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Tectonothermal evolution of the Central Indian Tectonic Zone and its implications for Proterozoic supercontinent assembly: the current status

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The Central Indian Tectonic Zone (CITZ) is a major E-W striking mobile belt dissecting the Indian Craton along which the northern and southern Indian cratonic blocks have joined to make the Greater Indian Landmass (GIL). CITZ has a long evolutionary history spanning over 1000 Myrs (2.1-0.9 Ga), overlapping with the assembly and dispersal of two supercontinents – Columbia and Rodinia. Despite a lot of recent work carried out on the CITZ, several outstanding issues remain, especially on the nature and timing of different orogenic events identified in the southern part of this mobile belt. The present contribution attempts to summarize the major petrological, structural and geochronological studies carried out in the CITZ and reappraise the tectonic models in the context of the current database. It is surmised that, while the northern part of CITZ records Paleoproterozoic (ca. 1.8 Ga) orogenic events, the southern part is dominated by a late Palaeoproterozoic-early Mesoproterozoic (ca. 1.6-1.5 Ga) collision, followed by crustal extension, and finally a late Mesoproterozoic to early Neoproterozoic (ca. 1.04-0.93 Ga) collision that led to the final stitching of the North and South Indian cratonic blocks. Tectonic evolution of the CITZ is discussed in the context of the Proterozoic supercontinent cycle.

Introduction

The Central Indian Tectonic Zone (CITZ) is an E-W trending crustal scale mobile belt that dissects the Indian craton (Radhakrishna and Naqvi 1986, Roy and Prasad 2003), along which the North Indian Block (NIB), comprising the Bundelkhand-Marwar craton (BKC)

and South Indian Block (SIB) comprising the Bastar-Dharwar-Singbhum craton (BC) were amalgamated in the Proterozoic, producing the Greater Indian Landmass (GIL) (Bhowmik et al. 2012 and references therein). The CITZ extends in the east through the Chhotanagpur Gneissic Complex (CGC) up to the southern part of the Shillong plateau (Acharyya 2001) (Fig. 1). Further westward extension of the CITZ has been traced up to Madagascar (Katz and Premoli 1979) and eastward up to Western Australia through Pinjara craton and Albani-Fraser orogen (Harris 1993), thus indicating its trans-continental nature. Even its connection with the Circum-Antarctic orogenic belt, through the Eastern Ghats Mobile Belt (EGMB) has been suggested, thereby making the CITZ an important tectonic element for the reconstruction of Rodinia and East Gondwana (Yoshida et al. 2001). Geological and geochronological data available from different parts of the CITZ, till the beginning of the present century, indicated a tectonothermal evolutionary history spanning nearly 1000 Myrs from Paleoproterozoic to Neoproterozoic (Acharyya and Roy 2000, Roy and Prasad 2003). Thus the evolution of CITZ overlapped with the assembly and dismemberment of two supercontinents, viz. Columbia (ca. 2.1-1.8 Ga) (Rogers and Santosh 2003) and Rodinia (ca. 1.2 -0.9 Ga) (Pisarevsky et al. 2003). The tectonothermal history of CITZ and its spatio-temporal correlation with other major continental mobile belts has, therefore, gained much importance toward the understanding of the Proterozoic supercontinent cycle.

Despite the geological significance and promise mentioned above, CITZ has been relatively less studied in comparison to the other major mobile belts of India (e.g. the Aravalli-Delhi Mobile Belt (ADMB) and the Eastern Ghats Mobile Belt (EGMB)). Specifically, geochronological data of different tectonothermal events are limited, making it difficult to correlate the tectonics of CITZ with the global events. In recent years, however, a lot of structural, metamorphic, geochemical, geophysical and geochronological data have been generated, especially from the southern part of CITZ (from the Sausar Mobile belt (SMB) and the underlying granite-gneiss-granulite (Ahmad et al. 2009, Bhandari et al. 2011, Bhowmik and Roy 2003, Bhowmik et al. 2005, 2011, 2012, 2014, Chattopadhyay and Khasdeo 2011; Chattopadhyay et al. 2003 a,b, 2008, 2014, 2015, 2017;

Figure 1. Simplified geological map of the CITZ in central India, showing all the supracrustal belts and tectonic lineaments. Selected geochronological data from different parts of CITZ are shown in the boxes (modified after Yedekar et al. 1990, Acharyya and Roy 2000, Chattopadhyay and Khasdeo 2011). Geochronological data are taken from Sarkar et al. 1998, Deshmukh et al. 2017 (for Mahakoshal belt), Bhowmik et al. 2012, Bhowmik and Chakraborty 2017, Chattopadhyay et al. 2015, 2017 (for Sausar belt, RKG and BBG).

Naganjaneyulu and Santosh 2010, Mohanty et al. 2010, 2015, Roy et al. 2006, Stein et al. 2014, to name a few). In spite of such a large amount of data, there is still much debate on the geology and tectonics of CITZ. Some of the major issues include – i) age of the metasedimentary Sausar Group (early Paleoproterozoic or Mesoproterozoic?); ii) status of the Tirodi Biotite Gneiss (TBG) (basement to the Sausar Group or a product of migmatization of the Sausar Group sediments?); iii) the age of Sausar metamorphism and deformation (Paleoproterozoic to Mesoproterozoic, or Early Neoproterozoic?); iv) timing of the final suturing of the NIB and the SIB (2.1-1.8 Ga or 1.1-0.9 Ga?), v) direction of polarity of the subduction (southward (i.e. NIB under SIB), or vice-versa?); vi) position of the final suture line (along the Central Indian Suture/Shear (CIS) in the south of SMB, or along the Tan shear (GTSZ) in the north of SMB?).

In the present review, we shall attempt to enlist and elucidate these controversies and the possible (or most plausible) solutions, and/or point out the necessity of further, more focussed, research work. Due to the constraint of space, we shall briefly describe the

geological and geochronological findings from the CITZ which are only relevant to these debates, avoiding much detailing of the smaller regional geological problems. For the same reason, geophysical and geochemical studies of different parts of the CITZ are not reviewed here in detail. These works are referred to, as and when required, in connection with the outstanding tectonic issues only. For the sake of brevity, we have referenced the papers related to the controversial issues of the CITZ only. Therefore, the present paper should not be considered as an exhaustive chronicle listing all the research contributions related to the geology/tectonics of the CITZ.

Geological and tectonic framework of the CITZ

The Central Indian Tectonic Zone (CITZ) trends E-W to ENE-WSW, and has a maximum width of about 200 km. It comprises three major supracrustal belts, viz. Mahakoshal, Betul and Sausar belts from north to south, set in a vast country of unclassified gneiss-migmatite-granitic rocks, variably named as Tirodi Biotite Gneiss, Amgaon Gneiss, Betul Gneissic Complex etc. The CITZ is traversed by many major tectonic lineaments – mostly parallel to its length, viz. Son-Narmada North Fault (SNNF), Son-Narmada South Fault (SNSF), Gavilgarh-Tan Shear Zone (GTSZ) and Central Indian Suture/Shear (CIS) from north to south (Fig. 1). While the Mahakoshal belt is confined between SNNF and SNSF, GTSZ separates Betul belt from the Sausar Belt and CIS is considered as the southern limit of CITZ,

south of which the N-S structural grain of the Bastar craton is observed. Three granulite belts are identified within CITZ, viz. Makrohar granulite (MG) in the south of Mahakoshal belt, Ramakona-Katangi granulite (RKG) along the northern margin of Sausar belt, and Balaghat-Bhandara granulite (BBG) along CIS (Fig. 1). Geological information from Makrohar granulite is limited, but a lot of information is now available on the tectonothermal evolution of the RKG and BBG belts (Bhowmik 2019 and references therein). Below we give a brief outline of the geology and tectonic framework of the different supracrustal belts/granulites and major shear zones, in context of the tectonics of CITZ.

Mahakoshal belt and Makrohar granulites:

The ENE-WSW to E-W trending Mahakoshal belt, bound between Son-Narmada-North Fault (SNNF) and Son-Narmada South Fault (SNSF), represents the northernmost supracrustal unit of the CITZ, and extends for nearly 600 km from south of Jabalpur in M.P. to Palamu district in Jharkhand. In the north, it is in direct contact with

the Meso-Neoproterozoic Vindhyan Supergroup, separated by the SNNF, except near Sidhi, where an inlier of the older gneiss-migmatites (Sidhi gneissic complex) occurs in-between the Mahakoshal and the Vindhyan rocks. The southern margin of Mahakoshal belt is marked by a vast expanse of Proterozoic granitic intrusives, or is juxtaposed against the Gondwana Supergroup, separated by the SNSF. The major rock types in the Mahakoshal Group include metasediments (e.g. quartzite-pelite-carbonate-greywacke-BIF), subordinate metabasalt and minor ultramafics together with intrusive mafic dyke swarms and granitoids. Occasional intrusives of albitite of alkaline affinity, and of carbonatite, are reported (Nair et al. 1995). Mafics-ultramafics and sedimentary units within the Mahakoshal belt were earlier designated as 'Jungel Group'. Subsequently, it has been suggested that the igneous assemblages belong to Mahakoshal Group, while the sedimentary lithounits represent outliers of Vindhyan (a separate sub-basin). Roy and Devrajan (2000), while giving a comprehensive and holistic view of the belt, divided the supracrustal assemblages into three formations. The basaltic volcanics along with minor ultramafics and shallow marine sediments are restricted in the lower part of the sequence, while the sediments dominate in the upper part. The sediment association is indicative of a pre-rift shallow marine intertidal to shelf-slope facies sedimentation. This was followed by limited rifting and emplacement of basic volcanics of arc affinity. This is overlain by moderate to deeper water sediments including BIF.

The Mahakoshal Group rocks show imprints of polyphase (D_1 , D_2 , D_3) deformation, of which D_1 and D_2 are strong in intensity, combined effects of which have produced the ENE-WSW tectonic trend/elongation of the belt (Roy and Bandyopadhyay 1990). The major folds are from D_1 deformation while D_2 superposition is broadly coplanar, geometry of both indicating flattening type of deformation (Fig. 2a). They are generally upright, low plunging in nature produced by N-S compression. At the advanced stage of flattening, a prominent ductile shear zone has formed along the southern margin of the belt, coinciding with SNSF, showing a reverse slip movement with vergence towards north. Along this shear/fault zone, the older basement (presently concealed) is thrust over the Mahakoshal Group (Roy and Devarajan, 2000, 2002). The ductile shear zone is the loci for the emplacement of a linear syn-tectonic granite body, which shows all stages of mylonitization in response to progressive sub-simple shear (Fig. 2b). D_3 is of very mild intensity producing small scale cross folds. The rocks have attained greenschist to amphibolite facies, low-pressure-high temperature type regional metamorphism (Roy et al. 2000, Roy and Prasad, 2003). Appearance of andalusite, staurolite, garnet and cordierite in metapelites, preferentially near the southern margin, suggest that higher grade assemblages are restricted close to SNSF near the granite bodies. Recently, Deshmukh et al. (2017) have studied the metamorphic evolution of pelitic schists and phyllites from northeast of Sidhi area, and concluded that peak metamorphism (M_2) occurred pre/syn- S_2 fabric ($P \sim 8$ kbar and $T \sim 520^\circ\text{C}$), followed by post S_3 isothermal decompression (M_3) up to 2-3 kbar. Based on U-Th-total Pb monazite age dating methods, the authors have suggested the following age constraints for the different metamorphic stages: M_1 (prograde): 1.8-1.9 Ga, M_2 (peak): 1.65-1.75 Ga and M_3 (retrograde): 1.5-1.6 Ga. In other words, the clockwise P-T path in the schists and phyllites of Mahakoshal belt evolved between ca. 1.9-1.8 and 1.6-1.5 Ga (Deshmukh et al. 2017, their figure 12).

Previously, a number of Rb-Sr dates of intrusive granitoid rocks were reported from the eastern part of the belt close to SNSF viz.

1576 $\pm$ 76 Ma, 1708 $\pm$ 36 Ma, 1731 $\pm$ 36 Ma, 1813 $\pm$ 65 Ma, 1850 $\pm$ 40 Ma, 1856 $\pm$ 68 Ma (Sarkar et al. 1998). More recently, high resolution U-Pb zircon SHRIMP dating of microgranular enclaves and their host granitoids from the Jhirkadandi pluton in the eastern part of Mahakoshal belt has yielded a more or less comparable age of ca. 1.75 Ga, indicating a broadly coeval nature of microgranular enclaves and the host granitoids through synchronous mixing-fractionation processes (Bora et al. 2013). As the ages of metamorphic evolution of Mahakoshal Group and the granitoids largely match, as shown above, it is likely that most of the granitic bodies were emplaced syn-tectonically with the deformation and metamorphism of the Mahakoshal Group (1.7-1.8 Ga). The younger (ca. 1.5-1.6 Ga) ages may represent either the timing of waning phase of the Palaeoproterozoic Mahakoshal orogeny or the emplacement age of post-tectonic granitoids.

Various tectonic models have been proposed for the evolution of Mahakoshal belt, like (i) rift-valley setting, (ii) fault-bound graben setting, (iii) back-arc setting etc. (see Roy and Devrajan, 2000 for a review). Considering all the attributes, it is inferred that a pericratonic basin initiated near the southern margin of the Bundelkhand craton around 2.0-2.2 Ga. After initial extension, rifting took place in a limited scale on an intracratonic setting. Calc-alkaline magmatism, contractional set-up, low pressure metamorphism (ca. 1.8 Ga) - all are suggestive of a back arc setting marginal to Bundelkhand craton (Roy and Prasad, 2003). South-directed compressional forces led to orogenic deformation and basin closure.

There is a narrow isolated strip of ENE-WSW trending litho-assemblage as inliers within the Gondwana terrain south of the Mahakoshal belt (near Waidhan, M.P.), called Makrohar granulites (MG). The rock types include three distinct suites of (i) granite gneiss and migmatite, (ii) enclaves of metasedimentary granulite, mafic granulite, amphibolite and (iii) gabbro-anorthosite-ultramafites. Metasedimentary rocks consist of sillimanite-bearing quartzite (with or without corundum), magnetite quartzite, garnet-cordierite-sillimanite-biotite rocks and calc-silicate rock (Roy and Prasad 2003, and references therein). Although the occurrence of some shear zones are mentioned (Solanki et al. 2003), their detailed description is lacking. Metamorphic P-T estimates in the mafic granulites suggest peak $T \sim 800^\circ\text{C}$, $P \sim 9$ kb, and in the metasediments $T \sim 740^\circ\text{C}$, $P \sim 6.5$ kb. The P-T trajectory shows a clockwise path indicating a continental collisional set-up. A granitoid with enclaves of metapelites yielded an Rb-Sr date of 1.73 Ga (Sarkar et al. 1998), which has broadly contemporaneous with the low-to-medium grade Mahakoshal belt.

Son-Narmada faults

Two steeply dipping, deep-reaching faults mark the northern and southern margin of the Mahakoshal belt, as discussed above. These two faults also define the margins of the Son-Narmada River valley, which is a major physiographic expression of central India, separating the Vindhyas and the Satpura mountain ranges. The Narmada valley is considered to be a result of Cretaceous rifting within the Indian cratonic mass (Biswas 1987), but the bounding faults have a known Precambrian ancestry (West 1962) which is only discussed here. The Son-Narmada North Fault (SNNF) can be traced from Markundi in the east to north of Narsingpur in the west, and it defines a tectonic contact between the Mahakoshal and the younger Vindhyan Supergroup of rocks except near Sidhi (Fig. 1). Interestingly where SNNF is identified as a thrust, e.g. south of Churhat, it is seen that

the younger Vindhyan (Semri Group) is thrust over the older Mahakoshal rocks showing vergence towards south. This is interpreted to represent reactivation of SNMF, the basin margin fault, during deformation of lower Vindhyan (Roy, unpublished work). The Son-

Narmada South Fault (SNSF) is mostly concealed under younger Gondwana cover, and where exposed, it is defined by a fault (e.g. Dudhi Fault) or a ductile shear (e.g. near Singrauli) along which intrusive granites (e.g. Madan Mahal granite near Jabalpur) have been

Figure 2. Field photographs from CITZ: a) Tight F_2 folds with axial planar S_2 fabric in the Mahakoshal Group, NW of Singrauli; b) Mylonitic fabric developed in syn-tectonic granite emplaced within a shear zone at the southern margin of Mahakoshal belt; c) Pre-full crystallization (PFC) fabric in porphyritic granite near Deogarh (GTSZ); d) 'Overturned' tails of mantled porphyroclasts in sheared monzodiorite of GTSZ; e) Recumbent F_1 folds in calc-silicate rocks of Sausar Group: note the upright fold (F_2) overprinting F_1 ; f) Polyphase high-grade metamorphism in the BBG domain as shown by multistage partial melting in the felsic gneiss, now recognised by segregation of leucosomes in stromatic migmatite banding at the isoclinal fold hinge and along its axial planes.

emplaced (Devarajan and Roy 2001, Roy et al. 2002). The SNSF shows a reverse-slip (or oblique reverse-slip) movement, thereby exposing rocks of deeper structural level in the south. A number of brittle reactivation (normal faulting in Permian, and reverse faulting in Tertiary and Quaternary) of this fault has been suggested (Devarajan and Roy 2003). Both the SNNF and SNSF have been imaged in geophysical (gravity) surveys as steeply dipping discontinuities transecting the crust-mantle boundary (Kaila and Krishna 1992).

Betul belt

ENE-WSW trending Betul belt is located between Mahakoshal belt in the north and Sausar belt in the south, separated by gneissic basement rocks, partly covered by younger Phanerozoic rocks of the Gondwana Supergroup and/or the Deccan Trap lava flows. Gavilgarh-Tan shear zone (GTSZ), described in detail in a later section, is tentatively taken as the southern limit of the Betul belt. Lithologically, the Betul belt comprises a basement gneiss-granitoid complex, low-to medium grade metamorphosed supracrustals, and intrusives of mafic-ultramafic, diorite and granitic rocks (Mahakud 1993). The belt is subdivided into a northwestern and a southeastern domain based on distinct lithological character, separated by a major fault/shear zone. The southeastern part is dominated by a supracrustal assemblage and the basement complex, while the northwestern part exposes the Padhar mafic-ultramafic complex, diorite and granite intrusive with occasional enclaves of high grade granulite facies rocks (Roy et al. 2004). Supracrustal rocks are represented by bimodal volcanic association of pillow bearing basic and acidic lava, tuffs/pyroclastics, metapelite, quartzite, subordinate calc-silicate rock and BIF. The contact between the gneissic basement (?) complex and the supracrustals is tectonic in nature marked by faults or shear zones. Details of the structural framework of the belt are lacking though several ENE-WSW trending ductile shear zones are reported. The prominent planar fabric is a subvertical transposed schistosity striking ENE-WSW, which is axial planar to a set of folds. Some of the shear zones are associated with syn-kinematic granite emplacement showing strong mylonitic foliation and stretching lineation. Lineation shows variable orientation on mylonite planes indicating 'sub-simple shear' deformation. The gneissic complex perhaps represents a reworked basement comprising amphibolite facies metamorphic assemblages including younger granulites of unknown age. Base metal mineralization is hosted by basic and acid volcanics and metapelites with the development of chlorite, chloritoid, garnet, staurolite, gahnite, fibrolite/sillimanite porphyroblasts (Ghosh and Praveen, 2007; Praveen and Ghosh, 2009). Andalusite porphyroblasts are also identified from this metapelites (Roy, unpublished work). Metamorphic mineral assemblages in the supracrustals are characteristics of low-pressure-medium temperature metamorphism closely similar to that of the Mahakoshal belt.

A very prominent mafic-ultramafic (M-UM) complex is exposed in the northwestern part of the belt, which is referred to Padhar M-UM complex (Chaturvedi, 2001; Roy et al. 2004). The geochemical trends coupled with complementary mineral assemblages indicate melt derivation (except for the diorite) from a common magmatic source and evolution through fractionation (Roy et al. 2004; Chakraborty and Roy, 2012). REE pattern suggests melt derivation from partial melting of an enriched mantle, and the complex has evolved through multiple phases of mafic magma emplacement, presumably produced as separate batches in a metasomatised subcontinental lithospheric

mantle (Chakraborty and Roy, 2012). The M-UM complex has been interpreted to represent arc-type magmatism. In the plate tectonic model for the evolution of CITZ, the Betul belt is generally considered to represent a continental magmatic arc near the periphery of Bundelkhand craton overlying the suture zone (Roy and Prasad, 2003; Chattopadhyay et al. 2017). It is further supported from the detailed petrochemistry of Padhar M-UM complex. Raut and Mahakud (2002) quoted an Rb-Sr age of ca. 1.5 Ga for a syntectonic intrusive granite from Betul belt. Details of the geochronologic data are not available. This may constrain the upper age limit of the Betul supracrustals which include both mafics and felsic volcanics. However, the intrusive mafic-ultramafic complex of Betul remains undated. So far no reliable geochronological data of Betul belt is available.

Gavilgarh-Tan Shear Zone

GTSZ is an ENE-WSW-trending, more than 300 km long and 2-3 km wide shear/fault zone running through the gneissic basement rocks exposed between the Betul and the Sausar Supracrustal belts (Fig. 1) (Golani et al. 2001, Chattopadhyay and Khasdeo 2011). The eastern part of this linear structure is expressed as a ductile shear zone comprising sheared gneisses and granulites, while the western part is mainly observed as a brittle fault zone affecting the Gondwana sandstone and the Deccan Trap basalt flows, within which slivers of sheared gneissic basement rocks are found, confirming the presence of the ductile shear zone below. GTSZ has a long history of multiple tectonic rejuvenations, spanning from Neoproterozoic through Ordovician, Permian, to Tertiary and Quaternary (Chattopadhyay et al. 2008, 2014; Bhattacharjee et al. 2016). For the present review, only the Proterozoic ductile shear zone is considered hereafter.

The ductile shear zone is best exposed in the Kanhan River and its tributaries as a series of outcrops of mylonitized granulites ranging in composition from granite to granodiorite and quartz monzonite. Geochemically, these granitic rocks are peraluminous and calc-alkaline in character suggesting their derivation from a crustal source, and show signatures of a continental collision setting (Chattopadhyay and Khasdeo 2011). Sheet-like intrusions of the granulites into the shear zone, mutually cross-cutting relationship between different types of granitic rocks, and presence of Pre-full crystallization (PFC) deformation fabric (Fig. 2c) indicate syn-kinematic intrusion of granites into the GTSZ. Intense shearing of the granulites has produced a variety of proto-, ortho- and ultramylonites with spectacular shear zone structures, e.g. tails of mantled porphyroblast (Fig. 2d), S-C-C¹ structure, mineral fish, core-and-mantle microstructure etc. which indicate sinistral strike-slip shearing at a depth of 15 km or more (Chattopadhyay et al. 2008). Kinematic vorticity analysis of the mylonites has demonstrated 'partitioned' transpression along GTSZ where the central part is dominated by simple shear and the marginal part largely accommodated pure shear (Chattopadhyay and Khasdeo 2011). U-Pb zircon and U-Th-total Pb monazite dating of these granulites point to an early Neoproterozoic age (ca. 1.05-0.95 Ga) of transpression and granite magmatism in GTSZ (Chattopadhyay et al. 2017).

Sausar Belt and the RKG domain

The 300 km long and 70 km wide arcuate (southward convex) Sausar Fold Belt (SFB) is the southernmost supracrustal belt of CITZ, lying between the GTSZ and the CIS (Fig. 1). SFB consists of

metasedimentary Sausar Group (SSG), which structurally overlies a vast expanse of gneissic rocks known as Tirodi Biotite Gneiss (TBG). Two granulite belts (RKG and BBG as mentioned before) occur within the basement gneisses (TBG) along the northern and southern margins of the SFB respectively. SFB, RKG and BBG have been named together as the Sausar Mobile belt (SMB) (Bhowmik et al. 2012). However, SFB and RKG share a similar and connected geological/tectonic history, while BBG has a different tectonic and geochronological framework. Therefore we describe the SFB and RKG together and BBG (and CIS) separately in this review.

The Sausar Group is a typical platformal assemblage of metamorphosed quartzite-pelite-carbonate that hosts India's largest stratabound manganese ore deposits. TBG, on the other hand, is a basket term for an ensemble of tonalite-granodiorite-granite gneisses, migmatites and intrusive granitoids. TBG structurally underlies the SSG and is generally considered as the basement over which Sausar sediments were deposited (Narayanaswami et al. 1963, Bhowmik et al. 1999, Chattopadhyay et al. 2003 a,b). Some workers (Mohanty 2010, and references therein) have argued that migmatization of Sausar sediments has generated TBG. This implies that TBG cannot be considered as the basement to the SSG. However, a conglomerate horizon, comprising pebbles of gneissic rocks and vein quartz, occurs at the base of the SSG overlying granulites and gneisses near Balaghat which implies that the Sausar Group had a gneissic basement (TBG or its equivalent) (Pal and Bhowmik 1998, Bhowmik 2019). The SSG rocks record at least four phases of deformation – an early phase of southward thrusting and associated recumbent/reclined folds (D_1/F_1) (Fig. 2e) was followed by E-W trending upright/steeply inclined folding (F_2) of the thrust allochthon ('Deolapar Nappe'). TBG was also co-folded with SSG at many places. Minor F_3 folds, observed in the southern part of SFB, have distorted the F_2 fold hinges and associated lineations. F_4 manifest as open N-S trending cross folds (Chattopadhyay et al. 2003 a,b). Sausar Group rocks have undergone Barrovian-type regional metamorphism, varying in grade from low greenschist facies in south and southeast to upper amphibolite facies ($T_{\text{Max}} \sim 675^\circ\text{C}$ at $P \sim 7$ kbar) in the northwest (near the contact with RKG domain) (Bhowmik et al. 1999). Sausar metasediments show a clockwise metamorphic P-T path of evolution indicating a continental collisional set-up during orogenesis (Bhowmik et al., 2012).

Pods and lenses of mafic and pelitic granulites, garnetiferous amphibolite and porphyritic charnockite occur within high grade felsic gneisses (TBG) as a linear belt of about 250 km length along the northern margin of SFB, named as the Ramakona-Katangi Granulite (RKG) belt (Bhowmik et al. 1999, 2012). Four phases of deformation and three phases of metamorphism have been established from metabasic granulites (Bhowmik and Roy 2003). The peak metamorphic condition reached $P \sim 9$ -10 kbar, $T \sim 750^\circ$ -800°C, followed by isothermal decompression at about 7 kbar/775°C and a later near-isobaric cooling at 6 kbar/650°C, recording a clockwise P-T path. A similar P-T path was established from pelitic granulites also (Bhowmik and Spiering 2004), indicating an overall collisional setting for the RKG granulites (Bhowmik 2019 and references therein).

Geochronological data from Sausar/RKG belt has led to many controversies. Rb-Sr whole rock age of ca. 1525 Ma and a mineral-whole rock isochron age of ca. 860 Ma from TBG were initially interpreted as the timing of Sausar metamorphism and migmatization (leading to TBG formation), and a terminal thermal overprint respectively (Sarkar et al. 1986). In contrast, a ca. 950 Ma $^{40}\text{Ar}/^{39}\text{Ar}$ age of cryptomelane was interpreted as the timing of terminal cooling

following Satpura (Sausar) orogeny (Lippolt and Hautman 1994). Roy et al (2006) reported ca. 1100 Ma Sm-Nd age of coronal garnets in garnetiferous metadolerites, and interpreted it as the age of decompression and cooling following the peak metamorphism in RKG. An Rb-Sr age of 800-900 Ma was interpreted by these authors as the age of 'Sausar metamorphic imprint' on the granulites. Bhowmik et al. (2012) used electron microprobe (EMP) dating of monazite to report Late Mesoproterozoic-Early Neoproterozoic ages from Sausar Group metasediments (ca. 1062 Ma and ca. 993 Ma for peak and retrograde metamorphism respectively). Similarly, EMP monazite dating of metapelitic granulites from RKG belt yielded weighted mean age of ca. 1043 Ma and 955 Ma for peak and retrograde metamorphism. The authors also obtained SHRIMP U-Pb zircon ages of magmatic charnockite from the RKG domain at ca. 938 Ma, and interpreted it as the timing of the decompression and syn-metamorphic emplacement of the charnockitic magma during extensional collapse of the thickened orogen (Fig. 3a). On the basis of similarity of metamorphic P-T path and ages (within error limits), Bhowmik et al. (2012) suggested a simultaneous, monocyclic tectonothermal evolution of RKG granulites and Sausar Group sediments in the earliest Neoproterozoic. Chattopadhyay et al (2015) reported EMP monazite ages of ca. 945 Ma from syntectonic (Syn- D_2) granites and ca. 928 Ma from post-tectonic granites intrusive into the Sausar Group. From the similarity of peak (Syn- D_2) metamorphism of SSG and age of retrograde metamorphism in RKG, they argued for a slightly younger tectonothermal history of SSG than that of RKG. Using SHRIMP zircon U-Pb dating, Bhowmik et al. (2011) obtained a magmatic emplacement age of ca. 1618 Ma for TBG, derived from a juvenile source with minor crustal contamination of broadly Paleoproterozoic age. Somewhat younger U-Pb zircon ages of TBG (ca. 1534 Ma of magmatic crystallization and ca. 1454 Ma of late thermal overprint) were obtained by Ahmad et al. (2009) (Fig. 1).

All the above data indicates a Mesoproterozoic age for the TBG and an early Neoproterozoic tectonothermal evolution for the SSG. In contrast, Stein et al (2014) reported a Re-Os age of 2.41-2.45 Ga from a molybdenite grain in a quartz-calcite vein within calc silicate gneisses of Sausar Group, implying the minimum depositional age of Sausar Group to be early Paleoproterozoic. Mohanty (2010) and Mohanty et al. (2015) have reinterpreted all the reported ages and structural-metamorphic studies of earlier workers, and suggested that Sausar Group was deposited as a glacial deposit in the early Paleoproterozoic and was subsequently deformed and metamorphosed through Palaeo- and Mesoproterozoic (1900-1800 Ma and, 1500-1400 Ma) while the last 'minor thermal event' occurred at ca. 1000-900 Ma. However, these interpretations seemingly contradict the basic field relationships and age data obtained from the Sausar Group in recent times, and are therefore open to questions (Chattopadhyay 2015, Bhowmik 2019).

BBG domain and the CIS

The granulite facies rocks occurring at the southern margin of the SMB, locally referred to as the Bhandara-Balaghat granulite (BBG) domain, and bound between the Sausar Group and the SIB is represented by detached, lensoidal (~ 500 -1000 meter long and ~ 50 -200 meter wide) bodies of a variety of pelitic, psammo-pelitic granulites, Banded Iron Formation (BIF, including quartzite) and two-pyroxene (cf. gabbro-norite suite) granulites within highly tectonised felsic gneisses (Ramchandra and Roy, 2001; Bhowmik et al., 2005,

Figure 3. Synoptic diagram of P-T-t path of (a) RKG and (b) BBG rocks (modified after Bhowmik 2012, Bhowmik 2019)

2011, 2014; Bhowmik, 2006; Alam et al., 2017). The granulites were intruded by two generations of mafic dykes: (a) an earlier variety of gabbro-norite dyke, extensively deformed and metamorphosed under granulite facies conditions (Bhowmik et al., 2005; Basu Sarbadhikari and Bhowmik, 2008) and (b) a later generation, undeformed olivine gabbro dyke, emplaced in an interlayered sequence of garnet-cordierite granulite and metanorite.

Combined metamorphic and geochronological (SHRIMP U-Pb zircon and EMP monazite dating) studies reveal lower crustal, ultra-high-temperature (UHT) granulite facies metamorphic conditions at ca. 1.6 Ga in three central segments of the BBG belt around Larsara, Dongargaon and Dongariya areas and a medium-pressure/medium temperature granulite facies metamorphism in other areas, further east and northeast (see Bhowmik, 2019 for a recent review). The UHT domain in the BBG belt is polyphase metamorphosed with three distinct cycles of metamorphism between 1.6 and 1.54 Ga: BM₁-BM₂-BM₃ (where B refers to the BBG belt) (Bhowmik et al., 2014). The BM₁, the most pervasive among the three, records a counterclockwise (CCW) P-T path of evolution with a segment of prograde heating accompanying loading, peak metamorphism at ~8-9.5 kbar, ~900-1000°C, leading to crustal anatexis and formation of granitic melts and a post-peak near isobaric cooling ($\Delta T \sim 250-300^\circ\text{C}$) to ~670°C at ~9 kbar (Bhowmik et al., 2005, Bhowmik, 2006). The

BM₁ granulites were subsequently re-metamorphosed during BM₂ along a clockwise metamorphic P-T path (Fig. 3b). The metamorphism caused mid-crustal heating ($T_{\text{Max}} \sim T \sim 725^\circ\text{C}$ at $P \sim 6.1$ kbar) that locally reached UHT metamorphic condition ($P \sim 6.8$ kbar, $T \sim 900^\circ\text{C}$). This was followed by cooling and exhumation to shallower crustal levels ($P \sim 3-4$ kbar, $T \sim 600-680^\circ\text{C}$) (Basu Sarbadhikari and Bhowmik, 2008; Bhowmik and Chakraborty, 2017). The subsequent BM₃ metamorphic cycle along a CCW P-T trajectory led to prograde burial to middle to lower crustal depths ($P \sim 7.3-9.4$ kbar, $T \sim 735-760^\circ\text{C}$) of the partially exhumed BM₂ granulites, followed by cooling ($T \sim 580^\circ\text{C}$) either at constant pressures (Bhowmik and Chakraborty, 2017) or accompanying decompression (Basu Sarbadhikari and Bhowmik, 2008) (Fig. 3b). Recurring short-lived heating/cooling and burial/exhumation cycles of ultra-hot ($T > 900^\circ\text{C}$) to hot ($700 < T < 800^\circ\text{C}$) thermal pulses at lower to middle crustal levels within one orogenic event of ~50 Myrs duration, and implying episodic mantle-scale thermal perturbations at 1.6-1.54 Ga is, therefore, a characteristic feature of the BBG belt (Bhowmik et al., 2014; Bhowmik & Chakraborty, 2017), and distinguishes it from other metamorphic belts of the CITZ.

A summary of proposed plate tectonic models of the CITZ

A number of plate tectonic models for the evolution of CITZ have been proposed by different workers over the last three decades. Yedekar et al. (1990) invoked southward subduction of BKC (NIB) under BC (SIB) at ca. 2.4 Ga which led to the development of rift basins and arc-related granitic intrusions (e.g. Dongargarh and Malanjkhanda granitoids) in the Bastar craton and finally manifested in a continent-continent collision at ca. 1.5 Ga. In this model, the BBG rocks were interpreted as obducted oceanic crust exhumed during the collisional orogeny. Later Roy and Prasad (2003) contested this model and proposed northward subduction of BC under BKC. They advocated that Mahakoshal belt opened as a back-arc rift basin in the early phase of this northward subduction (ca. 2.2 Ga). The basin was closed at ca. 1.8 Ga with voluminous calc-alkaline magmatism, low pressure metamorphism and reverse slip ductile shearing (along SNSF). The Betul belt, lying south of Mahakoshal, developed as intra-arc basin with sediments and bimodal volcanics, and possibly closed at ca. 1.5 Ga. The subduction led to continent-continent collision and formation of RKG belt at ca. 1.5 Ga, leading to suturing of BC and BKC. Finally the Sausar basin developed as a platformal sequence on the BC and closed by south-directed thrusting and folding by ca. 1.1 Ga. This model has been recently modified by Chattopadhyay et al. (2017), based on the new age data from Sausar Belt, RKG and GTSZ (e.g. Bhowmik et al. 2012, Chattopadhyay et al. 2015). These authors have proposed that northward subduction of BC under BKC resulted in oblique continental collision along RKG and transpressional deformation along GTSZ at ca. 1.1-1.0 Ga and deformation and metamorphism of Sausar Group (along with the thrust-imbricated RKG granulites) by ca. 0.95-0.93 Ga (Fig. 4a). Earlier, Acharyya (2003) suggested two subduction events of opposite polarity – first a southward subduction of BKC under BC (ca. 1.6-1.5 Ga) in which an Archean (ca. 2.6 Ga) BBG was partly exhumed, and a northward subduction of BC under BKC (ca. 1.1-1.0 Ga) that led to a collisional orogeny involving Sausar belt and RKG. A number of geophysical models have also tried to explain the plate tectonic

framework of CITZ. From deep seismic reflection data, Mall et al. (2008) advocated a northward subduction of SIB under NIB and thrusting of the Sausar belt over the Bastar craton, and implied a southward subduction of NIB (BKC) under SIB (BC) along the northern margin of the Sausar Belt (Fig. 4b). Naganjaneyulu and Santosh (2010) conducted magnetotelluric studies across CITZ. In conjunction with the then available seismic reflection data, they suggested a northward subduction of Bastar/Dharwar craton and southward subduction of Bundelkhand craton under the Satpura (Sausar) Mobile belt, akin to a pacific-type 'paired collision' orogeny (Fig. 4c). In contrast, Mandal et al. (2013) used seismic reflection profile across CIS to propose two northward subduction events – at first the subduction of BC under BKC (ca. 1.6-1.5 Ga) led to the formation of RKG and then another subduction and collision resulted in the emplacement of BBG along the CIS (see figure 7 of Mandal et al. 2013). This model implied that RKG is older than BBG, which is contrary to the geochronological data generated in recent years. Recently, Azeez et al. (2017) have interpreted new magnetotelluric images of CITZ and suggested that a north-dipping reflector (subducting slab?) can be traced right below the Tan shear (GTSZ) which possibly represents the line of suturing between the SMB (part of SIB) and the NIB (see figure 9 of Azeez et al. 2017). Interestingly, from geological standpoint, GTSZ has been interpreted as a zone of oblique collision and transpressional deformation in the late Mesoproterozoic to early Neoproterozoic (ca. 1.05-0.95 Ga) orogeny that affected the Sausar Belt and RKG (Chattopadhyay et al. 2017). Bhowmik (2019) has comprehensively reviewed the tectonics of Sausar Mobile Belt, and concluded that: i) an ultra-high temperature metamorphism and emplacement of anatectic granites took place along BBG between 1.60-1.54 Ga; ii) extensive felsic plutonism (now represented by TBG) affected SMB between 1.62-1.53 Ga; iii) the Sausar Group and RKG rocks underwent monocyclic high-pressure metamorphism in a collisional set-up at ca. 1.06-0.93 Ga. The first two events (BBG and TBG) occurred in response to recurrent slab advancement, roll back, and intermittent continent-arc collision during a south-directed subduction of NIB under SIB in the late Paleoproterozoic to early Mesoproterozoic. Sausar basin developed over SIB in the Mesoproterozoic (between 1.5-1.1 Ga). Later, a north-directed subduction of SIB under NIB led to a collisional orogeny that resulted in the

Figure 4. Plate tectonic models of the evolution of CITZ suggested by different workers: a) sequential crustal collision and accretion by northward subduction of BC under BKC (after Roy and Prasad 2003, Chattopadhyay et al. 2017); b) NW-ward subduction of Bastar craton and SE-ward subduction of Bundelkhand craton under the Satpura mobile belt leading to collision and suturing along CIS (after Mall et al. 2008); c) Pacific-type double-sided subduction and collision around the Satpura mobile belt (CITZ) (after Naganjaneyulu and Santosh 2010).

closure of Sausar basin, deformation and metamorphism of Sausar and RKG rocks, and emplacement of granites. This model therefore refutes some of the earlier tectonic models, e.g. 'paired collisional orogeny' discussed above (as the north- and south-directed subduction events are not simultaneous, but separated by almost 500 Myrs). Another proposition that Sausar sedimentation initiated as a Paleoproterozoic glacial deposit (Mohanty et al. 2015) and the deformation and metamorphism of Sausar Group took place in Paleothrough Meso- to Neoproterozoic (i.e. spanning over 1000 Ma) (Mohanty 2010) are also doubted on the basis of these robust set of geochronological and metamorphic data from SMB. The larger implication of this tectonic model in the context of the growth of GIL and its significance in Proterozoic supercontinent reconstruction is discussed in a separate section below.

Proterozoic orogenic events in CITZ: implications for supercontinent assembly

It is evident from the above review that the CITZ records three temporally separate orogenic events at ca. 1.75 Ga, ca. 1.62-1.54 Ga and ca. 1.06-0.94 Ga spanning the time period from the assembly of Columbia supercontinent through its break up and dispersal to the growth of Rodinia. The ca. 1.75 Ga event, which is recorded from the Mahakoshal belt represents a N-S compressional event synchronous with granite plutonism and metamorphism along a low-pressure/high-temperature metamorphic field gradient. The tectonic environment was akin to a back-arc basin marginal to the Bundelkhand craton, which closed by the N-S compression (Roy and Devrajan, 2000, Roy and Prasad 2003).

Following the closure of the Mahakoshal basin, the orogenic front shifted towards the southern margin of the CITZ. Given that vast stretches of geological formations along the axial spine of the CITZ are under the Deccan Trap cover and with inadequate petrological and geochronological information about the Betul belt, the plate tectonic framework between the Mahakoshal and Sausar Belts is poorly understood at present. Nevertheless, recent studies reveal the development of an active continental margin at ca 1.62 Ga (Bhowmik et al., 2011, 2014; Bhowmik & Chakraborty, 2017; Bhowmik, 2019), at the southern margin of the CITZ due to the subduction of an oceanic lithosphere attached with the now cratonised Mahakoshal supracrustal belt (?) beneath the SIB. This gave rise to the growth of an aerielly extensive magmatic arc, now represented by the Tirodi biotite gneiss in the SMB. Due to a subsequent slab roll back between 1.62 and 1.60 Ga, the tectonic setting evolved into a back-arc extension, producing an extremely high heat flow at the base of the attenuated back-arc crust (cf. BBG supracrustal sequence). With the subduction system reverting back to slab advancement mode between 1.60 and 1.59 Ga, a compressional event led to the collision between the SIB and the arc crust, closure of the back-arc basin, formation of a tectonically thickened hot orogen and a lower crustal UHT metamorphism along a CCW $P-T$ path in the BBG belt (cf. BM_1 metamorphic cycle). Recurring slab retreats and advancements between ca. 1.57 and 1.54 Ga, and attendant lithospheric extension and closure of the back-arc basin, produced BM_2 and BM_3 metamorphic cycles in the polyphase BBG granulites. Final suturing of arc-back arc systems at the southern margin of the CITZ led to large-scale cratonization of the BBG belt at 1.54 Ga. The imprints of a late Palaeoproterozoic to early Mesoproterozoic orogenesis have

also been recorded from the adjoining Chhotanagpur Gneissic Complex in the form of an ultra-high temperature granulite facies metamorphism at mid-crustal level ($\sim 1000^\circ\text{C}$, ~ 7 kbar) at ca. 1.65 Ga and anorthosite plutonism at 1.55 Ga (see Mukherjee et al., 2019 for a general review). Further east in the Shillong Plateau Gneissic Complex, ca. 1.63-1.60 Ga orogenesis produced medium-pressure granulite facies metamorphism along a CCW $P-T$ path (Chatterjee et al., 2007) and felsic magmatism (Yin et al., 2010; Santosh Kumar et al., 2017). There is an ongoing debate on the status of ca. 1.62-1.54 Ga orogenesis in the context of Columbia and Rodinia supercontinent assembly events: (a) whether it is a continuation of the long-lived Columbia supercontinent assembly event, (b) whether it is of regional significance, representing a localised crustal amalgamation of blocks dispersed during the break-up of the Columbia supercontinent and (c) whether it marks a globally significant collisional event, hitherto unrecognized. Bhowmik (2019) argued that the late Paleoproterozoic to early Mesoproterozoic orogenesis, producing granulite facies rocks is an integral feature of the central, eastern, north-eastern and south-eastern Indian Shield and former Gondwanaland and Laurentian crustal fragments. It has been suggested that the orogenesis is a globally significant amalgamation event separate from the Columbia Supercontinent assembly and gave rise to the first *nucleus of a proto-Greater Indian Landmass* (Bhowmik, 2019 and references therein).

The next stage of evolution in the CITZ is marked by the opening up of the Sausar sedimentary Basin in the middle Proterozoic - between 1.54 and 1.06 Ga, and most likely coinciding with the ~ 1.45 Ga extension tectonics in the adjoining Chhotanagpur Gneissic Complex. While the sedimentation in the Sausar Basin initiated with a basal conglomerate- sandstone unit at its southern margin (Pal and Bhowmik, 1998; Bhowmik, 2019) on the shoulders of the BBG granulite basement, lithological association reveals progressive deepening of the basin towards the north and northwest. Previous studies linked the middle Proterozoic crustal extension event as part of disintegration of the proto-Greater Indian Landmass (Mukherjee et al., 2018; Bhowmik 2019). While there is scanty geological data to infer the extent of development of oceanic crust in the Sausar basin, metamorphic and chronological information from the central and RKG domains reveal underthrusting of the amalgamated BBG and SIB crust beneath the combined Mahakoshal and NIB crust during a Himalayan-style continental collision orogeny between 1.06 and 0.93 Ga (Bhowmik and Roy, 2003; Bhowmik and Spiering, 2004; Bhowmik et al., 2012; Chattopadhyay et al., 2015, 2017). The collision event led to the closure of the Sausar basin and produced HP upper amphibolite to HP granulite facies rocks in the RKG domain. This north-directed (SIB beneath NIB) subduction and collision led to the final suturing between the NIB and SIB, and the oblique collision was partly adjusted by transpressional deformation and granite magmatism along the Gavilgarh-Tan shear (Chattopadhyay et al. 2017).

Recent studies show a broadly-coeval Grenville-aged continental collision tectonics in the adjoining Proterozoic mobile belts in eastern and north-western India, and involving at least three micro-continental blocks (e.g. North and South Indian Blocks and the Marwar Block). These cratonic blocks were amalgamated at ~ 1.0 Ga to produce the final configuration of the Greater Indian Landmass (Bhowmik et al., 2010, 2012, 2018; Prabhakar et al., 2014; Mukherjee et al., 2017; Chatterjee, 2018; Chakraborty et al., 2018). Although the exact location of India in the Rodinia supercontinent is debatable (Li et al.,

2008; Merdith et al., 2017), the Greater Indian Landmass being dissected by a network of interconnecting c.1.0 Ga orogenic belts resembles a *miniature Rodinia* (Bhowmik 2019).

Discussion

A comprehensive tectonic model of the CITZ is fraught with some controversies- the main being the age of the Sausar Group. As discussed in detail above, a large amount of recent structural, metamorphic and geochronological data indicate an early Neoproterozoic (~1.0 Ga) tectonothermal evolution of the Sausar belt and the RKG (Bhowmik et al. 2012, Chattopadhyay et al. 2015, 2017, Bhowmik 2019, and references therein). However, another group of workers (e.g. Mohanty 2010, Mohanty et al. 2015) have argued that the Sausar Group had a component of glacial deposit in the early Paleoproterozoic (ca. 2.4 Ga), based on isotopic studies of metamorphosed carbonates (designated as 'cap carbonate' horizons). This suggestion of the age of Sausar Group primarily hinges on a Re-Os age of 2.41-2.45 Ga obtained from a molybdenite grain in a calcite-quartz vein cross-cutting the amphibolite facies metamorphic fabric of calc silicate gneiss of Sausar Group (Stein et al. 2014). However, this Re-Os age is fraught with several problems – i.e. isotopic heterogeneity within the single molybdenite crystal, highly diverse ages obtained from different parts of the crystal (ranging from 3.1 – 1.4 Ga), report of 1.0 Ga age of titanite from the host rock by the same authors, etc. This makes the early Paleoproterozoic (or even older – Archean?) age of Sausar sedimentation, as implied by the above work, open to question. It may be mentioned here that there is no direct radiometric date of the Sausar Group sediments, mainly due to the lack of suitable material for dating. The standing controversy on the age of Sausar sedimentation can possibly be addressed by dating of detrital zircons from the basal part of SSG (e.g. conglomerate and sandstone) exposed in the eastern part of Sausar belt (i.e. near Balaghat) where the metamorphic imprint is relatively weak. If successful, it may give a lower age limit of the Sausar sedimentation.

Another issue is the position of the 'suture' between NIB and SIB. As discussed above, the CIS has long been considered as the suture zone along which obducted oceanic crust is represented by the BBG (Yedekar et al. 1990). However, recent work has explained the tectonics of BBG by an accretionary orogenic setting of repeated back-arc extensions and its closure due to recurring slab roll back and slab advancements of a southerly subducting oceanic lithosphere beneath the SIB (see Bhowmik 2019 for an updated review). The final closure due to collision of arc and back-arc systems (cf. BM₃ metamorphic event) led to the stitching of crustal blocks at the southern margin of the CITZ along the CIS. While the suture has been originally placed at the southern margin of the BBG belt, separating it from the South Indian Block (e.g. Yedekar et al., 1990), recognition of contrasting isotopic reservoirs of BBG anatectic granites (from Palaeoarchean mature crustal source) and Tirodi biotite gneiss (early Proterozoic near juvenile source) at c. 1.6 Ga (Bhowmik et al., 2011) suggests that the CIS is better placed at the northern boundary of the BBG belt. The current analysis reveals that the CIS marks a boundary between arc and back-arc systems in the SMB, and not between the NIB and SIB *sensu stricto*. On the other hand, a north-directed subduction of SIB (+BBG+TBG) under NIB led to the closure of the Sausar basin developed along the northern margin of SIB. Continued northward subduction resulted in an oblique continental collision along the RKG and/or GTSZ which finally stitched the NIB and SIB

(Bhowmik et al. 2012, Chattopadhyay et al. 2017). The northern suture may therefore be placed along (or close to) the Tan shear lineament (i.e. GTSZ), as is also suggested by recent geophysical studies (Azeez et al. 2017). From the detailed discussion presented in this paper, it is clear that a 'paired' double-sided pacific type subduction, suggested by Naganjanayelu and Santosh (2010) does not explain the tectonic evolution of CITZ in the context of the recent geochronological data, principally because the two subduction events of opposite polarity were widely time-separated (south-directed subduction at ca. 1.6-1.5 Ga, and north-directed subduction at ca. 1.04-0.93 Ga).

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