Mantle source heterogeneity in continental mafic Large Igneous Provinces: insights from the Panjal, Rajmahal and Deccan basalts, India

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Abstract: In this paper we illustrate the geochemical diversity of the basalts of Panjal (*c.* 289 Ma), Rajmahal (*c.* 117 Ma) and Deccan (*c.* 65 Ma) continental large igneous provinces (continental LIPs) from India as controlled by multiple mantle sources. The Panjal primitive basalts are formed by 5–20%, Rajmahal basalts by 10–20% and Deccan picritic basalts by 1–20% melting of the mantle. The depth of melting beneath Deccan is greater than beneath Rajmahal, which greater than beneath Panjal. We have categorized the Panjal, Rajmahal and Deccan basalts into Type I and Type II. The Type I basalts with lower La/Nb, Th/Nb and Th/Yb ratios and higher ε_{Nd_i} values ($\varepsilon_{Nd_i} = -3$ to $+8$) are derived from the sublithospheric sources; some of the Type I basalts represent lithosphere-contaminated melts. The Type II basalts with higher La/Nb, Th/Nb and Th/Yb ratios and lower ε_{Nd_i} values ($\varepsilon_{Nd_i} = -20$ to -3) are produced from the subcontinental lithosphere. We estimate that lithosphere and sublithosphere (plume and/or E-MORB patches within asthenosphere) have contributed, respectively, approximately 67 and 33% to the Panjal, 52 and 48% to Rajmahal, and 28 and 72% to Deccan LIPs. Fertility of the Indian subcontinental lithosphere may have increased with decreasing age related to the break-up of Gondwana.

Supplementary material: References for the geochemical data, extracted from the GEOROC database, on the basaltic rocks from Panjal, Rajmahal and Deccan Large Igneous Provinces are available at: https://doi.org/10.6084/m9.figshare.c.3821881

Spatially extensive and temporally restricted magmatic activity in the Earth's crust, labelled as Large Igneous Provinces (LIPs: White & Saunders 2005; Bryan & Ernst 2008), is recorded both in oceanic and continental settings. Although the origin of the oceanic Large Igneous Provinces (oceanic LIPs) is better understood (Hofmann 2003), reasons for enormous geochemical diversity in the continental Large Igneous Provinces (continental LIPs) are not yet fully resolved in terms of relative contributions of shallow- and deep-mantle reservoirs. Magmatism in the continental LIPs is initiated by either lithosphere stretching or plume impinging (Turcotte & Emerman 1983; Zeyen *et al.* 1997). Both lithosphere stretching and plume impinging induces continental rifting, which, in some cases, may eventually lead to the formation of new oceanic crust. The igneous activity in the continental LIPs, although dominated by basaltic volcanism, produces a wide range of magmatic rocks on the Earth in a particular tectonic setting. The magmatic spectrum includes basalts with variable silica saturation, sodic and potassic alkaline rocks, carbonatites and A-type rhyolites, and their plutonic differentiates. The possible sources that can contribute to the geochemical variability in the continental LIP magmas (see Vijaya Kumar & Rathna 2008) (Fig. 1) include: (1) subcontinental lithospheric mantle SCLM (plus metasomes) (Hawkesworth *et al.* 1990; Goodenough *et al.* 2002; Li *et al.* 2015); (2) depleted asthenospheric mantle (Wedepohl *et al.* 1994; Aldanmaz *et al.* 2006; Fitton 2007; Heinonen *et al.* 2016); (3) thermal boundary layer that was metasomatized by mantle plume–asthenospheric melts (Wilson *et al.* 1995; Thompson *et al.* 2005; Hole 2015); (4) delaminated subcontinental lithosphere mantle that recycled into the asthenosphere (Zindler & Hart 1986); (5) mantle plumes (Nicholson & Shirey 1990; Rogers *et al.* 2000; Johnson *et al.* 2005; Campbell 2007; Colon *et al.* 2015); and (6) underplated and/or metasomatized lower continental crust (Shellnutt *et al.* 2015*b*. Among the possible mantle sources, the continental LIP basaltic magmas are dominantly derived from mantle plume (Mahoney *et al.* 1991; Xu *et al.* 2001) and subcontinental lithosphere (Hawkesworth *et al.* 1988; Gallagher & Hawkesworth 1992). For alternate views to plume hypothesis, the reader is referred to Hamilton (2011 and references therein). For the lithosphere to contribute significantly to continental LIP magmatism, it needs to fulfill at least one of the following conditions: (i) a favourable thermal state (Arndt & Christensen 1992); (ii) enough extension to cause decompression melting (McKenzie & Bickle 1988); (iii) the presence of volatiles (Ivanov

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