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Paleoproterozoic granitoids of the Losevo terrane, East European Craton: Age, magma source and tectonic implications

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ABSTRACT

The Losevo terrane lies between the Sarmatia and Volgo-Uralia segments of the East European Craton and is considered to be part of the East-Sarmatian Orogen (ESO). Here we report the results from field, petrologic, geochemical, Sm–Nd isotopic and zircon U–Pb geochronological studies on a suite of granitoids from the Losevo terrane (LT). The LT granitoids are divided into four types: (1) migmatite leucosome (from quartz diorite to granodiorite); (2) tonalite, trondhjemite and granodiorite (TTG) with high Si, Na, Sr contents, high Sr/Y, La/Yb ratios and low Mg, K, Y, Yb contents; (3) trondhjemite, granodiorite, granite (TGG) spatially related to the TTG suite, but showing higher K, negative Eu anomalies and flat REE patterns; and (4) high-K calc-alkaline monzogranite and granodiorite of I-type. The early (2115 Ma) migmatites occur as lensoid and stromatic layers. The TTG and TGG (2100–2075 Ma) constitute about 20% of the LT and form batholiths (150–540 km^2) and stocks. Small massifs of the I-type granites (2081 ± 12 Ma) intrude the migmatites. The migmatites, TTG and TGG contain inherited zircon cores that yield ages between 2130 and 2172 Ma. The granitic suite shows positive εNd values ranging from +2.1 to +5.7 for the TTG and TGG and +2.1 and +2.2 for the migmatites, suggesting magma derivation from juvenile Paleoproterozoic sources (model ages = 2255–2450 Ma). In contrast, the I-type granite shows slightly negative εNd value of −0.5, suggesting that the magma sources involved a mixture of Archean and Paleoproterozoic components. All the granitoids from LT record varying degrees of fractional crystallization with or without crustal contamination. The temperature of parental melts of the granites are estimated to be in the range of 793 ± 33 °C to 878 ± 16 °C. The migmatites were derived mainly from metaigneous-sedimentary protoliths under $P \sim 5$–6 kbar; whereas the TTGs were derived from lower crustal metabasites under $P \sim 15$ kbar. The TGG were derived from mid crustal metagreywackes under $P < 10$ kbar, and the I-type granites were mainly derived from ancient lower crustal components involving amphibolites, gneisses and metagreywackes under $P \geqslant 12$ kbar. Our new data suggest that the anatexis and formation of migmatites occurred during the peak collisional event, and the other members of the granitoid suite including the TTGs formed during the post-collisional orogenic collapse of the ESO. The estimated average exhumation rate of the granitic suite during collision to post-collisional collapse is about 235 m/Ma.

1. Introduction

Felsic melts generated in the middle and lower crust and their intrusion into higher levels of the crust form an important part of continental crust differentiation and growth (Rudnick, 2003; Brown and Rushmer, 2006, among others). About 90% of continental crust in the Archean is estimated to be composed of tonalites, trondhjemites and granodiorites (TTG, Jahn et al., 1981; Martin et al., 1983). After the Archean, the TTG suites became less prevalent, giving way to potassic I-type granites (Moyen and Martin, 2012). Paleoproterozoic TTG suites (2.2–1.9 Ga) have been described from various localities including in the Amazon Craton (Almeida et al., 2007; Delor et al., 2003), the Leo-Man Craton of west Africa (Baratoux et al., 2011; Hirdes et al., 1992), San Francisco (Conceição de Araújo Pinho et al., 2011) and the East-European craton (Väisänen et al., 2012). They are associated with

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large volumes of calc-alkaline juvenile magmas (De Souza et al., 2007) or are the products of intracrustal melting (Moyen and Martin, 2012).

Opinions on the origin of TTG suites are diverse and include: (1) fractional crystallization of basaltic magma (e.g. Arth, 1979; Barker et al., 1979; Smith et al., 1983), direct melting of the mantle metasomatized by fluids (Moorbath, 1975), (3) partial melting of greywackes (Arth and Hanson, 1975), or (4) partial melting of hydrated basalts metamorphosed up to eclogite and garnet-amphibolite facies (Arth and Hanson, 1975; Barker et al., 1979; Condie, 1981, 1986; Jahn et al., 1981; Martin, 1994; Martin et al., 1983; Tarney et al., 1982, among others). Recent experimental and petrological studies have mostly favored the fourth model above (see review by Moyen and Martin, 2012).

Two major geodynamic settings have been proposed for the generation of TTGs (Moyen and Martin, 2012): (1) subduction environment (slab melting) and (2) intraplate setting (melting of lower crust thickened by means of tectonic stacking or plume activity). Moyen (2011) distinguished three types of TTG: high-, medium and low pressure groups and proposed that the first type is associated with subduction settings, and the third with intraplate and rift ones.

Geodynamic setting for the medium-pressure type is not determined and has no reliable examples. Despite this gap, basing on geothermal gradient of 15–20 °C/km, which is too low for intraplate setting and too high for subduction setting, an alternate model involving the collapse of thickened crust was proposed in order to explain the petrogenesis of medium-pressure type TTG (Moyen and Martin, 2012). TTGs belonging to this setting have not been described yet, although the adakite type Miocene rocks (adakites are considered to be younger analogues of TTG, Martin et al., 2005) in Tibet associated with melting of mafic crust in thickened continental lithosphere (Chung et al., 2003; Guo et al., 2007) and the Neoproterozoic TTG rocks in South China, represent examples of magma generation during the collapse of multiple collisional systems (Zhang et al., 2009).

In the Paleoproterozoic Losevo terrane (LT) of the Voronezh Crystalline Massif (VCM, Fig. 1) TTG suites formed during orogenic collapse (late- or postcollisional setting) include large (up to 540 km^2) massifs of sodic granitoids. The LT Usman complex granitoids are compositionally similar to TTG-series and have been referred to as adakitic plutons (Shchipansky et al., 2007). The unusual petrographic and geochemical characteristics, as well as geodynamic nature of the complex has been a topic of debate with diverse models proposed including: (1) subduction-related (Chernyshov et al., 1997; Shchipansky et al., 2007) or collision-related (Skryabin and Terentiev, 2014) origins.

In this study, we represent field observations, U–Pb geochronology, petrography and chemical composition of bulk samples and minerals of the Paleoproterozoic LT granitoids. The objectives of our study include determining the timing of crystallization of the LT granitoids, evaluating the source(s) of melts and range of differentiation; understanding the genetic relation of migmatites and sodic granites and establishing the geotectonic implications of the different types granitoids in the context of orogenic events along the eastern border of Sarmatia.

2. Background

The Losevo terrane was initially defined as Losevo-Usman zone of plagiogranite magmatism (Egipko, 1967). The plagioclase-rich granitoids in this belt defined by Egipko (1967) as an independent migmatite-plagiogranite complex, were included into the Losevo-Usman gabbro-plagiogranite complex in subsequent studies (Zaytsev, 1973; Gorbunov et al., 1969) Taking into account the heterogeneity of mafic and felsic units in the complex as well as the limited development of small scale gabbroic bodies, the formation of voluminous granitoids from parental mafic magma was excluded, and the Losevo-Usman complex was divided into the Rozhdestvenskoe gabbroic unit and the Usman migmatite-tonalite-plagiogranite units (Egipko et al., 1976).

A number of issues remained unresolved though the structure and petrography of the Usman complex plutons were discussed earlier by Egipko (1971), For example, the question of including migmatites into the complex and the transition zones from banded migmatites and gneiss-granites to massive granitoids remained unresolved. Intermediate rocks, such as quartz diorites and diorites, have been included without adequate explanation into the Usman complex (e.g., Bocharov and Chernyshov, 1985; Chernyshov et al., 1983). Recent investigations indicate separation of compositionally heterogeneous intrusions such as monzogranites, andesine anorthosites, gabbrodiorites, quartz diorites, among other rock types from the Usman and Rozhdestvenskoe complexes (Savko et al., 2014a; Terentiev, 2013a).

The available geochronological data indicate Paleoproterozoic age for the LT granitoids. Uncertainty and paucity of isotopic ages inhibited proper geodynamic interpretation of the Usman complex granitoids. The imprecise ages of 2053 ± 86 Ma for the Devitsa pluton monzogranites reported by Naydenkov et al. (1996) and differ from those of the Usman complex granitoids (Terentiev, 2013a). Furthermore, interpretation of the 2096.8 ± 3.3 Ma (Bibikova et al., 2009) and 2112 ± 32 Ma (Naydenkov et al., 1996) ages, estimated through TIMS method on zircon monofractions did not consider the xenocrystic cores of zircons in the Usman complex (Skryabin and Terentiev, 2014; Terentiev, 2014).

3. Geological framework

The Precambrian basement of the East European Craton is subdivided into three segments: the Fennoscandia, Sarmatia and Volgo-Uralia (Bogdanova, 1993; Fig. 1), which were amalgamated during Paleoproterozoic. The Sarmatian segment in the eastern part of the East European Craton represents the East-Sarmatian Orogen, formed through the collision between Sarmatia and Volgo-Uralia at ca. 2.1–2.0 Ga (Bogdanova et al., 2005; Shchipansky et al., 2007; Skryabin et al., 2008). The East Sarmatian Orogen (ESO) includes the Vorontsovka (eastern), Losevo (central) and Don (western) terranes. The Losevo terrane is composed of the Losevo series rocks (Zaytsev, 1966) represented by metavolcanic[1] rocks of bimodal basalt-plagiorhyolitic and polymodal basalt–andesite–plagiorhyolitic associations together with terrigenous units carrying tuffaceous and volcanic materials (Terentiev, 2014; Terentiev et al., 2014). The wide-spread tonalite–trondhjemite–granodiorite intrusions in this terrane are referred to the Usman complex (Skryabin and Terentiev, 2014).

The Usman complex granites occupy about 20% of the LT area, forming large composite 150–540 km^2 dome-shaped plutons and smaller stocks (Fig. 2). Intrusive massifs occur in zones of gneissic granites, migmatites (Egipko, 1971) and amphibolites of the Losevo series. Most of the plutons are characterized by negative magnetic anomaly and deep gravity minima with distinct borders and strong gradients (Fig. 3). Thermal influence on the host rocks is manifested in the progressive change of amphiboles composition and zoning, towards the intrusion contacts (Terentiev, 2004). The contacts are distinct and sharp; apophyses and veins of granitoids are present in the exocontacts, and the intrusions carry xenoliths of the host rocks at the endocontact zones.

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[1] Meta is implicit in all the host rocks described in this paper.