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Petrogenesis of composite dikes in granitoids of western Transbaikalia

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Abstract

The performed studies have revealed two varieties of composite dikes differing in morphology and internal structure depending on (1) the proportions of salic and basic components and (2) the rheologic state of the host environment. The latter can be both a solid substrate with open fractures and a melt at different stages of crystallization. The evaluated isotopic age of dikes in the Shaluta massif, 290.8 ± 2.7 Ma and 283.4 ± 3.4 Ma, is correlated with the time of the pluton formation. The age of the composite dike breaking through the metamorphic deposits on the eastern shore of Lake Baikal is 284.10 ± 0.96 Ma. The mass formation of composite dikes in western Transbaikalia is correlated with the Late Paleozoic magmatism, which resulted in one of the Earth's largest granitoid provinces. The intrusion of dikes was not a single-stage event; it lasted at least 10–12 Myr and was apparently related to the repeated intrusion of large volumes of salic magmas and the formation of granitoid plutons. Early Mesozoic composite dikes associated with alkali-granitoid plutons of the Late Kunalei igneous complex (230–210 Ma) are much scarcer. Basic magmas of the composite dikes were generated at depths greater than 75 km as a result of the melting of a modified (enriched in crustal components) mantle source. Salic components of the dikes, independently of their geologic position, are generally similar in composition to the granitoids of the plutonic facies, and the differences are apparently due to hybridization proceeding at great depths.

Keywords: composite dikes; granitoids; mixing; sources of magmas; U–Pb isotopic age; formation conditions; western Transbaikalia

Introduction

Composite dikes, consisting of coeval rocks of contrasting compositions (Wiebe, 1973; Wiebe and Ulrich, 1997), directly prove the coexistence and interaction of mantle basic and crustal salic magmas. The keen interest to such dikes is due, first of all, to the specific conditions and mechanisms of interaction of magmas differing radically in rheological properties and composition (Didier and Barbarin, 1991; Furman and Spera, 1985; Litvinovsky et al., 2012; Popov, 1984; Sklyarov and Fedorovskii, 2006; Wiebe and Ulrich, 1997; Wilcox, 1999). In recent years, it has become obvious that composite dikes are genetically related to large granitoid batholiths or granitoid provinces, e.g., western Transbaikalia or western Sangilen (Karmysheva et al., 2015; Litvinovskii et al., 1995a,b; Litvinovsky et al., 1993, 2012; Titov et al., 1998, 2000; Zanvilevich et al., 1995). This fact implies, first of all, the presence of basic-magma chambers, the major or additional source of heat and, probably, material (including fluids) necessary for crust melting and accounting for many geochemical features of granitoids. The magma chambers are a crucial argument in the discussion of the nature of large-scale intracontinental granitoid magmatism (Chen and Grapes, 2007; Dobretsov, 2011; Dobretsov et al., 2010; Kuzmin and Yarmolyuk, 2014; Rosen and Fedorovskii, 2001; Litvinovsky et al., 2011; Yarmolyuk et al., 2014, 2016).

In addition, the basic component of composite dikes bears geochemical information about the composition and melting conditions of the mantle source, which, in turn, can be used during testing of geodynamic (plume, delamination, and suprasubduction) models (Condie, 1997, 2005; Halliday et al., 1995; Kovalenko et al., 2009a,b; Kozlovsky et al., 2006; Zhang et al., 2008).

Composite dikes are subdivided into two types according to geologic structure and formation conditions (Wiebe and Ulrich, 1997). Dikes of type 1 have a basic margin (usually, with a chilled zone at the contact with the host rocks) and a predominant salic interior. The basic zone passes into the salic one gradually, via numerous intermediate compositions. Dikes of type 2 are of radically different composition. They are formed by pillow-like basic segregations (nodules and glob-

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ules) cemented by a salic material. The host rocks always make contact with the salic zone of the dike, amounting to no more than 10–15 vol.%.

Composite dikes are widespread in western Transbaikalia. They are of the above two types (Khubanov, 2009; Litvinovskii et al., 1995a,b; Litvinovsky et al., 1993, 2012; Titov et al., 1998, 2000; Vrublevskaya et al., 2013; Zanvilevich et al., 1995), but type 2 dikes are predominant. They are the object of our present study.

Based on new geological, mineralogical, geochemical, and isotope-geochronological data, we discuss the probable mechanisms of formation of type 2 dikes, substantiate the stages of dike magmatism, consider the relationship between dikes and plutonic complexes, and establish the geochemical type of the mantle source(s) of basic magmas.

Geological characteristics

In western Transbaikalia, outcrops of composite dikes form a band of NE strike, extending from the lower course of the Khilok River (a right tributary of the Selenga River) to the Svyatoi Nos Peninsula (Lake Baikal) and the right bank of the Barguzin River in its lower course (Fig. 1). The band is about 350 km long and comprises ten found groups of composite dikes of type 2 (hereafter, composite dikes (CD) or mingling dikes; we did not consider type 1 dikes in this work). Some of these outcrops were studied earlier (Litvinovskii et al., 1995a,b; Litvinovsky et al., 1993, 2012; Titov et al., 1998, 2000; Zanvilevich et al., 1995), and the rest were first discovered by us. Obviously, there are also other composite dikes in this region, which are of areal rather than linear occurrence, but we have found no data on this subject.

Most of CD are localized within plutons composed of the quartz syenites and quartz monzonites of the Chivyrkui, Zaza, and Lower Selenga complexes (Fig. 1) (Tsygankov et al., 2010) formed in the late Carboniferous–early Permian (~305–280 Ma). In the Kharitonovo Village area (lower course of the Khilok River), composite dikes occur among the alkali-feldspathic syenites of the Kharitonovo massif (Zanvilevich et al., 1995) dated at 230 Ma (Reichow et al., 2010). At the opposite end of the CD band, such dikes were found among the Precambrian(?) biotite–amphibole schists and gneisses of the Talanchan and Katkovo Formations (southeastern bank of Barguzin Bay (Maksimikha site), Cape Nizhnee Izgolov'e of the Svyatoi Nos Peninsula).

Although these CD are of the same type (type 2, according to the classification by Wiebe and Ulrich (1997)), they differ considerably in morphology and internal structure. The first variety (CD_1) is subhorizontal sill- and dike-like bodies with the fluctuating ratio of salic and basic components; sometimes they pass into synplutonic basic intrusions. A typical example is a dike at the left edge of the Selenga River near Starye Shaluty Village (Litvinovskii et al., 1995a; Litvinovsky et al., 2012). It occurs among the massive medium-grained quartz syenites of the first phase of the Shaluta quartz–syenite–granite massif of the Zaza intrusive complex (Fig. 2*a*) (Tsygankov et al., 2010). The content of basic material varies from fractions of percent to 30–40 vol.% along the dike strike. This material is present as irregular-shaped, often flame-like (indicating a plastic flow) or isometric nodules measuring 1–2 to 15–20 cm along the long axis (Fig. 2*a*). No chilled zones are observed in the nodules. There are scarce porphyroblasts of pelitized pink K-feldspar cemented by fine-grained granite, clearly seen on the background of the greenish-black fine-grained nodule groundmass. The dikes have convoluted contacts with the host quartz syenites. The dike body is 100–150 m in visible length; its thickness varies along the strike but generally does not exceed 2–3 m.

At the Zhirim site at the right edge of the Selenga River, ~55 km southwest of Ulan-Ude (Fig. 1), a composite dike passes into a synplutonic basic intrusion (Fig. 2*b*). Here it occurs among the quartz syenites and hybrid quartz monzonites of the Ust'-Khilok massif of the Lower Selenga intrusive complex (Tsygankov et al., 2010). The U–Pb isotopic age of the massif is estimated at 280 Ma (Reichow et al., 2010) to 289 Ma (Tsygankov et al., 2016a). The Zhirim dike has an extremely complex morphology. It reaches few tens of meters in thickness; basic material in it amounts to 80–85 vol.%.

Composite dikes in the Kharitonovo alkali-granitoid pluton (Late Kunalei complex (Zanvilevich et al., 1995)) at the left edge of the Khilok River are of the same morphologic type. Here, several subhorizontal dike bodies occur among coarse-grained alkali-feldspathic syenites. They are formed mostly by a basic material (85–90 vol.%) separated by quartz–syenite veinlets into rounded nodules. At their pinching-out, the dikes split into tongues. The dikes reach 500 m in total length and are no less than 3–4 m in thickness. The basic nodules are composed of ultrafine- and fine-grained aphyric diabases. The nodules have a scalloped edge and, often, discernible chilled zones (Fig. 2*c*). The central zone of the dikes almost totally consists of basic material, whereas the edge is formed by mingling structures.

Thus, the most specific features of CD_1 are their complex morphology and variations in the ratio of their basic and salic components along the strike, up to their transition into basic synplutonic intrusions. All this indicates the intrusion of a basic melt or a basite–granitoid mixture into a crystallizing granitoid magma chamber. Such dikes are not observed among metamorphic rocks.

The second variety of dikes (CD_2) is steep (30º–50º) (Shaluta site, Ulan-Burgasy Ridge, and Kurba River basin, Fig. 1) or subhorizontal (Maksimikha and Svyatoi Nos sites) bodies with cross-cutting distinct linear contacts (Fig. 2*d*). These dikes reach 9–10 m in thickness. They are similar in internal structure to CD_1 but show no serious variations in the ratio of salic and basic materials; the latter material amounts to 80–90 vol.%. In general, the basic nodules are isometric pillow-like or even spherical (Fig. 2*e*), with chilled zones (not always) and scalloped edges indicating the coexistence of two liquids (Didier and Barbarin, 1991). The salic component contains a dispersed basic material as individual femic-mineral crystals or their small clusters and angular xenoliths of the