SHRIMP geochronology for the 1450 Ma Lakhna dyke swarm: Its implication for the presence of Eoarchaean crust in the Bastar Craton and 1450–517 Ma depositional age for Purana basin (Khariar), Eastern Indian Peninsula

Kamleshwar Ratre, Bert De Waele, Tapas Kumar Biswal, Suspa Sinha

1. Introduction

The tectonic evolution of Craton–Mobile Belt boundaries is often enigmatic, primarily due to shearing and thermal activities that repeatedly take place in such regions over large spans of time. The margin between the Archaean Bastar Craton and the Proterozoic Eastern Ghats Mobile Belt (EGMB) of the Indian Peninsula poses such a problem (Fig. 1a and b). The area close to the interface, which has been marked by the terrane boundary shear zone (TBSZ), is characterised by a wide range of rock types from Archaean to Cambrian in age, and from almost undeformed and unmetamorphosed to multiply deformed and highly metamorphosed lithologies. The present study focuses on the tectonic correlation between the Khariar basin, the Bastar Craton and the EGMB and is based on a field study and historic isotopic ages. We also report new SHRIMP ages of dykes intruded into the basement and the TBSZ, shedding more light on the tectonic evolution of the area.

2. Regional geology

The eastern part of the Indian Peninsula exposes three geologically distinct terrains; the Mesoproterozoic EGMB, the Archaean Bastar Craton and the Purana basins. The Purana basins fringe the EGMB front (Fig. 1a). The EGMB runs over 1000 km along the east coast of India. It has been considered as a fragmented part of the ca. 1200 Ma old Rayner Complex of Enderby Land of East Antarctica, in the inferred Gondwana assembly (Yoshida, 1995). The EGMB consists of granulite facies rocks, namely charnockite, mafic granulite, calcic granulite, khondalite, graphite gneiss and enderbite that have been intruded by several phases of granite, anorthosite and nepheline syenite. The Mobile Belt depicts a juxtaposition of several terranes along longitudinal and transverse shear zones (Fig. 1b). Some of the terranes show Archaean Sm–Nd model ages (ca. 2000–3200 Ma for the orthogneiss), however, the granulite metamorphism is broadly divided into three phases with ca. 1600 Ma, 1000 Ma and 600 Ma ages (Rickers et al., 2001; Dasgupta and Sengupta, 2003; Dobmeier et al., 2006; Biswal et al., 2007). The EGMB is juxtaposed with the Dharwar, Bastar and the Singhbhum Cratons of the Peninsula, with the line of juxtaposition being marked by the TBSZ, which shows a thrust slip character in the west and southwest and strike slip in the north. The Mobile Belt on the NW front displays a fold-thrust belt (ftb) structure consisting of a stack of granulitic thrust sheets with the TBSZ acting as a basal décollement. Based on the SHRIMP age of synkinematic nepheline syenite plutons (Biswal et al., 2007) emplaced along the TBSZ, a Pan-African age of juxtaposition of the EGMB with cratons of the Peninsula has been suggested.

The Bastar Craton consists of vast exposure of undeformed and unmetamorphosed ca. 2500 Ma old potassic granites. Gneissic xenoliths, varying in dimension from a few meters to hundreds
of meters, occur in several places. These represent ca. 3500 Ma old tonalite–trondjhemite gneisses (TTG’s) that constitute major parts of the Indian Peninsula. Continuous gneissic outcrops occur far away from the EGMB front, where they show multiple phases of folding and shearing and amphibolite facies metamorphism. Greenstone belts occur within such gneisses in several places, namely the Sonakhan Belts (Das et al., 1990). Several dykes, varying in composition from basalt, dolerite, boninite, rhyolite to trachyte and with an age of ca. 1900 Ma, intrude the TTG–greenstone–granite sequence (Nanda et al., 1998; Srivastava and Singh, 2003; French et al., 2008; Heaman, 2008; Subba Rao et al., 2008). The majority of the dykes are unmetamorphosed, except for a few which show greenschist facies assemblages with relic igneous textures.

Circumscribing the EGMB front, a number of sedimentary basins have been developed within the Craton, hosting a Proterozoic platform sequence of rocks; these are known as the Purana basins (Fig. 1b). The Khariar basin is one of those basins and is dominated by a sandstone and shale sequence, while other basins like Chhattisgarh and Cuddapah, contain abundant carbonates. The Cuddapah basin contains synsedimentary basaltic flows, acid tuffs and ignimbrites and is intruded by kimberlite and lamproite dykes with intrusion ages of ca. 1100 Ma (Nagaraja Rao et al., 1987; Padmakumari and Dayal, 1987; Anand et al., 2003; Chalapathi Rao et al., 2004; Kumar et al., 2006). The Vindhyan and Marwar basins along the northern and western part of the Peninsula (Fig. 1a) have been included in the Purana group. The age of the Purana basins is poorly constrained between ca. 1800 and 650 Ma (Bhaskar Rao et al., 1995; Ray et al., 2002, 2003; Anand et al., 2003; Patranabis-Deb et al., 2007; French et al., 2008), although palaeomagnetic studies suggest an upper age limit of ca. 1000 Ma (Malone et al., 2008). The eastern edge of the Cuddapah basin is extremely tectonised due to thrusting of the Eastern Ghats fold-thrust belt (Chaudhuri et al., 2002; Saha and Chakraborty, 2003) while the other basins have escaped major deformation (Das et al., 1992). However, steep angle reverse faults occur within the basins at several localities.
3. Chemical analysis and U–Pb SHRIMP methodology

Five samples were analysed from the Lakha dyke swarm (TKB-6, 7, 8, 9, 10). Major-element oxides (Table 1) were obtained using the method suggested by Shapiro and Brannock (1956). Zircons were separated from three of these five samples and analysed for U–Th–Pb isotopic composition on the Perth Consortium SHRIMP (TKB-6, TKB-7 and TKB-8; Table 2).

Zircon grains were extracted from fresh rock samples following standard mineral separation techniques involving rock preparation (washing, crushing, pulverising and sieving), heavy liquid separation using bromoform, and magnetic separation using a hand magnet and a Frantz isodynamic separator. Zircon of all shapes and sizes were handpicked and mounted in epoxy resin together with zircon standard BR266 (Steen, 2001), TEMORA-2 (Black et al., 2003, 2004) and Phalaborwa (Kröner et al., 1999). The mount was polished to expose the zircon mid-section, and coated with carbon in preparation to imaging on a JEOL-6400 scanning electron microscope (SEM) fitted with a cathodo-luminescence (CL) detector. SEM imaging was conducted at a working distance of 39 mm, using an accelerating voltage of 15 keV and a beam current of ~5 nA. Back-scatter electron imaging was used to confirm that the mounted grains were zircon, and for suspect grains, energy dispersive spectrometry was used to identify the mineral. CL imaging was done on all zircon to reveal internal structure and growth patterns (Corfu et al., 2003). The mounts were also imaged using a petrographic microscope using both transmitted and reflected polarised light. The optical and CL imagery were used during analysis on SHRIMP to allow careful selection of analysis sites (spots) within zonal domains interpreted to form part of a single growth phase.

After SEM imaging, the mount was repolished slightly, to remove the carbon coating, thoroughly cleaned using organic and inorganic spirits (propan-2-ol and ethanol), soap solution and deionised water to minimise surface contamination (especially Pb) and coated with a thin layer of ultra-pure gold to provide surface conductivity. The mount was loaded in the SHRIMP sample lock 24 h prior to analysis, and pumped to ~5 × 10⁻⁷ Torr to allow degassing. Analysis procedure of the SHRIMP follows methods similar to those described in detail by Claué-Long (1994). Working

<table>
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<th>Spot Name</th>
<th>/206 (±1σ)</th>
<th>/207 (±1σ)</th>
<th>/208 (±1σ)</th>
<th>/207Pb/206Pb</th>
<th>/206Pb/204Pb</th>
<th>/207Pb/206Pb</th>
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<td>3.90664 ± 0.12520</td>
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<td>3.91158 ± 0.12538</td>
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Analyses conducted during a single session. 16 BR266 standard analyses yielded a 2σ error of the mean of 1.50%. Z/206 = proportion of non-radiogenic 206Pb in total 206Pb total denotes uncorrected ratios; 204 denotes 204-corrected ratios.
conditions for both sessions included a primary beam current of 2–3 nA, slightly elliptical spot size of ~25–30 μm, sensitivity of >20 counts per ppm Pb and per nA primary beam current, and a mass resolution of >4500. Measurements were conducted on ZrO₂⁺, 204Pb⁺, background, 207Pb⁺, 208Pb⁺, 238U⁺, 232ThO⁺ and 238UO₂⁺ in sets of six scans, with a total analysis time of about 15 min per sample spot. Analyses of unknown and BR266 standard zircon were interspersed at a ratio 3:1, allowing calibration of 238U/206Pb ratios and U content using an age of 559 Ma and U content of 909 ppm (Stern, 2001). TEMORA-2 and Phalaborwa were used as control standards and yielded 206Pb/238U ages within error of those reported for them (see Table 2, standard ages after Black et al., 2003; Black et al., 2004; Kröner et al., 1999). Common Pb correction is based on measured non-radiogenic 204Pb isotope, and a common Pb composition applied following the Pb-evolution model of Stacey and Kramers (1975). Because analyses that recorded high counts on 204Pb during the first scan were aborted, corrections are small and insensitive to the choice of common Pb composition. Nevertheless, some analyses were characterised by very low contents of U, which combined with the relatively young age, lead to significant proportions of radiogenic Pb based on low counts on 204Pb, barely above background. Because of the low signal to noise ratio of the 204Pb signal, 204-correction suffers from imprecision, particularly in these cases, and we therefore also report uncorrected ratios in the table (Table 2). Standard calibration errors are reported in the table, but were not included in single spot ages and pooled age calculations. Single spot ages are reported at 1σ confidence level, while pooled ages are reported at 95% confidence. The data was reduced using Excel plug-in SQUID 1.06 (Ludwig, 2001a) and ages calculated and plots constructed using Excel plug-in Isoplot 3.00 (Ludwig, 2001b).

4. Geology of the study area

The NW front of the EGMB represents a fold and thrust belt consisting of the Lathore, Turekela and Sinapalli Nappes (Biswal et al., 2007). The study area is located between Lakhna and Bodan (Fig. 1), where the Lathore nappes directly overlie the Bastar Craton with the TBSZ as the basal decollement.

4.1. Lakhna area (Fig. 2)

4.1.1. EGMB (the Lathore nappe)

4.1.1.1. Lithology. Khondalite, riebeckite granite and charnockitic gneiss form the major rock types in the Lathore nappe. Highly weathered outcrops of khondalite are mostly exposed in open cast mines for graphite. These rocks are characterised by alternate dark and white layers formed by the segregation of garnet, graphite, sillimanite, cordierite and biotite, and 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 (Fig. 3a). The charnockitic gneisses show various migmatitic structures; garnet, biotite and hypersthene-rich palaeosomes alternating with quartzofeldspathic neosomes define...
such structures. Under the microscope, myrmekitic structures are very common.

4.1.1.2. Structure. The above rock types show an early stage of coaxial folding between $F_1$ and $F_2$ along NE–SW axis; the granulite facies metamorphism is coeval with $F_1$ folding (Biswal et al., 2007). A penetrative $S_1$ 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 (Fig. 3a). $F_2$ folds are marked by shear bands parallel to the axial plane of the fold. Thrusting of the granulites has been interpreted to be synkinematic with $F_2$ folding. Late stage folding ($F_3$) 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 $F_3$ folding.

4.1.2. Bastar Craton
4.1.2.1. Granites. Virtually undeformed coarse to medium grained massive granites constitute the Bastar Craton, forming high hills and bouldery outcrops at several localities. These rocks represent the late-tectonic granites of ca. 2500 Ma (Sarkar et al., 1993). In thin section, the granites show quartz, microcline and biotite as major constituents with apatite, zircon and magnetite as accessories. Occasionally, xenoliths with a gneissic composition occur within the massive granites; these are augen gneisses, migmatites and stromatic gneisses of dimension varying from a few meters to hundreds of meters. The gneissic xenoliths represent the ca. 3500 Ma TTG’s component of the Bastar Craton. Though the massive granites are devoid of ductile deformational fabrics, multiple sets of vertical to subvertical brittle fractures are developed; N–S to NNE–SSW and WN–W to WNW–ESE sets are more common compared to others (Fig. 4a).

4.1.2.2. Dykes. Numerous dykes belonging to the Lakhna dyke swarm, are emplaced within the granites, the majority along N–S to NNE–SSW trend, with a few along E–W to WN–W direction (Fig. 2). Both sets are presumed to be broadly synkinematic and have been emplaced along the pre-existing fractures. The swarm shows a large variation in composition from dolerite, basalt, gabbro, rhyolite, trachyte to feldspar porphyry. The dykes are free from...
Fig. 4. (a) Rose diagram of 52 fractures from the Bastar Craton near Lakhna. The majority show NNE–SSW trend and second major direction is WNW–ESE. (b) 473 Mylonitic foliation, contours: 1–2 – 3–4 – 5–6 – 7–8 – 9–10% of 1% area; majority show southeasterly dip. (c) 341 Stretching lineation, contours: 1–2 – 3–4 – 5–6 – 7–8 – 9–10% of 1% area, majority show southeasterly plunge.

Fig. 5. TAS diagram (total alkali vs silica, Le Bas and Streckeisen, 1991) showing the chemical composition of the dykes. TKB-6 lies in the rhyolite, TKB-7 in trachyte, TKB-8 in phonolitic tephrite, TKB-9 trachyandesite and TKB-10 in basaltic andesite field.
deformation, although close to the TBSZ a crude mylonitisation can be developed due to shearing. Dolerites occur along N–S as well as WNW–ESE trend. They are medium grained rocks with plagioclase, olivine and augite as the major minerals (Fig. 3b). Rhyolite dykes are comprised of pink coloured rock with alkali feldspar phenocrysts. Under the microscope amoeboid quartz grains and euhedral orthoclase phenocrysts, embedded in a fine grained equigranular quartz-feldspathic matrix, in places showing microporphyric texture, can be observed (Fig. 3c). Magnetite and green biotite occur as accessories and spherulitic replacement textures are common. Chemical analyses indicate 72.8% SiO$_2$ and hypersthene normative composition (Table 1 and Fig. 5). Trachytes are greenish coloured, with well developed foliation due to the presence of flow layers which are defined by needle-shaped alkali feldspar grains (Fig. 3d). Glomeroporphyritic textures are developed due to segregation of multiple feldspar phenocrysts, with flow layers swerving around these aggregates. The trachytes are quartz and hypersthene normative with silica contents of about 60%. Medium to coarse grained feldspar porphyry dykes occur with abundant alkali feldspar phenocrysts set in a fine to medium grained matrix. The matrix shows dark colour due to presence of fine grained amphiboles. The feldspar porphyry dykes are quartz poor and rich in plagioclase and orthoclase and lie in the basaltic andesite field of the TAS diagram (TKB-10, Fig. 5). Alkali gabbro dykes carry alkali feldspar in addition to plagioclase, augite and olivine (Fig. 3e).

4.1.3. Terrane Boundary Shear Zone (TBSZ)

4.1.3.1. Mylonite and sense of shearing. The TBSZ is developed at the interface between the Bastar Craton and the EGMB and is characterised 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 (Fig. 4b and c). These features, in addition to other such as S–C fabric, mantled porphyroclasts and intragranular micro faults, indicate a top to the northwest vergence of the shear zone (Fig. 3f, Biswal et al., 2000). From the grain size analysis and S–C angle study, shear strain within the
TBSZ is estimated to lie between 2 and 6 and strain patterns vary from plane to flattening type with different degrees of volume gain in different sectors (Biswal and Sinha, 2003).

4.1.4. Khariar basin

4.1.4.1. Sedimentary succession. The outcrop of the Khariar basin is elliptical in shape and lies to the west of the EGMB terrane (Fig. 1b), surrounded by granites of the Bastar Craton. Along the eastern edge of the basin, the sedimentary succession occurs at a height of a hundred meters above the granite hills. The granites immediately underlying the sedimentary cover are extremely weathered. In several places, the basal part of the succession consists of lags containing angular fragments of basement granites and dykes. In a rare instance, one of the dolerite dykes is seen to be truncated by the unconformity plane underlying the sedimentary succession (Fig. 6a), suggesting that the emplacement of the dyke predated sedimentation. The sedimentary succession varies in thickness and reaches 300 m in the centre of the basin. The sequence invariably starts with a basal conglomerate of nearly two meter thickness with pebbles being a few centimeters to millimeter in diameter (Fig. 6b). The basal conglomerate occurs at different heights, which could be attributed to extremely undulated pre-depositional basin topography or post-depositional tectonic uplift. An F-1 fault marked by fault scarp and displacement of adjacent conglomerate bed over 50 m, subscribes to the latter explanation (shown schematically in Fig. 2). Quartz-arenite constitutes the major rock type in the lithosuccession, consisting of well-bedded medium- to coarse-grained well rounded sandstone with little matrix. The grain contacts show diagenetic growth of quartz providing hardness to the unit. It forms well jointed blocks forming rock cliffs along faulted margins. The quartz-arenite is pink to purple in colour in many places due to the presence of iron minerals and glauconite. At a few localities trough cross stratifications with opposite axes are observed, but in most instances they show a transportation direction from NW (Fig. 6c). Shale as well as arkose occurs as intercalated units within the quartz-arenite. A thick unit of shale has been reported in western part of the basin (Datta, 1998). The shale is generally silicic in nature, in places ferruginous, with well-developed laminations. The Khariar basin lacks carbonate deposition. There are no reported dyke intrusions in the basin. However, kimberlite pipes have been reported from the southern part of Khariar basin (Das et al., 1992).

4.2. Bodan area

4.2.1. Terrane boundary shear zone and nepheline syenite pluton

The Bodan area (Fig. 7) is represented by charnockitic gneisses belonging to the Lathore nappe of the EGMB and massive granites with sporadic xenoliths of TTG belonging to the Bastar Craton; these two units are juxtaposed along a thick zone of mylonites belonging to the TBSZ that shows northwesterly vergence. A number of linear shaped nepheline syenite plutons are emplaced along the TBSZ. Some of the plutons occur within the granitic-mylonites of the craton while some are within the amphibolitic-mylonites of the EGMB. Detailed structural analysis of the plutons indicates that the plutons were synkinematically emplaced during thrusting (Biswal et al., 2007). The SHRIMP dating shows an emplacement age of ca. 517 Ma and the xenocrystic population ages of ca. 1400, 1700, 2500 and 3100 Ma. From these ages it has been proposed that the final juxtaposition of the EGMB with the Indian Cratons took...
place during the Pan-African period. Probably this marks the closure of an ocean that existed between the Bastar Craton and the EGMB. The occurrence of ophiolites along the western margin of the Mobile Belt has been advocated as evidence of oceanic crust (Singh and Mishra, 2002; Radhakrishna Murthy et al., 2005). Furthermore, the Western Charnockite Zone (Fig. 2b) is considered to be part of an ophiolite sequence.

4.2.2. Khariar basin

In a rare occurrence (20° 11’ 12”: 82° 34’ 21”), immediately south of Bodan, the sedimentary sequence of Khariar basin marginally overlies the TBSZ on its western flank (A in Fig. 7a). The sequence consists of a basal conglomerate followed by shale and quartz-arenite (Fig. 7b). The formation shows a moderate dip towards the east. Fragments of mylonites occur in the basal conglomerate, suggesting the age of deposition to postdate thrusting. The shale member shows intense deformation with a prominent shear cleavage along which biotite has been recrystallised suggesting that greenschist facies metamorphism has taken place during shearing (Fig. 6d and e). The shear cleavage is axial planar to a set of NW-vergent asymmetric folds that have been developed on the bedding plane. The folds are converted to sheath-folds suggesting high shear strain. Comparing the deformational fabrics between basement mylonites and shale, the mylonitic foliation and shear cleavage are parallel and, more importantly, the mylonitic foliation in the granite shows a transition into the shear fabric of the shale. In contrast, the quartz-arenite unit that overlies the shale is absolutely undeformed (Fig. 7c) and even under the microscope no sign of strain is visible (Fig. 6f). This suggests that the quartz-arenite has been deposited after thrusting, and hence, the upper age limit of the Khariar basin could be as young as 517 Ma.

5. Zircon U–Pb SHRIMP data

5.1. Sample TKB-6

Sample TKB-6 was collected west of Chhindekelai (Fig. 2), from a light-coloured N–S striking rhyolite dyke which is fine grained with abundant pink feldspar phenocrysts (Fig. 3c). Zircon from the sample range in size from 50 to 200 μm, and are colourless to pinkish in colour (Fig. 8). The grains are clear, and contain a variable number of small inclusions. Most crystals are euhedral with well-developed crystal faces, and have length to width ratios between 2:1 and 3:1, typical for magmatic zircon. CL-imagery indicates oscillatory zoning patterns, also common for magmatic zircon. Eight analyses were conducted on eight zircons. The U and Th contents are in the range 76–333 and 29–113 ppm, respectively, with Th/U ratios between 0.09 and 1.19. The analysis recording the lowest Th/U ratio indicates a concordant 207Pb/206Pb age of 2563 ± 22 and is interpreted to represent a xenocryst (Fig. 9). The remaining seven data points indicate much higher Th/U ratios between 0.68 and 1.19 and plot in a broad cluster on concordia. Several of the data points do show some inverse discordance, either related to overcorrection for non-radiogenic Pb or to matrix effects on the sputtering. The four data points that fall within 5% of the concordia line correspond to a concordia age of 1450 ± 22 Ma.
(MSWD = 1.14), which we take to represent the crystallisation age of the rhyolite dyke.

5.2. Sample TKB-7

This sample has been collected from a trachyte dyke (Fig. 3d) close to Lakhna (Fig. 2). Zircons from this sample are small, between 50 and 100 μm, and have aspect ratios between 1:1 and 3:1. Many crystals appear broken, but the grains are colourless to pale pink and clear, with only a small number of inclusions (Fig. 8). CL-imagery indicates clear oscillatory zoning patterns, and the zircons are interpreted to be magmatic in origin. Eight spots were analysed on eight zircon grains. U and Th are in the ranges 66–135 and 64–141 ppm, respectively, with Th/U in the range 0.68 and 1.14 typical for magmatic zircon (Rubatto, 2002). The data plot in a concordant cluster on concordia (Fig. 9). Seven out of the eight analyses correspond to a concordia age of 1453 ± 19 Ma (MSWD = 1.7), which we take as the best age estimate for the emplacement of the dyke.

5.3. Sample TKB-8

Sample TKB-8 has been collected from an alkali gabbro (Fig. 3e) south of Chhindkekalai (Fig. 2). Not many zircons were recovered from the sample. The recovered grains are between 50 and 100 μm in size and have aspect ratios between 2:1 and 3:1, indicative of a magmatic origin. The grains are yellow to light brown in colour, and most are turbid owing to small inclusions (Fig. 8). CL imagery show zoning patterns, supporting a magmatic origin, although some cores appear to be present. Eight spots were analysed on eight separate zircon grains, two on core domains and six on single-growth zircon. The cores have Th/U contents of 0.57 and 0.59, while the remaining analyses have a wide range of Th/U between 0.33 and 1.73. All data are characterised by relatively high proportions of Pb, with f206 between 0.32 and 3.84%. The oldest data points correspond to analyses on core domains. Analysis TKB-8–2 recorded a slightly discordant 207Pb/206Pb age of 3726 ± 22 Ma (11% discordant data). Because of the discordance, this age is interpreted as a minimum age, and the zircon is interpreted as a xenocrystic core (Fig. 9). This is the oldest age reported for the Bastar Craton in particular, and for the entire Indian peninsula, and suggests the presence of Eoarchaean components in the Bastar Craton. Another analysis on zircon core, TKB-8–6, records a 207Pb/206Pb age of 2639 ± 20 Ma (4% inversely discordant data) and is also interpreted as a minimum age for the xenocrystic core. The remaining data groups in a younger cluster, but one of these analyses records much lower ratios than the main population. This analysis recorded a f206 common Pb component close to 4% related to...
a 3.8 Ga old crust of Indian Craton (Bastar) with 2.5 Ga granites

b Opening and deposition of the EGMB basin with ocean floor bottom 1.60 - 1.45 Ga.

Closure of EGMB basin through subduction (1.6 Ga - > 517 Ma)

d Fold-thrust belt (ftb) development at the western front of the EGMB 517 Ma

e Positive Inversion Tectonics: Uplift of Khariar basin by reverse slip due to compression generated from the thrusting of the nappes ( < 517 Ma)

Fig. 10. A schematic model of the tectonic evolution of the EGMB, Bastar Craton and Purana basin. (a) The Bastar Craton, with 3800 Ma old components. (b) Extensional stress in the lithosphere created the EGMB oceanic basin. (c) The oceanic basin is closed between the period 1600 and 517 Ma as evident from the compressional tectonism, folding and regional metamorphism in the rocks. The contact between the craton and the sediments of the EGMB basin acted as a zone of décollement. Synchronously, the western foreland experiences extension that created a large number of extensional fractures and faults. At 1450 Ma dyke emplacement took place. Following this, large size grabens developed due to ensialic rifting that hosted the Purana basins (Khariar). (d) At 517 Ma, the western edge of the EGMB is thrust onto the Bastar Craton. Thrusting and associated folding developed a fold-thrust belt (ftb). The frontal thrust of the ftb, designated as the TBSZ, represents the basal décollement; nepheline syenite plutons are emplaced within the TBSZ, synkinematic with thrusting. Deposition in the Purana basin continued up to the time of thrusting and beyond, as indicated by the occurrence of mylonite pebbles within the basal conglomerate and deformation in shale; the overlying quartzite is devoid of deformation. (e) Thrusting of the nappes onto the Bastar Craton created compression that was transferred to the basin. The normal faults were reactivated as reverse slip faults. Due to the reverse slip the basin sediments were uplifted.
Metamorphism took place during three broad phases: to retrace the earliest history of sedimentation in the Mobile Belt. Granites of the Bastar Craton. A lack of age data makes it difficult to send the basement rocks equivalent to TTG's and late-tectonic orthogneisses in the belt (Rickers et al., 2001). These rocks represent Nd model ages have shown the presence of ca. 3200–2600 Ma migmorphic, structural and petrological studies, but so far, no work has been done on the Bastar Craton was 3500 Ma (Sarkar et al., 1993). The present study shows a 3800 Ma xenocrystic zircon from the Aravalli Belt (Wiedenbeck et al., 1996). So far the oldest age recorded from various cratons are 3000 Ma from Dharwar (Bidyananda et al., 2003), 3500 Ma from Singhbhum (Hualin, 1999; Acharyya et al., this issue) and 3500 Ma for the Mewar Gneiss of the Aravalli Belt (Wiedenbeck et al., 1996). So far the oldest age reported from the Bastar Craton was 3500 Ma (Sarkar et al., 1993). The present study shows a 3800 Ma xenocrystic zircon from the alkali gabbro dyke intruding the Bastar Craton, suggesting that the Bastar Craton contains Eoarchaean components. Furthermore, ca. 1450 Ma SHRIMP ages for the dykes are reported for the first time. The dykes show a large variation in composition from basic and intermediate to acidic and lack any deformation (Nanda et al., 1998). It is unclear whether this suggests their emplacement took place in an anorogenic continental or in a rift setting.

6. Discussion and conclusion

6.1. Basement

Peninsular India is constituted of several craton blocks which are sutured by Proterozoic Mobile Belts. The cratons consist of extensive TTG's outcrops, mostly forming low lying topography. Greenstone belts of varying dimension occur within the TTG's, some forming formidable topography as in the Western Dharwar Craton. Late tectonic potassium granites have intruded the TTG's-greenstone association and form prominent peaks and ridges in several places. Granites occurring between the western and Eastern Dharwar Craton are ascribed to the Closepet Suite. The Hyderabadi project granites occur in the Bastar Craton. The TTG produce the oldest ages from the Peninsula. So far the ages recorded from various cratons are 3000 Ma from Dharwar (Bidyananda et al., 2003), 3500 Ma from Singhbhum (Hualin, 1999; Acharyya et al., this issue) and 3500 Ma for the Mewar Gneiss of the Aravalli Belt (Wiedenbeck et al., 1996). So far the oldest age reported from the Bastar Craton was 3500 Ma (Sarkar et al., 1993). The present study shows a 3800 Ma xenocrystic zircon from the alkali gabbro dyke intruding the Bastar Craton, suggesting that the Bastar Craton contains Eoarchaean components. Furthermore, ca. 1450 Ma SHRIMP ages for the dykes are reported for the first time. The dykes show a large variation in composition from basic and intermediate to acidic and lack any deformation (Nanda et al., 1998). It is unclear whether this suggests their emplacement took place in an anorogenic continental or in a rift setting.

6.2. The EGMB

Many studies have been made on the EGMB, including metamorphic, structural and petrological studies, but so far, no workable tectonic model for the entire belt has been proposed. Sm-Nd model ages have shown the presence of ca. 3200–2800 Ma orthogneisses in the belt (Rickers et al., 2001). These rocks represent the basement rocks equivalent to TTG's and late-tectonic granites of the Bastar Craton. A lack of age data makes it difficult to retrace the earliest history of sedimentation in the Mobile Belt. Metamorphism took place during three broad phases: $M_1 = 1600–1400$ Ma, $M_2 = 1000–900$ Ma and $M_3 = 600–500$ Ma (Dasgupta and Sengupta, 2003; Simmat and Raith, 2008; Upadhyay, 2008). However, an isolated age of 2640 Ma has been reported by Vinogradov et al. (1964) that could be an inherited age or represent Archaean metamorphism of an older terrane within the EGMB. The EGMB was probably connected with Enderby Land of East Antarctica. (Yoshida, 1995). Viewing the distribution of ages in the Napier Complex of Enderby Land and the Eastern Ghat's Block, a crude W and NW younging of terranes can be observed, the youngest occurring along the western margin (Dobmeier et al., 2006; Biswal et al., 2007). However, exotic blocks that deviate from this younging trend occur within the EGMB, suggestive of the presence of suspect terranes within the Mobile Belt.

6.3. Khariar basin

The Purana basins are developed on the craton, circumscribing the thrust front of the EGMB, as foreland deposits (Biswal and Sinha, 2003). These basins are dominantly siliciclastic, except for the Cuddapah and the western part of the Chhattisgarh basin, where carbonates have developed. The basins developed due to ensialic rifting of the craton (Das et al., 1992). The base of all these basins has been considered to be broadly synchronous. The study area provides an important clue to the maximum age of basin formation and sedimentation. The dykes truncate against the base of the sedimentary sequence and dyke clasts are present in the basal conglomerate. Since the emplacement age of the dykes is 1450 Ma, sedimentation must postdate this. The ca. 1450 Ma age recorded from monazite grains of a tuff unit of the lower part of the Khariar basin is therefore significant (Das et al., 2009). The upper age limit of sedimentation is not precisely known, as the top part of the sequence may not represent the end of sedimentation as many layers may have been removed during uplift. The upper age limit of sedimentation has been reported to be ca. 1000 Ma, based on the dating of a pyroclastic sequence from the Chhattisgarh basin (Patranabis-Deb et al., 2007) and a palaeomagnetic study (Malone et al., 2008). The present study reports the occurrence of mylonite pebbles in the conglomerate and deformation in the shalesynkinematic with thrusting. Hence the sedimentation probably continued up to ca. 517 Ma, the age of thrusting along the TBSZ.

6.4. Evolutionary model

A suggested evolution of the EGMB and development of the Khariar basin on the Bastar Craton is shown in Fig. 10. The up to 3800 Ma old Bastar Craton, containing 2500 Ma old massive granite plugs, underwent extension well before 1400 Ma, followed by rifting and ocean formation to host the EGMB sediments (Fig. 10a and b). As the age of deformation and metamorphism of the Mobile Belt (1600–500 Ma) overlaps with the formation of the Purana basin (<1400 Ma), it is shown in Fig. 10c that closure of the EGMB basin resulted in extension in the cratonic foreland. The extension in the foreland created rift basins and was accompanied by dyke emplacement. The contact between the craton and the EGMB sediments probably acted as a décollement so that the deformation in the latter could not be transmitted significantly to the former in large scale. The emplacement of dykes heralded the initial stage of extension as they truncate at the base of the Khariar basin. However, this may not be universally the case for all basins. For instance, in the Cuddapah basin, synsedimentary volcanic flows occur that suggest magmatism was partly synchronous with sedimentation. The deformation in the EGMB continued until the Neoproterozoic-Cambrian period when it was finally juxtaposed against the craton through thrusting (Fig. 10d), with synkinematic emplacement of nepheline syenite plutons at 517 Ma. The compression associated with thrusting reactivated the normal faults as reverse faults in the Purana basins (Fig. 10e). This is interpreted as inversion tectonics of the sedimentary basin as suggested by Williams et al. (1989). Through reverse slip, the sediments were uplifted to great heights and thrusting of the Mobile Belt and uplift of the Purana basin are considered to be synchronous.

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