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Large igneous provinces linked to supercontinent assembly

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ABSTRACT

Models for the disruption of supercontinents have considered mantle plumes as potential triggers for continental extension and the formation of large igneous provinces (LIPs). An alternative hypothesis of top-down tectonics links large volcanic eruptions to lithospheric delamination. Here we argue that the formation of several LIPs in Tarim, Yangtze, Lhasa and other terranes on the Eurasian continent was coeval with the assembly of the Pangean supercontinent, in the absence of plumes rising up from the mantle transition zone or super-plumes from the core–mantle boundary. The formation of these LIPs was accompanied by subduction and convergence of continents and micro-continents, with no obvious relation to major continental rifting or mantle plume activity. Our model correlates LIPs with lithospheric extension caused by asthenospheric flow triggered by multiple convergent systems associated with supercontinent formation.

1. Introduction

The breakup of Phanerozoic and Proterozoic supercontinents such as Pangea, Rodinia and Columbia has commonly been linked to mantle plumes generated from the mantle transition zone, or super-plumes rising from the core–mantle boundary, with the process accompanied by the formation of large igneous provinces (LIPs) and the related deep-mantle source magmas (Morgan, 1971, 1972; Griffiths and Campbell, 1991; Ernesto et al., 2002; Ernst et al., 2005, 2013; Ernst, 2014; Maruyama et al., 2007; Arndt et al., 2008; Murphy et al., 2009; Santosh et al., 2009; Bryan and Ferrari, 2013; Nance et al., 2014; Kawai et al., 2013). It has also been suggested that plate subduction and oceanic ridge formation are the result of mantle plumes or convective mantle flow in the asthenosphere (Peltier, 1989; Anderson, 1998). Recent investigations from the Eurasian continent (Fig. 1; Deccan, Lhasa, Emeishan, Tarim, and Siberia; Chung and Jahn, 1995; Pirajno, 2000; Zhang et al., 2010, 2012, 2014; Zhu et al., 2010) show that the formation of 290–250 Ma LIPs in Emeishan and Tarim may not be related to the breakup of Pangea, but may instead be related to the assembly of this supercontinent.

In the case of the Emeishan and Tarim LIPs and Traps, many workers have invoked a mantle plume or even super-plume connection (Chung and Jahn, 1995; Pirajno, 2000; Xu et al., 2004; Zhang et al., 2010, 2013; and references therein), although the plume hypothesis and the alternative lithospheric delamination hypothesis are both inconsistent with new geological, geochemical, and paleomagnetic data, as evaluated in this study. Here we emphasize the possible link between the formation of LIPs and the assembly of supercontinents, and attempt to resolve the debate on the origin of the Emeishan and Tarim LIPs through a careful analysis of the geology, tectonics, paleomagnetism, and magma compositions in relation to plate convergence. Based on our analysis, we propose a new model of asthenospheric flow caused by multiple subduction systems as the dominant trigger for extensional tectonics and LIP formation.

2. Evidence for the 290–250 Ma events and related global tectonics

2.1. Regional characteristics of two LIPs and their time-scales

The Tarim LIP formed during the period ~290–275 Ma (e.g. Zhang et al., 2010, 2012) or slightly earlier at ~300 Ma (Zhang et al., 2013) and is located in the interior and northern margins of the Tarim Block. Its tectonic setting is post- or syn-orogenic (Figs. 2A and 3A), suggesting that the LIP formed during the closure of the Central Asian Ocean, after or during the Tianshan orogeny. A rift system formed in the center of the Tarim Block and along its northern margin. The LIP contains basalt as well as some felsic volcanics, and dykes of gabbro formed mainly parallel to the rift zones, rather than as giant radiating swarms. The magmas included kimberlite, rhyolite, alkaline-basalt, diabase, and gabbro, and their geochemical features suggest OIB and fore-arc material (Zhang et al., 2010, 2012).

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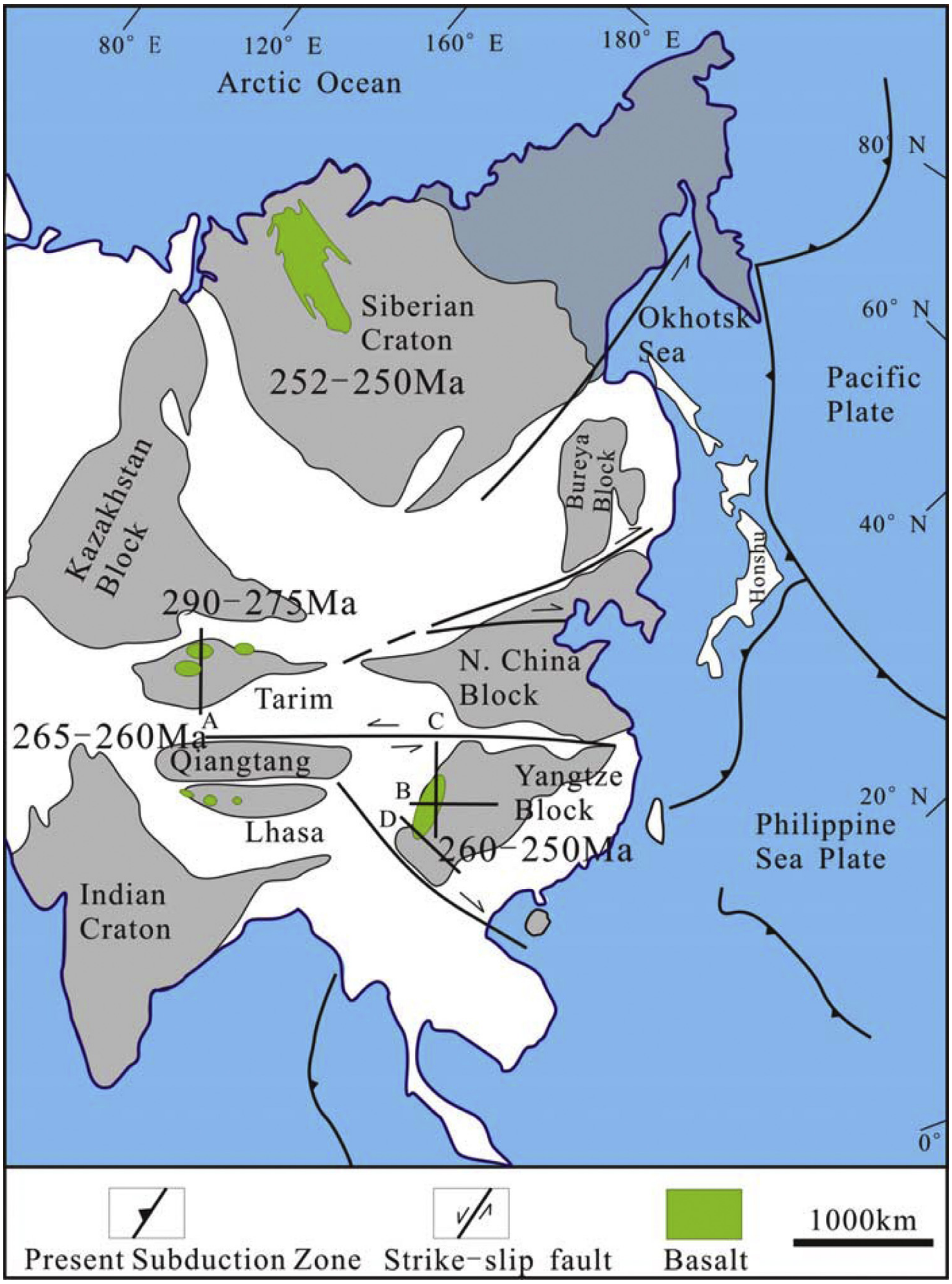

Fig. 1. Distribution of four major LIPs in the Eurasian continent and their regional tectonic settings (compiled from Sorkhabi and Heydari, 2008). Age data are from various studies (Deccan, Lhasa, Emeishan, Tarim, and Siberia; Pirajno, 2000; Zhang et al., 2010, 2012; Chung and Jahn, 1995; Zhu et al., 2010). Locations of geological cross sections of Fig. 3 are shown.

The Emeishan LIP occurs within the Yangtze Block, and Shellnutt et al. (2012) reported high precision zircon CA-TIMS U—Pb ages with a narrow range from 257 Ma to ~260 Ma (Figs. 2B and 3B–D) for the Panxi intrusive suite in the inner zone of the LIP. Prior to the LIP formation, this region witnessed coeval submarine sedimentation and subaerial basalt eruptions in time and space (Wang et al., 2014), but the sedimentation is not merely of shallow water setting (Ukstins Peate and Bryan, 2008). During the early stages of the LIP, rift systems formed along the western margin and in the interior of the Yangtze Block (Fig. 2B). Mafic–ultramafic dyke swarms and sheets formed along N–S trending rift zones, and V—Ti—Fe mineral deposits formed in association with the gabbros (Pang et al., 2013; Pecher et al., 2013).

The Emeishan basaltic rocks contain mega-phenocrysts of feldspar, and rhyolites occur in the bottom and upper layers. Overall, the rocks display OIB characteristics (Xiao et al., 2004) with the signature of recycled oceanic crust (Zhu et al., 2005). Some studies also reported the eruption of picrite, considered to be important evidence for a mantle plume (Zhang et al., 2006). However, more recently it has been argued that these picrites were actually sourced from the lithospheric mantle (Kamenetsky et al., 2012) or the asthenosphere (Hao et al., 2011), and that the subducted oceanic slab was remelted to form the picritic porphyries (Kou et al., 2012). These arguments suggest the rocks are not primary mantle material, contradicting the mantle plume hypothesis in earlier studies (e.g., Zhang et al., 2006; Xu et al., 2004). Moreover, the