Review Article

Proterozoic Basins of Peninsular India: Status within the Global Proterozoic Systems

VIVEK S KALE*

Advanced Centre for Water Resources Development & Management [ACWADAM], Sus Road, Pune 411 029, India

and

Department of Earth Sciences, Indian Institute of Technology (Bombay), Powai, Mumbai 411 076, India

(Received on 28 May 2016; Accepted on 10 June 2016)

This compilation is intended to present a snap-shot of the current status of the knowledge on the Proterozoic sediments and tectonic events that are preserved in Peninsular India; on the backdrop of the growing understanding of global events and environmental evolution during that period. Proterozoic sediments in Peninsular India are found in two contrasting categories of basins. Narrow linear intercratonic belts host terrigenous and marine sediments, often interbedded with volcanics and volcanoclastics; that are deformed, metamorphosed and occasionally intruded by granitic bodies. These belts abut with a tectonic contact with wide, unmetamorphosed platform sediments from epicratonic basins with limited igneous activity associated within them; clubbed as the *Purana Basins* of Peninsular India. Although traditionally the former (mobile belts) were considered to be older and different from the latter, emerging geochronological data demonstrates that they were coeval products of basins evolving adjoining each other in diverse tectonic setting. Available knowledge on these basins is summarised within the framework of the emerging understanding of the Proterozoic geohistory punctuated by assembly and break-up of supercontinents, progressive oxygenation of the atmosphere, changes in the sea-water chemistry; establishment of the continental free-board and the generic environments that laid the foundation of biotic evolution. Although significant advances have been made in the last decade in the knowledge of these sediments, much more is required to achieve the desired precision and resolution.

Keywords: Proterozoic; Tectonics; Sedimentation; Peninsular India

Introduction

The Archean history of Peninsular India is recorded in the five distinct cratonic nuclei, namely Rajasthan, Bundelkhand, Bhandara (also named Bastar/Central Indian/Deccan by some authors), Singhbhum and Dharwar (Naqvi and Rogers, 1987; Sharma, 2009; Ramakrishnan and Vaidyanadhan, 2010; Meert *et al.*, 2010; Valdiya, 2016). Constituted of a series of greenstone and high-grade metamorphic belts embedded in tonalite-thondhjemite gneissic complexes, their terminal Archaean accretion is marked by a major event of granitic activity that occurred around 2.5 ± 0.1 Ga. The cratonisation of the Bhandara nucleus appears to have continued through the Paleoproterozoic time culminating with the

Dongargarh Granite and equivalents at around 2.2 ± 0.1 Ga.

It is around these cratonic blocks of gneissic - greenstone complexes that subsequent Proterozoic events have unfolded, with the cratons providing the source of terrigenous sediments to the basins that evolved around them in diverse tectonic settings. Fig. 1 depicts the geographic distribution of the various independently recognisable Proterozoic belts/basins in Peninsular India.

These Proterozoic sediments have been a subject of some exciting additions to our knowledge in the last couple of decades. Major changes have been effected in the conventional correlations between

*Author for Correspondence: E-mail: dr.vivekale@gmail.com

Fig. 1: Simplified map of the Precambrian terrains of Peninsular India (modified after Naqvi and Rogers, 1987; Sharma, 2009; with some updates (in nomenclature) from works cited in this paper. The cratonic nuclei and Archean Gneissic complexes listed on the left are dominantly constituted of TTG-Granite Greenstone terrains. The Proterozoic mobile belts (hosting metamorphosed and deformed suites) are depicted with darker shading for Paleoproterozoic belts and green shades for the Mesoproterozoic belts). The Marwar basin (earlier termed as 'Trans-Aravalli Vindhyan') is arguably the host of the youngest Proterozoic sediments (Neoproterozoic – Cambrian transition) in Peninsular India

these sequences as a result of growing geochronological data. Sedimentological and structural studies have been supplemented by a series of biotic findings that have forced a reassessment of many established concepts. A greater appreciation of the basinal structure of these sedimentary suites has led to the recognition that traditional assumptions need to be replaced by modern concepts.

It would not be possible to discuss in depth the contributions made on each of them, but a precis of what is new to knowledge is enumerated here. Ramakrishnan and Vaidyanadhan (2010) provided a compilation of the state of the art for Indian Geology that was supplemented by the reviews of Meert *et al.* (2010), status reports of Bhowmik *et al.* (2012) and Chakraborty *et al.* (2012); followed by compilations in Sharma, Banerjee and Santosh–Eds (2014: Special Issue Journal of Asian Earth Sciences no: 91: Proterozoic Basins of India), Mazumder and Eriksson – Eds (2015: Geological Society London Memoir no. 43: Precambrian Basins of India – stratigraphic and tectonic context) and Valdiya (2016). For sake of brevity (without diluting any credit from the individual contributors), the citations made in these compilations are not listed individually here unless specific points require.

Age Data

Modern precision geochronological methods have helped create a robust data-base that permits correlations across continental blocks, leading to major revisions in the traditional equivalences of stratigraphic units. The available age data on various Proterozoic sequences is compiled in Fig. 2. The sources of the ages/correlations used in compiling this are listed in the figure title. The available geochronology is at best capable of providing the broad age ranges in which the deposition occurred, often using indirect data eg: ages of intrusives in them or their basement (Pradhan *et al.*, 2012; Kumar *et al.*, 2015) or detrital zircon ages (Malone *et al.*, 2008; Bickford *et al.*, 2011; Amarsinghe *et al.*, 2014; McKenzie *et al.*, 2014; 2013; Basu and Bickford, 2015; Joy *et al.*, 2015) to constraint the upper and lower ages of the component Groups from the various basins. Direct dating of the sediments and associated rocks (eg: Zachariah *et al.*, 1999; Conrad *et al.*, 2011; Gopalan *et al.*, 2013; Tripathi and Singh, 2015) is sparse. The overall

geochronological data lacks the resolution that would enable their precise inter-basinal correlation, akin to Phanerozoic correlations.

It is equally important to note that their preserved thicknesses suggest that a large majority of these sequences were deposited in time-spans of less than 10-20 million years, even if liberal estimates of subdued sedimentation rates are clubbed with very low preservation potential (see Kale and Phansalkar, 1991; Kale, 2015). The depositional environments of these sediments do not indicate muffled rates of accumulation if compared to modern analogues; barring exceptional horizons like black shales and glauconitic beds. Therefore while it is possible to bracket various ‘Groups’ as being within the same range of ages; it will be premature to consider them as being coeval (*sensu stricto*). These uncertainties are depicted in the chart by diagonal boundaries that also emphasis the possibility of their being time-transgressive.

Biotic Contents

These sequences have been reported to yield a diverse biotic record including stromatolitic assemblages, micro-organic remains, ichnofossils, casts and impressions of carbonaceous and other biotic forms.

Stromatolitic forms have been profusely reported from most of these Proterozoic sedimentary sequences, particularly those from the Purana basins. Till about 20 years back, stromatolite biostratigraphy (established in the Russian and Canadian Proterozoic platform deposits as well) appeared to have taken root in correlating these sequences and establishing a broad chronological framework. Over the years, this line of evidence appeared to yield diminishing returns and has now been almost abandoned in recent literature. The cyanobacterial material, carbonaceous bedding-plane markings, and microfossils reported from the stromatolitic strata is yielding significant information on the biotic remains preserved in these sedimentary sequences (Sergeev *et al.*, 2012). Similarly, microbial mat-related structures are being recorded in wider areas across these sediments (eg: Sarkar *et al.*, 2014) and there is a fair chance that some of the earlier interpreted dubio-structures may be explained by such mechanisms that accept the presence of microbial life but question the preservation of the body-form in the host sediments.

(Figure caption on page no. 465)

There is a series of findings of ichnofossils, bedding plane markings and dubiofossils from the Vindhyan, Chattisgarh, Bhima, Kaladgi and Cuddapah basins (Kulkarni and Borkar, 2004). While such forms provide a better understanding of the depositional systems, they have failed to yield concrete pointers to the age of the host sediments. On the other hand, the controversial findings of small shelly fauna from the Vindhyan (Azmi *et al.*, 2008; Bengtson *et al.*, 2009) have resulted in a reappraisal of the age-ranges of some of these forms. The discovery of fossils of distinctive Cambrian affinities from the Marwar basin (Kumar and Pandey, 2008; Kumar, 2012; Sharma *et al.*, 2014b and references therein) have demonstrated that these sediments (earlier termed as the Trans-Aravalli Vindhyan) need to be recognised separately and are the youngest of all Proterozoic sediments from Peninsular India.

The possibility of these sequences hosting a systematic record of biotic forms through the Meso-Neo-Proterozoic is not too remote (Patranabis-Deb *et al.*, 2007; Bengtson, 2009, Sharma *et al.*, 2014a & b). However, these studies need to be tempered with caution and collaborated with isotopic (eg: Banerjee *et al.*, 2006; Bhattacharya and Dutta, 2015; Patranabis-Deb *et al.*, 2015) and sedimentological studies to ensure that such organic remains are methodically and unambiguously documented. They present the promise of hosting one of the best assemblages of the roots of the Phanerozoic biotic explosion.

Unconformities

As the geochronological data emerged in the last 20–30 years, it also became evident that the erstwhile “Great Eoparchean Unconformity” that was presumed

to separate the crystalline metamorphic rocks (of ?Archean age) and the unmetamorphosed sedimentary cover (equated with the Proterozoic) is not a tenable entity. Several metamorphic sequences are much younger than 2.5 Ga, putting them well inside the Proterozoic Eon. All the Proterozoic sequences in Peninsular India rest on the crystalline cratonic basement, separated by an unambiguous angular and erosional unconformity. This points to a protracted period of emergent erosion and weathering of the cratonic blocks. Notwithstanding its diversity in age (as is evident in Fig. 2) for various basins, this basal unconformity is established to have contributed to the evolution of significant placer deposits of diamonds and noble metals, notably in the Vindhyan, Chattisgarh, Bastar, Cuddapah and Kaladgi basins.

What has emerged in the last couple of decades is the association of this unconformity with radioactive mineralisation. Unconformity related uranium and thorium deposits are now recorded from the Kaladgi, Bhima, Cuddapah basins in particular by the Atomic Minerals Directorate of Exploration and Research (Singh *et al.*, 1990; Dhana Raju *et al.*, 2002; Kumar, *et al.*, 2012b; Sridhar *et al.*, 2014; Thomas *et al.*, 2014). What appears to be a critical factor is the thermal rejuvenation of the basement by intrusion of either fertile granites or basic intrusives, followed by a phase of weathering that left behind a paleosol capable of hosting the enrichment of the radioactive minerals through epigenetic processes.

There is a strong case made out for assessing the paleosol horizons occurring atop the basement of these sequences. (eg: Och and Shields-Zhou, 2012; Mukhopadhyay *et al.*, 2014) This could throw significant light on the continental regimes prior to the

Fig. 2: Ages of Proterozoic and Neoproterozoic sequences in the Indian Peninsula. Data compiled based on Kale (1995) with updated age data from (1) Sharma *et al.*, 2014 b; (2) McKenzie *et al.*, 2013, Meert *et al.*, 2010 & Roy and Purohit, 2015; (3) Sharma *et al.*, 2014 a; (4) Mondal *et al.*, 2002, Pradhan *et al.*, 2012 (5) Chakraborty *et al.*, 2015; (6) Rassmussen *et al.*, 2002; Ray *et al.*, 2002; (7) Gopalan *et al.*, 2013; Tripathy and Singh, 2015; (8) Roy and Devarajan, 2000; (9) Dhurandhar *et al.*, 2005; (10) Upadhyay *et al.*, 2014; Meert and Pandit, 2015; (11) Roy *et al.*, 2002a & b; De *et al.*, 2015, (12) Ramakrishnan and Vaidyanadhan, 2010, (13) Roy *et al.*, 2002a; 2006 (14) Eriksson *et al.*, 2006; Valdiya, 2016; (15) Das *et al.*, 2009; Bickford *et al.*, 2011; (16) French *et al.*, 2008, Srivastava and Gautam, 2009; (17) Sarkar *et al.*, 1990; (18) Sarkar *et al.*, 1994; (19) Ghosh *et al.*, 1996; (20 & 21) Krishnamurthy, 1990, Sarkar *et al.*, 1994; (22) Sarkar, 1994; (23) Bandopadhyay *et al.*, 1990; (24) Ratre *et al.*, 2010, Pisarevsky *et al.*, 2012; (25) Roy *et al.*, 2006; (26) Mukherjee *et al.*, 2012 (27) Ratre *et al.*, 2010; (28) Santosh *et al.*, 2004; Amarsinghe *et al.*, 2014; (29) Dharma Rao *et al.* 2014; (30) Mezgar and Cosca, 1999; (31) Paul *et al.*, 1990; (32) Valdiya, 2016; (33) Kumar *et al.*, 2015; (34) Kumar *et al.*, 2012a; (35) Srivastava *et al.*, 2014; (36) Yang and Santosh, 2015; (37) Bidyananda *et al.*, 2003; (38) Kumar *et al.*, 1996, Ramakrishnan and Vaidyanadhan, 2010; (39) Clark *et al.*, 2009

transgressions that yielded the capping sediments. These paleosols and the basal conglomeratic beds in the sequences of different ages have the potential to yield critical data on the evolution of the climatic and weathering conditions through the Proterozoic for the Indian Peninsula.

Another interesting feature emerging from the compilation of the age data is the presence of an intrabasinal unconformity in all the sedimentary basins occurring around 1.1 ± 0.2 Ga. This unconformity separates the younger and older sequences in the Vindhyan, Chattisgarh, Bastar, Pranhita-Godavari, Cuddapah and Kaladgi basins. The implications of this on the classification of the Purana sequences (into bipartite or tripartite) is a matter of separate discussion (eg. Basu and Bickford, 2015; Meert and Pandit, 2015). What is remarkable is that it corresponds to the age of metamorphism, often involving anatectic granite emplacements in the adjoining Mesoproterozoic mobile belts (eg. Delhi, Sausar-Sakoli, Kolhan, Mahakoshal and Nellore).

Sedimentary Contents

The Proterozoic basins from Peninsular India exhibit an overwhelming dominance of quartzitic arenite (with subsidiary rudaceous components)- argillite - carbonate associations that characterise 'passive extensional basins' occurring on the edge of continental blocks. Although the relative proportions of the individual components is variable in different constituent 'Groups' (Kale, 1991) they are absent by exception only. For example, the Rewa Group (from the Vindhyan basin) is totally devoid of carbonate sedimentation.

These sediments are assigned to an array of supra-tidal, shore-face, inter-tidal and off-shore depositional systems, with occasional incidence of aeolian, evaporitic and euxinic environmental conditions. Some of the coarser detrital deposits are recognised to represent alluvial and off-shore (slope-break) fans; while most are attributed to either deltaic or shore-face/coastal deposition. The argillaceous and carbonate deposits have been recognised generally to be associated with the mud-flat, shelf or lagoonal environment with some being ascribed to lacustrine origin.

The outstanding feature emerging from the

review of the depositional environments deciphered for these sediments is their deposition in relatively shallow waters of less than 25 m depths (with maximum estimates of the deeper deposits being less than 100 m water columns).

Although sporadically recorded earlier, the occurrence of synsedimentary deformation in these sequences (eg: Kale *et al.*, 1998; Patil Pillai and Kale, 2011) provides an insight into the fact that these sequences cannot be assigned to transgressive events alone, but that such marine incursions on the stabilised and eroded basements were aided by tectonically driven subsidence of the basin-floor. The presence of chert-breccias in several of the Proterozoic basins has also been interpreted to evidence synsedimentary tectonics (Kale and Patil Pillai, 2011).

The presence of associated basic volcanics is observed in the Mesoproterozoic sequences (Gwalior, Bijawar, Abujhmar, Papaghni) older than 1.5 Ga. The post 1.5 Ga sequences from mobile belts (eg: Delhi, Kolhan, Nellore) do however have interbedded magmatic rocks testifying to their evolution in collisional tectonic regimes. Other sequences younger than 1.0 Ga are however characterised by a remarkable absence of associated igneous rocks (barring the tuffaceous horizons), suggesting that they were deposited on pericratonic platforms akin to extensional passive margins.

Basinal Histories

Traditional views interpreted many of these Proterozoic sequences (using the erstwhile correlations) as being the product of a series of marine incursions on the Indian shield at different times (e.g. Singh, 1980). Based on their contents, geometries and structural patterns, the Purana basins were recognised as independent epicratonic basins created in dominantly an extensional tectonic setting (Kale, 1991). It was also pointed out that their structural characters diagnostically demonstrate that they cannot be clubbed into a singular basin. Each of these sequences has a diverse subsidence history, geometry and contents. Nor does the age data support the assumption of unity.

That they are all 'supracrustal' (in the sense that they rest on crystalline continental crust) and none is an oceanic basin (using the classification of Allen

et al., 2015) is attested to by their basement and basal unconformities separating them from older supracrustal rocks. The terrigenous origin of most of the constituent sediments from these Proterozoic basins is unambiguous. The diversity in their structural patterns and sedimentary – igneous contents indicates that the individual basins, perhaps initiated as extensional supracrustal, (?) pericratonic basins, that underwent changes in their characters in course of their evolution. Some (like the Aravalli, Delhi, Mahakoshal, Satpura and Nellore) eventually suffered compressive tectonism and metamorphism; yielding the mobile belts; while others (~ Purana Basins) remained undeformed (except along some of their margins). The Bagalkot Group from the Kaladgi Basin may be considered as a ‘incomplete fold belt’ with strong axial folding (see Kale, 1991; Jayaprakash, 2007) that is analogous to folding encountered in the mobile belts, but lacks the degree of metamorphism suffered by them. Taken together, it is essential to point out that all the Proterozoic basins qualify as ‘polyhistory’ basins in context of the classifications of sedimentary basins, barring those (like the Bhima, Indravati) that are constituted of singular sequences. Miall *et al.* (2015) have refined the basinal classification of these basins based on modern concepts.

The association of the mobile belts adjoining them indicates that the tectonic histories of the Vindhyan (with the Aravalli – Delhi belt on the west and the Mahakoshal belt in the south), Bastar (with the Eastern Ghats on the east) and Cuddapah (with the Nellore belt on the east) were unquestionably tempered with the events of compressive (?) collisional tectonics occurring along their margins (eg: Collins *et al.*, 2014). This aspect has implications on the global reconstructions of Proterozoic supercontinental assemblies.

The Proterozoic Systems

As against the traditional view of the Proterozoic being a ‘gradual transitional period’ between the hot, oxygen-deficient, hyperactive Archean crustal and atmospheric regimes and the cooler, oxygenated and slower Phanerozoic regimes, the dramatic changes that happened during these ~2000 million years of the “earth’s middle ages” are nothing short of fascinating (see Cawood and Hawkesworth, 2014). The

understanding of the Proterozoic environment and crustal history that has unfolded in the last 10-15 years has led to several significant modifications in earlier established concepts. A graphical summary of the key crustal and environmental characters as well as the tectonic features that are documented through the Proterozoic is given in Fig. 3.

The Proterozoic period shows that the crustal history is more episodic and punctuated with events than was earlier believed. Supercontinental assemblies and break-ups (based on paleomagnetic data that demonstrates proximity of cratonic blocks during specific time intervals and supported by tectonostratigraphic similarities in the constituent blocks) manifest these events on a global scale. Several contributions to the Proterozoic sequences of Peninsular India have attempted to establish their connection with these supercontinental cycles.

Distribution of zircon ages (Fig. 3A) have been used by several authors to identify such supercontinental cycles during the Proterozoic. The names of these assemblies have undergone changes in the last decade. Recent compilations of large datasets of a variety of geological events by Evans (2013), Condie and Kroner (2013), Cox and Hawkesworth (2014), Rooney *et al.* (2015), Condie *et al.* (2015, 2016) appear to conclude that the Proterozoic record is marked by Kenorland (~2.7–2.4 Ga); Nuna (erstwhile Columbia: ~1.8–1.5 Ga), Rodinia (1.1–0.9 Ga) and nascent Gondwana – Laurentia (starting around 0.7 Ga) supercontinental assemblies. Kenorland may have been preceded by ‘Ur’ (~ 3.0 Ga) during the Archean. These analyses of the temporal distribution of various tectonic and environmental parameters through the Proterozoic (Fig. 3) show that:

- Number of cratons has reduced during the Archean – Proterozoic transition (Fig. 3B)
- The number of collisional orogens display distinctive peaks starting with the break-up of the existing supercontinents and reducing with the period of amalgamation and stability (Fig. 3C)
- Mantle temperatures (determined from the crystallisation of non-arc basalts) have reduced progressively through time (Fig. 3D)
- Passive margin abundance increases with time,

Fig. 3: Temporal distribution of Proterozoic environmental conditions and crustal features. Compiled from Kah and Riding, 2007; Evans, 2013; Cawood and Hawkesworth, 2014; Condie and Kroner, 2013; Rooney *et al.*, 2015; Condie *et al.*; 2015, 2016

but is punctuated by periods of supercontinental assemblies when there is an abrupt decrease in them (Fig. 3E).

All these features contribute to a revision in the assumption of a systematic (and progressively decelerating) growth of the continental crust through time. They indicate that it may be more appropriate to consider the possibility of an aperiodic stepped growth model (as shown in the 2 curves (modified after Eriksson *et al.*, 2006 and Condie and Kroner, 2013) in Fig. 3E. The thicker and cooler continental crusts also have contributed to a slower cooling rate of compressive orogens over time, although it does not seem to have affected intracontinental and transpressional orogens (Fig. 3F). These crustal characters have obvious effects on the environments that existed during the Proterozoic.

During periods of supercontinental assembly, sea-levels are likely to be lower, with a dominance of continental climates promoting aridity and generally

Fig. 4: (B) Assembly of continental blocks at around 2.0 Ga based on paleomagnetic data reconstructed by Piper (2013). The contemporary supercontinental assembly is now recognised as the Nuna supercontinent

Fig. 4: (A) Projected configuration of supercontinent assemblies of UR and Arctica at the Archean – Proterozoic boundary as compiled by Rogers and Santosh (2004). This assembly is now recognised as the Kenorland supercontinent

Fig. 4: (C) Assembly of continental blocks at around 1.0 Ga based on paleomagnetic data reconstructed by Piper (2013). The Mesoproterozoic supercontinental assembly is termed as Rodinia in recent literature. Note the 'overturning' of the Indian peninsular that is required for it to fit into the "Rodinia (eventually East Gondwana) assembly

cooler environments that may lead to continental glaciations. On the other hand, dispersals promote higher sea-levels, increasing prevalence of wetter climates and higher temperatures (due to heat loss at spreading centres adding to existing solar insolation) leading to greenhouse-like environments. An added feature that results due to low gradients of the continental shelf systems is that small rises in sea-levels will lead to larger flooded areas on the continents (Eriksson *et al.*, 2006; Bradley, 2011). The available global records of volumes of iron formations (as a proxy of chemical weathering systems on continents) as well as glaciations (Fig. 3 G & H) are consistent with these projections; but are characterised by a major gap of almost a billion years between 1.75 Ga and 0.8 Ga. The correlation of the global glaciation in the Paleoproterozoic (~ 2.2 Ga) and the late Neoproterozoic (Sturtian [0.72-0.66 Ga] and Marinoan [~ 0.63 Ga]; Rooney *et al.*, 2015) with Kenorland and Rodinia bears out this proposition rather strongly. The earlier assumption of progressive oxygenation of the atmosphere through the Proterozoic has also undergone significant revision, with the recognition of the 'great oxygenation event' (Och and Shields-Zhou, 2012; Lyons *et al.*, 2014) that occurred during the Archean - Proterozoic transition (Fig. 3 H). There is now a far better understanding of the changes that occurred during the Proterozoic in the sea-water chemistry in terms of ($^{87}\text{Sr}/^{86}\text{Sr}$ ratios as a proxy of) the volume of continental runoff contributions to primitive sea water, dissolved salts (or salinity) of the sea water (Fig. 3I) and the CO_2 levels in the environment.

Supercontinental Assemblies

Notwithstanding the fact that there have been attempts to correlate the events from the Indian subcontinent with global cycles (eg: Naqvi and Rogers, 1987; Meert *et al.*, 2010; Basu and Bickford, 2015; Valdiya, 2016); Proterozoic paleomagnetic data and the paleo-positions of the Indian subcontinent have remained poorly studied. A sample of the 'fits' of the Indian peninsular block in projected assemblies of Kenorland (~ 2.5 Ga); Nuna (2.0 Ga) and Rodinia (1.0 Ga) is given in Fig. 4. Apparently, this block has undergone several twists and turns in its position during the Proterozoic. Kumar *et al.* (2012b), Radhakrishna *et al.* (2013) Belica *et al.* (2014: Fig. 16), and Pirajno and Santosh (2015: Fig. 15) have reinforced the fact that the

peninsular block displays a very high mobility in terms of its pole-position deduced from paleomagnetic data. Was the Indian Peninsular block indeed so mobile, while other blocks display only a limited movement during equivalent periods of time? This requires a re-appraisal to say the least.

All these assemblies assume that the entire peninsular shield of India was unified throughout the Proterozoic. The collisional tectonics recorded in the Aravalli - Delhi, Sausar - Sakoli, Dhanjori - Dalma - Kolhan and Eastern Ghats - Nellore belts (earlier clubbed as the MPMB by Radhakrishna and Naqvi, 1986) suggest that this singularity may be open to debate. It is not unlikely that the smaller segments (=Rajasthan - Bundelkhand; Bhandara and Singhbhum) of the Peninsular India remained as independent nuclei separated from the Dharwar craton during the Paleoproterozoic times and assembled only during Mesoproterozoic times. Analogy is drawn from the emerging data and interpretations that demonstrate that smaller constituent blocks of African, Laurentian, Chinese shields were actually separated from each other and operated as independent nuclei until their assembly in Rodinia (Collins and Pisarevsky, 2005; Piper, 2013; Radhakrishna *et al.*, 2013); while the entire Indian Peninsular continues to be shown as a single block.

A serious reassessment of this notion is not only desired, but also essential. A better justification of the accretionary tectonics (including its merger with the East Antarctic block) along the mobile belts during the Mesoproterozoic period leading to the development of 'Greater India' may emerge through this evaluation. The record of the unmetamorphosed sediments available in the adjoining Purana basins testify to a limited break-up of the accreted cratons, leading to elevated sea levels that flooded on the eroded continental crust.

Concluding Remarks

The Proterozoic record in the Indian Peninsula is an episodic one. It holds promise of hosting significant evidences of the contemporary atmospheric, oceanic, continental and biospheric systems. Bits and pieces of this have started to emerge and are yielding exciting and encouraging results. While fully appreciating the contributions that have been made to their knowledge in the last few decades (including numerous that

remain uncited in this compilation for want of space) and the exponentially increasing data that is emerging, it remains short of the desired precision and unambiguous repeatability. The requirement is of a sustained, focussed and dedicated effort to look at these sequences in an integrated manner.

Acknowledgements

The patient encouragement of D M Banerjee is the primary driver of this compilation and I am enormously

grateful to him for the same. Ashok Singhvi is thanked for inviting this review and allowing some extra time for its submission. It is a pleasure to extend my gratitude to my peers A B Roy, R S Sharma, K S Valdiya for their sustained blessings and guidance; and to Rajat Mazumder, Sarbani Patranabis-Deb, Subir Sarkar and Mukund Sharma who very kindly flooded me with literature on the subject. This compilation would not have been possible without the efforts and support extended by Shilpa Patil Pillai.

References

- Allen P A, Eriksson P G, Alkmim F F, Betts P G, Catuneanu O, Mazumder R, Meng Q and Young G M (2015) Precambrian basins of India: stratigraphic and tectonic context. In: Precambrian Basins of India: stratigraphic and tectonic context (Eds: Mazumder R and Eriksson P G) *Geol Soc London Mem* **43** 5-28
- Amarsinghe U, Chaudhuri A, Collins A S, Deb G and Patranabis-Deb S (2014) Evolving provenance in the Proterozoic Pranhita-Godavari basin, India dyke swarm from south India: Constraints on Paleoproterozoic reconstruction *Geosci Frontiers* DOI: 10.1016/j.gsf.2014.03.009 12 p
- Azmi R J, Joshi D, Tiwari B N, Joshi M N, Mohan K and Srivastava S S (2008) A synoptic view on the current discordant geo- and biochronological ages of the Vindhyan Supergroup, central India *Him Geol* **29** (2) 177-191
- Bandyopadhyay B K, Bhaskar K G, Ramachandra H M, Khodse V K, Roy A, Mohan M, Sreeramchandra Rao K, Roy Burman T, Bishui P K and Gupta S N (1990) Recent geochronological studies in parts of the Precambrians of Central India *Spl Pub Geol Surv India* **28** 199-210
- Banerjee D M, Rastogi S P and Virender Kumar (2012) Some evaporite deposits of India *Proc Indian Nat Sci Acad* **78** (3) 401-406
- Banerjee S, Bhattacharya S K and Sarkar S (2006) Carbon and oxygen isotope compositions of the carbonate facies in the Vindhyan Supergroup, central India *J Earth Sys Sci* **115** 113-134
- Banerjee S, Dutta S, Paikary S and Mann U (2006) Stratigraphy, sedimentology and bulk organic geochemistry of black shales from the Proterozoic Vindhyan Supergroup (central India) *J Earth Sys Sci* **115** 37-47
- Basu A and Bickford M E (2014) Contributions of zircon U-Pb geochronology to understanding the volcanic and sedimentary history of some *Purana* basins, India *J Asian Earth Sci* **91** 252-262
- Basu A and Bickford M E (2015) An alternate perspective on the opening and closing of the Intracratonic Purana Basins in Peninsular India *J Geol Soc India* **85** 5-25
- Basu A, Patranabis-Deb S, Schieber J and Dhang P C (2008) Stratigraphic position of the ~ 1000 Ma Sukhda Tuff (Chattisgarh Supergroup, India) and the 500 Ma question *Precamb Res* **167** 383-388
- Belica M E, Pilspa E J, Meert J G, Pesonen L J, Plado J, Pandit M K, Kamenov G D and Celestino M (2014) Paleoproterozoic mafic dyke swarms from the Dharwar craton: paleomagnetic poles for India from 2.37 to 1.88 Ga and rethinking the Columbia supercontinent *Precamb Res* **244** 100-122
- Bengtson S, Belivanova V, Rasmussen B and Whitehouse M (2009) The controversial "Cambrian" fossils of the Vindhyan are real but more than a billion years older *Proc Nat Acad Sci* DOI 10.1073/pnas.0812460106
- Bhattacharjee I, Mukundhan A R, Sachan A S, Tiwary K N, Sinha R M and Gupta R K (2005) Proterozoic unconformity related uranium mineralisation around Chitakhhol, Korba district, Chattisgarh, India *J Geol Soc India* **65** 619-623
- Bhattacharya S and Dutta S (2015) Neoproterozoic - Early Cambrian biota and ancient niche: A synthesis from molecular markers and palynomorphs from Bikaner - Nagaur Basin, western India *Precamb Res* **266** 361-374
- Bhowmik S K, Chattopadhyay A, Gupta S and Dasgupta S (2012) Proterozoic tectonics: an Indian perspective *Proc Indian Nat Sci Acad* **78** 385-391
- Bickford M E, Basu A, Patranabis-Deb S, Dhang P C and Schieber J (2011) Depositional history of the Chattisgarh basin, central India: constraints from new SHRIMP zircon ages *J Geol* **119** 33-50
- Bickford M E, Saha D, Schieber J, Kamenov G, Russell A and Basu A (2013) New U-Pb ages of zircons in the Owk

- Shale (Kurnool Group) with reflections on Proterozoic porcellanites in India *J Geol Soc India* **82** 207-216
- Bidyananda M, Deomurari M P and Goswami J N (2003) ^{207}Pb – ^{206}Pb ages of zircons from the Nuggihalli schist belt, Dharwar craton, southern India *Current Science* **85** 1482-1485
- Bose P K, Sarkar S, Das N G, Banerjee S, Mandal A and Chakraborty N (2015) Proterozoic Vindhyan Basin: configuration and evolution. In: Precambrian basins of India: stratigraphic and tectonic context (Eds: Mazumder, R and Eriksson P G) *Geol Soc London Mem* **43** 85-102
- Bradley D C (2011) Secular trends in the geological record and supercontinental cycles *Earth Sci Rev* **108** 16-33
- Buchan K L (2013) Key paleomagnetic poles and their use in Proterozoic continent and supercontinent reconstructions: a review *Precamb Res* **238** 93-110
- Cawood P A, Wang Y, Xu Y and Zhao G (2013) Locating South China in Rodinia and Gondwana: a fragment of greater India lithosphere? *Geology* **41** 903-906
- Cawood P A and Hawkesworth C J (2014) Earth's middle age *Geology* **42** 503-506
- Chakraborty K and Roy A (2013) Petrogenesis of ultramafic - mafic to felsic plutonic rock associations from southern portion of Chottanagpur Gneissic Complex in central India: A multi-stage crust-mantle interaction process *J Geol Soc India* **81** 309-329
- Chakraborty P P, Pant N C and Paul P P (2015) Controls on sedimentation in Indian Palaeoproterozoic basins – clues from the Gwalior and Bijawar basins, central India. In: Precambrian Basins of India: Stratigraphic and Tectonic Context (Eds: Mazumder R and Eriksson P G) *Geol Soc London Mem* **43** 67-83
- Chakraborty P P, Sarkar S and Patranabis-Deb S (2012) Tectonics and sedimentation of Proterozoic basins of Peninsular India *Proc Indian Nat Sci Acad* **78** 393-400
- Clark C, Collins A S, Timms N E, Kinny P D, Chetty T R K and Santosh M (2009) SHRIMP U-Pb age constraints on magmatism and high-grade metamorphism in the Salem Block, southern India *Gond Res* **16** 27-36
- Collins A S and Pisarevsky S A (2005) Amalgamating eastern Gondwana: the evolution of the circum-Indian orogens *Earth Sci Rev* **71** 229-270
- Collins A S, Patranabis-Deb S, Alexander E, Bertram C N, Falster G M, Gore R J, Mackintosh J, Dhang P C, Saha D, Pyne J L, Jourdan F, Backe G, Halverson G P and Wade B P (2014) Detrital mineral ages, radiogenic isotopic stratigraphy and tectonic significance of the Cuddapah basin, India *Gond Res* DOI: 10.1016/j.gr.2014.10.013
- Condie K C and Kroner A (2013) The building blocks of continental crust: evidence for a major change in tectonic setting of continental growth at the end of the Archean *Gond Res* **23** 394-402
- Condie K C, Aster R C, Van Hunen J (2016) A great thermal divergence in the mantle beginning 2.5 Ga: geochemical constraints from greenstone basalts and komatiites *Geosci Frontiers* DOI: 10.1016/j.gsf.2016.01.006
- Condie K C, Davaille A, Aster R C and Arndt N (2014) Upstairs - downstairs: supercontinents and large igneous provinces, are they related? *Int Geol Rev* DOI: 10.1080/00206814.2014.963170
- Conrad J E, Hein J R, Chaudhuri A K, Patranabis-Deb S, Mukhopadhyay J, Deb G K and Beukes N J (2011) Constraints on the development of Proterozoic basins in central India from $^{40}\text{Ar}/^{39}\text{Ar}$ analysis of authigenic glauconitic material *Bull Geol Soc America* **123** 158-167
- Condie K C, Pisarevsky S A, Korenaga J and Gardoll S (2015) Is the rate of supercontinent assembly changing with time? *Precamb Res* **259** 278-289
- Crowe S A, Dossing L N, Beukes N J, Bau M, Kruger S J, Frei R and Canfield D E (2013) Atmospheric oxygenation three billion years ago *Nature* **501** 535-538
- Das K, Chakraborty P P, Hayasaka Y, Kayama M, Saha S and Kumura K (2015) c. 1450 Ma regional felsic volcanism at the fringe of the East India craton: constraints from geochronology and geochemistry of tuff beds from detached sediments basins. In: Precambrian Basins of India: Stratigraphic and tectonic context (Eds: Mazumder R. and Eriksson P G) *Geol Soc London Mem* **43** 207-221
- Das N, Yokoyama K, Chakraborty P P and Sarkar A (2009) U-Th-Pb monazite dating and trace element geochemistry of tuff units from the basal part of the Chattisgarh and Khairiar basin, central India: implications for basin initiation and depositional contemporaneity *J Geol* **117** 88-102
- Dayal M, Mani D, Madhavi T, Kavitha S, Kalpana M S, Patil D J and Sharma M (2014) Organic geochemistry of the Vindhyan sediments: implications for hydrocarbons *J Asian Earth Sci* DOI: 10.1016/j.jseae.2014.03.010
- De C (2006) Ediacaran fossil assemblage in the Upper Vindhyan of central India and its significance *J Asian Earth Sci* **27** 660-683
- De S, Mazumder R, Ohta T, Hegner E, Yamada K, Bhattacharyya T, Chiarenzelli J, Alterman W and Arima M (2015) Geochemical and Sm-Nd isotopic characters of the Late Archean – Paleoproterozoic Dhanjori and Chaibasa metasedimentary rocks, Singhbhum craton, E.India:

- implications for provenance and contemporary basin tectonics *Precamb Res* **256** 62-78
- De Kock M O, Beukes N J and Mukhopadhyay J (2015) Paleomagnetism of Mesoproterozoic limestone and shale successions of some Purana basins in southern India *Geol Mag* DOI: 10.1017/S0016756814000727
- Deb M and Pal T (2015) Mineral potential of Proterozoic intracratonic basins in India. In: Precambrian basins of India: stratigraphic and tectonic context (Eds: Mazumder R. and Eriksson P G) *Geol Soc London Mem* **43** 309-325
- Dehler C M (2014) Advances in Neoproterozoic biostratigraphy spark new correlations and insight into evolution of life *Geology* **42** 731-732
- Dhana Raju R, Kumar M K, Babu E V S S K and Pandit S S (2002) Uranium mineralisation in the Neoproterozoic Bhima Basin at Gogi and near Ukinal: An ore petrological study *J Geol Soc India* **59** 299-321
- Dharma Rao C V, Santosh M and Zhangda S (2014) Neoproterozoic massif-type anorthosites and related magmatic suites from the Eastern Ghats Belt, India: Implications for slab window magmatism at the terminal stage of collisional orogeny *Precamb Res* **240** 60-78
- Dhurandar A P, Latha A and Krishna V (2005) Geochronology and Petrochemistry of the Dubha Granite, Sonbhadra district, Uttar Pradesh *J Geol Soc India* **65** 459-467
- Dobmeier C, Lutke S, Hammerschmidt K and Mezger K (2006) Emplacement and deformation of the Vinukonda meta-granite (Eastern Ghats, India) - Implications for the geological evolution of peninsular India and for Rodinia reconstructions *Precamb Res* **146** 165-178
- Eriksson P G, Mazumder R, Catuneanu O, Bumby A J and Ilando B O (2006) Precambrian continental freeboard and geological evolution: a time perspective *Earth Sci Reviews* **79** 165-204
- Eriksson P G and Condie K C (2014) Cratonic sedimentation regimes in the ca. 2450-2000 Ma periods: Relationship to a possible widespread magmatic slowdown on Earth? *Gond Res* **25** 30-47
- Evans D A D (2013) Reconstructing pre-Pangean supercontinents *Geol Soc America Bull* **125** 1735-1751
- French J E, Heaman L M, Chacko T and Srivastava R K (2008) 1891-1883 Ma southern Bastar - Cuddapah mafic igneous event, India: A newly recognised large igneous province *Precamb Res* **160** 308-322
- Ghosh D K, Sarkar S N, Saha A K and Ray S L (1996) New insights on the early Archean crustal evolution in eastern India: Revaluation of Pb-Pb, Sm-Nd, and Rb-Sr geochemistry *Ind Min* **50** 175-188
- Ghosh J G (2004) 3.56 Ga tonalite in the central part of the Bastar craton, India: oldest Indian date *J Asian Earth Sci* **23** 359-364
- Gilleaudeau G J and Kah L C (2015) Heterogeneous redox conditions and a shallow chemocline in the Mesoproterozoic ocean: evidence from carbon - sulfur - iron relationships *Precamb Res* **257** 94-108
- Goldberg A S (2010) Dyke swarms as indicators of major extensional events in the 1.9–1.2 Ga Columbia supercontinent *J Geodyn* **50** 176-190
- Gopalan K, Kumar A, Kumar S and Vijaygopal B (2013) Depositional history of the upper Vindhyan succession, central India: time constraints from Pb–Pb isochron ages of its carbonate components *Precamb Res* **233** 108-117
- Jayaprakash A V (2007) Purana Basins of Karnataka *Mem Geol Surv India* **129** 140
- Joy S, Jelsma H, Tappe S and Armstrong R (2015) Shrimp U-Pb Zircon Provenance of the Sullavai Group of Pranhita - Godavari Basin And Bairenkonda Quartzite of Cuddapah Basin With Implications for the Southern Indian Proterozoic Tectonic Architecture *J Asian Earth Sci* **111** 827-839
- Kah L C and Riding R (2007) Mesoproterozoic carbon dioxide levels inferred from calcified cyanobacteria *Geology* **35** 799-802
- Kale V S (1991) Constraints on the evolution of the Purana basins of Peninsular India *J Geol Soc India* **38** 231-252
- Kale V S (1995) Association of the Purana basins and the Middle Proterozoic Mobile belts in Peninsular India : Implications on targeting Uranium deposits *Expl Res Atomic Min* **8** 95-110
- Kale V S (2015) Discussion on “An alternate perspective on the opening and closing of the Intracratonic Purana basins in Peninsular India” *J Geol Soc India* **85** 627-631
- Kale V S and Patil Pillai S (2011) A reinterpretation of two Chertbreccias from the Proterozoic basins of India *J Geol Soc India* **78** 429-445
- Kale V S and Phansalkar V G (1991) Purana Basins of Peninsular India: a review *Basin Res* **3** 1-36
- Kale V S, Nair S and Patil S (1998) Testimony of intraformational limestone breccias on Lokapur-Simikeri disconformity, Kaladgi Basin *J Geol Soc India* **51** 43-48
- Kamber B S (2015) The evolving nature of terrestrial crust from the Hadean, through the Archean, into the Proterozoic *Precamb Res* **258** 48-82
- Kemp D B and Sexton P F (2014) Time scale uncertainty of abrupt events in the geologic record arising from unsteady

- sedimentation *Geology* DOI: 10.1130/G35783
- Krishnamurthy P (1990) Magmatic rocks of the Dongargarh Supergroup, Central India - Their petrological evolution and implications on metallogeny *Spl Publ Geol Surv India* **28** 303-309
- Kulkarni K G and Borkar V D (2004) Scrutiny of the earliest records of biogenic sedimentary structures from the Proterozoic rock formations of the Indian shield *J Geol Soc India* **62** 222-226
- Kumar A, Parasharumulu V and Nagaraju E (2015) A 2082 Ma radiating dyke swarm in the Eastern Dharwar Craton, southern India and its implications to Cuddapah basin formation *Precamb Res* **266** 490-505
- Kumar A, Nagaraju E, Besse J and Bhaskara Rao Y J (2012a) New age, geochemical and paleomagnetic data on a 2.21 Ga dyke swarm from southern India: constraints on Paleoproterozoic reconstruction *Precamb Res* **220-221** 123-138
- Kumar A, Venkatesh A S, Ramesh Babu P V R and Nayak S (2012b) Genetic implications of rare uraninite and pyrite in quartz-pebble conglomerates from Sundargarh district of Orissa, eastern India *J Geol Soc India* **79** 279-286
- Kumar S (2012) Stratigraphy and correlation of the Neoproterozoic deposits of central and western India: an overview *Sp Publ Geol Soc London* **366** 75-90
- Kumar S and Pandey S K (2008) *Arumberiabanksi* and associated fossils from the Neoproterozoic Maihar Sandstone, Marwar Supergroup, Vindhyan Supergroup, central India *J Palaeont Soc India* **53** 83-97
- Luo G, Ono S, Huang J, Algeo T J, Chao L, Zhao L, Robinson A, Lyons T W and Xie S (2015) Decline in oceanic sulfate levels during the early Mesoproterozoic *Precamb Res* **258** 36-47
- Lyons, T W, Reinhard C T and Planavsky N J (2014) The rise of oxygen in the Earth's early ocean and atmosphere *Nature* **506** 307-315
- Malone S J, Meert J G, Banerjee D M, Pandit M K, Tamrat E, Kamenov G D, Pradhan V R and Sohl L E (2008) Palaeomagnetism and detrital zircon geochronology of the Upper Vindhyan sequence, Son valley and Rajasthan, India: a ca 1000 Ma closure age for the Purana basins? *Precamb Res* **164** 137-159
- Martin A P, Condon D J, Prave A R and Lepland A (2013) A review of temporal constraints for the Paleoproterozoic large, positive carbonate carbon isotope excursion (the Lomagundi- Jatuli Event) *Earth Sci Rev* **127** 242-261
- Mazumder R and Eriksson P G (2015) Eds. Precambrian basins of India: stratigraphic and tectonic context *Geol Soc London Mem* **43** 352 p
- Mckenzie N R, Hughes N C, Gill B C and Myrow P M (2014) Plate tectonic influence on Neoproterozoic - early Paleozoic climate and animal evolution *Geology* **42** 127-130
- Mckenzie N R, Hughes N C, Myrow P M, Banerjee D M, Deb M and Planavsky N J (2013) New age constraints for the Proterozoic Aravalli-Delhi successions of India and their implications *Precamb Res* **238** 120-128
- Meert J G and Pandit M K (2015) The Archean and Proterozoic history of Peninsular India: tectonic framework for Precambrian sedimentary basins in India. In: Precambrian basins of India: stratigraphic and tectonic context (Eds: Mazumder R. and Eriksson P G) *Geol Soc London Mem* **43** 29-54
- Meert J G, Pandit M K, Pradhan V R, Banks J, Sirianni R, Stroud M, Newstead B and Gifford J (2010) Precambrian crustal evolution of Peninsular India: a 3.0 billion year odyssey *J Asian Earth Sci* **39** 483-515
- Mezger K and Cosca M A (1999) The thermal history of the Eastern Ghats Belt (India) as revealed by U-Pb and ⁴⁰Ar/³⁹Ar dating of metamorphic and magmatic minerals: implications for the SWEAT correlation *Precamb Res* **94** 251-271
- Miall A D, Catuneanu O, Eriksson P G and Mazumder R (2015) A brief synthesis of Indian Precambrian basins: classification and genesis of basin-fills. In: Precambrian basins of India: stratigraphic and tectonic context (Eds: Mazumder R and Eriksson P G) *Geol Soc London Mem* **43** 339-347
- Mishra D C (2011) Long hiatus in Proterozoic sedimentation in India: Vindhyan, Cuddapah and Pakhal basins - a Plate tectonic model *J Geol Soc India* **77** 17-25
- Mishra D C and Ravi Kumar M (2013) Proterozoic orogenic belts and rifting of Indian cratons: Geophysical constraints *Geosci Frontiers* DOI: 10.1016/j.gsf.2013.03.003, 17 p
- Mondal M E A, Goswami J N, Deomurari M P and Sharma K K (2002) Ion microprobe 207Pb/206Pb ages of zircon from the Bundelkhand massif, northern India: implications for crustal evolution of the Bundelkhand - Aravalli protocontinent *Precamb Res* **117** 85-110
- Mukherjee A, Bickford M E, Hietpas J, Schieber J, and Basu A (2012) Implications of a newly dated ca. 1000 Ma rhyolitic tuff in the Indravati basin, Bastar craton, India *J Geology* **120** 477-485
- Mukhopadhyay J, Crowley Q G, Ghosh S, Ghosh G, Chakrabarti K, Misra B, Heron K and Bose S (2014) Oxygenation of

- the Archean atmosphere: new paleosol constraints from eastern India *Geology* DOI: 10.1130/G36091.1
- Naqvi S M and Rogers J J W (1987) *Precambrian Geology of India* Oxford Monographs Geology & Geophysics; Clarendon Oxford Press, Oxford 223p
- Och LM and Shields-Zhou G A (2012) The Neoproterozoic oxygenation event: environmental perturbations and biogeochemical cycling *Earth Sci Rev* **110** 26-57
- Pandey U K, Bhattacharya D, Sastry D V L N and Pandey B K (2011) Geochronology (Rb-Sr, Sm-Nd and Pb-Pb), isotope geochemistry and evolution of granite and andesite hosting Mohar cauldron *Expl Res Atomic Min* **21** 103-116
- Pandey U K, Sastry D V L N, Pandey B K, Roy M, Rawat T P S, Ranjan R and Shrivastava V K (2012) Geochronology (Rb-Sr and Sm-Nd) studies on intrusive gabbros and dolerite dykes from parts of Northern and Central Indian cratons: Implications for the age of onset of sedimentation in Bijawar and Chattisgarh basins and Uranium mineralisation *J Geol Soc India* **79** 30-40
- Parihar P S (2013) Uranium and thorium resources in India: UNFC system www.unece.org/fileadmin/DAM/energy/se/pp/unfc/UNFC_ws_India_Oct2013/5b.2_Parihar.pdf.
- Parihar P S and Srinivasa Rao J (2012) Cuddapah Basin - an Uranium province *Expl Res Atomic Min* **22** 1-5
- Patil Pillai S and Kale V S (2011) Seismites in the Lokapur Subgroup of the Proterozoic Kaladgi Basin, south India: A testimony to syn-sedimentary tectonism *Sed Geol* **240** 1-12
- Patra I, Chaturvedi A K, Srivastava P K and Ramayya M S (2013) Integrated interpretation of satellite imagery, aeromagnetic, aero-radiometric and ground exploration data sets to delineate favourable target zones for Unconformity related Uranium mineralization, Khariar Basin, central India *J Geol Soc India* **81** 299-308
- Patranabis-Deb S, Bickford M E, Hill B, Chaudhuri A K and Basu A (2007) SHRIMP ages of zircon in the uppermost tuff in Chattisgarh Basin in central India require ~ 500 Ma adjustment in Indian Proterozoic stratigraphy *J Geology* **115** 407-415
- Patranabis-Deb S, Schieber J and Chaudhuri A K (2007) Microbial mat features in mudstones of Mesoproterozoic Somanpalli Group, Pranhita-Godavari Basin, India. In: Atlas of microbial mat features preserved within the clastic rock record (Eds: Schieber J, Bose P K, Eriksson P G, Banerjee S, Sarkar S, Altermann W. and Catuneanu O). 171-180, Elsevier
- Patranabis-Deb S, Slowakiewicz M, Tucker M E, Pancost R D and Bhattacharya P (2015) Carbonate rocks and related facies with vestiges of biomarkers: clues to redox conditions in the Mesoproterozoic ocean *Gond Res* DOI: 10.1016/j.gr.2015.06.007, 15 p
- Paul D K, Barman T, McNaughton N J, Flether I R, Potts P J, Ramakrishnan M and Augustine P F (1990) Archean-Proterozoic evolution of Indian charnockites isotopes and geochemical evidence from granulites of the Eastern Ghat Belt *J Geology* **98** 253-263
- Piper J D A (2013) A planetary perspective on Earth evolution: Lid tectonics before plate tectonics *Tectonophysics* **589** 44-56
- Pirajno F and Santosh M (2015) Mantle plumes supercontinents intracontinental rifting and mineral systems *Precamb Res* DOI: 10.1016/j.precamres.2014.12.016, 19 p
- Pisarevsky S A, Biswal T K, Wang X C, Waele B D, Ernst R, Soderlund U, Tait J A, Ratre K, Singh Y K and Cleve M (2012) Paleomagnetic, geochronological and geochemical study of Mesoproterozoic Lakhna Dykes in the Bastar Craton, India: Implication for the Mesoproterozoic supercontinent *Lithos* doi:10.1016/j.lithos.2012.07.015
- Pradhan V R, Meert J G, Pandit M K, Kamenov G and Mondal M E A (2012) Paleomagnetic and geochronological studies of the mafic dyke swarms of Bundelkhand craton, central India: implications for the tectonic evolution and paleogeographic reconstructions *Precamb Res* **198** 57-76
- Radhakrishna B P and Naqvi S M (1986) Precambrian continental crust of India and its evolution *J Geology* **94** 145-166
- Radhakrishna T, Krishnendu N R and Balasubramonian G (2013) Palaeoproterozoic Indian shield in the global continental assembly: evidence from the palaeomagnetism of mafic dyke swarms *Earth Sci Rev* **126** 370-389
- Ramakrishnan M and Vaidyanadhan R (2010) Geology of India (Volume 1) *Geol Soc India Bangalore* **1** 556 p
- Rasmussen B, Bose P K, Sarkar S, Banerjee S, Fletcher I R and McNaughton I J (2002) 1.6 Ga U-Pbzircon age for the Chorhat Sandstone, Lower Vindhyan: Possible implications for the early evolution of animals *Geology* **30** 103-106
- Ratre K, De Waele B, Biswal T K and Sinha S (2010) SHRIMP geochronology for the 1450 Ma Lakhna dyke swarm: its implications for the presence of Eoarchean crust in the Bastar Craton and 1450-517 Ma depositional age for Purana basin (Khariar), Eastern Indian Peninsula *J Asian Earth Sci* **39** 565-577
- Ray J S, Martin M W, Veizer J and Bowring S A (2002) U-Pb zircon dating and Sr isotope systematics of the Vindhyan Supergroup, India *Geology* **30** 131-134

- Retallack G J (2014) Volcanosedimentary paleoenvironment of Ediacaran fossils in Newfoundland *Geol Soc Am Bull* **126** 619-638
- Ries J B, Fike D A, Pratt L M, Lyons T W and Grotzinger J P (2009) Superheavy pyrite ($\delta^{34}\text{S}_{\text{pyr}} > \delta^{34}\text{S}_{\text{CAS}}$) in the terminal Proterozoic Nama Group, southern Namibia: as consequence of low seawater sulfate at the dawn of animal life *Geology* **37** 743-746
- Roberts N M W, Slagstad T and Viola G (2015) The structural, metamorphic and magmatic evolution of Mesoproterozoic orogens: Editorial *Precamb Res* **265** 1-9
- Rogers J J W and Santosh M (2004) *Continents and Supercontinents* Oxford Univ Press NY, 292 p
- Rooney A D, Strauss J V, Brandon A D and Macdonald F A (2015) A Cryogenian chronology: two long-lasting synchronous Neoproterozoic glaciations *Geology* **43** 459-462
- Roy A and Devrajan M K (2000) A reappraisal of the stratigraphy and tectonics of the Palaeoproterozoic Mahakoshal supracrustal belt, Central India. In: Proc. Int. Nat. Sem. Precambrian crust in Eastern and Central India, UNESCO-IUGS-IGCP-368, *Spl Publ Geol Surv India* **57** 79-97
- Roy A, Kagami H, Yoshida M, Roy A, Bandyopadhyay B K, Chattopadhyay A, Khan A S, Huin A K and Pal T (2006) Rb-Sr and Sm-Nd dating of different metamorphic events from the Sausar Belt, central India: Implications for Proterozoic crustal evolution *J Asian Earth Sci* **26** 61-76
- Roy A, Sarkar A, Jeyakumar S, Aggrawal S K and Ebi-hara M (2002a) Mid-Proterozoic plume related thermal event in eastern Indian craton: evidence from trace elements, REE geochemistry and Sr-Nd isotope systematics of basaltic intrusives from Dalma volcanic belt *Gond Res* **5** 133-146
- Roy A, Sarkar A, Jeyakumar S, Aggrawal S K and Ebi-hara M (2002b) Sm-Nd age and mantle characteristics of the Dhanjori volcanic rocks, Eastern India *Geochem J* **36** 503-518
- Roy A B and Purohit R (2015) Lithostratigraphic, geochronological and depositional framework of the Precambrian basins of the Aravalli mountains and adjoining areas, Rajasthan, India. In: Precambrian basins of India: stratigraphic and tectonic context (Eds: Mazumder R and Eriksson P G) *Geol Soc London Mem* **43** 55-65
- Saha D and Mazumder R (2012) An overview of the Paleoproterozoic geology of Peninsular India, and key stratigraphic and tectonic issues *Geol Soc London Spl Publ* **365** 5-29
- Saha D and Tripathy V (2012) Tuff beds in Kurnool subbasin, southern India and implications for felsic volcanism in Proterozoic intracratonic basins *Geosci Frontiers* **3** 429-444
- Santosh M, Yokoyama K and Acharyya S K (2004) Geochronology and tectonic evolution of Karimnagar and Bhopalpatnam granulite belts, central India *Gond Res* **7** 501-518
- Sarkar A, Sarkar G, Paul D K and Mitra N D (1990) Precambrian geochronology of the central Indian Shield - A review *Spl Publ Geol Surv India* **28** 453-482
- Sarkar G, Corfu F, Paul D K, McNaughton, N J, Gupta S N and Bishui P K (1993) Early Archean crust on Bastar craton, central India - a geochemical and isotopic study *Precamb Res* **62** 127-137
- Sarkar S, Banerjee S, Samanta P, Chakraborty N, Chakraborty P P, Mukhopadhyay S and Singh A K (2014) Microbial mat records in siliciclastic rocks: examples from four Indian Proterozoic basins and their modern equivalents in Gulf of Cambay *J Asian Earth Sci* **91** 362-377
- Sarkar S N, Sarkar S S and Ray S L (1994) Geochemistry and genesis of the Dongargarh Supergroup Precambrians of Bhandara-Durg, central India *Indian J Earth Sci* **21** 117-126
- Sergeev V N, Sharma M and Shukla Y (2012) Proterozoic fossil cyanobacteria *Paleobotanist* **61** 189-358
- Sharma M and Shukla Y (2012) Megascopic carbonaceous compression fossils from the Neoproterozoic Bhima Basin, Karnataka, India. In: Geology and hydrocarbon potential of Neoproterozoic - Cambrian basins in Asia (Eds: Bhat G M, Craig J, Thurow J W, Thusu B and Cozzi A) *Geol Soc London Spl Publ* **366** 277-293
- Sharma M, Banerjee D M and Santosh M (2014a) Editorial: Proterozoic basins of Peninsular India *J Asian Earth Sci* **91** 227-229
- Sharma M, Pandey S K and Kumar S (2014b) *International Field Workshop on the Marwar Supergroup, Rajasthan, India-Field Guide* The Society of Earth Scientists, Lucknow, 80 p
- Sharma R S (2009) *Cratons and fold belts of India* Springer - Verlag, Berlin 304 p
- Singh G, Banerjee D C, Dhana Raju R and Saraswat A C (1990) Uranium mineralization in the Proterozoic mobile belts of India *Expl Res Atomic Min* **3** 83-101
- Singh I B (1980) Precambrian sedimentary sequences in India: Their peculiarities and comparison with modern sediments *Precamb Res* **12** 411-436
- Sridhar M, Chaturvedi A K and Rai A K (2014) Locating new

- Uranium occurrences by integrated weighted analysis in Kaladgi basin, Karnataka *J Geol Soc India* **84** 509-512
- Srivastava R K and Gautam G C (2014) Geochemical characteristics and petrogenesis of four Palaeoproterozoic mafic dike swarms and associated igneous provinces from the eastern Dharwar craton, India *Intern Geol Rev* DOI: 10.1080/00206814.2014.938366 24 p
- Srivastava R K, Samal A K and Gautam G C (2009) Precambrian mafic magmatism in the Bastar Craton, central India *J Geol Soc India* **73** 52-72
- Thomas P K, Thomas T, Thomas J, Pandian M S, Banerjee R, Ramesh Babu P B, Gupta S and Vimal R (2014) Role of hydrothermal activity in uranium mineralization in Palnad Sub-basin, Cuddapah Basin, India *J Asian Earth Sci* DOI: 10.1016/j.jseas.2014.02.013
- Tripathy G R and Singh S K (2015) Re-Os depositional age for black shales from the Kaimur Group, Upper Vindhyan, India *Chem Geol* **413** 63-72
- Upadhyay D (2008) Alkaline magmatism along the southeastern margin of the Indian shield: Implications for regional geodynamics and constraints on craton - Eastern Ghats Belt suturing *Precamb Res* **162** 59-69
- Upadhyay D, Chattopadhyay S, Kooijman E, Mezger K and Berndt J (2014) Magmatic and metamorphic history of Palaeoarchean tonalite-trondhjemite-granodiorite (TTG) suite from the Singhbhum craton, eastern India *Precamb Res* **252** 180-190
- Valdiya K S (2016) The making of India - Geodynamic Evolution. Springer International Switzerland, 924 p
- Verma A and Shukla U K (2015) Deposition of the Upper Rewa Sandstone Formation of Proterozoic Rewa Group of the Vindhyan Basin, M.P.: A reappraisal *J Geol Soc India* **86** 421-437
- Yang Q-Y and Santosh M (2015) Zircon U-Pb geochronology and Lu-Hf isotopes from the Kolar greenstone belt, Dharwar Craton, India: Implications for crustal evolution in an ocean-trench-continent transect *J Asian Earth Sci* **113** 797-811
- Yedekar D B, Jain S C and Nair K K K (1990) The Central Indian collision suture. In: Precambrian of Central India *Geol Surv India Spl Publ* **28** 1-27
- Zachariah J K, Bhaskar Rao Y J, Srinivasan R and Gopalan K (1999) Pb, Sr and Nd isotope systematics of Uranium mineralised stromatolitic dolomites from the Proterozoic Cuddapah Supergroup, South India: Constraints on age and Provenance *Chem Geol* **162** 49-64
- Zao G, Sun M, Wilde S A and Li S Z (2004) A Paleo-Mesoproterozoic supercontinent assembly, growth and breakup *Earth Sci Rev* **67** 91-123.