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Phanerozoic hot spot traces and paleogeographic reconstructions of the Siberian continent based on interaction with the African large low shear velocity province

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A R T I C L E I N F O

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A B S T R A C T

We review intraplate magmatism in Siberia and its folded surroundings from 480 Ma to the present. We describe several large igneous provinces (LIPs) and the intervals in which they were continuously formed within the limits of the Siberian continent: the Altay–Sayan Early Paleozoic magmatic area (598–446 Ma), the Altay–Sayan LIP (408–393 Ma), the Viluy LIP (380–350 Ma), the Barguzin–Vitim LIP (310–275 Ma), the Late Paleozoic rift system of Central Asia (318–242 Ma), the Siberian traps and West Siberian rift system (250–249 Ma), the East-Mongolian and West-Trans-Baikalian LIP (228–195 Ma), and a number of various aged Late Mesozoic and Cenozoic rift zones and magmatic areas (from 160 Ma to the present day).

Following Lawver and Muller (1994), Kharin (2000), Lawver et al. (2002) and Chernysheva et al. (2005), we accept the position of the Icelandic hot spot under the Siberian trap area at the Permo-Triassic boundary. That enables us to estimate the geographic coordinates of the Siberian trap location at 250 Ma (they are the same as Iceland today). Presently the Icelandic hot spot is situated above the African large low shear velocity province (LLSVP) that indicates a hot mantle plume. We suggest a set of paleogeographic reconstructions of the Siberian continent for which we evaluate the paleolatitude based on the paleomagnetic data and estimate the paleolongitude position by placing Siberia above the African LLSVP. Furthermore, we estimate the geographic coordinates for other ancient hot spots in the framework of the African LLSVP that we consider to be responsible for the intraplate magmatism during different time periods in the Phanerozoic eon.

Available rare element and isotopic characteristics of the intraplate magmatic rocks of Siberia enable us to determine three primary sources – moderately depleted mantle (PREMA), enriched mantle (EM-I and EM-II) – of the mantle origin magma. We propose that the model explains the interaction of the hot mantle plume including hot spots (plume tails) with the Siberian intraplate magmatism areas throughout the Phanerozoic eon.

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1. Introduction

Plume tectonics, a relatively new field in the Earth Sciences, studies the movements of mantle plumes and the interactions of mantle plumes with tectonic plates. Beginning with the pioneering works of Wilson (1963, 1965, 1973) and Morgan (1971, 1972), many authors have related intraplate events to hot spot activities induced by hot upwelling mantle plumes. Zonenshain and Kuzmin (1983, published in Russian) and then Zonenshain et al. (1991a) suggested that the hot spots on the Earth's surface do not have a random distribution and can be reliably grouped into regions they called hot mantle fields (presently called hot plumes) with cold mantle fields (presently subducting zones) in between. They proposed that hot plumes are surficial expressions of hot upwelling deep mantle flows, and that cold plumes correspond to downgoing branches that reflect convective cells in the lower mantle.

Seismotomography demonstrated the different natures of hot and cold mantle plumes and defined their distinct locations in the Earth's interior. Dziewonski et al. (1977, 1984), Fukao et al. (1994), and Maruyama (1994) reported higher and lower shear velocity zones in the mantle, and traced them from the lithospheric base to the core. Two of the largest low shear velocity zones or provinces (LLSVP) correspond to the excess temperature mantle located under Africa and the surrounding area and under the Pacific Ocean (Fig. 1) (Zonenshain and Kuzmin, 1983; Dziewonski, 1984; Zonenshain et al., 1991a; Zhao, 2001; Romanowicz and Gung, 2002; Romanowicz, 2008). These LLSVPs are usually called the African and Pacific superplumes. Superplume locations are characterized by positive anomalies of the geoid (McNutt and Judge, 1990; Davies and Pribac, 1993; Lithgow-Bertelloni and Silver, 1998), clusters of hot spots mostly along their peripheries (Anderson, 1982; Courtillot et al., 2003; Jellinek and Manga, 2004), and large igneous provinces (Burke and Torsvik, 2004; Burke et al., 2008).

Davies and Richards (1992) proposed co-existence of plate tectonics and plume tectonics. A number of recent studies show that mantle plumes (hot spots) are most likely produced by instability in the D″ layer at the core–mantle boundary (CMB) that lies between the Earth's solid silicate mantle and its liquid iron–nickel outer core (Davaille, 1999; Campbell and Kerr, 2007). Such plumes separate into a distinct head and tail and carry only about 10% of the Earth's heat to the surface today. In contrast, hot mantle material upwellings or superplumes that rise in response to radiogenic heating of the mantle account for at least 60% of the heat were carried to the surface. Many plumes may be contained within a single mantle upwelling. Mantle plumes are commonly used to estimate plate movements (Besse and Courtillot, 2002; Steinberger and Torsvik, 2008) as it is assumed that they are relatively stable in relation to the mantle and the lithosphere. It is largely accepted that an array of hot spots may produce upper mantle material displacement in the asthenosphere leading to continental breakup (Morgan, 1971; Storey 1995; Condie, 2002; Li and Zhong, 2009). Such phenomena indicate that mantle plumes can drive lithospheric plate dynamics. At the same time it is suggested that plate tectonics effectively control the location and growth of mantle plumes (Steinberger and O'Connell, 1998; Zhong et al., 2000; Gonnermann et al., 2004; Li and Zhong, 2009). Seismotomography also demonstrates that subducting slabs experience significant flattening and stagnation in the lower mantle and can sink to the CMB (Zhao, 2007; Fukao et al., 2009), participating in whole-mantle convection. Such convective movement in the mantle interacts with the hot mantle plume columns rising from the CMB and may aggravate the rise of the hot material. The upwelling rises through the lower mantle in the form of a huge mushroom, breaking into a number of isolated plumes in the upper mantle and a chain of hot spots in the lithosphere (Fukao et al., 1994; Maruyama, 1994; Maruyama et al., 2007).

Present day hot spots, superficial indicators of mantle plumes like the African and Pacific plumes, and large igneous provinces (LIPs) are located in two areas away from subduction slabs (Anderson, 1982; Hager et al., 1985; Weinstein and Olson, 1989; Duncan and Richards, 1991; Romanowicz and Gung, 2002; Courtillot et al., 2003; Burke and Torsvik, 2004; Burke et al., 2008). This suggests a close association between mantle plumes and plate tectonics as opposed to the earlier

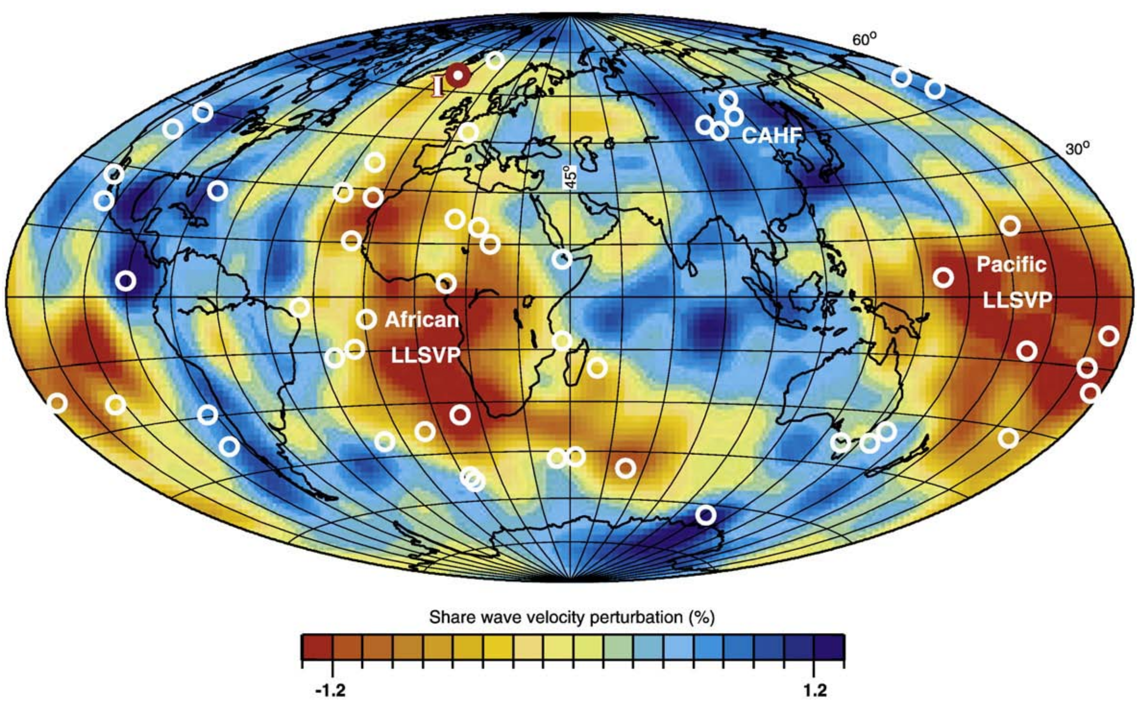

Fig. 1. Distribution of the 49 hotspots (white circles) from Courtillot et al. (2003) superimposed on a section at 2800 km depth through tomographic model S20RTS for shear wave velocity (Ritsema et al., 1999). Color code from −1.2% (red hues) to +1.2% (blue hues) shows the share wave velocity perturbation in %. Letter I corresponds to Icelandic hot spot. Central Asia Hot Field (CAHF) represents the recent occurrences of the intraplate volcanism in Southern Siberia and Mongolia (Zonenshain et al., 1991b). Hammer–Aitoff projection of the Earth is used.