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Decoding evolutionary history of provenance from beach placer monazites: A case study from Kanyakumari coast, southwest India

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Mineral chemical and geochronological studies of beach placer monazites from Kanyakumari coast, SW India were carried out to understand growth history of monazite and its bearing on tectono-thermal evolution of the source rock. In chemically zoned monazites lowest backscattered electron (BSE) response domains (dark gray) comprising the thick core region are mantled by highest BSE response rim domains (light gray region). Dark gray BSE domains are enriched in LREEs (La and Ce), U and Y, and depleted in Th and Pb compared to the light gray BSE domains. Chemical variability between these two domains can be linked with dominantly huttonitic substitution. Two U–Th–total Pb chemical age clusters between 555–578 Ma and 508–536 Ma were obtained respectively for low Th/U monazite cores and high Th/U monazite rims.
$^{147}Sm/^{144}Nd$ ratios in the analyzed monazites vary from 0.0733 to 0.1039 with an average value of 0.0902. High negative ε_{Nd} (t = 0) values in the range of −26.5 to −30.8 indicate derivation of monazites from light LREE enriched igneous and metamorphic rocks. T_{CHUR} and T_{DM} model ages vary from 1687 Ma to 2364 Ma and 2035 Ma to 2702 Ma respectively. Average T_{DM} age of 2375 (+96/−44) Ma for placer monazites fits with ~2.4 Ga crustal accretionary episode in Southern Granulite Terrane (SGT). EPMA Sm–Nd ratios of beach placer monazites (~0.153) are similar with the monazites in granites and granodiorites (0.150) of Nagercoil (NG) and Trivandrum Block (TB) of SGT. A comparison with available Th–U–total Pb EPMA monazite ages from various tectonic units within SGT suggests that growth history and crystallization age of monazites also correlate well with the Pan-African granulite facies metamorphism (570 Ma) and post-peak evolution (535 Ma) of NG and TB.
The results obtained in this study augment the growing evidences that beach placer monazites can be used as a proxy for provenance study. A corollary of the study further confirms similar geological history of NG and TB since 2.1 Ga.

1. Introduction

Provenances of modern and older clastic sediments are discriminated by comparing mineral assemblage, major and trace elemental abundances, ε_{Nd} values and Nd model ages (O'Nions et al., 1983; Li and McCulloch, 1996; Jacobsen, 1988; Richards et al., 2005; Chakraborty et al., 2012). However, each of the above methods has limitations in definitively establishing the provenance, for e.g. Nd model ages assume that there was no fractionation of Sm/Nd ratios during deposition of clastic sediments. However, rare earth element and Sm–Nd isotope studies on clastic sediments have found that Sm/Nd ratios in sediments are fractionated relative to their source during transport, deposition and diagenesis (McLennan et al., 1990, 1993; McCulloch and Bennett, 1994; McDaniel et al., 1994; Gruau et al., 1996; Rainbird et al., 1997).

The other potential approach is to compare geochemical, isotope and age characteristics of individual heavy minerals with that of the provenance. A number studies have compared U–Pb ages on detrital zircons with potential sources to identify their provenance (e.g., McCulloch and Bennett, 1994; Lahtinen et al., 2002; Moecher and Samson, 2006). Although zircons can provide precise crystallization ages of protoliths, timing of metamorphism cannot be determined if they were abraded and rounded to varying degrees during transport (Cliff et al., 1991; McLennan, 2001; Lahtinen et al., 2002; Richards et al., 2005) or the grade of metamorphism is not high enough for zircon crystallization or overgrowth to occur. Hietpas et al. (2011) reported that in situ U–Pb isotope studies on detrital zircons from Appalachian foreland basin sandstones could not identify several younger Palaeozoic tectono-thermal events while detrital monazites unambiguously recorded these events.

U–Th–total Pb ages on monazites of clastic sediments can provide information about the timing of monazite crystallization and growth which can be matched with tectono-thermal histories of potential source regions (Maas and McCulloch, 1991; Parrish, 1990; Chen et al., 2006; Iizuka et al., 2010; Hietpas et al., 2011). Whereas, timing of separation of protoliths from mantle can be determined using Sm–Nd isotopic studies on monazite, useful complementary information to identify the provenance. As monazites retain the Sm/Nd ratio of the protolith,

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they truly preserve Nd isotope evolutionary history of provenance better than bulk sediments (Frost and Winston, 1987; Cliff et al., 1991; Ross et al., 1991; McFarlane and McCulloch, 2007; Garcon et al., 2011, 2013). Objective of this coupled study of U–Th–total Pb ages and Sm–Nd isotope system on monazites from beach placers is to test suitability of placer monazites as proxy for crustal and tectono-metamorphic evolution of the provenance.

Beach placers commonly host economic concentration of minerals with high density such as monazite, rutile, zircon, ilmenite and garnet (Rao and Misra, 2009; Garcon et al., 2011). Similar to river sediments that are widely used as proxy for isotopic composition and temporal evolution of the continental crust (Gaillardet et al., 1995; Allègre et al., 1996; Goldstein and Jacobsen, 1988; Millot et al., 2004; Kamber et al., 2005), monazite-rich beach sands seem to have immense potential for provenance study. Garcon et al. (2011) documented that monazites, with abundance as low as 0.5 wt.%, dominantly control the Nd isotopic signature in beach placer and are reliable proxy for Nd isotopic composition of the provenance.

Beaches along southern and southwestern coast of India are enriched in monazites as well as other heavy minerals. This is due to the presence of suitable lithologies in the provenance, coastal geomorphology, climate, physical and chemical environment, hydro-dynamic regime and sea level fluctuations (Mallik et al., 1987; Chandrasekharan and Murugan, 2001; Kurian et al., 2001; Mohanty et al., 2003a,b; Jayaraju, 2004; Acharya et al., 2009). The hinterland region comprises a collage of Paleoproterozoic ($T_{DM} > 2$ Ga) granulite terranes (Fig. 1a) with lithologic ensemble such as, orthopyroxene bearing granulites (commonly referred as charnockites), high-grade metasediments, and igneous rocks of syenitic and granitic to intermediate composition. The tectonothermal evolutionary history of the hinterland region is characterized by pervasive Pan-African reworking (650–500 Ma) that coincided with east and west Gondwanaland assembly (Harris et al., 1994; De Wit et al., 1998; Yoshida et al., 1999; Santosh et al., 2005a,b, 2006a,b, 2009b; Kröner et al., 2012; Taylor et al., 2014, 2015).

The beach placers of southwest Indian coast provide a natural laboratory to test the suitability of placer monazites as proxy for crustal evolution of the provenance because, a) monazites along with other heavy minerals (ilmenite, sillimanite, garnet, zircon) are derived from granulitic rocks occupying highlands within a short distance of ~40 km, b) monazites are least weathered and c) ages of monazites in various rocks and tectono-thermal history of the source region have been well established (Braun et al., 1998; Braun and Bröcker, 2004; Cenki et al., 2004; Collins et al., 2007; Rajesh et al., 2011; Ravindra Kumar and Sreejith, 2010; Santosh et al., 2003, 2004, 2005a,b, 2006a,b, 2009a; Kröner et al., 2012, 2015; Taylor et al., 2014).

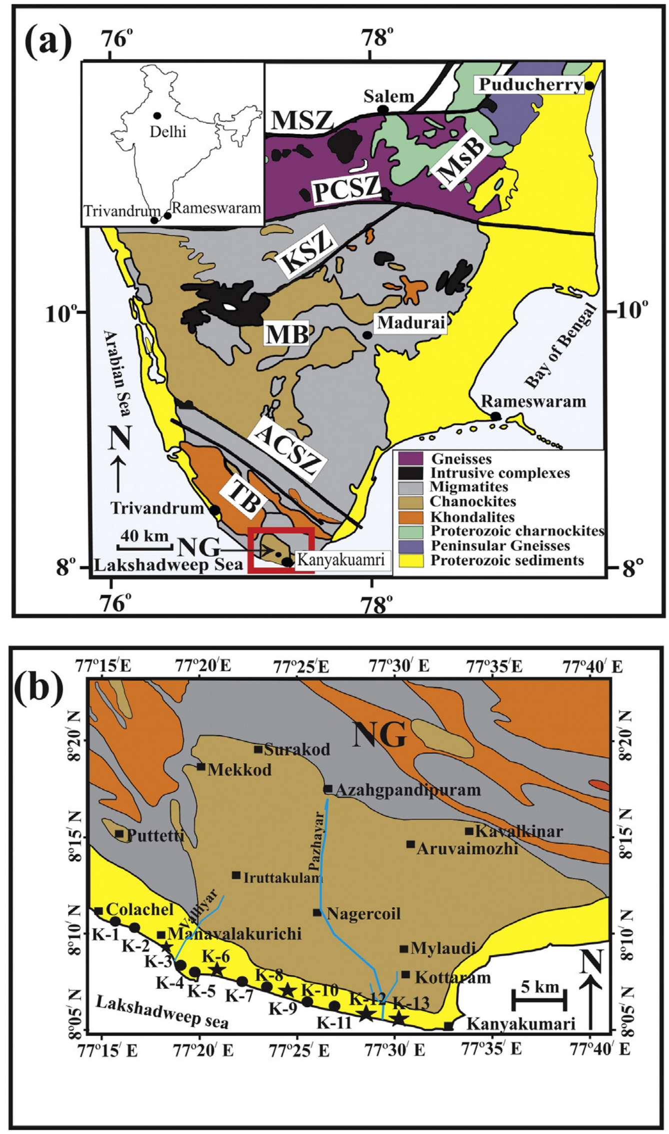

Fig. 1. a) General geological map of Southern Granulite Terrane (SGT) of India comprising different granulite blocks separated by major shear zones (after Valdiya, 2010). The box indicates the study area. b) Map of the study area showing sample locations (K stands for Kan), lithologies and major streams draining the hinterland of the SW coast line from Colachel to Kanyakumari. Chemistry and geochronology of monazites documented in this study are from the sample locations marked with star. Lithological index is same for both figures. Acronyms — ACSZ: Achankovil shear zone, KSZ: Karur shear zone, MB: Madurai Block, MSZ: Moyar shear zone, MsB: Madras Block, NG: Nagercoil granulites, PCSZ: Palghat cauvery shear zone, TB: Trivandrum Block.

2. Geological setting

2.1. General geology

Tropical climate combined with abundant rainfall over the escarpment along the west coast of India (Western Ghats) facilitate rapid weathering. West flowing, short perennial rivers carry the sediments from the Western Ghats and debouch into the Arabian Sea. The sediments are sorted by waves and currents and heavy minerals concentrated particularly in bays and curvatures formed between the promontories of the southwestern coast (Mallik et al., 1987).

Longshore currents, along the southwestern coast, flow southwards during the southwest monsoon (June–September), and northwards in the remaining part of the year with a net southerly longshore drift (Kunte et al., 2001). However, transport of sediments by longshore currents is limited by the presence of bays, headlands and curvatures. This is also supported by the presence of distinct beach placer mineral assemblages in different sectors of the western and southwestern coast. Ratnagiri coast of Maharashtra is dominated by ilmenite with minor hematite and magnetite (Nair, 2001). Northern sector of Kerala is characterized by pyribole and sillimanite. Southern Kerala contains ilmenite and sillimanite (Mallik et al., 1987; Krishnan et al., 2001). Kanyakumari coast contains ilmenite, garnet and sillimanite (Chandrasekharan and Murugan, 2001). The variation of heavy mineral assemblages along the southwestern coast of India has been attributed to the types of rocks present in the catchment of the rivers. Consequently, Ravindra Kumar and Sreejith (2010) recognized four types of placer deposits showing distinct compositional variation and characteristic of southern Kerala, central Kerala and northern Kerala and Kanyakumari coasts.

The hinterland region of the southwestern coast is well known as Southern Granulite Terrane (SGT) that exposes mid to lower parts of continental crust (Mohan and Jayananda, 1999) and consists of clinopyroxene and orthopyroxene bearing granulites, granitoid, gneisses, granites and syenites with intrusive pegmatite (Fig. 1a). The Achankovil shear zone (ACSZ, Fig. 1a) divides the SGT into a northern