GEODYNAMICS & TECTONOPHYSICS

PUBLISHED BY THE INSTITUTE OF THE EARTH'S CRUST
SIBERIAN BRANCH OF RUSSIAN ACADEMY OF SCIENCES

2017 VOLUME 8 ISSUE 3 PAGES 435–440

ISSN 2078-502X

https://doi.org/10.5800/GT-2017-8-3-0256

Proceedings of the Second Russia–China International Meeting on the
Central Asian Orogenic Belt (September 6–12, 2017, Irkutsk, Russia)

ORIGIN OF MELTING ANOMALIES IN THE JAPAN-BAIKAL CORRIDOR OF ASIA AT THE LATEST GEODYNAMIC STAGE: EVOLUTION FROM THE MANTLE TRANSITION LAYER AND GENERATION BY LITHOSPHERIC TRANSTENSION

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For citation: *Chuvashova I.S., Rasskazov S.V., Sun Y., Yang C.*, 2017. Origin of melting anomalies in the Japan-Baikal corridor of Asia at the latest geodynamic stage: evolution from the mantle transition layer and generation by lithospheric transtension. *Geodynamics & Tectonophysics* 8 (3), 435–440. doi:10.5800/GT-2017-8-3-0256.

At the latest geodynamic stage that is characterized by forces and processes of the last 90 Ma the lithosphere of Asia has been reactivated due to four main force factors: 1) mantle melting anomalies, 2) subduction-related interaction between the Pacific plates and the continental eastern margin, 3) convergent interaction between India and the continental southern margin, and 4) quasiperiodic orbital variations of the Earth. The starting point of the latest geodynamic stage [*Rasskazov, Chuvashova, 2013*] is consistent with the change of the Earth's rotation due to the resonant interaction of its orbit with the orbit of the Mars in the time interval of 87–85 Ma [*Ma et al., 2017*].

A mantle melting anomaly is expressed by volcanic eruptions on the earth's surface and low-velocity root in the mantle. Convective instability of the lower mantle at its lower or upper boundary generates a melting anomaly of the plume or transition layer type, respectively. Each is supposed to be primary, because of energetic relation to the original source that causes instability. A primary melting column might change due to relative motions of the lithosphere and underlying

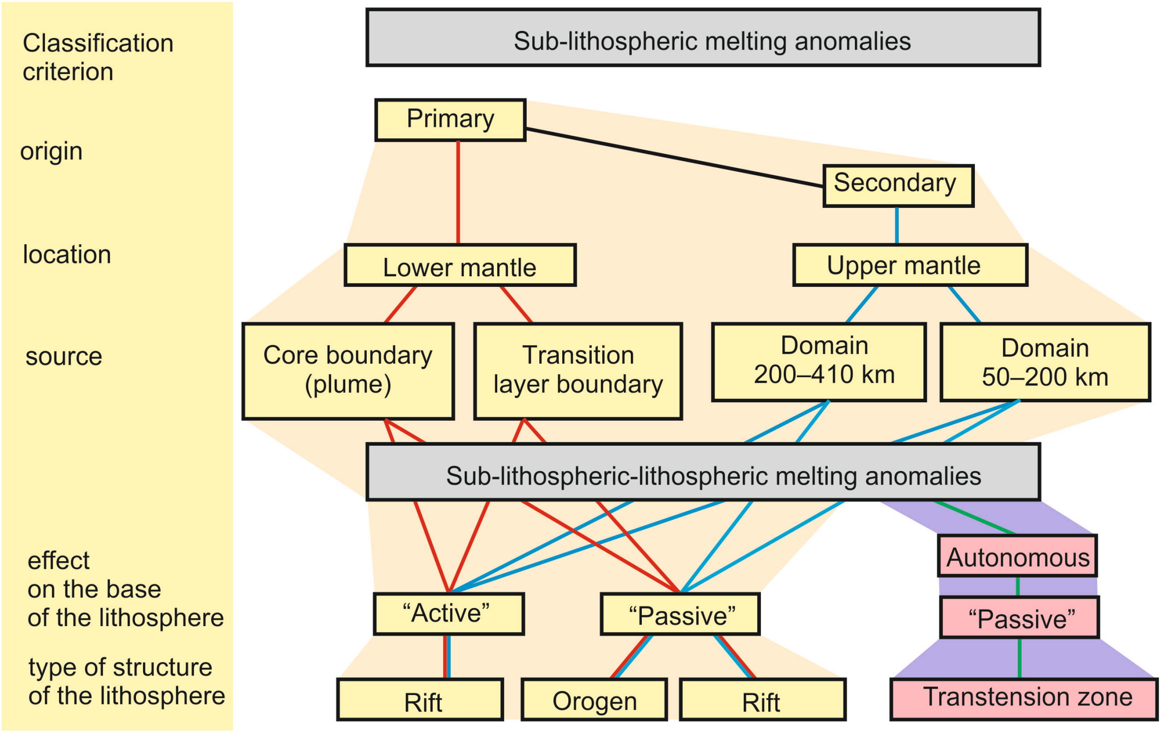

Fig. 1. Designation of processes in the lithosphere and sub-lithospheric mantle, associated with the evolution of a primary melting anomaly, and autonomous, developed independently. Primary melting anomaly, evolving into secondary ones, contributes to riftogenic and orogenic deformations of the lithosphere. Autonomous melting anomaly might develop in a lithospheric transtension zone.

levels of sub-lithospheric mantle. The low-velocity region of the upper mantle can be explained when considering its origin as probable derivative of a primary melting anomaly. Such an upper mantle region acquires the status of a secondary melting anomaly.

Melting anomalies can provide thermal thinning of the lithosphere, corresponding, by definition, to "active" rifting. In this definition, the term "active" is not a rift structure, but a melting anomaly that affects the base of the lithosphere. Besides, there is a "passive" deformation of the lithosphere with extension (rifting) (in a particular case, extension with strike-slip i.e. transtension) or with compression (orogeny) (in a particular case, contraction with strike-slip i.e. transpression). In this definition, "passive" means not a rift or orogenic structure, but a melting anomaly resulted from deformations of the lithosphere (Fig. 1). Such a melting anomaly gets the status of an autonomous, i.e. not having a direct connection with the primary melting anomaly. As a result of tectonically-induced lithospheric processes, an autonomous melting anomaly can originate in the lithosphere without connection to any primary or secondary melting anomaly.

At the latest dynamics stage of Asia, there were the Gobi and West-Transbaikal primary melting anomalies of the transition layer that evolved into secondary upper mantle domains of 200–410 and 50–200 km [*Chuvashova et al., 2017b*]. At least two melting anomalies (Wudalianchi and Udokan) were clearly controlled by transtension structures. In this paper, we demonstrate differences between the melting patterns, evolved from the transition layer and displayed autonomously.

Melting anomalies generated from the transition layer. The primary melting anomalies, associated with the Late Cretaceous volcanic events in Asia, are recorded from low S-wave velocities at the transition layer beneath Gobi and Western Transbaikal. Similar anomalies were generated beneath Northern Transbaikal, Dariganga, and Changbai but were destroyed by subsequent subduction [*Chuvashova et al., 2017b*]. The volcanic fields have been shifted from the sites of initial instabilities at the transition layer east-southeastwards for 400–600 km due to subsequent motion of the lithosphere. The related secondary melting anomalies are marked by spatial-temporal evolution of the late Cretaceous through Cenozoic volcanism and by various combinations of low- and high-velocity upper mantle regions.

In the interpretation, which takes into account the latest motion of the Asian lithosphere, orogenic and rifting processes are explained by dynamics of asthenospheric flows within the Japan-Baikal corridor that was limited by the lateral zones of the convergent interactions between India and Asia in the south-west

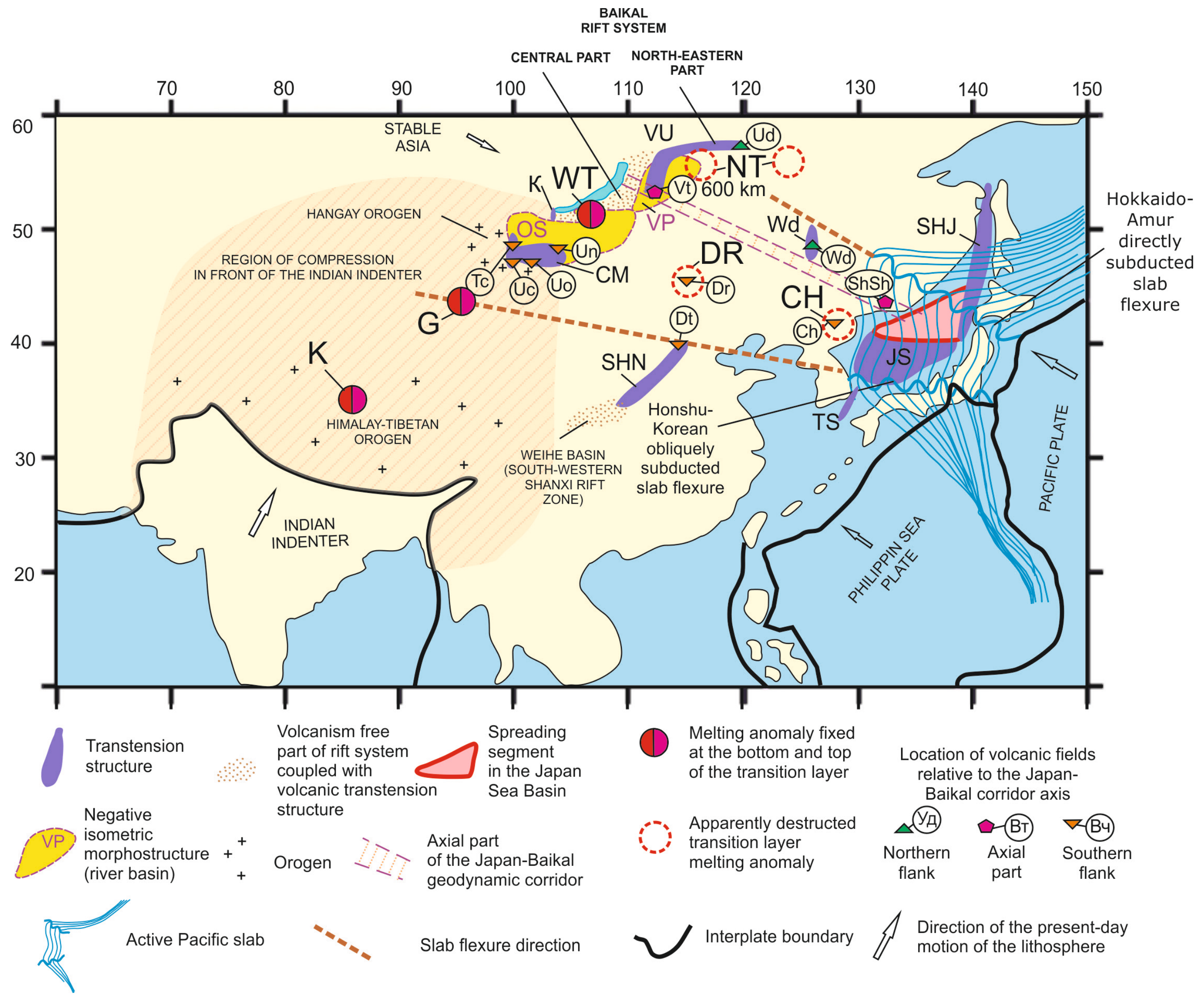

Fig. 2. Distribution of volcanically active transtension zones relative to the axis of the Japan-Baikal geodynamic corridor.

The transtension structures: VU – Vitim-Udokan, K – Kultuk, CM – Central Mongolia, Wd – Wudalianchi, SHN – Shanxi. The Japan Sea (JS) pull-apart structure, its transtension zones: SHJ – Sakhalin-Hokkaido-Japan Sea, TS – Tsushima. Volcanic fields (in circles): axis of the Japan-Baikal corridor (Vt – Vitim, ShSh – Shkotov-Shufan), its southern flank (Uc – Upper-Chulutyn, Tc – Taryat-Chulutyn, Uo – Upper-Orkhon, Un – Ugii-Nur, Dr – Dariganga, Dt – Datong, Ch – Changbai), and its northern flank (Ud – Udokan, Wd – Wudalianchi). Large intermontane basins: Orkhon-Selenga (OS), Vitim Plateau (VP). The structures of the Sea of Japan and the Tatar Strait are shown after [*Jolivet et al., 1994*].

and between North America and Asia in the northeast. This geodynamic corridor is considered as a melting structure a one-order to the convergent Central Asian region originated in front of the Indian indenter. The secondary melting anomalies that are spatially associated with the development of lithospheric transtension play a key role in both orogenic and rifted areas. In the southwestern part of the Baikal rift system, the Sayan-Mongolian low-velocity domain was formed at depths of 50–200 km in Central Mongolia and Eastern Sayans. The Late Cenozoic lithospheric-asthenospheric magmatism of these areas was derived through the natural course of the upper mantle evolution related to the Gobi and West Transbaikal transition layer melting anomalies and were only locally controlled by the lithospheric transtension zones of Central Mongolia and Southwestern Pribaikal (Fig. 2).

In the Japan-Baikal geodynamic corridor, there are three melting regions, distributed relative to the subducted Pacific slab edge: 1) the distant, Baikal-Mongolian, which spatially corresponds to the late Cenozoic Baikal rift system and adjacent areas, 2) the middle, Hannuoba-Heilongjiang, which comprises volcanic fields of the North and North-Eastern China and adjacent Eastern Mongolia, and 3) the close, Tanlu-Primorye, which includes volcanic fields of Eastern China in the Tanlu fault zone north of Bohai Gulf and the continental part that extends eastwards to Southern Primorye of Russia.

Autonomous melting anomalies. The Udokan autonomous melting anomaly is located on the northern flank of the Japan-Baikal geodynamic corridor. The spatial-temporal evolution of the magmatic liquids of this area responded to the activity of the Vitim-Udokan transtension structure. In the middle Miocene, high-Mg (high-temperature) volcanism first displayed in the Vitim and then in the Udokan volcanic fields. Later on, there were three intervals of the delayed responses of volcanism in the Udokan field after volcanic events in the Vitim field (Fig. 3). Unlike the Vitim and other volcanic fields of Inner Asia, the Udokan area was characterized by eruptions of trachytes that were strictly controlled by tectonic zones.

Similar to the tectonically-induced Udokan melting anomaly, the Wudalianchi one is also located on the northern flank of the Japan-Baikal geodynamic corridor. It is defined due to specific high-potassic compositions of erupted liquids. The uniqueness of volcanic sources from the Wudalianchi zone for the whole East China was emphasized in multiple papers [*Zhang et al., 1995; Chuvashova et al., 2009; Chu et al., 2013; Rasskazov et al., 2016*; and other]. The established spatial-temporal variations of rock compositions in the Wudalianchi volcanic field are explained in terms of the magma generation control by the north-south transtension zone in the layer of the lithospheric base that shielded the underlying sub-lithospheric convective mantle from the overlying more enriched lithosphere. Sub-lithospheric liquids were distinct due to the initial ^{87}Sr/^{86}Sr ratio of about 0.7052, melts from the boundary shielding layer due to the same and lower ratios, and those from the overlying enriched lithosphere due to the same and higher ratios.

It was proposed that the local venue of the convective mantle material from below the shielding layer and the melting enriched background material above was governed by transtension deformations. The eruptions of sub-lithospheric melts from the axial part of the main transtension zone, which took place at 2.5–2.0 Ma, were followed by the propagation of the background liquids from the wider segment of the enriched lithospheric region at 1.3–0.8 Ma. In the past 0.6 Ma, background melting progressed at the margins of the transtension segment simultaneously with local melting along the crack that propagated in the boundary shielding layer under the central part of the background melting region [*Rasskazov et al., 2016*].

Discussion. Due to subduction along the Hokkaido-Amur and Honshu-Korean flexure of the Pacific slab and inverse flow of the asthenospheric material under the margin of the continent, the lithosphere was rifted and a moment of its motion, directed towards the subducted slab, was created. The convergence between India and Asia, on the contrary, led to the shrinking lithosphere and orogenesis. Sub-lithospheric and lithospheric force factors were complicated by superimposed quasiperiodic effects on the Earth's layers caused by its orbital motion.

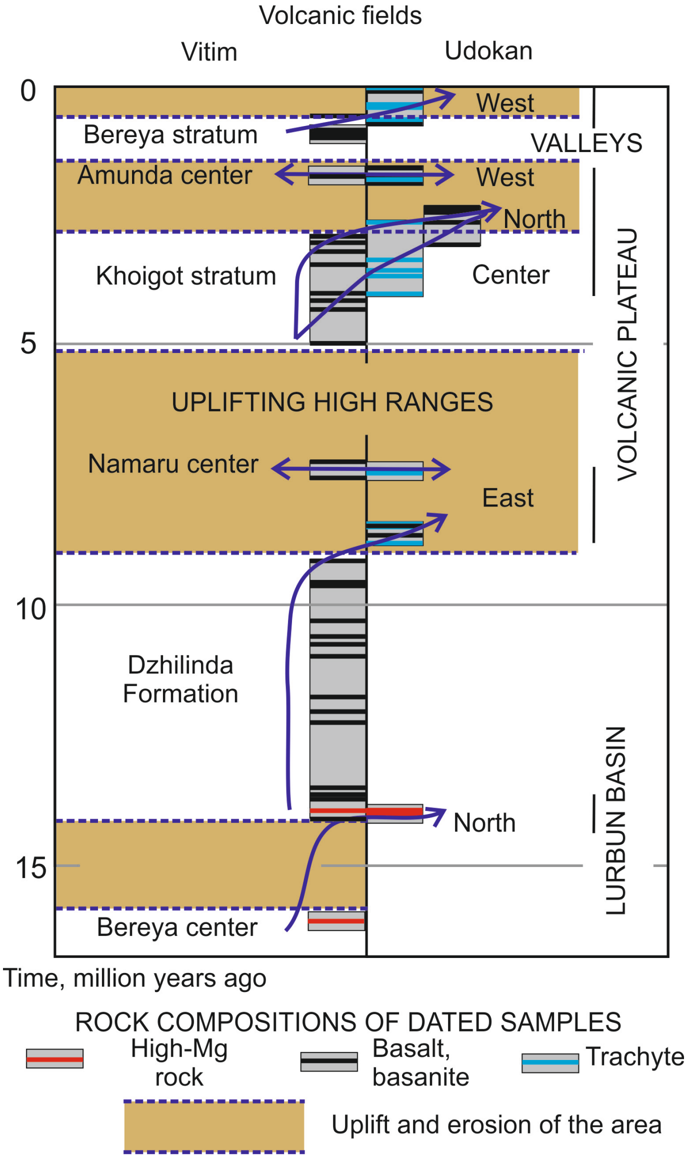

Fig. 3. Comparisons between volcanic episodes of the Vitim and Udokan fields. The arrows show the lags of the Udokan volcanic episodes relative to the Vitim ones. Two-sided arrows denote synchronous episodes.

At the latest geodynamic stage, volcanic responses of Inner Asia did not occur in the Late Cretaceous, Early and Middle Cenozoic and affected the lithosphere only in the Late Cenozoic. Under prevailing compression, volcanism accompanied the formation of the Hangay orogen in Central Mongolia with orbital cyclicity. Cyclic variations of Earth's orbital parameters are recorded in the Late Cenozoic at the most sensitive transtension structures of the lithosphere: within the Chulutyn segment of the Hangay orogen on the southern flank of the Japan-Baikal corridor, and in the northeastern part of the Baikal rift system, on its northern flank.

Under prevailing extension, volcanism with orbital cyclicity took place in the north-south Tsipa-Muyakan and west-east Muya-Udokan segments of the Vitim-Udokan transtension structure. Volcanic evolution in the Vitim field of the Tsipa-Muyakan segment was affected by the deformation of the lithosphere at the axial part of the Japan-Baikal geodynamic corridor, volcanic evolution in the Udokan field of the Muya-Udokan segment was due to deformation of the lithosphere on the northern periphery of this corridor. From isotopic-geochemical study of volcanic rocks [*Chuvashova et al., 2017a*], it was found that the primary lithospheric transtension at the southern part of the Vitim- Udokan structure resulted in eruptions of the sub-lithospheric liquids, not contaminated by lithospheric material, in the Vitim field. The responses of lithospheric transtension in the eastern part of the Vitim-Udokan structure led to eruptions of liquids in the Udokan field from sources that belong to the mantle portion of the lithosphere and crust.

The activities of lithospheric-asthenospheric sources were governed by quasiperiodic orbital variations. In Hangay, where background lithospheric compression predominated, volcanic eruptions responded to the 2.4 million-years cyclic variations of the Earth's eccentricity with a transition in the Quaternary to those of the 0.4 million-years eccentricity. In the north-eastern part of the Baikal rift system, which was affected with prevailing stretching since the Middle Miocene, the eruptions were shifted from the axis to the periphery of the geodynamic corridor with quasiperiodic responses to the 2.4 million-years cyclic variations of the Earth's eccentricity from about 10 Ma, including the Quaternary.

Conclusion. It was shown that the Japan-Baikal corridor was active at the latest geodynamic stage, in which primary melting anomalies were generated due to instability of the mantle transitional layer in the Late Cretaceous and were evolved into the upper mantle flows responsible for creating secondary melting domains. We infer that in the late Cenozoic, the tectonically initiated magmatic processes became more intensive in the geodynamic corridor that resulted in regular responses of lithospheric-asthenospheric sources to quasiperiodic orbital variations of the Earth.

From general examination of volcanic evolution, the structural pattern of the southwestern part of the Baikal rift system was explained by dominated sub-lithospheric processes related to evolution of the Gobi and West Transbaikal transition layer melting anomalies. There was evidence on local lithospheric transtension displayed in Central Mongolia and southwestern Baikal area. We showed that on the northern flank of the Japan-Baikal geodynamic corridor, transtension deformations of the lithosphere were persistently induced from its axial part that resulted in autonomous responses of volcanic eruptions from lithospheric-asthenospheric sources in the Udokan field and Wudalianchi zone.

Acknowledgments. This work was done in the Chinese-Russian Wudalianchi-Baikal Research Center on volcanism and environment (Scientific Research Fund of the Heilongjiang Academy of Sciences, 2017).

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