Neodymium isotopes do fractionate in magmatic environments

A.O. Kalashnikov*, P.A. Serov, J.A. Mikhailova, V.N. Yakovenchuk

Geological Institute, Kola Science Centre, Russian Academy of Sciences, Russia

*Corresponding author e-mail: kalashnikov@geoksc.apatity.ru

Summary We have revealed that $\epsilon\text{Nd}(\text{T})$ changes from positive to negative near magmatic contacts, in the gabbro-norite Nyud and the peralkaline Lovozero massifs (NW Russia). We suppose that these reversions are caused by fractionation of neodymium isotopes by thermal diffusion near the contacts.

1. Introduction and background to current research

Recently, the fractionation of isotopes of various elements has been reported, but not for neodymium. For example, fractionation of isotopes of lithium (Marks et al. 2007), oxygen (Baumgartner and Valley 2001), magnesium (Teng et al. 2011), silicon (Savage et al. 2011) and iron (Schuessler et al. 2009) are used as geochemical tools. Fractionation of strontium isotopes is mentioned, too (Morse 1983). Obviously, the lighter an element, the more its isotopes mass difference, the easier their fractionation. For example, mass difference of ^7Li – ^6Li is an order of magnitude greater, and ^{57}Fe – ^{56}Fe is 2.5 times greater than that of ^{144}Nd – ^{143}Nd . So, it is not expected that Nd isotopes fractionate in magmatic–postmagmatic processes.

We investigate the Lovozero layered peralkaline massif (the Kola Peninsula, NW Russia). The massif consists of two complexes: the Layered (bottom) and the Eudialyte (top) complexes. The Layered complex is a stack of ‘rhythms’ (layered lithounits) (Fig. 1a). Each rhythm usually consists of a sequence of alkaline rocks (from top to bottom): malignite, foyaite, and urtite (Fig. 1b) (Gerasimovsky et al. 1966; Busen and Sakharov 1972). There are loparite enrichment on borders between the rhythms, sometimes up to economic concentration (so called the Loparite Horizons).

Figure 1. The Lovozero peralkaline massif: a – scheme of magmatic stratigraphy of the Layered Complex of the Lovozero massif; b – a general structure of a ‘rhythm’ (layered lithounit) of the Layered Complex ((Gerasimovsky et al. 1966; Busen and Sakharov 1972; Kalashnikov et al. 2016); c – variations of $\epsilon\text{Nd}(\text{T})$ along the transections across the Loparite Horizons LV-III-2 and LV-III-5. T = 362 Ma (Kramm et al. 1993).

2. Results

We sampled two transections across the Loparite Horizons III-2 and III-5 (studied earlier by G.Yu. Ivanyuk, V.N. Yakovenchuk and Ya.A. Pakhomovsky (Pakhomovsky et al. 2014; Ivanyuk et al. 2015)) and performed Sm-Nd isotopic analyses. On average, ϵ_{Nd} for the Lovozero massif is positive (Kramm and Kogarko 1994). However, in these transections, ϵ_{Nd} becomes suddenly negative on the contacts of rhythms, in the loparite horizons (Fig. 2c).

To exclude an artifact and randomness, we performed a similar investigation in another pluton, the Nyud gabbro-norite massif (Murmansk Region, NW Rusia). There is a so-called Critical Horizon with sulphide enrichment within the massif. We sampled two transections across its bottom contact (Fig. 2a). Surprisingly, ϵ_{Nd} becomes negative at the contact (Fig. 2b), again! What is a cause of this behaviour of neodymium isotopes?

Figure 2. The Nyud gabbro-norite massif: a – a geological scheme, after (Chashchin et al. 2016); red lines are transections showed in Fig. 2b; b – variations of $\epsilon_{\text{Nd}}(T)$ along the transections across the bottom contact (the red lines) of the Critical Horizon. $T = 2500$ Ma (Chashchin et al. 2016).

3. Discussion and conclusions

According to Lundstrom and colleagues, there is strong fractionation of elements (Fe, Ti, Mg, Ca, Na, Al, K, Si) and isotopes of Mg and Fe along the thermal gradient (Huang et al. 2009), and they concluded that the thermal diffusion is a key cause of the fractionation (Huang et al. 2009; Lacks et al. 2012; Lundstrom 2016).

There is a point of view that large plutons were not crystallized from ‘big magmatic tank’, but formed as amalgamated small intrusions (Bartley et al. 2006; Annen et al. 2015). We believe that the Lovozero rhythms are sills emplaced sequentially (Féménias et al. 2005; Mikhailova et al. 2021), i.e. the Lovozero is an amalgamated pluton. So, there was a rather large thermal gradient on the contacts of “new” and “old” sills. It caused the thermal diffusion and probably fractionation of neodymium isotopes. Similar situation could take place in the Nyud pluton, if the Critical Horizon is a later sill emplaced between melanocratic olivine norite and leuco-mesocratic norite.

So, we have drawn the following conclusions. 1. We have found that $\epsilon_{\text{Nd}}(T)$ changes from positive to negative on magmatic contacts within two layered plutons, the Lovozero and the Nyud. 2. We have supposed that these reversions are caused by fractionation of neodymium isotopes by thermal diffusion near the contacts. 3. If so, the variation of $\epsilon_{\text{Nd}}(T)$ can be a tool for decomposition of amalgamated plutons.

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