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Origin of high-velocity anomalies beneath the Siberian craton: A fingerprint of multistage magma underplating since the Neoarchean

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Abstract

Despite the violent eruption of the Siberian Traps at ~250 Ma, the Siberian craton has an extremely low heat flow (18–25 mW/m^2) and a very thick lithosphere (300–350 km), which makes it an ideal place to study the influence of mantle plumes on the long-term stability of cratons. Compared with seismic velocities of rocks, the lower crust of the Siberian craton is composed mainly of mafic granulites and could be rather heterogeneous in composition. The very high V_p (> 7.2 km/s) in the lowermost crust can be fit by a mixture of garnet granulites, two-pyroxene granulites, and garnet gabbro due to magma underplating. The high-velocity anomaly in the upper mantle (V_p = 8.3–8.6 km/s) can be interpreted by a mixture of eclogites and garnet peridotites. Combined with the study of lower crustal and mantle xenoliths, we recognized multistage magma underplating at the crust–mantle boundary beneath the Siberian craton, including the Neoarchean growth and Paleoproterozoic assembly of the Siberian craton beneath the Markha terrane, the Proterozoic collision along the Sayan–Taimyr suture zone, and the Triassic Siberian Trap event beneath the central Tunguska basin. The Moho becomes a metamorphism boundary of mafic rocks between granulite facies and eclogite facies rather than a chemical boundary that separates the mafic lower crust from the ultramafic upper mantle. Therefore, multistage magma underplating since the Neoarchean will result in a seismic Moho shallower than the petrologic Moho. Such magmatism-induced compositional change and dehydration will increase viscosity of the lithospheric mantle, and finally trigger lithospheric thickening after mantle plume activity. Hence, mantle plumes are not the key factor for craton destruction.

Keywords: Siberian craton; Siberian Traps; seismic velocities; eclogites; Moho

Introduction

Cratons are the ancient and stable cores of continents (>2.5 Ga), characterized by the thick (>180 km), cold (40 mW/m^2), refractory, buoyant and rheologically strong lithospheric keel (e.g., Eaton et al., 2009; Griffin et al., 2003; Wang, 2010). The Archean crust accounts for only 7% of the total area of the present continents (Prodehl et al., 2013). However, analysis of detrital zircons suggests that at least ~60–70% of the present continental crust had been generated at least 3.0 Ga ago (Belousova et al., 2010; Cawood et al., 2013). Therefore, stability or destruction of cratons is closely related with the crustal growth history of the Earth. Mantle plumes can produce high-degree mantle melting and develop large igneous provinces (LIPs), where large volumes (10^6 to 10^7 km^3 at the provincial scale; >10^8 million km^3 for event clusters or periods of supercontinent breakup) of mafic, and generally subordinate silicic and ultramafic magmas erupted within 1–5 Ma (Bryan and Ferrati, 2013). The large igneous province record has been traced back from the Cenozoic to the Precambrian, with the oldest one at 3.79 Ga (Ernst and Buchan, 2001; Isley and Abbott, 1999, 2002).

Although magmatism-related thermal erosion has been regarded as an important mechanism for the lithospheric thinning and craton destruction (e.g., Foley, 2008; Koptev et al., 2015; Xu, 2001), it is noteworthy that several cratons contain LIPs but still keep their long-term stability, e.g., the Yangtze craton with the Emeishan Flood Basalt Province in 260 Ma, the Kaapvaal craton with the Bushveld Complex in

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2055–2060 Ma and the Karoo LIP in 183 Ma, and the Indian craton with the Deccan Traps in 66 Ma (Bryan and Ferrati, 2013 and references therein). In addition, a strong shear velocity reduction was found in the lower mantle beneath southern and eastern Africa, which is referred as the African Superplume with a longevity of more than ~50 Ma (Steinberger and Torsvik, 2010). Therefore, although mantle plumes can change the thermal state and composition of the cratonic lithosphere, they do not necessarily destroy cratons.

As the largest continental flood basalt province, the Siberian Traps erupted at ~250 Ma have been linked with the end-Permian environmental crisis, the largest known mass extinction event characterized by the sudden loss of >90% of marine species and >70% of terrestrial species (Erwin, 1994; Reichow et al., 2009; Wignall, 2001). The Siberian craton still preserves its thick and stable lithosphere after the Siberian Trap event, which makes it an ideal place to investigate the influence of mantle plumes on the stability of cratons. In this study, based on seismic and electrical properties of rocks at high pressure and high temperature, we interpret the seismic and electrical structures of the Siberian craton, with focus on the high velocity layers and high resistivity anomaly in the lower crustal and upper mantle. The interplay between magmatism-induced heating and dehydration changed the viscosity of the Siberian cratonic lithosphere, which is the key for its long-term stability.

Geological setting

Surrounded by orogenic belts, the Siberian craton consists of four major blocks (Pisarevsky et al., 2008; Rosen et al., 1994, 2006) (Fig. 1). The Aldan province in the south is separated from the Anabar province by the Proterozoic Akitkan fold belt. The Anabar province collided with the Tungus province in the west and the Olenek province in the northeast along the north-striking Sayan–Taimyr suture zone and the northwest-striking Bilyakh suture zone, respectively. Most of the Siberian craton is covered by thick (2–14 km) sedimentary sequences, together with voluminous Triassic basaltic lavas of the Siberian Traps. The basement outcrops occur in the Aldan and Anabar shields and in uplifted areas along the craton boundaries. These basement outcrops, together with xenoliths from numerous kimberlite and lamprophyre pipes and alkali basalts, allow us to investigate the composition and evolution of the Siberian cratonic lithosphere.

Kimberlite pipes only occur in the Anabar and Olenek provinces. Widespread kimberlite pipes in the Daldyn–Alakit district intruded into the central Anabar province in late

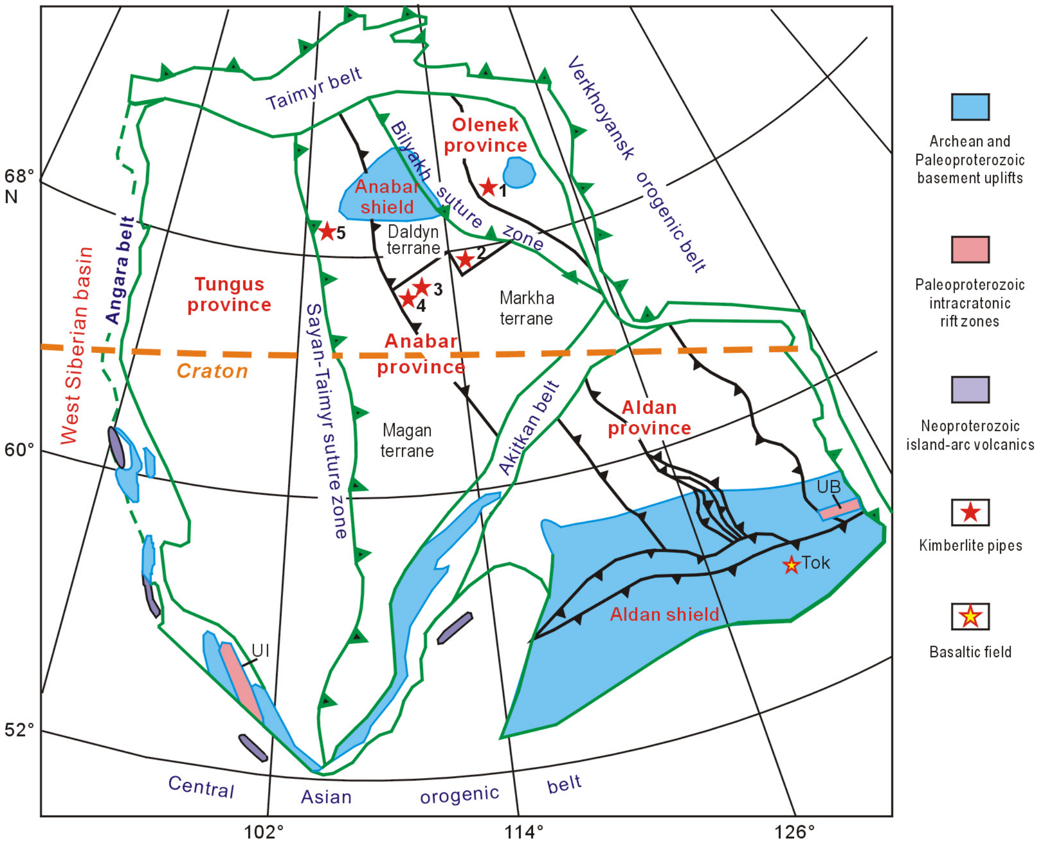

Fig. 1. Geological scheme of the Siberian craton (modified after Rosen et al. (1994) and Gladkochub et al. (2006)). Green lines delineate boundaries of the Siberian craton and its major units. The orange line shows the long-term seismic profile *Craton*. Red stars represent kimberlite fields: 1, Kuoyka field (Obnazhennaya pipe); 2, Muna field (Novinka and Zapolyarnaya pipes); 3, Daldyn field (Udachnaya, Leningradskaya, and Zarnitsa pipes); 4, Alakit field (Komsomolskaya pipe); 5, Kharamai kimberlite field. Yellow star indicates the basaltic field Tokinsky Stanovik (Tok). Abbreviations: UB, Ulkan–Billikchan graben; UI, Urik–Iya graben.