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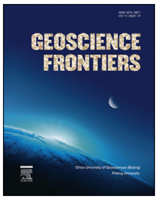

Focus paper

The latest geodynamics in Asia: Synthesis of data on volcanic evolution, lithosphere motion, and mantle velocities in the Baikal-Mongolian region

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ABSTRACT

From a synthesis of data on volcanic evolution, movement of the lithosphere, and mantle velocities in the Baikal-Mongolian region, we propose a comprehensive model for deep dynamics of Asia that assumes an important role of the Gobi, Baikal, and North Transbaikal transition-layer melting anomalies. This layer was distorted by lower-mantle fluxes at the beginning of the latest geodynamic stage (i.e. in the early late Cretaceous) due to avalanches of slab material that were stagnated beneath the closed fragments of the Solonker, Ural-Mongolian paleoceans and Mongol-Okhotsk Gulf of Paleo-Pacific. At the latest geodynamic stage, Asia was involved in east–southeast movement, and the Pacific plate moved in the opposite direction with subduction under Asia. The weakened upper mantle region of the Gobi melting anomaly provided a counterflow connected with rollback in the Japan Sea area. These dynamics resulted in the formation of the Honshu-Korea flexure of the Pacific slab. A similar weakened upper mantle region of the North Transbaikal melting anomaly was associated with the formation of the Hokkaido-Amur flexure of the Pacific slab, formed due to progressive pull-down of the slab material into the transition layer in the direction of the Pacific plate and Asia convergence. The early–middle Miocene structural reorganization of the mantle processes in Asia resulted in the development of upper mantle low-velocity domains associated with the development of rifts and orogens. We propose that extension at the Baikal Rift was caused by deviator flowing mantle material, initiated under the moving lithosphere in the Baikal melting anomaly. Contraction at the Hangay orogen was created by facilitation of the tectonic stress transfer from the Indo-Asian interaction zone due to the low-viscosity mantle in the Gobi melting anomaly.

1. Introduction

From a long-lasted discussion on origin of mantle magmatism (Morgan, 1971; Hofmann, 1997; Anderson, 2007; Maruyama et al., 2007; Foulger, 2010; Karato, 2012), it follows that magmatic sources might originate at different levels of the mantle (Fig. 1). Local decreasing of seismic velocities may be interpreted in terms of: (1) a plume, starting from the lower thermal boundary layer of the mantle, (2) a counterflow from the lower mantle after an avalanche of slab material from the transition layer through its lower boundary 660 km, (3) a melting anomaly of a domain that extends above the transition layer at depths of 200–410 km, (4) a melting anomaly of a domain that occurs beneath the lithosphere at depths of 50–200 km, (5) a melting anomaly of the lower part of the lithosphere, activated due to rifting, and (6) a melting anomaly at the crust–mantle boundary originated through delamination of an orogenic root. A melting anomaly in the upper mantle may be associated, on the one hand, with rifting or orogenesis in the lithosphere, on the other hand, with a plume or a counterflow from the lower mantle. The definition of each type of melting anomaly requires high-resolution seismic tomography and synthesis of the identified low-velocity anomalies and mantle volcanism evolution.

From the geochemical difference between mid-ocean basalts (MORB) and oceanic island basalts (OIB), it was proposed that the source of the latter occurs in the deep mantle (Morgan, 1971). This

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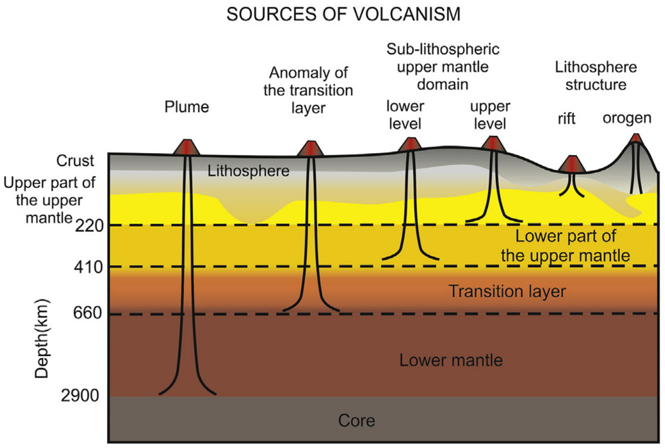

Figure 1. Systematics of mantle melting anomalies in continents.

hypothesis has been confirmed by high-resolution seismic tomography of the mantle beneath Hawaii and other islands (Montelli et al., 2004; Zhao, 2009). Another kind of geodynamic regime seems to operate due to the accumulation of subducted oceanic slab material in the transition layer. After some residence time, the material collapses into the lower mantle, inducing a reverse flow of hot material (Mitrovica et al., 2000; Yoshioka and Sanshadokoro, 2002; Zhao, 2009). In the case of hot material rising from the lower to the upper mantle through the transition layer, the latter thins from the top and bottom as inferred from the opposite Clapeyron slopes (Ito and Takahashi, 1989; Anderson, 2007; Maruyama et al., 2007). Studies of hotspots generally confirm the anticorrelated transition zone thinning (Shen et al., 1998; Li et al., 2000, 2003; Owens et al., 2000; Hooft et al., 2003), although in some regions (for instance, in the western North America), the 410 and 660 km discontinuities show no anticorrelation (Houser et al., 2008).

Under Central and East Asia, the transition layer is "cool" and the lower mantle has relatively high velocities (Castillo, 1988; Montelli et al., 2004; Maruyama et al., 2007) that makes rising plumes here doubtful. One can assume only deep dynamics governed by slab avalanches from the transition layer to the lower mantle. Meanwhile, these regions reveal upper mantle low-velocity anomalies comprised into the shallow (depth less than 200 km) Sayan-Mongolian and deeper (depth up to the transition layer) Transbaikalian upper mantle domains, the origin of which has been explained by processes related to convergent interaction between India and Asia in the south and the Pacific plate subduction in the east, respectively (Rasskazov et al., 2003a,b, 2004).

The mantle dynamics in Asia was an object for speculations in terms of (1) interpreting geophysical data on present-day mantle structure without examination of volcanism (Zorin, 1971; Zorin et al., 2003, 2006), (2) ascertaining spatial or spatial-temporal distribution of late Mesozoic and Cenozoic volcanism without examination of deep mantle structure (Rasskazov, 1994; Yarmolyuk et al., 2007), (3) recording low-speed anomalies in the mantle under Quaternary volcanic fields (Lei and Zhao, 2005; Zhao, 2009; Wei et al., 2012), and (4) study of relations between low-velocity mantle anomalies and volcanism evolution (Rasskazov et al., 2003a,b, 2004, 2012; Rasskazov and Taniguchi, 2006).

Unlike the previous studies, we consider the present-day state of Asia in this paper first of all as a result of the latest geodynamic stage, and decipher deep geodynamics using basic models of seismic tomography of the mantle and evidence on spatial-temporal distribution of volcanic activity in key areas, along with motions of the lithosphere and structural reorganizations at the boundary between the Pacific plate and Asia.

2. Global and regional expressions of the latest geodynamic stage

The latest geodynamic stage comprises processes of the Earth's unidirectional evolution. This stage likely began at the last Phanerozoic (mid-Cretaceous, 118–83 Ma) paleomagnetic superchron. "The Quiet Cretaceous period" corresponded to a high-temperature ("superplume") state of the mantle, reflected in the maximum rate of oceanic crust formation, extreme greenhouse conditions, sea level rise, and enhanced organic productivity (Larson, 1991a,b; Tatsumi et al., 1998; Larson and Erba, 1999; Condie, 2001; Jenkyns et al., 2004; Courtillot and Olson, 2007; Trabucho et al., 2010).

An initial global reference point of the final geodynamic stage is defined through marine $^{87}Sr/^{86}Sr$ records that exhibit the net effect of continental (crustal) and oceanic (mantle) processes. The predominated dissolution of crustal material, which is enriched by ^{87}Sr, was provided in convergent conditions and was displayed by the upper envelope line of the main evolutionary trend. An episodic increasing dissolution effect of oceanic material, exhibited by relative decreasing $^{87}Sr/^{86}Sr$, was due to divergent events that resulted in the lower envelope line of the main trend. This main trend demonstrates a general decreasing role of convergence in the early–middle Phanerozoic and its increasing in the late Phanerozoic (Fig. 2). The contribution of the crustal and oceanic components was changed drastically at the main trend bend. The divergent $^{87}Sr/^{86}Sr$ minimum of 160 Ma corresponded to the global structural reorganization that launched formation of the new (Pacific) lithospheric plate from the center of a former ridge triple junction between the Kula, Farallon, and Phoenix plates in Southern Paleo-Pacific (Hilde et al., 1977) and closing the Mongol-Okhotsk Gulf in Northwestern Paleo-Pacific (Parfenov et al., 2003). At about 90 Ma, relative variations of $^{87}Sr/^{86}Sr$ were negligible, i.e. the lower and upper limiting lines of the main trend converged. The descending early–middle Phanerozoic portion of the main trend changed to the late Phanerozoic one at ca. 90 Ma. The unique meaning of this time was matched also by the episode of komatiite magmatism in Gorgona Island (Arndt et al., 2008).

The global transition from the early–middle to the late Phanerozoic geodynamic stage had regional consequences in Asia. Due to accommodation of interplate convergent processes in Central Mongolia, high-K latites from crustal sources changed to moderate-K mantle-derived basalts. From trace-element and Nd–Sr–Pb isotope signatures, it was inferred that the 91–31 Ma basalts were derived from sources related to the reactivated Gobi system of paleoslab fragments that stagnated in the mantle after closing the Solonker and Ural-Mongolian paleoceans (Rasskazov et al., 2012; Rasskazov and Chuvashova, 2013). Afterwards, the 32–0 Ma basalts were spatially related to the development of the Hangay orogen. The alternation of high- and moderate-potassic lava eruptions demonstrated cycles as long as 20 million years at the 91–31 Ma time interval, relatively short cycles of 2.5 million years between 32 and 2 Ma, and more short ones of 0.7–0.3 Ma in the past 2 Ma (Rasskazov et al., 2010).

A change of magmatism was recorded at ca. 90 Ma in Shandong Peninsula (Xu et al., 2004). There was a magmatic lull here, lasting from 90 to 75 Ma, that separated late Cretaceous and Cenozoic basaltic eruptions from the early–middle Phanerozoic granitic and basic intrusions. The Nd and Sr isotopic signatures of these older intrusions indicate their origin from enriched mantle and crustal sources. Some 75 Ma basaltic lavas still possess these isotopic

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