Journal of Asian Earth Sciences 116 (2016) 81–96

Contents lists available at ScienceDirect

Journal of Asian Earth Sciences

journal homepage: www.elsevier.com/locate/jseaes

Stable isotope composition of minerals in the Belaya Zima plutonic complex, Russia: Implications for the sources of the parental magma and metasomatizing fluids

A.G. Doroshkevich [a,c,*], I.V. Veksler [b], I.A. Izbrodin [a], G.S. Ripp [a], E.A. Khromova [a], V.F. Posokhov [a], A.V. Travin [c], N.V. Vladykin [d]

[a] Geological Institute SB RAS, Ulan-Ude, Sakhyanovoy Str., 6a, 670047, Russia
[b] GFZ German Research Centre for Geoscience, Potsdam, Telegrafenberg Str., D-14473, Germany
[c] Sobolev Institute of Geology and Mineralogy SB RAS, Novosibirsk, Akademika Koptyuga Str., 3, 630090, Russia
[d] Vinogradov Institute of Geochemistry SB RAS, Irkutsk, Favorsky Str., 1a, 664033, Russia

ARTICLE INFO

Article history:
Received 16 January 2015
Received in revised form 13 October 2015
Accepted 13 November 2015
Available online 14 November 2015

Keywords:
Belaya Zima carbonatite complex
Carbonatites and alkaline silicate rocks
Age of carbonatite emplacement
Evolution of minerals
Stable isotopes
Low-$\delta^{18}O$ magma

ABSTRACT

The Belaya Zima alkaline–carbonatite complex in the East Sayan Mountains, Russia, is a multiphase concentric intrusion, which comprises diverse alkaline silicate rocks and carbonatites. Melteigites are the earliest products of crystallization and they are followed by ijolites–urtites, nepheline syenites, and finally, calcite, calcite–dolomite and ankerite carbonatites. In this paper, we present new geochronological data (Ar–Ar method), chemical and stable isotope (H, C and O) compositions of the main rock-forming minerals in carbonatites and the silicate rocks of the complex. The Ar–Ar dating of phlogopite from ankerite carbonatites is consistent with the age of syenite emplacement and implies that the silicate rocks and carbonatites are likely to be comagmatic. The evolutionary trends of pyroxene, fluorapatite, amphibole and phlogopite are consistent with fractional crystallization from a single parental magma. Primary Nb mineralization is represented by pyrochlore, whereas columbite-(Fe) is a replacement product of pyrochlore at the post magmatic, hydrothermal stage. At that stage, interaction of calcite carbonatites with hydrothermal fluids resulted in the formation of hydrothermal paragenesis comprising dolomite–ankerite, monazite-(Ce), ancylite-(Ce), minerals of burbankite group and Ca–REE fluorcarbonates. The hydrothermal processes were also responsible for cation leaching from pyrochlore, the replacements of phlogopite by tetraferriphlogopite and early Ca-rich pyroxene by aegirine. The stable isotope data suggest that the rocks crystallized from a ^{18}O-depleted magma. Shifts toward higher $\delta^{18}O$ values relative to the primary compositions are commonly observed in minerals from carbonatites, which is attributed to hydrothermal processes.

1. Introduction

Carbonatites are known from 527 localities worldwide (Woolley and Kjarsgaard, 2008). They are the product of low-degree partial melting of carbonate-bearing mantle and can provide valuable insights into the nature of the sub-continental mantle (e.g. Bailey, 1993; Bell and Blenkinsop, 1989; Harmer and Gittins, 1998). Carbon and oxygen stable isotopes in carbonates from carbonatites are widely used to constrain the source of CO_2 in mantle. Published information concerning the stable isotopes in oxides, phosphates and silicates from carbonatite complexes is limited (e.g. Conway and Taylor, 1969; Haynes et al., 2003; Tichomirowa et al., 2006; Doroshkevich et al., 2010), though it is essential to understand the petrogenesis, relationship with alkaline silicate rocks and sources of these unusual igneous rocks. In fact, because of their volatile-rich nature and the widespread alteration by late-stage magmatic, meteoric and hydrothermal fluids, the primary composition of carbonatites has proven difficult to constrain. This investigation has been motivated by discovery that the rocks of the complex are depleted with respect to the ^{18}O isotope. We present the results of new Ar–Ar dating of carbonatites and new data on petrography, mineral chemistry and H, C and O isotope compositions of key rock-forming minerals from alkaline silicate rocks and carbonatites of the complex. In addition, stable isotope data were used to constrain crystallization temperatures and calculate aqueous fluid, which is in equilibrium with minerals from

* Corresponding author at: Geological Institute SB RAS, Ulan-Ude, Sakhyanovoy Str., 6a, 670047, Russia.
E-mail address: doroshkevich@igm.nsc.ru (A.G. Doroshkevich).

http://dx.doi.org/10.1016/j.jseaes.2015.11.011
1367-9120/

rocks of the complex. These findings shed light on the source of the parental magma and metasomatizing fluids, and lead to a model for the origin of the low-$\delta^{18}O$ melts.

2. Geological background

The Belaya Zima complex in the East Sayan Mountains of Russia is a multiphase intrusion comprising a diverse group of alkaline silicate rocks and carbonatites. The carbonatites host major resources of niobium and the light rare-earths. The estimated mineral reserves are at 103 million tonnes of Nb (the average grade of 0.27 wt.%), 60 million tonnes of REE oxides (at the average grade of 1.8 wt.%), and 7.8 billion tonnes of phosphorus (at the average grade of 4.6 wt.% P_2O_5, Belov and Frolov, 2011).

General geological information and detailed descriptions of the main rock types have been presented in several publications (e.g., Chernyscheva and Gormascheva, 1966; Pozharitskaya and Samoylov, 1972; Frolov and Belov, 1999; Bagdasarov, 2002). The Belaya Zima carbonatite complex is part of the Ziminskii ore district (Frolov and Belov, 1999) associated with the fault zone along the border between the Siberian craton and a younger orogenic belt (Fig. 1). The complex is located in the northern part of the East Sayan Mountains, 140 km south of Tulun settlement (Irkutsk region, Russia). The complex intruded sedimentary–metamorphic rocks. The contacts with country rocks are sharp and marked by a fenite aureole up to a few hundred meters wide. The complex is a multiphase onion-like intrusion of elliptical shape covering an area of about 18 km^2 in surface exposures (Fig. 1). The interior of the complex has a concentrically zoned structure with carbonatite units cropping out over an area of about 10 km^2 in the center. Rings of alkaline silicate rocks surround the carbonatite core. The sequence of rocks (from the earliest to the latest) comprises melteigite, ijolites–urtites, nepheline syenites, calcite carbonatites, and ankerite carbonatite post-dating calcite carbonatites (Pozharitskaya and Samoylov, 1972). Melteigite and the rocks of ijolite–urtite series show mutual gradual transitions. Nepheline syenites form steep-dipping ring dykes up to 1 km long and 100 m thick within melteigite and ijolites–urtites. Carbonatites were apparently emplaced in several stages. Early calcite carbonatites form a plug in the center of the complex and surrounding dykes up to 100 m thick and over 1 km long. Calcite–dolomite carbonatites form linear bodies striking NW up to 1.5 km wide and 3 km long. Late ankerite carbonatites comprise lens-shaped and vein-like bodies oriented in a north–south direction.

According to U–Pb dating (Yarmolyuk et al., 2005), the nepheline syenites were emplaced at 643 Ma, whereas the K–Ar dating of phlogopite from calcite carbonatite yielded the age of 543 Ma (Bagdasarov et al., 1980). The latter age determination is, however, of dubious quality, as Ar can be easily lost from mica, and the age may correspond to a younger metamorphic event.

Most investigators (e.g., Chernyscheva and Gormascheva, 1966; Pozharitskaya and Samoylov, 1972) have attributed the origin of calcite carbonatites of the Belaya Zima complex to metasomatism of alkaline silicate rocks by hydrothermal carbonate fluids. The proponents of metasomatic model also suggest that some calcite carbonatites were further metasomatized by Mg-Fe hydrothermal solutions to form ankerite carbonatites. In contrast, Andreeva

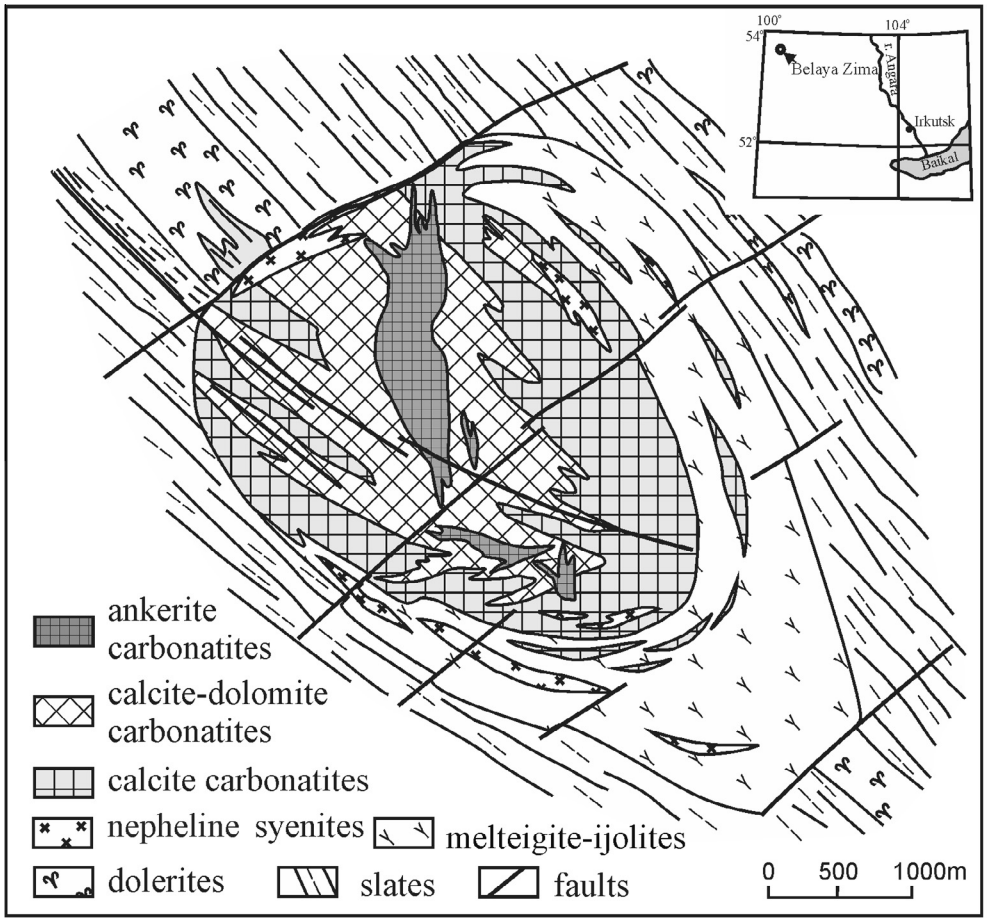

Fig. 1. Simplified geological map of the Belaya Zima carbonatite complex based on Frolov and Belov (1999).