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Review

Configuration, geodynamic evolution and metallogeny of Paleoproterozoic mobile belt, Eastern India: An overview

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ABSTRACT

Paleoproterozoic mobile belt of Eastern India well known as Singhbhum Mobile Belt (SMB) bears the evidences of tectono-magmatic processes and crustal evolution like many other major Precambrian terrains of the world. Because of some significant major stratigraphic, structural, geochemical and isotopic constraints SMB could not considered as plume related continental rift basin as proposed by earlier workers. Geological evidence in favor of global melting events at 2.7 and 1.9 Ga are absent. TTG-type 3.5 Ga old gneisses (OMTG) and volcanic arc/*syn*-collision geochemical signatures of 3.2–3.4 Ga old Singhbhum Granitoid Complex (SBGC) occurring in the south of Singhbhum Shear Zone (SSZ) suggest that on the regional scale plate-tectonic processes were operational during Mesoarchean or slightly earlier. Lack of K-rich granites, a characteristic feature of Neoarchean suggests that cratonization in the Singhbhum Proto-continent did not complete till the end of Archean at 2.5 Ga. Flysch-type characters of Chaibasa Formation imply an early *syn*-orogenic evolution of the metasediments. Subduction zone geochemical characteristics of Ongarbira and Dhanjori metavolcanic rocks further corroborate plate convergence. Dalma metavolcanic rocks have an unconformable relationship with the underlying Dhalbhum Formation. Available radiometric age data from SMB (2.8 to 1.0 Ga) suggests that there is no tectonic or metamorphic discontinuity across the SSZ but the contact of SMB supracrustal rocks with SBGC marks out a tectonic and metamorphic break. Structural evidence indicates that SSZ came into existence quite early in the orogenic history perhaps around 2.6 Ga and there have been later reactivations up to 1.0 Ga.

Contents

1. Introduction

Extensive studies undertaken in the Singhbhum Proto-continent (Fig. 1) has generated heated debates on many of the aspects of the operated geodynamic processes and crustal evolution. Among the outstanding controversies, tectonic status of

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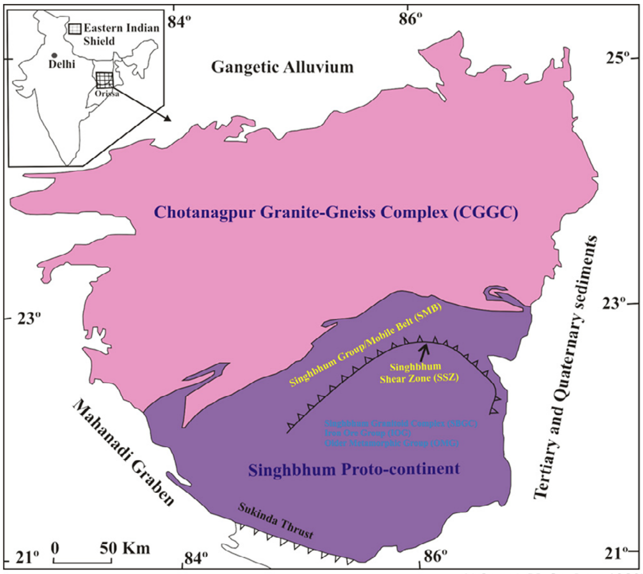

(After, A.N. Sarkar, 1982)

Fig 1. Generalized geological map of Eastern Indian Shield showing different tectono-stratigraphic components (after Sarkar, 1982). Chotanagpur Granite-gneiss Complex is a Paleoproterozoic suspect terrain. The Paleoarchean to Paleoproterozoic successions are well preserved in the Singhbhum Proto-continent.

Singhbhum Shear Zone (SSZ) and geodynamic evolution of Paleoproterozoic Singhbhum Mobile Belt (SMB) is of prime importance. Sarkar and Saha (1963) revised the stratigraphy of the Singhbhum Proto-continent given by the Geological Survey of India (Dunn, 1929, 1940; Dunn and Dey, 1942). In the revised stratigraphic succession, the metasedimentary and volcano-plutonic rocks of different ages occurring in between Chotanagpur Granite-Gneiss Complex (CGGC) and SSZ are clubbed together into a younger Singhbhum Group / Singhbhum Mobile Belt (SMB) of the Proterozoic (<2.5 Ga) age. The rocks occurring in the south of SSZ are classified as Iron Ore Group (IOG) of Archean (>2.5 Ga) age. Around 200 km long, arcuate shaped and highly mineralized SSZ was thought to mark the orogenic front of the Singhbhum Group / SMB against the Archean (Iron Ore Group) rocks occurring in the south of SSZ (Fig. 2). An intraplate subduction model was also proposed for the SSZ (Sarkar and Saha, 1977; Saha, 1994). Although a number of subsequent workers have questioned the validity of revised stratigraphy of Sarkar and Saha (1963), Sarkar and Saha (1977) it is still in use with some modifications (Table 1). It is emphasized here that tectonic status of SSZ and stratigraphic positions of Chaibasa and Dhalbhum Formation and Dalma metavolcanic suite is highly debated due to the contradictory concepts on the geodynamic evolution of SMB (Sarkar and Saha, 1963; Sarkar and Chakraborti, 1982; Iyengar and Murthy, 1982). As a result, suggested evolutionary models of SMB ranging from (i) intraplate northward subduction along the SSZ (Saha, 1994), (ii) back-arc origin with a southward subduction zone lying far to the north, considering CGGC as magmatic arc (Bose et al., 1989), (iii) continent–continent collision between the southern Singhbhum plate and northern Chotanagpur plate resulting in obduction along the Dalma (Sarkar,1982) and (iv) plume generated continental rifting, emplacement of Dalma, Dhanjori and Ongarbira metavolcanic rocks along the crustal fractures and subsequent tectonization (Gupta and Basu, 2000; Roy et al., 2002a; Roy et al., 2002b, Mazumder and Arima, 2009; Bhattacharya et al., 2015) are unable to accommodate the different rock types and metallogenic events (ranging from 2500 Ma to 900 Ma) in an acceptable plate-tectonic frame work.

Our perception regarding Precambrian tectono-magmatic processes, crustal evolution and metallogeny has changed rapidly (Abbott and Isley, 2002; Augé et al., 2003; Condie, 2001, 2005; Groves and Bierlein, 2007; Smithies et al., 2007; Condie and Kroner, 2008) with the accumulation of observational data from different Precambrian terrains of the world. Undoubtedly, there are many events and evidences preserved in the Precambrian rock record of Singhbhum Proto-continent of Eastern India that point towards the operation of plate tectonic processes at that time (Saha et al., 2004; Mukhopadyay et al, 2008; Mondal, 2009; Tait et al., 2011, Mir et al., 2015). Significantly, evidences favoring any plume related melting events at 2.7 and 1.9 Ga (Condie, 1998, 2001) are absent in the Singhbhum Proto-continent. Across the Archean-Proterozoic boundary certain geochemical characteristics of volcanic rocks and mineral deposit types are diagnostic of specific plate tectonic settings and can be used not only in defining these settings in conjunction with more conventional tectonic and petrogenetic evidence but also in constraining the geodynamic evolution of the Earth and its environmental consequences (Groves and Bierlein, 2007). Hence, in the present contribution we attempted to highlight the problems on SMB modeling and by comparing the available geological, geochemical and isotopic nature and evolution of different rock types we tried to recognize the tectono-magmatic processes that are fundamental to crustal evolution and metallogeny of SMB of Eastern India.

2. Geological setting

9000 m to 11500 m thick rock succession of SMB (Gupta and Basu, 2000) can be longitudinally classified into five domains: (i) Dhalbhum Formation i.e. metasedimentary rocks occurring in the north of Dalma metavolcanic suite (ii) Dalma metavolcanic suite (iii) Chaibasa Formation occurring in the south of Dalma metavolcanic suite up to SSZ (iv) Singhbhum Shear Zone (SSZ) and (v) Low grade metasedimentary rocks lying in the south of SSZ, containing Ongarbira and Dhanjori metavolcanic rocks, each one having different Petro-tectonic assemblage, tectonic-thermal imprints and metallogenic associations. A generalized chrono-stratigraphy of the Singhbhum and adjoining region is given in Table 1. It is emphasized here that representative sequence of Neoarchean (2.5–3.0 Ga) age has not been given in the revised stratigraphic succession of Sarkar and Saha, 1963) and Saha (1994). Is this gap real or the reflection of scarcity of data? Answer to this question has to be provided (Naqvi, 2005). The characteristic of Neoarchean igneous activity is the development of K- rich granite which was particularly common during 2.8–2.5 Ga. Such occurrence is lacking despite of a thick crust in the Singhbhum Proto-continent at ca. 3100 Ma (Mazumder et al., 2000; Mazumder and Arima, 2009). Considering the diachronous nature of the crustal evolution, it is suggested that perhaps cratonization in the Singhbhum Proto-continent did not complete till the end of Archean at 2.5 Ga.

Sarkar and Saha (1963) and Saha (1994) while revising the stratigraphy retained the observation of Dunn (1929) and Dunn and Dey (1942) that a geo-anticline (Chaibasa stage) overfolded and overthrust against the Iron-ore stage (and Dhanjori Stage) to the south. If Chaibasa rocks, north of SSZ, are regarded as younger than the rocks on the south side of the SSZ (ignoring the significance of the Dhalbhum Formation that was considered by Dunn (1929) and Dunn and Dey (1942) as part of their Iron-ore Stage), the whole structure poses an extraordinary illogical anomaly: the age relationships as reported by Sarkar and Saha (1963), Sarkar and Saha (1977) are the reverse. The older rocks would be expected on the northern side of SSZ and the younger rocks to the south (Dunn, 1966). Significantly, SSZ does not have a sharp border and there is no evidence of any stratigraphic or tectonic discontinuity

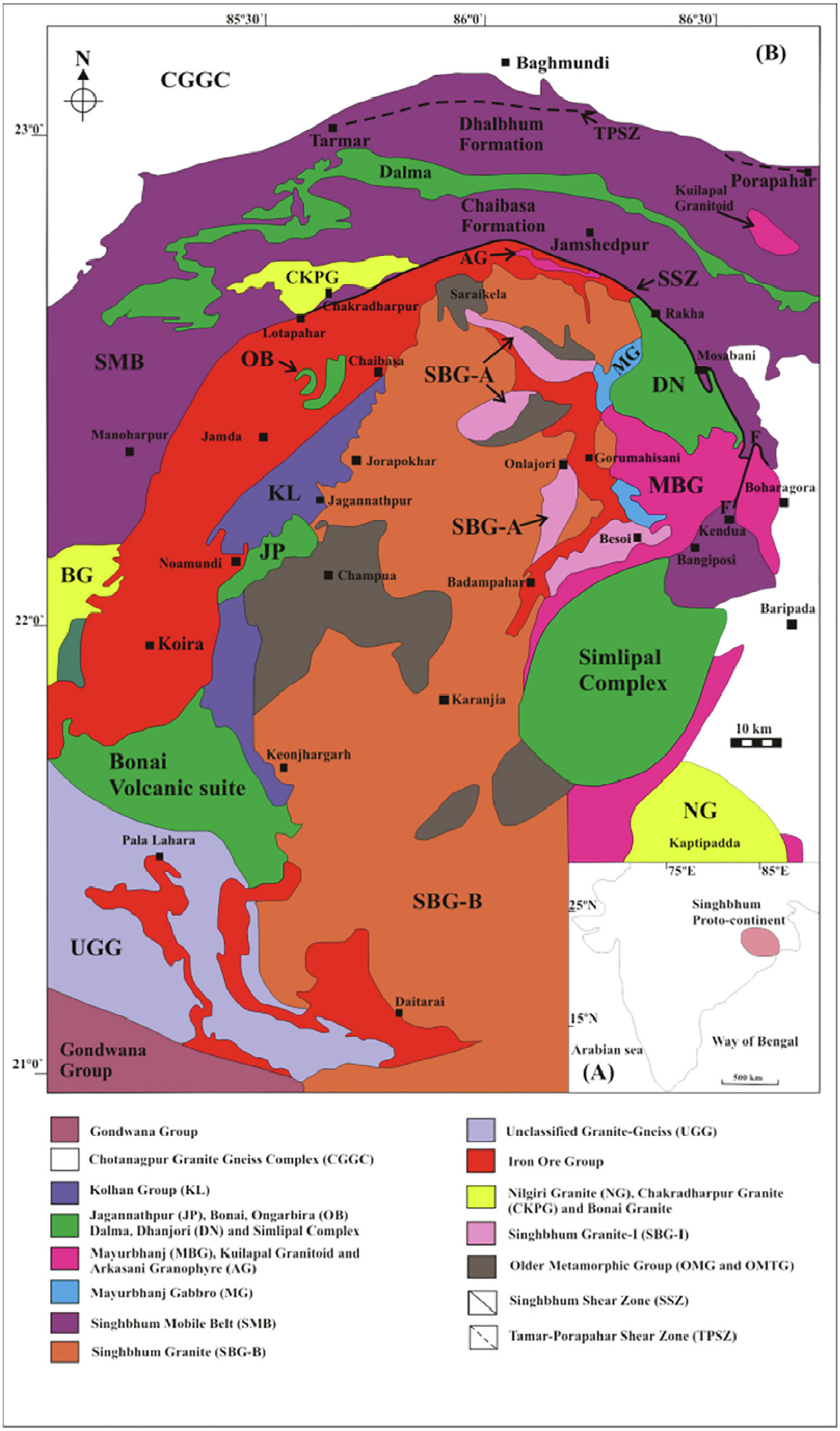

Fig 2. Simplified geological map of Singhbhum proto-continent including the Singhbhum Mobile Belt (SMB) (Saha, 1994).

Table 1
Chrono-stratigraphy of SMB and adjoining region (modified after Alvi, 2006).

South of Singhbhum Shear Zone (SSZ)	North of Singhbhum Shear Zone (SSZ)
Kolhan Group	Dalma Metavolcanic Suite and associated acidic tuff Kuilapal Granitoid Complex Arkasani Granophyre
Dhanjori/Ongarbira/Jagannathpur metavolcanic suite and Newer Dolerite (phase II) Dhanjori/Sahedba metsedimentary rocks	Newer Dolerite (Phase II)
Noamundi- Koira BIF and associated Mn-deposits	Dhalbhum Formation
Bonai metavolcanic Suite/Simlipal Complex/ Gabbro-Anorthosite and associated Newer Dolerite (Phase I)	Gabbro-Anorthosite
	Chakradharpur Granite-Gneiss Complex/Soda Granite
Chaibasa Formation	Chaibasa Formation
Singhbhum Granitoid Complex/Bonai Granitoids	
Gorumahisani- Badampahar BIF	
Older Metamorphic Tonalite Gneisses	
Older Metamorphic Group (OMG)	
Basement	Basement

across the SSZ (Sengupta and Ghosh, 1997). In the western part, SSZ is more than 25 km wide where three major shear slices are recognized. These slices are compressed into a narrow zone of about 1 km in the centre but widen again to more than 5 km in the eastern part (Sarkar, 1982).

On the north western margin of SBGC, Ongarbira metavolcanic suite having general ENE -WSW trend occurs discordant to the underlying platform type Chaibasa metasediments and Sahedba metasediments (Sarkar and Chakraborti, 1982). Since the lithological make up and structural geometry of Ongarbira metavolcanic suite and underlying Sahedba and platform type Chaibasa metasediments is more conformable to Singhbhum Group /SMB, it could not be regarded as part of Iron Ore Group (Banerjee, 1982; Blackburn and Srivastava, 1994). Mixed N-MORB and Arc-like geochemical signatures of Ongarbira metavolcanic rocks suggest that their back-arc origin cannot be completely disregarded (Blackburn and Srivastava, 1994). On the north eastern margin of SBGC, folded and highly metamorphosed rocks of Chaibasa Formation are unconformably overlain by slightly metamorphosed Dhanjori Group of rocks (Sarkar and Saha (1977). However, occurrences of 3.04–3.09 Ga old (Acharyya et al., 2010) U-bearing Quartz-Pebble-Conglomerate (QPC) at the base of Dhanjori metasediments (Sunilkumar et al., 1998), Pb-Pb WR and Sm-Nd WR isochron ages of 2858 ± 17; 2749 ± 210 Ma respectively obtained for Dhanjori

Table 2
Geochronological data on Singhbhum Mobile Belt (SMB), Singhbhum Shear Zone (SSZ) and Singhbhum-Odisha Craton (SBOC).

Rock Suite / Event	Radiometric Age and Data Source	Geochronological Method
Singhbhum Mobile Belt (SMB)		
Sushina Nepheline-Syenite	922.4 ± 10.4 Ma; Reddy et al., 2009	U-Pb SHRIMP concordant age
Kuilapal Granite-Gneiss	1638 ± 38 Ma; Sengupta et al., 1994	Rb-Sr WR isochron age
Dalma Acidic Tuff	1487 ± 34 Ma;1484 ± 34 Ma; Sengupta et al., 2000	Rb-Sr WR isochron age
Dalma metavolcanic rocks	1631± 6 Ma; Bhattacharya et al., 2015 1547 ± 20 Ma; Saha,1994 2487 ± 270 Ma; 2396 ± 110 Ma; Misra and Johnson, 2005	SHRIMP U-Pb Zircon age K-Ar age Rb-Sr WR isochron age
Chandil rhyolite: crystallization	1628.5 ± 4.3 Ma; Reddy et al., 2009 ~1600 Ma; Nelson et al., 2007	U-Pb SHRIMP concordant age
Basic-ulltrabasic Dalma	1619 ± 38 Ma; Roy et al., 2002a 2039; 2050; 2442; 2799; 2977 Ma; Roy et al., 2002a 3138; 2825; 3371; 2439; 2445 Ma; Roy et al., 2002a	Rb-Sr WR isochron age Sm-Nd (T_{DM}) age Sm-Nd (T_{CHUR}) age
Singhbhum Shear Zone (SSZ)		
Tectono-thermal event (Dhanjori Group)	793 ± 37; 835 ± 100;1031 ± 45 Ma; Achayya et al., 2010	U-Pb zircon concordia age
Arkasani Granophyres	1052 ± 84 Ma; Sengupta et al., 1994 1861 ± 6 Ma; Bhattacharya et al., 2015	Rb-Sr age SHRIMP U-Pb Zircon age
Uraninites (Jaduguda)	1464; 1478,1492; 1583 Ma; Krishna Rao et al., 1979	Pb-Pb age
Uranium mineralization (Jaduguda)	~ 1.88; 1.65; 1.0 Ga; Pal et al., 2011	U-Pb age
Apatite (SSZ)	1950 ± 100 Ma;1650 ± 50 Ma; Vinogradov et al., 1964	Pb-Pb age
Tectono-thermal events in Soda Granitoid	1633 ± 6; 1677± 11 Ma; Sarkar et al., 1986 2017; 2220 Ma; Sarkar et al., 1986 2100 ± 200Ma; Vinogradov et al., 1964 1420 ± 17 Ma; Pandey et al., 1986	Rb-Sr WR age, Pb-Pb WR age Pb-Pb WR age Rb-Sr WR age
Emplacement of Soda Granitoid	2460; 2498 Ma; 2517; 2519 Ma; Pandey et al., 1986	Sm-Nd (T_{DM}) age
Chaibasa metasedimentary rocks	2.5, 2.56, 2.52, 2.39, 2.49, 2.39, 2.60; 2.59 Ga; De et al., 2015	Sm-Nd (T_{DM}) age
Dhanjori metasedimentary rocks	2.82, 3.20, 2.54, 3.61; 2.48 Ga;De et al., 2015	Sm-Nd T_{DM} model ages
Dhanjori metavolcanic rocks	2072 ± 106 Ma; Roy et al., 2002b	Sm-Nd WR isochron age
Dhanjori Volcanism	2858 ± 17 Ma; Misra and Johnson, 2005 2749 ± 210 Ma; Misra and Johnson, 2005 3.13; 2.99; 2.99; 3.08; 3.21Ga; Mishra and Johnson, 2005	Pb-Pb WR isochron age Sm-Nd WR isochron age Sm-Nd (T_{CHUR}) age
Singhbhum- Odisha Craton (SBOC)		

Table 2 (*continued*)

Rock Suite / Event	Radiometric Age and Data Source	Geochronological Method
Tecono-thermal events in recorded in Newer Dolerites	2105 ± 38; 2144 ± 39; 2004 ± 35; 2068 ± 38; 1241 ± 25; 1264 ± 25; Mallik and Sarkar, 1994 1540 ± 16; 1960 ±16; 1069; 1220; 950; 1080; 1456; 1290; Saha, 1994	K-Ar WR age K-Ar WR rock age
Tectono-thermal event in Jagannathpur Volcanic rocks	1629 ± 30; Saha, 1994	K-Ar WR age
WNW-ESE trending Newer Dolerite Dykes	1766.2 ± 1.1 and 1764.5 ± 0.9 Ma; Ravi Shankar et al., 2014	^{207}Pb-^{206}Pb *baddeleyite* ages
Jagannathpur Volcanism	2250 ± 81; Misra and Johnson, 2005	Pb-Pb WR isochron age
Katipada Dolerite dykes	2256 ± 6 Ma; Olierook et al., 2019	U-Pb *baddeleyite* age
Keshargaria ultramafic dyke	2613 ± 177 Ma; Roy et al., 2004	Rb-Sr WR isochron age
NNE-SSW trending Newer Dolerite swarm	2763.7 ± 0.8, 2764.4 ± 0.8, 2763.5 ± 0.8, 2763.5 ± 0.9, 2760.0 ± 0.6, 2761.0 ± 0.1 and 2800.2 ± 0.7 2752.0 ± 0.9 Ma; Kumar et al., 2017	^{207}Pb/^{206}Pb *baddeleyite* age
Mayurbhanj Granite (Tectono-thermal event)	~2008 Ma; Iyenger et al.,1981	Rb-Sr WR isochron age
Mayurbhanj Granite (Tectono-thermal event)	~1960 Ma; Vohra et al.,1991	Rb-Sr WR isochron age
Temperkola Granite (Emplcement)	2809 ± 12; 2822 ± 67 MaBandyopadhyay et al., 2001	^{207}Pb-^{206}Pb age
Mayurbhanj Granite (Emplacement)	~2800 Ma; Acharyya et al., 2010	U-Pb SHRIMP zircon age
Keshargaria ultramafic dyke	2800.2 ± 0.7 Ma; Kumar et al., 2017	U-Pb *baddeleyite* age
Gabbro intrusion, Baula Complex	3122 ± 5 Ma; Auge et al., 2003	U-Pb SHRIMP zircon age
PGE mineralized Breccia	3123 ± 7; 3119 ± 6;Auge et al., 2003	U-Pb SHRIMP zircon age
Granitoid Emplacement in SBGC	3241 ± 7 Ma; Mishra et al., 1999 3288 ± 8 Ma; Reddy et al., 2009 3328 ± 7 Ma; Mishra et al., 1999 3290 ± 8.6 Ma; Tait et al., 2011 ~3350 Ma; Basu et al.,1996	^{207}Pb-^{206}Pb age U-Pb SHRIMP concordant age U-Pb age ^{207}Pb-^{206} Pb ageU-Pb Zircon age
Emplacement of OMTG	3437 ± 9 Ma; Mishra et al., 1999 3448 ± 19 Ma; Basu et al., 2008;Acharyya et al., 2010	^{207}Pb-^{206}Pb age Sm-Nd (T_{DM}) age
Paleoarchean TTG magmatism	3394 Ma; 3452 Ma3495.9 ± 5.3 Ma; Tait et al., 2011	SHRIMP U-Pb zircon age
Dacitic volcanism, Diatri-Tomka BIF belt	3506.8 ± 2.3 Ma; Mukhopadhyay et al., 2008	U-Pb SHRIMP zircon age
Detrital zircons, OMG	3590 ± 32; 3553 ± 18; 3525 ± 243583 ± 25; 3555 ± 21; 3522 ± 193501± 21; 3627 ± 39 Ma; Mishra et al., 1199	^{207}Pb-^{206}Pb zircon age

metavolcanic rocks (Mishra and Johnson, 2005) and Sm-Nd T_{DM} model ages of 2.82, 3.20, 2.54, 3.61 and 2.48 Ga for Dhanjori metasediments, 2.5, 2.56, 2.52, 2.39, 2.49, 2.60 and 2.59 Ga for Chaibasa metasediments (De et al., 2015) and 2460, 2498, 2517, 2519 Ma obtained for Soda Granitoids (Pandey et al, 1986) perhaps points towards an older age of Dhanjori Group which corroborates the observation of Mukhopadhyay (1976), Mukhopadhyay (1988) and Gupta et al. (1985) that rocks of Chaibasa Formation conformably overlie the Dhanjori Group of rocks. Thus, the age of the Dhanjori Group may be tentatively considered to range from 2.8 to 2.1 Ga. Alvi and Raza (1992) on the basis of decoupled trace element data suggested that Dhanjori metavolcanic rocks represent volcanic arc tholeiites emplaced on a thin continental margin which is in accord with the observation of Mazumder and Sarkar (2004) that at the time of Dhanjori volcanism the continental crust was thin perhaps it was 15–20 km thick.

3. Discussion

Available radiometric ages of the minerals and rocks indicate continuity of Paleoproterozoic geological processes on both sides of SSZ (Table 2). A summary of geological events based on the radiometric ages is given in Table 3. The tectono-thermal events that affected the rocks of SMB and SSZ appear to be 2.5, 2.2, 1.8, 1.6 and ~1.0 Ga. Chakradharpur Granite-Gneiss Complex, Arkasani Granophyres and Soda Granite are emplaced within the mylonitized metasediments of SSZ. Major Proterozoic large scale intracrustal shear zones such as SSZ consisting of a complicated mosaic of mylonite belts have been described from several continents and record ductile deformation at varying crustal levels (Kroner, 1991). Some of these have been equated with modern large-scale transform faults (Grocott, 1977) accommodating ancient transcurrent plate motion or resulting from large scale rotation of crustal blocks (Coward, 1984) while others as seen as resulting from compressional over thrusting or a combination of all these processes (Korstgard et al., 1987). Whatever their cause, most investigators agree that they are intimately linked to Proterozoic accretion and collision process (Kroner, 1991).

The problem involved with the geodynamic evolution is whether the SMB was developed as a Paleoproterozoic ensialic rift or was evolved through crustal accretion along a Paleoproterozoic active continental margin. Volcanic arc/*syn*-collision geochemical signatures of SBGC (Saha, 1994) suggest that on the regional scale modern-style plate-tectonic processes were operational during 2800 Ma to 3200 Ma or slightly earlier. The flysch character of Chaibasa rocks also suggests an early *syn*-orogenic evolution of the sediments (Sarkar, 1982). Geochemical characteristics of Chakradharpur granite-gneisses, Arkasani granophyres, Dalma, Ongarbira and Dhanjori metavolcanic suites also have significant bearings on the geodynamic evolution of SMB. Calc-alkaline and

Table 3
Summary of the Geological Events recorded in Singhbhum- Odisha Region, Eastern India.

Age (Ma)	Geological Event	Major Lithology
700–1000 Neoproterozoic [Tonian]	Emplacement of Sushina Nepheline-Syenite	Nepheline -Syenite
	Tectonic-thermal event [recorded in Dhanjori metasediments, Arkasani Granophyres, Newer Dolerites and Kolhan Group metasediments]	
1000–1200 Mesoproterozoic [Stenian]	Uranium Mineralization in SSZ (III phase)	
	Tectonic-thermal event [recorded in Noamundi –Koira BIF, Newer Dolerites]	
1200–1400 Mesoproterozoic [Ectasian}	*Tectonic-thermal event* [recorded in Newer Dolerite, Dhanjori Group]	
1400–1600 Mesoproterozoic [Calymmian]	*Tectonic-thermal event* [recorded in Kuilapal Granite-Gneiss , Chandil rhyolite, Dalma metavolcanic rocks, Soda Granitoid, Kolhan Group, Noamundi- Koira BIF, Newer Dolerites]	
1600–1800 Paleoproterozoic [Statherian]	Deposition of Kolhan Group	Shale, sandstone, Limestone
	Emplacement of Dalma Volcanic Rocks	ultramafic to acidic volcanic rocks, agglomerate
	Uranium mineralization in SSZ (Phase- II)	
	Copper mineralization in SSZ;	
	Tectonic-thermal event [recorded in Soda Granitoids, Jagannathpur volcanic rocks	
	Emplacement of Newer Dolerite dykes	Dolerite dykes
1800 – 2000 Paleoproterozoic [Orosirian]	Uranium mineralization in SSZ (Phase-I)	
	Emplacement of Arkasani Granophyres	
	Tectonic-thermal event [recorded in Simlipal, Mayurbhanj Granitoid]	
	Deposition of Dhalbhum Formation	Phyllites, micaceous schists quartzites and carbonaceous rocks
	Deposition of Noamundi-Koira BIF	Manganese ore, Manganiferous shales, Iron ore, BHJ, BHQ, tuffaceous shales
2000–2300 Paleoproterozoic [Rhyacian]	*Tectonic-thermal event* in Newer Dolerites, Mayurbhanj Granitoids, Noamundi-Koira BIF	
2300–2500 Paleoproterozoic [Siderian]	Emplacement of Jagannthpur volcanic Rocks	
	Emplacement of Soda Granitoids	
	Chaibasa – Ghatshila sedimentation	Phyllites and mica schists with intercalated bands and flat lenses of micaceous quartzite and gritty quartzite
2500 – 2800 Neoarchean	Dhanjori Sedimentation	QPC, Quartzite, Pelitc-schists
	Emplacement of Dhanjori Volcanic Rocks	Ultramafic to acidic volcanic rocks, agglomerate
	Emplacement of Keshargaria ultramafic dyke/ Newer Dolerite dykes	Dolerite dykes
	Tectonic-thermal event SBGC	
2800–3200 Mesoarchean	Emplacement of Temperkola Granitoids Emplcement of Mayurbhanj Granitoids	
	Gabbro intrusion, PGE mineralization in Baula Complex	
	Granitoid Emplacement in SBGC	Singhbhum Granitoid –B
	Deposition of Gorumahisani-Badampahar BIF	Iron ore, BMQ, quartzite, fuchsite quartzite, cherty quartzite
3200–3600 Paleoarchean	Granitoid Emplacement in SBGC	Singhbhum Granitoids -A
	Tectonic-thermal event	
	OMG amphibolites	
	Emplacement of OMTG and Keonjhargarh- Bhanura TTG	TTG
	Dacitic volcanism, Daitari-Tomka BIF	
	OMG Sedimentation	Quartzites, mica- schists, calc-silicates, amphibolites

volcanic arc affinity of Chakradharpur granite-gneisses and Arkasani granophyres (Sengupta et al., 1983; Bhattacharya et al., 2015) do not corroborate with the rifted basin model of the SMB. Occurrence of unconformity between the Chaibasa and Dhalbhum Formation clearly displayed in Subarnarekha River left bank, southwest of Kanderberia (Banerjee, 1982) invalidates the consideration of a conformable relationship between the Dalma suite (Gupta et al., 1980; Sarkar, 1982; Saha, 1994) and underlying Dhalbhum and Chaibasa rocks. Hence, the central theme of the intraplate extension model of Gupta and Basu (2000) that "*intracratonic extension induced by a thermal plume that led to rift-related Dalma volcanism and the concurrent development of basins and sub-basins of sedimentation in SMB*" becomes invalid.

The marginal basin model of Bose and Chakraborti (1981) is also not acceptable for the SMB in view of the given stratigraphic, sedimentologic considerations and the petrochemical affinity of the Dalma metavolcanic rocks (Alvi et al., 2019) and underlying metasedimentary rocks (Mir et al., 2015). CGGC also appears to be a suspect terrane (Radhakrishna, 1989). A pronounced angular unconformity occurs below the Dalma lavas in the Thakuran pahari area of Midnapur district (De et al., 1963) and in Dhalbhumgarh-Nischintapur area of SMB (Sarkar and Saha, 1977). A number of earlier workers have used major element geochemistry of the Dalma, Ongarbira and Dhanjori metavolcanic suites without the proper consideration of element mobility during post-igneous alteration processes including metamorphism. As a result, their investigations revealed chemical characteristics of komatiite, high-Mg and high-Fe tholeiite, N-MORB and back-arc basalts from these metavolcanic suites. Spinifex texture and a strong within-plate basalt geochemical affinity is absent in these metavolcanic

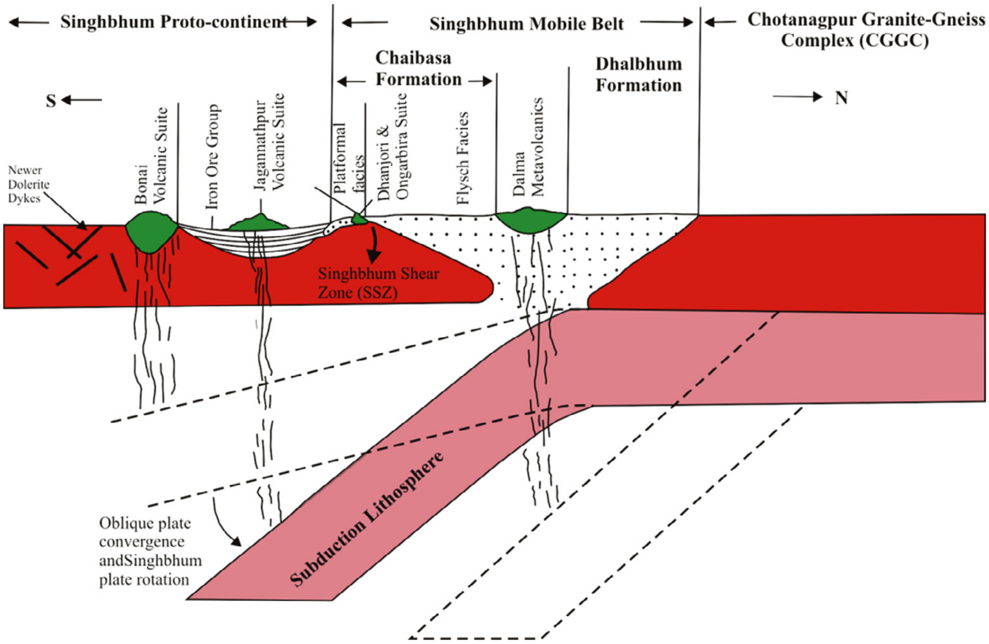

Fig. 3. Schematic cross-section showing purposed evolution of Singhbhum Mobile Belt (SMB).

suites. A review of incompatible trace element geochemical features of Dalma, Dhanjori and Ongarbira metavolcanic rocks (Alvi, 2006) lead us to infer the volcanic arc affinity of these metavolcanic rocks. A schematic diagram for the evolution of Singhbhum Mobile Belt is given in Fig. 3. The only possible direction for subduction during Paleoproterozic appears towards the south below the margin of SBGC. SMB did not evolve as an ensialic rift as purposed by different workers (Gupta et al., 1980; Roy et al., 2002ab; Mazumder and Arima, 2009).

4. Metallogeny

Two distinct types of U-mineralization are recorded from the Dhanjori basin and adjacent SSZ: (i) Quartz Pebble Conglomerate (QPC) of Neoarchean identifying SBGC as provenance (Sunilkumar et al., 1998) and (ii) SSZ controlled hydrothermal vein deposits of Paleoproterozoic age. Pal et al. (2011) has identified three distinct events of hydrohermal activity at ~1.88, 1.65 and 1.0 Ga in the SSZ. Variation in host lithology from biotite-chlorite schist around Kanyaluka, to chlorite-biotite-quartz- apatite-magnetite- ilmenite-tourmaline rock (termed as granular rock) in Jaduguda, to chlorite-sericite schist around Narwapahar-Turamdih to tourmaline bearing quartzite in Mahuldih is a convincing evidence for structurally controlled U-mineralization along the SSZ. Au in association with base metal sulfides occurs in several localities in vicinity of Dhanjori and Dalma metavolcanic rocks. Apatite-magnetite deposits is closely associated with the chlorite schist and its variants and also hosted at places by Dhanjori metavolcanic rocks. Radiometric age of 1950 ± 100 Ma and 1600 ± 50 Ma obtained for apatite-magnetite and apatite indicates two phases of apatite mineralization. Reported $\delta^{34}S$ values (0.00‰ to + 10‰) and $\delta^{18}O$ (4.17‰ to 7.14‰) from the Cu-deposits (Saha, 1994) also suggest volcanic arc-hydrothermal activity associated with subduction related Dhanjori volcanism. Soda Granite representing S-type granite is the characteristic feature of collision belt, back-arc fold thrust belt and perhaps outer arcs. Sm-Nd (T_{DM}) ages, Rb-Sr isotopic ages with high initial Sr ratio and Pb-Pb isotopic dates (Table 2) suggest that Soda Granite was emplaced/ crystallized around 2500 Ma and due to remobilization during shear movements, Rb-Sr clock was reset at 1600 Ma and 1400 Ma. Pb-Pb isotopic data scatter between 2200 Ma and 1450 Ma is perhaps due to Pb-loss during deformation and remobilization during shear movements along SSZ.

5. Summary and conclusions

Mantle plume events can be identified by the recognition of igneous rocks associated with mantle plumes, commonly called as plume proxies (Abbott and Isley, 2002; Ernst and Buchan, 2002). A number of workers (Gupta et al., 1980; Roy et al., 2002a, 2002b; Mazumder and Arima, 2009) suggested that Dalma and Dhanjori metavolcanic rocks were genetically connected with the mantle plume. However, plume proxies such as (i) spinifex textured komatiites and associated high-Mg basalts, (ii) massive flood basalt provinces with an original surface area greater than 410,000 km^2, (iii) maximum feeder dyke widths greater than 70 m and (iv) layered intrusions with enrichments in Cr and/or PGE, as listed by Abbott and Isley (2002) are not found in the Singhbhum Group or in the SMB rocks.

Converging micro-plate model (Sarkar, 1982) and intra-plate subduction model (Saha, 1994) considered that: (i) Singhbhum-Odisha cratonic margin during the Neoarchean started converging towards north. However, volcanic arc/syn- collision geochemical signatures of SBGC (Saha, 1994) place a major constraint on its northward convergence. Continents or arcs are generally too buoyant to be converged. (ii) In the 'Singhbhum ocean basin' developed in the north during Paleoproterozoic, deposition of Chaibasa and Dhalbhum Formation, and Dalma and associated magmatic episodes took place under extensional tectonic regime (Saha, 1994). However, the flysch characteristics and sedimentary structures of Chaibasa Formation suggest a *syn*-orogenic evolution (Sarkar, 1982). Calc-alkaline/volcanic arc geochemical signatures of Chakradharpur Granite-gneisses (Sengupta et al, 1983), Ongarbira and Dhanjori metavolcanic suites (Alvi and Raza, 1992; Raza et al., 1995), and Arkasani granophyres (Bhattacharya et al., 2015) lead to suggest their emplacement on an active continental margin. If these magmatic suites are lying on the down going plate, there is no other subducting slab that could cause subduction zone related magmatism on the margin of SBGC. The only possible direction of subduction during the Paleoproterozoic appears towards the south below the margin of SBGC. It therefore appears that geological evolution of SMB did not take place as an ensialic rift as proposed by Sarkar and Saha (1963) and Saha (1994). It was evolved through the crustal accretion along an active margin now represented by SBGC.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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