Neoproterozoic-Pan-African Orogen in the Indian Peninsula and its Tectonic Significance for the East Gondwana Assembly: An Example from South Delhi Terrane, Southern Granulite Terrane and Eastern Ghats Mobile Belt

Tanushree Mahadani,1 Sundaralingam K.,1 and Tapas Kumar Biswal1*

Abstract: Peninsula India has long been considered to be existed in the East Gondwana assembly since Meso-Proterozoic period. However, recent work on South Delhi Terrane, Southern Granulite Terrane and Eastern Ghats Mobile Belt reveals that Neo-Proterozoic and Pan African mobile belts were existing surrounding the central Indian cratons. These mobile belts were probably contiguous with the Madagascar, Sri Lanka and Antarctica and therefore it has been interpreted in this paper that the Indian Peninsula coalesced with other continents of the East Gondwana during Neo-Proterozoic-Pan-African period. Structural study of the granulites from the above mentioned Indian terranes shows strong similarities in that the granulites have been exhumed through thrusting during Neo-Proterozoic-Pan-African period forming granulitic thrust belts over the craton and in the process juxtaposing the mobile belts with the craton, thrusting is pre to syn-kinematic with F2 stage of folding, strain along the thrusts varies from flattening to constriction with association of pure to general shear component depending on the direction of convergence between different blocks and the granulites have been retrograded to schists and amphibolites along the shear zones.

Key words: Neoproterozoic-Pan African Orogen, Indian Peninsula, South Delhi Terrane, Southern Granulite Terrane, Eastern Ghats Mobile Belt.

Introduction

The Indian Peninsula represents agglomeration of several terranes ranging in age from 3.8 Ga to 0.5 Ga. These terranes have been stitched together by collision and accretion. In the pre-Gondwana break-up assembly India was placed in the surrounding of Antarctica, Australia, Madagascar and Africa forming the East Gondwana.

1 Department of Earth Sciences, Indian Institute of Technology Bombay, Powai, Mumbai, India.
*Author for correspondence: tkbiswal@iitb.ac.in
The recent study reveals that Neoproterozoic-Cambrian terranes were existing surrounding the central part of the Indian Peninsula suggesting that the final juxtaposition of Peninsula with other blocks of the East Gondwana probably took place during that period. The Neoproterozoic-Cambrian terranes were fragmented during Gondwana rift and have been drifted to Arabian-Nubian Shield, Madagascar, East African Orogen, Sri Lanka, Antarctica and Australia. A correlative study with respect to the tectonic evolution of the granulites between South Delhi Terrane (SDT), Southern Granulite Terrane (SGT) and western margin of Eastern Ghats Mobile Belt (EGMB) of the Indian Peninsula brings out the above fact vividly. In line with this study, existence of Neoproterozoic-Cambrian age Circum-Indian Orogens as an evidence of amalgamation of eastern Gondwana has been opined (Collins et al., 2005).

**South Delhi Terrane (SDT)**

The Neoproterozoic SDT forms the western edge of the Aravalli Mobile Belt in the northwestern India. The SDT is flanked by Paleoproterozoic Aravalli Groups of rocks to the east and the Marwar Craton to the west. Sirohi Group of rocks which are of Neoproterozoic age occur as an island within the vast exposures of granite and granite gneisses of the Marwar Craton, hence for all practical purposes the Sirohi and Delhi rocks have been included in a single terrane. The Marwar Craton has been extensively intruded by Neoproterozoic Erinpura (ca. 850-735 Ma) and Malani granitic suite (ca. 793-818 Ma) (Crawford, 1975; Choudhary et al., 1984; Bhushan, 2000), therefore, the Archaean components have been reduced to minor and doubtful occurrences; even from those rare outcrops, no Archean age has been reported so far. Internally the SDT has been subdivided into a number of longitudinal tectonic zones; the eastern zones are dominated by arenaceous facies while the western zones are represented by calcareous facies rocks (Heron, 1953; Sen, 1981). Generally, the rocks of the SDT are marked by multiple stages of folding and amphibolite facies of metamorphism. However, the terrane shows sporadic occurrence of granulites, ophiolites, blue schists and basement gneisses that occur as tectonic slices within the fold belt (Desai et al., 1978; Biswal, 1988; Biswal et al., 1998a; 1998b; Fareeduddin and Kröner, 1998; Srikurni et al., 2004; Singh et al., 2010). In this paper we have studied the structural setting of the Ghoda-Kengora granulite that occurs in the southern extreme of the terrane. The folding and shear zone patterns in the SDT granulites are important features for correlation with that of the other granulite belts.

**The shear zones of SDT**

Figure 1 shows multiple shear zones intersecting the granulites and granites association of the SDT. The granulites include pelitic granulites consisting of spinel, sillimanite, cordierite, garnet, biotite and zircon with rare kyanite, andalusite and sapphireine; calcareous granulites are made up of diopside, plagioclase, wollastonite, scapolite and zoisite forming resistant layers; garnet is rare and diopside carries inclusions of plagioclase and relict hornblende. The gabbro-norite-basic granulite plutons are of gabbro-norite composition in the centre, while towards the periphery the plutons
show metamorphism to basic granulites with opx, cpx and plagioclase; metamorphic foliation has been developed by the shape preferred growth of tabular hornblende and hypersthenes. The granulites are intruded by three phases of Ambaji granites; the G1 phase is produced from the melting of the pelitic granulites and show an age of ca. 840 Ma; G2 occurs as large scale batholiths showing an age of ca. 800 Ma and the G3 phase occurs as dykes and linear bodies showing an age of ca. 750 Ma. The granulites have undergone three stages of folding, the F1 is tight isoclinals reclined and have developed pervasive axial planar gneissosity fabric as the peak granulite facies metamorphism is synkinematic with this stage of folding; the F2 folds are coaxial with F1 and have developed hook pattern in small to large scale. Shearing has occurred parallel to the axial plane of the fold and large scale shear zones are developed during this period of folding. The F3 folding is developed in NW-SE and NE-SW axes and modified the trend of the shear zones.

The rock types in the shear zones vary depending on the host rock over which it
has been developed. While proto-, ortho and ultramylonites are developed in granites, the pelitic, calc and basic granulites are extremely sheared and kyanite-andalusite schist in pelitic granulite, epidote-zoisite schist in calc granulite and hornblende schist are developed in basic granulites. However, the shear zone fabrics have been studied in granitic mylonites and hence they are discussed here.

Structures
The mylonitic foliations are marked by stretched quartz and feldspar ribbons, segregation of feldspar clast into layers; they dip east and southeast and stretching lineation moderately plunging southeasterly (Figure 1a, 1b). At several places the S-fabrics are prominent making an angle to the C-fabric suggesting an oblique thrust slip to NW (Figure 2a). The S-C angle varies across the shear zone, the smaller angle occurs at the centre suggesting higher shear strain. Asymmetric porphyroclasts, microfaults and mica fishes point towards NW vergence of shearing (Figure 2b, 2c, 2d, 2e, 2f). Thus it has been interpreted from features that the granulite block has been thrust up over the low grade rocks to the west. Based on these thrusting criteria (Figure 1c), a model showing imbricate thrusting of different granulitic blocks has been drawn where the eastern most shear zone show normal faulting suggesting that the granulite block has been exhumed with respect to low grade terrain.

Geochronology of SDT
The SDT dominantly shows Neoproterozoic age (Choudhary et al., 1984; Crawford, 1975; Roy et al., 2005; Meert et al., 2008; Deb et al., 2001; Pantl et al., 2003; Singh et al., 2010) with beginning of sedimentation at ca. 966 Ma as indicated by the zircon age of the syn-sedimentary rhyolite flows in the basin. The granulite facies metamorphism took place ca. 861 Ma and the last igneous activity took place around ca. 759 Ma (Singh et al., 2010). The diorite of Ranakpur which shows an age of ca 1.0 Ga (Volpe and Macdougall 1990) has intruded during the opening of the basin. The Erinpura granite intrusion shows diverse ages (ca. 735-863 Ma) (Crawford, 1975; Just et al., 2011) this may be syn-kinematic to major deformation and metamorphism of Delhi-Sirohi rocks. Singh et al., 2010 dated granulite from Balaram-Kui-Surapaga-Kengara (BKSK) shear zone of SDT have been reported as ca. 860 Ma. The source rocks for the Delhi sediments are as old as ca 1.6 Ga (Singh et al., 2010). The BKSK granulites shows the much younger age compare to other Indian granulite such as, Sandmata Granulite Complex of northern part of the AFB, the Saussar granulites of the Central India Mobile Belt and granulites in the EGMB. Instead, they show similarities to the Neoproterozoic granulites of the Circum Indian Orogens that include the East African Orogen (East Africa and Madagascar), the Southern Granulite Terrane of India and much of Sri Lanka.

Southern Granulite Terrane (SGT)
The SGT forms the southern tip of Indian Peninsula. It is demarcated from the northern granulite terrane by a group of E-W trending shear zones including Moyar-Bhavani-Salem-Attur shear zone (MBSASZ) and Palghat-Cauveri shear zone (PCSZ),
the zone between the above shear zones was reported as Cambrian suture zone (Santosh et al., 2009; Singh et al., 2010). The northern granulite continues northward into Dharwar granite-greenstone terrane, the Fermor line defines the transition between the schist belts and the granulites (Ravindra Kumar et al., 1985). Madras, Salem and Nilgiri blocks are the prominent features in the northern granulite terrane that show Archaean/Palaeoproterozoic age. Contrarily, the Southern Granulite terrane (Madurai
and Trivandrum block) shows Neoproterozoic-Pan-African age. The northern granulite terrane consists of large charnockitic massif in the high land and mylonitised hornblende-biotite gneiss in the low land. Apart from this several rock types like granite-gneiss, migmatite, syenite and younger intrusive granite and ultra mafic, ultra basic rocks such as anorthosite, dunite, and pyroxenite occurs within it. The Madurai block of the SGT consist of charnockitic massif in the western part and basement gneisses and related meta-sedimentary rocks in the eastern part while the Trivandrum block is represented by khondalites, two pyroxene granulites and cale silicate rocks. The southern end of the Trivandrum block consist of large charnockitic massifs and is often referred as Nagarcoil block.

**Salem Attur Shear Zone (SASZ)**

SASZ has been studied around Salem (Figure 3). The shear zone is nearly 10 km wide and consists of mylonites compositionally represented by hornblende-biotite gneisses and quartzofeldspathic gneisses. However, at places large scale ridges and domal outcrops of banded magnetite quartzite, charnockite, and basic granulites occur, eg., Kanjamalai and Godumalai hills, interrupting the mylonitic country. These hills thus represent the low shear strain zone.

**Rock types in shear zone**

The granulites show opx + cpx + grt + plag + qtz and small amount of hornblende; charnockites contain quartz, plagioclase and alkali feldspars and banded magnetite quartzites show rhythmic layering of quartz rich and hematite-magnetite rich layers. At several places charnockitisation phenomenon (Figure 4a) is observed, the granite gneisses close to carbonate veins show growth of hypersthenes from biotite. The granulites and charnockites have been retrograded to hornblende-biotite gneiss and quartzofeldspathic gneisses during thrusting and occupy the low lying regions. Apart from these rocks, alkali syenites, granite, pegmatite, aplite veins and dolerite dykes have intruded the mylonites. At places, enclaves of retrograde eclogites occur within the alternate layers of hornblende-biotite gneiss and quartzofeldspathic gneisses; the eclogites show decompression corona structure around garnets.

**Structures in shear zone**

The rocks have undergone multiple stages of folding and shearing. The F1 and F2 folds are coaxial; the F1 folds occur as an intrafolial, tight, recumbent, reclin ed folds marked by S1 fabric (Figure 4b). The granulite facies metamorphism is associated with this stage of en e of shear, (f) Intrgranular fault shows sinistral shear sense that is sympathetic to the main shear folding. The F2 folds are coaxial with F1, as a result type 3 interference has been produced (Figure 4c). Parallel to the F2 fold shear band and cleavage are produced (Figure 4d). The F3 folds are open and has produced dome and basin pattern with F2 fold. The shearing is pre to syn F2 folding. The mylonites are best developed on quartzofeldspathic gneiss in the south of Godumalai hill. Stretching lineation, sigma and delta type pophyrclos, S-C fabric, asymmetric fold and intragranular faults are observed on the outcrops (Figure 4e, 4f). However,
under thin section, the oblique fabrics associated with S-C mylonites are replaced by static reocrystallisation that follows the mylonitisation.

The shear zone trends E-W in Salem area and takes a southerly turn near Kanjamalai hill which shows an elliptical outcrop in form of sheath produced from high degree of strain. At several places, subhorizontal thrust planes and shear fabric are observed suggesting that the original attitude of the Salem-Attur thrust was subhorizontal and slip was towards N and NE (Figure 3a, 3b). However, thrust zone has been steepened due to subsequent folding. In the north-south trend of the thrust south of Kanjamalai Hill (Figure 3c, 3d), dextral as well as sinistral slips are observed (Figure 4e, 4f). Hence it is interpreted that the E-W trend of the SASZ represents the frontal thrust while the N-S part is the lateral ramp. Granite, aplite and pegmatite veins have been emplaced synkinematically with thrusting.

**Geochronology of SGT**
The Dharwar Craton shows Sm-Nd ages of 3300-2680 Ma (Devaraju et al., 2007; Drury et al., 1983; Beckinsale et al., 1980). While the northern granulite terrane is ca. 2500 Ma (Peucat et al., 1993; Bhaskar Rao et al., 2003; Clark et al., 2009). The Kanjamalai Hill which occurs within the Salem Attur shear zone produces U-Pb age of 2477.6±1.8 Ma (Kei et al., 2011). The synkinematic granitic intrusions within the shear zone produce an age around ca.750-500 Ma (Naganjaneyulu and Harinarayana,
The mylonite of the shear zone has produced the age of 629-842 Ma (Meißner et al., 2002). The Madurai block produces an age between 560-480 Ma (Collins et al., 2004; Santosh et al., 2003; Bartlett et al., 1998). Trivandrum block which lies in the west of Madurai block shows the dominance of 560-520 Ma (Santosh et al., 2003; Soman et al., 1983; Bartlett et al., 1998). Thus it is evident that the SGT is
broadly Pan-African in age and it has been thrusted over the Archaean northern granulite terrane during Pan-African period. The thrusting is probably synkinematic to the collision between the northern granulite terrain and southern granulite terrain, thus both Archaean (Kanjamalai Hill) and Neo-proterozoic rocks occur together in the shear zone.

**Eastern Ghats Mobile belts (EGMB)**

The Eastern Ghats Mobile Belt occurs as linear belt along the east coast of Peninsula. It is a Meso-Proterozoic mobile belt that was contiguous with Rayner Mobile Belt of Antarctica in the Pre-Gondwana assembly. However, recent study shows that the final juxtaposition of the mobile belt with the Peninsula completed during Pan-African period (Biswal et al., 2007). Here, we have studied the NW front of the EGMB. The mobile belt is juxtaposed against the cratons of the Peninsula along well defined thrust which has been named as the Terrain Boundary shear zone (TBSZ), (Biswal et al., 2000) (Figure 5). It is a moderately inclined thrust toward the EGMB and the granulites of the EGMB have been tectonically emplaced over the craton in form of nappes. The cratons are dominated by potassic granite close to the EGMB. Granites are intruded by Lakhna dyke swarm that shows wide variation in composition from rhyolite to feldspar porphyry, trachyte and dolerite (Figure 6a). The dykes and the granites have been affected by shearing along the TBSZ. Over the granitic basement in the craton the platform rocks known as Purana are deposited in several basins implying foreland deposits. Nepheline syenites have been intruded along the TBSZ.

**Rock types in the EGMB**

Khondalite, riebeckite granite, charnockitic gneiss and basic granulites are the major rock types in the EGMB (Figure 5). Khondalites are typical rocks of the upper most Turekela nappe, these are characterised by alternate dark and white layers formed by the segregation of garnet, graphite, sillimanite, cordierite and biotite, quartz and alkali feldspar. Riebeckite-bearing granite gneisses form sharp ridges and are marked by blue stringers of riebeckite and green hypersthene aligned parallel to the foliation plane. Basic granulites are dominant rocks of the lower most Sinapali nappe. Decompression texture is quite prominent around garnet forming hypersthene corona. The charnockitic gneisses are the major rocks of the Lathore nappe, they show various migmatitic structures; garnet, biotite and hypersthene-rich palaeosomes alternating with quartzofeldspathic neosomes define such structures. Under the microscope, myrmecitkic structures are very common.

**Structures in the EGMB**

The above rock types show an early stage of co-axial folding between F1 and F2 along NE-SW axis; the granulite facies metamorphism is coeval with F1 folding (Biswal et al. 2000; Biswal et al., 2007; Ratre et al., 2010). A penetrative S1 planar fabric is developed in the rock, marked by parallel alignment of sillimanite, biotite, graphite and garnet in the khondalite, hypersthene and platy quartz in the charnockitic gneiss, and
riebeckite and hypersthene in the granite gneiss. F2 folds are marked by shear bands parallel to the axial plane of the fold. Thrusting of the granulites has been interpreted to be pre to syn-kinematic with F2 folding. Late stage folding (F3) along NW-SE axis has been folded the shear bands as well as modified the axes of the earlier folds, producing domes and basins. An amphibolite facies assemblage has been superimposed on the granulites during F3 folding. The TBSZ is developed at the interface between the Craton and the EGMB and is characterized by intense mylonitisation. Hence both granites of the Craton and the granulites of the mobile belt are mylonitised. From the margin to the centre of the shear zone, the size and proportion of the clasts varies gradually, thus creating zones of proto-, ortho- and ultramylonites respectively. The mylonitic foliation shows moderate dips towards the southeast and the stretching lineations are oriented down the dip on the foliation (Figure 5a, 5b). These features,
in addition to other such as stretching lineation, S-C fabric, mantled porphyroclasts (Figure 6b, 6c, 6d, 6e, and 6f) indicate a top to the northwest vergence of the shear zone.
Geochronology of the EGMB
A predominant Grenvillian-age granulite facies metamorphism (ca. 1.0 Ga) and charnockite emplacement characterize the EGMB (Aftalion et al., 1988; Shaw et al., 1997). A Pan-African thermal event, represented by amphibolite facies metamorphism, emplacement of nepheline syenite and pseudotachylite formation is reported in the vicinity of the shear zones including that from TBSZ. Emplacement of granites, charnockites and anorthosites show a broad age range from ca. 1.5 Ga to ca. 0.9 Ga (Aftalion et al., 1988; Paul et al., 1990). The nepheline syenite dyke emplaced along the TBSZ has been dated to be 0.517 Ga (Biswa et al., 2007) which indicate that the juxtaposition of granulite belt with the craton took place during Pan-African period. Further, the potassic granites of the craton and the Lakhna dyke swarms result an age of ca. 2.5 Ga and 1.4 Ga respectively (Sarkar et al., 1993; Krishnamurthy et al., 1988; Bandopadhyay et al., 1990; Ratre et al., 2010). This reflects that the craton was stabilized by the end of Archean and it went a stage of extensional tectonics during Meso-Proterozoic time when dykes were emplaced and Purana basins were created.

Strain analysis

Determination of state of strain in shear zones of different terranes
In the present study traditional strain analysis techniques have been adopted to examine the strain geometry. Original grains underwent shape changes through predominantly dislocation glide and recrystallization, thus estimates of the strain ellipsoid can be made from the aspect ratio of these deformed grains. Two dimensional strain measurements can be made on different planes in order to estimate the three dimensional strain geometry. These ratios when plot on Flinn diagram (Flinn, 1962) indicate the state of strain. The Flinn plot shows the field of apparent flattening, apparent constriction and plane strain (k=1).

To know the state of strain in the mylonite the aspect ratio of the dynamically recrystallized quartz grains has been measured. The grains are considered to represent the strain ellipsoid at that point. L-sections provide the X/Z values while T-sections provide the Y/Z values of the strain ellipsoid for a particular sample. When the average X/Y verses Y/Z of each sample are plotted in Flinn's diagram it has been observed that the concentration is in the flattening field for SDT (Figure 7a). For Salem-Arur Shear zone in SGT and for TBSZ in EGMB, the samples are plotted in constriction zone (Figure 7c, 7e).

Kinematics of flow (Vorticity Analysis)
In penetratively deformed rocks, in order to estimate the mean kinematic vorticity number (Wk) using porphyroclasts rotating in a flowing matrix, it is important to quantify the relative contributions of pure and simple shear (Jessup et al., 2007). Wk defined the vorticity which connects with the non-coaxiality of deformation, or the rotationality of flow with respect to an internal frame of reference. Wk is measured on a scale between 0 and 1 for pure shear and simple shear respectively, and 0<Wk<1.
for a combination of pure and simple shear (general shear). The Wk scale is not linear, but can be converted to a linear scale by considering the percent of a deformation resultant from simple shear (Forte et al., 2007). Various techniques have been proposed to measure the Wk in naturally deformed rocks. In the present study attempt has been made to determine Wk from mantled porphyroclasts by the Porphyroclast Hyperbolic Distribution (PHD) method (Simpson and De Paor, 1993; 1997) in mylonites, as described below.

Porphyroclast Hyperbolic Distribution (PHD) method- For this method the thin sections are cut parallel to the stretching lineation and perpendicular to the mylonite foliation and studied under optical microscope. An individual porphyroclast is identified as a forward rotated ? or backward rotated ? type (Simpson and De Paor, 1997). The axial ratios (R) of the porphyroclasts were calculated by measuring the major and minor axes of the elliptical clast. The angle between the long axis of the grain and the normal to foliation is the phi (θ) angle, with positive θ values indicating forward rotated grains and negative θ values indicating back-rotated grains. These R and θ data were plotted on a hyperbolic stereonet (De Paor, 1988), using the vertical axis of the net for the axial ratio (R) and the peripheral graduations for the angle of orientation (θ). After plotting the data, a best fit hyperbola was drawn to incorporate all the points on the plot, and the angle between the two limbs of the hyperbola represents the acute angle between the two eigenvectors (θ), such that the cosine of this angle (n) yields the kinematic vorticity number (Wk) (Simpson and De Paor, 1993; 1997 and Bödyarchick, 1986):

\[ Wk = \cos(\theta) \]

From the data potted, Porphyroclast Hyperbolic Distribution in different shear zones shows the different Wk values. In case of SDT, Wk value is = 0.54 indicating pure shear dominated flow (37% simple shear) (Forte et al. 2007) (Figure 7b). In contrast the TBSZ and SGT shows the Wk value 0.64 and 0.62 respectively (Figure 7d, 7f) indicating the general shear flow (44% - 42% simple shear). From the Wk values, it is indicate that all three shear zones are deformed heterogeneously.

Discussion and conclusion

1. SDT, SGT and EGMB show the Neo-Proterozoic-Pan-African age for shearing and thrusting of granulite belts over the Craton. The granulites are explained to have been exhumed by such thrusting and have undergone decompression and retrogression. The strain in the thrusts varies from flattening to constriction and from pure shear to general shear. This variation is attributed to right angle to oblique convergence of the adjoining blocks. This happens when the intercontinental shear zones change their trend or the direction of movement varies along the strike of the shear zone. Based on structure, strain and geochronology, the shear zones of the SDT, SGT and EGMB have been correlated and explained to be a continuous thrust belt that was active during Neo-Proterozoic- Pan-African period.
2. The shear zones occur within the granulites and they have been developed synkinematic with F2 stage of folding. The peak metamorphism has taken place during F1 folding. Hence the granulites have been decompressed as indicated by decompressive corona textures in them. Along the thrust plane, water activity has taken place as a result they have been retrograded to amphibolites. Alkaline rocks have been emplaced along the thrust in EGMB and SGT suggesting that the thrusts must be deep rooted. Further, granite, aplite and pegmatite veins have been intruded along the mylonitic bands. This suggests the decompressional melting of the metasediments. The convergence of blocks varies in different terranes as a result the strain variation is observed. Based on these common criteria the shear zones of the SDT, SGT and EGMB have been viewed as a part of a continuous shear belt.

3. In Figure 8 these three belts have been connected. The shear zones pass through Madagascar, Sri Lanka, Dronning Maud Land (DML) and Grove mountains of Antarctica. The Madagascar consists of 550 and 530 Ma old granulite belts (Kröner, 2000) with exhumation history related to thrust tectonics. The terranes of Sri Lanka were juxtaposed to the SGT of India at around 550 Ma (Kehelpannala, 2004). The central DML sector of east Antarctica forms an important segment because the suture between east and west Gondwana extends to this region (Jacobs et al., 2003). The emplacement of Gruber anorthosite and associated charnockite and their subsequent metamorphism are around
530-515 Ma (Jacobs et al., 2003). It has also been proposed that in DML, Mesoproterozoic (ca. 616-660 Ma) orogen is juxtaposed against a Pan-African orogen (ca. 570-530 Ma) (Pant et al., 2007). Similarly, the Grove Mountains of Prydz Bay area shows that the granulite facies metamorphism and emplacement of granitoids took place at ca. 530-500 Ma (Liu et al., 2006).

4. From these discussions it is evident that the central part of the Peninsula was surrounded by Neo-Proterozoic- Pan-African thrust belts. These belts probably
represents the Neo-Proterozoic Pan African suture zones resulted from the closure of Mozambique and adjoining oceans through subduction and collision of the continents with India (Santosh et al., 2009). The absence of 560-520 Ma metamorphism (or at least the localized and minor impact of such events), in the Seychelles and SDT, indicate that those terranes were distal to the collisional front. Thus the Indian Peninsula was not a coherent block until the Neoproterozoic but that various crustal blocks finally amalgamated during the late-Neoproterozoic-Cambrian "Pan-African" period (Mezger et al., 1999; Gregory et al., 2008; Biswal et al., 2007).

Acknowledgements

We would like to thank IIT Bombay, Mumbai for providing infrastructure and financial support, and also thank to Department of Science and Technology, New Delhi for financial help.

References


Biswal, T.K., Jena, S. K., Datta, S., Das, R. and Khan, K. 2000. Deformation of the Terrane Boundary Shear Zone (Lakhna shear zone) between the Eastern Ghats Mobile Belt and
the Bastar Craton, in the Balangir and Kaliahandi districts of Orissa. Journal of Geologi-
cal Society of India 55, 367-380.
Biswal, T.K., Waele B. D. and Ahuja H. 2007. Timing and dynamics of the juxta-
position of the Eastern Ghats Mobile Belt against the Bhandara Craton, India: A structural and
circon U-Pb SHRIMP study of the fold-thrust belt and associated nepheline syenite
Bobbyarchick, A. 1986. The eigenvalues of steady state flow in Mohr space. Tectonophysics
122, 35-51.
of the Precambrian rocks of Rajasthan. Tectonophysics 105, 131-140.
U-Pb age constraints on magmatism and high-grade metamorphism in the Salem Block,
southern India. Gondwana Research 16, 27-36.
of the Circum-Indian Orogens. Earth Sciences Reviews 7, 229-270.
Collins, A.S., Santosh, M. 2004. New protolith provenance, crystallisation and metamor-
pic U-Pb zircon SHRIMP ages from southern India", In: Chetty, T.R.K., Bhaskar Rao,
Y.J. (Eds.), International Field Workshop on the Southern Granulite Terrane, National
Geophysical Research Institute, Hyderabad, India, pp. 73-76.
Crawford, A. R. 1975. Rb-Sr age determination for the Mount Abu Granite and related
Geology 10, 323-333.
Pb isotope evidence an approximate 1.0 Ga terrane constituting the western margin of
the Aravalli-Delhi orogenic belt, northwestern India. Precambrian Research 108, 195-213.
area, north Gujarat and southwestern Rajasthan. Journal Geological Society of India 19,
383-394.
Devaraju, T. C., Viljien, R. P., Sawkar, R. H. and Sudhakara, T. L. 2007. Mafic and ultrama-
fic magmatism and associated mineralization in the Dharwar craton. Journal of Geological
Society of India 70, 535-556.
ages for Archaean rocks from western Karnataka, South India. Journal of Geology 92, 3-
20.
Fareeduddin and Kröner, A. 1998. Single zircon age constraints on the evolution of
Rajasthan granulite", In: Paliwal B. S. (Ed.), The Indian Precambrian, Scientific Publish-
ers (India), Jodhpur, pp. 547-556.
Fitzsimons, I. C. W. 2003b, Proterozoic basement provinces of southern and southwestern
Australia, and their correlation with Antarctica. In: M. Yoshida, B.F. Windley and S.
Dasgupta (Ed.), Proterozoic East Gondwana: Supercontinent Assembly and Breakup.
Fitzsimons, I.C.W. 2003a. Does the late Neoproterozoic Darling Fault Zone of Western
Australia extend all the way to the Transantarctic Mountains? SGTS Field meeting-
Abstracts, Geological Society of Australia 72, pp.130.
Liu Xiaochun, Jahn Bor-ming, Zhaoa Yue, Li Mia and Li Huimin, Liu Xiaohan 2006. Late Pan-African granitoids from the Grove Mountains, East Antarctica: Age, origin and tectonic implications. Gondwana Research 145, 131-159.


Sen, S. 1981. Proterozoic palaeotectonics in the evolution of crust and location of metallif-