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A Status Report on Age, Depositional Motif and Stratigraphy of Chhattisgarh, Indravati, Kurnool and Bhima Basins, Peninsular India

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An attempt has been made to collate information obtained in recent past from four Proterozoic basins in Peninsular India viz. Chhattisgarh, Indravati, Kurnool and Bhima, hosted within two different cratons viz. Bastar and Dharwar. It is apparent that the larger basins viz. Chhattisgarh, Kurnool has attracted more attention compared to small-scale basins e.g. Indravati, Bhima. Proposition of a new stratigraphic unit of 'Group' status viz. Kharsiya Group and subdividing the basin succession in four-tier viz. Singhora, Chandarpur, Raipur and Kharsiya Formations is a major contribution in Chhattisgarh geology in recent time. Geochronology of tuff beds from both bottom and topmost part of the Chhattisgarh succession and upper part of Indravati succession allowed i) age bracketing the Chhattisgarh depositional history, and ii) drawing correlation between Chhattisgarh and Indravati basin on strong foot hold. The age of Kurnool basin remained elusive because of non-convergence of evidences reported from within and outside the basin. From microfossil assemblage a pre-Varanger glaciation age i.e. >750 Ma is proposed for the Bhima basin. All the four basins are represented by clastic-carbonate mixed sediment succession recording transition from continental/shallow marine to distal marine depositional set up. Sediment was mostly sourced within these basins from adjoining cratons.

Keywords: Chhattisgarh; Indravati; Kurnool; Bhima; Geochronology; Clastic; Carbonate

Introduction

Traditionally, the unmetamorposed and dominantly undeformed Proterozoic basins in peninsular India are described as intra-/epicratonic basins of dominantly Neoproterozoic age with good scope for documentation of Precambrian-Cambrian boundary. Overlying continental crust of stable cratons (Archean/ Paleoproterozoic granitic basement), these basins largely preserve successions of shallow marine, deltaic and fluvial settings with alluvial fans mostly restricted at basin margins.

Recent studies, in last one and a half decades, have seen a trend shift in this perception, principally because i) introduction of sequence stratigraphic paradigm to understand filling history of these basins and ii) availability of state-of-the-art geochronological facility either by increase in international collaboration or establishment of new analytical facility in India. These new studies not only allowed revamping sedimentation history of these basins going beyond the classical shallow marine doctrine but also established major perception change regarding age of these basins; tracking back sedimentation history of many of these basins by ~500 Ma (Das *et al.,* 2015). There is also a growing tendency to interpret the development of these basins in relation to plate-margin processes (Meert and Pandit, 2015; Basu and Bickford, 2015) and global tectonic events related to 'Supercontinent' amalgamation and fragmentation. Indeed, some recent reviews on these basins (Meert and Pandit, 2015, Basu and Bickford, 2015, Kale, 2016; Chakraborty *et al.,* in press) have suggested development (and closure) of these basins in some key time intervals i.e. late Paleoproterozoic (2.5 to 1.6 Ga), Mesoproterozoic (1.6 to 1.00 Ga) and late Neoproterozoic (Ediacaran-Cambrian interval) in connection with intervals pertaining to amalgamation and fragmentation of two 'Supercontinent's viz. Columbia (1.9-1.8 Ga) and Rodinia (1-0.9 Ga).

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In this contribution we limit our discussion on four Proterozoic basins viz. Chhattisgarh, Indravati, Kurnool and Bhima basins from two different Archean-Paleoproterozoic cratons of peninsular India (Fig. 1) and aim at collation of recently generated data. Whereas the Chhattisgarh and Indravati basins are hosted within the Bastar Craton, the Dharwar Craton forms the basement for the Kurnool and Bhima basins (Fig. 1). The idea is to include both siliciclastic and carbonate sediments present in these basins in order to provide idea about uniqueness of Proterozoic sedimentation in both continental and marine realm. Since amongst the discussed basins the Chhattisgarh basin is the largest in aerial extent followed by Indravati, Kurnool and Bhima basins, our discussion in this contribution follows the same sequence

Basins in the Bastar Craton

Chhattisgarh Basin

The Chhattisgarh basin constitutes the largest basin in the Bastar Craton with aerial extent over 33,000 km^2. A number of publications in recent years (Chakraborty *et al.,* 2015; Das *et al.,* 2017; Bickford *et al.,* 2017; George *et al.,* 2019) have enriched our understanding not only about stratigraphy and depositional history of the basin but also helped us in age bracketing the basin on strong foothold.

Chakraborty *et al.* (2015) attempted collation of recent data from the basin with emphasis on erstwhile debates (Basu and Bickford, 2015) on stratigraphy and tectonics of the basin and argued in favour of independent stratigraphic status of the Singhora Group in Chhattisgarh stratigraphy based on structural data, AMS data and detrital zircon geochronology and ruled out the proposition of equating it with the Chandrapur Group by earlier workers. They pointed out the variation in stratigraphic subdivision between the eastern and western parts of the basin; and suggested a four-tier stratigraphic subdivision of the basin. The sequence in the eastern part of the basin was divided into Singhora Group, Chandrapur Group, Raipur Group and Kharsiya Group, while the western part comprised of Chandrapur, Raipur and Kharsiya Groups (Fig. 13.2 of Chakraborty *et al.,* 2015). From U-Pb detrital zircon geochronology, Nd isotope mapping and sediment geochemistry, Das *et al.* (2017) have drawn a convincing correlation between sedimentation history of the Singhora Group of Chhattisgarh Supergroup and sedimentation histories of neighbouring Ampani and Khariar basins.

Availability of tuffaceous layers at lowermost and uppermost parts of the Chhattisgarh succession helped workers in putting a Mesoproterozoic age bracket for the basin. From Sm-Nd monazite systematics, an age of ~1450 Ma (~1500 Ma by Bickford *et al.,* 2011a; using U-Pb zircon) is established from a tuffaceous layer present within the Saraipalli Formation of the Singhora Group from eastern part of the basin. Also, from two tuffaceous layers (Sukda and Sapos tuff) present within uppermost part of the basin succession in the west, an age of ~1000 Ma is suggested for closing of the basin. Availability of these geochronological data allowed workers tracking back the age of the basin by ~500 Ma and propose Mesoproterozoic time frame for the basin on strong foothold.

Figure 2 provides the revised stratigraphic subdivision and generalised sequence stratigraphic framework for the basin succession. Bounded by Type-I unconformities, demarked by abrupt encroachment of alluvial fan/fluvial system on middle to distal marine shelf, a number of depositional cycles of 'sequence' rank stacked together to build up the basin succession. Products of an array of environments belonging to forced regression (alluvial fan, braided fluvial), lowstand (aggradational shoreface bar-interbar, tidal bar-interbar) and transgression (estuarine, shelf) are described by workers (Banerjee *et al.,* 2015 and several earlier workers) from different stratigraphic levels of the basin succession. From paleocurrent, detrital zircon geochronology and Nd isotope mapping, Das *et al.* (2017) argued in favour of tectonic forcing behind unconformity formation across Saraipalli- Bhalukona Formation transition. Other unconformities claimed from field evidences, however, warrants supplementation by independent proxies. From carbonate formations (Charmuria and Chandi Limestone) present in 'Sequence' 3 (Fig. 2) two isotopic studies are worth mentioning. From $\delta^{34}S$ values (26.3 ± 0.9‰; n=12) of pyrites present within the Charmuria limestone, Sarkar *et al.* (2010) argued for sulphidic deep marine condition in the Mesoproterozoic Chhattisgarh Sea. Recently, George *et al.* (2019) carried out C-O-Sr isotope analysis from the Charmuria and Raipur Limestone Formations and

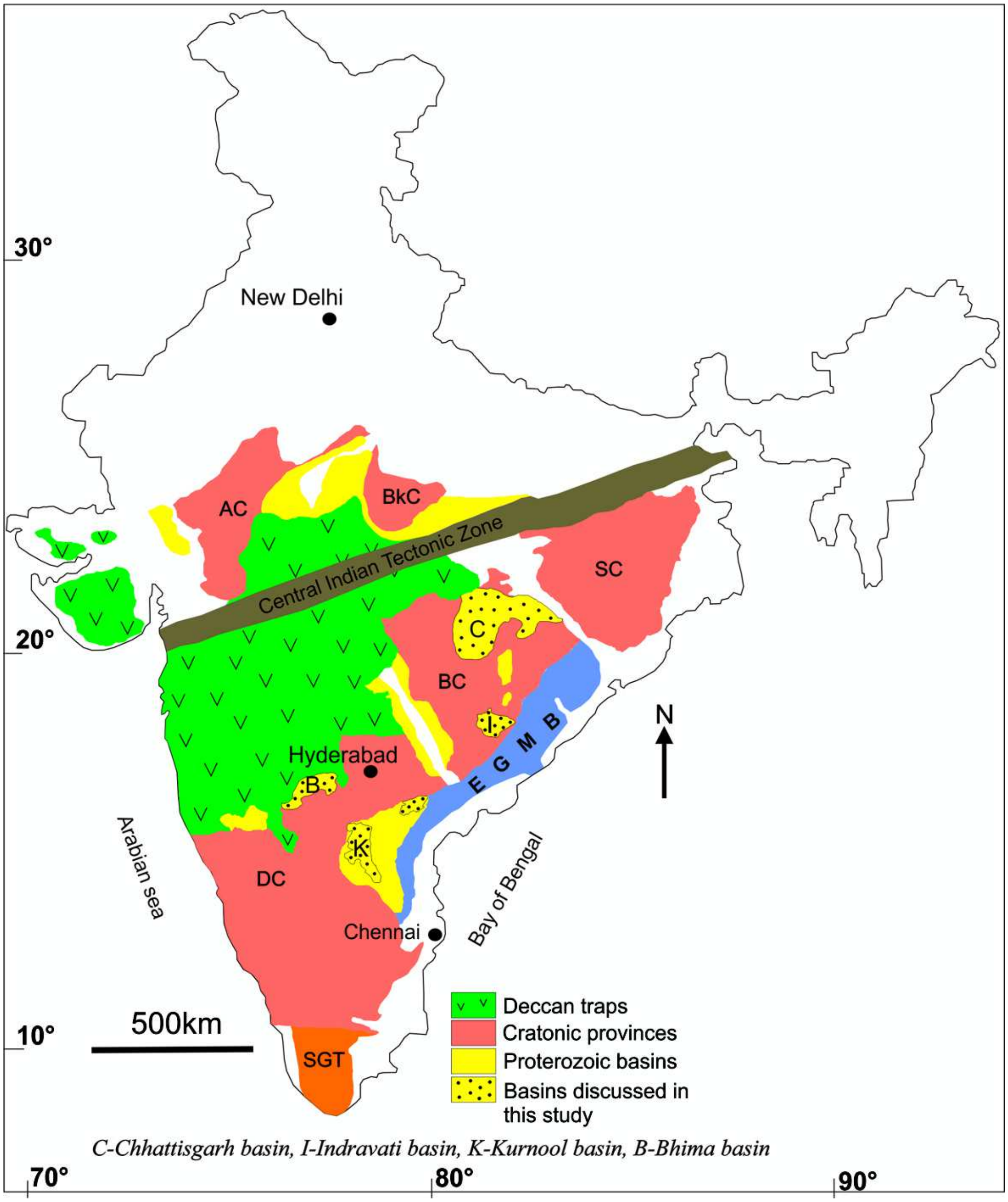

Fig. 1: Map of Peninsular India showing distribution of Proterozoic basins. Basins discussed in this contribution viz. Chhattisgarh, Indravati, Kurnool and Bhima are marked in stipples

recorded elevated $\delta^{13}C$ values ranging between 2.6‰ and 3.6‰ (see also Chakraborty *et al.,* 2002) and interpreted it as signature of higher organic carbon burial. Indeed results from two different isotopic systems(C and S) supplement each other as an anoxic and sulphidic deep ocean would certainly help in higher organic matter burial and preservation. The basin-scale occurrence of black, pyritiferous Charmuria Limestone possibly justifies this interpretation. Further, the steady increase of $\delta^{13}C$ value from 1.4‰ to 4.3‰ in Charmuria and Chandi limestones well corroborate with late Mesoproterozoic rise of the $\delta^{13}C$ value in global oceans (George *et al.,* 2019).

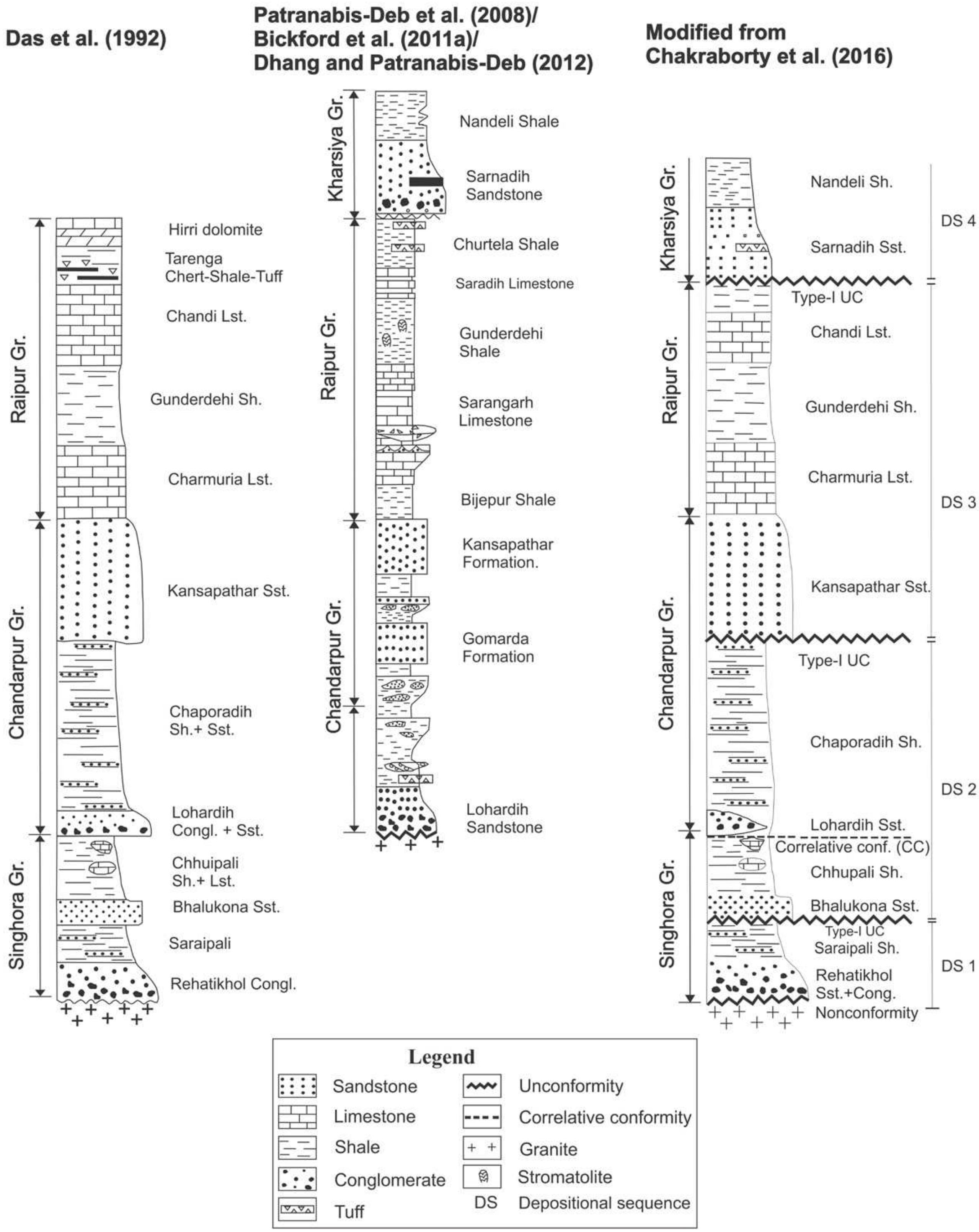

Fig. 2: Lithostratigraphic column of the Chhattisgarh Supergroup proposed by different workers: (a) Das *et al*. 1992 (b) Patranabis-Deb & Chaudhuri 2008 and others and (c) the present study (modified after Chakraborty, 2016). Note four depositional sequences deciphered from the basin succession, in contrast to two depositional sequences shown by Patranabis-Deb & Chaudhuri (2008)

Indravati Basin

Overlying Archean basement, the Indravati succession is non-conformably exposed over 900 sq.km area in the south of the Chhattisgarh basin. An East-West trending fault viz. Sirisguda Fault, paralleling the Indravati River, divides the basin into two halves. Radhakrishnan (1987) classified the basin succession (represented by conglomerate, pebbly coarse-grained arenites, shale, stromatolitic limestone and dolomite) into four Formations viz. Tirathgarh, Cherakur, Kanger and Jagdalpur. From geochemical signatures, in particular from relatively higher chalcophile elements viz. V, Ni, Cr, Co, Cu, Zn, Pb concentration (with respect to Post Archean Australian Shale; PAAS) within arenites and shales of the basin succession, Kumar *et al.* (2017) envisaged granites and metasediments of the Bengpal Group as sediment source for the basin. From positive cerium (Ce) anomaly in Kanger and Jagdalpur limestone, Guhey and Kotha (2017) suggested an oxygen-deficient seawater condition in the basin. A shoreline to shallow shelf depositional environment in a passive margin tectonic set up is suggested for different lithological variants of the Indravati sequence (Kumar *et al.,* 2017). From tight folds with axial planar cleavages in the eastern margin of the basin, co-deformation of sediments with the deformation of the EGMB is suggested. Kimberlite pipes, pyroclastic breccia and tuffs are reported from different stratigraphic intervals. The pyroclastics, hosted within the Kanger and Jagdalpur Formations, have yielded a LA-ICPMS U-Pb 620 ± 30 Ma age from autometasomatic titanite (Lehmann *et al.,* 2007). This date, however, clearly at odd with recent U-Pb zircon date obtained from a tuff layer present within the basin succession. From U-Pb isotopic analyses (LA MC-ICPMS) of magmatic zircons separated from a tuff layer present near the top of the Indravati succession, Mukherjee *et al.* (2012) suggested a weighted mean crystallization age of 1001 ± 7 Ma and correlated the Indravati tuff with Sukda and Dhamda tuffs present in the topmost part of Chhattisgarh succession (Fig. 3). These authors suggested a ca. 1000 Ma rhyolitic flare-up in connection with docking of India and East Antarctica and the suturing of north and south Indian cratonic blocks along the Central Indian Tectonic Zone (CITZ); all in course of Rodinia assembly. From geochemical data and Hf isotopic composition of zircons separated from the dated tuff layer and the Archean basement, Bickford *et al.* (2014) constrained the source of parent magma of the tuff as mafic granulite that contains garnet, titanium and at cases plagioclase, possibly in the lower crust. From radiometric study including radon emanometry and target sub-surface drilling data, Kumar *et al.* (2018) reported uranium mineralization (U-Cu-Zr-Cr) in the basal part of Tirathgarh Formation along the unconformity with basement.

Basins in the Dharwar Craton

Kurnool Basin

The Cuddapah basin, recently modelled to be originated in course of separation between Napier Complex and Dharwar craton, represents the largest Proterozoic basin in Dharwar craton with an aerial spread above 44000 sq.km (Matin, 2015; Meert and Pandit, 2015). Three unconformity-bound sequences viz. the Papaghani Group, the Chitravati Group and the Srisailam Formation together constitute the Cuddapah Supergroup. Unconformably overlying the Cuddapah Supergroup or onlapping the gneissic basement that extends over the entire Papaghani subbasin, the Kurnool Group, exposed in two sub-basins viz. Kurnool and Palnad, represents the youngest unconformity-bound cyclic sequence. From U-Pb detrital zircon geochronology and Hf isotope data from sandstones covering entire stratigraphic range of the Cuddapah Supergroup and some detrital muscovite 40Ar/39Ar data from selected samples from the Srisailam Formation, Collins *et al.* (2015) suggested i) evolution of Papaghni and Chitravati Groups in a rift to passive margin mode with sediment sourced from the Dharwar craton, ii) Nallamalai Group evolved in a foreland mode with Krishna orogeny as its provenance. The Kurnool Group comprises of sandstone, limestone and shale with a total thickness > 500 m, deposited in form of two fining-upward sandstone-limestone-shale cycles. Banganapalle Quartzite, conformably and successively overlain by the Narji limestone and Owk shale, constitute the first cycle and is followed upward by Panium Quartzite, Koilkuntala Limestone and Nandyal shale that constitute the second cycle.

Taking into consideration absence of any imprint of deformation in the Kurnool lithopackage as is observed in the Nallamalai fold belt and the Cuddapah Supergroup, younger timeframe is suggested for the

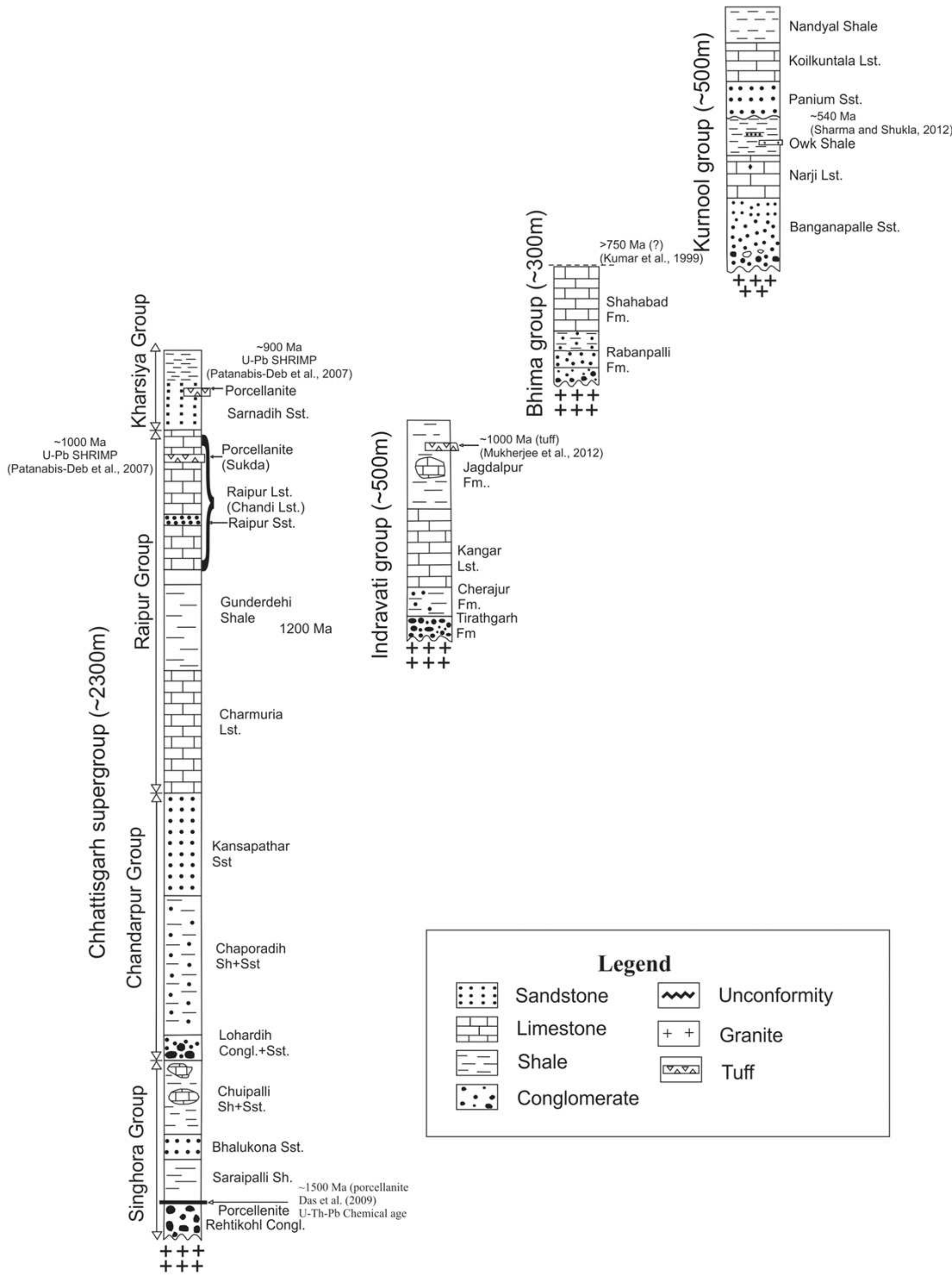

Fig. 3: A chronostratigraphic framework and mutual correlation for the four discussed basin successions. Note closing of Chhattisgarh and Indravati basins at ~1000 Ma. The Bhima and Kurnool basins still awaits robust geochronological age control

Kurnool Group. The Kurnool basin is considered Neoproterozoic in age and equivalent to Bhima, Marwar and upper most part of the Vindhyan, holding the similar fossil assemblages. However, U-Pb detrital zircon geochronology from the Banganapalle sandstone and Owk shale Formations overwhelmingly record grains of >2.5 Ga with very minor peaks of 1.8 Ga and 1.3 Ga (Bickford *et al.,* 2013) with no grain of <1000 Ma. Suggesting maximum depositional age of the Kurnool Group as 1.3 Ga, Basu and Bickford (2015) though casted doubt on Neoproterozoic age of the Kurnool Group in absence of any <1000 Ma grain, favoured keeping the status-co of Neoproterozoic age from the paleontological evidence (Fig. 3). In a discussion on Basu and Bickford (2015) contribution, Kale (2015) argued that paleocurrent data from the Kurnool succession and boulders within Banganapalle Quartzite bear suggestion of sediment source in the basin either from the Dharwar basement or earlier deposited sediments within the Cuddapah basin. Collins *et al.,* (2015) though modeled the basin as a long-wavelength foreland of the Tonian Eastern Ghat orogeny, supported the Dharwar craton as provenance for the basin. However, absence of <1000Ma detrital zircon grains in Kurnool succession, which otherwise is considered as Neoproterozoic in age, may be because of absence of any <1000 Ma provenance in the hinterland or absence of any major tectonic event in the provenance that could trigger supply of <1000 Ma zircon in the basin (cf. Kale, 2015).

Lakshminarayana and Vijay Kumar (2018) reported IOCG (?) type of mineralization of iron, copper and gold from a dyke-sill-vein complex near Gani inlier in the Kurnool sub-basin and suggested a late-stage melt-fluid activity associated with igneous activity. Around Kuppunuru area of Palnad subbasin, Ramesh Babu *et al*. (2012) recorded radioactive anomalies in basement granitoids, at fault contact with northern part of Palnad sub-basin. The Banganapalle Formation, resting unconformably above the basement, is identified as main pay horizon for uranium. Lean mineralization ranging from 0.010 to 0.017 % U_3O_8 grade and 0.20m to 1.70m thickness recorded in granitoids, 11-17 m below the unconformity (Banerjee *et al.,* 2012).

Bhima Basin

The NE-SW trending en-echelon Bhima Basin is smaller in aerial extent (5200 sq.km), though the northern extension of the basin is concealed under the cover of Deccan Trap. The basin succession (~300 m thick) dominantly comprised of limestone and shale with thin but laterally continuous arenaceous package (conglomerate and sandstone) confined in the southern margin where the basin succession non-conformably overlie the basement of Archean granite-greenstone. A two-tier classification is suggested for the basin succession; comprised of Rabanpalli Formation (arenaceous) and Shahbad Formation (limestone and shale). Overall, the basin succession is of fining-upward character with coarse clastics including conglomerates giving way upward to siltstone and shale within the Rabanpalli Formation and, in turn, gradationally overlain by limestone and shale succession of the Shahbad Formation. Considering the steady fining- and deepening-upward character as registered in upward transition from continental-near shore (fluvial, deltaic, tidal flat; Joy *et al.*, 2018) to distal marine products, the basin succession is inferred as product of single transgressive episode. Recently, Absar *et al.* (2019) noted high positive $\delta^{13}C$ value (3.8‰) from the basal part of Shahabad Formation with successive decreasing values up the stratigraphic column and inferred it as a result of mixing of isotopically heavy coastal waters with global dissolved inorganic carbon (DIC) reservoir in course of transgression. Upwelling of oxygen minimum zone (OMZ) is inferred by these workers from short-term negative excursions in $\delta^{13}C$ value in the tune of 5‰ in course of transgression. From geochemical analyses (major, trace element and REE) of calcareous shales from the basin succession, granitoids of the Dharwar craton are identified as the major source of sediment for the basin. From low U/Th ratio and low authigenic uranium content (less than 5 ppm) in calcareous and grey shales of the basin, these authors concluded an oxic hydrospheric condition in the basin. A well oxygenated water column in the basin is also claimed by Absar *et al*. (2019) from high negative Cerium (Ce) anomaly in carbonates of the basin succession.

The basin lacks robust geochronology input and hence, debate continues in literature regarding its Mesoproterozoic/Neoproterozoic time frame. Considering similar $\delta^{13}C$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$ values, Bhima limestones are correlated with Late Neoproterozoic carbonate successions e.g. carbonates of Kurnool Group and carbonates of Rohtas Formation, Vindhyan Supergroup. However, such correlation is never beyond doubt, particularly in the backdrop of recent detrital zircon data obtained from the uppermost Bhander sandstone of the

Vindhyan Supergroup that suggests closure of the Vindhyan basin ~1000 Ma. From absence of typical Vendian achritarch assemblage (*Cyamatio-sphaeroides, Leiosphaeridia*) and presence of *Chuaria circularis* and *Leiosphaeridia* in Halkal Formation, several workers concluded that the Bhima Group is older than pre-Varanger glaciation i.e. older than 750 Ma (Fig. 3).

Discussion

A collation of data generated in recent past from basin successions discussed herein clearly shows interest of sedimentologists in large-scale basins e.g. Chhattisgarh, Kurnool. In comparison, small scale basins viz. Indravati and Bhima basins maintain near status-co of available understanding in recent past. In case of the Indravati basin one worth-mentioning outcome in recent past is age data obtained from a tuff layer present in the upper part of basin succession that helped in correlation of basin succession with the upper part of Chhattisgarh succession.

In Chhattisgarh basin one major outcome of research in recent time is the introduction of a new stratigraphic unit of 'Group' status i.e. 'Kharsiya Group' and revision of traditional three-tier stratigraphy into a four-tier stratigraphy comprised of Singhora Group, Chandarpur Group, Raipur Group and Kharsiya Group, in order of superposition. An early Mesoproterozoic (1.45-1.5 Ga) opening for the basin is established on strong foothold by dating of a concordant tuff layer present at the basal part of basin succession (at the transition of Rehtikhol Formation and Saraipalli Formation) and a discordant mafic dyke present within the argillaceous Saraipalli Formation. From detrital zircon geocronology and documentation of deformation pattern from Saraipalli, Bhalukona and Chuipalli Formations, Das *et al*. (2017) convincingly established the independent stratigraphic status for the Singhora Group and an angular unconformable relationship between the deformed Singhora group and overlying undeformed Chandarpur Group of rocks.

In Kurnool basin the claim for presence of a tuff bed within the Owk shale (Saha and Tripathy, 2012) not only generated hope for application of robust geochronology to date the basin but also allowed workers to use its geochemical signatures to suggest rhyolitic to rhyodacitic phreatomagmatic character and derivation from low degree continental crust melting. However, Bickford *et al*. (2013) in a subsequent study completely refuted the tuff origin and identified the unit as a sandy mudstone with variable volcaniclastic input and concluded that the unit cannot be used for any geochronological study. The geochronological age for the Kurnool basin, in general, and of the Owk shale, in particular, thus remained elusive and the claim of phreatomagmatic igneous activity in course of Kurnool sedimentation needs further validation with search of parent tuff bed and cogenetic rhyolite. It is, however, interesting to note that Bickford *et al*. (2013) could not find any zircon grain younger than 1880 Ma. in their study from the Kurnool basin despite its proposed Neoproterozoic time frame and strong evidences of felsic magmatism between 1500 and 1000 Ma from the Bastar Craton (reported from Chhattisgarh, Khariar and Indravati basins) and from Mangampeta in the south of Nallamalai fold belt. Attempt has been made to justify the Neoproterozoic (near Ediacaran) time frame for the basin with the reasoning that felsic magmatism of Bastar Craton and Mangampeta were not wide spread to act as a sediment source in the basin and from presence of *skolithos* and *glossifungite* assemblages within the Narji Limestone that bear strong evidence for presence of mobile organisms. This understanding, however, cannot justify the occurrence of limestone xenoliths sourced either from the Kurnool basin or the Bhima basin within 1.1 Ga Siddanpalli dyke, reported half-way between the two basins. Taking cognizance of evidences, Basu and Bickford (2015) commented 'if the xenoliths are indeed from these basins, then the basins must have been formed >1.1 Ga', which of course do not commensurate with present understanding of age of these basins on the basis of paleontological evidence. A comprehensive study is warranted in the Kurnool basin involving sedimentology, detrital zircon geochronology, microfossil and ichnology to address non-converging evidences presently available from the basin.

Concluding Remarks

Indian Proterozoic basins occupy a unique position to unravel the record of early history of planet Earth when atmosphere was dominated by greenhouse gases promoting intense weathering and mass wasting, hydrosphere evolving from an essentially anoxic to fully oxic condition, land was without any vegetation and shallow marine realms were overwhelmingly dominated by microbial life in absence of borers and feeders. Opening, closing and tectonic set-up of these basins also remains topics of discussion in the backdrop of 'Supercontinent' assembly and break-up. Studies carried out in Chhattisgarh, Indravati, Kurnool and Bhima basin successions in last couple of years offered good database to constrain many of these issues, though studies mostly remained confined within the realm of geochronology and sediment geochemistry. Physical sedimentology, sequence stratigraphy and basin analysis remained in backseat. In clastic settings it is felt that the fluvial deposits present within these basin successions hold unique potential for future research in view of reports of temporary and localized ponding of muddy sediments in otherwise bed-load dominated sandy braided channel systems described both from India and South Africa. Further, studies are needed to address a recently raised question (Hashimoto *et al.,* 2008; Mukhopadhyay *et al.,* 2014) whether the observation of non-existence of paleoslope gap between alluvial fan and riverine systems is unique in Precambrian or the observation of paleoslope gap between modern alluvial fan and river systems, as observed by Blair and Mcpherson (1994), suffers from data artifact created by omission of wet fans. In carbonate successions, studies, whenever attempted, mostly remained geochemistry-based, though a large degree of uncertainty still hangs over modeling of Precambrian carbonate genesis vis-à-vis paleo-atmospheric and paleo-hydrospheric evolution during this epoch.

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