# Isotope systematics of ore-bearing granites and host rocks of the Orlovka-Spokoinoe mining district, Eastern Transbaikalia (Russia)

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**Abstract.** Pb, Rb and Sr isotope data are reported for the Khangilay, Orlovka and Spokoinoe granite massifs and their host rocks in the Orlovka-Spokoinoe mining district, Eastern Transbaikalia, Russia. Pb isotope analyses indicate one common Pb source for all three granite massifs reflecting a homogenous source melt from which all magmatic members generated. Pb isotope systematics identified two possible scenarios for the source of Li-F granites: 1) a crust-mantle source where a mixture of MORB and continental-derived material were brought together in an orogenic environment; and 2) a type II enriched mantle source where subducted continental material could have been strongly implicated in volcanic suites. New Rb-Sr isotope age data yielded a 143.8±4.2 Ma age for barren granites of Orlovka and Khangilay massifs.

## 1 Introduction

The rare-metal granite-related Orlovka tantalum deposit and the Spokoinoe tungsten vein quartz-greisen deposit are located in Eastern Transbaikalia 140 km and 148 km SE of Chita, respectively. Both deposits are hosted by the Khangilay granite pluton and are believed to be its satellites (Figure 1) (Badanina et al., 2004; Beskin et al., 1994; Kovalenko et al., 1999; Syritso et al., 2001). In recent years the evolution of rare-metal granites, formation stages and relation to intraplate magmatism was studied. Specifically, Rb-Sr and Sm-Nd isotopic systems were used to reveal the sources of rare-metal granite melts from the study area and results indicate that sources were likely to be either crustal, mantle or combined crustal-mantle (Kostitsyn, 2001; Kovalenko et al., 1999, 2002, 2003; Yarmolyuk et al., 2001, 2003). Our study uses Pb isotopes for the granites of the Orlovka, Spokoinoe and Khangilay massifs and their host rocks with the aim to study the evolution trends and features of the Khangilay pluton and the Orlovka and Spokoinoe deposits (barren versus mineralized granites, ores, host rocks) by examining fluid-rock and crust-mantle interaction in the development of granitoid magmatism, the genetic relationship of the three massifs and controls of similarities and differences among them. Rb, Sr isotopes provide additional insights into the age of granites of the Orlovka-Spokoinoe mining site.

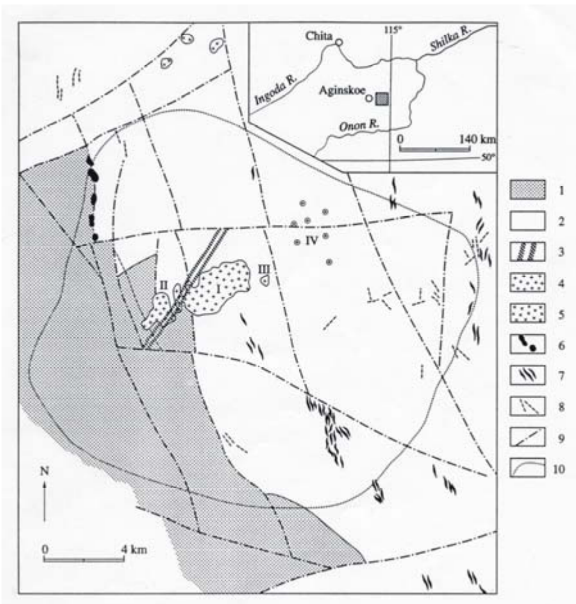


**Fig. 1** Schematic geological map of the Khangilay pluton (after Beskin et al., 1994). 1-Triassic terrigenous rocks and volcanoclastic sediments; 2-Paleozoic metasedimentary rocks; 3-Cenozoic diabase dikes; 4-6-Mesozoic intrusives: 4-granites, 5-granodiorites, 6-gabbro-diorites; 7-granite-porphyry; 8-pre-granite lamprophyres; 9-faults; 10-contour of a hidden granite pluton (based on gravity data). I-IV-Granite massifs and hosted deposits: I-Khangilay Massif; II - Orlovka Massif; III-Spokoinoe Massif; IV-minor W and Sn deposits and showings.

## 2 Geological setting

The Orlovka-Spokoinoe mining district belongs to the Central Asian Orogenic Belt (CAOB) (Jahn et al., 2000) or Transbaikal-Mongolian orogenic collage where several oroclinally bent magmatic arcs separated by accretionary complexes and ophiolitic sutures are located between the major cratons. Rare-metal Li-F enriched granites and pegmatites are widespread as products of continental crustal growth and associated intraplate magmatism. The Khangilay pluton is located in the central portion of the Paleozoic Aginskaya microplate that is made up of predominantly sandstone and shales (Beskin et al., 1994; Syritso et al., 2001). The granitoids of the pluton cut Proterozoic to Carboniferous shales and volcanics, a Triassic terrigenous and volcano-sedimentary sequence, and gabbro-diorite, granodiorite, and lamprophyre bodies (Kovalenko et al., 1999). The microplate was intruded by granite plutons, the largest of which, from gravimetric data, is 24 km by 22 km in dimension at a depth of 500-2500 m. It is exposed at the surface as three separate granitic massifs of Khangilay, Spokoinoe and Orlovka. The Khangilay granite massif is composed of biotite granite and biotite-muscovite granites. The Orlovka satellite is a highly differentiated Ta-(Nb-Sn-) bearing intrusion of lithionite-amazonite-albite granite. The Spokoinoe body is composed of muscovite-albite granite with W (Sn, Be) mineralization.

To assess magma – host-rock interactions of the Khangilay-Orlovka intrusions with the regional geochemical framework, greisenized granites from Spokoinoe and a representative suite of intruded host rocks (volcanics, hornfelses, metasediments, gabbro-diorite) were also included in the study.

## 3 Results and discussion

The mixing diagram (Figure 2) shows a strong relationship between the barren parental granites of the Khangilay pluton and the ore-bearing granites of the Orlovka and Spokoinoe massifs. They all plot within a single line trend. Despite a wide range of Pb isotope compositions within each granite body, they do not differ significantly among all three granite massifs (Dolgopolova et al., 2004). Lead isotope signatures of the host rocks are more scattered than those of the granite rocks and are off the granites mixing line.

The Orlovka ore-bearing amazonite granites with the highest Pb concentration were used to identify the isotopic composition of the initial Pb component that was transferred to the ore-bearing rocks. Although Pb isotopes of a magma or hydrothermal fluid can be changed due to interaction with country rocks, ore-bearing amazonite granites in our case are well protected against such changes due to high Pb concentrations in these rocks (up to 190 ppm). They are characterized by the lowest rate of radiogenic Pb accumulation because of their very low $^{238}U/^{204}Pb$ ($\mu_{average}$ = 1.3). The calculated initial values for these "least sensitive" ore-bearing granites are very similar and their averages are: $^{206}Pb/^{204}Pb = 18.41 \pm 0.02$; $^{207}Pb/^{204}Pb = 15.562 \pm 0.006$ and $^{208}Pb/^{204}Pb = 38.30 \pm 0.03$ (Dolgopolova et al., 2004).

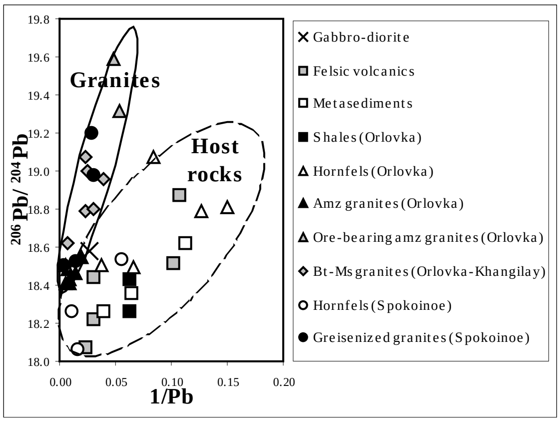


**Fig. 2** $^{206}Pb/^{204}Pb$ vs. 1/Pb mixing plot for Khangilay-Spokoinoe-Orlovka granites and their host rocks.

Pb isotope compositions were also determined in two separate grains of K-feldspars from the ore-bearing amazonite granite of the Orlovka Ta-Nb deposit. Pb isotope analyses and U, Pb isotope dilution measurements were carried out for blue-green individual feldspars core and white rim parts. Differences between core and rim Pb isotopic compositions are negligible within the limits of statistical significance. The averages of measured initial Pb isotope compositions of feldspars are shown in Table 1. The average values of initial Pb isotope composition of ore-bearing granites were calculated previously to assess sources of the granitic magmas and were in the range of: $^{206}Pb/^{204}Pb = 18.49 \pm 0.05$; $^{207}Pb/^{204}Pb = 15.57 \pm 0.01$ and $^{208}Pb/^{204}Pb = 38.23 \pm 0.06$ (Dolgopolova et al., 2004). Our new data on Pb isotope compositions of K-feldspars (Table 1) showed a very good agreement with the calculated initial Pb isotopic composition of the Orlovka granite pluton.

**Table 1.** Pb isotope composition of Orlovka K-feldspars

| $^{206}Pb/^{204}Pb$ | ±2SE (%) | $^{207}Pb/^{204}Pb$ | ±2SE (%) | $^{208}Pb/^{204}Pb$ | ±2SE (%) |
|---|---|---|---|---|---|
| 18.387 | *0.003* | 15.564 | *0.002* | 38.331 | *0.016* |
| 18.384 | *0.001* | 15.562 | *0.001* | 38.329 | *0.013* |
| 18.384 | *0.003* | 15.563 | *0.002* | 38.326 | *0.016* |
| 18.374 | *0.002* | 15.547 | *0.002* | 38.272 | *0.014* |

Pb isotope systematics shows the presence of a mantle source in the formation of the studied granites (Figure 3). A mantle-derived component is in a transitional field between mid-ocean ridge basalt (MORB) and type II enriched mantle (EM II) (Zartman and Doe, 1981) but closer to the latter. There is a mixture of different time episodes presented on Figure 3. The mantle arrays indicate present mantle Pb isotopes while granite data reflects "frozen" Jurassic Pb isotope compositions. If the mantle arrays are traced back to a Jurassic age with less radiogenic EM II and MORB sources than the plotted arrays, they would slightly shift to the lower left part of the plot and therefore indicating EM II type input preferable.

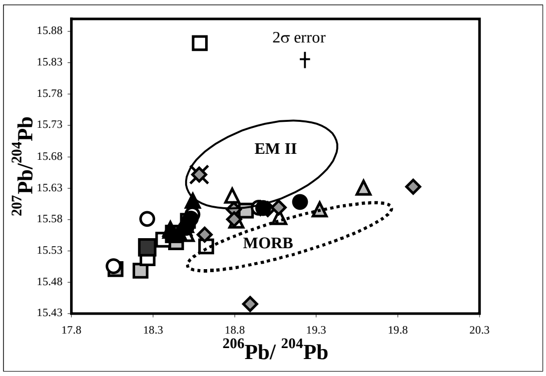


**Fig. 3** $Pb^{206}/Pb^{204}$ vs. $Pb^{207}/Pb^{204}$ diagram for Khangilay-Spokoinoe-Orlovka granites and their host rocks. All symbols are identical to those in Figure 2. EM II (type II enriched mantle) and MORB (mid-ocean ridge basalt) represent two types of mantle end members (Zindler and Hart, 1986).

Therefore, Pb isotopic data suggest two possible sources contributed to the formation of the studied granites: 1) a crust-mantle source where a mixture of MORB and upper crustal-derived material were brought together in an orogenic environment; and 2) type II enriched mantle source where subducted continental material could have been strongly implicated in several island-arc volcanic suites and the corresponding isotopic signatures, thus reflecting a strong similarity of EM II with upper continental crust or continentally derived sediment.

## 4 Regional evidence for the proposed model

Evidence from Sr, Nd and O isotope investigations (Kovalenko et al., 1999, 2002, 2003; Yarmolyuk et al., 2003) is consistent with our lead isotope data that exhibit two possible common sources for all granitic magmas of the Orlovka-Spokoinoe mining district. However, there is no unequivocal indication that would permit either a mixed upper crust-mantle source or a type II enriched mantle source to be favoured.

Regional studies of Transbaikalian granitoids consider geochemical, geophysical and geodynamic indications for both crustal and mantle input that trigger granitic melt generation of all petrochemical series (Jahn et al., 2000; Kovalenko et al., 1996; Litvinovsky et al., 2002). The isotopic heterogeneity of these granites was predetermined by the isotopic heterogeneity of their sources (Kovalenko et al., 1996). Blocks of consolidated pre-Riphean crust were overthrust during the accretionary collision of the foldbelts onto the younger crustal complexes of within-block oceanic basins contributing to an anomalous crustal thickness. The Riphean age of the crust in Caledonian structures most probably reflects the same average composition of a mixed source (basites + pelites) of the granitoid magmas; the source formed at 450-500 Ma. The isotopic evolution of this source resulted in $\varepsilon Nd_{(T)}$ ~ 0 of the mixed source by 100-200 Ma. Some of the young (~120 Ma) granites show evidence of assimilation of the pre-Riphean crust (Kovalenko et al., 1996).

Some metaluminous and peralkaline syenite-granite suites and closely associated comendites of Transbaikalia constrain A-type granitoid magma generation emplaced at ca. 280 Ma as a result of fractional crystallization of syenite magmas. Alkali-rich silicic magma formed at a depth of 50-60 km (?) far exceeding the normal crust thickness. The Sr-Nd isotope data advocate the main role of mantle-derived material in the source region from which the alkali-rich syenitic and granitic magmas were produced (Litvinovsky et al., 2002). Also, the alkali monzodiorite-syenite series that are widespread in Transbaikalia are explained by fractional crystallization from tephritic magma intrusions at ca. 130 Ma.

In contrast to the calc-alkaline granite batholiths generated during continental crustal growths, subalkaline granites of Transbaikalia are often accompanied by basalt-trachyte-pantellerite-alkaline granite associations that mark rift structures of intraplate "hotspots" (Kovalenko et al., 1996). The related Li-F and alkaline granites represent A-type granites with high heat production.

Sr, Nd and O isotope investigations of late Oligocene–Holocene volcanics from the adjacent area of the Southern Baikal region (Yarmolyuk et al., 2003) showed that the isotopic signature of the magma source was formed by the contribution from moderately depleted mantle and enriched mantle reservoirs of types I and II enriched mantle (EM I and EM II).

EM II source has been reported to be one of the mantle sources that contributed to the formation of Early Mesozoic rocks of the Mongolia-Transbaikalia magmatic area and has been listed among mantle sources for the CAOB as a whole (Kovalenko et al., 2002). The published data on Sr and Nd isotopes for the Orlovka massif with the values of initial $^{87}Sr/^{86}Sr$ of 0.706 ± 0.005 and $\varepsilon Nd = 0.1$ (Kovalenko et al., 1999) also favors EM II mantle input. It hints at the possibility that an EM II source controlled intraplate activity in Eastern Transbaikalia during late

Mesozoic times when the Orlovka and Spokoinoe deposits were formed.

## 5 New Rb-Sr age data

Barren and ore-bearing granites of Khangilay and Orlovka massifs (7 samples in total) were analysed for their Rb and Sr isotope composition. The analyses of four samples from the barren granites yield a whole rock isochron age of 143.8 ± 4.2 Ma with an initial $^{87}Sr/^{86}Sr$ ratio of 0.7065 ± 0.0012 (Figure 4). The newly obtained data for barren biotite-muscovite granites show an excellent agreement with the published data of the Orlovka-Spokoinoe granites, where the determined age of granites was 142.9 ± 1.8 Ma at initial $^{87}Sr/^{86}Sr$ of 0.706 ± 5 (Kovalenko et al., 1999).

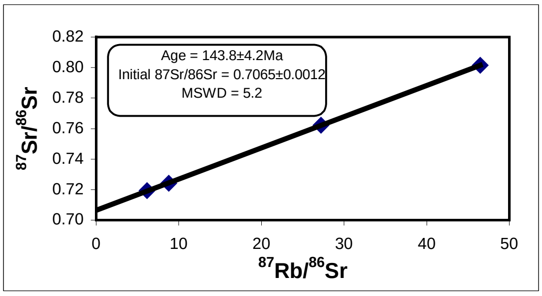


**Fig. 4** Rb-Sr isochron for biotite–biotite-muscovite granites of the Orlovka-Spokoinoe mining site.

## 6 Conclusions

Pb isotope data of crustal rocks and ore deposits of the Orlovka-Spokoinoe mining district complement the existing Nd and Rb, Sr data for this region. Our results indicate that all three granite massifs have uniform Pb isotope compositions and show a strong genetic relationship between the barren biotite-muscovite granites of Khangilay, and the Spokoinoe and Orlovka ore-bearing granites suggesting a common source for the three massifs. Pb isotope data also confirm that the Khangilay pluton can be considered as the parental intrusion for its hosted mineralized apical intrusions.

Pb isotope systematics outlines two possible scenarios for the sources of granitic melts: a mixed upper crust-mantle source, and a type II enriched mantle source.

New Rb-Sr isotope data confirms the age of 143.8±4.2 Ma for biotite–biotite-muscovite granites of Khangilay and Orlovka massifs.

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## References

Badanina EV, Veksler IV, Thomas R, Syritso LF, Trumbull RB (2004) Magmatic evolution of Li-F, rare-metal granites: a case study of melt inclusions in the Khangilay complex, Eastern Transbaikalia (Russia). Chemical Geology 110(1-4): 113-133

Beskin SM, Grebennikov AM, Matias VV (1994) The Khangilai granite pluton and the related Orlovskoe Ta deposit in the Transbaikal region. Petrol. 2: 56-74

Dolgopolova A.V, Seltmann R, Kober B, Weiss D, Stanley C, Dulski P (2004) Geochemical characteristics and Pb isotope systematics of highly fractionated Li-F enriched amazonite granites and related host rocks of the Orlovka-Spokoinoe mining district, Eastern Transbaikalia (Russia). IMM Transact. B: Appl. Earth Sci. 113, 83-99

Jahn B, Wu F, Chen B (2000) Granitoids of the Central Asian Orogenic Belt and continental growth in the Phanerozoic. Transactions Royal Society of Edinburgh, 91: 181-193

Kostitsyn YuA (2001) Sources of rare metals in peraluminous granites: a review of geochemical and isotopic data. Geochem. International, 39(1): 543-559

Kovalenko VI, Yarmolyuk VV, Kovach VP, Kotov A.B, Kozakov LK, Sal’nikova EB (1996) Sources of Phanerozoic granitoids in Central Asia: Sm-Nd isotope data. Geochemistry International, 34(8): 628-640

Kovalenko VI, Kostitsyn YuA, Yarmolyuk VV,. Budnikov SV, Kovach VP, Kotov AB, Sal’nikova EB, Antipin VS (1999) Magma sources and isotopic (Sr, Nd) evolution of Li-F rare-metal granites. Petrol., 7 (4): 383-409

Kovalenko VI, Yarmolyuk VV, Vladykin NV, Ivanov VG, Kovach VP, Kozlovsky A.M, Kostitsyn YuA, Kotov A.B, Sal’nikova EB (2002) Epochs of formation, geodynamic setting, and sources of rare-metal magmatism in Central Asia. Petrol., 10 (3): 227-253

Kovalenko VI, Yarmolyuk VV, Sal’nikova EB, Budnikov SV, Kovach VP, Kotov AB, Ponomarchuk VA, Kozlov VD, Vladykin NV, Khanchuk A.I (2003) Sources of igneous rocks and genesis of the Early Mesozoic tectonomagmatic area of the Mongolia-Transbaikalia magmatic region: 2. Petrology and geochemistry. Petrol., 11 (3): 227-254

Litvinovsky BA, Jahn BM, Zanvilevich AN, Saunders A, Poulain S, Kuzmin DV, Reichow MK, Titov AV (2002) Petrogenesis of syenite-granite suites from Bryansky Complex (Transbaikalia, Russia): implications for the origin of A-type granitoid magmas. Chemical Geology, 189: 105-133

Syritso LF, Tabuns EV, Volkova EV, Badanina EV, Vysotskii YuA (2001) Model for the genesis of Li-F granites in the Orlovka massif, E. Transbaikalia. Petrol., 9 (3): 268-289

Yarmolyuk VV, Litvinovsky BA, Kovalenko VI, Jahn BM, Zanvilevich AN, Vorontsov AA, Zhuravlev DZ, Posokhov VF, Kuz’min DV, Sandimirova GP (2001) Formation stages and sources of the peralkaline granitoid magmatism of the Northern Mongolia-Transbaikalia Rift Belt during Permian and Triassic. Petrol., 9 (4): 350-380

Yarmolyuk VV, Ivanov VG, Kovalenko VI, Pokrovskii BG (2003) Magmatism and geodynamics of the Southern Baikal volcanic region (mantle hot spot): results of geochronological, geochemical and isotopic (Sr, Nd & 0) investigations. Petrol., 11 (1): 1-30

Zartman RE, Doe BR (1981) Plumbotectonics - The model. Tectonophysics 75: 135-162

Zindler A and Hart S (1986) Chemical geodynamics. Ann. Rev. Earth Planet. Sci, 14: 493-571.