

Geochemical evidence for the fractionation of iridium group elements at the early stages of crystallization of the Dovyren magmas (northern Baikal area, Russia)

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Received 21 April 2017; received in revised form 11 October 2017; accepted 20 October 2017

Abstract

We have first generalized geochemical and mineralogical data indicating the important role of crystallization of Os–Ir–Ru phases and fractionation of refractory iridium subgroup of PGE (IPGE) at the early stages of the evolution of parental magmas and primitive cumulates from the Yoko–Dovyren layered massif (northern Baikal area, Russia). The object of study was two types of plagioclase peridotites from the lower part of the intrusion, differing in the porosity of primary olivine cumulates: less melanocratic (but more primitive) type I and more melanocratic type II. Inclusions of refractory IPGE (Os, Ir, and Ru) discovered during LA–ICP–MS studies of aluminochromite from type I rocks are the first evidence for the presence of Os–Ir–Ru phases. Subsequent electron microscopy examinations revealed more than 25 grains of laurite and Ir-containing osmium in aluminochromite from plagioperidotites of both types. Attention is focused on the importance of the Ru/Cr₂O₃ and Ir/Cr₂O₃ ratios in rocks for the separation of IPGE at early and late fractionation stages. The conclusion is drawn that the higher Ru/Cr₂O₃ and Ir/Cr₂O₃ ratios in type I plagioperidotites indicate higher enrichment of aluminochromite in inclusions of refractory IPGE minerals. This is consistent with the fact that these rocks are assigned to the most primitive high-temperature ultramafites genetically related to the parental magma, which was in equilibrium with olivine Fo₈₈ at ~1290 °C. We have established that the parental Dovyren magma was already depleted in IPGE and rhodium before its entrance into a chamber. No signs of early sulfide–silicate immiscibility have been detected. © 2018, V.S. Sobolev IGM, Siberian Branch of the RAS. Published by Elsevier B.V. All rights reserved.

Keywords: plagioperidotite; parental magma; aluminochromite; IPGE; fractionation; laurite; Ir-containing osmium; Dovyren

Introduction

The Yoko–Dovyren layered intrusion (northern Baikal area, Russia) bears a wide variety of sulfide ores and variably mineralized ultramafic rocks and gabbroids (Kislov, 1998; Tolstykh et al., 2008). The main types of low-sulfide mineralization include: (1) horizons of olivine gabbro and plagioperidotites with separated phenocrysts and nests of sulfide–silicate material in sill-like bodies in the base of the massif; (2) slightly mineralized plagioperidotites (80–90%

olivine) in the zone bordering upon plagioclase-containing dunites (Ariskin et al., 2016a); (3) PGE-mineralized anorthosites and leucogabbro at the boundary between troctolites and olivine gabbro (Distler and Stepin, 1993; Konnikov et al., 2000; Orsoev et al., 1995). Information about other sulfide-containing horizons in the gabbroids of the upper part of the intrusion is scarce (Tolstykh et al., 2008). Recent studies have revealed a new type of Pt–Pd mineralization in schlieren of sulfide–plagioclase–olivine aggregates in the base of the troctolite zone of the Yoko–Dovyren massif: This part of the section was called the “Konnikov zone” (Ariskin et al., 2015; Kislov et al., 2016). Of particular interest is the zone of the near-roof gabbroids containing up to 5–7 wt.% sulfides (Fig. 1).

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The reasons for sulfide–silicate immiscibility and the mechanisms of formation of low-sulfide horizons in the rocks of the Yoko–Dovyren massif (including the PGE mineralization zones) are still debatable. These problems cannot be solved based only on geological observations or mineralogical studies. It is necessary to invoke physicochemical methods of study and description of sulfide–silicate systems. One of the key issues is the composition of the initial (the most primitive) immiscible sulfide liquid, the regularities of its fractionation synchronously with magmatic melt, and the composition of the crystallization products at the late magmatic stage. This intricate evolution of “sulfur-closed” magmatic systems might be complicated by additional scenarios involving the reaction of sulfides with fresh portions of basaltic melt (possibly unsaturated with sulfur) or the interaction of magmas with the enclosing rocks. In any case, physicochemical reconstructions of the primary composition of the sulfide liquid and its derivatives should be based on experimental data on the separation of PGE in the system sulfide–magmatic-melt. The use of this information for the interpretation of natural data and the construction of geological and petrological models is complicated by the extremely high partition coefficients of refractory iridium group elements (Os–Ir–Ru, melting points of 2700–2450 °C) and low-melting platinum group elements (Rh–Pt–Pd, 1966–1555 °C) between the sulfide and silicate melts. According to experimental data, the partition coefficients vary from 3×10^4 to 10^6 for Os and Ru and from 1.5×10^4 to 5.4×10^5 for Pt and Pd (Mungall and Brenan, 2014). These constants show that even the first sulfide drops almost completely extract platinoids from the magmatic melt. The subsequent evolution of PGE-rich sulfide material must be accompanied by a rapid depletion in PGE as a result of the successive dilution of the early sulfide liquid with the newly formed sulfide.

This specific feature of sulfide–silicate equilibria in a closed magmatic system implies a relationship between the amount and the composition of the sulfide liquid (Campbell and Naldrett, 1979; Leshner and Burnham, 2001). Both factors are crucial for the reconstruction of the early (high-temperature) history of the PGE behavior in magma chambers. For a successive description of these relations, it is necessary to determine exactly the stage of crystallization when separation of an immiscible sulfide phase from the evolution products of the parental magma (in particular, solidifying cumulates) begins. These issues were considered in our previous papers (Ariskin et al., 2016a, 2017). The main object of the proposed research was the most primitive Dovyren rocks: picrodolerite from the chill zone and plagioperidotites from the massif base.

Calculations with the use of the sulfide version of the COMAGMAT-5 model (Ariskin et al., 2013) showed the undersaturation of the parental magma with sulfide sulfur and the beginning of sulfide segregation in the “mixture” of crystals and the residual melt at temperatures below 1240 °C (at the stage of postcumulus crystallization). The concentrations of highly and moderately chalcophile elements (Cu, Pd, Re, Ag, and Cd) in the primitive and derived sulfide liquids were first estimated. The covariance of these concentrations

demonstrated agreement between the model and natural trends constructed from LA–ICP–MS data (Ariskin et al., 2016a). Correlations were established between the maximum concentrations of the iridium subgroup of PGE (IPGE) in the average sulfide¹ and two maximum concentrations of Ir–Ru in plagioperidotites (Fig. 1). Both maxima coincided with the maximum contents of Cr₂O₃ in the studied samples having low sulfur contents. These observations led us to the conclusion that the behavior of refractory IPGE in the most primitive magmas and cumulates was controlled not only by sulfide but also by the Os–Ir–Ru phases, which might be present in aluminochromite. This assumption was confirmed by pilot LA–ICP–MS studies of spinel composition (Ariskin et al., 2016a). Therefore, we put forward the goal to search for Os–Ir–Ru phases in the Dovyren peridotites. The first findings of laurite and Ir-containing osmium were described earlier (Ariskin et al., 2016a). Subsequent systematic studies of the mineral composition of samples from the zone of transition from plagioclase peridotites to plagioclase-containing dunites revealed more than 25 inclusions of laurite (1–4 μm) and Ir–Os alloys (1–5 μm) in aluminochromite (Spiridonov et al., 2018).

In this paper we present data on the contents of Os, Ir, and Ru in ultramafic rocks and aluminochromite from a ~30 m thick zone of transition from plagioperidotites to plagioclase-containing dunites in the Yoko–Dovyren layered massif (Fig. 1). This information is used to discuss the early fractionation of IPGE in the Dovyren magma at the stage preceding the silicate–sulfide immiscibility.

The section structure and samples

The studied horizon is located in the thickest central part of the Yoko–Dovyren massif. Its base (near the Bol’shoi Brook) is formed by chilled gabbronorites changed by 10–15 m thick picritoid gabbronorites, called “picrodolerites” because of their ophitic texture (Ariskin et al., 2009; Kislov, 1998). The successive upsection increase in the content of olivine is expressed as the appearance of still more magnesian and highly melanocratic gabbronorites, up to pyroxene-containing plagioclase peridotites and pyroxene-poor (<1–3%) plagioclase-containing dunites. The thickness of this essentially peridotite unit is about 200 m (Fig. 1). In the dunite zone (~970 m in total thickness) overlapping this horizon, the content of plagioclase decreases to 3–6%. In the upper half of the dunite zone (including xenoliths of apocarbonate skarns (Kislov, 1998; Konnikov, 1986)), olivine (plus spinel) accumulates are predominant; the total content of plagioclase and pyroxene in them is seldom higher than a few percent. Above, there is a zone of alternating mesocratic and melanocratic troctolites (~950 m thick) containing no more than 1–3% Cpx and virtually lacking orthopyroxene. Leucotroctolites are

¹ Weighted average composition of the sulfide phase, calculated as an additive function of the relative proportions and concentrations of elements in pyrrhotite, pentlandite (mss), chalcopyrite, and kubanite (iss).

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