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Vindhyans of the Chambal Valley: Ediacaran Complex Acanthomorphs and associated acritarchs evidence for an Infra-Cambrian sedimentary basin in south-eastern Rajasthan, India

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Fresh biostratigraphic studies on the Vindhyan successions of the Chambal Valley in the newly drilled boreholes SK-A, JP-A, and KP-A have shown the rich occurrences of distinctive Early Ediacaran complex acanthomorphs in the Lower Vindhyan succession, typical Late Ediacaran acritarchs in the overlying upper Suket Shale and Kaimur Group, and Early Cambrian marker acritarchs in the Rewa-Bhander Groups of Upper Vindhyan succession, along with other a geopotential microfossils. The newly documented complex acanthomorph assemblages are fairly similar to those previously recorded from this area in CH-A and PL-A boreholes and marked by the several species of key taxa, like *Apodastoides, Appendisphaera, Asterocapsoides, Cavaspina, Ceratosphaeridium, Densisphaera, Ericiasphaera, Gyalosphaeridium, Hocosphaeridium, Knollisphaeridium, Schizofusa, Sinosphaera, Tanarium* and *Variomargosphaeridium* that worldwide typify the Ediacaran Complex Acanthomorph Palynoflora (ECAP) in the Lower Ediacaran rocks. Various species of these taxa first appear in the basal part of lower Vindhyan succession, show their abundance in the middle with the addition of some new forms, and become rare in the upper part of this succession, with their complete disappearance in the middle part of Suket Shale. The fresh record of ECAP assemblages from the above boreholes corroborates their earlier records from this area and shows their widespread occurrences in the purported lower Vindhyan succession of the western part of the Vindhyan Basin. Complex acanthomorph assemblages of the Chambal Valley closely resemble known ECAP assemblages earlier recorded from the Lower Ediacaran rocks of East European and Siberian platforms, Australia and China that lie above the glacial Gaskiers/Hankalchough Formations of ca. 580 Ma or their correlatable diamictites, and strongly suggest upper Early Ediacaran (ca. 580-550 Ma) age for the purported lower Vindhyan succession of the western part of the Vindhyan Basin (Chambal Valley), which, till now, is dated as Meso-Neoproterozoic by varied fossils and radiometric data.

The upper part of the Suket Shale and overlying Kaimur Group show the prolific occurrence of several species of *Leiosphaeridia, Lophosphaeridium, Vandalosphaeridium* and *Obruchevella.* The abundance of these taxa, and a conspicuous absence of ECAP assemblages, suggest Late Ediacaran (ca. 550-541 Ma) age for the above litho units. The overlying Rewa and Bhander Groups of Upper Vindhyan succession in the studied boreholes show the consistent occurrence of various species of *Dictyotidium, Cristallinium* and *Asteridium,* along with the frequent occurrence of *Lophosphaeridium tentativum, L. truncatum, Baltisphaeridium cerinum, Comasphaeridium strigosum, Skiagia cilosa,* and *S. brevispinosa* which globally mark the Early Cambrian (ca.541-515Ma) palynofloras, and suggest similar age for these rocks, with Precambrian-Cambrian boundary close to the Kaimur-Rewa Group's lithological contact.

The occurrence of distinctive Ediacaran complex acanthomorphs of ECAP assemblages in the lower Vindhyan succession, and small acanthomorphs and herkomorphs in upper Vindhyan succession of the Chambal Valley, suggest that the sedimentation in the western part of the Vindhyan Basin began in the upper Early Ediacaran (ca. 580 Ma) and ended during late Early Cambrian (ca. 515 Ma). The conspicuous absence of ECAP in Lower, as well as Upper Vindhyan sequences of the eastern part of the basin (Son Valley), suggests that the purported Vindhyan successions of the Chambal Valley are entirely different and younger from the Son Valley, and represent the Infracambrian sedimentary successions in south-eastern Rajasthan region which are, now, classed as the Chambal Supergroup. Ediacaran-Lower Cambrian successions of the Chambal Valley are opined to be deposited in a separate Infracambrian Chambal Basin with its distinctive depositional history, and detached from the Late Palaeoproterozoic-Meso/Neoproterozoic Son Basin (*sensu-stricto* Vindhyan Basin) by a prominent NNE-SSW aligned subsurface Archeozoic basement ridge of the "Hoshangabad-Rajgarh High", and not by the Bundelkhand Granitic Complex (BGC) as largely presumed.

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INTRODUCTION

Proterozoic sedimentary successions of the Chambal Valley region are largely known as the western continuation of Vindhyan sequences from the eastern part (Son Valley) of the Vindhyan Basin to south-eastern Rajasthan (Fig. 1) as opined by several workers (Auden, 1933; Heron, 1936; Prasad, 1984; Sastry and Moitra,1984). Vindhyan successions of both the areas have been broadly assigned early Mesoproterozoic to Late Neoproterozoic-Early Cambrian through various micro-and megafossil evidence like acritarchs, filamentous microfossils, stromatolites, small shelly microfossils, metaphyses and trace-fossils (Kumar 1984, 2001; Maithy, 1992; Venkatachala *et al.,*1996; Maithy and Babu, 1997; Azmi, 1998; Prasad *et al.,* 2005; De, 2006; Prasad, 2007; Kumar and Pandey, 2008). In addition, the available absolute age of 1721 ± 90-1409 Ma (Late Palaeoproterozoic-Early Mesoproterozoic) for the Semri Group (Kumar *et al*., 2001; Rasmussen *et al.,* 2002; Ray *et al.,* 2002, 2003; Sarangi *et al.,*2004; McKenzie *et al*., 2011), 1150-1044 ± 22 Ma (Late Mesoproterozoic) for Kaimur Group (Paul *et al.,* 1975; Smith, 1992; Kumar *et al.,*1993; Gregory *et al.,* 2006; McKenzie *et al*., 2011), and 750-650 ± 24 Ma (Middle to Late Neoproterozoic) for the Rewa-Bhander Groups (Srivastava and Rajagopalan, 1988, 1990; Ray *et al.,* 2002, 2003) have also indicated the age range of Late Palaeoproterozoic (ca. 1721 Ma) to Late Neoproterozoic(ca. 650 ± 24 Ma) for the Vindhyan successions.

Nevertheless, the above studies were mainly carried out in the Son Valley part of Vindhyan Basin, and very limited biostratigraphic and geochronological studies were carried out on the Vindhyan successions of the Chambal Valley part of the basin which provided very perplexing but had interesting results (Vinogradov *et al.,* 1964; Salujha *et al.,* 1971a; Srivastava and Rajagopalan, 1988, 1990; Malone *et al*., 2008). Though the radiometric dating on the Lower Vindhyan succession of the Chambal Valley is not attempted to date, few radiometric age data are available on the Upper Vindhyan rocks of this region. Vinogradov *et al.* (1964) dated the lower and upper Kaimur sandstones (Kaimur Group) of the Chittorgarh area as 940 ± 30 Ma and 910 ± 30 Ma by K-Ar method. Additionally, Srivastava and Rajagopalan (1988, 1990) estimated 690 ± 125 Ma (≥700 Ma) age for the Upper Rewa (Govindgarh) Sandstone and 625 ± 24 Ma for the Lower Bhander Sandstone of the Chambal Valley region by Fission-Track (F-T) method which indicated Middle to Late Neoproterozoic age for the Rewa-Bhander Groups. In contrary to the above largely accepted absolute age of ca.700-625 ± 24 Ma for the purported Rewa-Bhander Groups of this region, recent absolute datings of Upper Bhander Sandstone as ~1020 Ma (Malone *et al*., 2008) and Lakheri Limestone as 1073 ± 210 Ma (Gopalan *et al.,* 2013) of the Chambal Valley

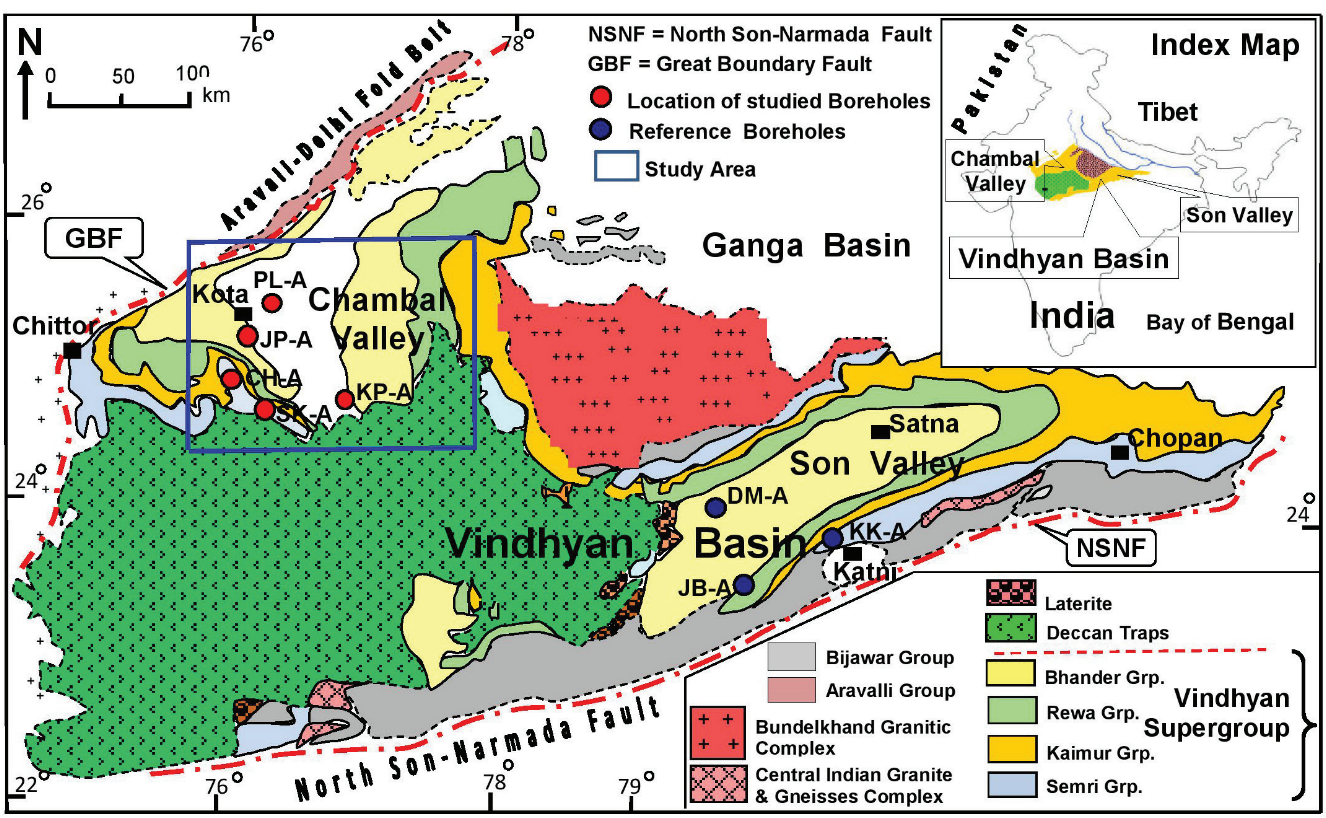


Fig. 1.Generalised geological map of the Vindhyan Basin (after Ahmed, 1962), showing the exposures of major lithological groups/lithounits of Vindhyan Supergroup in the Son and Chambal valley areas, and position of the investigated area in the Chambal Valley, with locations of the studied boreholes (inbox), along with the locations of reference boreholes in the Son Valley part of the basin. (Inset, index map of India, showing the setting of the Vindhyan Basin in northern India, with centrally placed Bundelkhand Granitic Complex which broadly separates the Chambal Valley in the west from the Son Valley in the east).

by U-Pb (Zircon) method, advocating the closing of Vindhyan sedimentation in this area during latest Mesoproterozoic, further complicating the existing age dispute on the Vindhyan successions of both the areas of the basin, particularly for the Chambal Valley part (Fig.1). Yet, it is worth noting that before the cropping of the above controversy, Salujha *et al*. (1971a) recorded abundant Leiosphaerids (*Leiosphaeridia* spp.), sculptured sphaeromorphs (*Lophosphaeridium* spp.), small acanthomorphs (*Micrhystridium* spp., *Priscogalea echinata*), herkomorphs (*Dictyotidium areolatus, Cymatiosphaera compta*), and oomorphs (*Oodium* sp.) from the sediments of Kaimur, Rewa, and Bhander Groups of Kota-Karauli areas, and suggested Cambrian-Ordovician age for the Upper Vindhyan succession of the Chambal Valley. However, the above important finding of Cambro-Ordovician acritarchs from the upper Vindhyan rocks of this region were doubted and ignored by many workers since the upper age limit of Late Mesoproterozoic (~1020 Ma) or Late Neoproterozoic (ca. 625 ± 24 Ma) for the Vindhyan sequences of both the areas, estimated by radiometric methods, were given preference (for details see Kumar, 2001, 2016).

A major shift from the prevailing notion of Meso-Neoproterozoic age for the Vindhyan successions of Chambal Valley part of the basin came through a very significant recent finding of the abundant and well-preserved Early Ediacaran age marker complex acanthomorphs from the Lower Vindhyan succession, and typical Late Ediacaran and Early Cambrian small acanthomorphs (micrhystrids) and herkomorphs (*Dictyotidium*, *Cristallinium*) from the upper part of the Suket Shale and overlying Upper Vindhyan succession in the two-deep boreholes of CH-A and PL-A (Prasad and Asher, 2016) drilled around Kota-Jhalawar area of the valley that largely covers the western part of Vindhyan Basin (Fig.1). The important complex acanthomorph taxa documented by them from the Lower Vindhyan succession in the above two boreholes included the several species of *Apodastoides, Appendisphaera, Cavaspina, Ceratosphaeridium, Densisphaera, Gyalosphaeridium, Knollisphaeridium, Schizofusa, Sinosphaera* and *Tanarium* that were previously recorded from the worldwide well-known Lower Ediacaran successions. Based on the above important findings, Prasad and Asher (2016) suggested Early Ediacaran age for the major parts of Lower Vindhyan succession, Late Ediacaran for the upper part of Suket Shale and overlying Kaimur Group, and Early Cambrian for the Rewa and Bhander Groups of Upper Vindhyan sequence of the Chambal Valley. They argued that the purported Vindhyan successions of the western part of Vindhyan Basin (Chambal Valley) were entirely different from the Late Palaeoproteozoic-Meso/Neoproterozoic Vindhyan successions of the eastern part (Son Valley) and represented by the Infracambrian (Ediacaran-Lower Cambrian) sedimentary successions in south-eastern Rajasthan with its own unique positional history. Though findings of the Early Ediacaran complex acanthomorphs from the Lower Vindhyan rocks of Chambal Valley have been validated by several well-known Ediacaran biostratigraphers (Xiao *et al.,* 2016; Hughes, 2017), some workers are still skeptical on the above significant findings by Prasad and Asher (2016).

In this contribution, authors have validated their earlier findings of Early Ediacaran complex acanthomorphs from Lower Vindhyan succession and Late Ediacaran-Early Cambrian acritarchs from Upper Vindhyan sequence of the Chambal Valley part of Vindhyan Basin through fresh documentation of these microfossils from the new deep boreholes of SK-A, JP-A, and KP-A, recently drilled in this part of the basin (Fig.1). Additional documentation of complex acanthomorphs and other Ediacaran-Early Cambrian acritarchs and associated organic-walled microfossils are also done from the earlier studied boreholes of CH-A and PL-A of this area to augment the fresh record.

GENERAL GEOLOGY AND STRATIGRAPHY

The Vindhyan Basin is a large intracratonic Proterozoic basin in northern India that extends from Chittorgarh in south-eastern Rajasthan (Chambal Valley) in the west to the southern Uttar Pradesh and northern Madhya Pradesh (Son Valley) in the east (Fig.1). The centrally located Palaeoproterozoic (ca. > 2500 Ma) Bundelkhand Granitic Complex (BGC) is considered to be broadly subdividing the basin into two parts (sub-basins), and also serves as the basement surfaces for the deposition of Vindhyan successions. The eastern part of the basin largely covers the Son Valley area, whereas the western part includes the Chambal Valley region in south-eastern Rajasthan (Fig.1). The sedimentary-fills of this basin mainly include the thick mixed carbonate-siliciclastic Proterozoic sequence which is classed as the Vindhyan System/Supergroup (Auden, 1933; Prasad, 1984; Sastry and Moitra, 1984) and is broadly subdivided into Lower and Upper Vindhyan successions/sub supergroups (Fig. 2). Several lithostratigraphic classifications were proposed for this sequence, however, Auden's (1933) scheme is widely in use which has been later modified by Prasad (1984) and Sastry and Moitra (1984) conforming to the International Code of Stratigraphic Nomenclature, and the same scheme is being largely followed. In the Son Valley region, Lower Vindhyan succession is also classed as the Semri Group with Mirzapur, Deonar, Kheinjua, and Rohtas subgroups having various litho units, while the Upper Vindhyan sequence includes Kaimur, Rewa and Bhander Groups with various marker litho units (Fig. 2).

The above classifications for the Vindhyan successions are based on the geological works mainly carried out in the Son Valley part of the basin, with very little work in the Chambal Valley part. Although the difficulties were faced in the lithological and biostratigraphic correlations of Lower as well as Upper Vindhyan successions of the Son Valley with those occurring in the Chambal Valley, a broader correlation between the two areas were presented by several workers (Auden, 1933; Prasad, 1984; Sastry and Miotra, 1984; Kumar, 2012) [Fig. 2]. Because of the mismatch in the lithological attributes of the Vindhyan successions of these two areas, Prasad (1984) outlined a separate classification scheme for the Lower Vindhyan succession of Chambal Valley and subdivided it into the newly proposed Satola, Sand, Lasrawan, and Khorip Groups, with identification of several new formations on the basis their distinctive lithological features, instead of grouping them into the widely known Mirzapur, Deonar (Porcellanite), Kheinjua and Rohtas Subgroups (Fig.

2). Yet, Prasad (1984) retained the Auden's classification for the Upper Vindhyan succession of the Chambal Valley, subdividing it into Kaimur, Rewa, and Bhander Groups, with some new litho units other than the Son Valley (Fig. 2) which is widely in use (Sastry and Moitra, 1984; Kumar, 2012; Prasad and Asher, 2016). It is worth noting that Prasad and Asher (2016), based on the record of distinctive Ediacaran complex acanthomorphs in Lower Vindhyan succession and Early Cambrian acritarchs assemblages in the Upper Vindhyan succession of the Chambal Valley, opined that the Vindhyan rocks of the south-eastern Rajasthan were of much younger age of Ediacaran-Early Cambrian (ca. 600-515Ma) than those of the Late Palaeoproterozoic-Meso/ Neoproterozoic (ca 1721- 650±24 Ma) age in the Son Valley, and both have their typical depositional set-up in separate basins, and addressed those occurring in the Chambal Valley as "purported Vindhyan successions".

MATERIALS AND METHODS

Cutting and core samples from SK-A, JP-A, and PL-A boreholes, which are very recently drilled in the Chambal Valley area (Fig. 1), are processed at 5m depth-interval using conventional maceration techniques for the isolation of organic-walled microfossils. Borehole SK-A is drilled near the Suket town on the Suket Shale (topmost part of Lower Vindhyan) and ended in the Precambrian granite with the basement top at 1752 m, and encountered the same thickness of Lower Vindhyan succession covering all the established litho units (Figs. 1, 3). Borehole JP-A is located south of the Kota town which is drilled on the Lower Bhander Sandstone of Upper Vindhyan succession and terminated in the Bari Shale unit of Lower Vindhyan succession at 4050m depth. The borehole KP-A is drilled on the Upper Bhander Sandstone near Barlan town, terminated in the lower part of Suket Shale at 3100 m depth, and both the boreholes intersected the known litho units of the Upper Vindhyan succession (Figs. 1, 3, 4, 5).

Fresh samples from the boreholes of CH-A and PL-A, that earlier recorded the rich and fairly diversified Early Ediacaran complex acanthomorphs of ECAP assemblages from the Lower Vindhyan succession and Early Cambrian acritarchs from the Upper Vindhyan sequence (Prasad and

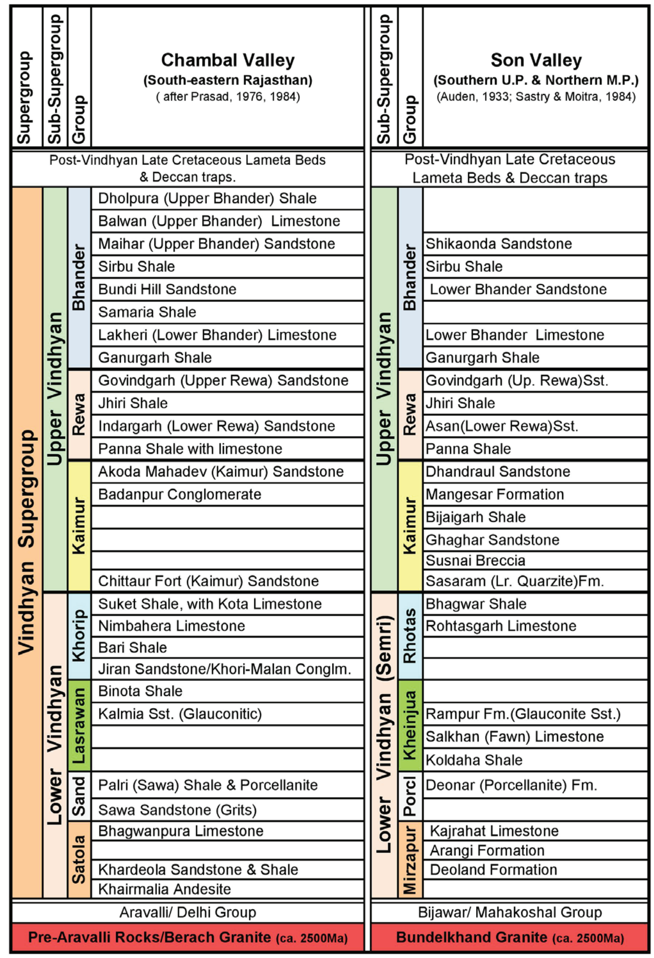


Fig. 2.Generalised lithostratatigraphy of the Vindhyan successions in Son and Chambal valleys parts of the Vindhyan Basin.

Asher, 2016), are also processed for augmenting the present microfossil records, and confirming their reproducibility. In this work, the term "Infracambrian" is used for Ediacaran and Lower Cambrian successions up to the first appearance level of the trilobite fossils (ca. 635-513 Ma).

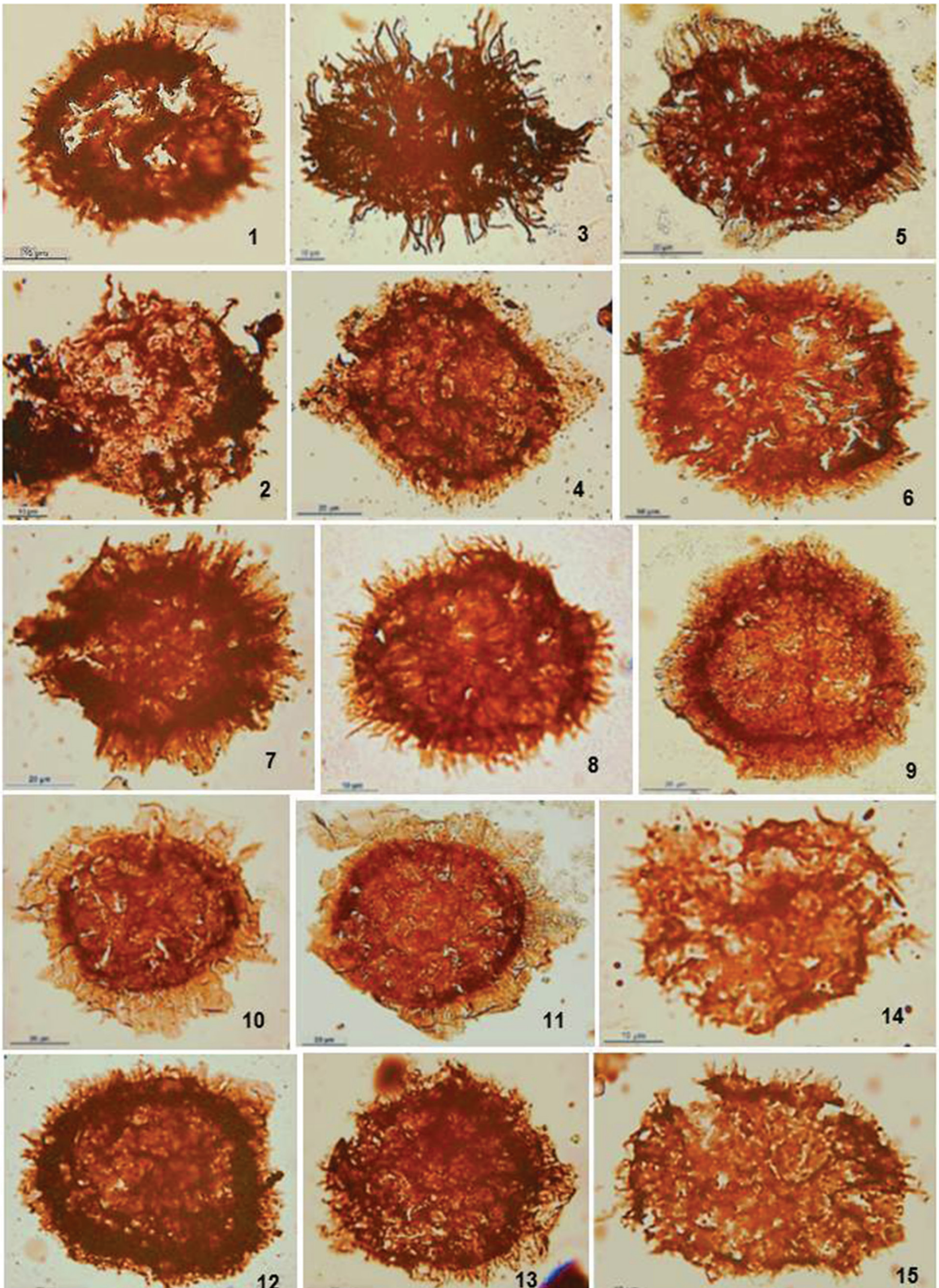
Slides of the studied samples from the above boreholes are stored in the Repository Section of the Palynology Division at KDM Institute of Petroleum Exploration, Dehradun, India.

EXPLANATION OF PLATE I

→

Fig. 1-15: Early Ediacaran complex acanthomorphic acritarchs of ECAP from the subsurface purported lower Vindhyan succession of Chambal Valley. Illustrated taxa are addressed by their borehole name, documented depth-interval with associated litho unit, and microscope coordinates with England Finder readings (EFR). 1. *Apodastoides* sp. aff. *A. basileus*, CH-A, 1750-55m/1 (Khardeola Fm.), 97.5x59, U-59/2; 2. *Apodastoides* sp. aff. *A. verobturatus*, PL-A, 3150-55m/1 (Sawa Sandstone), 97.5x71, U-72/2; 3. *Appendisphaera anguina,*CH-A, 1870-71m/1 (Khardeola Fm.), 112x31, D-31/2; 4. *Appendisphaera crebra*, SK-A, 1700-05m/1 (Khardeola Fm.), 94.5x59, W-59/4; 5. *Appendisphaera fragilis,*CH-A, 1870-71m/1 (Khardeola Fm.), 107x41, J-43/2; 6. *Appendisphaera brevispina,* PL-A,3150-55m/1 (Palri Shale), 99x46, R-46/23; 7. *Appendisphaera grandis*, SK-A,72-78m/2 (Lr. Shale memb. of Lower Suket Shale),108x25, H-25/1; 8. *Appendisphaera grandis*, CH-A, 1790-95m/1 (Khardeola Fm.), 106x64, K-65; 9. *Appendisphaera barbata*, CH-A,1810-15m/1 (Khardeola Fm.), 103x59, O-60/2; 10. *Appendisphaera tabifica*, CH-A,1810-15m/2 (Khardeola Fm.), 105.5x62.5, L-63/4; 11. *Appendisphaera tabifica*, CH-A,1790-95m/2 (Khardeola Fm.), 101.5x52, P-53; 12. *Appendisphaera tenuis,* SK-A,750-52m/1 (Jiran Sandstone), 110.5x70, F-71/1; 13. *Appendisphaera tenuis,* CH-A,1830-35m/1 (Khardeola Fm.), 100x53, Q-53/4; 14. *Chambalasphaeridium guchchaensis,* PL-A, 3150-55m/2 (Palri Shale), 109x27, G-27/1; 15. *Chambalasphaeridium guchchaensis,* CH-A,1790-95/2 (Khardeola Fm.), 103.5x42, N-42/4.

Plate I



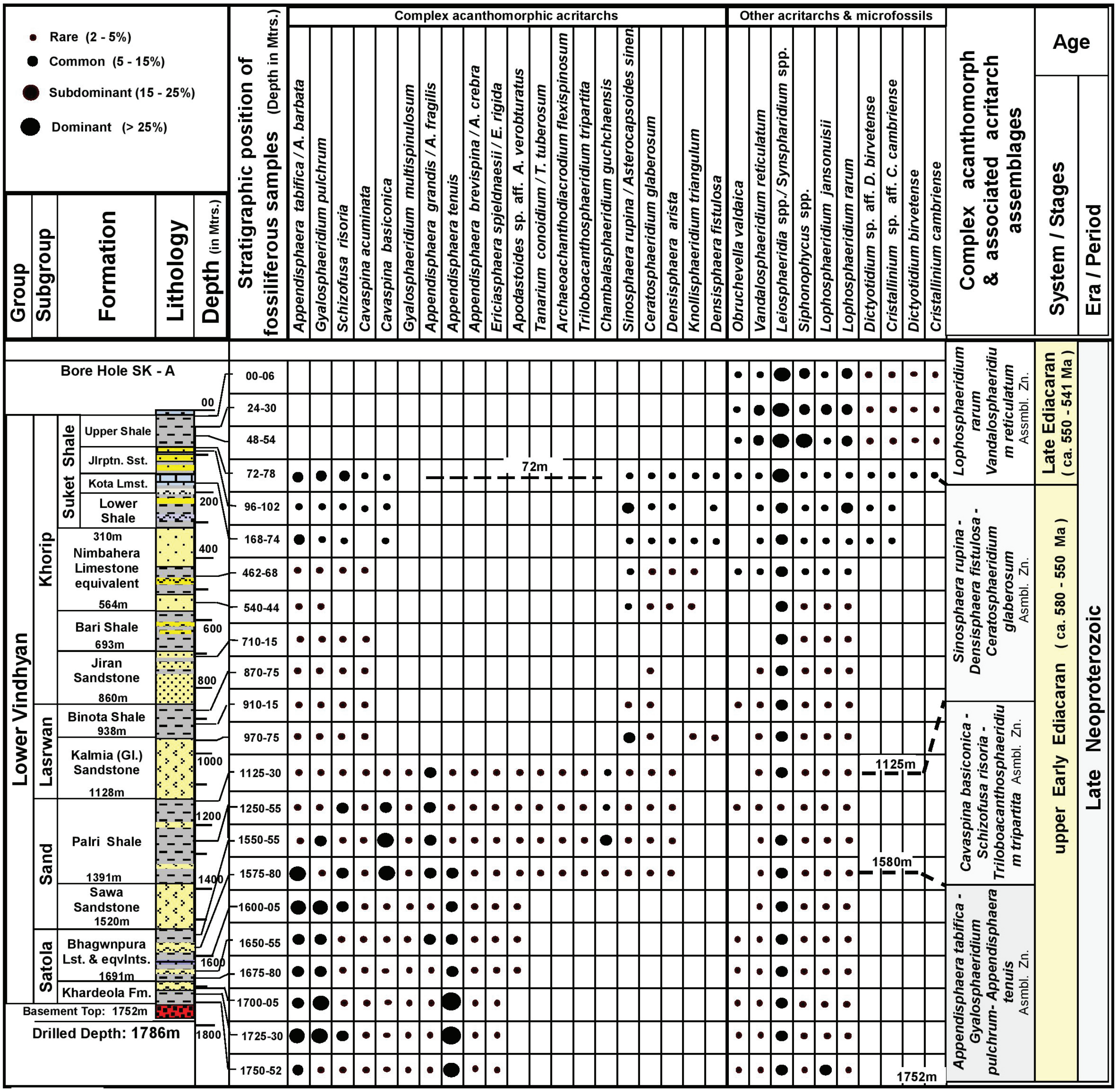


Fig. 3. Stratigraphic distribution of important Early Ediacaran marker complex acanthomorphs, characteristic Late Ediacaran acritarchs, and associated organic-walled microfossils in the purported Lower Vindhyan succession of SK-A borehole of Chambal Valley, with identified acritarch assemblages and their inferred age.

EXPLANATION OF PLATE II

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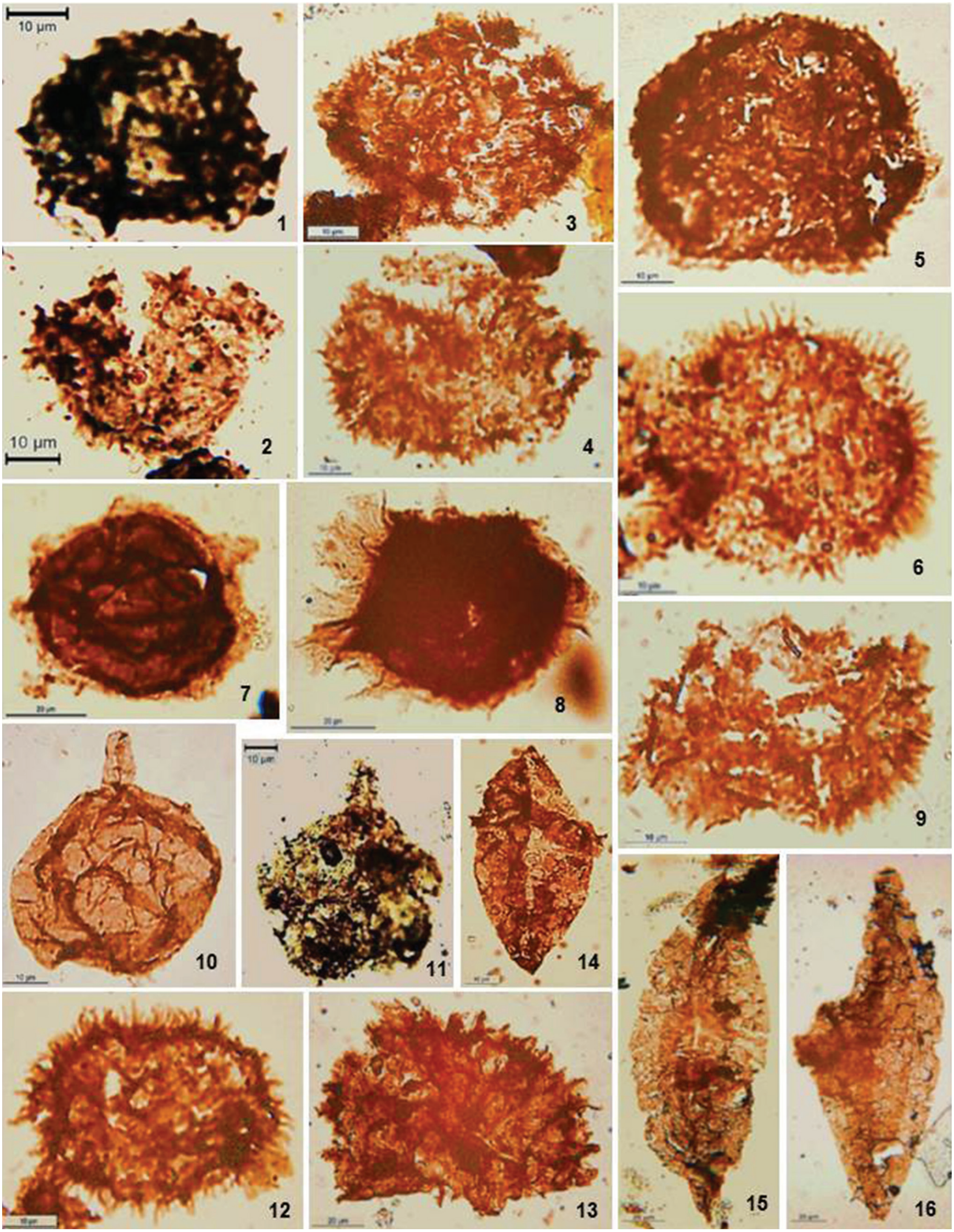
Fig. 1-16: Early Ediacaran complex acanthomorphic acritarchs of ECAP from the purported lower Vindhyan succession of the Chambal Valley. Illustrated taxa are addressed by their borehole name, documented depth-interval with associated lithounit, and microscope coordinates with England Finder readings (EFC). *Cavaspina acuminata*, JP-A, 3935-40m/1 (Lower Shale memb., Lr. Suket Shale), 103.5x34; 2. *Cavaspina acuminata*, JP-A,4045-50m/1(Bari Shale), 92.5x44; 3. *Cavaspina basiconica*, PL-A, 3150-55m/2 (Palri Shale), 109x69.5, G-71; 4.*Cavaspina basiconica*, JP-A, 3615-20m/1 (Jhalrapatan Sst., Lr. Suket Shale), 107.5x69; 5. *Ericiasphaera spjeldnaesii*, CH-A,1710-15m/2 (Sawa Sandstone), 104.5x51, M-51/4; 6. *Ericiasphaera rigida*, SK-A, 1550-55mm/1 (Bhagwanpura Limestone/Shale), 95.5x31, W-31/3; 7. *Densisphaera fistulosa*, PL-A, 2925-30m/1 (Bari Shale), 100.5x73; 8. *Densisphaera arista*, CH-A, 1790-95m/1 (Khardeola Fm.), 104x55. M-55/4; 9. *Archaeoacanthodiacrodium flexispinosum* PL-A, 3150-55m/2 (Kalmia Sandstone), 109.5x68.5, G-67; 10. *Ceratosphaeridium glaberosum* CH-A, 1750-55m/1(Khardeola Fm.), 98.5x48, S-49/1; 11. *Ceratosphaeridium glaberosum,* JP-A, 4010-15m/1 (Nimbahera Limestone), 95x23; 12. *Gyalosphaeridium pulchrum*, CH-A, 1710-15m/1 (Sawa Sandstone), 101x23, Q-22/2; 13. *Gyalosphaeridium multispinulosum* SK-A, 72-78m/1 (Jhalrapatan Sst., Lr. Suket Shale), 105x27, L-27/1; 14. *Schizofusa risoria* CH-A, 1790-95m/2 (Khardeola Fm.), 100x47, Q-4; 15. *Schizofusa risoria* PL-A, 3175-80m/1 (Palri Shale), 104.5x50.5, M-51; 16. *Schizofusa risoria* PL-A, 3150-55m/2 (Palri Shale), 107x24, J-24/1.

Plate II



BIOSTRATIGRAPHY

Major parts of the Lower Vindhyan succession, including lower and middle portions of Suket Shale in the boreholes of SK-A (1752-72 m), JP-A (4050-3625 m), and KP-A (3100-3035 m) documented moderate to the rich occurrence of distinctive Early Ediacaran complex acanthomorphic acritarchs attributable to the Ediacaran Complex Acanthomorph Palynoflora (ECAP), along with other age diagnostic organic-walled microfossils (Figs. 3, 4, 5). Additionally, the upper part of Suket Shale and overlying Kaimur Group in SK-A(72-00 m), JP-A (3625-3505 m; 3505-3130 m), and KP-A (3035-2970 m; 2970-2605 m) yielded *Leiosphaeridia, Lophosphaeridium* and *Vandalosphaeridium* dominated assemblage of the Late Ediacaran aspect.The succeeding Rewa and Bhander Groups of upper Vindhyan succession in JP-A (3130-00 m) and KP-A (2605-00 m) recorded herkomorphs (*Dictyotidium, Cristallinium*) and small acanthomorphs (*Asteridium, Baltisphaeridium*) dominated assemblages of Early Cambrian age (Figs. 3, 4,5). Identified species of the Ediacaran complex acanthomorphs and other acritarch taxa from Lower Vindhyan succession and Early Cambrian acritarchs from Upper Vindhyan succession in the above boreholes are listed below, along with other age potential organic-walled microfossils, and microphotographs of important taxa (Pl. I-IV) and their stratigraphic distributions (Figs. 3, 4). Morphological features of the listed taxa have already been described in detail earlier by Prasad and Asher (2016) from CH-A and PL-A boreholes with their microphotographs and stratigraphic distributions which have also recorded almost all the taxa listed below. The precise age of the purported Lower and Upper Vindhyan successions of Chambal Valley is inferred by comparing the freshly and previously documented acritarch assemblages of this area with their worldwide known records and established age ranges (Figs. 3, 4, 5). The below listed various species of complex acanthomorph taxa, and other Ediacaran-Early Cambrian acritarchs and associated organic-walled microfossils, are identified based on their complete morphological circumscriptions and details provided by the corresponding authors cited with the identified genera and species.

List of complex acanthomorphic acritarchs from Lower Vindhyan succession

Apodastoides Zhang, Yin, Xiao and Knoll (1998) emend.Grey, 2005.

Apodastoides sp. aff. *A. basileus* Zhang, Yin, Xiao and Knoll (1998) Grey, 2005 (Pl. I, Fig. 1).

Apodastoides sp. aff. *A. verobturatus* Grey, 2005 (Pl. I, Fig. 2).

Appendisphaera Moczydlowska, Vidal and Rudavskaya (1993) emend. Moczydlowska, 2005.

Appendisphaera sp.aff.*A. anguina* Grey, 2005 (Pl.I, Fig. 3).

A. brevispina Liu, Xiao, Yin, Chen, Zhou and Li, 2014 (Pl. I, Fig.6).

*A. barabata*Grey, 2005 (Pl. I, Fig. 9).

A.crebra (Zang in Zang and Walter, 1992) emend. Liu, Xiao, Yin, Chen, Zhou and Li, 2014 (Pl. I, Fig. 4).

A.dilutopila (Zang and Walter, 1992) Grey, 2005.

A.fragilis Moczydlowska, Vidal and Rudavskaya (1993) emend. Moczydlowska,2005 (Pl. I, Fig. 5).

A. grandis Moczydlowska, Vidal and Rudavskaya (1993) emend. Moczydlowska, 2005Pl. I, Figs. 7, 8).

A. tabifica Moczydlowska, Vidal and Rudavskaya (1993) emend. Moczydlowska, 2005 (Pl. I, Figs.10, 11).

A. tenuis Moczydlowska, Vidal and Rudavskaya (1993) emend. Moczydlowska, 2005 (Pl. I, Figs. 12, 13).

Archaeoacanthodiacrodium Prasad and Asher,2016.

A. flexispinosum Prasad and Asher, 2016 (Pl. II, Fig. 9).

Asterocapsoides (Yin and Li, 1978) emend. Xiao, Zhou, Liu, Wang and Yuan, 2014.

A. sinensis (Yin and Li, 1978) emend. Xiao, Zhou, Liu, Wang and Yuan, 2014 (Pl. III, Fig. 1).

A.wenganensis (Chen and Li, 1986) emend. Xiao, Zhou, Liu, Wang and Yuan, 2014 (Pl. III, Fig. 2).

Cavaspina Moczydlowska, Vidal and Rudavskaya, 1993.

C. acuminata (Kolosova, 1991) Moczydlowska, Vidal and Rudavskaya,1993 (Pl. II, Figs. 1, 2).

C. basiconica Moczydlowska, Vidal and Rudavskaya, 1993 (Pl. II, Figs. 3, 4).

Ceratosphaeridium Grey, 2005.

C. glaberosum Grey, 2005 (Pl. II, Figs. 10, 11).

Chambalasphaeridium Prasad and Asher, 2016.

C. guchchaensis Prasad and Asher, 2016 (Pl. I, Figs. 14, 15).

Densisphaera Nagovitsin and Moczydlowska, in Moczydlowska and Nagovitsin, 2012.

D. fistulosa Nagovitsin and Moczydlowska, in Moczydlowska and Nagovitsin, 2012 (Pl. II, Fig. 7).

D.arista Nagovitsin and Moczydlowska, in Moczydlowska and Nagovitsin, 2012 (Pl. II, Fig. 8).

Ericiasphaera (Vidal, 1990) emend. Grey, 2005.

E. spjeldnaesii Vidal, 1990 (Pl. II, Fig. 5).

E. rigida Zhang, Yin, Xiao and Knoll,1998 (Pl.II, Fig. 6).

Gyalosphaeridium Zang in Zang and Walter (1992) emend. Grey, 2005.

G. pulchrum Zang in Zang and Walter (1992) emend. Grey, 2005 (Pl. II, Fig. 12)

G. multispinulosum Grey, 2005 (Pl. II, Fig. 13).

Hocosphaeridium (Zang in Zang and Walter, 1992) emend. Xiao, Zhou, Liu, Wang and Yuan, 2014.

H. anozos (Willman in Willman & Moczydlowska,2008) Xiao,Zhou, Liu, Wang and Yuan, 2014(Pl. III, Fig.5).

H.dilatatum Liu, Xiao, Yin, Chen, Zhou and Li, 2014 (Pl. III, Fg. 10).

Knollispharidium Willman and Moczydlowska, 2008.

K. maximum (Yin, L.,1987) emend. Willman and Moczydlowska, 2008.

K.triangulum (Zang in Zang and Walter, 1992) emend. Willman and Moczydlowska, 2008 (Pl. III, Fig. 3).

Schizofusa Yan, 1982.

S.risoria Grey, 2005 (Pl. II, Figs. 14, 15, 16) .

Sinosphaera (Zhang, Yin, Xiao and Knoll, 1998) emend. Xiao, Zhou, Liu, Wang and Yuan, 2014

S. rupina (Zhang, Yin, Xiao and Knoll, 1998) Liu,Xiao, Yin, Chen, Zhou and Li, 2014 (Pl. III, Figs. 8, 9).

Tanarium (Kolosova, 1991) emend. Moczydlowska, Vidal and Rudavskaya, 1993.

T.conoideum Kolosova (1991) emend. Moczydlowska, Vidal and Rudavskaya,1993 (Pl. III, Fig. 6).

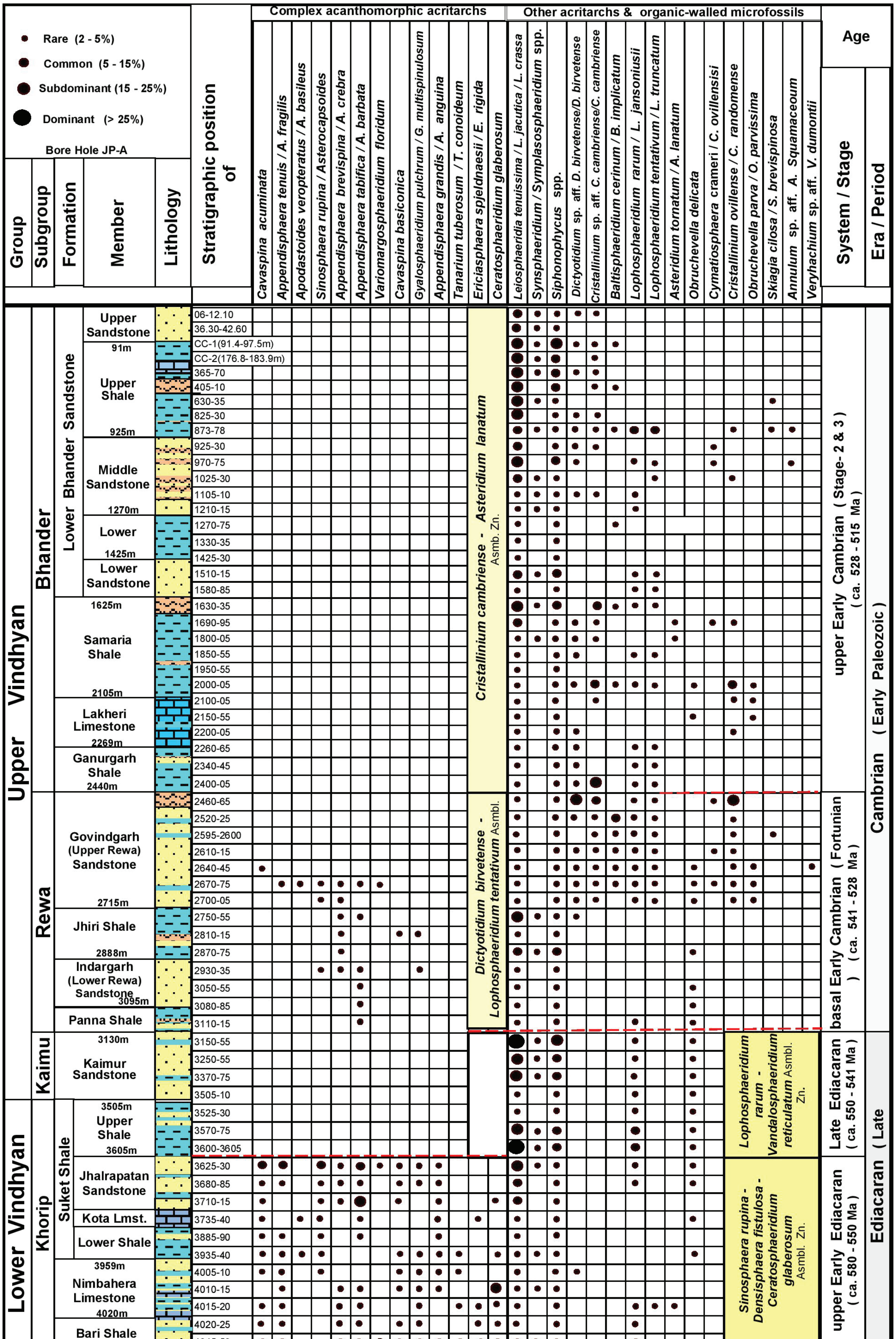


Fig. 4. Stratigraphic distribution of selected early Ediacaran complex acanthomorphs in purported Lower Vindhyan succession, Late Ediacaran acritarchs in the upper part of Suket Shale and overlying Kaimur Group, and Early Cambrian acritarchs in Rewa and Bhander Groups of Upper Vindhyan succession, and other related microfossils in JP-A borehole of the Chambal Valley, with identified assemblages and their inferred age.

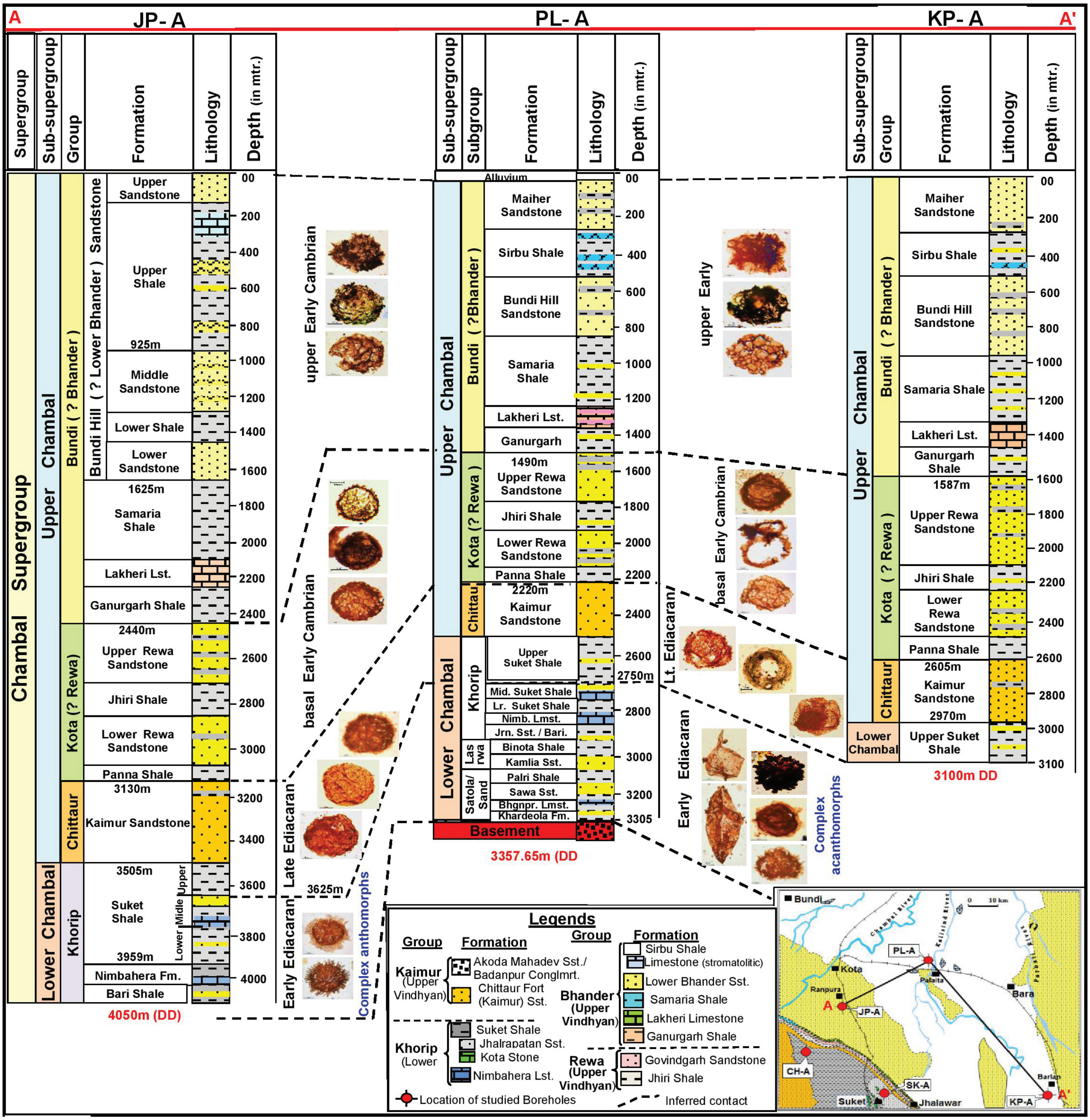


Fig. 5. Intrabasinal litho-biostratigraphic correlation of Infracambrian (Ediacaran-Early Cambrian) Lower and Upper Chambal successions of the Chambal Supergroupin Chambal Basin (till now known as "Vindhyan Supergroup" in Chambal Valley) along the JP-A, PL-A and KP-A borehole traverse, with recognized acritarch assemblages and their inferred age.

T. tuberosum Kolosova (1991) emend. Moczydlowska,Vidal and Rudavskaya, 1993 (Pl. III, Fig. 7).

T. mattoides Grey, 2005 (Pl. III, Fig. 11).

T. pycnacanthum Grey, 2005 (Pl. III, Fig. 12).

Triloboacanthosphaeridium Prasad and Asher, 2016.

T. tripartita Prasad and Asher, 2016 (Pl. III, Fig. 4).

Variomargosphaeridium Zang,1992.

*V.floridum*Nagovitsin and Moczydlowska, in Moczydlowska and Nagovitsin, 2012 (Pl. III, Fig. 13).

List of acritarchs and associated microfossils from Lower and Upper Vindhyan successions, other than the complex acanthomorphs

Sphaeromorphitae

Leiosphaeridia (Eisenack, 1958) Downie and Sarjeant, 1963, emend. Turner, 1984.

L. jacutica (Timofeev, 1966) Mikhaylova and Yankauska, in Yankauskas, Mikhaylova and German, 1989.

L. tenuissima Eisenack, 1958 (Pl. III, Fig. 14).
L. pellucid Salujha, Rehman and Arora, 1971b.
Lophosphaeridium (Timofeev, 1959, ex. Downie, 1963) emend. Lister,1970.
Ljansoniusii Salujha, Rahman and Arora, 1971b (Pl.III, Fig. 16).
L. rarum Timofeev, 1959 (Pl.III, Fig.17).
L. tentativum Volkova, 1968 (Pl. III, Fig. 18).
L. truncatum Volkova, 1969 (Pl. III, Fig.19).
Synsphaeridium Eisenack, 1965.
S. sorediforme Eisenack,1965 (Pl. III, Fig. 15).

Acanthomorphitae
Asteridium Moczydlowska, 1991.
A. tornatum (Volkova 1968) Moczydlowska, 1991.
A. lanatum (Volkova 1969) Moczydlowska,1991 (Pl. IV, Fig. 9).
Annulum Naumova, 1960
Annulum sp. aff. *A. squamaceum* (Volkova, 1968) Martin in Martin and Dean, 1983 (Pl. IV, Fig. 10).
Baltisphaeridium Eisenack,1958) emend. Eisenack, 1969.
B. implicatum Fridrichsone, 1971 (Pl. IV, Fig. 7).
B. cerinum Volkova, 1968 (Pl.IV, Fig.13).
Comasphaeridium (Staplin, Jansonius and Pocock, 1965) emend. Sarjeant and Stancliffe, 1994.
Comasphaeridium strigosum Yankauskas in Yankauskas and Posti, 1976 (Pl. IV, Fig. 2).
Comasphaeridium sp.aff.*C.strigosum*Yankauskas, in Yankauskas and Posti, 1976 (Pl. IV, Fig. 3).
Skiagia Downie, 1982.
S. cilosa (Volkova 1969) Downie, 1982 (Pl. IV, Fig. 11).
S. brevispinosa Downie, 1982 (Pl. IV, Fig. 12).
Vandalosphaeridium Vidal, 1981.
V. reticulatum (Vidal, 1976b) Vidal, 1981a (Pl. IV, Fig. 1).
Trachyhystrichosphaera German and Yankauskas, in Yankauskas, Mikhailova and German, 1989.
Trachyhystrichosphaera truncata German and Yankauskas, in Yankauskas, Mikhailova and German, 1989 (Pl. IV, Fig. 4).

Herkomorphitae
Dictyotidium Staplin, 1961.
Dictyotidium sp. aff. *D. birvetense* Paskevicieue, 1980 (Pl. IV, Fig. 14).
D. birvetense Paskevicieue, in Volkova, N.A., Kir'ianov. V.V., Piscun, L.V., Paskeviciene, L.T., Yankauskas, T.V., 1979 (Pl. IV, Fig. 15).
Cristallinium Vanguestaine,1978.
Cristallinium sp. aff. *C.cambriense* (Slavíková, 1968) Vanguestaine, 1978 (Pl. IV, Fig.17).
C.cambriense (Slavíková, 1968) Vanguestaine, 1978 (Pl. IV, Fig.16).
C.ovillense (Cramer and Diez, 1972) Martin in Matin and Dean, 1981.
C.randomense (Cramer and Diez, 1972) Martin in Matin and Dean, 1981 (Pl. IV, Fig. 18).
Cymatiosphaera Defladre, 1954.
C.crameri Slavíková, 1968 (Pl. IV, Fig. 20).
Cymatiosphaera sp. aff.*C. ovillensis* Cramer and Diez, 1972 (Pl. IV, Fig. 19).

Polygonomorphitae
Veryhachium (Deunff, 1954) Sarjeant and Stancliffe, 1994
Veryhachium sp. aff. *V. dumontii* Vanguestaine, 1973 (Pl. IV, Fig. 8)
Nematomorphitae (Filamentous microfossils)
Obruchevella (Reitlinger, 1948) emend. Yakshchin and Luchinina, 1981.
O. valdaica Yankauskas, Mikhailova and German, 1989.
O. delicata Reitlinger, 1948.
O. parva Reitlinger,1959 (Pl. IV, Fig. 6).
O. parvissima Song, 1984 (Pl. IV, Fig. 5).

In addition to the above-listed taxa, several species of *Siphonophycus* and *Symplassosphaeridium* are also abundantly present in the entire Vindhyan successions of the studied boreholes, along with the frequent occurrence of *Gangasphaera, Simia, Pterospermopsimorpha, Trachysphaeridium* and *Pterospermella.*

MICROFOSSIL ASSEMBLAGES OF THE VINDHYAN SUCCESSIONS OF CHAMBAL VALLEY, THEIR COMPARISONS, AND AGE

Early Ediacaran complex acanthomorphic acritarch assemblages of purported Lower Vindhyan succession

The fresh record of abundant and diverse Ediacaran complex acanthomorphs from the major parts of Lower Vindhyan succession, including lower and middle parts of Suket Shale, in the boreholes of SK-A, JP-A and KP-A are very significant. These acritarchs provided a very important microfossil data that enabled precise dating of the purported lower Vindhyan succession of Chambal Valley part of Vindhyan Basinas Early Ediacaran (Figs. 1, 3, 4, 5). The key complex acanthomorph taxa identified are the several species of *Apodastoides, Appendisphaera, Archaeoacanthodiacrodium, Asterocapsoides, Cavaspina, Ceratosphaeridium, Chambalasphaeridium, Densisphaera, Ericiasphaera, Gyalosphaeridium, Hocosphaeridium, Knollisphaeridium, Schizofusa, Sinosphaera, Tanarium, Triloboacanthosphaeridium,* and *Variomargosphaeridium* that all together include 35 species of the above taxa which are illustrated by microphotographs (Pl. I, figs.1-15; Pl. II, figs.1-16; Pl. III, figs. 1-13). The new record of these distinctive Ediacaran complex acanthomorphs from the above boreholes corroborates their earlier records from the purported Lower Vindhyan succession in CH-A and PL-A boreholes by Prasad and Asher (2016) which are also located in the Chambal Valley part of this basin (Fig. 1). The occurrence of these forms is rather moderate in JP-A and KP-A as these boreholes were ended in the upper part of Lower Vindhyan succession in Bari Shale and Suket Shale respectively (Figs. 4, 5). Yet, stratigraphic distributions of the identified species of complex acanthomorphs in SK-A (Fig. 3), and re-studied boreholes of

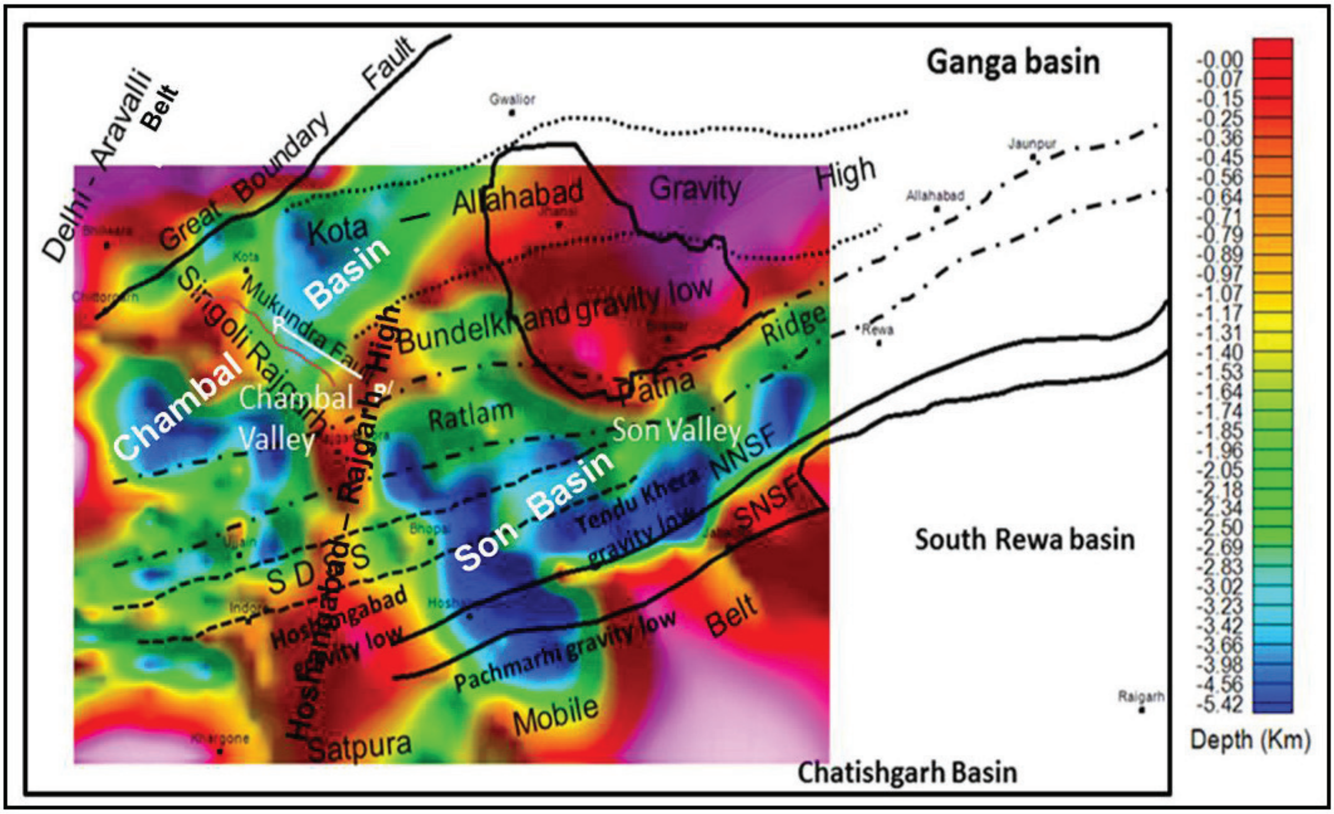


Fig. 6. Basement top contour map of the greater Vindhyan Basin in northern India, prepared by integrating Bouguer gravity anomaly, aeromagnetic and seismic data (after Nabakumar *et al.,* 2015), showing the geophysical evidence on the existence of two distinct and entirely separate sedimentary basins north of SNNF. The Late Palaeoproterozoic-Meso/Neoproterozoic Son Basin (*sensu-stricto* Vindhyan Basin) in the east (Son Valley) and Infracambrian Chambal Basin in the west (Chambal Valley, south-eastern Rajasthan) which are detached by the centrally placed NNE-SSW aligned subsurface basement ridge of "Hoshangabad-Raigarh High", and not by the Bundelkhand Granitic Complex (BGC).

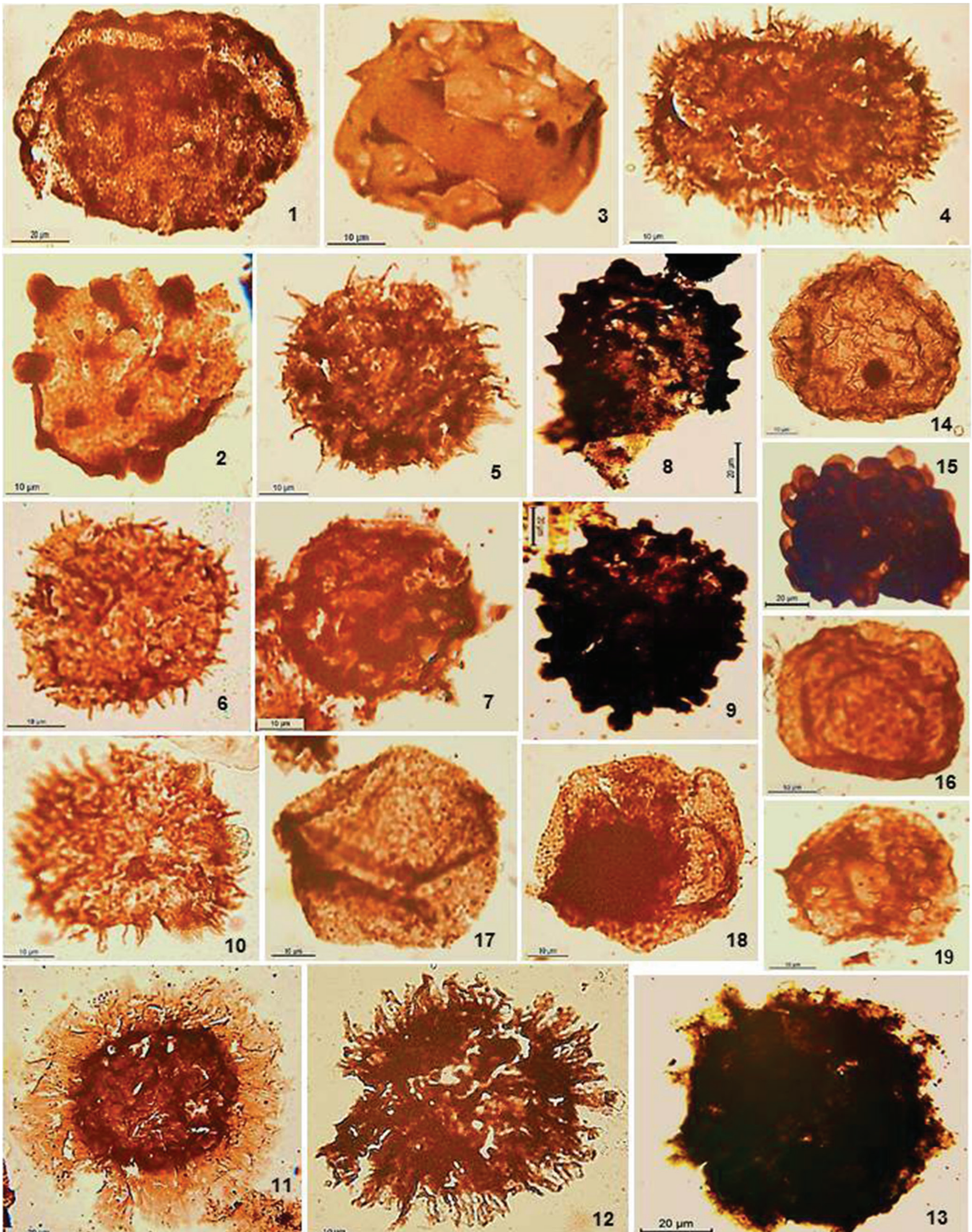
CH-A and PL-A which were terminated in the Precambrian granitic basement (Figs. 3, 4 of Prasad and Asher, 2016), show their first appearance with abundance in the basal part of lower Vindhyan succession in KhardeolaFormation, and become very rich and diverse with the arrival of some new taxa in the middle part in the Bhagwanpura Limestone, Palri Shale, Kalmia Sandstone and Binota Shale (Fig. 3). These taxa continue to occur prominently in the upper part of this succession in the Jiran Sandstone, Bari Shale, and Nimbahera Limestone units, and become rare in lower and middle parts of Suket Shale, with their complete disappearance in the middle part of this formation in the Jhalrapatan Sandstone (Figs. 3, 4).

Various species of *Leiosphaeridia*, *Lophosphaeridium, Vandalosphaeridium*, *Trachysphaeridium, Siphonophycus,* and *Obruchevella* consistently occur in the entire Lower Vindhyan succession in association with the above-listed complex acanthomorph taxa. Rare occurrences of forms assignable to *Dictyotidium* and *Cristallinium* are also observed (Figs. 3,4), which, till now, were recorded from the Late Ediacaran-Cambrian successions only.

EXPLANATION OF PLATE III →

Figs. 1-13 show the Early Ediacaran complex acanthomorphs of ECAP from the subsurface purported Lower Vindhyan succession. Figs. 14-19 show the important late Ediacaran-Early Cambrianacritarchs (other than complex acanthomorphs) from the uppermost part of Suket Shale Formation (Lower Vindhyan), and overlying Kaimur, Rewa and Bhander groups of Upper Vindhyan succession in Chambal Valley. Illustrated taxa are addressed by their borehole name, depth-interval with lithounit, and microscope coordinates with England Finder readings). *Asterocasoides sinensis*, CH-A, 1040-45m/2 (Jiran Sandstone), 93x65.5, X-66/4; 2. *Asterocasoides wenganensis*, CH-A, 1040-45mm/2 (Jiran Sandstone), 93.5x41, X-41; 3. *Knollisphaeridium triangulum*, CH-A, 1140-45m/1 (Binota Shale), 100x28, Q-28; 4. *Triloboacanthosphaeridium tripartita*, CH-A, 1790-95m/1 (Khardeola Fm.), 111x49, E-60; 5. *Hocosphaeridium (Tanarium) anozos,* CH-A, 1810-15m/1 (Khardeola Fm.), 102.5x59, O-60/1; 6. *Tanarium conoideum*, CH-A, 1790-95m/1, (Khardeola Fm.), 107x55, J-56/3; 7. *Tanarium tuberosum*, PL-A, 3085-90m/1 (Binota Shale), 111x36, E-34/1; 8. *Sinosphaera rupina* JP-A, 3700-05m/1 (Jhalrapatan Sandstone, Lr. Suket Shale), 100x47; 9. *Sinosphaera rupina* JP-A, 3670-75m/1 (Jhalrapatan Sandstone, Lr. Suket Shale), 106x59; 10. *Hocosphaeridium dilatatum*, CH-A, 1790-95m/2 (Khardeola Fm.), 97x35, U-35; 11. *Tanarium mattoides,* PL-A,3150-55m/1 (Kalmia Sandstone), 107x67, J-68/3; 12. *Tanarium pycnacanthum*, CH-A, 1870-75m/2 (Khardeola Fm.), 100x25, R-25; 13. *Variomargosphaeridium floridum*, JP-A, 3670-75m/1 (Jhalrapatan Sst., Lr. Suket Shale), 97x40; 14. *Leiosphaeridia tenuissima*, PL-A, 325-30m/1 (Sirbu Shale, Upper Bhander Group), 97x49, T49/4; 15. *Synsphaeridium sorediforme* JP-A,365-70m/1 (Upper Shale, Lr. Bhander Sandstone), 96.5x46.5; 16. *Lophosphaeridium jansoniusii,* PL-A, 1400-05m/1 (Lower Shale, Lr. Bhander Sst.), 98.5x45, S-45; 17. *Lophosphaeridium rarum,* CH-A, 1140-45m/1 (Binota Shale), 100x26, Q-26/4; 18. *Lophosphaeridium tentativum*, PL-A; 350-55m/1 (Upper Shale, Lr. Bhander Sandstone), 101x40, P-40/4; 19. *Lophosphaeridium truncatum*, CH-A; 30-35m/1 (Upper Shale, Suket Shale), 102x52, P-53.

Plate III



Comparisons and Age - The newly recorded complex acanthomorph assemblages from Lower Vindhyan succession in the above boreholes of Chambal Valley (Figs. 1, 3, 4) are closely comparable with the well-known Ediacaran Complex Acanthomorph Palynoflora (ECAP) acritarch assemblages earlier documented from the Lower Ediacaran successions worldwide that lie above the Marinoan glacial beds of ca. 635-600 Ma. Yet, the Chambal Valley ECAP assemblages closely resemble ECAP assemblages of Khamaka Formation of Yakutia from cental Siberian Platform (Moczydlowska *et al.,* 1993; Moczydlowska, 2005), Ura Formation of Baikal-Patom Uplift from East Siberian Platform (Nagovitsin *et al.,* 2004; Sergeev *et al.,* 2011; Moczydlowska and Nagovitsin, 2012), Upper Vychegda Formation (UA Assemblage) of East European Platform (Veis *et al.,* 2006; Vorob'eva *et al.,* 2009a, 2009b), and Upper Doushantuo Formation (Member III)of Yangtze Gorges and Weng'an of South China (Zhang *et al.,* 1998; Liu *et al.,* 2014; Xiao *et al.,* 2014). ECAP assemblages of the above areas were recorded from the upper parts of Lower Ediacaran successions which overlie the glacial Gaskiers/Hankalchough Formations of ca. 580 Ma or their correlative diamictites and successive rocks with *Tianzhushania spinosa* acritarch zone. Various species of the ECAP taxa,like *Apodastoides, Appendisphaera, Asterocapsoides, Cavaspina, Ceratosphaeridium, Densisphaera, Ericiasphaera, Gyalosphaeridium, Hocosphaeridium, Knollisphaeridium, Sinosphaera, Schizofusa, Tanarium*and *Variomargosphaeridium,* which were earlier recorded from the upper parts of Lower Ediacaran sequences from the above areas, are abundantly present in the purported Lower Vindhyan succession of the Chambal Valley (Figs. 3, 4).

Yet, the complex acanthomorph assemblages of Chambal Valley are fair identical to the ECAP acritarch assemblages of the Dey Dey Mudstone and Karlaya Limestone Formations (eastern Officer Basin) and Pertataka Formation (Amadeus Basin) of South Australia (Zang and Walter, 1992; Grey, 2005; Willman *et al.,* 2006; Willman and Moczydlowska, 2008, 2011) as the majority of the complex acanthomorph taxa recorded from the above litho units, abundantly occur in the purported Lower Vindhyan succession of Chambal Valley (Figs. 3, 4,5; Pl. I, Figs. 1-15; Pl. II, Figs. 1-16; Pl. III, Figs. 1-13). Above lithounits of the eastern Officer Basin, with distinctive ECAP assemblages, lie well above the isotopic age constrained Acraman impact ejecta layer (AIEL) of ca. 580-570 Ma and successive rock-units with leiospherids dominated assemblage of the Ediacaran Leiosphere Palynoflora (ELP). Moczydlowska (2005), while reviewing the worldwide distribution of ECAP assemblages, also suggested upper early Ediacaran (ca. 580-550 Ma) age for the ECAP assemblages of East European-Siberian platforms, South China and South Australia.

Meager assemblages of complex acanthomorphs have also been reported from the Infrakrol Formation and Krol Group of Lesser Himalaya from Solan and Nainital areas in India (Tiwari and Knoll, 1994; Shukla *et al.,* 2008; Shukla and Tiwari, 2014; Joshi and Tiwari, 2016). The above records mainly include the taxa, like*Asterocapsoides* sp., *Echinosphaeridium maximum, Ericiasphaera spjeldnaesii, E. rigida, Filisphaeridium* sp., *Meghystrichosphaeridium perfectum, Tianzhushania spinosa* and*Papillomembrana compact* along with poorly identifiable *Appendisphaera fragilis*, *A. grandis*, *Cavaspina acuminata* and *C. basiconica.* Above recorded complex acanthomorph assemblages are inferred to be represented by the *Tianzhushania spinosa* acritarch zone of lower early Ediacaran (ca. 600-580 Ma), and appear older than the distinctive upper early Ediacaran (ca. 580-550 Ma) ECAP assemblages of purported Lower Vindhyan succession of Chambal Valley as marker ECAP taxa are absent in the Infrokrol-Krol assemblages.

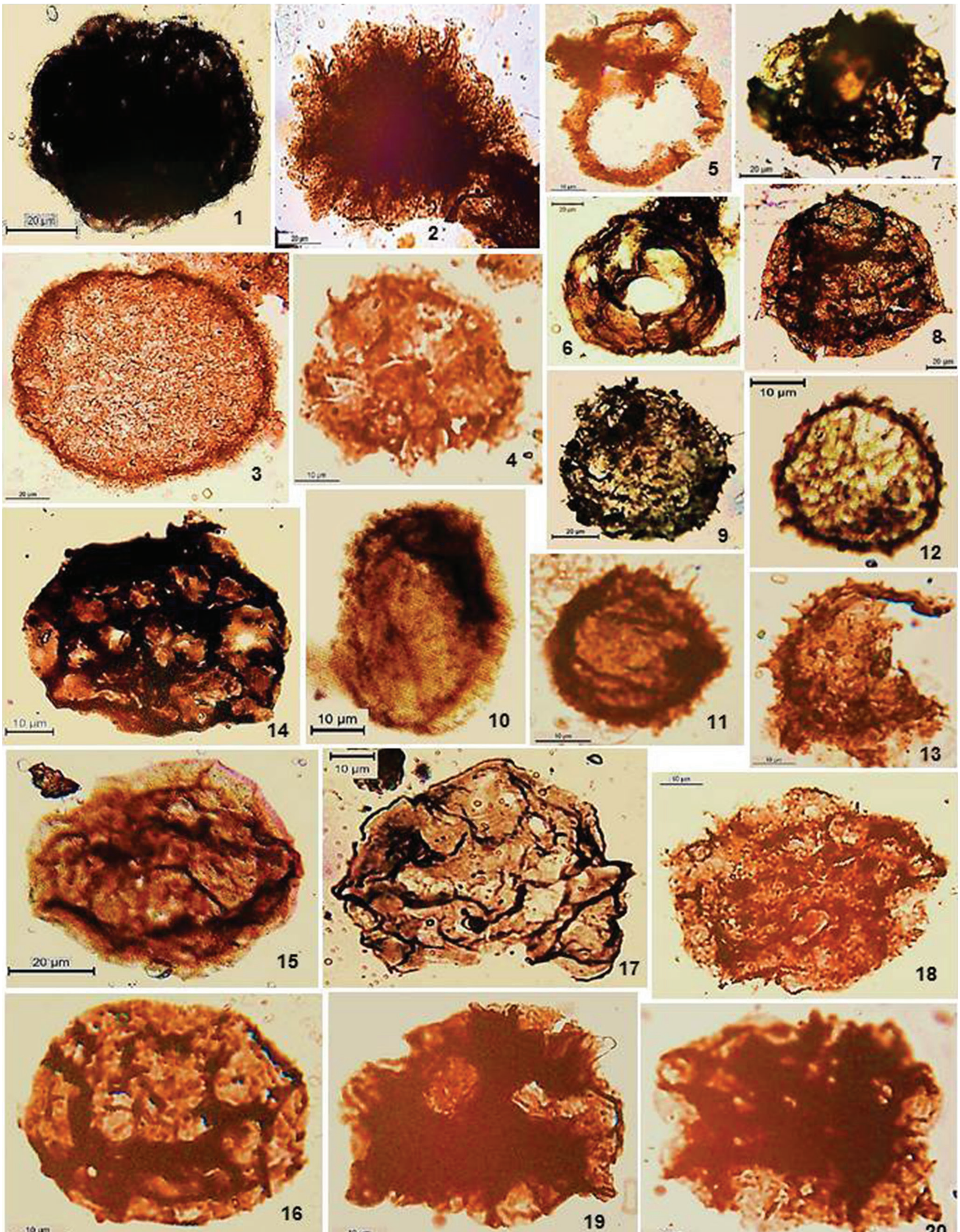
Thus, the close resemblance of the freshly recorded complex acanthomorph assemblages with the globally known ECAP assemblages, conclusively suggests upper ealy Ediacaran age (ca. 580-550 Ma) for the purported lower Vindhyan succession of the Chambal Valley as ECAP acritarchs first appear in abundance in the lowermost without of this succession (Khardeola Formation) which directly rests on the Precambrian granitic basement in the studied boreholes, and the key taxa of the *Tianzhushania spinosa* acritarch zone are absent (Figs. 3, 4, 5). The above age inference categorically suggests a much younger age of upper early Ediacaran (ca. 580-550 Ma) for the purported lower Vindhyan succession of the Chambal Valley part of Vindhyan Basin (Figs. 3, 4, 5, 7) which, till now, is dated Late Palaeoproterozoic to Meso-Neoproterozoic (ca. 1721-650 ± 24 Ma) age through varied micro-megafossils and radiometric data. In addition, a fresh record of distinctive ECAP assemblages from SK-A, JP-A and KP-A boreholes, and their previous records from CH-A

EXPLANATION OF PLATE IV

→

Late Ediacaran - Early Cambrian acritarchs from upper part of Suket Shale (uppermost Lower Vindhyan), and overlying Kaimur, Rewa and Bhander Groups of Upper Vindhyan succession in Chambal Valley. Illustrated taxa arelocated by borehole name, depth-interval, and microscope coordinates with England Finder reading. 1. *Vandalosphaeridium reticulatum,* JP-A, 2100-2105m/1 (Samaria Shale, Bhander Group), 105x40.6; 2. *Comasphaeridium strigosum,* PL-A, 2160-65 m/1 (Indargarh Sandstone, Rewa Group.), 110.5x33, E- 33; 3. *Comasphaeridium* sp. aff. *C. strigosum,* PL-A, 2100-05m/1 (Indargarh Sst., Rewa Group.), 106x35.5, J-35/4; 4. *Trachyhystrichosphaera truncata*, PL-A, 2565-70/1 (Upper Shale, Suket Shale Fm.), 109x29, G-29/1; 5. *Obruchevella parva,* PL-A, 350-55m/1 (Sirbu Shale, Upper Bhander Group), 99.5x33, R-33/2; 6. *Obruchevella parvissima*, JP-A, 2640-45m/1 (Govindgarh Sandstone, Rewa Group), 94.5x63.5; 7. *Baltisphaeridium implicatum*, JP-A, 2520-25m/1 (Govindgarh Sandstone, Rewa Group), 107x35.6; 8. *Veryhachium* sp. aff. *V. dumontii*, JP-A, 2640-45m/1 (Govindgarh Sandstone, Rewa Group), 95x53; 9. *Asteridiumlanatum*, JP-A, 4015-20m/1, (Nimbahera Limestone, Khorip Group), 108x40; 10. *Annulum* sp. aff. *A. squamaceum*, JP-A, 873-78m/1 (Upper Shale, Lower. Bhander Sandstone), 105.5x35; 11. *Skiagia cilosa*, KP-A, 2595-2600m/1 (Panna Shale, Rewa Group), 105.5x35.5; 12. *Skiagia brevispinosa* JP-A, 405-10m/1 (Upper Shale, Lower. Bhander Sandstone), 105 x71; 13. *Baltisphaeridium* sp. aff. *B. cerinum*, PL-A 1895-1900m/1 (Jhiri Shale, Rew Group), 107.5x43, H-43/4; 14. *Dictyotidium birvetense*, JP-A, 2400-2405m/1 (Ganurgarh Shale, Bhander Group), 112.5x58.5; 15. *Dictyotidium birvetense*, JP-A, 970-75m/1 (Middle Sandstone, Lr. Bhander Sandstone), 92x57; 16.*Cristallinium cambriense,* PLA, 350-55m/1 (Sirbu Shale, Bhander Group), 97x65, U-66/2; 17. *Cristallinium cambriense*, JP-A, 2460-65m/1 (Govindgarh sandstone, Rewa Group), 95x 73; 18. *Cristallinium* sp. aff. *C. randomense*, PL-A, 350-55m/1 (Sirbu Shale, Bhander Group), 102x72, O-70/4; 19. *Cymatiosphaera ovillensis,* PL-A, 48-90m/1 (Maihar Sandstone, Bhander Group), 109 x26, G-26; 20. *Cymatiosphaera crameri*, SK-A, 72-78m/1 (Upper Shale, Suket Shale),103x40, N-39/1.

Plate IV



and PL-A boreholes (Prasad and Asher, 2016) which are also located in the Chambal Valley part of this basin, reveal widespread occurrences of the ECAP microfossils in the purported Lower Vindhyan succession present in the western part of Vindhyan Basin (Figs. 1, 5).

Early Ediacaran complex acanthomorphic acritarch zones in purported Lower Vindhyan succession of Chambal valley: Stratigraphic distributions of Ediacaran complex acanthomorphs in the purported Lower Vindhyan succession of the newly studied boreholes of SK-A, JP-A, and KP-A, and re-studied boreholes of CH-A and PL-A, reveal that some key ECAPtaxashow their dominance within the specific stratigraphic intervals, along with the appearance and/or disappearance of the certain taxa at different stratigraphic levels. This distribution pattern enables the recognition of 3 distinct ECA Passemblage zones (zones I, II &III) within the major parts of purported Lower Vindhyan succession of Chambal Valley (Table 1; Figs. 3, 4) which are briefly outlined below:

Zone-I: Appendisphaera tabifica - Gyalosphaeridium pulchrum - Appendisphaera tenuis Assemblage Zone

Definition: Abundant occurrence of *Appendisphaera tabifica, A. tenuis* and *Gyalosphaeridium pulchrum.*

Reference section: Borehole SK-A, depth-int. 1752-1580m; Khardeola and Bhagwanpura formations (Fig. 3).

Other sections: Boreholes of CH-A (depth-int. 1871-1790m) andPL-A (depth-int. 3305-3175m).

Significant accessory forms: *Gyalosphaeridium multispinulosum, Appendisphaera* aff. *A. anguina, A. brevispina,A. fragilis, Apodastoides* sp. aff. *A. verobturatus, Cavaspina basiconica* and *Schizofusa risoria*.

Other important forms: Rare occurrence of *Vandalosphaeridium reticulatum*, *Lophosphaeridium jansoniusii, Obruchevella valdaica,* and several species of *Leiosphaeridia.*

Comparisons: This assembbalge resembles *Appendisphaera barbata* (*A. tabifica*) - *Alicesphaeridium medusoideum -Gyalosphaeridium pulchrum* Zone recognised inthe middlepart of Dey Dey Mudstone Formation (early Ediacaran) of eastern Officer Basin, South Australia (Willman *et al.,* 2006). However, key taxa like *Alicesphaeridium medusoideum* and *Multifronsphaeridium pelorium* of the Australian zone are absent in the Chambal assemblage (Fig. 3).

Suggested age: upper Early Ediacaran (ca. 580-550Ma).

Zone-II: Cavaspina basiconica - Schizofusa risoria-Triloboacanthosphaeridium tripartita Assemblage Zone

Definition: Dominance of *Cavaspina basiconica, Schizofusa risoria* and *Triloboacanthosphaeridium tripartita.*

Reference section: Borehole SK-A, depth-int. 1580-1125 m; Sawa Sandstone and Palri Shale, Sand Group (Fig. 3).

Other sections: Boreholes of CH-A (1790-1140 m)and PL-A (3175-3000 m).

Significant accessory forms: Appendisphaera brevispina, A. fragilis, A. grandis, A. tabifica, Cavaspina acuminata and *Gyalosphaeridium pulchrum* continue to occur here from the underlying zone. OtherECAP taxa of*Apodastoides basileus, Archaeoacanthodiacrodium flexispinosum, Chambalasphaeridium guchchaensis, Densisphaera arista, Ericiasphaera spjeldnaesii, E. rigida, Hocosphaeridium anozos, H. dilatatum, Tanariumconoideum, T. Tuberosum* and *T. mattoides* show their restricted occurrence, with their first appearance in the lower part of this zone (Fig. 3).

Forms, such as *Vandalosphaeridium reticulatum*, *Lophosphaeridium jansoniusii, Leiosphaeridia* spp. and *Obruchevella* spp. occur in rarity, along with the appearance of taxa referable to *Dictyotidium* (*Dictyotidium* sp. aff. *D. birvetense*) and *Cristallinium* (*Cristallinium* sp. aff. *C. cambriense*) in the lower part of this zone (Fig. 3).

Comparisons: The ECAPassemblage of this zone is broadly comparable with the *Tanarium conoideum-Schizofusarisoria - Variomargosphaeridium lithoschum* Zone recognized in the middle and upper parts of Dey Dey Formation of eastern Officer Basin, South Australia (Grey, 2005; Willman *et al.,* 2006; Willman and Moczydlowska, 2011). Key taxa of the above-mentioned Australian zone, like *Variomargosphaeridium lithoschum, Tanarium irregulare,* and *T. muntense* are absent in Zone-II of the purported Lower Vindhyan assemblages of the Chambal Valley (Fig. 3).

Suggested age: upper early Ediacaran (ca. 580-550 Ma).

Zone-III: Sinosphaera rupina- Densisphaera fistulosa-Ceratosphaeridium glaberosum Assemblage Zone

Definition: Consistent and restricted occurrence of *Sinosphaera rupina, Densisphaera fistulosa, Ceratosphaeridium glaberosum,* and *Knollisphaeridium triangulum,* and rare presence of *Appendisphaera tabifica* and *Schizofusa risoria*.

Reference section: Borehole SK-A, depth-int. 1125-72 m; Kalmia Sandstone, Binota Shale, Jiran Sandstone, Bari Shale and Nimbahera Limestone, and lower and middle parts of Suket Shale (Fig.3).

Other sections: Boreholes of CH-A (1140-162 m), PL-A (3000-2750 m), JP-A (4050-3605 m) & KP-A (3100-3050 m).

Significant accessory forms: Asterocapsoides sinensis, Cavaspina acuminata, C. basiconica, Gyalosphaeridium pulchrum, Tanarium tuberosum and *Variomargosphaeridium floridum* show their frequent occurrence. In addition, *Vandalosphaeridium reticulatum*, *Lophosphaeridium rarum, L. jansoniusii, Obruchevella valdaica, Leiosphaeridia* spp., *Dictyotidium* sp. aff. *D. birvetense* and *Cristallinium* sp. aff. *C. cambriense* are is present in rarity (Figs. 3, 4).

Remarks: All the complex acanthomorph species, mentioned above, become rare in the lower and middle parts of Suket Shale, with their complete disappearance in the Jhalrapatan Sandstone of this formation (Figs. 3, 4).

Comparisons: ECAP assemblage of this zone largely compares with the *Tanarium irregulare-Ceratosphaeridium glaberosum-Multifronspheridium pilorium* Zone recognized in the upper part of Dey Dey Formation and lower part of Karlaya Limestone in eastern Officer Basin (Grey, 2005; Willman *et al.,* 2006). Key taxa of the above-mentioned Australian zone, like *V. litoschum* and *L. Intertexum* is absent in this zone of the Chambal Valley (Figs. 3, 4).

Suggested age: upper Early Ediacaran (ca.580-550Ma).

Table 1. Distributions of identified Ediacaran complex acanthomorph assemblage zones, and other acritarch zones, in Lower and Upper Chambal subsupergroups (up till now referred as lower and upper Vindhyan successions) in CH-A, SK-A, PL-A, JP-A and KP-A boreholes of the Chambal Basin (Chambal Valley).

<table>
<tr><th rowspan="2">Group</th><th colspan="3" rowspan="2">Acritarch zones</th><th rowspan="2">Inferred age</th><th colspan="5">Acritarch zones distribution in drilled boreholes with depth-intervals</th></tr>
<tr><th>CH-A</th><th>SK-A</th><th>PL-A</th><th>JP-A</th><th>KP-A</th></tr>
<tr><td rowspan="3">Upper Chambal (Vindhyan) Grp.</td><td rowspan="4">Non-complex acanthomorphic acritarch zones</td><td>VI</td><td>Cristallinium cambriense-Asteridium lanatum Asmbl. Zn.</td><td>Early Cambrian (ca. 528-515 Ma)</td><td rowspan="3">Borehole drilled on the Recent Alluvium, encountering the Suket Shale Formation of Lower Vindhyan succession at 30m deph</td><td rowspan="3">Borehole drilled on the top of Shuket Shale Formation of Lower Vindhyan succession</td><td>1490-00m</td><td>2440-00m</td><td>1587-00m</td></tr>
<tr><td>V</td><td>Dictyotidium birvetense - Lophosphaeridium tentativum Asmbl. Zn.</td><td>basal Early Cambrian (ca. 541-528 Ma)</td><td>2220-1490m</td><td>3130-2440m</td><td>2605-1587m</td></tr>
<tr><td rowspan="2">IV</td><td rowspan="2">Lophosphaeridium rarum - Vandalosphaeridium reticulatum Asmblg. Zn.</td><td rowspan="2">Late Ediacaran (ca. 550-541 Ma)</td><td>2530-2220m</td><td>3505-3130m</td><td>2970-2605m</td></tr>
<tr><td rowspan="4">Lower Chambal (Vindhyan) Group</td><td>162-30m</td><td>72-00m</td><td>2750-2530m</td><td>3605-3505m</td><td>3050-2970m</td></tr>
<tr><td rowspan="3">Complex acanthomorphic acritarch zones</td><td>III</td><td>Sinosphaera rupina - Densisphaera fistulosa - Ceratosphaeridium glaberosum Asmblg. Zn.</td><td>upper Early Ediacaran (ca. 580-550 Ma)</td><td>1140-162m</td><td>1125-72m</td><td>3000-2750m</td><td>4050-3605m</td><td>3100-3050m</td></tr>
<tr><td>II</td><td>Cavaspina basiconica - Schizofusa risoria - Triloboacanthosphaeridium tripartita Asmblg. Zn.</td><td>upper Early Ediacaran (ca. 580-550 Ma)</td><td>1790-1140m</td><td>1580-1125m</td><td>3175-3000m</td><td rowspan="2">Borehole ended in Bari Shale Formation of Lower Vindhyan succession at 4050m depth</td><td rowspan="2">Borehole ended in lower part of Shuket Shale Formation of Lower Vindhyan succession at 3100m depth</td></tr>
<tr><td>I</td><td>Appendisphaera tabifica - Gyalosphaeridium pulchrum - Appendisphaera tenuis Asmblg. Zn.</td><td>upper Early Ediacaran (ca. 580-550 Ma)</td><td>1871-1790m</td><td>1752-1580m</td><td>3305-3175m</td></tr>
<tr><td colspan="5">Paleoproterozoic Berach Granite basement (2530±3.6 Ma)</td><td>1871-1885m+</td><td>1752-1786m+</td><td>3305-3358m+</td><td></td><td></td></tr>
</table>

Late Ediacaran acritarch assemblage of Upper Suket Shale and Kaimur Group

The upper part of the Suket Shale (Upper Shale member), representing the topmost unit of Lower Vindhyan succession in the Chambal Valley, and the overlying litho units of the Kaimur Group in the newly drilled boreholes of SK-A, JP-A, and KP-A, and re-studied boreholes of CH-A and PL-A, are marked by the dominance of several species of *Leiosphaeridia, Synsphaeridium,* and *Siphonophycus,* subdominance of *Lophosphaeridium rarum, L. jansoniusii* and *Vandalosphaeridium reticulatum,* and the frequent occurrence of *Obruchevella delicata* and *O. Parva* (Figs. 3, 4; Pl. III, Figs. 14-17; Pl. IV, Figs. 1-5) that largely characterize the Upper Ediacaran rocks worldwide. Though, these taxa consistently occur in the preceding ECAP assemblages of Lower Vindhyan succession but become prominent here. The most important feature of this assemblage is the complete absence of distinctive complex acanthomorphs which are very abundant in the underlying litho units of the Lower Vindhyan succession (Figs. 3, 4, 5).

Comparisons and age: The leiosphaerids (*Leiosphaeridia* spp.), ornamented sphaeromorphs (*Lophosphaeridium* spp., *Vandalosphaeridium* spp.), and nematomorphs (*Siphonophycus*) dominated assemblage of the upper part of Suket Shale and overlying Kaimur Group, with a significant occurrence of *Obruchevella delicata* and *O. parva*, closely resembles leiosphaerids dominated acritarch assemblages earlier recorded from the Upper Ediacaran (Late Vendian) successions of Estonia (Volkova, 1968, 1985; Volkova, *et al.,* 1979), South Sweden (Vidal, 1974, 1976a), northern

Norway (Vidal, 1981a; Vidal and Sieddlecka, 1983) and southern Poland (Burzin, 1994; Moczydlovska, 1991) of East European Platform, East Greenland (Vidal, 1976b, 1979a) and Siberian Platform (Sergeev, 1992, 2002). In all the above globally distributed late Ediacaran assemblages and in Upper Suket Shale-Kaimur Group assemblage, various species of *Leiosphaeridia* and *Siphonophycus* occur in abundance, along with the prominence of *Lophosphaeridium* spp., *Vandalosphaeridium* spp. and *Obruchevella* spp., and thus strongly suggesting late Ediacaran (ca. 550-541 Ma) age for the above-mentioned two litho units of the Chambal Valley. Moreover, the conspicuous absence of Early Ediacaran complex acanthomorphs, which are abundantly present in the underlying litho units of Lower Vindhyan sequence, and the rare presence of small acanthomorphs (*Asteridium* spp.) and herkomorphs (*Dictyotidium* sp. and *Cristallinium* sp.), whose first occurrences in rarity during Late Ediacaran are now well-established (Moczydlovaska, 1991; Molyneux *et al.,* 1996; Sergeev, 2009), evidently corroborates Late Ediacaran age inference for the upperpart of Suket Shale and the overlying Kaimur Group (Figs. 3,4, 5).

Late Ediacaran acritarch zone of Upper Suket Shale and Kaimur Group: Stratigraphic distributions of the recognized acritarchs and associated microfossils in upper Suket Shale and overlying Kaimur Group in the studied boreholes enable recognition of only one assemblage zone (Table 1; Figs. 3, 4, 5) which is briefly outlined below:

Zone-IV: Lophosphaeridium rarum -Vandalosphaeridium reticulatum Assemblage Zone

Definition: Prominent occurrence of *Lophosphaeridium rarum, Vandalosphaeridium reticulatum, Obruchevella delicate* and *O. parva,* and abundant occurrence of several species of *Leiosphaeridia* and *Siphonophycus*.

Reference section: Borehole PL-A; depth-int. 2750-2220 m; upper part of Suket Shale (2750-2530 m) and overlying Kaimur Group (2530-2220 m) [Fig. 5 in present work Fig. 4 of Prasad and Asher, 2016].

Other sections: CH-A (162-30 m), SK-A (72-00 m), JP-A (3605-3130 m), and KP-A (3050-2605 m) [Figs. 3, 4, 5].

Significant accessory forms: Trachyhystrichsphaera truncate and *Pterospermopsimorpha saccata* (Figs. 3, 4).

Remarks: All the complex acanthomorph taxa, which are very abundant in the major parts of Lower Vindhyan succession, and overlying lower and middle parts of Suket Shale Formation, are completely absent in this zone that covers the upper part of Suket Shale Formation and overlying Kaimur Group (Figs. 3, 4, 5).

Suggested age: Late Ediacaran (ca.550-541 Ma).

Early Cambrian acritarch assemblages from Rewa-Bhander Groups of Upper Vindhyan succession

Various litho units of the Rewa and Bhander Groups of Chambal Valley in JP-A, KP-A, and PL-A boreholes, (Fig. 1) are represented by the acritarch assemblages that include the common and consistent occurrence of *Dictyotidium birvetense, Cristallinium cambriense, C. randomense, C. ovillense, Lophosphaeridium tentativum, L. truncatum, Asteridium tornatum* and *A.lanatum*which chieflycharacterise the Early Cambrian (ca. 541-515 Ma) assemblages worldwide. Other key Early Cambrian taxa, like *Comasphaeridium strigosum, Baltisphaeridium implicatum, B.cerinum, Skiagia cilosa, S. brevispinosa, Annulum* sp. aff. *A. squamaceum, Cymatiosphaera crameri, C. ovillensis, Veryhachium* sp. aff. *V. dumontii* and *Obruchevella parvissima*show their sporadic, yet significant presence (Fig.4; Pl. IV, Figs. 6-20). Importanttaxa of the underlying Late Ediacaran assemblage of Upper Suket Shale-Kaimur Group (Zone IV), *viz*., *Lophosphaeridium jansoniusii, L. rarum, Vandalosphaeridium reticulatum, Obruchevella delicate,* and *O. Parva* continue to occur herein rarity. Yet, various species of *Leiosphaeridia, Synsphaeridium,* and *Siphonophycus*still constitute the dominant component of the Rewa-Bhander Group assemblages (Fig. 4).

Stratigraphic distributions of the above-listed taxa from Rewa and Bhander Groups in the studied boreholes allow the recognition of two acritarch assemblage zones. The older one (Zone V) mainly covers the Rewa Group, while younger one (Zone VI) includes the Bhander Group (Table 1; Figs. 4, 5), and both are briefly described below:

Zone - V: Dictyotidium birvetense-Lophosphaeridium tentativum Assemblage Zone

Definition: Consistent occurrence of *Dictyotidium birvetense, Lophosphaeridium tentativum, L. truncatum* and *A.lanatum,* and rare yet significant presence of *Cristallinium cambriense, Baltisphaeridium implicatum*, *B.cerinum, Asteridium tornatum, Skiagia cilosa, Comasphaeridium strigosum, Obruchevella parva* and *O. parvissima.*

Reference section: Borehole PL-A; depth-int. 2220-1490 m; Rewa Group (Fig. 5; Fig. 4 of Prasad and Asher, 2016).

Other sections: Boreholes JP-A (3130-2440 m) and KP-A (2605-1587 m) [Figs. 4, 5].

Comparisons and age: Acritarch assemblage of this zone, largely covering the Rewa Group, is closely comparable with the globally known basal Early Cambrian acritarch assemblages mainly recorded from the East European and Siberian platforms (Volkova, 1968; Volkova *et al*., 1979; Moczydlowska, 1991; Sergeev, 1992; Burzin, 1994). Yet, the Rewa assemblage closely resembles basal Early Cambrian acritarch assemblages of the Tokammane Formation of Spitsbergen (Knoll and Swett, 1987), and Rovno/Lontova Beds (Sub-Holmia stage) of Estonia (Volkova, 1971), Poland (Moczydlovaska, 1981) and Scandinavia (Vidal, 1981b; Vidal and Knoll, 1983) as several taxa of the above assemblages abundantly occur in the acritarch assemblage of Rewa Group in the Chambal Valley (Figs. 4, 5).

The Rewa Group assemblage also resembles Chert-Phosphorite (Lower Tal Formation) acritarch assemblage of the Lesser Himalaya succession of Mussoorie syncline (Prasad *et al.,* 1990; Tiwari, 1999) which is precisely dated as basal Early Cambrian (Tommotian) by small shelly microfossils and conodonts (Azmi, 1983). Key basal Early Cambrian Taxa, like *Lophosphaeridium tentativum, L. truncatum, Asteridium tornatum, A. lanatum* and *Baltisphaeridium* sp. are common in both the assemblages. This assemblage also appears fairly similar to the pre-trilobite Early Cambrian (Meishucunian) chert-phosphorite acritarch assemblages of the Yangtze Platform (South China) and Yurtis-Xishanblaq Formations of Tarim, north-west China (Yin, 1995; Yao *et al.,* 2005), and suggests basal Early Cambrian age (541-528 Ma)for the Rewa Group's sediments of the Chambal Valley area (Figs. 4,5,7).

Suggested age: basal Early Cambrian (ca.541-528 Ma).

Zone-VI: Cristallinium cambriense-Asteridium lanatum Assemblage Zone

Definition: All the lithounits of Bhander Group, representing the youngest sequence of the Upper Vindhyan succession in the Chambal Valley, showed the prominent occurrence of *Cristallinium cambriense, C. randomense, Asteridium lanatum, Skiagia brevispinosa, Cymatiosphaera crameri, C. ovillensis* and *Veryhachium* sp. aff. *V. dumontii,* and define the newly proposed *C. cambriense-A. lanatum* Assemblage Zone (Figs. 4, 5). Key taxa of the preceding Rewa Group assemblage, like *Baltisphaeridium cerinum, B. implicatum, Skiagia cilosa, Dictyotidium birvetense, Lophosphaeridium tentativum, L. truncatum, Obruchevella parva,* and *O. parvissima* continued to occur here in rarity. Taxa like *Cristallinium randomense, C. ovillense* and *Cymatiosphaera cramer i*s how their first occurrence. Yet, various species of *Leiosphaeridia* and *Siphonophycus* still dominate the assemblage (Figs. 4, 5).

Reference section: Borehole JP-A; depth-int. 2440-00 m; Bhander Group (Fig. 4).

Other sections: Boreholes PL-A (1490-000 m) and KP-A (1587-00 m) [Figs. 4, 5].

Comparisons: This acritarch assemblage of the Bhander Group is mainly comparable with the upper Early Cambrian acritarch assemblages earlier recorded from the sedimentary successions referable to the Atdabanian Stage from the East European Platform (Volkova *et al.,* 1979; Moczydlowska, 1991, Sergeev, 1992, 2009). However, the assemblage from Bhander Group shows close resemblance with the upper Early Cambrian acritarch assemblage of Hell's Mouth Formation (St. Tudwal's Peninsulsa), northwest Wales (Young *et al.,*1994) as key taxa, like *Skiagia brevispinosa, Asteridium* spp., *Annulum squamaceum*, *Comasphaeridium strigosum*, *Cristallinium cambriense,* and *Cymatiosphaera ovillensis* are common in both the assemblages. The later assemblage is precisely dated as upper Early Cambrian based on associated trilobite fossils. Sergeev (2009) opined that the upper Early Cambrian (Atdabanian) acritarch assemblages globally marked by the abundant small acanthomorphs (*Skiagia, Asteridium,* and *Baltisphaeridium*), and a similar case is with the acritarch assemblage of Bhander Group also (Fig. 4). Thus, the close similarity of the present assemblage with the above assemblage suggests upper Early Cambrian (ca. 528-515 Ma) age for the sediments of Bhander Group of this area, and a similar upper age limit for the purported Vindhyan succession of the Chambal Valley part of the Vindhyan Basin (Figs. 1,4, 5, 7).

Suggested age: upper Early Cambrian (ca. 528-515 Ma).

Remarks: It is perplexing to observe that the rocks of Rewa and Bhander Groups also show the rare occurrence of complex acanthomorphs in JP-A and KP-A boreholes that include *Appendisphaera tenuis, A. tabifica, A. brevispina, Gyalosphaeridium pulchrum, Cavaspina acuminate, C. basiconica* and *Sinosphaera rupina.*These forms are poorly preserved, highly biodegraded and matured, and interpreted as recycled from the underlying Lower Vindhyan succession which is with the abundant occurrences of the Ediacaran complex acanthomorphs of ECAP (Figs. 3, 4).

DISCUSSION

Geological implications of microfossil assemblages from Vindhyan successions of Chambal Valley

Age and status of the purported Vindhyan successions of the Chambal Valley

The abundant occurrence of distinctive Ediacaran complex acanthomorphs in the purported lower Vindhyan succession of the Chambal Valley part of Vindhyan Basin, with fairly diverse assemblages, is very important (Figs. 1, 3, 4, 5) as their worldwide known occurrences are restricted to the lower Ediacaran successions only. Stratigraphic distributions of the previously documented well-known Ediacaran Complex Acanthomorph Palynoflora (ECAP) assemblages in the globally dispersed Ediacaran successions revealed that these distinctive forms mainly occur in the lower Ediacaran sedimentary successions which lie much above the Marinoan glacial beds of ca. 635-600 Ma and succeeding beds with simple sphaerpmorphs (Leiosphaerids) dominated assemblage (Moczydlowska, 2005; Grey, 2005). Moczydlowska (2005), while reviewing the spatial and temporal distributions of ECAP assemblages from East European and Siberian platforms, northwest and south China, and South Australia, opined that these Early Ediacaran distinctive complex acanthomorphs first appear in the sedimentary beds that resting on the diamictite beds of Gaskiers and Hankalchough Formations or their correlative diamictites of ca. 580 Ma. The ECAP microfossil assemblages showed their subsequent radiation and diversification by addition of some new complex acanthomorph taxa during upper Early Ediacaran (ca. 580-570 Ma), and finally disappeared at the end phase of Early Ediacaran at ca. 550 Ma as opined by various workers (Grey, 2005; Moczydlowska, 2005; Sergeev, 2009). An additional complex acanthomorphic acritarch assemblage, assigned as the *Tianzhushania spinosa* biozone, is also recognized from the Lower Doushantuo Formation (Member II) just below the distinctive ECAP assemblages of Upper Doushantuo Formation (Member III) in South China which is mainly characterised by the presence of *Tianzhushania spinosa*, *T. ornata*, *Ericiasphaera spjeldnaesii*, *E. rigida* and *Knollisphaeridium maximum* (Liu *et al.*, 2013, 2014; Xiao *et al.,* 2014). However, complex acanthomorph taxa referable to *T. spinosa*zone are not recorded even from the lowermost litho unit of the purported Lower Vindhayn succession of the Chambal Valley which rests over the Precambrian granitic basement in SK-A, PL-A, and CH-A boreholes. Instead, these rocks are marked by the abundant occurrence of distinctive Early Ediacaran complex acanthomorphs of the ECAP microfossil assemblages (Figs. 3, 4, 5).

The occurrence of fairly diverse assemblages of Ediacaran Complex Acanthomorph Palynoflora (ECAP) in the major parts of Lower Vindhyan succession of Chambal Valley, as listed above and illustrated by microphotographs (Pl. I, Figs. 1-15; Pl. II, Figs. 1-16; Pl. III, Figs. 1-13), and

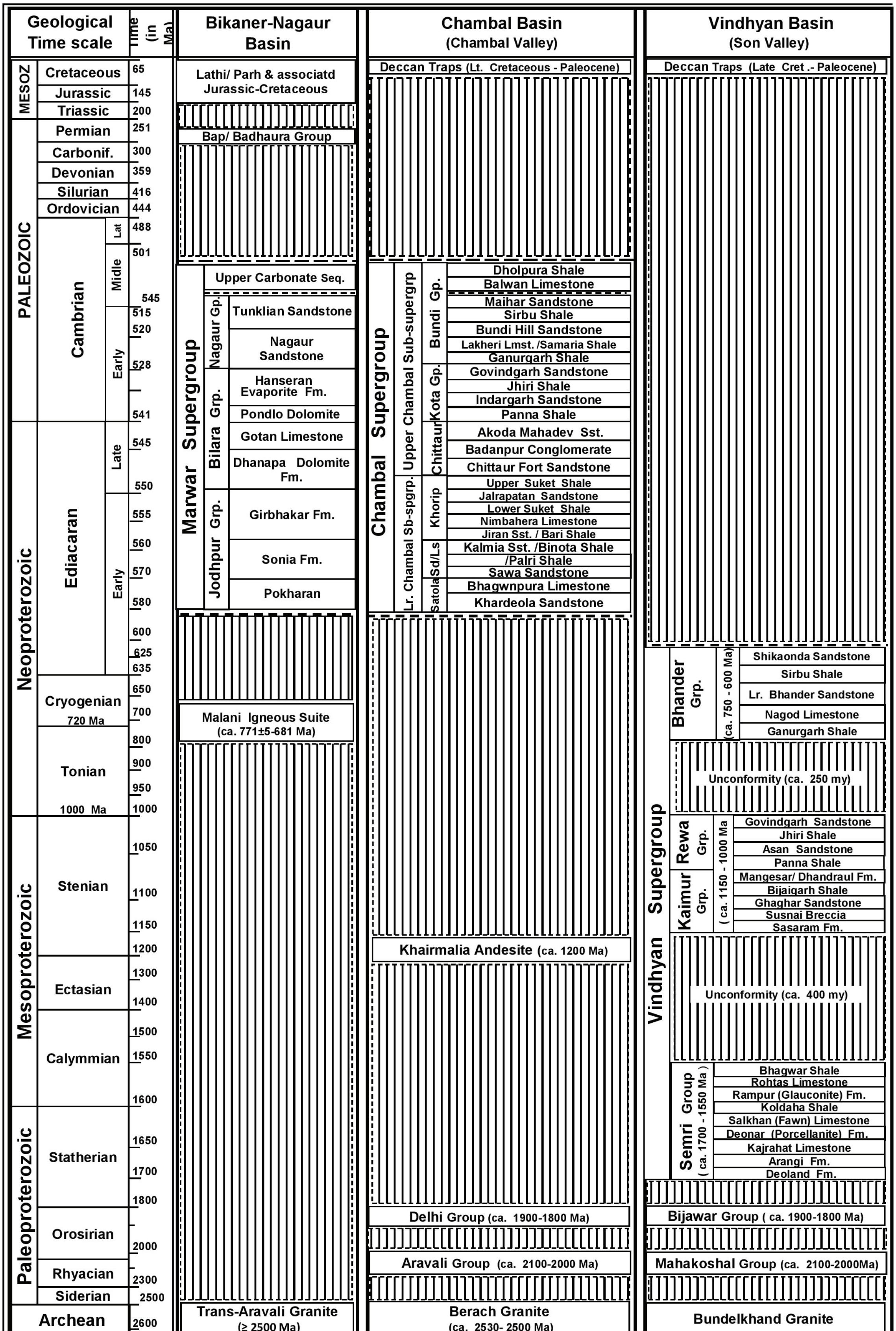


Fig.7. Litho-biostratigraphic correlation of the Infracambrian Chambal Supergroup (purported Vindhyan successions) of Chambal Basin (Chambal Valley) with Late Palaeoproterozoic-Meso/Neoproterozoic Vindhyan Supergroup of the Son Basin (*sensu-stricto* Vindhyan Basin) of the Son Valley in the east and Infracambrian Marwar Supergroup of the Bikaner-Nagaur Basin (western Rajasthan) in the west.

the absence of acritarch assemblage of the *Tianzhushania spinosa*/*Leiospheridia jacutica*-*Leiosphaeridia crassa* zones below it, conclusively suggests upper Early Ediacaran (ca. 580-550 Ma) age for this succession occurring in the western part of Vindhyan Basin (Figs. 1, 3, 4, 5, 7). The Early Ediacaran complex acanthomorph taxa of ECAP assemblage abundantly occur in all the litho units of purported Lower Vindhyan succession of the Chambal Valley, except the upper part of Suket Shale (Upper Shale Member) which is marked by the *Leiosphaeridia* dominated Late Ediacaran acritarch assemblage (Figs. 3, 4, 5, 7).

The close resemblance of complex acanthomorph assemblages of the Chambal Valley with the globally known Early Ediacaran ECAP microfossil assemblages provides strong biostratigraphic evidence of upper Early Ediacaran (ca. 580-550Ma) age for the major parts of purported Lower Vindhyan succession of the western part of Vindhyan Basin (Figs. 1, 3, 4, 5, 7), which, till now, was assigned Late Palaeoproterozoic-Early Mesoproterozoic (ca.1700-1400Ma) age in this region also. Though, the above-mentioned much older age data were mainly obtained from the Lower Vindhyan rocks of the Son Valley part of Vindhyan Basin by varied radiometric dates and micro-macrofossil evidence (for details, Malone *et al.,* 2008; Mckenzie *et al.,*2011; Kumar, 2001, 2012, 2016). Present findings of the exclusive upper Early Ediacaran ECAP acritarchs from the purported Lower Vindhyan succession of the Chambal Valley raises serious doubts on the prevailing much older age of Late Palaeoproterozoic-Early Mesoproterozoic (ca. 1700-1400 Ma) allocated to the purported Lower Vindhyan rocks of the western part of this basin (Fig. 7).

As stated above, the upper part of the Suket Shale (Upper Shale Member), representing the topmost unit of Lower Vindhyan sequence, and the overlying litho units of Kaimur Group of Upper Vindhyan sequence in the studied boreholes are marked by an acritarch assemblage (*Lophosphaeridium rarum*-*Vandalosphaeridium reticulatum* Zone) mainly dominated by the several species of *Leiosphaeridia*, *Lophosphaeridium* and *Vandalosphaeridium*, along with the consistent occurrence of *Obruchevella delicata* and *O. parva* (Figs. 3, 4, 5). The resemblance of this assemblage with the globally established late Ediacaran acritarch assemblages, and the conspicuous absence of Early Ediacaran marker ECAP assemblages, conclusively suggests late Ediacaran (ca. 550-541Ma) age for the upper part of Suket Shale and overlying Kaimur Group in the Chambal Valley part of Vindhyan Basin (Figs.1, 3, 4, 5, 7).

The succeeding litho units of purported Rewa and Bhander Groups of upper Vindhyan sequence in the Chambal Valley are represented by two distinct Early Cambrian acritarch assemblages (Figs. 4, 5). Among these, Rewa Group is marked by the *Dictyotidium birvetense* and *Lophosphaeridium tentativum* dominated assemblage that resembles basal Early Cambrian (ca. 541-528 Ma) acritarch assemblages worldwide, whereas Bhander Group is represented by the *Cristallinium cambriense* and *Asteridium lanatum* dominated assemblage of upper Early Cambrian (ca. 528-515 Ma) age. The resemblance of the above-mentioned two assemblages with known Early Cambrian acritarch assemblages conclusively suggest similar age for the Rewa and Bhander rocks of purported Upper Vindhyan succession of the Chambal Valley region (Figs. 4, 5). Record of acritarch assemblages of Late Ediacaran from the Kaimur Group and basal Early Cambrian from the overlying Rewa Group indicates the Precambrian-Cambrian boundary very close to lithological contacts of the above-mentioned two sedimentary groups (Figs. 4, 5). Recent U-Pb (zircon) datings of Upper Bhander Sandstones as ~1020 Ma (Malone *et al.,* 2008) and Lakheri Limestones as 1073 ± 210 Ma (Gopalan *et al.,* 2013) of the Chambal Valley area, suggesting Late Mesoproterozoic age for the purported Bhander Group of this region, requires a re-look in the light of the present record of globally established exclusive Early Cambrian acritarch assemblage from the Bhander Group rocks of the western part of Vindhyan Basin(Figs. 4, 5).

It is worth noting that Salujha *et al*. (1971a) documented diverse Early Paleozoic acritarch assemblages from the exposed Upper Vindhyan rocks of Kota-Karauli areas of the Chambal Valley. They recorded the *Leiosphaeridia* spp., *Symplassosphaeridium* spp. and *Lophosphaeridium jainii* (= *L. rarum*) dominated assemblage from the Kaimur Group, and suggested the Late Cambrian age. However, re-assessment of the above assemblage reveals that it is fairly similar to the newly recorded acritarch assemblage of the Kaimur Group and indicative of the Late Ediacaran age. Salujha *et al*. (1971a) also recorded a variety of acanthomorphs, herkomorphs, and oomorphs from the succeeding Rewa and Bhander Groups, and assigned Late Cambrian-Early Ordovician age to them. A review of their illustrated taxa shows the presence of *Lophosphaeridium tentativum, L. truncatum*, *Dictyotidium birvetense, Cristallinium camabriense, C. ovillense, Baltisphaeridium cerinum,* and *Aranidium izhoricum* in these rocks, and their acritarch assemblages appear quite similar to the freshly recorded assemblages of the Rewa-Bhander rocks, suggesting an Early Cambrian age. However, this important contribution by Salujha *et al.* (1971a) from Chambal Valley was ignored by many workers as the widely accepted biostratigraphic and radiometric age of Late Mesoproterozoic-Early Neoproterozoic (ca.1150-940Ma) for Kaimur Group, and Middle to Late Neoproterozoic (ca.750-650 Ma) for Rewa-Bhander rocks were given priority, although these dates were obtained from the Son Valley part of the basin.

Radiometric age data are not available for the lower Vindhyan rocks of the Chambal Valley to date, except for the Khairmalia Andesite as ca.1250 Ma (by Crawford as cited in Prasad, 1984) that occurs at the base of this succession, and broadly assigned Meso-Neoproterozoic age based on stromatolites (Prasad, 1980) and acritarchs (Maithy and Shukla, 1977) evidence. The above older age for this succession is not in agreement with the present precise age inference for the purported Lower Vindhyan succession of the Chambal Valley as upper Early Ediacaran (ca.580-550 Ma) based on the record of distinctive Ediacaran marker complex acanthomorphic acritarchs (Figs. 3, 4, 5).

The available radiometric age data on the Upper Vindhyan succession of Chambal Valley, indicating ca.1140-940±30 Ma (Late Mesoproterozoic-EarlyNeoproterozoic) age for the Kaimur Group (Vinogradov *et al.,*1964), ca. 710±120 Ma (Middle Neoproterozoic) for the Rewa Group (Srivastava and Rajagopalan,1988), and ca. 650-625±24 Ma (Late Neoproterozoic) for the Bhander Group (Srivastava and Rajagopalan, 1990; Ray *et al.,*2003) are also not in conformity with the present precise age inference of Late

Ediacaran (ca. 550-541 Ma) for the Kaimur Group and Early Cambrian (ca. 541-515 Ma) for the Rewa-Bhander Groups based on the record of distinctive acritarch assemblages of the above ages from the rocks of above groups (Figs. 3, 4). Recent absolute dating of Upper Bhander Sandstone as ~1020 Ma (Malone *et al.,* 2008) and Lakheri Limestone as 1073±210 Ma (Gopalan *et al.,* 2013) of the Chambal Valley area by U-Pb method, suggesting the closing of Vindhyan sedimentation in this region during Late Mesoproterozoic, need re-assessment in the light of the present record of marker early Cambrian acritarchs from the Rewa-Bhander rocks of upper Vindhyan succession in the Chambal Valley part of Vindhyan Basin (Figs. 3, 4, 5).

It would be rather illogical if the fresh and previous records (Prasad and Asher, 2016) of exclusive upper Early Ediacaran (ca. 580-550 Ma) complex acanthomorphs of ECAP from the purported Lower Vindhyan succession and Late Ediacaran-Early Cambrian (ca. 550-515 Ma) acritarch assemblages from the Upper Vindhyan succession of Chambal Valley shall be viewed as doubtful, and this important finding too erroneously interpreted in the milieu of existing and much-publicized absolute age of ca.1721-1409 Ma for the Lower Vindhyan succession, ca. 1150-1000 Ma for the Kaimur Group, and ca. 750-650 Ma for the Rewa-Bhander rocks, though these absolute age data were mainly obtained from the Son Valley part of Vindhyan Basin (Fig. 7).

Thus, the occurrence of distinctively Ediacaran complex acanthomorphs of ECAP assemblages in the lower Vindhyan succession and Late Ediacaran-Early Cambrian acritarchs in the upper Vindhyan rocks of the Chambal Valley suggest upper Early Ediacaran-Early Cambrian (ca. 580-515 Ma) age for the purported Vindhyan successions of the western part of Vindhyan Basin (Figs.1, 3, 4, 5,7). The conspicuous absence of the complex acanthomorphs of ECAP in the Lower as well as upper Vindhyan rocks of the eastern part of this basin (Son Valley) suggests that the purported Vindhyan successions of the Chambal Valley area are entirely different, and are much younger from the Vindhyan successions of the Son Valley, and represent the Infracambrian sequences in south-eastern Rajasthan (Fig. 7). Ediacaran-Early Cambrian rocks of the Chambal Valley area are opined to be deposited in an entirely separate basin (Chambal Basin) with its depositional history and do not belong to the typical Vindhyan successions of the Son Valley which range in age from Late Palaeoproterozoic to Late Neoproterozoic (ca. 1700-650±24 Ma). Infracambrian rocks of the Chambal Valley area were deposited much later during upper Early Ediacaran-Early Cambrian (ca. 580-515 Ma) time after the closing of the typical Vindhyan sedimentation in the Son Valley during Late Neoproterozoic (Cryogenian; ca. 650±24 Ma) or little later during lower Early Ediacaran (ca. 625-600 Ma) time (Figs. 6, 7).

Age and status of the Vindhyan succession of the Son Valley

The geological age of the Vindhyan succession, deposited in a large intracratonic Vindhyan Basin in northern India, remained controversial since its recognition in the mid-nineteenth century (Oldham, 1856) which covers the large areas extending from Son Valley in the east to the Chambal Valley in the west (Fig. 1) Several biostratigraphic and radiometric studies were attempted for precise dating of this distinctive Proterozoic sequence, mainly in the Son Valley region since this area includes the reference sections for almost all the litho units of this succession (Auden, 1933; Prasad, 1984; Sastry and Moitra, 1984). The majority of the macro-and microfossil (acritarchs, filamentous and coccoid microfossils, stromatolites, soft-body medusoid, and trace-fossils) evidence from the Son Valley part broadly suggested its age range from Early Mesoproterozoic to Late Neoproterozoic, with Mesoproterozoic for the Semri Group, Late Mesoproterozoic-Early Neoproterozoic for Kaimur Group and Middle to Late Neoproterozoicfor the Rewa-Bhander Groups (Maithy, 1992; Sharma *et al.,*1992; Venkatachala *et al.,* 1996; Maithy and Babu, 1997; Kumar, 2012, 2016; Kumar and Pandey, 2008; Prasad *et al.,* 2005; De, 2006; Prasad, 2007).

In addition, records of small acanthomorphs (*Micrhystridium*) and herkomorphs (*Cymatiosphaera, Dictyotidium*) of Late Precambrian-Cambrian age from the Rohtas Limestone and Cambro-Ordovician aspect from Kaimur, Rewa, and Bhander Groups (Salujha *et al.,* 1971b, 1973), Early Cambrian small shelly microfossils (SSM) from the Rohtas Limestone (Azmi, 1998, Azmi *et al.,* 2006; Bengtson *et al*., 2009), acanthomorphic acritarch *Cymatiosphaeroides kulungii* of Late Neoproterozoic aspect from Chitrakoot Formation of Semri Group (Anbarasu, 2001) and Ediacaran fossil ?*Spriggina* from the Pulkoa Shale (Kathal *et al.*, 2000) also suggested a younger age of Late Neoproterozoic-Early Cambrian for Lower Vindhyan succession and Cambro-Ordovician for the Upper Vindhyan rocks. This fossil evidences indicated a much younger age of Late Neoproterozoic to Cambrian (ca.750-480Ma) for the Vindhyan successions of Son Valley in contrary to the widely accepted biostratigraphic age of Early Mesoproterozoic to Late Neoproterozoic-Ediacaran (ca.1600-541 Ma) for these rocks of the Son Valley. However, the above fossil evidence was rejected by many workers, and doubts were raised on these fossil records (for details, Kumar, 2001, 2016).

Nevertheless, the recently obtained radiometric age data from various litho units of lower and upper Vindhyan successions by more reliable U-Pb (Zircon) / Pb-Pb/Ar-Ar/Rb-Sr methods finally resolved the age dispute on the Vindhyan rocks of the Son Valley area. These datings precisely constrained the absolute age of 1721 ± 90-1599 ± 48 Ma (Late Palaeoproterozoic-Early Mesoproterozoic) for the Semri Group (Ray *et al.,*2002, 2003; Rasmussen *et al.,* 2002; Sarangi *et al.,* 2004; Bengtson *et al.,* 2009; McKenzie *et al*., 2011), and~1100/1073.5 ± 13-1044 ± 22 Ma (Late Mesoproterozoic) for the Kaimur Group (Smith, 1992; Kumar *et al.,*1993; Gregory *et al.,*2006; McKenzie *et al*., 2011). Likewise, absolute age for the Rewa Group is estimated ≤ 1000 Ma of the latest Mesoproterozoic (McKenzie *et al*., 2011) and for the Bhander Group as ≥ 770/750-650 Ma of Middle to Late Neoproterozoic (Late Tonian-Cryogenian) (Rathore *et al.,* 1999; Ray *et al.,* 2002, 2003). In addition, the recent record of Late Palaeoproterozoic-Early Mesoproterozoic marker acanthomorphs (*Tappania* spp.) and filamentous microfossils (*Spiromorpha* spp.) from the Semri Group (Prasad *et al.,* 2005) also indicated similar age for the Lower Vindhyan rocks of Son Valley. Thus, the latest radiometric and microfossil data precisely constrained the age of the Lower Vindhyan succession in the Son Valley as Late Palaeoproterozoic-Early Mesoproterozoic (~1721-1550 Ma) which is about 1000 Ma older than the newly ascertained precise age of upper Early Ediacaran (ca. 580-550 Ma) for the purported Lower Vindhyan rocks of the Chambal Valley based on the occurrence of Early Ediacaran marker distinctive complex acanthomorphs, and biostratigrahically not correlatable with each other at all. (Fig. 7). The latest estimated absolute age of ≥770/750-650 Ma (Middle to Late Neoproterozoic) for the Bhander Group, and recent inference by Kumar (2016)on the cessation of Vindhyan sedimentation during the latest Cryogenian (ca. 635 Ma) in the Son Valley, are broadly matching and appear robust. Yet, the recent records of abundant helically coiled filamentous microfossils of *Obruchevella delicata* and *O. Parva* that typify the Ediacaran rocks worldwide, and the rare occurrence of sculptured sphaeromorphs (*Lophosphaeridium* spp.), small micrhystrids (*Asteridium* spp.), and herkomorphs (*Dictyotidium* spp., *Cristallinium* spp.) in the Bhander rocks of the Son Valley (Prasad, 2007), whose first occurrence in rarity during Early Ediacaran are now well-established (Knoll, 1996, 2000; Sergeev, 2009), extend its upper age limit as lower Early Ediacaran (ca.625-600 Ma), but essentially predating the globally established Marinoan glaciation event of ca. 600 Ma as signatures of this glaciation are not reported so far from the Son Valley part of the Vindhyan Basin (Fig. 7).

An assessment of the above-mentioned recently acquired radiometric and biostratigraphic data from the Vindhyan successions of the Son Valley suggst the presence of three discrete first-order Proterozoic sedimentary sequences (> 50-250 Ma) within the larger mega-sequence of Vindhyan Supergroup in this part of the basin. Each sequence was deposited during different Proterozoic times and is bounded by very long non-depositional hiatuses (ca. 150-500 Ma) in its lower and upper boundaries (Fig. 7). Latest Pb-Pb and U/Pb dates of ~1721 ± 90 Ma for the Kajrahat Limestone (Sarangi *et al.,* 2004), 1630.7 ± 0.4-1628 ± 8 Ma for Deonar Formation (Ray *et al.,* 2002; Rasmussen *et al.,* 2002), 1600/1599 ± 8 Mafor the Rampur Formation (Rasmussen *et al.,* 2002; Mckenzie *et al.,* 2011) and 1601 ± 130 to 1599 ± 48 Ma for the Rohtas Limestone (Ray *et al.,* 2003; Sarangi *et al.,* 2004; Bengtson *et al,* 2009) led to conclude that the Lower Vindhyan (Semri) succession of the Son Valley was deposited in a short time-span of ca. 150 Ma during late Palaeoproterozoic-Early Mesoproterozoic (ca.1700-1550Ma) time, and represents the lowermost sequence of the Vindhya mega-sequence (Fig. 7). Similarly, the estimated U-Pb/Pb-Pb absolute ages for the Majhgawan kimberlites of Kaimur Group as 1140 ± 10 Ma (Crawford and Compston, 1970), 1044 ± 22 Ma (Smith, 1992), 1067 ± 31 Ma (Kumar *et al.,* 1993), 1073.5 ± 13.7 Ma (Gregory *et al.,* 2006) and ≤ 1100 Ma (McKenzie *et al.,*2011), and for the Govindgarh Sandstones of Rewa Group as ≤ 1000 Ma (Mckenzie *et al,* 2011), suggest the precise age of Late Mesoproterozoic (ca.1150-1000 Ma) for the Kaimur-Rewa Groups. Sedimentary rocks of these two groups represent the middle sequence, with their sedimentation period of about 150 Ma, and rest over the first sequence with the non-depositional gap of ca. 400 Ma (Fig. 7). The latest estimated absolute age of ≥ 750-650 Ma for the Bhander Limestone (Ray *et al.,* 2002, 2003) and 741 ± 9 Ma for the Sirbu Shale (Rathore *et al.,* 1999), precisely suggest Middle to Late Neoproterozoic (Late Tonian-Cryogenian; ca. 750-650 Ma) age for the Bhander Group. Yet, the recent records of basal Early Ediacaran acritarchs and other organic-walled microfossils (Prasad, 2007; Kumar and Pandey, 2008) from the Bhander rocks extend the upper age limit of this sequence up to basal Early Ediacaran ca. 625-600 Ma), with deposition time of about 150 Ma. The span of hiatus in between the Kaimur-Rewa sequence (ca. 1150-1000 Ma) and overlying Bhander sequence (ca. 750-600 Ma) is about 250 my. Entire Vindhyan successions of the Son Valley are capped by Late Cretaceous-Early Paleocene (ca. 71-62 Ma) Deccan Traps and associated Lameta Beds (Fig. 7).

The above-mentioned three identified discrete sequences of Late Palaeoproterozoic-Early Mesoproterozoic (ca.1700-1550 Ma) Semri Group, Late Mesoproterozoic (ca.1150-1000 Ma) Kaimur-Rewa Groups, and Middle to Late Neoproterozoic-lower Early Ediacaran (ca.750-600 Ma) Bhander Group indeed represent the typical sedimentary successions of the Vindhyan Supergroup in the Son Valley that were deposited during the above-mentioned different Proterozoic times, and occur in the real Vindhyan Basin (Son Basin) that mainly covers the Son Valley area only (Figs. 1, 6, 7). Distinctive litho units of the typical Vindhyan succession of on Valley (*sensu-stricto* Vindhyan Basin) do not show any lithological or biostratigraphic similarities with the purported Vindhyan rocks of the Chambal Valley which are much younger, upper Early Ediacaran-Early Cambrian (ca. 580-515 Ma), and represent the Infracambrian successions in south-eastern Rajasthan. Infracambrian rocks of the Chambal Valley are inferred to be deposited after the closing of typical Vindhyan sedimentation during latest Neoproterozoic-lower Early Ediacaran (ca. 635-600 Ma) in the real Vindhyan Basin (Son Basin) which includes the Son Valley area only (Figs. 1, 6, 7).

The concept of Infracambrian Chambal Basin in South-eastern Rajasthan

The fresh and earlier records of exclusive Early Ediacaran complex acanthomorphs of ECAP from the major parts of Lower Vindhyan succession, Late Ediacaran acritarchs from the upper part of the Suket Shale and overlying Kaimur Group, and Early Cambrian marker acritarchs from the Rewa-Bhander Groups of Upper Vindhyan succession in the widely located deep boreholes of the Chambal Valley, categorically suggest upper Early Ediacaran-Early Cambrian (ca. 580-515 Ma) age for the purported Vindhyan successions of the western part of Vindhyan Basin (Figs. 1, 3, 4, 7). The above age inference suggests that the purported Vindhyan successions of the Chambal Valley area are entirely different and much younger than the Late Palaeoproterozoic-Mesoproterozoic to Late Neoproterozoic-lower Early Ediacaran (ca.1700 to 625-600 Ma) typical Vindhyan successions of the Son Valley, and represent the Infracambrian sedimentary successions in south-eastern Rajasthan (Figs. 1, 6, 7).

Latest geological and sedimentological studies on the Vindhyan successions in Chambal and Sonvalley parts of the Vindhyan Basin by the authors, both in outcrops and subsurface sections of more than 10 deep exploratory boreholes (Fig. 1), have reflected major difficulties in intra-basinal correlation, showing no lithological or biostratigraphic similarities of the lower or upper Vindhyan sequences of the two areas, in addition to their different geological ages as detailed above (Figs. 1, 2, 7). Moreover, there are three major geological/lithological dissimilarities between the Vindhyan successions of the above areas. Firstly, the Lower Vindhyan succession is very thick (≥ 4500 m) and Upper Vindhyan succession is very thin (~450-700 m) in the Son Valley part as revealed by the geological data obtained from the outcrop and subsurface sections in JB-A (Pandey *et al.,* 1996), DM-A (Prasad *et al.,* 2005) and KK-A boreholes located in this area (Fig. 1). Purported lower Vindhyan succession in the Chambal Valley part is very less in thickness (≥1800 m), and Upper Vindhyan succession is exceptionally very thick (~3500-4000 m), with more than 2400 m thickness of Lower Bhander rocks in the JP-A borehole (Figs. 3, 4, 5). Secondly, there are major lithological differences in the broadly comparable litho units of the two areas. For instance, marker lower Vindhyan lithologies of cherts/porcellanites and black shales of Porcellanite (Deonar) Formation, Fawn (Salkhan) Limestone (with rich stromatolites), and Glauconitic Sandstone (Rampur Formation)of the Son Valley are not represented in the Chambal Valley, and are instead, marked by different lithologies (Figs. 2, 5). Additionally, the age marker acanthomorph *Tappania,* which characterizes the Late Palaeoproterozoic-Early Mesoproterozoic (ca. 1721-1550 Ma) Lower Vindhyan rocks in the Son Valley (Prasad *et al.,* 2005), and is also recorded from the sediments of similar age from Ganga (Prasad and Asher, 2001) and Chhattisgarh (Singh *et al.,* 2019) basins in India, and abroad from Australia (Zang and Walter, 1989) and China (Yin, 1997), is conspicuously absent in the purported lower Vindhyan rocks of Chambal Valley. Likewise, the Early Ediacaran complex acanthomorphs, which marks the lower Vindhyan succession of the Chambal Valley, were not reported, till now, from Lower or Upper Vindhyan successions of the Son Valley.

Thus, the current precise dating of the purported Vindhyan successions of the Chambal Valley as upper Early Ediacaran to Early Cambrian (ca. 580-515Ma) led to infer that these successions indeed represent the Infracambrian sedimentary successions in south-eastern Rajasthan which are entirely different and much younger from the Late Palaeoproterozoic to Late Neoproterozoic-lower Early Ediacaran (ca. 1700-600Ma) Vindhyan successions of the Son Valley. Instead, above sedimentary successions of the Chambal Valley compare with the Infracambrian Marwar Supergroup of the Bikaner-Nagaur Basin located at western margins of the ChambalValley (Figs. 6, 7). It is opined that the sedimentary successions of the Chambal and Son valley areas were independently deposited in two separate basins with their distinctive depositional histories during different geological times as cited above (Figs. 6, 7). The Chambal Valley part of the Vindhyan Basin (Chambal Basin) developed much later during Early Ediacaran (ca. 580 Ma) and sedimentation in this basin ended during the Early Cambrian (ca. 515Ma). The real Vindhyan Basin (Son Basin) in the Son Valley area evolved much earlier during Late Palaeoproterozoic (ca. 1700 Ma), with thick successions of Late Paleoproterozoic to Late Neoproterozoicrocks, and ended lower Early Ediacaran (ca. 600Ma) time (Figs. 6, 7).

The newly prepared basement top contour map, integrated with Bouguer gravity anomaly map, aeromagnetic and seismic data (Nabakumar *et al.,* 2015), also indicated the presence of two distinct sedimentary basins towards north side of the North Son-Narmada Fault (NSNF) [Fig. 6]. The eastern one largely covers the Son Valley area, and here termed as the "Son Basin" or *sensu-stricto* real "Vindhyan Basin" which includes the distinctive late Palaeoproterozoic to Late Neoproterozoic-lower Early Ediacaran (ca.1700-600 Ma) sedimentary rocks of the Vindhyan Supergroup. The western basin geographically covers the Chambal Valley area in south-eastern Rajasthan, with Early Ediacaran to Early Cambrian (Infracambrian) sedimentary rocks (ca. 550-515 Ma), which is now referred to as the "Chambal Basin" (Figs. 1, 6, 7). The Infracambrian Chambal Basin is separated from the *sensu-stricto* Vindhyan Basin of the Son Valley area by a prominent and well-defined NNE-SSW aligned subsurface Archeozoic granitic basement ridge of the "Hoshangabad-Rajgarh High", and not by the Bundelkhand Granitic Complex (BGC) as generally being assumed (Fig. 6) as interpreted by Nabakumar *et al.* (2015) and by the present authors also. Thus, the area covering the Chambal Valley region between the Hoshangabad-Rajgarh High in the east and Aravalli-Delhi Orogenic Belt in the west, with thick Early Ediacaran-Early Cambrian (Infracambrian) sedimentary successions, is defined here as the "Chambal Basin" in south-eastern Rajasthan (Fig. 6). The area east of the above Archeozoic high, covering the Son Valley area with distinctive Late Palaeoproterozoic to Late Neoproterozoic-lower Early Ediacaran(ca. 1700-600 Ma) rocks of typical Vindhyan successions, now referred to as real "Vindhyan Basin" or the "Son Basin" (Figs. 1, 6, 7).

In the light of the above geological and biostratigraphic inferences, the Ediacaran to Early Cambrian (Infracambrian) successions of the Chambal Valley, which are bounded by the Palaeoproterozoic Berach Granite (ca. 2500 Ma) at the base and Late Cretaceous-Early Paleocene (ca. 71-62 Ma) Deccan Traps and associated Lameta beds at the top, are now defined as the "Chambal Supergroup", and subdivided into two sub-supergroups (Fig.7). The older, Early to Late Ediacaran "Lower Chambal Subsupergroup" includes Satola, Sand, Lasrawan, and Khorip groups with their existing distinctive litho units (Figs. 5, 7), as outlined by Prasad (1976, 1984). The younger, latest Ediacaran-Early Cambrian "Upper Chambal Subsupergroup" includes the newly proposed Chittaur, Kota, and Bundi Groups that were the earlier known Kaimur, Rewa, and Bhander Groups respectively. However, existing names of different formations within the newly proposed above-mentioned groups are retained as defined by Prasad (1976,1984) [Fig. 7].

Nevertheless, more integrated geological and biostratigraphic studies are required in the Chambal Valley area (Chambal Basin) to augment the newly offered concept on the purported Vindhyan successions of south-eastern Rajasthan as Infracambrian successions (now Chambal Supergroup) in the milieu of new findings of distinctive Early Ediacaran complex acanthomorphs of ECAP assemblages from the Lower Chambal (?Lower Vindhyan) succession and Late Ediacaran-Early Cambrian acritarchs from Upper Chambal (?Upper Vindhyan) sequence of this area.

CONCLUSIONS

1. The record of distinctive Early Ediacaran marker complex acanthomorphs of the ECAP assemblages from the purported lower Vindhyan succession and typical Late Ediacaran-Early Cambrian acritarchs from the upper Vindhyan succession of Chambal Valley conclusively suggests upper Early Ediacaran to Early Cambrian (ca. 580-515Ma) age for the purported Vindhyan successions of the western part of Vindhyan Basin.
2. The above age inference indicates a much younger age of upper Early Ediacaran to Early Cambrian for the purported Vindhyan successions of Chambal Valley which are different from the precisely age-constrained Late Palaeoproterozoic to Late Neoproterozoic-lower Early Ediacaran (ca.1700-600Ma) Vindhyan successions of the Son Valley. Ediacaran-Early Cambrian rocks of the western part of Vindhyan Basin (Chambal Valley) are entirely different in their lithological and biostratigraphic attributes from those of the eastern part (SonValley), and embody distinctive Infracambrian successions in south-eastern Rajasthan which were deposited in an entirely separate Infracambrian "Chambal Basin" during Early Ediacaran-Early Cambrian (ca. 580-515Ma) time.
3. The newly prepared basement contour map of northern India shows the presence of two distinct sedimentary basins at the northern side of the North Son-Narmada Fault (NSNF) which are detached by a prominent NNE-SSW aligned subsurface Archeozoic granitic basement ridge of "Hoshangabad-Rajgarh High", and not by the Bundelkhand Granitic Complex as generally believed. The western basin mainly covers the Chambal Valley area in south-eastern Rajasthan, now referred to as the Chambal Basin, whereas the eastern one represents the *sensu-stricto* Vindhyan Basin or the Son Basin that largely includes the Son Valley area.
4. Ediacaran-Early Cambrian (Infracambrian) successions of the Chambal Valley are now defined as the "Chambal Supergroup", with two subsupergroups. The older Early to Late Ediacaran "Lower Chambal Subsupergroup" includes Satola, Sand, Lasrawan, and Khorip Groups with various distinctive litho units as originally identified by Prasad (1984). The younger Late Ediacaran-Early Cambrian "Upper Chambal Subsupergroup" includes the newly defined Chittaurgarh, Kota, and Bundi Groups which replaced the existing and widely referred Kaimur, Rewa and Bhander Groups respectively in the Chambal valley area, yet with the previously known litho units.

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