassa* (Fig. 4A, B, E-H, L) and other forms are attributed to *L.* sp. (Fig. 4C, D, I). *Leiosphaeridia crassa* is described as laevigate leiospheres that are <70 μm in diameter; walls of moderate thickness (> 0.5 μm), commonly with broad, well-defined folds in the compressed specimens (Jankauskas *et al*., 1989). No opening has been seen in the Owk Shale assemblage. An assessment of the available data suggests that *Leiosphaeridia crassa* is widely distributed in the Meso and Neoproterozoic microfossil assemblages but show their abundance in Neoproterozoic. It is known from Upper Riphean to Lower Cambrian strata in Russia and elsewhere (Yin and Guan, 1999 and reference therein). Among Leiosphaerids, *L. crassa* shows an affinity with chlorophycean algae.

Jacutianema, the thin walled elongate flat to round ended cylindrical vesicle compared to the extant algae of the order Vaucheriales, has also been recovered from the Owk assemblage. The taxon was originally described from the Lakhanda Group of Siberia (Timofeev and Hermann, 1979). *Jacutianema* was recorded in the Middle Neoproterozoic Svanbergfjellet Formation (ca.750 Ma), Spitsbergen of Arctic Norwegian island, where the earliest known filamentous algal fossil (*Proterocladus*) was also identified (Butterfield, 2004). These two *Vaucheria*-like fossils, however, may also be interpreted as filamentous green algae due to their simple morphology.

Reitlinger (1948) described *Obruchevella* as a mineralized undivided tubular chamber that coiled to form a cylindrical helix. It is easily distinguished from other microfossils by its distinctive coiled shape. Various species of *Obruchevella* are established based on coiling shapes. Presence of pyrite

Fig. 3. Helically coiled microfossils *Obruchevella* recorded from the Owk Shale of the Kurnool Group. In this and the following figure, slide catalogue number for the Birbal Sahni Institute of Palaeosciences Museum (BSIP) and England Finder coordinates for each illustrated fossil are given in parenthesis. (A-F, H) Tightly coiled helical structure in *O. delicata* Reitlinger; (G and K) *O. parva* Reitlinger show loosely coiled helical structure; (I and J) Spirally coiled and helically twisted filament *O. valdaica* (Schepeleva ex msc.), Aseeva, 1974 forming one or two whorls. Scale bars = 50 μm for A, F; 20 μm for B-E, H-K. (A) (BSIP14581; H60), (B) (BSIP-14405; R36/3), (C) (BSIP-14405; N66/4), (D) (BSIP-14405; E56/1), (E) (BSIP-14402; H34/1), (F) (BSIP-14580; V41/4), (G) (BSIP-14407; X42/2), (H) (BSIP-14403; R54/3), (I) (BSIP-14578; G57/1), (J) (BSIP14577; M43/3), (K) (BSIP-14579; P48/2). Scale bars = 50 μm for A, F; 20 μm for B-E, H-K.

crystals in the sheaths of some of the specimens and benthic mode of occurrence compare with modern cyanobacterium genus *Spirulina*. It is interpreted as oscillatorian cyanobacteria consisting of spirally coiled tubular filaments that are helically twisted around an open center. *Obruchevella parva* Reitlinger may imply an Ediacaran age.

DISCUSSION

The International Commission on Stratigraphy has fixed the Mesoproterozoic-Neoproterozoic boundary at about 1000 Ma (Gradstein *et al.*, 2004). Earlier, it has been suggested that the stratigraphically confined diamond-bearing conglomerates and/or the tuffs associated with kimberlites, be considered as the datum to define the base of the Neoproterozoic (Chaudhuri *et al.*, 1999). Only a few geochronological dates are available of Purana rocks which are mainly derived from the authigenic glauconitic minerals or from magmatic rocks that intrude the successions or are inter-bedded with them. Several age determinations have been made on the kimberlite and lamproites where the widespread data, between 1350 and 840 Ma, have been reported (Chaudhury *et al*., 1999 and references therein; Dongre *et al*., 2008; Chalapathi Rao *et al*., 2010b). The dates were obtained by Rb-Sr and K-Ar methods. It has been noted that the spread in the measured ages is reduced significantly when Rb-Sr dates or K-Ar dates are considered separately. The age data indicate that the Kurnool Group, with a diamond-bearing conglomerate at its base, is younger than 1090 Ma. The age of the conglomerates is constrained by the clasts derived from the pipe rocks from the Vajrakarur in the west (Nagaraja Rao *et al.,* 1987), with

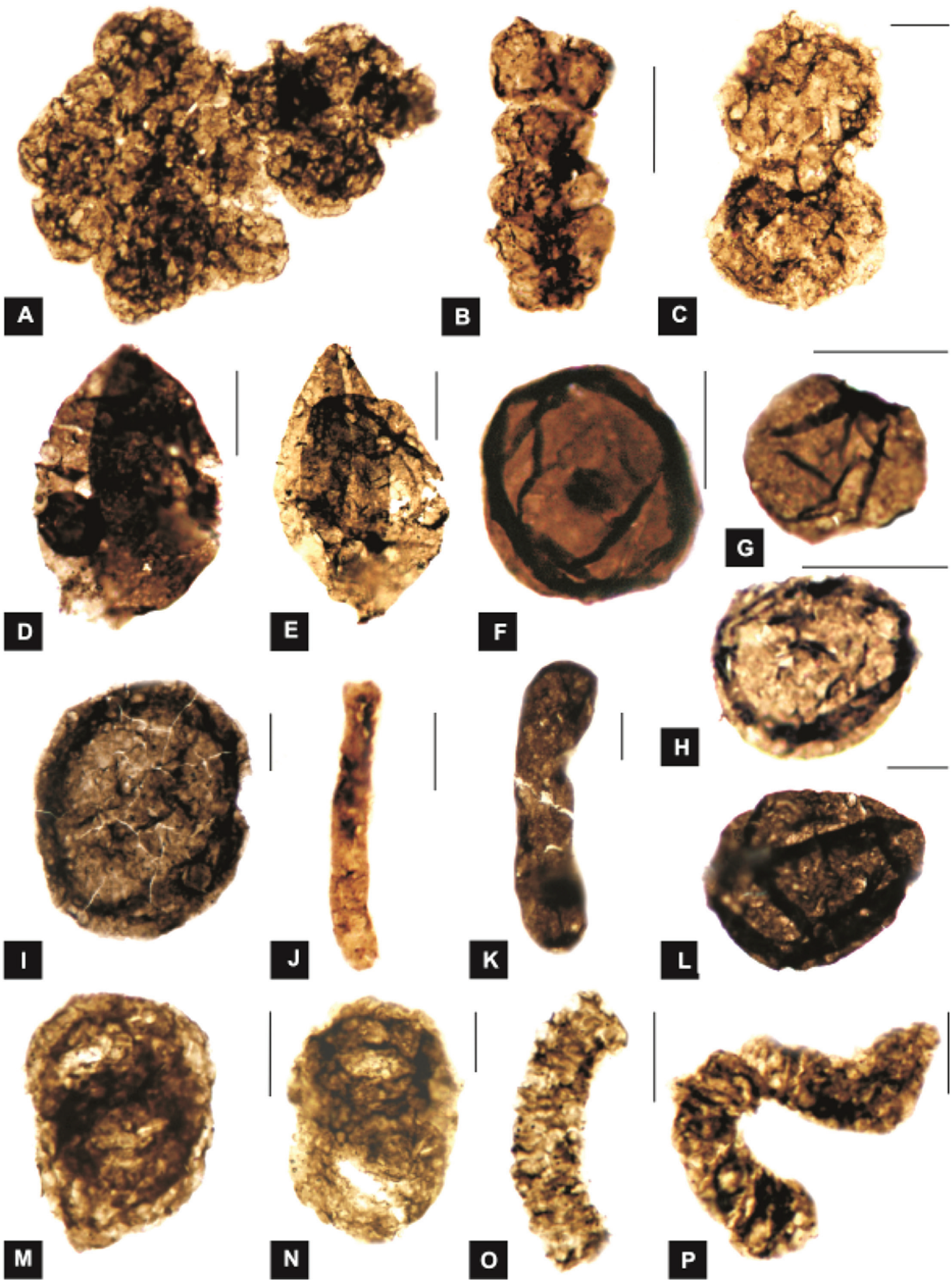

Fig. 4. Kurnool microfossils assemblage recorded from the Owk Shale of the Kurnool Group. (A-I, L) *Leiosphaeridia* (Eisenack 1958); (A, B, E-H, L) *Leiosphaeridia crassa*, note well defined folds in the compressed specimens; (C, D, I) *Leiosphaeridia* sp. forms are very much similar to *L. crassa* but folds are not clearly visible; (J and K) *Jacutianema* sp. elongate flat to round ended cylindrical vesicle; (M-P) helically coiled microfossils *Obruchevella* Reitlinger, Note the coiled helical structure of each specimen (M and N) *Obruchevella delicata*, (O and P) *Obruchevellaparva* (A) (BSIP-14405; G63), (B) (BSIP-; 14404; M16/3), (C) (BSIP-14530; D39), (D) (BSIP-14528; G39), (E) (BSIP-14527; C57), (F) (BSIP-14529; N40/4), (G) (BSIP-14528; R55/1), (H) (BSIP-14528; R42/4), (I) (BSIP-14394; G63), (J) (BSIP-14398; D37/2), (K) (BSIP-14399; U46), (L) (BSIP-14528; H62/4), (M) (BSIP-14526-; O45), (N) (BSIP-14526; P53/4), (O) (BSIP-14395; T63), (P) (BSIP-14394; V55/1), Scale bars = 50 μm for A, B; 20 μm for C-P.

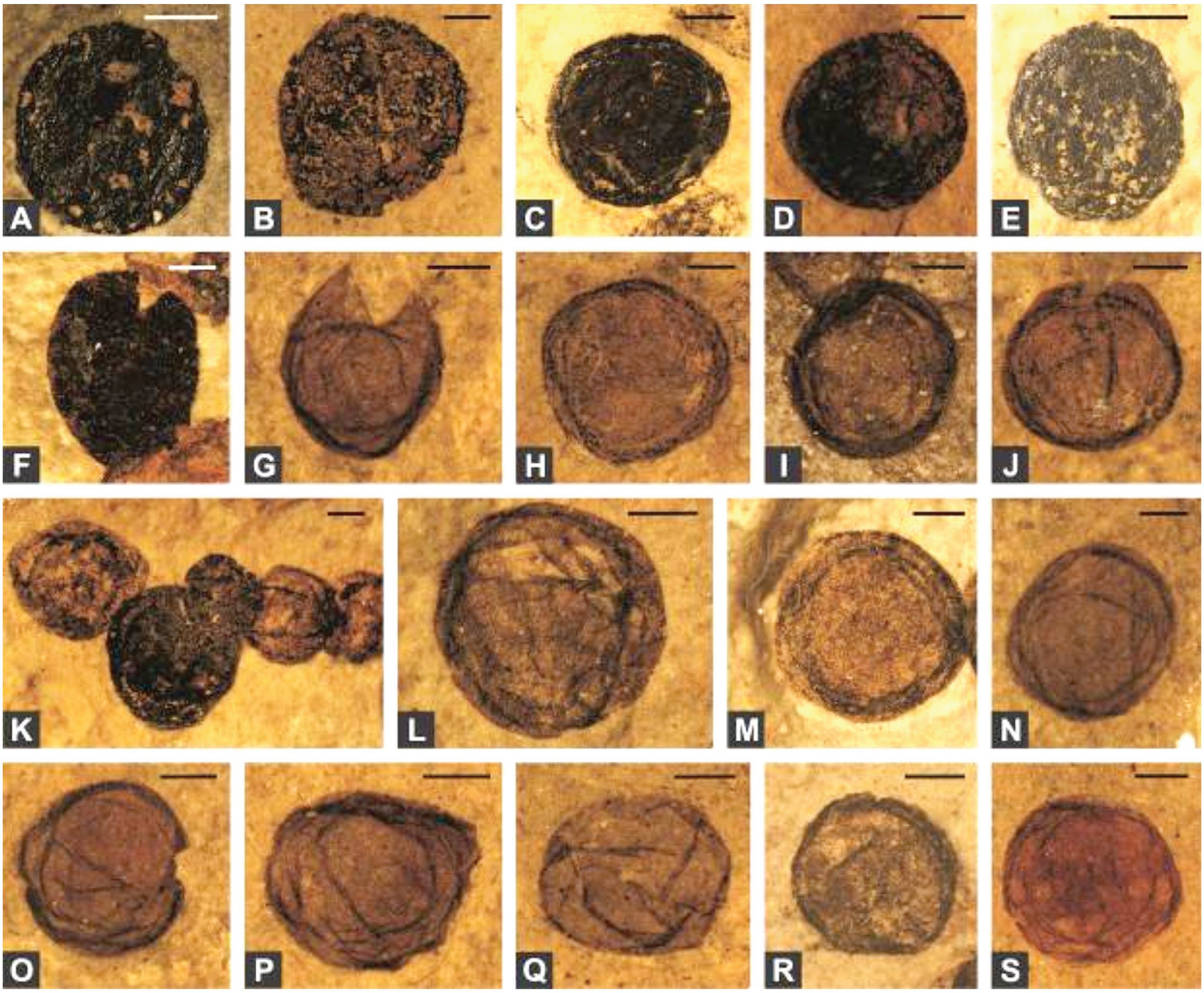

Fig. 5. *Chuaria circularis* Walcott recorded from the Owk Shale of Kurnool Group. Numbers in the parentheses denote the specimen registration number in BSIP museum. Variations in morphology are noted in the specimens preserved both as impressions and compressions. (A-F) Thick carbonaceous specimens preserved as compressions; In (F and G) V-shaped notches are clearly seen; (H, I and M) showing concentric rings concentrated mostly on periphery of the specimens; (K) cluster of *Chuaria circularis*, specimens overlap at some places; (N-S). Specimens preserved as impressions with fine to thick folds. (A) (BSIP-40085), (B) (BSIP-40086), (C) (BSIP-40087), (D) (BSIP-40088), (E) (BSIP-40089), (F) (BSIP-40090), (G) (BSIP-40086), (H) (BSIP-40091), (I) (BSIP-40092), (J) (BSIP-40093), (K) (BSIP-40094), (L) (BSIP-40095), (M) (BSIP-40096), (N) (BSIP-40097), (O) (BSIP-40098), (P) (BSIP-40099), (Q) (BSIP40100), (R) (BSIP-40101) (S) (BSIP-40102). Scale bars = 1mm for each specimen.

ages between 1090 Ma and 1140 Ma. The ages of the basic dykes which do not affect the Kurnools but intrude only the underlying formations also indicate that the Kurnool sediments are not older than 1090 Ma, and may even be younger than 870 Ma (Crawford and Compston, 1973). The Kurnool Group that unconformably overlies the Cuddapah Supergroup comprises two major cycles of siliciclastic-carbonate sedimentation on a stable shelf condition.

There is a consensus that all virtually undeformed and unmetamorphosed sedimentary basins in the peninsular India, *viz*. Vindhyan, Chhattisgarh, Bhima, Kurnool, Kaladgi are coeval (Singh, 1985; Chaudhuri *et al.,* 1999, Chakraborthy, 2006).

Although the occurrence of Ediacaran fossils are claimed from the Vindhyan (De, 2003, 2006) and the Chhattisgarh

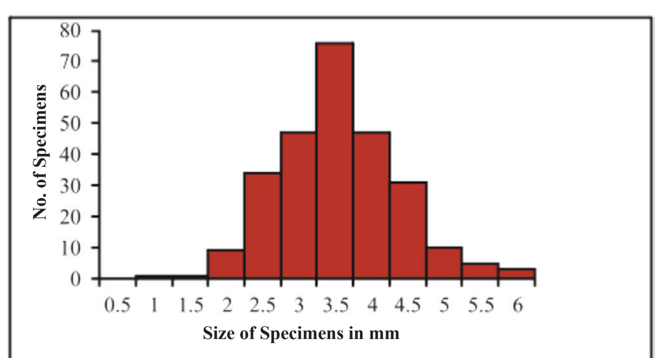

Fig. 6. Size frequency distribution chart of *Chuaria cuircularis* in the Owk Shale Formation.

(Moitra 1999) basins, yet minimum depositional ages of the Bhander and the Raipur Groups have been determined to be ~1000 Ma (Malone *et al.,* 2008; Patranabis-Deb *et al.,* 2007). Another basin of southern India, the Bhima Basin, is also correlated with the Kurnool Basin. Generally, the sedimentary rocks of the Bhima Basin are equated with those of the Vindhyan and the Kurnool basins. As there is no evidence of igneous activity in the presently exposed Bhima Basin to help determine the age, it was suggested to be Neoproterozoic on the basis of stratigraphic correlation with sedimentary horizons in other sedimentary basins with better constrained ages. The presence of complicated annulated carbonaceous remains in the Hulkal Formation and the Ediacaran remains in the Hotpet Formation collectively indicate a Neoproterozoic, possibly pre-Sturtian age for the Bhima Group (Sharma and Shukla, 2012b). The parameters of geochronology and palaeobiology bring out the difference between the absolute age of the same rock units inferred from fossils evidence and the other geochronological evidence.

To resolve the age discordance between fossil evidence and those from provenance analysis and palaeomagnetic considerations, an argument has been made that the complex advanced life forms evolved much earlier, perhaps as early as 1800 Ma but were fewer in number and were not preserved (Basu, 2009). Studies on the Precambrian life during the last sixty years have increased manifold and reveal that the Proterozoic fossil record is abundant and better preserved and can be compared with modern forms, so much so that their biogenicity and affinity can easily be established. Varied prokaryotes, eukaryotes, protista, fungi and lichens are identified and established in the Precambrian successions with considerable evidence arising from the Indian Precambrian sedimentary successions. In comparison to the Palaeo-Mesoproterozoic, fossil assemblages of the Neoproterozoic Era are diversified and quantitatively abundant; however, the explosive diversification of morphologically complex eukaryotes sharply changed the composition of microbiotas near the end of the Mesoproterozoic (Knoll, 1992; Knoll and Sergeev, 1995; Sergeev *et al.,* 1996). Ediacaran metaphyte assemblage is very diverse. These fossils include diverse assemblage of micro- and macrofossils and can be interpreted unambiguously as colonial prokaryotes or multicellular algae. Some of them were phylogenetically derived coenocytic green algae as they possessed regularly bifurcating thalli comparable to red and brown algae. Some species have been interpreted as metazoans by previous workers (Xiao *et al.,* 2002).

In the Indian Neoproterozoic successions, various types of organic forms, metaphytes and metazoans are recorded. These include Ediacaran-age fossil remains: *Vendotaenia*, *Tyrasotaenia*, *Protoarenicola*, *Pararenicola*, *Sinosabellidites*, helically coiled *Obruchevella* (Kumar and Rai, 1992; Prasad and Asher, 2001; Prasad, 2007; Mathur, 2008; Sharma, 2008; Sharma and Shukla, 2012a, b).

Solitary organic-walled vesicles of *Leiosphaeridia* are assigned to acritarchs. Acritarchs are considered to be the cyst, spore or vegetative unicells belonging to eukaryotic algae but these might also represent prokaryotes, protozoans or even metazoans. Most of the organic-walled vesicles of the Owk Shale are simple, thin-walled spheroids ranging in size from few micrometers to few hundreds of micrometers in diameter. No bedding plane parallel thin sections are studied; therefore, it is difficult to ascertain their true nature whether they were planktic or benthic, but generally small, smooth, spheroidal forms are considered as occurring in shallow open-water environments (Butterfield and Chandler 1992). At present, no ornamented acritarchs are recorded in the Owk Shale assemblage. On the size parameter, smooth-walled leiosphaerid acritarchs are divided into four distinct species: *L. minutissima* are thin walled, <70 µm in size; *L. tenuissima* also thin walled, 70-200 µm; *L. crassa* thick walled, <70 µm in size; *L. jacutica* thicker walled 70-800 µm in size (Jankauskas *et al.,* 1987, 1989). *L. crassa* are abundant in the acid maceration residue of the Owk Shale.

Although the leiosphaerids are cosmopolitan and stratigraphically long ranging, they constitute most common and abundant form taxa in the Neoproterozoic and Cambrian (Vidal and Peel, 1993). *Jacutianema* is recorded from the Neoproterozoic successions of Siberia, Spitsbergen, South Kazakhstan, and East European platform. Certain distinctive fossils in the assemblage represent elements in microbiota that were previously known from certain formations attributed to the Ediacaran age. Of special interest is the presence of spirally coiled fossil *Obruchevella*, which has previously been reported mainly as a characteristic constituent of the Ediacaran microbiota, although also present in the Lower Cambrian. The genus *Obruchevella*, however, ranges up to strata as young as Ordovician. Majority of *Obruchevella* species show their appearance at various stages during Neoproterozoic to Ediacaran-Cambrian time. It has a modern analogue in the living blue-green alga *Spirulina* and is most frequently reported from the rocks of the Early Cambrian. Four species of *Obruchevella*, *viz*. *O. delicata*, *O. minor*, *O. parva* and *O. valdaica* have been recorded from the Owk Shale of the Kurnool Group (Sharma and Shukla, 2012a). Distribution of all *Obruchevella* species recovered from the Owk Shale and the age of the horizons containing them is discussed in detail in the following section.

Obruchevella delicata has a wide distribution and is recorded from the Ediacaran to Lower Cambrian and up to the Ordovician (Bykova, 1961 in Mankiewicz, 1992) successions of Siberia, Russia, Kazakhstan, China and Canada. Similarly, *O. parva* is recorded from Ediacaran (Vendian) and Lower Cambrian silicified and organic-walled assemblages of Siberia, Soviet Union, Saudi Arabia, China, Svalbard, Greenland (Reitlinger, 1959; Kolosov, 1977; Yakschin and Luchinina, 1981, Golovenok and Belova, 1983; Cloud *et al.,* 1979; Song, 1984). *O. minor* is reported from Sinian, Doushantou Formation, Western Hubei, China (Zhang 1984). *O. valdaica* also has a wide distribution and is recorded from the Ediacaran to the Lower Cambrian strata of the Soviet Union, Ukraine, Northwest Greenland, Canada and India. The abundance of these forms in the Ediacaran to the Lower Cambrian is biostratigraphically a very important indicator. As stated above, the oldest record of these forms are from the Early Ediacaran. Carbonaceous mega-remains of Ellypsophysid, Moranid and Beltinid groups have been recorded from the Owk Shale by Sharma and Shukla (1999). *Chuaria* is extensively reported from Meso-Neoproterozoic sediments, except a few Palaeoproterozoic occurrences (Hofmann and Chen, 1981) and it has a global distribution (Krischvink, 1992; Dutta *et al.,* 2006; Shukla, 2011). Most of the *Chuaria* assemblages fall in the time period of 1000-700 Ma (Sun, 1987). Presence of *Chuaria,* along with *Tawuia,* and the other carbonaceous remains in the Owk Shale, Kurnool Group indicate the age of the sediments closer to 900-700 Ma.

The occurrence of worm burrows in the underlying Narji Limestone was viewed as the evidence of existence of

Table 2: Occurrences of Species of *Obruchevella* with reference to their age.

Name of Species	Horizon/Formation	Locality	Age (Reference)	Reference
O. delicata	Kutorgina Formation	Southeastern Siberian Platform, Yakutia (Aldan Massif), Siberia	Lower Cambrian (Atdabanian Stage) (Missarzhevskii, 1989)	Reitlinger, 1948; Luchinina, 1975
	Tinov Formation	Southeastern Siberian Platform, Yakutia (Aldan Massif), Siberia	Lowermost Cambrian (Missarzhevskii, 1989; Mel'nikov, 2005)	Reitlinger, 1959; Golovenok and Belova, 1989
	Medvezhenskaya Formation	Siberian Platform, Anabar massif, Siberia	Lower Cambrian (Atdabanian Stage) (Missarzhevskii, 1989)	Yakschin and Luchinina, 1981; Pyatiletov *et al*., 1981
	Zhongyicum Member	Meishucun section, Jinning, Yunnan, China	562.8 ± 7.9 Ma and 562.1 ± 5.7 Ma (Sm-Nd) isotope (Jie-Dong *et al*., 1996)	Song, 1984
	Chulaktau Formation	Maly Karatau (South Kazakhastan)	Lower Cambrian (Missarzhevskii, 1989)	Sergeev and Ogurtsova, 1989; Sergeev, 1992
	Stephen Formation	Burgess Shale, British Columbia, Canada	Middle Cambrian	Mankiewicz, 1992
	Ganurgarh Shale, Nagod Limestone, Sirbu Shale	Damoh, Bhander Group, Son Valley, northern Madhya Pradesh, India	K-Ar ages of (glauconite) 741± 9 Ma (Rathore *et al*., 1999)	Prasad *et al*., 2005; Prasad, 2007
O. parva	Tinov Formation	Southeastern Siberian Platform, Yakutia (Aldan Massif), Siberia	Lowermost Cambrian (Missarzhevskii, 1989; Mel'nikov, 2005)	Reitlinger, 1959; Kolosov, 1977; Yakschin and Luchinina, 1981; Pyatiletov *et al*., 1981; Golovenok and Belova, 1989
	Jubaylah Group	Northern Saudi Arabia	K-Ar whole-rock age (on andesitic basalt) of ~ 540 Ma	Cloud *et al*., 1979
	Chulaktau Formation	Maly Karatau (South Kazakhastan)	Lower Cambrian (Missarzhevskii, 1989)	Golovenok and Belova, 1983; Sergeev, 1989; Sergeev and Ogurtsova, 1989; Sergeev, 1992
	Zhongyicun Member	Meishucun section, Jinning, Yunnan, China	562.8 ± 7.9 Ma and 562.1 ± 5.7 Ma (Sm-Nd) isotope (Jie-Dong *et al*., 1996)	Song, 1984
	Rozniche Formation (Redkino Horizon)	Eastern European Platform, Volhynia, Ukraine	Ediacaran (Sokolov and Fedonkin, 1990; Martin *et al*., 2000; Grazhdankin, 2003)	Burzin, 1995
	Doushantuo Formation	China	Ediacaran (635-551 Ma) (Condon *et al*., 2005)	Zhang *et al*., 1998
	Ganurgarh Shale, Nagod Limestone, Sirbu Shale	Damoh, Bhander Group, Son Valley, northern Madhya Pradesh, India	K-Ar ages of (glauconite) 741±9 Ma (Rathore *et al*., 1999)	Prasad *et al*., 2005; Prasad, 2007
O. minor	Toushantou Formation	Late Sinian of western Hubei China	635 – 551Ma (Condon *et al*., 2005)	Zhang, 1984
O. valdaica	Yaryshev Formation	Podolia, Ukraine	Ediacaran (Sokolov and Fedonkin, 1990; Martin *et al*., 2000; Grazhdankin, 2003)	Aseeva, 1974; Hermann, 1985
	Rozniche Formation (Redkino Horizon)	Eastern European Platform, Volhynia, Ukraine	Ediacaran (Sokolov and Fedonkin, 1990; Martin *et al*., 2000; Grazhdankin, 2003)	Velikanov *et al*., 1983; Burzin, 1995
	Valdey Group, Redkino Horizon, Arkhangelsk Member	Eastern European Platform, Northwest of Arkhangelsk	Ediacaran (Sokolov and Fedonkin, 1990; Martin *et al*., 2000; Grazhdankin, 2003)	Ragosina and Sivertseva, 1985
	Vanavara Formation	Southeastern Siberian Platform, Kattanga saddle and adjacent territories, Siberia	Ediacaran (Mel'nikov, 2005)	Pyatiletov, 1986
	Mogilev-Podolsk Group; Redkino Horizon	Podolia, Ukraine; Archangelsk Region	Ediacaran (Sokolov and Fedonkin, 1990; Martin *et al*., 2000; Grazhdankin, 2003)	Jankauskas *et al*., 1989
	Borden Rift Basin of northern Baffin Island and Bylot Island	Bylot Supergroup, Baffin Island, Canada	1270-750 Ma (Hofmann and Jackson, 1994, p. 7)	Hofmann and Jackson, 1994
	Ujhani Formation, Madhubani Group, Sarda Formation and Avadh Formation, Bahraich Group	Ganga basin	Mesoproterozoic (1320 Ma) to Latest Vendian (?)-Lower Cambrian (Prasad and Asher, 2001)	Prasad and Asher, 2001
	Ganurgarh Shale, Nagod Limestone, Sirbu Shale	Damoh, Bhander Group, Son Valley, northern Madhya Pradesh, India	K-Ar ages of (glauconite) 741±9 Ma (Rathore *et al*., 1999)	Prasad *et al*., 2005; Prasad, 2007
	Buxa Dolomite	West Siang District, Arunachal Lesser Himalaya	Late Neoproterozoic (Shukla *et al*., 2006)	Shukla *et al*., 2006

invertebrates and thus, the uppermost Proterozoic or Lower Cambrian age was assigned to this formation. The Ediacaran fossils have been recently reported from the overlying Panium Quarzite of the Kurnool Group. Sharma (2008) reported forms like Twitiya discs and *Cyclomedusa* sp. from Panium Quartzite that was considered Ediacaran in age. Taken together, the above evidence implies that the Kurnool Group is older than Cambrian but possibly younger than the Mesoproterozoic.

All the known occurrences of the species of *Obruchevella* recorded from the Owk Shale are considered to ascertain its worthiness as biostratigraphic marker (Table 2). *Obruchevella* has been recorded from Siberia, Mongolia, China, Saudi Arabia, Australia, Alaska, Canada and Greenland. The species mentioned in the present paper were also are recorded from different horizons of Siberian Platform, Maly Karatau (South Kazakhstan); Burgess Shale, Canada; Jubaylah Group, Northern Saudi Arabia; Eastern European Platform, Podolia, Ukraine; Bylot Supergroup, Baffin Island, Canada, India and China. Misssarzhevskii (1989) provided the age range for the occurrences reported from the Siberian Platform or Maly Karatau Range as the Lower Cambrian. Different species of *Obruchevella* are recorded from the Kutorgina Formation and the Tinov Formation of Southeastern Siberian Platform, Yakutia (Aldan Massif), Siberia (Reitlinger, 1948, 1959; Luchinina, 1975; Golovenok and Belova, 1989; Yakschin and Luchinina, 1981; Pyatiletov *et al.,* 1981). The Kutorgina, Tinov and Medvezhenskaya Formations are the Lower Cambrian in age. Similarly, the Chulaktou Formation, Maly Karatau (South Kazakhstan) is also Lower Cambrian in age. Ages for the *Obruchevella*-bearing lithostratigraphic units located on the Eastern European Platform are given in Sokolov and Fedonkin (1990); Martin *et al.* (2000); Grazhdankin (2003). The Rozniche Formation, Valdey Group, Eastern European Platform; Mogilev-Podolsk Group, Podolia, Ukraine; Yaryshev Formation, Podolia, Ukraine; Vanavara Formation, Southeastern Siberian Platform are typical Ediacaran in age. The age of the Jubaylah Group based on K-Ar whole rock age (on andesitic basalt) of ~ 540 Ma which is very close to Precambrian-Cambrian boundary, while the Stephen Formation, Burgess Shale, Canada is a Middle Cambrian succession. The Zhongyicun Member of the Meishucun Section, Jinning, Yunnan, China is dated as 539.4±2.5 Ma (Jiang, G. *et al.,* 2012 Fig. 1C, column 1). The Doushantou Formation is also well dated [635 – 551Ma (Condon *et al.,* 2005)].

In the peninsular region of India, the *Obruchevella* occurs in the Vindhyan Supergroup, the Ganga Basin and the Kurnool Group. Prasad and Asher (2001, pl. 9.9, fig. 7) recorded *O. valdaica* from the Avadh Formation of the Bahraich Group and the Ujhani Formation of the Madhubani Group in the Ganga Basin. The age of these two formations have been suggested as Mesoproterozoic (1300 Ma) and Latest Vendian (?)–Lower Cambrian to Lower Ordovician, respectively (Prasad and Asher, 2001, p. 13 and p. 38). Prasad (2007) reported four different species of the *Obruchevella* in the Bhander Group. Along with the characteristic Terminal Proterozoic organic-walled microfossils, *O. parva*, *O. valdaica* show their appearance in the Ganurgarh Shale, become abundant in the Nagod Limestone with the addition of *O. delicata*. Persistence of these species and further appearance of *O. parvissima* in the Sirbu Shale suggests a latest Cryogenian to Late Ediacaran age of the Bhander Group.

There are only two records (Prasad and Asher, 2001; Rai and Singh, 2004) where a species of *Obruchevella* has been documented from the Mesoproterozoic and Palaeoproterozoic sediments. Rai and Singh (2004) reported *Obruchevella parva* from the Late Palaeoproterozoic Salkhan Limesone of the Vindhyan Supergroup. However, Prasad (2007) is sceptic of their presence in such old rocks. *Obruchevella* finds in these older rocks are doubtful due to uncertain interbasinal correlation (Rai and Singh, 2004) and unreliable dating of microfossiliferous rocks (Prasad and Asher, 2001). Except these two records, all other known occurrence, are from Terminal Proterozoic or Early Cambrian. The profuse appearance of *Obruchevella* may be considered as an *Obruchevella* biozone corresponding to the Ediacaran-Lower Cambrian time period. It is, therefore, proposed and should be considered as an index fossil of Ediacaran to Early Cambrian age. Most palaeobiologists consider that the sediments bearing *Obruchevella* are definitely Ediacaran strata (Mankiewicz, 1992; Prasad, 2007; Sharma and Shukla, 2012a).

In the Peninsular region of India, four different species of *Obruchevella* are recorded from the Bhander Group and on that basis latest Cryogenian to Late Ediacaran age (Ca 650-544 Ma) has been proposed for the Bhander Group (Prasad, 2007). In the Lesser Himalaya, *Obruchevella* has been reported from the Krol 'A' Member of the Krol Formation near Solan (Kumar and Rai, 1992). On the basis of its presence, age of the Krol 'A' Member has been suggested to be Neoproterozoic age. *Obruchevella* is also recorded from the Deoban Limestone (Srivastava and Kumar, 2003) and the Buxa Dolomite (Shukla *et al.,* 2006). From the Deoban Limestone, three species are recorded, viz. *O. parva, O. valdaica* and *O. minor*. Former two species are recorded from Buxa Dolomite (Shukla *et al.,* 2006). The Deoban Limestone is considered as Neoproterozoic in age (Srivastava and Kumar, 2003), whereas the Buxa Dolomite has been considered to be Late Neoproterozoic (Shukla *et al.,* 2006).

The presently available data reveal that the four species of *Obruchevella* are known from the Ediacaran to Early Cambrian age successions. *Obruchevella* is common in the Ediacaran but has also been found in older and younger rocks. Some of them are also recorded from Late Proterozoic but their abundance in Terminal Proterozoic is well established. Thus, the abundance of above species of *Obruchevella* is suggestive of the Ediacaran age for the Owk Shale of the Kurnool Group. The other fossil taxa *Chuaria* and *Jacutianema* reported from Owk Shale are often found in rocks older than the Ediacaran, are common elements in the early Neoproterozoic. The microfossil assemblage favours the Neoproterozoic (possibly Ediacaran) age of the basin.

CONCLUSIONS

The assemblage of the Owk Shale provides the new important information on the microfossils as well as the age of fossil bearing rocks, especially when the sedimentary succession is deprived of any mineral suitable for isotopic age determination. The presence of Ediacaran species of *Obruchevella*, viz. *O. delicata*, *O. minor*, *O. parva* along with *O. valdaica* favours Ediacaran age. The present palaeobiological data and previous report of occurrence of *Tawuia* in the Owk Shale, together with worm burrows in the underlying Narji Limestone and Ediacaran forms in the overlying Panium Quartzite, collectively indicate plausible Ediacaran age close to the Cambrian for the Owk Shale, whereas other fossil taxa *Chuaria* and *Jacutianema* are often found in the rocks older than the Ediacaran. The present assemblage collectively suggests Neoproterozoic (possibly

Ediacaran) age for the Owk Shale as well as for the Kurnool Group.

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