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Mesoproterozoic suturing of Archean crustal blocks in western peninsular India: Implications for India–Madagascar correlations

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ABSTRACT

The Kumta and Mercara suture zones welding together Archean crustal blocks in western peninsular India offer critical insights into Precambrian continental juxtapositions and the crustal evolution of eastern Gondwana. Here we present the results from an integrated study of the structure, geology, petrology, mineral chemistry, metamorphic *P–T* conditions, zircon U–Pb ages and Lu–Hf isotopes of metasedimentary rocks from the two sutures. The dominant rocks in the Kumta suture are greenschist- to amphibolite-facies quartz–phengite schist, garnet–biotite schist, chlorite schist, fuchsite schist and marble. The textural relations, mineral chemistry and thermodynamic modelling of garnet–biotite schist from the Kumta suture indicate peak metamorphic *P–T* conditions of ca. 11 kbar at 790 °C, with detrital SHRIMP U–Pb zircon ages ranging from 3420 to 2547 Ma, εHf (t) values from −9.2 to 5.6, and $T_{DM}{}^{c}$ model ages from 3747 to 2792 Ma. The K–Ar age of phengite from quartz–phengite schist is ca. 1326 Ma and that of biotite from garnet–biotite schist is ca. 1385 Ma, which are interpreted to broadly constrain the timing of metamorphism related to the suturing event. The Mercara suture contains amphibolite- to granulite-facies mylonitic quartzo-feldspathic gneiss, garnet–kyanite–sillimanite gneiss, garnet–biotite–kyanite–gedrite–cordierite gneiss, garnet–biotite–hornblende gneiss, calc-silicate granulite and metagabbro. The textural relations, mineral chemistry and thermodynamic modelling of garnet–biotite–kyanite–gedrite–cordierite gneiss from the Mercara suture indicate peak metamorphic *P–T* conditions of ca. 13 kbar at 825 °C, followed by isothermal decompression and cooling. For pelitic gneisses from the Mercara suture, LA-ICP-MS U–Pb zircon ages vary from 3249 to 3045 Ma, εHf (t) values range from −18.9 to 4.2, and $T_{DM}{}^{c}$ model ages vary from 4094 to 3314 Ma. The lower intercept age of detrital zircons in the pelitic gneisses from the Mercara suture ranges from 1464 to 1106 Ma, indicating the approximate timing of a major lead-loss event, possibly corresponding to metamorphism, and is broadly coeval with events in the Kumta suture. Synthesis of the above results indicates that the Kumta and Mercara suture zones incorporated sediments from Palaeoarchean to Mesoproterozoic sources and underwent high-pressure metamorphism in the late Mesoproterozoic. The protolith sediments were derived from regions containing juvenile Palaeoarchean crust, together with detritus from the recycling of older continental crust. Integration of the above results with published data suggests that the Mesoproterozoic (1460–1100 Ma) Kumta and Mercara suture zones separate the Archean (3400–2500 Ma) Karwar–Coorg block and Dharwar Craton in western peninsular India. Based on regional structural and other geological data we interpret the Kumta and Mercara suture zones as extensions of the Betsimisaraka suture of eastern Madagascar into western India.

1. Introduction

Transcrustal shear/suture zones hold prime importance as 'piercing points' (e.g., Katz and Premoli, 1979) and are among the critical parameters used for palaeogeographic configurations of supercontinental assemblies. The direct correlation between continental fragments through time has often been hindered by the effect of multiple tectonic events within the same terranes, coupled with differential degrees of weathering and alteration, and variable rates of exhumation, uplift and erosion. These palaeo-subduction zones/sutures are considered to be tectonic boundaries, where two different continents were juxtaposed by the

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subduction of oceanic lithosphere (Dewey, 1977). Palaeo-suture zones are characterised by, at least in the recent geological past, the presence of high-pressure rocks, ophiolitic remnants, relict continental shelves, accretionary wedges, granitoids related to arc magmatism, thrusts and tectonic mélanges (Dewey, 1977). Some suture zones are characterised by mylonitic ductile shears and the crustal blocks on either side of the suture may have different lithologies, structure, age, geochemistry, isotopic characteristics and metamorphic histories and different orientations of palaeo-magnetic vectors (Moores and Twiss, 1995).

The period between the assembly of Rodinia and its break-up to form the Gondwana supercontinent in the Neoproterozoic marks an important stage in the tectonic history of southern peninsular India (Santosh et al., 2009). One of the major factors to be determined for paleo-geographic reconstruction is to delineate the zone of amalgamation or suturing within the present continent, based on the above criteria, to establish correlations with other continental fragments. Katz and Premoli (1979) suggested that crustal-scale tectonic lineaments/shear zones/suture zones across continental fragments are one of the major features that can be used for paleo-geographic reconstruction, based on which they proposed a correlation between India and Madagascar. Following this study, several workers attempted to place India and Madagascar into their Gondwana setting, based on regional lithological, structural, geochronological, geochemical and geophysical evidence (e.g., Agarwal et al., 1992; Collins and Windley, 2002; Collins et al., 2007; Ghosh et al., 2004; Ishwar-Kumar et al., 2013b, 2015; Raharimahefa and Kusky, 2006, 2009; Ratheesh-Kumar et al., 2015; Raval and Veeraswamy, 2003; Rekha and Bhattacharya, 2014; Rekha et al., 2013, 2014; Tucker et al., 2011a, 2011b; Windley et al., 1994). However, the many and varied models have led to considerable inconsistency, mismatch and disagreement about specific correlations. Some of the reasons for this inconsistency are variation in age, the precise position/extent of the shear/suture zones, problems with bathymetry, and the variation or distortion in scale. Although some correlations have minimum scale distortion that does not affect the proposed correlation (e.g., Collins et al., 2007; Ishwar-Kumar et al., 2013b, 2015; Katz and Premoli, 1979; Ratheesh-Kumar et al., 2015; Tucker et al., 2011a, 2011b, 2014), other correlations have large-scale distortions so that, when corrected, the correlation of shear zones proposed is not supported (e.g., Rekha et al., 2013, 2014) (Supplementary Fig. S1). To minimise the distortion in scale in the present study the Geographic Information System (GIS) platform (Arc GIS 10 software) was used.

The Betsimisaraka suture in eastern Madagascar separates the Archean–Neoproterozoic Antananarivo Block (2700–2500 Ma gneisses and 824–550 Ma granitoids) to the west from the Archean Antongil–Masora block (3300–2490 Ma gneisses and granitoids) to the east (Supplementary Fig. S2). The Betsimisaraka belt contains cataclastic/mylonitic, banded and augen gneisses (Hottin, 1969) and was established as a suture zone by Collins et al. (2000), Collins and Windley (2002), Kröner et al. (2000) and Raharimahefa and Kusky (2006, 2009), which they considered was formed during the amalgamation of East and West Gondwana in the Neoproterozoic.

However, recently the Betsimisaraka suture, particularly its age and correlation with other shear/suture zones has become a major controversy (Brandt et al., 2014; Ishwar-Kumar et al., 2013b, 2015; Key et al., 2011; Plavsa et al., 2014; Rekha et al., 2013, 2014; Tucker et al., 2011a, 2011b, 2014). Recent studies by Tucker et al. (2011a, 2014) have dismissed the concept of the Betsimisaraka as a Neoproterozoic suture. They proposed that, the zone was occupied by a sedimentary basin (the Manampotsy Group) that was deposited in the period 840–760 Ma. According to Tucker et al. (2011a) there may have been an ocean on the site of the Manampotsy basin in the Neoarchean, which was destroyed at 2550–2480 Ma when the Antananarivo Block was amalgamated with the Dharwar Craton of India and the Antongil–Masora Craton of Madagascar. They further correlated the Angavo Shear Zone of Madagascar with the Moyar Shear Zone of southern India and this correlation is comparable with that of Brandt et al. (2014). Based on structural, geological and geochronological data, along with mineral chemistry and thermodynamic modelling, Ishwar-Kumar et al. (2013b) proposed the existence of Mesoproterozoic (ca. 1300 Ma) Kumta and Coorg ("Mercara" hereafter) sutures in western India and interpreted them as the eastern extension of the Betsimisaraka suture and this correlation was supported by Ratheesh-Kumar et al. (2015) based on geophysical results. Based on geochemical and geochronological results, Santosh et al. (2015) identified the Mesoarchean Coorg block as an exotic micro-continent that amalgamated with the Dharwar Craton after ca. 2500 Ma along the Mercara suture. Rekha et al. (2014) proposed a Paleo–Mesoproterozoic South Maharashtra Shear Zone (SMSZ) and interpreted it as the northern boundary of the western Dharwar Craton, and consequently it is located in the northern segment of the Kumta suture (Figs. 1, 2a). Rekha et al. (2014) disputed the Mesoproterozoic age of the Kumta suture and correlated the Betsimisaraka Suture Zone of Madagascar directly to the proposed Manjeshwara–Sullia shear zone, which lies within the northern segment of the Mercara Shear Zone as proposed by Chetty et al. (2012), Ishwar-Kumar et al. (2013a, 2013b), Krishnaraj et al. (1994) and Santosh et al. (2015) (Figs. 1, 2b). Based on mesoscopic structures and monazite age data, Rekha et al. (2014) suggested that the Mercara suture formed at 2300–2500 Ma, and proposed that if the Betsimisaraka suture extended into western India, it should correlate with the 2300–2500 Ma Mercara suture and hence it should be a Neoarchean suture.

The above inconsistencies and disagreements about the existence and correlation of different shear/suture zones constitute the major barrier in understanding the tectonic evolution of eastern Gondwana. Defining the actual shear/suture zones and estimating their ages are critical factors and require detailed studies of rocks on either side, and within, the proposed sutures; particularly a detailed study of metasedimentary rocks within the suture zones that might provide evidence of their provenance prior to ocean closure. In addition, the timing of collision of the surrounding blocks and their metamorphic history are key features that need to be established. In the present study, we therefore focus on metasedimentary rocks from the Kumta and Mercara suture zones. We discuss the detailed geology, structure and metamorphic conditions of these rocks and present zircon U–Pb geochronological and hafnium isotope results. Based on these results, we estimate the time of suturing and establish the metamorphic evolution of rocks within these zones and use this information to constrain the possible correlations between India and Madagascar.

2. The Kumta and Mercara suture zones

2.1. The Kumta suture

The Kumta suture is located at the western margin of peninsular India (Figs. 1, 2a), and has been interpreted as the eastern extension of the Betsimisaraka Suture Zone of Madagascar (Ishwar-Kumar et al., 2013b). The suture separates ca. 3200 Ma tonalite–trondhjemite–granodiorite (TTG) and amphibolite of the Karwar block in the west from ca. 2571 Ma quartzo-feldspathic gneisses of the Dharwar Craton in the east. Rekha et al. (2013) reported Th–U–Pb monazite ages from granitoids and gneisses of the Karwar block that show a range from 2436 to 2958 Ma. The Sirsi shelf on the eastern side of the suture is a ca. 80 km-wide, westerly-dipping sequence of sedimentary/metasedimentary rocks (limestone, phyllite, shale, banded iron formation, sandstone and quartzite) that makes up a passive continental margin or shelf along the western margin of the Dharwar Craton. The ca. 15 km-wide curvilinear Kumta suture changes in strike from NW–SE to N–S to NE–SW (progressing southwards) and generally dips to the west at 30°–65°. Rocks in the Kumta suture are at greenschist- to amphibolite-facies, and are highly sheared and deformed schistose lithologies that include garnet–biotite schist (Fig. 3a; Supplementary Fig. S3a, b), quartz–phengite schist (Fig. 3b; Supplementary Fig. S3c,