Proc Indian natn Sci Acad **78** No. 3 September 2012 pp. 393-400

Status Report

Tectonics and Sedimentation of Proterozoic Basins of Peninsular India

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The less disturbed and unmetamorphosed Proterozoic sedimentary basins in peninsular India, also known as the *Purana Basins*, overlie the deformed and metamorphosed Archaean/Palaeoproterozoic basement and were formed in a narrow time window spanning between late Palaeoproterozoic and early Mesoproterozoic (1.9-1.6 Ga). There are eight such large basins shared by all the major cratonic blocks of peninsular India (Fig. 1). Amongst them the Vindhyan, Chhattisgarh and Cuddapah basins are the three most aerially extensive ones and those have attracted attention of sedimentologists for over five decades. Studies on these basin-fills have not only yielded significant database on the continental and shallow-marine sedimentation processes in the early vegetation-free, microbiota-dominated greenhouse Earth and the advent of early lifeform, but also data from the igneous inputs within these basin packages contributed in understanding the concomitant deep crustal processes. Besides, the U-Pb SHRIMP and Sm–Nd monazite geochronological dates from these basin successions are also emerging as major constraining parameters for reconstructions of Proterozoic Supercontinents. The aim of this contribution is to give a brief overview on the understandings obtained so far from these five Proterozoic basins of Peninsular India viz. Vindhyan, Chhattisgarh, Cuddapah, Marwar and Pranhita-Godavari (P-G) basins. While the first three overlie the granites and gneisses of Bundelkhand, Bastar and Dharwar cratons, respectively, acid volcanic rocks of 780-681-Ma-old Malani rhyolite underlies the fourth. A crustal-scale NW–SE lineament at the margin of the Bastar and Dharwar cratons represents the fifth.

Key Words: Proterozoic; Tectonics; Sedimentation; Peninsular India; Geochronology

The Vindhyan Basin

The Vindhyan Basin is the largest among all the 'Purana Basins' and second largest among all the Proterozoic basins of the world (Chakraborty, 2006). The Palaeo- to Neoproterozoic Vindhyan Supergroup, represents one of the world's best exposed repeated transitions between platform-type shallow marine and non-marine deposits (Bose and Chakraborty, 1994; Bose *et al*., 2001; Sarkar *et al*., 1996, 2011a, b; Chakraborty and Sarkar, 2005). Vindhyan sediments are exposed mainly in two areas, on eastern and western sides of the Bundelkhand Massif. The western, southern and eastern margins of the basin are bordered by older sedimentary formations comprising the Aravallis, Delhis and Satpura Orogenic belts; Tewari (1968) considered the contacts as thrusted. The southern part of the basin is locally concealed under the Deccan lava that erupted during the end-Cretaceous. The Vindhyan succession in the central India overlies the early Proterozoic metasediments of Bijawar and Mahakoshal Groups and underlies the Gondwanas.

Since the Aravalli, Delhi and Satpura orogenic belts border it, some workers considered the Vindhyan basin as a peripheral foreland basin related to the southerly dipping subduction prior to the collision of Bhandara and Bundelkhand cratons (Auden, 1933; Chakraborty and Bhattacharyya, 1996; Raza and Casshyap, 1996). Chakraborti *et al*. (2007) supported the idea from the Nd-isotope study of sediment succession. Another view postulated an intracratonic rift origin (Verma and Banerjee, 1992; Ram *et al*., 1996). Bose *et al*. (2001) correlated the sedimentary and geophysical attributes to an intracratonic rift to sag transition. However, the broad consensus now exists about deposition within a westward opening epicontinental basin in an intracratonic setting (Banerjee, 1974; Chanda and Bhattacharyya, 1982; Bose *et al*., 2001).

A basin-wide unconformity and its laterally correlatable conformity, divides the Supergroup into two Groups referred as the Lower and Upper Vindhyans, the former having another formal name, the Semri Group. The Semri Group is subdivided in five formations, viz., Basal Sandstone, Kajrarahat limestone, Porcellanite, Kheinjua and

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Rohtas. The Upper Vindhyan, on the other hand is represented by three formations, viz., the Kaimur, Rewa and Bhander. The dominant lithologies are mature sandstone, shale and carbonate. Conglomerate is rare and is intraformational in most cases. All the formations, irrespective of the Groups they belong to, are characterized by a lower shaley and/or calcareous part and an upper sandstone part. Although there are some significant differences, carbonates are volumetrically more dominant and more commonly dolomitized in the Lower Vindhyan than in the upper and red sandstones are more common in occurrence within the Upper Vindhyan. Volcanics are important lithologies in the Lower Vindhyan while those in the Upper Vindhyans have only minor occurrences (Chakraborty *et al*., 1996). Pseudomorphs after halite and gypsum are more common in Upper Vindhyan. Lateral facies consistency is contrastingly higher within every member comprising the Upper Vindhyan. The paleogeographic setting of the Vindhyan basin had initially been identified as near shore marginal marine, belonging to barrier bar, lagoon, tidal flat & beach with intermittent sub-aerial exposure (Banerjee, 1964; Singh, 1973, 1985; Chanda and Bhattacharya, 1982; Soni *et al*., 1987; Prasad and Verma, 1991; Akhtar, 1996). Later workers, however, extended the palaeogeography to the shelf on one hand and also recorded extensive occurrence of fluvial, aeolian and lacustrine deposits (Bose *et al*., 1999). The only disconcerting view was that of Bhattacharya (1996) who suggested that the Vindhyan sedimentation took place entirely in terrestrial environment such as lacustrine, fluvial and aeolian and refuted his own earlier emphasis on marginal marine sedimentation. This view, however, did not receive favour from later workers. The depositional paleoslope has been estimated to be gentle throughout the basinal history. Paleocurrent direction had consistently been northwestward implying terrigeneous supply from a southern source; dominance of fine- grained and texturally mature siliciclastics as well as carbonates points to the low relief of the source (Bose *et al*., 2001). Analysing framework composition and geochemistry (major, trace and REE) of Bhander sandstones in the Maihar-Nagod area, Banerjee and Banerjee (2010) suggested a possible continental interior to recycled orogen provenance for the clastics. Paleoclimate had probably been overall warm and humid to facilitate large scale elimination of the labile minerals (Bose *et al*., 2001). Organo-sedimentary structures have been well documented from different carbonate formations of Vindhyan Supergroup (Kumar, 1978; Sharma, 2006 a&b) and the discovery of debated Metazoan traces by Seilacher *et al*. (1998) drew the attention of the geologic community worldwide. Integrated paleontologic- geochronologic investigation in recent time (Bengtson *et al*., 2009) has confirmed presence of fossils viz. annulated tubes, coccoidal microbial fabrics similar to *Grivanella* and *Renalcis* etc. within the Paleoproterozoic Semri rocks of the Vindhyan, which otherwise resemble those found elsewhere in the Cambrian deposits. Recently microbial mat induced sedimentary structures (MISS) have been reported profusely (Sarkar *et al*., 2006, 2011a; Schieber *et al*., 2007 and references therein) from the 1.6-Ga Chorhat Sandstone (Rasmussen *et al*., 2002; Ray *et al*., 2002) and Koldaha Shale Formations (Banerjee and Jeevan Kumar, 2005). From detrital zircon geochronology and palaeomagnetic evidence, Malone *et al*. (2008) argued against the traditionally believed Neoproterozoic time frame (~750 Ma) for uppermost Vindhyan sequence i.e., the Rewa and Bhander Formations and instead, assigned an age between 1000 and 1070 Ma. Overall sequence stratigraphic frame has been put forward for the entire Vindhyan sediment (Bose *et al*., 2001; Chakraborty, 2006).

The Chhattisgarh Basin

The Chhattisgarh basin (33,000 km^2 in area) documents ~2.3-km-thick succession of mixed siliciclastic-carbonate lithology and lies unconformably over the Bastar craton. Based on sedimentation pattern, the basin has been divided into three sub-basins: (i) the Singhora Protobasin, (ii) the Baradwar Sub-basin, and (iii) the Hirri Sub-basin and the sedimentary succession is classified under three constituent groups viz. Singhora, Chandarpur and Raipur. While the flat-lying east–west striking Chandarpur Group define an angular unconformity with its underlying compressively deformed, regional- scale non-plane non-cylindrical folded Singhora Group, its upper contact with the Raipur Group laterally varies from unconformable to conformable. A string of publications in recent time (Patranabis-Deb and Chaudhuri 2007; Das *et al*., 2009; Bickford *et al*., 2011a,b,c) have convincingly established the Mesoproterozoic time frame for the basin i.e. between ~1500 Ma and 1000 Ma.

Proximity to crustal-scale geotectonic features viz. rift (P-G, Mahanadi), orogenic fold-thrust belt (EGMB) etc. biased the tectonic modelling of the Chhattisgarh basin. Features such as i) a shrinking, bowl-shape for the basin with a somewhat concentric outcrop pattern, and ii) evaporites alternating with and overlying the carbonate successions to mark the cessation of basin deposition (Das *et al*., 1992), point towards a probable "desiccated-basin setting" in an intracratonic sag depositional mode. Yet, the two recently discussed tectonic models for the basin are inclined either towards rift (Patranabis-Deb, 2001, 2004; Chaudhuri *et al.*, 2002; Patranabis-Deb and Chaudhuri, 2007 and Dhang and Patranabis-Deb, 2011) or a foreland (Biswal *et al.*, 2002; Chakraborty and Paul, 2008; Gupta, 2011) depositional setting.

Products of continental (alluvial fan and braid-plain; Patranabis-Deb and Chaudhuri, 2007; Chakraborty *et al*., 2009), transitional (shoreface, foreshore and beach, tidal estuary and delta; Chakraborty and Paul, 2008); shallow marine (storm-dominated, intertidal and subtidal, occasionally lagoonal; Datta *et al*., 1999; Moitra, 1995; Patranabis-Deb and Chaudhuri, 2002) and deep marine below wave base (Chakraborty and Paul, 2008) are recorded from different stratigraphic levels of Chhattisgarh succession. A marine subtidal to intertidal paleogeography has been invoked for the dominantly stromatolitic succession of the Raipur Limestone (Moitra, 1995). Development of a sabkha condition towards the terminal part of the Chhattisgarh sedimentation history is surmised from the occurrence of gypsum beds within the Kodwa and Dotu Formations of the Raipur Group. Chakraborty *et al*. (2002) observed enriched $^{13}C/^{12}C$ ratio (2.27-3.89‰) from carbonates of the Raipur Group and interpreted in terms of higher productivity. Igneous inputs within the basin are in the form of basic sills, flows and dykes, pyroclastic flow and fall deposits, The tuffs of the Singhora Group is rhyodacite and andesite in composition and characterized by enrichment of large ion lithophile elements (Rb, Ba, Th, etc.) and light-REE with average (La/Nb)N value of 8.9 in chondrite-normalized plot (Das *et al*., 2009). In contrast, the Sukda tuff at the topmost part of the basin-fill shows strongly fractionated REE pattern (La/Yb)N = 56.08 with high content of Sr (416 ppm) (Subba Rao *et al*., 2006). The LILE and Pb-enriched and Nb,

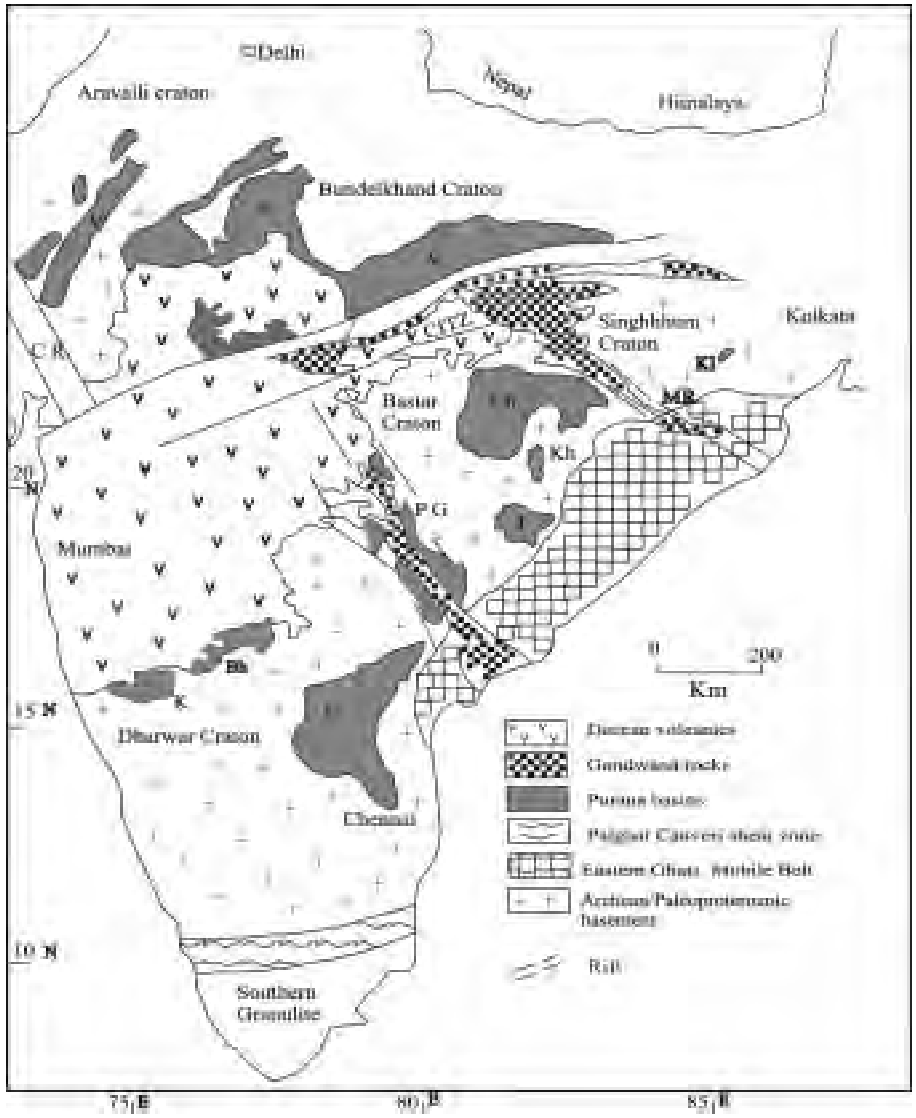

Fig. 1: Distribution of the Proterozoic (*Purana*) basins in the Indian shield. Also shown are the major tectonic features (after Naqvi and Rogers, 1987). Basins: V–Vindhyan and its equivalents, Ch–Chhattisgarh, Kh–Khariar, I–Indravati, PG–Pranhita–Godavari, C–Cuddapah, K–Kaladgi, Bh–Bhima. Tectonic features: CITZ–Central Indian Tectonic zone, CR–Cambay Rift, MR–Mahanadi Rift

P-depleted diabasic intrusive within the Saraipalli Formation is identified as of within-plate affinity and preserving an indication of non-plume source with significant recycled components (Das *et al*., 2011).

The Cuddapah Basin

The crescent-shaped Cuddapah basin occupies an area of about 44,500 sq. km on the eastern part of the Dharwar craton and hosts ~12-km-thick package of sediments and volcanics (Nagaraja Rao *et al*., 1987). The Cuddapah sediments nonconformably overlie Archaean gneisses K-granites, and greenstone belts on the northern, western and southern margins. The eastern margin of the basin is demarcated by a thrust contact along which the metamorphics of the Eastern Ghat Mobile Belt (EGMB) are brought over it. Geophysical studies including deep seismic sounding (DSS) (Kaila *et al*., 1987) indicate presence of: (a) a 10-11-km-thick sedimentary pile over a 40-km-thick crust in the eastern part of the basin; (b) step faults in the basement; (c) a mafic-ultramafic lopolith at a shallow depth under the southwestern part of the basin where mafic sills and volcanics are exposed, and (d) an easterly dipping thrust fault at the eastern margin where high-density lower crust of the EGMB is upthrusted. The sediments of the basin are divided into the Cuddapah Supergroup and the Kurnool Group. The Cuddapah sediments in the western part (Papaghni and Srisailam sub-basins) are unmetamorphosed and almost undeformed whereas in the eastern part, the Nallamalai Fold Belt shows considerable deformation in the form of a fold-thrust belt (Saha and Chakraborty, 2003).

A peripheral foreland origin is proposed for the basin whereby eastward subduction of the Dharwar craton is invoked for the collision and resultant deformation within the Nallamalai Fold Belt (Singh and Mishra, 2002). The Kurnool Group within the Kurnool and Palnad sub-basins are mildly deformed and metamorphosed. Opinions vary on the mechanism of accommodating sediments of huge thickness (>12 km) within the basin. A model involving heating and thermal upwarping of the crust followed by thermal relaxation and crustal thinning, subsidence and gravity faulting was proposed for the deposition of the basal Papaghni Group (Nagaraja Rao *et al*., 1987). Repeated heating caused upliftment of the crust and break in depositional cycle followed by subsidence and deposition of the Chitravati Group (Chatterjee and Bhattacharji, 2001). Repetition of the same cycle of events caused tilting of crust and shifting of the depositional centre to the east where the Nallamalai Group of sediments were deposited. Ramam and Murty (1997), however, have suggested a foreland basin set-up behind a collision belt for the Cuddapah basin where high order of crustal sagging was possible. Alkaline and acid volcanic and intrusive igneous activity within the Nallamalai Group and in the adjacent basement rocks was responsible for localized crustal thinning, domal upwarp and break in deposition of the Nallamalai sediments (Chatterjee and Bhattacharji, 2001). Subsequent subsidence and gravity-induced block faulting produced isolated sub-basins like Srisailam and Palnad where younger sediments (Srisailam Quartzite and Kurnool Group) were deposited. Assigning the conglomerates, immature feldspathic sandstoneas as products of rift stage and highly mature quartz-arenite-carbonate succession as that of post-rift, passive subsidence stage, Patranabis-Deb *et al*. (2012) divided the basin succession under syn-to-post-rift cycles punctuated by regional unconformities.

From lithological and petrological consideration, the Cuddapah sediments are visualized as products of alluvial fan, fan delta, complex beach, barrier-spit complex, subtidal to intertidal, offshore and carbonate shelf environments (Nagaraja Rao *et al*., 1987; Laxminarayana *et al*., 2001). The basin depocenter shifted with time, which is evident from the deposition of the Cuddapah Supergroup in different sub-basins (viz. Papaghni, Nallamalai and Srisailam) and that of the Kurnool Group within the Kurnool and Srisailam sub-basins.

Manikyamba *et al*. (2008) have studied the geochemistry of Cumbum shales and concluded that they are predominantly derived from an intensely weathered (Chemical Index of Alteration, CIA varying between 85 and 100) extracratonic provenance like average Proterozoic, Andean-type continental margin granite. Isotopic age data indicate the initial phase of volcanism and extension in the basin have occurred at least 1900 Ma ago. The Chelima lamproites intruding the Cumbum Formation, dated at 1418 Ma (Chalapathi Rao *et al*., 1999), constrain the lower age limit of the Cuddapah Supergroup. On the basis of fossil evidence and lithostratigraphic correlation the Kurnool Group has been assigned the Neoproterozoic age (Kale and Phansalkar, 1991).

The Marwar Basin

The Marwar Supergroup, traditionally referred as the Trans-Aravalli Vindhyans, is well exposed in western Rajasthan and subdivided into three Groups viz. Jodhpur Group, Bilara (Hanseran) Group and Nagaur Group, in order of superposition. The basal Jodhpur Group is further subdivided into three Formations viz. Pokhran boulder bed, Sonia Sandstone Formation and Girbakhar Formation. Together the Sonia Sandstone Formation and the Girbakhar Formation is informally referred to as the Jodhpur Sandstone and has drawn attraction of sedimentologists and paleobiologists for its exceptional preservation of sedimentary and microbial mat structures. Sarkar *et al*. (2008) carried out process-based paleo-environmental analysis on the rocks of the Sonia Sandstone and suggested deposition under coastal marine, aeolian and fluvial influence. The wide spectrum and abundant examples of microbial mat or mat-derived structures reported from the Sonia sandstone (Sarkar *et al*., 2008; Samanta, *et al*., 2011) are considered to impart enough cohesiveness in otherwise granular sandstones that helped in abundant preservation of delicate primary sedimentary structures and their replication in the overlying beds. From stable isotope (^{13}C and ^{18}O) stratigraphy within the carbonates of overlying Bilara Formation, Mazumdar and Bhattacharya (2004) proposed its deposition transgressing the Neoproterozoic-early Cambrian (Pc-C) boundary.

Pranhita- Godavari (P-G) Valley

One of the key ties between India and North America in the Mesoproterozoic 'Columbia' Supercontinent is the fit of two rifts in India (Mahanadi and P-G) with two rifts in North America (Belt and Uinta). The P-G rift system has been episodically active from the Mesoprotrozoic or earlier (Saha and Chaudhuri, 2002) and the sedimentary fills within it are strongly asymmetrical both in geomorphic features and in sedimentation pattern (Saha, 1992). The Proterozoic rocks of about 6 km thickness, termed as the Godavari Supergroup, are exposed in two linear belts (eastern and western belt) flanking the Gondwana rocks and are classified into several groups and subgroups. The Pakhal and Penganga groups of the western belt and the Somanpalli group of the eastern belt are of mixed carbonate-silicciolastic lithology, whereas the Sullavai and Albaka groups comprise only siliciclastics. The conglomerate and coarse-grained arkosic sediments of the Mulug and Penganga groups are interpreted as coastal fan and fan-delta deposits (Chaudhuri and Deb, 2004) or the sediment gravity flow influenced deepwater base of slope deposit (Bandopadhyay, 1996). For the carbonate-shale intervals, widely varying depositional milieu spanning from shallow marine (viz. tidal flat, lagoon; Chaudhuri and Howard, 1985) to slope to basin (Mukhopadhyay *et al*., 1996) are suggested with signatures of thick autoclastic carbonate mass-flow deposition (Sarkar and Bose, 1992). Shoreface to shelf depositional regime are also surmised for rocks of the Somanpalli group and the Albaka group (Sreenivasa Rao, 1987). Operations of braided alluvial and aeolian erg depositional systems (Chakraborty and Chaudhuri, 1993) are suggested only for the upper part of the succession (i.e. the Sullavai group).

Chaudhuri and Deb (2004) assigned Supersequence status for the Godavari Supergroup bound between two interregional unconformities at the base and the top, and further divided it into six intra-basinal unconformity bound sequences having the stratigraphic status of Group and Subgroup. Authigenic glauconites from the arenites of the Mallampalli Subgroup and lower part of the Penganga Limestone are dated using K–Ar and Rb–Sr systematics (Vinogradov *et al*., 1964). Whereas the Mallampalli sample yielded an age of 1330 ± 53 Ma, the samples from Penganga provided 775 ± 30 and 790 ± 30 Ma age. Considering possible loss of Ar on deep burial of sediment, an age older than 1500–1600 Ma is suggested for the initiation of the Proterozoic sedimentation in the P-G valley.

Summary

The Proterozoic basins in India are mostly represented by mixed siliciclastic-carbonate lithology and offer excellent opportunity for the study of Precambrian siliciclastic and carbonate depositional systems. Within the siliciclastic system the continental deposits are most commonly represented by braided river deposits with subordinate descriptions of aeolian and lacustrine products; no undoubted glacial deposit is described so far. Within the transitional realm although the descriptions of beach and shoreface are plenty, the reports of bar-lagoon, foreshore, chenier and delta products are undoubtedly limited. The descriptions of shelf deposits are heavily biased with storm products. In the carbonate system most of the illustrations are related to description of stromatolites; their geometrical variability and habitat. In recent times, spectacular signatures indicating profuse microbial activity in Proterozoic siliciclastic environments have been documented from the Vindhyan and Marwar basins. Many of the basins, earlier thought to be Neoproterozoic in age, are established to be Mesoproterozoic on geochronological ground. The available geochronological data from the Purana basins suggest regional-scale events at ~1900 Ma, ~1600 Ma, ~1400 Ma, ~1000 Ma and ~800 Ma on the Indian craton. Comparable dates for tectonothermal and tectonomagmatic events are also obtained from the Proterozoic mobile belts of India. In this backdrop, studies of the Purana basins become more crucial for understanding the evolution of Indian shield in diverse tectonic settings in relation to crustal-scale tectonics.

Traditionally, sedimentation within the Purana basins is modelled within the ambit of epeiric sea framework. Recent studies have put forward rift and foreland models for the initiations of many of the Purana basins going beyond the long-held intracratonic sag doctrine. Unanimity among the ideas can only be possible with the understanding of response of basement, associated with the development of Purana basins, under the crustal deformation processes. This calls for deep seismic studies penetrating the entire crust to reveal the structural features present in the basement, their relationship with the adjoining regional structural features (faults, mobile belts, etc.), if any and to understand their implication for the development and subsequent evolution of the basins. Comprehensive studies involving sequence stratigraphy with identification of unconformities (inter- and intra-basinal) and their nesting patterns, geophysical surveys across the mobile belt–craton and cover sediment assemblages backed by robust geochronology within the Purana basin fills will be able to address many of the unresolved questions.

Acknowledgements

The knowledgebase obtained from the Proterozoic basins of India is enormous. The authors apologise for any simplification or omission in their write-up. The authors are also sincerely thankful to Prof. DM Banerjee and AK Singvi for inviting them to present the write-up. Continuous encouragement from Prof. Banerjee was inspiring for them.

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