Chapter 3
Tracking India Within Precambrian Supercontinent Cycles

Sarbani Patranabis-Deb, Dilip Saha, and M. Santosh

Abstract The term supercontinent generally implies grouping of formerly dispersed continents and/or their fragments in a close packing accounting for about 75% of earth's landmass in a given interval of geologic time. The assembly and disruption of supercontinents rely on plate tectonic processes, and therefore, much speculation is involved particularly considering the debates surrounding the applicability of differential plate motion, the key to plate tectonics during the early Precambrian. The presence of Precambrian orogenic belts in all major continents is often considered as the marker of ancient collisional or accretionary sutures, which provide us clues to the history of periodic assembly of ancient supercontinents. Testing of any model assembly/breakup depends on precise age data and paleomagnetic pole reconstruction. The record of dispersal of the continents and release of enormous stress lie in extensional geological features, such as rift valleys, regionally extensive flood basalts, granite-rhyolite terrane, anorthosite complexes, mafic dyke swarms, and remnants of ancient mid-oceanic ridges.

Indian shield with extensive Precambrian rock records is known to bear signatures of the past supercontinents in a fragmentary manner. Vast tracts of Precambrian rocks exposed in peninsular India and in the Lesser Himalaya and the Shillong plateau further north and east provide valuable clues to global tectonic reconstructions and the geodynamics of the respective periods. The Indian shield is a mosaic of Archean cratonic nuclei surrounded by Proterozoic orogenic belts, which preserve the records of geologic events since the Paleoarchean/Eoarchean. Here we discuss the sojourn of the Indian plate from the Archean through Proterozoic, in light of available models for supercontinent assembly and breakup in the Precambrian. We also discuss the issues in constraining the configuration, which is mainly due to scanty exposures, lack of reliable paleomagnetic poles from different cratons, and their time of formation or amalgamation. In this chapter, we briefly review Precambrian geology of India to track her participation in the making of the supercontinents through time.

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3.1 Introduction

This review adopts interdisciplinary approaches to understand how the proto India plate moved around the globe and grew since its initial formation in the Eoarchean/Paleoarchean till about the Eocambrian. We consider aspects of geochronology, geochemistry, plate kinematics, and geodynamic models, constrained by a variety of geological and geophysical observations published till date. India with its four major Archean cratons together with the Proterozoic southern granulite terrane and the Indian Precambrian rocks of the Lesser Himalaya constitutes a tectonic collage (Fig. 3.1), which records a complex history of structural and tectonic evolution. Paleomagnetic, geochemical, and tectonostratigraphic data establish that the Precambrian era was a dynamic period when several configurations of the amalgamation and breakup of the supercontinents occurred. Record of the dispersal of continents and the dynamic evolution of our planet are read from the large-scale expression of geological features across the continents and the study of the mantle underneath. Our understanding of the geodynamic evolution of the Earth developed over a century from the “continental drift” of Wegener (1912) to modern plate tectonics through the seminal geophysical and geological input from the oceans (Hess 1962). Many geological features, such as rift zones, continental margin depositional environments, calc-alkaline volcanic-plutonic belts, lithospheric sutures, and orogenic belts, follow from this plate motion process (Cawood et al. 2006). Following the plate tectonics paradigm, the concept of a huge united landmass consisting of most of the earth’s continental regions and surrounded by a global sea constituting the supercontinents gradually established itself (Dewey 1969; Rogers and Santosh 2004; Nance and Murphy 2013). Episodic peak of collisional orogenesis, continental amalgamation, and mantle plume-related mafic dyke swarms were recognized in the rock record as manifestation of the supercontinent cycles. Initially, the late Paleozoic supercontinent of Pangaea (Wegener 1912, 1922) was rigorously defined, but the knowledge of Precambrian supercontinents was very vague at that point of time. Even the existence of early earth supercontinents was questioned by many scientists (Davies 1992; Stern 2007; Stern et al. 2008, 2016; Dewey 2007; Brown 2008). With time, more research appeared wherein paleomagnetic, geochemical, and tectonostratigraphic data established that plate tectonics has been active since at least 3.1 Ga and that supercontinents played a key role in earth’s history, since its formation (Meert 2012; Nance et al. 2014; Meert and Santosh 2017). Deeply eroded ancient orogens provide insight into the hidden roots of modern orogens and offer

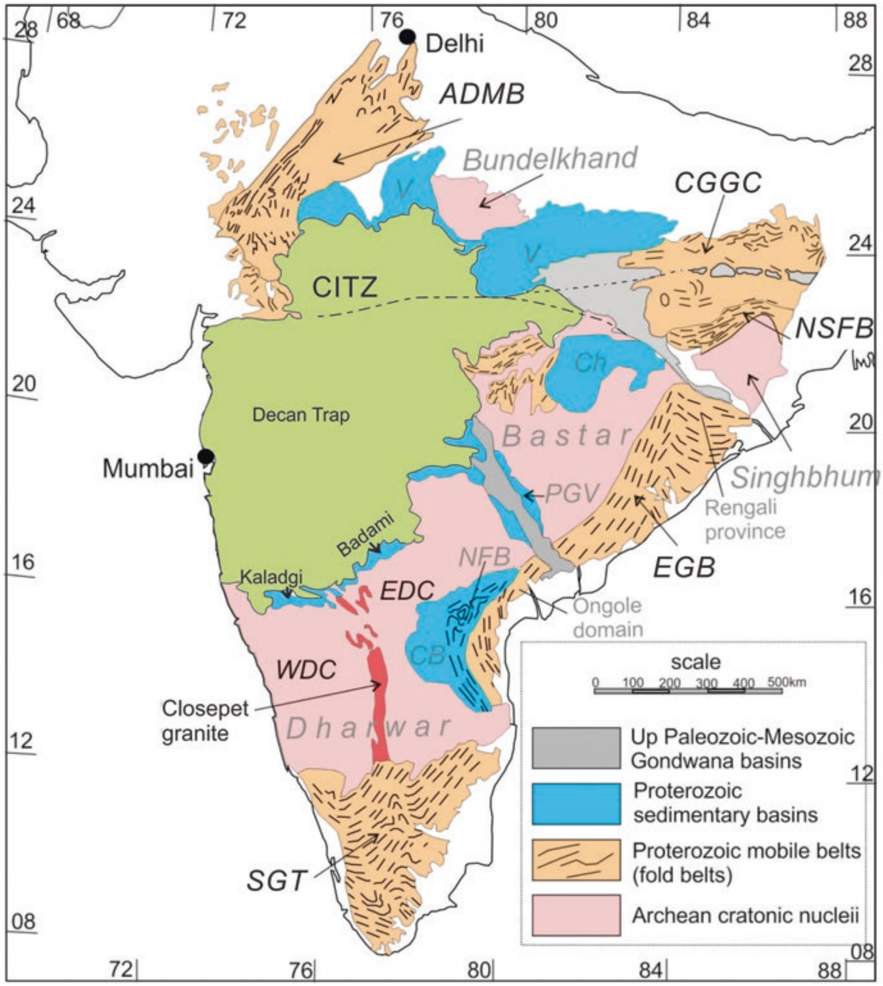

Fig. 3.1 Cratonic blocks and major Proterozoic basins of peninsular India. *ADMB* Aravalli Delhi mobile belt, *CB* Cuddapah basin, *CGGC* Chotanagpur granite gneiss complex, *Ch* Chhattisgarh basin, *CITZ* Central Indian tectonic zone, *EDC* eastern Dharwar craton, *EGB* eastern Ghats belt, *NFB* Nallamalai fold belt, *NSFB* North Singhbhum fold belt, *PGV* Pranhita Godavari basin, *SGT* Southern granulite terrain, *V*, Vindhyan basin, *WDC* western Dharwar craton. (After Saha et al. 2016a)

an opportunity to address the nature of the earth's geodynamic processes and ultimately earth's history.

The Archean greenstone belts in peninsular India and elsewhere preserve some of the oldest terranes which are keys to the understanding of tectonic processes on the early earth (Jayananda et al. 2018). The supracrustal rocks in these belts often retain primary magmatic features and sedimentary structures, which provide us clues to the environment of deposition. In spite of the debate (Eriksson et al. 2004) about the modus operandi of the Precambrian plate movement and supercontinent formation, it is commonly considered that plate tectonics has been an active component of earth's processes possibly since the formation of the first continental crust >4.3 Ga (Cawood et al. 2006). The plate motions are a response to heat loss and cooling within the earth's interior and are also influenced by episodic emplacement of mantle-derived magmas in large igneous provinces.

In this chapter, we aim to synthesize knowledge of Indian geology in the light of the plate tectonic reconstruction models and breakup of the Indian plate for the Precambrian. Furthermore, we consider the increased understanding of the Archean and Proterozoic tectonics within the four major cratons and the Shillong plateau; their relationship along the margins; large-scale tectonic features like remnant orogenic belts, rifts, dyke swarms, paleo-sutures, and ophiolite domains in the cratons; and their implications for the interpretation of plate motions and orogenesis. Though the northern margin of the Indian plate is subducted below the Himalayas, the remaining part preserves the record of the interaction between the Indian plate and its tectonic neighbors. The tectonic plates witnessed assembly and breakup of the major Precambrian supercontinents Nuna/Columbia, Rodinia, and Gondwana and their timings and models. Finally, we review some of the main tectonic issues and uncertainties, bearing on the fit of Indian cratons in one or other of these models. Thus, this chapter is divided into three major parts: (1) a review and discussion of constraints provided by the Precambrian geology of the Indian cratons and their margins, (2) a review and discussion of constraints provided by the Precambrian tectonic history of the neighboring plate margins to get the best fit, and (3) unresolved tectonic issues.

3.2 Tectonic Features of Indian Cratons and Their Place (Status) in Models of Proterozoic Supercontinent Assembly and Breakup

3.2.1 Supercontinents Through Time

The earth's plate motion sculptures its surface with distinctive and unique features, which are preserved in rock record through time. It has been proposed that cooling of the earth's interior due to heat loss and episodic emplacement of mantle-derived magma in large igneous provinces (LIP) are the main drivers of plate's horizontal movement (Cawood and Pisarevsky 2006). These two mechanisms of heat loss may have varied through time perhaps in response to decreasing heat flow (e.g., Davies 1999). This raises questions about the time of initiation of plate tectonic processes and formation of the first supercontinent. Was it very early in its history (Kröner 1981; Ernst 1983; Sleep 1992; Smithies et al. 2003, 2005; Condie 2005; Cawood and Pisarevsky 2006; Dilek and Polat 2008; Turner et al. 2014; Santosh et al. 2017a) or considerably later (Davies 1992; Hamilton 2007, 2011; Stern 2005, 2007; Stern

Table 3.1 Precambrian supercontinents (after Rogers and Santosh 2004)

Name	Age (Ga: Giga annum)
Vaalbara	3.2
Ur	3.0
Kenorland/Arctica	2.7–2.5
Nuna	2.5–1.5
Columbia (first coherent supercontinent by definition)	1.8–1.9
Rodinia	1.1

et al. 2008, 2016; Dewey 2007; Brown 2008; Shirey and Richardson 2011)? How to recognize them? Substantial work has been done in this field; still, the time of initiation of plate tectonic processes remains debated. However, paleomagnetic, geochemical, and tectonostratigraphic data that are in favor of considering plate tectonics operating during the Precambrian and existence of supercontinents dating back to 3.2 Ga have been proposed (Table 3.1). The presence of ophiolites associated with island arc assemblages, occurrences of ultra-high pressure (UHP) rocks, and large igneous provinces dating back to the Precambrian offer us indication that lateral movement of lithospheric plates at divergent and convergent margins was operative during that time. Since our oceans are relatively new (Jurassic and younger), the clues to past supercontinents are not available from present ocean basins. Older oceanic crusts have been consumed in subduction zones. However, a host of geological features, such as past rift zones, continental margin depositional settings, calc-alkaline volcanic-plutonic belts, lithospheric sutures, and orogenic belts, gives us clues to the tearing apart and stitching together of the continents. The signatures, usually in bits and pieces from now widely separated continents, reveal the nature and evolutionary pattern of each of the supercontinents (e.g., Cocks and Torsvik 2002; Halverson et al. 2009; Meert and Lieberman 2004; Valentine and Moores 1972). We look for proxies to get the idea about the plate margins and their changes through time. Paleomagnetic data, the correlation of orogenic belts formed during accretion of the supercontinents, the correlation of extensional features that developed when the supercontinent fragmented, and the recognition of sedimentary provenance across the continents are four mostly used techniques for reconstructing supercontinents (Rogers and Santosh 2004).

3.2.2 Indian Scenario

The Indian tectonic plate, presently situated in the northern hemisphere, is bounded by four major tectonic plates, namely, the Eurasian plate to the north, the Australian plate to the southeast, the African plate to the southwest, and the Arabian plate to the west (Fig. 3.2). The northern part of the Indian plate is subducted beneath the

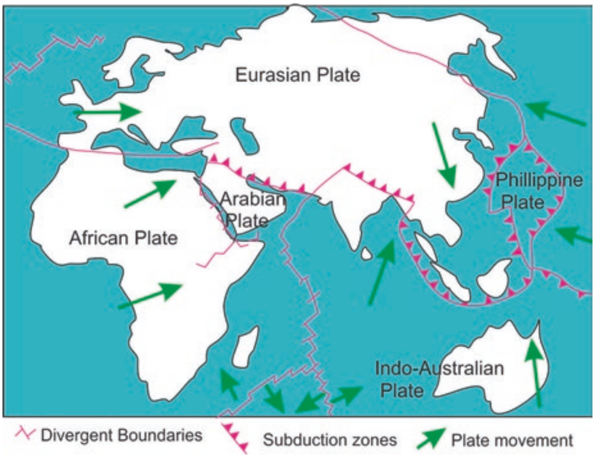

Fig. 3.2 Tectonic plates around India. The subduction zone and the divergent plate boundaries are marked with purple lines. Green arrows mark plate movement directions

Eurasian plate, but the peninsular India constituting the Precambrian Indian shield preserves fragmentary records of the past supercontinents. The Central Indian Tectonic Zone (CITZ) divides the Indian Precambrian shield into a northern tectonic block and southern tectonic block, which is a collage of four Archean cratons, namely, Dharwar, Bastar, Singhbhum, and Aravalli–Bundelkhand, and the (Proterozoic) Shillong plateau in the northeast (Fig. 3.1). These cratons are composed mostly of granites, gneisses, and remnants of greenstone/schist belts of the Archean age and the cratonic basins of the Proterozoic age which overlie the Archean basement (Jayananda et al. 2015, 2016, 2018; Manikyamba et al. 2017; Radhakrishna and Naqvi 1986; Ramakrishna and Vaidyanadhan 2008; Meert et al. 2010; Saha and Mazumder 2012; Saha et al. 2016a). Large-scale tectonic features like exhumed orogen, rift basins, dyke swarms, paleo-sutures, ophiolite domains in the cratons, and their margins are being used as clues to unravel the history of the moving plates, focusing on India through time.

The Proterozoic orogenic/mobile belts rim the Archean cratons in peninsular India—the eastern Ghats belt and the southern granulite terrane (SGT) bordering the Dharwar craton and the Central Indian Tectonic Zone (CITZ) separating the Bundelkhand craton in the north from the southern and eastern Indian cratons, namely, the Bastar, Singhbhum, and Dharwar cratons. In addition, the Aravalli-Delhi fold belt borders the western part of the Bundelkhand craton (Fig. 3.1). By the end of the Archean or early Proterozoic, the cratonic nuclei were possibly amalgamated into a number of stable microcontinents, which coalesced to form larger continental masses. Occurrences of tonalite–trondhjemite–granodiorite (TTG) rocks, supracrustal rocks including Archean greenstone belts, and the late Neoarchean intrusive granitic plutons bear the signature of amalgamation (Santosh et al. 2015, 2016; Jayananda et al. 2013, 2018). High-grade Proterozoic metamorphic belts at the junction of the neighboring cratons were the stitching line between them. The junction between the Dharwar craton and the Bastar craton is marked by the Karimnagar and Bhopalpatnam granulites, whereas the ultra-high-temperature (UHT) granulites along the Central Indian Tectonic Zone (CITZ: Bhowmik et al. 2005; Bhowmik 2006) suture the Bundelkhand craton in northern India to Bastar and the adjoining blocks of southern India. In addition, the vast cratonic sedimentary basins are the repositories of Proterozoic geological records roughly contemporaneous with the high heat-producing rocks in the surrounding orogens to its east and south (Collins et al. 2007; Dobmeier and Raith 2003; Santosh et al. 2006). Widespread development of the undeformed or little metamorphosed sedimentary successions of the Proterozoic cratonic basins (Purana successions of Holland 1909) of the peninsular India points to development of stable shield by the end of the Archean.

The stratigraphic successions of the cratonic basins of peninsular India, namely, the Chhattisgarh and its satellite basins in the Bastar craton; the Cuddapah, Bhima, and Kaladgi basins of the Dharwar craton; and the Vindhyan basin in Bundelkhand craton, ranging in age from the Paleoproterozoic through the Neoproterozoic, represent major cycles of sedimentation with significant similarity in development as well as wide variations in their depositional milieu. The depositional milieu of each of these major cycles is manifested in the varied facies associations, which represent the record of possible fluctuations in the sea level. The two key factors, namely, (1) epeirogenic movements in cratonic interiors and (2) changes in sea level, or combination of the two is responsible for the development of the craton interior unconformities. The unconformity bound sequences and the cyclicality pattern influenced by the global sea-level change curve have been used for intrabasinal correlations of the successions of the cratonic basins of peninsular India with an attempt to find possible tectonic links with the supercontinent cycles (Patranabis-Deb et al. 2018; Saha 1994; Mazumder et al. 2012).

We also take up Singhbhum craton and the Shillong plateau and adjoining NE Himalayan belt, with its subsequent activities to resolve the geodynamic puzzle through geological record preserved in them.

In this contribution, we deal with the published models of the supercontinents through time and the place of India in the amalgamation and dispersal patterns of the supercontinents. The craton interior sedimentary successions and the craton margin fold belts which may have correlatable counterparts in other continents are briefly described and discussed to highlight the Precambrian dynamics of the Indian plate. The techniques usually used to get an understanding of the older supercontinents are often indirect, because of loss of older record due to subduction processes through ages. The overall geological framework in each craton is discussed with emphasis on those stratigraphic records and tectonothermal events that are regionally significant and provide clues to regional and tentative global correlation.

3.3 Precambrian Supercontinents

3.3.1 Vaalbara: The Archean Supercontinent ~3.2 Ga

Vaalbara, the earliest supercontinent described so far, derived its name from last four letters of the Kaapvaal craton, now located in eastern part of South Africa and the Pilbara craton, presently located in north-western Australia (Fig. 3.3; Cheney 1996). Cheney (1996) correlated these two widely dispersed continents, by comparing 100–1000 m thick unconformity bound sequences, which show remarkable similarities in their depositional environment. Sequence stratigraphic correlation is supported by the paleomagnetic data (Zegers et al. 1998; Strik et al. 2003) and chronostratigraphic data (Zegers and Ocampo 2003), which placed Vaalbara to be the earth's earliest craton. Further, it has been noted that the oldest impact-related layers, dated as ca. 3470 Ma, are recognized within greenstone sequences of these two cratons (Byerly et al. 2002). Though the existence of this 3.6–3.2 Ga continent cannot be unequivocally proven and debate about the existence of Vaalbara still persists, it matches chronologically with the volcano-sedimentary succession of the Dharwar greenstone belts of peninsular India. 3.5–3.0 Ga age for the Sargur Supergroup (Nutman et al. 1992; Peucat et al. 1995; Jayananda et al. 2008; Lancaster et al. 2015) and 3.0–2.7 Ga for the Dharwar Supergroup (Taylor et al. 1986; Kumar et al. 1996; Nutman et al. 1996; Jayananda et al. 2000, 2013), which led us to rethink about India's participation during the making of Vaalbara as the nearest neighbor. However, recent study by Jayananda et al. (2018) shows that the Archean geological history and crust-forming events of the Dharwar craton are correlatable with the Bundelkhand craton in central India, Pilbara and Yilgarn cratons in western Australia, and Kaapvaal and Tanzania cratons in southern Africa. More research and authenticated data are still needed to confirm the participation of the Archean greenstone belts that were subsequently spread out across Gondwana and Laurasia.

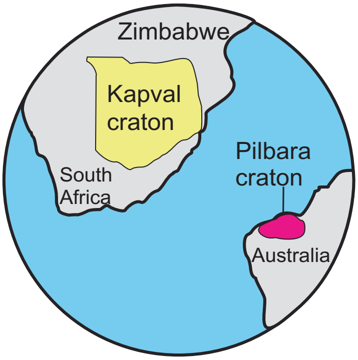

Fig. 3.3 The earth's earliest known supercontinent Vaalbara, formed around 3.3 billion years ago. Vaalbara connects South Africa's Kaapval craton and Australian Pilbara craton

3.3.2 Ur: The Archean Supercontinent ~3 Ga

“Ur,” meaning “original” in German, signifies the oldest craton, which possibly formed a core for a continental block as late as 1.8 Ga (Rogers and Santosh 2004). Ur supercontinent formed at ~3.0 Ga and accreted to the greater part of the east Antarctica in the middle Proterozoic to form east Gondwana (Rogers 1996). Initial configuration of Ur (Fig. 3.4) was proposed by Rogers (1993, 1996) which included the Kaapvaal craton of South Africa; the Madagascar, west Dharwar, Bhandara (Bastar), and Singhbhum cratons of India; and the Pilbara craton of Australia. Later on, parts of small cratons from east Antarctica, namely, Dronning Maud Land, Napier, Vestfold, and Yilgarn from Australia, were added to form expanded Ur supercontinent (Rogers and Santosh 2004). The correlation was based mostly from available age and roughly similar history of the origin and development of the cratons which actively took part in the amalgamation process to form Ur (Barley 1993; Blewett 2002; Jayananda et al. 2000, 2018; Mazumder et al. 2000; Goswami et al. 1995). However, tests of existence of “Ur” and specific correlation of the rocks from each of the cratons are very difficult because of its age, and hence large uncertainties remain.

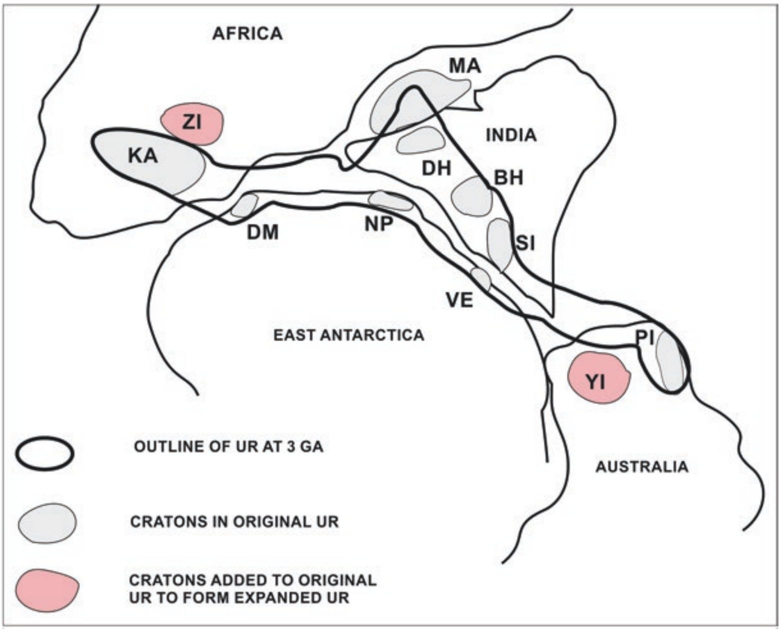

Fig. 3.4 Maps of “Ur” and “expanded Ur” at 3.0 Ga (Rogers and Santosh 2004). Symbols designate the following cratons: KA, Kaapvaal; MA, Madagascar; DH, Dharwar (west and east); BH, Bhandara (Bastar); SI, Singhbhum, DM, Dronning Maud Land; NP, Napier; VE, Vestfold; YI, Yilgarn; ZI, Zimbabwe; PI, Pilbara. Subsequent growth of Ur occurred to form the East Gondwana landmass

Recent studies also suggest that the cratonic fragments of late Archean continents embedded in younger continents are part of the supercraton Superia (Bleeker 2003). The supercraton derived its name from the Superior craton, which represents one of the larger and better preserved fragments and occupies the central piece of supercraton Superia. Based on their paleomagnetic interpretation, Bleeker et al. (2008) argue that the Kaapvaal, Superior, and Wyoming were the nearest neighbors in supercraton Superia, representing the fragment that originated from the reentrant to the southwest of a combined Superior-Wyoming.

3.3.3 Arctica/Kenorland ~2.7–2.5 Ga

North America and Siberian cratons were considered to be part of a large continent, which was named as Arctica (~2.7 Ga), because of the presence of Arctic Ocean through them. However, Arctica's position against North America is debatable. A group of scientists, in their reconstruction placed Siberia against the northern margin of N. America (Condie and Rosen 1994), while the others placed it along the western edge of North America (Sears and Price 2000, 2003). Secondly, history of the cratons in the Canadian Shield was not matching with the proposed reconstruction of Arctica. Williams et al. (1991) proposed the name "Kenorland" for the supercontinent at ~2.5 Ga, which encompasses Canadian cratons of Arctica. This study with detailed analysis of six thematic tectonic maps was used to comment on the makeup of the North American continent. They have also suggested that essentially similar plate tectonic processes controlled continental breakup and assembly from the Archean onwards, albeit with gradual increase in size of continental lithospheric plates and quantitative change in other parameters such as heat flow and character of the mantle (Williams et al. 1991). It has been suggested, but it was also questioned later that Kenorland underwent widespread rifting and collision along Trans-Hudson orogeny and Taltson magmatic belt between 1.9 and 1.8 Ga time interval (Fig. 3.5; Rogers and Santosh 2004). The breakup of Kenorland was contemporaneous with the glaciation event which persisted for up to 60 million years. The timing also matches with the atmospheric changes and rise in oxygen level and formation of habitable earth. The banded iron formations (BIF) also show their worldwide acme in development in this period, thus indicating a massive increase in oxygen buildup from an estimated 0.1% of the atmosphere to about 1% (see Hashizume et al. 2016). The alternate silica- and iron-rich laminae of banded iron formations (BIFs) are thought to reflect the dynamics of the paleo-environments and point to biological influence during 2.7–2.9 Ga on BIF (Hashizume et al. 2016).

Despite many persisting problems about the timing and assembly of Kenorland, it is accepted that by Middle Proterozoic, it took active part and grew up to be part of the supercontinent Rodinia at ~1 Ga (Bowring and Grotzinger 1992). Comprehensive stratigraphic and geochronologic investigation of early Proterozoic sedimentary basins related to Wopmay and Thelon orogens located in the northwest Canadian shield indicates that the duration of the passive margin sedimentation in

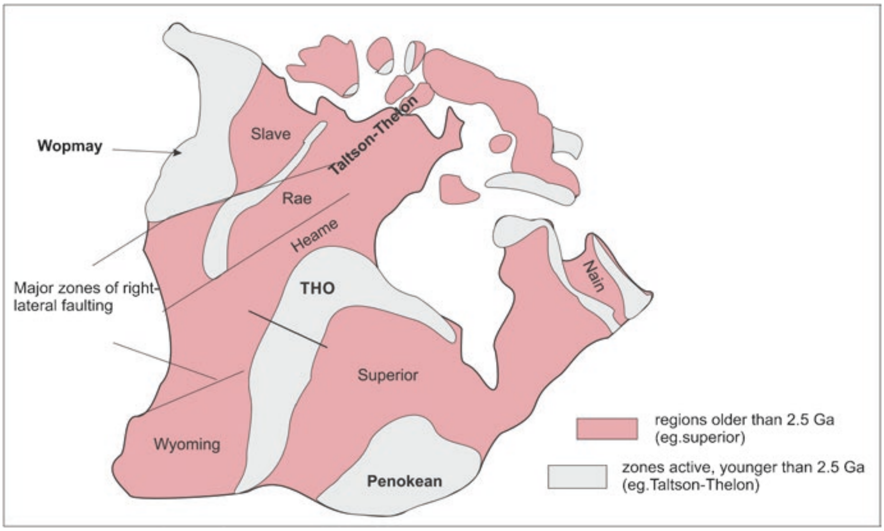

Fig. 3.5 Map of Kenorland (after Rogers and Santosh 2004). Major post-Archaean orogenic belts are named in bold. THO stands for the Trans-Hudson Orogen

the Wopmay province was of the order of 80–90 Ma, which is in contrast with the earlier notion of about 10 Ma (Bowring and Grotzinger 1992).

3.3.4 Nuna/Columbia ~2.5–1.5 Ga

Hoffman (1997) proposed the name "Nuna" for their reconstruction of a giant continent which involved the lands bordering the northern oceans, namely, Laurentia, Baltica, and, to a lesser extent, the Angara craton of Siberia. This was not very different from the "Nena" as proposed by Gower et al. (1990). Careful examination made by Meert (2012) revealed that although "Nuna" was published prior to "Columbia," the "Nuna" proposal in terms of the configuration of the giant continent does not fit well. Therefore, the proposal is made that "Columbia" consists of several core elements one of which is "Nuna" (Meert 2002; Meert and Santosh 2017). Rogers and Santosh (2002) proposed the name Columbia (Fig. 3.6a) for the Paleo-Mesoproterozoic supercontinent, where the Archean to Paleoproterozoic cratonic blocks were welded by the global 2.1–1.8 Ga collisional belts, with signatures of extreme metamorphism (Santosh et al. 2006). Columbia supercontinent was the first coherent supercontinent by definition, which contains nearly all of the earth's continental blocks at some time between 1.9 and 1.5 Ga. In the initial configuration of Rogers and Santosh (2002), South Africa, Madagascar, India, Australia, and attached parts of Antarctica are placed adjacent to the western margin of North America, whereas Greenland, Baltica (Northern Europe), and Siberia are positioned

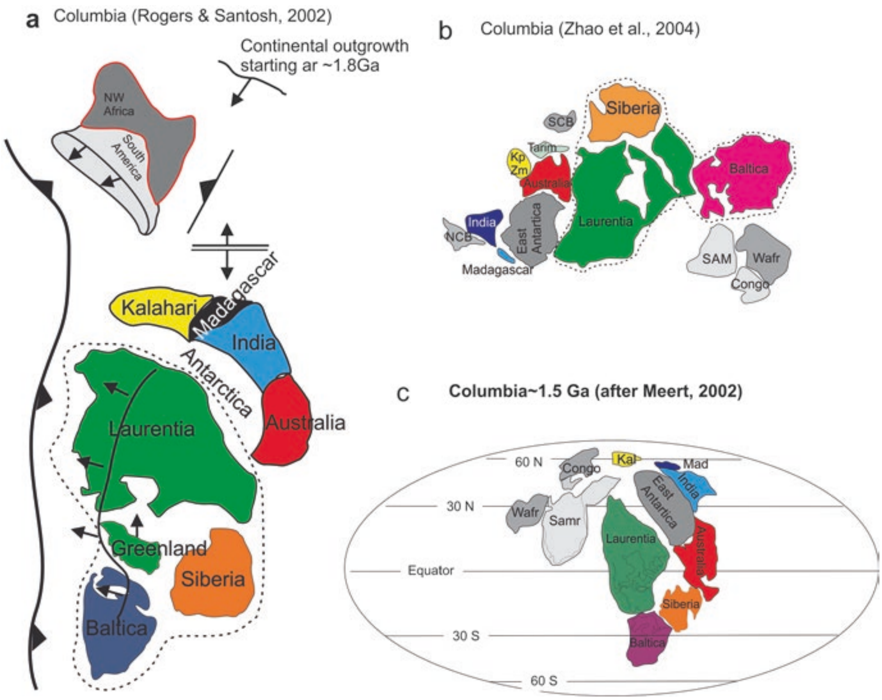

Fig. 3.6 (**a**) "Columbia" fit of Rogers and Santosh (2002) showing the approximate relationship between the various elements comprising the supercontinent without considering a specific map projection such that the continents are distorted. The dashed outline shows the "Nuna" core within the Columbia supercontinent, (**b**) a simplified image of the "Columbia" supercontinent according to Zhao et al. (2004), and (**c**) "Columbia" at 1.5 Ga using slightly modified rotation parameters (Laurentia fixed) originally given in Meert (2002) to approximate the Rogers and Santosh (2002) archetypal fit. Laurentia, along with all the other elements, is then rotated according to the ~1.5 Ga St. Francois mountains pole of Meert and Stuckey (2002)

adjacent to the northern margin of North America, and South America is placed against West Africa. In the same year (2002), Zhao et al. (2002) proposed an alternative configuration of Columbia, in which the fits of Baltica and Siberia with Laurentia and the fit of South America with West Africa are similar to that of the configuration proposed by Rogers and Santosh (2002), whereas the fits of India, East Antarctica, South Africa, and Australia with Laurentia are similar to their corresponding fits in the configuration of Rodinia. Zhao et al. (2002) proposed that the assembly of the supercontinent Columbia was completed by global-scale collisional events during 2.1–1.8 Ga, considering lithostratigraphic, tectonothermal, geochronological, and paleomagnetic data from around the world. India played a key role in the configuration of the Columbia. The South and North Indian Blocks were amalgamated along the Central Indian Tectonic Zone (Deshmukh et al. 2017); and the Eastern and Western Blocks of the North China Craton were welded together by ~1.85 Ga Trans-North China Orogen (Deshmukh et al. 2017; Naganjaneyulu and

Santosh 2010). The existence of Columbia is consistent with late Paleoproterozoic to Mesoproterozoic sedimentary and magmatic records. Following its final assembly at ca. 1.82 Ga, the supercontinent Columbia underwent long-lived (1.82–1.5 Ga), subduction-related growth via accretion at key continental margins, forming at 1.82–1.5 Ga great magmatic accretionary belt (Condie 2002; Zhao et al. 2002, 2004; Rogers and Santosh 2004). In a recent study, Evans and Mitchell (2011) provided an update on the assembly and breakup of the center of Nuna, between Laurentia, Baltica, and Siberia. They have used Nuna and Columbia as equivalent terms for their study and used very precise paleomagnetic results from ten sites of acid volcanic rocks from North China, and from Australia, India, and Amazonia, to examine the positions of these continental blocks in Nuna. Evans and Mitchell (2011) proposed Laurentia–Baltica–Siberia connection for the bulk of Nuna (also known as Columbia) on the basis of paleomagnetic and geologic studies. Nuna reconstruction, constrained by the updated global paleomagnetic dataset, is also consistent with key geological features including the ca. 1.8 Ga orogenic belts. The Mesoproterozoic global intraplate extensional basins and large igneous province (LIP) record were possibly related to the breakup of Nuna. The breakup of Nuna may have commenced after ca. 1.4 Ga, but available paleomagnetic data are not yet complete enough to allow a more precise depiction of Nuna's fragmentation. Models available for the breakup of Columbia indicate that it began to fragment about 1.5–1.35 Ga, associated with continental rifting along the western margin of Laurentia (Belt-Purcell Supergroup) (Zhao et al. 2004, James et al. 2015), eastern India (Godavari Supergroup), southern margin of Baltica (Telemark Supergroup), southeastern margin of Siberia (Riphean aulacogens), northwestern margin of South Africa (Kalahari Copper Belt), and northern margin of the North China Block (Zhaertai-Bayan Obo Belt). The fragmentation corresponded with widespread anorogenic magmatic activity, forming anorthosite-mangerite-charnockite-granite (AMCG) suite in North America, Baltica, Amazonia, and North China, and continued until the final breakup of the supercontinent at about 1.3–1.2 Ga, marked by the emplacement of the 1.27 Ga Mackenzie and 1.24 Ga Sudbury mafic dyke swarms in North America (Zhao et al. 2004). Other dyke swarms associated with extensional tectonics and the breakup of Columbia include the Satakunta-Ulvö dyke swarm in Fennoscandia and the Galiwinku dyke swarm in Australia. Very recently, Hou et al. (2008) proposed the new configuration of the Columbia supercontinent on the basis of giant radiating dike swarms.

3.3.5 Rodinia

Valentine and Moores (1970) were probably the first to recognize a Precambrian supercontinent, which they named "Pangaea I." McMenamin and McMenamin, in the 1990s, renamed it as Rodinia and proposed temporal framework for the supercontinent, which reached its maximum packing at around 1.0 Ga. The name Rodinia was derived from the Russian word *rodít* meaning "to beget" or "to give birth" and proposed plausible reconstruction which involved two Neoproterozoic continents (east Gondwana and west Gondwana) that were derived from the breakup of an older supercontinent Columbia (Rogers and Santosh 2004; Yoshida et al. 2003).

Following Powell et al.'s (1993) work, Rodinia became the dominant name used to refer to a wide variety of Neoproterozoic supercontinental reconstructions (see also Torsvik et al. 1996; Weil et al. 1998; Meert and Torsvik 2003; Li et al. 2008). Rodinia was assembled through worldwide orogenic events between 1300 and 900 Ma, with all, or virtually all, the then existing continental blocks likely being involved. Reports of major orogenic events at around 1.0 Ga from many parts of the world coincide with the maximum packing of Rodinia. Rodinia is the supercontinent that gave birth to all subsequent continents, and its continental shelves were the cradle of earliest animals (McMenamin and McMenamin 1990). Increased volcanic activity of the period also introduced into the marine environment biologically active nutrients, which may have played a significant role in the development of the earliest animals. The corresponding superocean surrounding Rodinia is called Mirovoi (McMenamin and McMenamin 1990). Till recent years, different models of reconstruction of Rodinia are put forward matching Grenvillian age belts (~1.0 Ga), where the configuration of the core cratons remains the same, but differ in many details. Dalziel (1991), Hoffman (1991), and Moores (1991) were among the pioneering workers who proposed this Precambrian supercontinent model by integrating geological evidence with paleomagnetic data. Most commonly referred model is that by Hoffman (1991), which included blocks surrounding Laurentia and attached East Antarctica and western North America along a series of Grenville age belt (Fig. 3.7). The assembly process features the accretion or collision of continental blocks around the margin of Laurentia. Meert (2001) proposed similar reconstruction for Rodinia, integrating geological evidence with Paleomagnetic data. Principally, these reconstructions matched the east coast of Australia-Antarctica with the west coast of Laurentia. Hoffman (1991) proposed that all Grenvillian belts are zones of ocean closure between continental blocks. It is also consistent with juxtaposition of Southwest North America and East Antarctica (Dalziel 1991), referred to as SWEAT hypothesis, proposed by Moores (1991). Wingate et al. (2002) proposed an AUSMEX connection where Australia and Mexico were adjacent to each other or AUSWUS, where Australia was placed against North America leaving room for Siberia to be joined to western Canada as proposed by Sears and Price (2003). Brookfield (1993), Karlstrom et al. (1999), and Burrett and Berry (2000, 2002) proposed a configuration for one part of Rodinia, which is different from the Rodinia proposed by Hoffman (1991). Merdith et al. (2017) points out that the existing models predict less subduction (ca. 90%) with respect to what we see on the modern Earth. This confusion led them to adopt conservative model, which shows notable departures of previous Rodinia reconstruction models, where India and South China were omitted from Rodinia completely, due to long-lived subduction preserved on the margins of India and conflicting paleomagnetic data for the Late Neoproterozoic, such that these two cratons act as "lonely wanderers" for much of the Neoproterozoic.

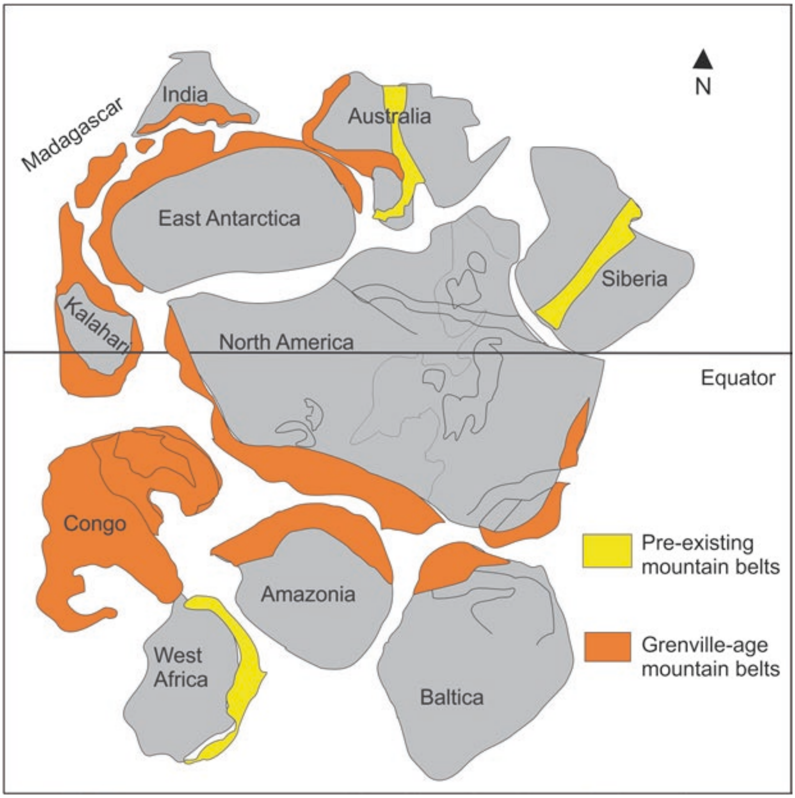

Fig. 3.7 "Rodinia at about 700 Ma" (after Hoffman 1991). Orange shows Grenville age mountain belts, and yellow shows preexisting mountain belt

Fragmentation of the supercontinent is recorded in Neoproterozoic rift and passive margin successions, as it broke apart (Burke and Dewey 1973; Bond et al. 1984; Dalziel 1991; Hoffman 1991; Powell et al. 1993, 1995). After the assembly of bulk of Rodinia, it moved to the higher latitudes and then returned toward equatorial–mid latitudes by ca. 800–825 Ma, with Laurentia occupying a low–mid latitude position and Australia-Antarctica and Siberia lying on the equator. The breakup of Rodinia started about this time resulting with the opening of the Proto-Pacific Ocean between Australia-Antarctica-Tarim and Laurentia. The spreading system separating Laurentia and Australia likely extended further north and is inferred to be the spreading ridge associated with Siberia's dextral movement against Laurentia between 800 and 700 Ma (Pisarevsky et al. 2013). Mantle avalanches, caused by the sinking of stagnated slabs accumulated at the mantle transition zone surrounding the supercontinent, plus thermal insulation by the supercontinent, led to the formation of a mantle superplume beneath Rodinia, 40–60 million years after the completion of its assembly. Different models for breakup of Rodinia are available, but many disparities still exist, leaving space for further revision of the models with high precision data. However, it is generally accepted that widespread continental rifting between 825 and 740 Ma, with episodic plume events at 825, 780, and 750 Ma separated the continents (Rogers and Santosh 2004).

Rodinia broke apart, and its successor, Gondwana, began to amalgamate (Meert 2003; Boger and Miller 2004; Collins and Pisarevsky 2005) in four stages between 825 and 550 Ma (Bogdanova et al. 2008; Li et al. 2008). There is an overlap between the last stage of Rodinia amalgamation in geological records of one continent and the first stage of breakup in another continent, which implies that the record of time of amalgamation and breakup of this supercontinent vary between continents. Consequences of rifting are best recorded in North America being the central part of Rodinia. Rifting between the Amazonia craton and the southeastern margin of Laurentia started at approximately the same time, but only led to breakup after ca. 600 Ma. By this time, most of the western Gondwanan continents had joined together, although the formation of Gondwanaland was not complete until ca. 530 Ma. In the interval 650–550 Ma, several events overlapped: the opening of the Iapetus Ocean; the closure of the Braziliano, Adamastor, and Mozambique oceans; and the Pan-African orogeny, resulting in the formation of Gondwana.

3.4 Dynamics and Evolutionary Perspectives

3.4.1 Role of Indian Shield

The Precambrian era is very important and crucial because of many reasons, among which most important is the transition from an inhabitable earth to development of soft bodied, multicellular creatures. Numerous models of the wandering plates are being proposed since the widespread acceptance of the plate tectonic paradigm. The long-term trends and variations in mantle dynamics are preserved in rock record (e.g., Tackley 2000), faunal diversity and evolutionary patterns, distribution of ore deposits (e.g., Barley and Groves 1992; Bierlein et al. 2009; Butterworth et al. 2016; Meyer 1988; Pehrsson et al. 2016), seawater chemistry (Halverson et al. 2007; Hardie 1996), paleogeography, and climate (Hoffman et al. 1998; Kirschvink 1992). In this section, we will be looking at how the Indian cratons fit, if at all, in one or other of the available models of the assembly and breakup of the supercontinents and discuss about the unresolved issues and future directions.

In the following section, we discuss the events preserved in the rock records of Indian Peninsula in light of assembly and dispersal of the proposed supercontinents. Models for the supercontinents often rely on the history of orogenic belts within the continents and their nearest match to the other continent (matching piercing points). Accretion and dispersal of the slabs or continental blocks take place due to mantle convection. Supercontinents possibly accrete above the down going limb of very large convection cells and disperse above rising convection cells (Runcorn 1962; Rogers and Santosh 2004).

3.4.2 Vaalbara

The 3.2 Ga supercontinent's existence is still in doubt, but the time frame and the greenstone succession match with some of the data from peninsular India, namely, the 3.5–3.0 Ga depositional age of the volcano-sedimentary successions of the Sargur Group, Dharwar craton (Jayananda et al. 2008, 2018), the Sonakhan Greenstone belt of Bastar craton (Das et al. 2009; Saha et al. 2000), and the Iron Ore Group of Gorumahisani–Badampahar area of Singhbhum craton (Mazumder et al. 2012; Mukhopadhyay et al. 2008). The stratigraphic history and the paleomagnetic data, the latter as yet unknown, of the Neoarchean–Paleoproterozoic greenstone belts from peninsular India might throw some light on India's participation during the formation of the Vaalbara supercontinent (de Kock et al. 2009). The recently reported 3.2–3.5 Ga ages from arc-type magmatism and continental growth within the Coorg Block in southern India (Santosh et al. 2016) might also provide evidence for the existence of one of the cores of Vaalbara within Peninsular India.

3.4.3 Ur

Ur, the supercontinent which stabilized at 3.0 Ga, has records of India's active participation. Dharwar, Singhbhum, and Bastar cratons (Figs. 3.1 and 3.4) formed the central part of Ur and were connected with Kaapval craton of South Africa in the west, Pilbara to the southeast and Napier, Vestfold and Dronning Maud Land of East Antarctica to the south. The reconstruction was done mainly on the basis of the available dates. Emplacement ages of the Singhbhum granite show wide range starting from 3.3 to 3.1 Ga (Saha 1994; Reddy et al. 2009). Older Metamorphic Tonalite Gneiss (OMTG) was dated to be 3.4 (Moorbath and Taylor 1988) and 3.5 Ga (Acharyya 2005). Saha (1994) reported 3.8 Ga for Older Metamorphic Group (OMG) and 3.3 Ga by Sharma et al. (1994) for the same Group. Mukhopadhyay et al. (2008) assigned 3.55 Ga sedimentation age for the Iron Ore Group, Daitari basin, representing the oldest shelf sedimentation in eastern India. On the other hand, the western Dharwar craton consists of 3.3–3.0 Ga old tonalite–trondhjemite–granodiorite (TTG) rocks (Jayananda et al. 2000, 2013, 2015; Chardon et al. 2011; Guitreau et al. 2017; Maibam et al. 2016; Ishwar-Kumar et al. 2013). Peninsular Gneiss, with enclaves of greenstone belts of the Sargur Group, was reported by Naha et al. (1991), which ranges in age between 3.3 and 3.1 Ga (Jayananda et al. 2015; Meert et al. 2010). The Bastar craton includes TTG and greenstones about 3.5 Ga age (Sarkar et al. 1993).

Mahapatro et al. (2012), Misra and Gupta (2014), Bose et al. (2016a), Chattopadhyay et al. (2015a, b), and Ghosh et al. (2016) are among the recent workers in the eastern Ghats belt, who suggested that the time of juxtaposition of Rengali province against the Eastern Ghats or its connection with the Bastar craton to be Late Archean in age. They correlated the granulite facies metamorphism, from one domain of the eastern Ghats belt with the thermal pulses in the Singhbhum craton and suggested possible connection with the assembly of the Archean supercontinent "Ur" (Mahapatro et al. 2012). Alternative hypothesis by Chattopadhyay et al. (2015a, b) suggests ~0.98 Ga amphibolite facies metamorphism and transpression of Rengali at ~0.5 Ga. Whether juxtaposition of the Rengali province with the eastern Ghats occurred during the Grenvillian orogeny (Chattopadhyay et al. 2015a, b) or Pan African orogeny (Ghosh et al. 2016) is a matter of debate, and additional data is needed to resolve it.

Despite the fact that Dharwar, Bhandara (Bastar), and Singhbhum cratons of peninsular India give overlapping age, the tests of the existence of Ur and the place of India in it are yet to emerge, because of its old age and limited outcrop. However, there is scope for better understanding by identification of similar depositional history and recognition of unconformity bound sequences within the greenstone succession, supported by paleomagnetic and geochronologic data.

3.4.4 *Kenorland*

The role of Indian shield in the formation of Kenorland is not known yet, but recently published data from Indian Paleoproterozoic orogenic belts suggest some connection in making up the supercontinent as against the common notion of global tectonic quiescence at 2.6–2.4 Ga (Condie et al. 2011; Mazumder et al. 2012).

3.4.5 *Columbia Supercontinent*

The Columbia is still believed to be the first coherent supercontinent which contained nearly all of earth's continental blocks at some point of time between 1.9 and 1.5 Ga. During amalgamation around ~1.9–1.8 Ga (Rogers and Santosh 2002), the eastern India, Australia, and Antarctica were sutured to western North America (Rogers and Santosh 2004) and finally to the main landmass stated above. Zhao et al. (2004) put forward a different model with slight deviation from the original model proposed by Rogers and Santosh (2002). In his model, North China is attached to India with Trans-North China Orogen connected to central India (Fig. 3.6b).

Ramakrishna and Vaidyanadhan (2008) proposed that the small outcrop of Proterozoic basement gneisses and deformed metasedimentary rock groups of the Shillong plateau may be considered as part of the Indian craton. Rb-Sr method of dating gave ~1.7 Ga age for the gneissic basement complex of the plateau (Ghosh et al. 1994), while Yin et al. (2010) assigned 1.6 Ga migmatization age for the Shillong–Meghalaya basement gneissic complex. Based on the age distribution of detrital zircon population, Yin et al. (2010) concluded that the Shillong Group is possibly younger than 1100 Ma (see also Chatterjee et al. 2007; cf. Mitra and Mitra 2001).

The Lesser Himalayan augen gneisses (Bomdila gneiss) in Arunachal Pradesh, intruded into the phyllite–quartzite succession of the Bomdila Group, yield ages of 1.76–1.74 Ga (Yin et al. 2010). Paleoproterozoic sedimentation in the Lesser Himalaya may be broadly contemporaneous with the lower Vindhyan (Semri Group) sedimentation in the Aravalli–Bundelkhand craton, or similar elements preserved in the Mahakoshal belt or the Chotanagpur Granite Gneiss terrane (see Ramakrishna and Vaidyanadhan 2008). On the whole, the available evidence suggests that the amalgamation of the Shillong plateau basement with the rest of the Indian craton is a late Paleoproterozoic–Mesoproterozoic phenomenon, which corresponds to the amalgamation of Columbia supercontinent. However, no data on paleomagnetism is available, so the validity is still untested.

3.4.6 Imprints in the Aravalli–Bundelkhand Craton

Aravalli–Bundelkhand craton (ABC), situated in the north of the Central Indian Tectonic Zone (CITZ), preserves continuous record of deposition, deformation and cratonization starting from 3.3 to 0.5 Ga. Our description will be limited within 1.9–1.4 Ga events that coincide with amalgamation of Columbia supercontinent. The geophysical data of the craton indicate that the Aravalli–Bundelkhand craton constitutes the basement beneath the Lesser Himalayan successions and the Quaternary alluvium of the Indo-Gangetic plain (Kailasam 1976). About 700 km long NE-SW trending Aravalli-Delhi Orogenic Belt (ADOB) marks the NW border of the Aravalli–Bundelkhand craton, with Paleo–Mesoproterozoic deposition of the volcano-sedimentary successions (Choudhary et al. 1984). Compilation of petrological, geochemical, and geological investigations reveals that ADOB is a mosaic of geological terrane, juxtaposed against each other, separated by crustal scale shear zones (Gupta 1934; Heron 1953; Roy and Jakhar 2002; Ramakrishna and Vaidyanadhan 2008). These major ductile shear zones represent either Proterozoic sutures or ophiolite melange zones (Sinha-Roy et al. 1995).

The Paleoproterozoic Aravalli fold belt is generally considered to be separated from the Mesoproterozoic Delhi fold belt by a tectonic contact (Gupta 2004; Deb et al. 2001). Emplacement of syntectonic granitic plutons, namely, Darwal granite or Amet granite at ~1.8 Ga, has been linked with the early deformation of Aravalli Supergroup (Sharma 2009). Similarly, the protolith of the Anasagar Granite Gneiss was emplaced within supracrustal metasedimentary rocks (Aravalli Supergroup) at around 1.85 Ga (Mukhopadhyay et al. 2000; Chattopadhyay et al. 2012). Buick et al. (2006) assign granulite metamorphism age to be 1.72 Ga for the Sandmata complex. The Central Indian Tectonic Zone (CITZ) records ~1.8 Ga closure of the northern and southern tectonic blocks (Acharyya and Roy 2000). Harris (1993) compared the tectonothermal history of CITZ with the Albany belt of Australia.

The chronological data obtained from the cratonic basin sedimentary succession of the Son Valley Vindhyan record ~1.72 Ga age for the oldest sediments and 1.6 Ga for the youngest rocks in the basin (Ray et al. 2002; Sarangi et al. 2004; Ray 2006). However, Malone et al. (2008) proposed 1000–1070 Ma age for the Upper Vindhyan on the basis of detrital zircon analysis of the Upper Bhander sandstones. This clearly indicates that the craton margin orogenic activity coincides with basin formation in the craton interior. The basin filling succession keeps record of the eroded past, and they should be taken care of during supercontinent reconstructions.

3.4.7 Dharwar Craton

The term Dharwar craton was introduced by the Geological Survey of India in 1978 (cf. Radhakrishna and Vaidyanadhan 1997), to accommodate Dharwar Supergroup which includes the "Dharwar greenstone granite" and "Sargur Schist complex." On the basis of major differences in lithology and ages of rock units, a dividing line, along a steeply dipping mylonite zone (Chitradurga shear zone) (Nutman et al. 1992; Kaila et al. 1979) and the Closepet granite (Ramakrishna and Vaidyanadhan 2008), was proposed to divide the craton into Eastern Dharwar craton and Western Dharwar craton (Fig. 3.1). More recent studies show that the craton contains three microblocks with independent thermal records and accretionary histories, which amalgamated into cratonic framework ca. 2.56 Ga (Peucat et al. 2013; Jayananda et al. 2013, 2018). The craton is bordered to the south by the Pan-African Pandyan mobile belt, also referred to as the southern granulite terrane (Ramakrishna and Vaidyanadhan 2008). The northeastern fringe is marked by the Pranhita–Godavari (PG) Valley rift, and the Deccan basalts cover its northern fringes, where the Proterozoic Bhima and Kaladgi basins occur (Fig. 3.1). Intracratonic Cuddapah basin, ranging in age from the Paleoproterozoic to the Neoproterozoic, occurs in the East Dharwar craton. 5–6 km thick sedimentary succession in the basin with occasional interruption by magmatism holds clue to the happenings during the Proterozoic time. They also preserve record of the changing provenance through time. Paleoproterozoic–Mesoproterozoic tectonic development of the Indian shield is well preserved in the orogenic belt along the eastern margin of the Dharwar craton (Saha et al. 2010). The high grade Eastern Ghats belt, the Nellore schist belt with remnants of ocean plate stratigraphy, and the Nallamalai fold belt with their Paleoproterzoic to Neoproterozoic tectonic history are important in constraining the craton and subsequently the supercontinent development (Saha 2002, 2011; Saha and Chakraborty 2003; Saha et al. 2016b). 1.9 Ga mafic dykes and sills (French et al. 2008) of Dharwar craton mark extension and initiation of sedimentation in the cratonic basins of Dharwar. The interval, 1.5–1.1 Ga, marks wide emplacement of kimberlites/lamproites (Osborne et al. 2011) in Indian shield, pointing toward a link with global extensional episode. The hypothesis of an approximately 1900 Ma old large igneous province (French et al. 2008) incorporating the Cuddapah dykes, that is, those occurring in the basement (Dharwar batholith), is yet to be tested properly with data from other continental fragments.

3.4.8 Ongole Domain: EGMB

There are recent suggestions of the Paleoproterozoic to the Mesoproterozoic ancestry of the Ongole Domain of the southern eastern Ghats belt (Henderson et al. 2014; Sarkar et al. 2014). They have proposed that the sedimentary and igneous rocks showing granulite facies metamorphism preserve fundamental clues to the reconstruction of Columbia. Approximately 1850–1750 Ma LA ICP-MS age of detrital zircons from the sedimentary protoliths constrains the timing of deposition, which can be correlated with detritus from the Napier complex and the North Australian craton to a lesser extent North China Craton. Dasgupta et al. (2013) discussed about the tectonic evolution of the domain and suggested it to be part of accretionary belt of Columbia between Napier and Dharwar blocks at about 1.8–1.6 Ga. Conflicting views prevail regarding the source of the sediments. Sarkar et al. (2014) suggest the provenance was from the present geographic west, i.e., the Dharwar craton, while Henderson et al. (2014) preferred easterly source from the Napier complex. The final collisional episode between Indian and east Antarctic blocks in keeping with its record of high-pressure metamorphism at ca. 1.54 Ga (Sarkar and Schenk 2014; Sarkar et al. 2014) is also considered as cratonization age of the Ongole Domain.

3.4.9 Mahakoshal Belt

Mahakoshal belt (MB), the northernmost of the supracrustal belt of Central Indian Tectonic Zone (CITZ), records the emplacement of late to post-tectonic granitoid bodies and associated mafic microgranular enclaves (MME), some of which gave robust date between 1.76 and 1.75 Ga by U-Pb SHRIMP zircon geochronology (Bora et al. 2013). The emplacement age of the plutons fits well with continental collision during the assembly of Columbia (Bora and Kumar 2015). The collision was followed by mantle plume activity, with lithospheric thinning and rifting of the Mahakoshal belt, which is tentatively constrained at ca. 1.6 Ga (Srivastava 2013). The volcanic sequence and the sediments are in general intercalated in the MB, where the volcanic rocks are mostly tholeiitic in composition, and occur in association with gabbros, dunite, and pyroxenite, representing platform volcanism (Roy et al. 2000).

3.4.10 Southern Granulite Terrane

It is now becoming increasingly evident that a large part of the crustal basement south of the Palghat-Cauvery Suture Zone in the southern granulite terrane, up to the tip of the peninsula, comprises Paleoproterozoic rocks generated in arc magmatic setting (Yellappa et al. 2010). The basements of the central and southern Madurai Blocks and the Trivandrum and Nagercoil Blocks are now known to be widely composed of Paleoproterozoic (ca. 2.0–1.8 Ga) rocks (e.g., Kroner et al. 2015; Santosh et al. 2017b). Thus, it is possible that large parts of the southernmost part of India were part of the Columbia supercontinent.

3.5 Breakup of Columbia

It has been generally accepted that the demise of the supercontinent Columbia started at around 1.5 Ga (Rogers and Santosh 2002). The signatures of the Mesoproterozoic rifting are well preserved throughout the world. Rogers and Santosh (2002) correlated the Mahanadi-Lambert and Godavari rifts of India with the Belt and Uinta rifts of North America, respectively, thus placing India against western North America in Columbia (Fig. 3.8). Eastern India preserves remnants of ~1.5 Ga granite-rhyolite in the rifts and marginal basins at initial phase of rifting, comparable with granite-rhyolite terrane of type area, namely, central and southwestern United States (Anderson and Morrison 1992; Anderson and Cullers 1999).

3.6 Breakup of Rodinia

The world experienced major orogenies around the period ~1.0 Ga, commonly correlated with the Grenville orogeny in Canada. The Grenville orogeny and its correlatives across the world hold the key to the reconstruction of the supercontinent Rodinia. Since the early Neoproterozoic, tectonic geography was dominated by the formation of the supercontinent Rodinia, its breakup, and the subsequent amalgamation of Gondwana. We discuss the Neoproterozoic orogenic record in Indian shield in the context of the dynamics of Rodinia supercontinent. The Neoproterozoic time range is crucial, that is, the earth went through the most extreme climate swings known, from "Snowball Earth" icy extremes to super-hot greenhouse conditions, when the atmosphere got a major injection of oxygen and when multicellular life appeared and exploded in diversity. All these individual events left distinct records in rocks, which could be traced across the continents.

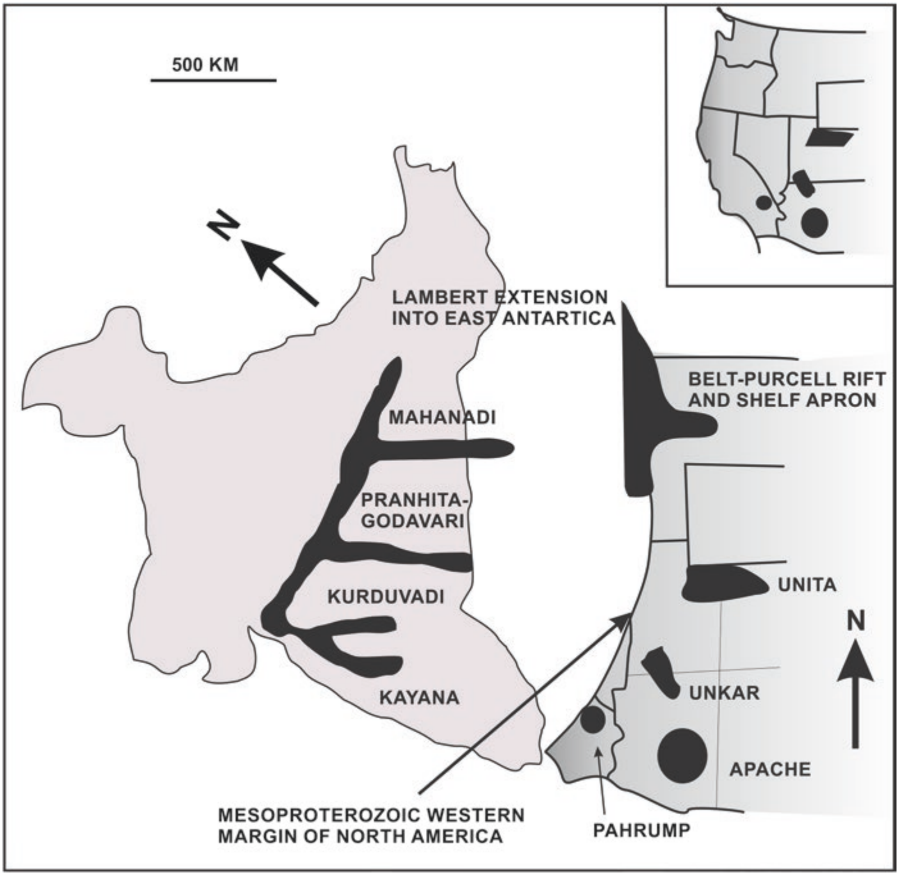

Fig. 3.8 Rifts in eastern India (left) and western North America (right). "N" shows present north of each area. (After Rogers and Santosh 2004)

3.6.1 *Eastern Ghats and Rayner Belt*

The eastern Ghats mobile belt (EGMB), lying in the east coast of India, is a composite terrain with multiple cycles of orogenesis recorded in different domains, which underwent, in general, granulite facies metamorphism during the Proterozoic. The mobile belt extends over 900 km along strike, and the width varies from less than 50 km in the south to 300 km in the north, bordering the Dharwar, Bastar, and Singhbhum cratons with a ductile shear zone in between (Chetty and Murthy 1993).

Three distinct orogenic events clustered into three domains within the EGMB are the 1.7–1.54 Ga orogenesis of the Ongole Domain (Henderson et al. 2014; Dasgupta et al. 2013; Sarkar and Schenk 2014; Sarkar et al. 2014, 2015); the most prevalent 1.07–0.90 Ga Grenvillian orogenesis, recorded from the eastern Ghats province, north of the Godavari rift (Dasgupta et al. 2013; Korhonen et al. 2013); and the 0.55–0.50 Ga record of the Pan African orogenesis preserved in the northern part of the eastern Ghats province and adjacent Rengali province (Chattopadhyay et al. 2015a, b; Bose et al. 2016b). New data emerging from the EGMB opens better resolution of transcontinental correlation, either supporting or rejecting the old datasets (Saha et al. 2016a).

Here we focus on the eastern Ghats province with records of the Grenvillian Orogeny and Rodinia connection. In the reconstruction models, the EGMB is often shown to have links with East Antarctica (Bose et al. 2011; Yoshida et al. 2003; Rogers and Santosh 2004; Dasgupta and Sengupta 2003) based on the matching of ~0.95–0.90 Ga granulite facies metamorphic events of the eastern Ghats province with that in the Rayner province (Saha et al. 2016a). After docking of the Rayner province with the eastern Ghats, these two belts evolved simultaneously as a part of the amalgamated continent (Dasgupta et al. 2013). The ultra-high-temperature (UHT) metamorphism experienced by these rocks is the extreme manifestation of high crustal geothermal gradients that affected this region, whereas it was being deformed over a billion years ago which holds key to the Proterozoic tectonic development of the Indian shield. Controversies exist, and debate remains regarding the stages of evolution of the eastern Ghats granulites. Korhonen et al. (2013) suggested single, long-lived orogenic pulse between ~1.07 and ~0.90 Ga, against the existing two-stage evolution of the granulites. Back arc model for the generation of UHT metamorphism in the eastern Ghats is being proposed by Dasgupta et al. (2013). The cratonization age of the EGMB is considered as ~0.90 Ga, though minor activities were still going on around 0.85 Ga, when India and South China were located at the North Pole (Tucker et al. 2001; Santosh et al. 2016). Afterward, the united mass moved south toward Gondwana. Yangtze and northwestern India were fully assembled by this time, and a hiatus between 0.85 and 0.80 Ga in subduction is inferred when magmatism along the southern margin of India (Tucker et al. 2001), in the Seychelles and on the (present-day) northern margin of the Yangtze Craton (Yan et al. 2004; Zhou et al. 2002), started again. This collision orogeny of Grenvillian age welded proto-India against eastern Antarctica, and resultant eastern Ghats belt-Rayner complex terrane, which was not separated during the breakup of Rodinia, remained an entity until the fragmentation of Gondwana (Fitzsimons 2003). Recent work emphasizes that eastern Ghats belt (EGB) played important role in India-East Antarctica connection (Dasgupta et al. 2017).

3.6.2 Central Indian Tectonic Zone (CITZ): Its Continuation in the South Purulia Shear Zone (SPSZ) and Singhbhum Shear Zone (SBSZ)

The CITZ, the main tectonic feature of central India, extends over 1200 km in an E-W to ENE-WSW trend from the west coast to the Bay of Bengal to the east. Its southern contact merges with Bilaspur-Raigarh belt, situated north of Chhattisgarh basin, and is often covered by younger sequences at many places (Chetty 2017). The CITZ, also known as the Central Indian Shear/Suture Zone, is bounded by the Son-Narmada North Fault (SNNF) to the North and the Central Indian Shear (CIS), the most significant ductile shear zone to the south (Yedekar et al. 1990). With the width of the zone varying between a few tens of meters to a few kilometers, the CITZ stitches the North and South Indian Cratonic Blocks (NIB and SIB, respectively) and is characterized by intense mylonitization of granite gneisses and other supracrustal rocks of Precambrian age. The rock successions record >800 million years of protracted Proterozoic tectonothermal and tectonomagmatic history from the Paleoproterozoic to the early Neoproterozoic. The tectonic evolution of the CITZ overlaps with two supercontinent assembly events, namely, Columbia (between 2.1 and 1.8 Ga) described above and Rodinia (between 1.2 and 0.9 Ga) described above.

Debate persists about the eastern continuation of the CITZ, where the northern branch is termed as South Purulia Shear Zone (SPSZ) and the southern branch coincides with Singhbhum Shear Zone (SSZ) via Jharsuguda-Rourkela-Jamshedpur. However, some works consider that the SPSZ is the southern boundary of the CITZ (Ramakrishna and Vaidyanadhan 2008). Bhoumik et al. (2010) proposed that final amalgamation of the northern and southern block of India took place during 1.0 Ga continent-continent collisional orogeny. Regional gravity anomaly map of central India shows a broad region of ENE-WSW trending “gravity high,” indicating thick pile of high-density mafic-ultramafic suits (Qureshy and Hinze 1989; Kaila et al. 1979). The CITZ along the northern border of the Bastar craton has been shown to contain possible sites of Proterozoic ocean closure (e.g., Roy et al. 2002). More recently, CITZ is considered as a possible link in alternative models of end-Proterozoic supercontinent reconstruction involving India and Australia (e.g., Bhowmik et al. 2012; Naganjaneyulu and Santosh 2010).

3.6.3 Proterozoic Cratonic Basins

Peninsular India contains several cratonic basins that include sedimentary rocks deposited at approximately the same time as the high heat-producing (now metamorphosed) sedimentary rocks in the surrounding orogens. The intracratonic Proterozoic sedimentary basins of India, namely, Chhattisgarh and its satellite basins of the Bastar craton, Cuddapah basin of eastern Dharwar craton, Bhima

Kaladgi basins of the western Dharwar craton Vindhyan, and Marwar basins of Aravalli craton, preserves thick piles of unconformity bound sequences, which may be looked upon as successive sedimentation cycles, with prominent breaks in deposition (Saha et al. 2016b). The depositional milieu of each of the cycles is manifested in the facies association, which represents the record of fluctuations in the sea level and deposition of siliciclastic-carbonate cycles. The coarse siliciclastic deposit represents early rifting stage, followed by extensive shallow-marine carbonate sedimentation where storm and tide played important role in sculpturing the sediments. Occasional presence of pelagic carbonates and deep-water shales in some of the basins further point to deposition in a wide range of environments, starting from shallow shelf to deep basin (Saha et al. 2016b; Chaudhuri et al. 2012). The cessation of deposition, initiation of erosion, and reestablishment of depositional regimes are responsible for regional and interregional unconformities. Thus, two key factors (1) epeirogenic movements of continental interiors and (2) changes in sea level, or the combination of these two, are responsible for the development of these unconformities. The cyclicity pattern reflecting the global sea-level curve is used for correlation of the succession of the cratonic basins of peninsular India with an attempt to link it with the supercontinent cycle (Saha et al. 2016b). Distinct correlation between acme of passive margin sedimentation and supercontinent breakup has already been established by Bradley (2011). Global sea-level rise is also correlated with the supercontinent breakup, making the sedimentary records even in the so-called cratonic basins more relevant. However, uncertainties remain because of lack of precise geochronologic and paleomagnetic data from many of these sedimentary successions.

3.6.4 Rodinia Breakup and Gondwana Assembly

Rodinia broke up between 800 and 600 Ma, leaving evidences of extension over a broad area by relaxation of stress throughout the supercontinent. In India, major rift valley systems are developed and/or reactivated because of extension, where the post-Rodinia sedimentation continued in rift valleys. The Indian rifts are unique among all the earth's known rift systems because they remained active as basins of subsidence from the Middle Proterozoic to the present (Rogers and Santosh 2004). Eastern Ghats province records evidences of several assembled crustal units with their own complex and often polymetamorphic histories (Dasgupta et al. 2017). Petrological, geochemical, and geochronological investigations of the western boundary of the eastern Ghats record three distinct events. The first one 0.95–0.93 Ga is related with the major granulite metamorphism, followed by decompression at 0.78–0.75 Ga, related to the breakup of the Rodinia. The third event with late thermal overprint at 0.525–0.51 Ga is inferred to coincide with the timing of amalgamation of Gondwana during the final phase, recording its connection with Prydz Bay region in east Antarctica (Chatterjee et al. 2017).

It is now well established that the orogenic events related to the formation of Gondwana supercontinent were described as the “Pan African” episode or event (Clifford 1968). Subsequent studies suggest that the west Gondwana which includes cratons of South America and Africa was amalgamated between 650 and 600 Ma. The east Gondwana was assembled in the last two stages, between 750 and 620 Ma, which is called East African Orogen (EAO) and 570–500 Ma (Kunga Orogen) (Meert 2001). The Kunga Orogen was originally defined on the basis of geochronological data and interpreted to be related to the collision between Australia/Antarctica and an already combined India-East Africa.

The southernmost domains of Indian peninsula preserve rock records of major late Neoproterozoic–Cambrian (Pan-African) events (Santosh et al. 2009) correlated to subduction and accretion events prior to the final assembly of Gondwana. These include multiple arc magmatic events during Neoproterozoic, such as those recorded from the southern part of the Madurai Block (Santosh et al. 2017b), and widespread regional metamorphism reaching up to ultra-high temperatures during the terminal stages of Gondwana assembly (Santosh et al. 2009). Post-collisional mafic magmatism during extensional collapse of the Gondwana orogen in Cambrian has also been recorded in recent studies (Yang et al. 2017).

3.7 Synthesis of Current Understanding and Outlook

Mantle dynamic processes exert fundamental controls over the accretion and movement of continents. It has been noticed that the formation and breakup of supercontinents follow a natural rule of repetitive pattern. Granites and detrital zircons having notably similar and episodic appearances in the rock record led Hawkesworth et al. (2010) to constrain the Precambrian supercontinent cycles with the peak of zircon appearance. Subduction zone proxies in the rock record provide good evidence for the existence of continent-margin and intra-oceanic subduction zones through time. Volcanic arc protoliths accreted in continent-continent or continent-arc collisions, or as the detritus of these volcanic arcs preserved in successor basins, give us clues to reconstruct the old supercontinents.

The characteristics and similarities among the orogenic belts of India suggest that the crustal architecture of India is developed during the Proterozoic period possibly through stitching of several microcontinents, though uncertainties remain due to an inadequate paleomagnetic data base (summarized in Li et al. 2008).

Better understanding of the Precambrian geodynamics as applied to the Archean cratons and Proterozoic mobile belts in India lies in integrated geochronologic and isotopic studies combined with classical geology. While some of the areas like the EGMB and SGB are well studied and significant data and newer interpretations are coming up in recent years, some areas like the Chotanagpur granite gneiss complex, Satpura mobile belt, and even parts of Aravalli-Delhi mobile belt are yet to be investigated in a comprehensive manner to yield pertinent data. While some suggestions relating to the place of India in reconstructions of Gondwana and Rodinia are getting validated by the recently emerging geochronologic, paleomagnetic, and geologic datasets, paucity of data impedes the understanding of India's position in global models of older supercontinents.

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References

Acharyya SK (2005) Geology and tectonics of NE India. J Geophys 26:35–49

Acharyya SK, Roy A (2000) Tectonothermal history of the Central Indian Tectonic Zones and Reactivation of Major faults/shear Zones. J Geol Soc India 55:239–256

Anderson JL, Cullers RL (1999) Paleo- and Mesoproterozoic granite plutonism of Colorado and Wyoming. Rock Mount Geol 34:149–164

Anderson JL, Morrison J (1992) The role of anorogenic granites in the Proterozoic crustal development of North America. In: Condie KC (ed) Proterozoic crustal evolution. Elsevier, New York, NY, pp 263–299

Andrew S. Merdith AS, Williams SE, Müller RD, Collins AS (2017) Kinematic constraints on the Rodinia to Gondwana transition. Precambrian Res 299:132–150

Barley ME (1993) Volcanic, sedimentary and tectonic stratigraphic environments of the approximately 3.46 Ga Warrawoona Megasequesnce; a review. Precambrian Res 60:47–67

Barley ME, Groves DI (1992) Supercontinent cycles and distribution of metal deposits through time. Geology 17:826–829

Bhowmik SK (2006) Ultra-high temperature metamorphism and its significance in the Central Indian tectonic Zone. Lithos 92:485–505

Bhowmik SK, Basu SA, Speiring B, Raith MM (2005) Mesoproterozic reworking of Palaeoproterozoic ultrahigh temperature granulites in the Central Indian Tectonic Zone. J Petrol 46:1085–1119

Bhoumik SK, Bernhardt HJ, Dasgupta S (2010) Grenvillian age high-pressure upper amphibolite-granulite metamorphism in the Aravalli-Delhi Mobile Belt, Northwestern India: New evidence from monazite chemical age and its implication. Precambrian Research 178:168–184

Bhowmik SK, Wilde SA, Bhandari A, Pal T, Pant NC (2012) Growth of the greater Indian landmass and its assembly in Rodinia: geochronological evidence from the Central Indian Tectonic Zone. Gondw Res 22:54–72

Bierlein FP, Groves DI, Cawood PA (2009) Metallogeny of accretionary orogens - the connection between lithospheric processes and metal endowment. Ore Geol Rev 36:282–292

Bleeker W (2003) The late Archean record: a puzzle in ca. 35 pieces. Lithos 71(2):99–134

Bleeker W, Chamberlain KR, Kamo SL, Hamilton M, Kilian TM, Buchan KL (2008) Kaapvaal, Superior and Wyoming: nearest neighbours in superCraton Superia. Paper Number: 5222. American Geosciences Institute, Alexandria, VA

Blewett RS (2002) Archaean tectonic processes: a case for horizontal shortening in the North Pilbara granite-greenstone terrane, Western Australia. Precambrian Res 113:67–120

Bogdanova SV, Bingen B, Gorbatschev R, Kheraskova TN, Kozlov VI, Puchkov VN, Volozh YA (2008) The East European Craton (Baltica) before and during the assembly of Rodinia. Precambrian Res 160:23–45

Boger SD, Miller JML (2004) Terminal suturing of Gondwana and the onset of the Ross-delamarian orogeny: the cause and effect of an early Cambrian reconfiguration of plate motions. Earth Planet Sci Lett 219:35–48

Bond GC, Nickeson PA, Kominz MA (1984) Breakup of a supercontinent between 625 Ma and 555 Ma: new evidence and implications for continental histories. Earth Planet Sci Lett 70:325–345

Bora S, Kumar S (2015) Geochemistry of biotites and host granitoid plutons from the Proterozoic Mahakoshal Belt, Central India tectonic zone: implication for nature and tectonic setting of magmatism. Int Geol Rev 57:1686–1706

Bora S, Kumar S, Yi K, Kim N, Lee TH (2013) Geochemistry and U-Pb SHRIMP zircon chronology of granitoids and microgranular enclaves from Jhirgadandi Pluton of Mahakoshal Belt, Central India Tectonic Zone, India. J Asian Earth Sci 70-71:99–114

Bose S, Dunkley DJ, Dasgupta S, Das K, Arima M (2011) India–Antarctica–Australia–Laurentia connection in the Paleoproterozoic–Mesoproterozoic revisited: evidence from new zircon U–Pb and monazite chemical age data from the Eastern Ghats Belt, India. Bull Geol Soc Am 123:2031–2049

Bose S, Das K, Kimura K, Hidaka H, Dasgupta A, Ghosh G, Mukhopadhyay J (2016a) Neoarchean tectonothermal imprints in the Rengali Province, Eastern India and their implication on the growth of Singhbhum Craton: evidence from zircon U-Pb SHRIMP data. J Metam Geol 34:743–764

Bose S, Das K, Torimoto J, Arima M, Dunkley DJ (2016b) Evolution of the Chilka Lake granulite complex, Northern Eastern Ghats Belt, India: first evidence of ~780 Ma decompression of the deep crust and its implication on the India–Antarctica correlation. Lithos 263:161–189

Bowring SA, Grotzinger JP (1992) Implications of new chronostratigraphy for tectonic evolution of Wopmay orogeny, North West Canadian shield. Am J Sci 292:1–20

Brookfield ME (1993) Neoproterozoic Laurentia-Australia fit. Geology 21:683–686

Bradley DC (2011) Secular trends in the geologic record and the supercontinent cycle. Earth Sci Rev 108:16–33

Brown M (2008) Characteristic thermal regimes of plate tectonics and their metamorphic imprint throughout Earth history: when did earth first adopt a plate tectonics model of behavior? In: Condie KC, Pease V (eds) When did plate tectonics begin on planet earth? GSA special paper, vol 440. Geological Society of America, Boulder, CO, pp 97–128

Buick IS, Allen C, Pandit M, Rubatto D, Hermann J (2006) The Proterozoic magmatic and metamorphic history of the banded gneissic complex, Central Rajasthan, India: La-ICP-MS U/Pb zircon constraints. Precambrian Res 151:119–142

Burke KCA, Dewey JF (1973) Plume-generated triple junctions: key indicators in applying plate tectonics to old rocks. J Geol 86:406–433

Burrett C, Berry R, (2000) Proterozoic Australia-Western United States (AUSWUS) fit between Laurentia and Australia. Geology 28:103–106

Burrett C, Berry R (2002) A statistical approach to defining Proterozoic crustal provinces and testing continental reconstructions of Australia and Laurentia- SWEAT or AUSWUS? Gondw Res 5:109–122

Butterworth N, Steinberg D, Müller RD, Williams S, Merdith AS, Hardy S (2016) Tectonic environments of South American porphyry copper magmatism through time revealed by spatiotemporal data mining. Tectonics 35:2847–2862

Byerly GR, Lowe DR, Wooden JL, Xie X (2002) An Archaean impact layer from the Pilbara and Kaapvaal Cratons. Science 297:1325–1327

Cawood PA, Pisarevsky SA (2006) Was Baltica right-way-up or upside-down in the Neoproterozoic? J Geol Soc 163:753–759

Cawood PA, Kröner A, Pisarevsky SA (2006) Precambrian plate tectonics: Criteria and evidence. GSA Today 16:5–11

Chardon D, Jayananda M, Peucat JJ (2011) Lateral constructional flow of hot orogenic crust: insights from the Neoarchean of South India, geological and geophysical implications for orogenic plateaux. Geochem Geophys Geosyst 12:Q02005. https://doi.org/10.1029/2010GC003398

Chatterjee N, Mazumadar AC, Bhattacharya A, Saikia RR (2007) Mesoproterozoic granulites of the Shillong–Meghalaya plateau: evidence of Westward continuation of the Prydz Bay Pan-African suture into Northeastern India. Precambrian Res 152:1–26

Chatterjee A, Das K, Bose A, Ganguly P, Hidaka H (2017) Zircon U-Pb SHRIMP and monazite EPMA U-Th-total Pb geochronology of granulites of the Western boundary, Eastern Ghats Belt, India: a new possibility for Neoproterozoic exhumation history. In: Pant NC, Dasgupta S (eds) Crustal evolution of India and Antarctica: the supercontinent connection. Geological Society, London, Special Publications, vol 457. Geological Society of London, London, pp 105–140

Chattopadhyay N, Mukhopadhyay D, Sengupta P (2012) Reactivation of basement: example from Anasagar Granite Gneiss Complex, Rajasthan, Western India. In: Mazumder R, Saha D (eds) Palaeoproterozoic of India. Geological Society, London, Special Publications, vol 365. Geological Society of London, London, pp 217–242

Chattopadhyay A, Das K, Hayasaka Y, Sarkar A (2015a) Syn and post-tectonic granite plutonism in the Sausar Fold Belt, Central India: age constraints and tectonic implications. J Asian Earth Sci 107:110–121

Chattopadhyay S, Upadhyay D, Nanda JK, Mezger K, Pruseth KL, Berndt J (2015b) Proto-India was a part of Rodinia: evidence from Grenville-age suturing of the Eastern Ghats Province with the Paleoarchean Singhbhum Craton. Precambrian Res 266:506–529

Chaudhuri AK, Deb GK, Patranabis-Deb S, Sarkar S (2012) Paleogeographic and tectonic evolution of the Pranhita-Godavari Valley, Central India: a Stratigraphic perspective. American Journal of Science 312:766–815

Cheney ES (1996) Sequence stratigraphy and plate tectonic significance of the Transvaal succession of Southern Africa and its equivalent in Western Australia. Precambrian Res 79:3–24

Chetty TRK (2017) Proterozoic orogens of India. A critical window to Gondwana. Elsevier, Amsterdam, p 426

Chetty TRK, Murthy DSN (1993) Landsat Thematic Mapper data applied to structural studies of the Eastern Ghats Granulite Terrane in part of Andhra Pradesh. J Geol Soc India 42:37–391

Choudhary AK, Gopalan K, Sastry CA (1984) Present status of the geochronology of the Precambrian rocks of Rajasthan. Tectonophysics 105:131–140

Clifford TN (1968) Radiometric dating and the pre-Silurian geology of Africa. In: Hamilton EI, Farquhar RM (eds) Radiometric dating for geologist. Interscience, London, pp 299–416

Cocks LRM, Torsvik TH (2002) Earth geography from 500 to 400 million years ago: a faunal and palaeomagnetic review. J Geol Soc Lond 159:631–644

Collins AS, Pisarevsky A (2005) Amalgamating Eastern Gondwana: the evolution of the Circum-Indian Orogens. Earth Sci Rev 71(3):229–270

Collins AS, Santosh M, Braun I, Clark C (2007) Age and sedimentary provenance of the Southern Granulites, South India: U–Th–Pb SHRIMP secondary ion mass spectrometry. Precambrian Res 155:125–138

Condie KC (2002) Breakup of Palaeoproterozoic supercontinent. Gondw Res 5:41–43

Condie KC (2005) TTG and adakites: are they both slab melts? Lithos 80:33–44

Condie KC, Rosen OM (1994) Laurentia-Siberia connection revisited. Geology 22:168–170

Condie KC, Bickford ME, Aster RC, Belousova E, Scholl DW (2011) Episodic zircon age, Hf isotopic composition, and the preservation rate of the continental crust. Geol Soc Am Bull 123:951–957

Dalziel IWD (1991) Pacific margins of Laurentia and East Antarctica–Australia as a conjugate rift pair: evidence and implications for an Eocambrian supercontinent. Geology 19:598–601

Das K, Yokoyama K, Chakraborty PP, Sarkar A (2009) Basal tuffs and contemporaneity of the Chhattisgarh and Khariar basins based on new dates and geochemistry. J Geol 117:88–102

Dasgupta S, Sengupta P (2003) Indo-Antarctic correlation: a perspective from the Eastern Ghats Granulite Belt, India. In: Yoshida M, Windley BF, Dasgupta S (eds) Proterozoic East Gondwana:

supercontinent assembly and breakup. Geological Society, London, Special Publications, vol 206. Geological Society of London, London, pp 131–143

Dasgupta S, Bose S, Das K (2013) Tectonic evolution of the Eastern Ghats Belt. Precambrian Res 227:247–258

Dasgupta S, Bose S, Bhoumik SK, Sengupta P (2017) The Eastern Ghats Belt, India, in the context of supercontinent assembly. In: Pant NC, Dasgupta S (eds) Crustal evolution of India and Antarctica: the supercontinent connection. Geological Society, London, Special Publications. Geological Society of London, London, p 457

Davies GF (1992) On the emergence of plate tectonics. Geology 20:963–966

Davies GF (1999) Dynamic Earth plates, plumes and mantle convection. Cambridge University press, Cambridge. 458 p

Deb M, Thorpe R, Kristc D (2001) Hindoli Group of rocks in the Eastern fringe of the Aravalli-Delhi orogenic belt – Archean secondary greenstone belt or Proterozoic supracrustals. Gondw Res 5:879–883

Deshmukh T, Prabhakar N, Bhattacharya A, Madhavan K (2017) Late Paleoproterozoic clockwise *P–T* history in the Mahakoshal Belt, Central Indian Tectonic Zone: implications for Columbia supercontinent assembly. Precambrian Res 298:56–78

Dewey JF (1969) Structure and sequence in the paratectonic Caledonides. In: Kay M (ed) North Atlantic geology and continental drift. American Association of Petroleum Geologists, Memoir, vol 12. American Association of Petroleum Geologists, Tulsa, OK, pp 309–335

Dewey JF (2007) Origin and evolution of plate tectonics and the continental crust: a tectonic perspective. Geol Soc Am Spec Paper 142:10–17

Dilek Y, Polat A (2008) Suprasubduction zone ophiolites and Archean tectonics. Geology 36:431–432

Dobmeier CJ, Raith MM (2003) Crustal architecture and evolution of the Eastern Ghats Belt and adjacent regions of India. Geol Soc Lond Spec Publ 206(1):145–168

Eriksson PG, Catuneanu O, Nelson DR, Mueller WU, Altermann W (2004) Towards a synthesis. In: Eriksson PG, Altermann W, Nelson DR, Mueller WU, Catuneanu O (eds) The Precambrian Earth: tempos and events. Elsevier, Amsterdam, pp 739–769

Ernst WG (1983) Mineral parageneses in metamorphic rocks exposed along Tailuko Gorge, Central Mountain Range, Taiwan. J Metam Geol 1:305–329

Evans DAD, Mitchell RN (2011) Assembly and breakup of the core of Paleoproterozoic–Mesoproterozoic supercontinent Nuna. Geology 39:443–446

Fitzsimons ICW (2003) Proterozoic basement provinces of Southern and Southwestern Australia, and their correlation with Antarctica. In: Proterozoic East Gondwana supercontinent assembly and breakup, vol 206. Geological Society of London, London, pp 93–130

French JE, Heaman LM, Chacko T, Rivard B (2008) 1891–1883 Ma Southern Bastar Craton-Cuddapah mafic igneous events, India: a newly recognized large igneous province. Precambrian Res 160:308–322

Ghosh SK, Chakravorty S, Bhalla JK, Paul DK, Sarkar A, Bishui PK, Gupta SN (1994) New Rb – Sr isotopic ages and geochemistry of granitoids from Meghalaya and their significance in Middle to late Proterozoic crustal evolution. Indian Miner 48:33–44

Ghosh G, Bose S, Das K, Dasgupta A, Yamamoto T, Hayasaka Y, Chakrabarti K, Mukhopadhyay J (2016) Transpression and juxtaposition of middle crust over upper crust forming a crustal scale flower structure: insight from structural, fabric, and kinematic studies from the Rengali Province, Eastern India. J Struct Geol 83:156–179

Goswami JN, Mishra S, Wiedenbeck M, Ray SL, Saha AK (1995) 207Pb/206Pb ages from the OMG, the oldest recognized rock unit from Singhbhum–Orissa Iron Ore Craton, E. India. Curr Sci 69:1008–1012

Gower CF, Ryan AB, Rivers T (1990) Mid-Proterozoic Laurentia-Baltica; an overview of its geological evolution and a summary of the contributions made by this volume. In: Gower CF, Ryan AB, Rivers T (eds) Mid-proterozoic Laurentia-Baltica. Geological Association of Canada Paper, vol 38. Geological Association of Canada, St. John's, NL, pp 1–20

Guitreau M, Mukusa SB, Loudin L, Krishnan S (2017) New constraints on early formation of Western Dharwar Craton (India) from igneous zircon U-Pb and Lu-Hf isotopes. Precambrian Res 302:33–49

Gupta BC (1934) The Geology of Central Mewar. Geol SurvIndia Mem 65:107–168

Gupta A (2004) A manual of the geology of India, Vol. I: Precambrian, Part IV: Northern and northwestern part of the Peninsula. Geological Survey of India Special Publication. Geological Survey of India, Kolkata, p 77

Halverson GP, Dudás FÖ, Maloof AC, Bowring SA (2007) Evolution of the 87Sr/86Sr composition of Neoproterozoic seawater. Palaeogeogra Palaeoclimatol Palaeoecol 256(3):103–129

Halverson GP, Hurtgen MT, Porter SM, Collins AS (2009) Neoproterozoic-Cambrian biogeochemical evolution. In: Gaucher C, Sial AN, Halverson GP, Frimmel HE (eds) Neoproterozoic-Cambrian tectonics, global change and evolution: a focus on Southwestern Gondwana. Developments in Precambrian geology, vol 16. Elsevier, Amsterdam, pp 351–365

Hamilton WB (2007) Driving mechanism and 3-D circulation of plate tectonics. Geol Soc Am Spec Paper 433:1–25

Hamilton WB (2011) Plate tectonics began in Neoproterozoic time, and plumes from deep mantle have never operated. Lithos 123:1–20

Hardie LA (1996) Secular variation in seawater chemistry: an explanation for the coupled secular variation in the mineralogies of marine limestones and potash evaporites over the past 600 my. Geology 24(3):279–283

Harris LB (1993) Correlations of tectonothermal events between Central Indian Tectonic Zone and the Albany Mobile Belt of Western Australia. In: Findlay RH, Unrug R, Banks MR, Veveers JJ (eds) Gondwana Eight: assembly, evolution and dispersal. A.A. Balkema, Rotterdam, pp 165–180

Hashizume K, Pinti DL, Orberger B, Cloquet C, Jayananda M (2016) A biological switch at the ocean surface as a cause of laminations in a Precambrian Iron Formation. Earth Planet Sci Lett 446:27–36

Hawkesworth CJ, Dhuime B, Pietranik AB, Cawood PA, Kemp AIS, Storey CD (2010) The generation and evolution of the continental crust. J Geol Soc London 167:229–248

Henderson B, Collins AS, Payne J, Forbes C, Saha D (2014) Geologically constraining India in Columbia: the age, isotopic provenance and geochemistry of the protoliths of the Ongole Domain, Southern Eastern Ghats, India. Gondw Res 26(3):888–906

Heron AM (1953) Geology of Central Rajasthan, Memoir, vol 79. Geological Survey of India, Kolkata. 339 p

Hess HH (1962) History of ocean basins. In: Engel AEJ, James HL, Leonard BF (eds) Petrologic studies-a volume in honor of AF Buddington. Geological Society of America, New York, NY, pp 599–620

Hoffman PF (1991) Did the breakout of Laurentia turn Gondwanaland inside out? Science 252:1409–1412

Hoffman PF (1997) Tectonic genealogy of North America. In: van der Pluijm BA, Marshak S (eds) Earth structure: an introduction to structural geology and tectonics. McGraw-Hill, New York, NY, pp 459–464

Hoffman PF, Kaufman AJ, Halverson GP, Schrag DP (1998) The Neoproterozoic snowball earth. Science 281:1342–1346

Holland TH (1909) The Imperial Gazetteer of India: the Indian Empire Volume 1 (Descriptive). Clarendon Press, Oxford, pp 50–103

Hou GT, Santosh M, Qian XL, Lister S, Li JH (2008) Configuration of the Late Paleoproterozoic supercontinent Columbia: insights from radiating mafic dyke swarms. Gondw Res 14:395–409

Ishwar-Kumar C, Windley BF, Horie K, Kato T, Hokada T, Itaya T, Yagi K (2013) A Rodinian suture in Western India: new insights on India-Madagascar correlations. Precambrian Res 236:227–251

James V. Jones JV, Daniel CG, Doe MF (2015) Tectonic and sedimentary linkages between the Belt-Purcell basin and southwestern Laurentia during the Mesoproterozoic, ca. 1.60–1.40 Ga. Lithosphere 7:465–472

Jayananda M, Moyen JF, Martin H, Peucat JJ, Auvray B, Mahabaleswar B (2000) Late Archaean (2550-2520 Ma) juvenile magmatism in the Eastern Dharwar Craton, Southern India: constraints from geochronology, Nd–Sr isotopes and whole rock geochemistry. Precambrian Res 99:225–254

Jayananda M, Kano T, Peucat JJ, Channabasappa S (2008) 3.35 Ga komatiite volcanism in the Western Dharwar Craton, Southern India: constraints from Nd isotopes and whole rock geochemistry. Precambrian Res 162:160–179

Jayananda M, Peucat J-J, Chardon D, Krishna Rao B, Corfu F (2013) Neoarchean greenstone volcanism, Dharwar Craton, Southern India: constraints from SIMS zircon geochronology and Nd isotopes. Precambrian Res 227:55–76

Jayananda M, Chardon D, Peucat J-J, Fanning CM (2015) Paleo- to Mesoarchean TTG accretion and continental growth, Western Dharwar Craton, Southern India: SHRIMP U-Pb zircon geochronology, whole-rock geochemistry and Nd-Sr isotopes. Precambrian Res 268:295–322

Jayananda M, Duraiswami RA, Aadhiseshan KR, Gireesh RV, Prabhakar BC, Kafo K-u, Tushipokla, Namratha R (2016) Physical volcanology and geochemistry of Palaeoarchaean komatiite lava flows from the Western Dharwar Craton, Southern India: implications for Archaean mantle evolution and crustal growth. Int Geol Rev 58:1569–1595

Jayananda M, Santosh M, Aadhiseshan KR (2018) Formation of Archean (3600–2500 Ma) continental crust in the Dharwar Craton, Southern India. Earth Sci Rev 181:12–42

Kaila KL, Roy Chowdhury K, Reddy PR, Krishna VG, Narain H, Subboti SI, Sollogub VB, Chekunov AV, Kharetcko GE, Lazarenko MA, Ilchenko TV (1979) Crustal structure along Kavali-Udipi profile in the Indian Peninsular shield from Deep Seismic Soundings. J Geol Soc India 20:307–333

Kailasam LN (1976) Geophysical studies of the major sedimentary basins of the Indian Craton, their deep structural features and evolution. In: Bott MHP (ed) Sedimentary basins of continental margins and cratons. Tectonophysics, vol 36. Elsevier, Amsterdam, pp 225–245

Karlstrom KE, Harlan SS, Williams ML, McLelland J, Geissman JW (1999) Refining Rodinia: geologic evidence for the Australia–Western U.S. connection in the Proterozoic. GSA Today 9:1–7

Kirschvink JL (1992) Late Proterozoic low-latitude global glaciation: the snowball Earth. In: Schopf JW, Klein C (eds) The proterozoic biosphere. Cambridge University Press, Cambridge, pp 51–52

Kinematic constraints on the Rodinia to Gondwana transition Andrew S. Merdith AS, Williams SE, Müller RD, Collins AS (2017) Precambrian Res 299:132–150

de Kock MO, Evans DAD, Beukes NJ (2009) Validating the existence of Vaalbara in the Neoarchean. Precambrian Res 174(1):145–154

Korhonen FJ, Clarke C, Brown M, Bhattacharya S, Taylor R (2013) How long-lived is ultrahigh temperature (UHT) metamorphism? Constraints from zircon and monazite geochronology in the Eastern Ghats orogenic belt, India. Precambrian Res 234:322–350

Kumar A, Bhaskar Rao YJ, Sivaraman TV, Gopalan K (1996) Sm-Nd ages of Archaean metavolcanic of the Dharwar craton, South India. Precambrian Res 80:206–215

Kröner A (1981) Precambrian plate tectonics. In: Kröner A (ed) Precambrian plate tectonics. Elsevier, Amsterdam

Kroner A, Santosh M, Hegner E, Shaji E, Geng H, Xie J, Wong H, Wang Y, Shan DK, Liu D, Sun M, Nanda-Kumar V (2015) Palaeoproterozoic ancestry of Pan-African high-grade granitoids in Southernmost India: implications for Gondwana reconstructions. Gondw Res 27:1–37

Lancaster PJ, Dey S, Storey CD, Mitra AM, Bhunia RK (2015) Contrasting crustal evolution processes in the Dharwar craton: Insights from detrital zircon U–Pb and Hf isotopes. Gondw Res 28:1361–1372

Li ZX, Bogdanova SV, Collins AS, Davidson A, De Waele B, Ernst RE, Fitzsimons ICW, Fuck RA, Gladkochub DP, Jacobs J, Karlstrom KE, Lu S, Natapov LM, Pease V, Pisarevsky SA, Thrane K, Vernikovsky V (2008) Assembly, configuration, and break-up history of Rodinia: a synthesis. Precambrian Res 160(1):179–210

Mahapatro SN, Pant NC, Bhowmik SK, Tripathy AK, Nanda JK (2012) Archaean granulite facies metamorphism at the Singhbhum Craton-Eastern Ghats Mobile Belt interface: implication for the Ur supercontinent assembly. Geol J 47:312–333

Malone SJ, Meert JG, Banerjee DM, Pandit MK, E. Tamrat E, Kamenov GD, Pradhan VR, Sohl LE (2008) Paleomagnetism and detrital zircon geochronology of the upper Vindhyan sequence of Son Valley, Rajasathan, India: a c. 1000 Ma closure age for the Purana basins. Precambrian Res 164:137–159

Maibam B, Gerdes A, Goswami JN (2016) U-Pb and Hf isotope records in detrital and magmatic zircon from Eastern and Western Dharwar Craton, Southern India: evidence for coeval Archaean crustal evolution. Precambrian Res 275:496–512

Manikyamba C, Ganguly S, Santosh M, Subramanyam KSV (2017) Volcano-sedimentary and metallogenic records of the Dharwar greenstone terranes, India: Window to Archean plate tectonics, continent growth, and mineral endowment. Gondw Res 50:38–66

Mazumder R, Bose PK, Sarkar S (2000) A commentary on the tectono-sedimentary record of the pre-2.0 Ga continental growth of India vis-a-vis a possible pre-Gondwana Afro-Indian supercontinent. J Afr Earth Sc 30:201–217

Mazumder R, Eriksson PG, De S, Bumby AJ, Lenhardt N (2012) Palaeoproterozoic sedimentation on the Singhbhum Craton: global context and comparison with Kaapvaal. In: Mazumder R, Saha D (eds) Paleoproterozoic of India. Geological Society, London, Special Publications, vol 365. Geological Society of London, London, pp 49–74

McMenamin MAS, McMenamin DLS (1990) The emergence of animals: the Cambrian breakthrough. Columbia University Press, New York, NY, p 217

Meert JG (2001) Gondwana and refining Rodinia: a paleomagnetic perspective. Gondw Res 4:279–288

Meert JG (2002) Paleomagnetic evidence for a Paleo-Mesoproterozoic supercontinent, Columbia. Gondw Res 5:207–215

Meert JG (2003) A synopsis of events related to the assembly of Eastern Gondwana. Tectonophysics 362:1–40

Meert JG (2012) What's in a name? The Columbia (Paleopangaea/Nuna) supercontinent. Gondw Res 21:987–993

Meert JG, Stuckey W (2002) Revisiting the paleomagnetism of the 1.476 Ga St. Francois Mountains igneous province, Missouri. Tectonics 21:1007

Meert JG, Lieberman BS (2004) A palaeomagnetic and palaeobiogeographical perspective on latest Neoproterozoic and early Cambrian tectonic events. J Geol Soc London 161(3):477–487

Meert JG, Santosh M (2017) The Columbia supercontinent revisited. Gondw Res 50:67–83

Meert JG, Torsvik T (2003) The making and unmaking of a supercontinent: Rodinia revisited. Tectonophysics 375(1):261–288

Merdith AS, Collins, A.S., Williams, S.E., Pisarevsky, S., Foden, J.F., Archibald, D.A., Blades, M.L., Alessio BL, Armistead S, Plavsa D, Clark C, Müller RD (2017) A full-plate global reconstruction of the Neoproterozoic. Gondw Res 50

Meert JG, Pandit MK, Pradhan VR, Banks J, Stroud M, Newstead B, Gifford J (2010) Precambrian crustal evolution of Peninsular India: a 3.0 billion year odyssey. J Asian Earth Sci 39:483–515

Meyer C (1988) Ore deposits as guides to geologic history of the Earth. Annu Rev Earth Planet Sci 16:147

Mitra SK, Mitra SC (2001) Tectonic setting of the Precambrian of Northeast India (Meghalaya plateau) and age of the Shillong Group of rocks. In: Saxena, M. B. L. (ed.) Recent Advances in the Field of Earth Sciences and Their Implications in National Development. Geological Survey of India, Special Publications 64:653–658

Misra S, Gupta S (2014) Superposed deformation and inherited structures in an ancient dilational step-over zone: post-mortem of the Rengali Province, India. J Struct Geol 59:1–17

Moorbath S, Taylor PN (1988) Early Precambrian crustal evolution in Eastern India: ages of the Singhbhum Granite and included remnants of older gneiss. J Geol Soc India 31:82–84

Moores EM (1991) Southwest US–East Antarctica (SWEAT) connection: a hypothesis. Geology 19:425–428

Mukhopadhyay D, Bhattacharyya T, Chattopadhyay N, Lopez R, Tobisch OT (2000) Anasagar gneiss: a folded granitoid in the Proterozoic South Delhi fold belt, Central Rajasthan. Proc Indian Acad Sci (Earth Planet Sci) 109:21–37

Mukhopadhyay J, Beukes NJ, Armstrong RA, Zimmermann U, Ghosh G, Medda RA (2008) Dating the oldest Greenstone in India: a 3.51 Ga precise U–Pb SHRIMP Zircon Age for Dacitic Lava of the Southern Iron Ore Group, Singhbhum Craton. J Geol 116:449–461

Naganjaneyulu K, Santosh M (2010) The Central India Tectonic Zone: a geophysical perspective on continental amalgamation along a Mesoproterozoic suture. Gondw Res:547–564

Naha K, Srinivasan R, Jayaram S (1991) Sedimentational, structural and migmatitic history of the Archaean Dharwar tectonic province, Southern India. Proc Indian Acad Sci (Earth Planet Sci) 100:413

Nance RD, Murphy JB (2013) Origins of the supercontinent cycle. Geosci Front 4(4):439–448

Nance R, Murphy J, Santosh M (2014) The supercontinent cycle: a retrospective essay. Gondw Res 25:4–29

Nutman AP, Chadwick B, Ramakrishnan M, Viswanatha MN (1992) SHRIMP U–Pb ages of detrital zircon in Sargur supracrustal rocks in Western Karnataka. South India J Geol Soc India 39:367–374

Nutman AP, Chadwick B, Krishna Rao B, Vasudev VN (1996) SHRIMP U–Pb zircon ages of acid volcanic rocks in the Chitradurga and Sandur Groups and granites adjacent to Sandur schist belt. J Geol Soc India 47:153–161

Osborne I, Sherlock S, Anand M, Argles T (2011) New Ar-Ar ages of southern Indian kimberlites and a lamproite and their geochemical evolution. Precambrian Res 189:91–103

Patranabis-Deb S, Majumder T, Khan S (2018) Lifestyles of the Palaeoproterozoic stromatolite builders in the Vempalle Sea, Cuddapah Basin, India. J Asian Earth Sci 157:360–370

Pehrsson SJ, Eglington BM, Evans DAD, Huston D, Reddy SM (2016) Metallogeny and its link to orogenic style during the Nuna supercontinent cycle. In: Li ZX, Evans DAD, Murphy JB (eds) Supercontinent cycles through earth history. Geological Society, London, Special Publications, vol 424. Geological Society of London, London, pp 83–94

Peucat JJ, Bouhallier H, Fanning CM, Jayananda M (1995) Age of Holenarsipur schist belt, relationships with the surrounding gneisses (Karnataka, south India). J Geol 103:701–710

Peucat JJ, Jayananda M, Chardon D, Capdevila R, Fanning Marc C, Paquette JL (2013) The lower crust of Dharwar craton, south India: patchwork of Archean granulitic domains. Precambrian Res 227:4–29

Pisarevsky SA, Gladkochub DP, Konstantinov KM, Mazukabzov AM, Stanevich AM, Murphy JB, Tait JA, Donskaya TV, Konstantinov IK (2013) Paleomagnetism of Cryogenian Kitoi mafic dykes in South Siberia: implications for Neoproterozoic paleogeography. Precambrian Res 231:372–382

Powell CM, Li ZX, McElhinny MW, Meert JG, Park JK (1993) Paleomagnetic constraints on timing of the Neoproterozoic breakup of Rodinia and the Cambrian formation of Gondwana. Geology 21(10):889–892

Powell CM, Dalziel IWD, Li ZX, McElhinny MW (1995) Did Pannotia, the latest Neoproterozoic Southern supercontinent, really exist? Eos (Transactions, American Geophysical Union). Fall Meet 76:172

Qureshy MN, Hinze WJ (1989) Regional geophysical lineaments: their tectonic and economic significance. J Geol Soc India 34:124

Radhakrishna BP, Naqvi SM (1986) Precambrian continental crust of India and its evolution. J Geol 94:145–166

Radhakrishna BP, Vaidyanadhan R (1997) Geology of Karnataka, 2nd edn. Geological Society of India, Bangalore. 553 p

Ramakrishna M, Vaidyanadhan R (2008) Geology of India, vol I. Geological Society of India, Bangalore, p 556

Ray JS (2006) Age of the Vindhyan Supergroup: a review of recent findings. J Earth Syst Sci 115:149–160

Ray JS, Martin MW, Veizer J, Bowring SA (2002) U-Pb zircon dating and Sr isotope systematic of the Vindhyan Supergroup, India. Geology 30:131–134

Reddy S, Clarke C, Mazumder R (2009) Temporal constraints on the evolution of the Singbhum Crustal Province from U–Pb SHRIMP data. In: Saha D, Mazumder R (eds) Abstract volume. International Conference on Paleoproterozoic Supercontinents and Global Evolution. IAGR Confernce Series, vol 9. IAGR, Beijing, pp 17–18

Rogers JJW (1993) India and Ur. J Geol Soc India 42:217–222

Rogers JJW (1996) A history of continents in the past three billion years. J Geol 104:91–107

Rogers JJW, Santosh M (2002) Configuration of Columbia, a Mesoproterozoic supercontinent. Gondw Res 5:5–22

Rogers JJW, Santosh M (2004) Continents and supercontinents. Oxford University Press, Oxford. 289 p

Roy AB, Jakhar SR (2002) Geology of Rajasthan (Northwestern India), Precambrian to recent. Scientific Publisher, Jodhpur, p 421

Roy A, Ramachandra HM, Bandopadhyay BK (2000) Supracrustal belts and their significance in the crustal evolution of Central India. Geol Surv India Spec Publ 55:361–380

Roy A, Devaranjan MK, Hanuma Prasad M (2002) Ductile shearing and syntectonic granite emplacement along the Southern margin of the Palaeoproterozoic Mahakoshal supracrustal belt of Central India. Gondw Res 5:489–500

Runcorn SK (1962) Convection currents in the Earth's mantle. Nature 195:1248–1249

Saha AK (1994) Crustal Evolution of Singhbhum–North Orissa, Eastern India. Geological Society of India, Memoir, vol 27. Geological Society of India, Bangalore

Saha D (2002) Multi-stage deformation in the Nallamalai fold belt, Cuddapah basin, South India – implications for Mesoproterozoic tectonism along Southeastern margin of India. Gondw Res 5:701–719

Saha D (2011) Dismembered ophiolites in Paleoproterozoic nappe complexes of Kandra and Gurramkonda, South India. J Asian Earth Sci 42:158–175

Saha D, Chakraborty S (2003) Deformation pattern in the Kurnool and Nallamalai groups in the Northeastern part (Palnad area) of the Cuddapah basin, South India and its implication on Rodinia. Gondw Res 6:73–83

Saha D, Mazumder R (2012) An overview of the Paleoproterozoic geology of peninsular India, and key stratigraphic and tectonic issues. In: Mazumder R, Saha D (eds) Paleoproterozoic of India. Geological Society, London, Special Publications, vol 365. Geological Society of London, London, pp 5–29

Saha D, Deb GK, Dutta S (2000) Granite greenstone relationship in the Sonakhan Belt, Raipur District, Central India. Geol Surv India Spec Publ 57:67–78

Saha D, Chakraborti S, Tripathy V (2010) Intracontinental thrusts and inclined transpression along Eastern margin of the East Dharwar Craton, India. J Geol Soc India 75:323–337

Saha D, Bhowmik S, Bose S, Sajeev K (2016a) Proterozoic tectonics and trans-Indian mobile belts: a status report. Proc Indian Natl Sci Acad 82:445–460

Saha D, Patranabis-Deb S, Collins AS (2016b) Proterozoic stratigraphy of Southern Indian Cratons and global context. In: Montenari M (ed) Stratigraphy & timescales, vol 1. Elsevier, Amsterdam, pp 1–59

Santosh M, Sajeev K, Li JH (2006) Extreme crustal metamorphism during Columbia supercontinent assembly: evidence from North China Craton. Gondw Res 10:256–266

Santosh M, Maruyama S, Sato K (2009) Anatomy of a Cambrian suture in Gondwana: Pacific-type orogeny in Southern India? Gondw Res 16:321–341

Santosh M, Yang QY, Shaji E, Tsunogae T, Ram Mohan M, Satyanarayanan M (2015) An exotic Mesoarchean microcontinent: the Coorg Block, Southern India. Gondw Res 27:165–195

Santosh M, Yang QY, Shaji E, Ram Mohan M, Tsunogae T, Satyanarayanan M (2016) Oldest rocks from Peninsular India: evidence for Hadean to Neoarchean crustal evolution. Gondw Res 29:105–135

Santosh M, Arai T, Maruyama S (2017a) Hadean Earth and primordial continents: the cradle of prebiotic life. Geosci Front 8:309–327

Santosh M, Hu CN, He XF, Li SS, Tsunogae T, Shaji E, Indu G (2017b) Neoproterozoic arc magmatism in the Southern Madurai block, India: subduction, relamination, continental outbuilding, and the growth of Gondwana. Gondw Res 45:1–42

Sarangi S, Gopalan K, Kumar S (2004) Pb–Pb age of earliest megascopic eukaryotic alga bearing Rohtas Formation, Vindhyan Supergroup, India: implications for Precambrian atmospheric oxygen evolution. Precambrian Res 132:107–121

Sarkar T, Schenk V (2014) Two-stage granulite formation in a Proterozoic magmatic arc (Ongole domain of the Eastern Ghats Belt, India): Part 1. petrology and pressure temperature evolution. Precambrian Res 255:485–509

Sarkar G, Corfu F, Paul DK, McNaughton NJ, Gupta SN, Bishui PK (1993) Early Archaean crust in Bastar Craton, Central India: a geochemical and isotopic study. Precambrian Res 62:127–132

Sarkar T, Schenk V, Appel P, Berndt J, Sengupta P (2014) Two-stage granulite formation in a Proterozoic magmatic arc (Ongole domain of the Eastern Ghats Belt, India): Part 2. LA-ICP-MS zircon dating and texturally controlled in situ monazite dating. Precambrian Res 255:467–484

Sarkar T, Schenk V, Berndt J (2015) Formation and evolution of a Proterozoic magmatic arc: geochemical and geochronological constraints from meta-igneous rocks of the Ongole domain, Eastern Ghats Belt, India. Contrib Mineral Petrol 169:1–27

Sears JW, Price RA (2000) New look at the Siberian connection: No SWEAT. Geology 28:423–426

Sears JW, Price RA (2003) Tightening the Siberian connection to western Laurentia. Geol Soc Am Bull 115:943–953

Sharma R (2009) Aravalli mountain belt. In: Cratons and fold belts of India. Lecture notes in Earth sciences, vol 127. Springer Nature, Cham, pp 143–176

Sharma M, Basu AR, Ray SL (1994) Sm–Nd isotopic and geochemical study of the Archaean tonalite amphibolite association from the Eastern Indian Craton. Contrib Mineral Petrol 117:45–55

Shirey SB, Richardson SH (2011) Start of the Wilson cycle at 3 Ga shown by diamonds from subcontinental mantle. Science 333:434–436

Sinha-Roy S, Malhotra G, Guha DB (1995) A transect across Rajasthan Precambrian terrain in relation to geology, tectonics and crustal evolution in South-Central Rajasthan. Geol Soc India Mem 31:63–89

Sleep HN (1992) Time dependence of mantle plumes: some simple theory. J Geophys Res Solid Earth 97(B13):20007–20019

Smithies RH, Champion DC, Cassidy KF (2003) Formation of Earth's early Archaean continental crust. Precambrian Res 127:89–101

Smithies RH, Van Kranendonk MJ, Champion DC (2005) The Mesoarchean emergence of subduction. Gondw Res 11:50–68

Srivastava R (2013) Petrological and geochemical characteristics of Paleoproterozoic ultramafic lamprophyres and carbonatites from the Chitrangi region, Mahakoshal Supracrustal Belt, Central India. J Earth Syst Sci 122:759–776

Stern RJ (2005) Evidence from ophiolites, blueschists, and ultra-high pressure metamorphic terranes that the modern episode of subduction tectonics began in neoproterozoic time. Geology 33:557–560

Stern RJ (2007) When did plate tectonics begin? Theoretical and empirical considerations. Chin Bull Sci 52:578–591

Stern RJ, Avigad D, Miller N, Beyth M (2008) From volcanic winter to snowball earth: an alternative explanation for Neoproterozoic biosphere stress. Links between geological processes, microbial activities & evolution of life. Springer, Dordrecht, pp 313–337

Stern RJ, Leybourne MI, Tsujimori T (2016) Kimberlites and the start of plate tectonics. Geology 44:799–802

Strik G. Blake TS, Zegers TE, White SH, Langereis CG (2003) Palaeomagnetism of flood basalts in the Pilbara Craton, Western Australia: Late Archaean continental drift and the oldest known reversal of the geomagnetic field. J Geophys Res, Solid Earth 108 (B12) 2551

Tackley PJ (2000) Self-consistent generation of tectonic plates in time-dependent, three-dimensional mantle convection simulations. Geochem Geophys Geosyst 1(8):2000GC000043

Taylor SR, Rudnick RL, McLennan SM, Eriksson KA (1986) Rare earth element patterns in Archean high-grade metasediments and their tectonic significance. Geochim Cosmochim Acta 50:2267–2279

Torsvik TH, Smethurst MA, Meert JG, Van der Voo R, McKerrow WS, Brasier MD, Sturt BA, Walderhaug HJ (1996) Continental break-up and collision in the Neoproterozoic and Palaeozoic—a tale of Baltica and Laurentia. Earth Sci Rev 40(3):229–258

Tucker RD, Ashwal LD, Torsvik TH (2001) U–Pb geochronology of Seychelles granitoids: a Neoproterozoic continental arc fragment. Earth Planet Sci Lett 187(1):27–38

Turner S, Rushmer T, Reagan M, Moyen JF (2014) Heading down early on? Start of subduction on Earth. Geology 42(2):139–142

Valentine JW, Moores EM (1970) Plate-tectonic regulation of faunal diversity and sea level: a model. Nature 228:657–659

Valentine JW, Moores EM (1972) Global tectonics and the fossil record. J Geol 80:167–184

Wegener A (1912) Die entstehung der kontinente. Geologische Rundschau 3(4):276–292

Wegener A (1922) Die Entstehung der Kontinente und Ozeane [On the Origin of Continents and Oceans]. English translation of 3rd edition by JGA Skerl (1924). Methuen, London, p 212

Weil AB, Van der Voo R, MacNiocall C, Meert JG (1998) The Proterozoic supercontinent Rodinia: paleomagnetically derived reconstructions for 1100 to 800 Ma. Earth Planet Sci Lett 154:13–24

Williams H, Hoffman PF, Lewry JF, Monger JWH, Rivers T (1991) Anatomy of North America. Tectonophysics 187:117–134

Wingate MT, Giddings JW (2000) Age and palaeomagnetism of the Mundine Well dyke swarm, Western Australia: implications for an Australia-Laurentia connection at 755 Ma. Precambrian Res 100:335–357

Wingate MT, Pisarevsky SA, Evans DA (2002) Rodinia connections between Australia and Laurentia: no SWEAT, no AUSWUS? Terra Nova 14:121–128

Yan Q, Hanson AD, Wang Z, Druschke PA, Yan Z, Wang T, Liu D, Song B, Jian P, Zhou H, Jiang C (2004) Neoproterozoic subduction and rifting on the Northern margin of the Yangtze Plate, China: implications for Rodinia reconstruction. Int Geol Rev 46(9):817–832

Yang QY, Ganguly S, Santosh M, Shaji E, Dong Y, Nanda-Kumar V (2017) Extensional collapse of the Gondwana orogen: evidence from Cambrian mafic magmatism in the Trivandrum Block, Southern India. Geosci Front 10:263

Yedekar DB, Jain SC, Nair KKK, Dutta KK (1990) The Central Indian collision suture. Precambrian of Central India. Geol Surv India Spec Publ 28:1–37

Yellappa T, Chetty TRK, Tsunogae T, Santosh M (2010) The Manamedu complex: geochemical constraints on Neoproterozoic suprasubduction zone ophiolite formation within the Gondwana suture in Southern India. J Geodyn 50:268–285

Yin A, Dubey CS, Webb AAG, Kelty TK, Grove M, Gehrels GE, Burgess WP (2010) Geologic correlation of the Himalayan orogen and Indian Craton: Part 1. Structural geology, U-Pb zircon geochronology, and tectonic evolution of the Shillong Plateau and its neighboring regions in NE India. Geol Soc Am Bull 122:336–359

Yoshida M, Jacobs J, Santosh M, Rajesh HM (2003) Role of Pan-African events in the Circum-East Antarctic orogen of East Gondwana: a critical overview. In: Yoshida M, Windley BF, Dasgupta S (eds) Proterozoic East Gondwana: supercontinent assembly and breakup. Geological Society, London, Special Publications, vol 206. Geological Society of London, London, pp 57–75

Zegers TE, Ocampo A (2003) Vaalbara and tectonic effects of a mega impact in the early archean 3470 Ma. Third International Conference on Large Meteorite Impacts, Nordlingen, Germany. Lunar and Planetary Institute, Houston, TX

Zegers TE, de Wit MJ, Dann J, White SH (1998) Vaalbara, Earth's oldest assembled continent? A combined structural, geochronological, and palaeomagnetic test. Terra Nova 10:250–259

Zhao G, Cawood PA, Wilde SA, Sun M (2002) Review of global 2.1–1.8 Ga orogens: implications for a pre-Rodinia supercontinent. Earth Sci Rev 59:125–162

Zhao G, Sun M, Wilde SA, Li S (2004) A Paleo-Mesoproterozoic supercontinent: assembly, growth and breakup. Earth Sci Rev 67(1):91–123

Zhou MF, Kennedy AK, Sun M, Malpas J, Lesher CM (2002) Neoproterozoic Arc-Related Mafic Intrusions along the Northern Margin of South China: Implications for the Accretion of Rodinia. The Journal of Geology 110 (5):611–618