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Carbonatites derived from primary magmas with different Ca-contents: geochemical evidence

IRINA RASS

Institute of Geology of Ore Deposits, Petrography, Mineralogy and Geochemistry, Russian Academy of Sciences

ABSTRACT. — Rock geochemistry in two alkaline-ultrabasic-carbonatite complexes, the Odikhincha (Polar Siberia) and the Kaiserstuhl massifs, was investigated. In both massifs, trace element and P distributions in the sequential derivatives of melilite-bearing and melilite-free series are in accordance with the Rayleigh model of crystal fractionation of different parental magmas. The analysis of trace-element logarithmic relations and of triangular diagrams shows that nor nepheline syenites (phonolites), neither carbonatites could not be derived by fractional crystallization of both Ca-rich and Ca-poor parental magmas. They may be formed by liquid immiscibility of some primary magma, parental for the melilite-bearing series, at a certain degree of differentiation.

RIASSUNTO. — Sono state studiate, sotto il profilo geochimico, le rocce di due complessi alcalini-ultrabasici-carbonatitici: Odikhincha (Siberia Polare) e massiccio di Kaiserstuhl. In entrambi i massicci, la distribuzione degli elementi in traccia e P nelle rocce derivate sequenzialmente da serie di rocce contenenti o non contenenti melilite, sono in accordo con il modello di Rayleigh per la cristallizzazione frazionata da diversi magmi parentali. L'analisi delle relazioni tra gli elementi in traccia in diagrammi logaritmici e in diagrammi triangolari mostra che né le nefelin-sieniti (fonoliti) né le carbonatiti possono derivare da cristallizzazione frazionata partendo da magmi parentali sia ricchi che poveri in Ca. Questi quindi potrebbero essersi formati da immiscibilità allo stato liquido di alcuni magmi primari, capostipiti della serie di rocce a melilitite, una volta che questi hanno raggiunto un certo grado di differenziazione.

E-mail: rass@igem.ru

KEY WORDS: *Trace element fractionation, Fractional crystallization, Carbonatites, Nepheline syenites, Phonolites, Melilite-bearing rocks*

INTRODUCTION

Trace element contents in carbonatites are essentially different depending on the presence of melilite-bearing rocks in the alkaline-ultrabasic complexes (Rass, 1998). Carbonatites could be derived from different magmas parental of melilite-bearing and melilite-free series. The difference in the trace element compositions of carbonatites can be explained by the specific differentiation paths of their primary magmas, either Ca-rich (Rass, Plechov, 2000, Solovova *et al.*, 2002) or Ca-poor (Sobolev *et al.*, 1991).

The distributions of trace elements, REE, and P in melilite-bearing and melilite-free rocks from the Guli, Kugda, Odikhincha and Kara-Meni massifs of the Maimecha-Kotui Province (Polar Siberia) are fundamentally different in the Ca-poor and Ca-rich rocks of similar degrees of differentiation (Rass *et al.*, 2001; Rass, 2003). Among other points, Sr-contents in the rocks of high-Ca melilite-bearing series are an order of magnitude higher than those of the melilite-free rocks. On the contrary, P concentrations are higher in melilite-free rocks.

TRACE ELEMENT FRACTIONATION IN ALKALI - CARBONATITE COMPLEXES

Trace element contents of sequential derivatives of the two series from the Odikhincha massif form linear trends on logarithmic plots (Fig. 1a). This attests that their evolution during differentiation of the parental magmas of the two series, Ca-rich and Ca-poor, is in accordance with the Rayleigh model of crystal fractionation with different partition coefficients.

The petrological interpretation of the Kaiserstuhl alkaline volcanic complex implied the existence of a sodic and a potassic series (Keller, 2001). Olivine nephelinites and coeval olivine melilitites from the immediate surrounding are of Na-alkaline character and represent the most primitive melts of Kaiserstuhl; and ultrabasic, highly fractionated melilitites (bergalites) also belong to the sodic clan but they are rich in Ca. The rocks of the Na-dominated series, including olivine nephelinites, olivine melilites, and bergalites, exhibit Sr isotopic ratios lower than 0.704 (Schleicher *et al.*, 1990). Tephrites and essexites are dominant among the volcanics and form the potassic series, which is derived from a hypotetical K-basanite parent magma. Along with these rock groups, there are phonolitic dike rocks with high K/Na, and carbonatites.

The analysis of trace-element logarithmic relations (Fig. 1b) of Kaiserstuhl rocks shows that the olivine melilitites and bergalites compose a single series with a linear P-Sr dependency; the essexites and tephrites represent an other series; and the phonolites and carbonatites are not affiliated to the above series, and compose two rock groups with different trace element contents.

The analysis of triangular diagrams, using a decreasing Mg-content as a differentiation index, also shows that nor phonolites, neither carbonatites of the Kaiserstuhl complex could be derived by fractional crystallization from the parental magma of essexites and tephrites. It is reasonable to suppose that the Kaiserstuhl phonolites and carbonatites were formed by liquid immiscibility of a derivative of the magma that was compositionally similar to olivine melilitite (Fig. 2a). The Odikhincha data (Fig. 2b) also demonstrates that carbonatites and nepheline syenites could not be derived by fractional crystallization of the magma parental of the melilite-free series and supports a possibility for nepheline syenites and carbonatites to be formed by liquid immiscibility of some primary magma, parental for the melilite-bearing series, at a certain degree of differentiation. Carbonatite – silicate magma immiscibility has been repeatedly reproduced in experiments with alkaline-ultrabasic low-Ca melts. High-Ca nephelinite was used as a starting material only in the experiments of Kjarsgaard (1998), which also demonstrates the same immiscibility.

The average P (carbonatite) / P (phonolite) and Sr (carbonatite) / Sr (phonolite) in Kaiserstuhl are 15 and 1.1, respectively; and the average (carbonatite) / (nepheline syenite) ratios in Odikhincha are 3 for P, and 4.9 for Sr. These values are similar to experimental data (Kjarsgaard, 1998) on P and Sr partitions at 5kbar and a temperature of about 1000^{O}C for Kaiserstuhl, and at lower pressures (2kbar?) and 950^{O}C for Odikhincha.

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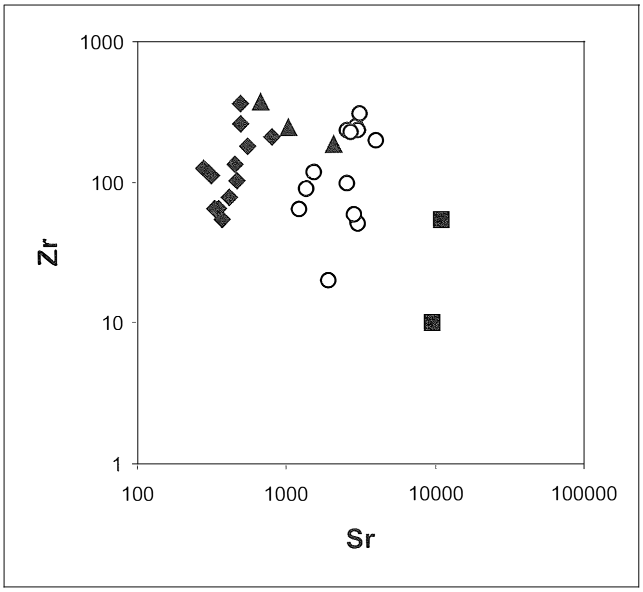
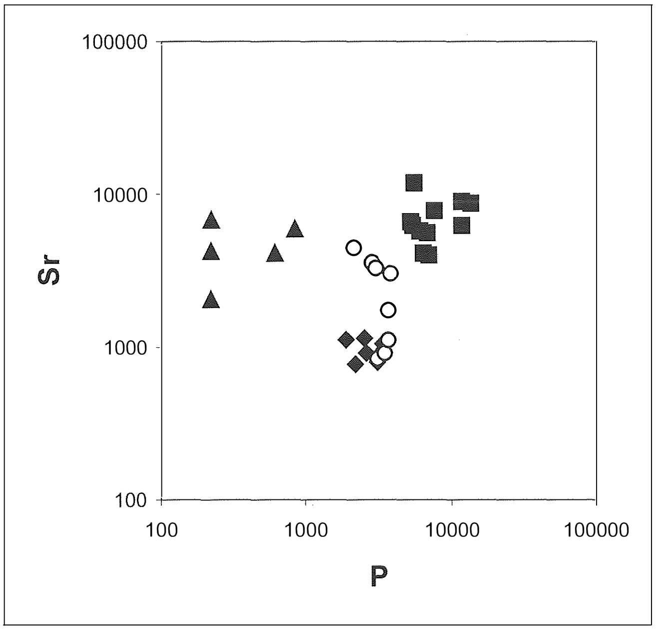


a)



b)

Fig. 1 – Variations of trace element contents
(a) in melilite-free (black diamonds) and melilite-bearing (circles) series (Rass, 2003), nepheline syenites (triangles, after Kononova, 1984) and carbonatites (squares, after Samoilov, 1984) in the Odikhincha massif, Siberia;
(b) in essexite-tephrite (black diamonds) and melilite-bearing (circles) series, also in phonolites (triangles) and carbonatites (squares) in the Kaiserstuhl massif; data on Kaiserstuhl rocks are after Keller, 2001; Dunworth, Wilson, 1998, and unpublished author's data on olivine melilitites.

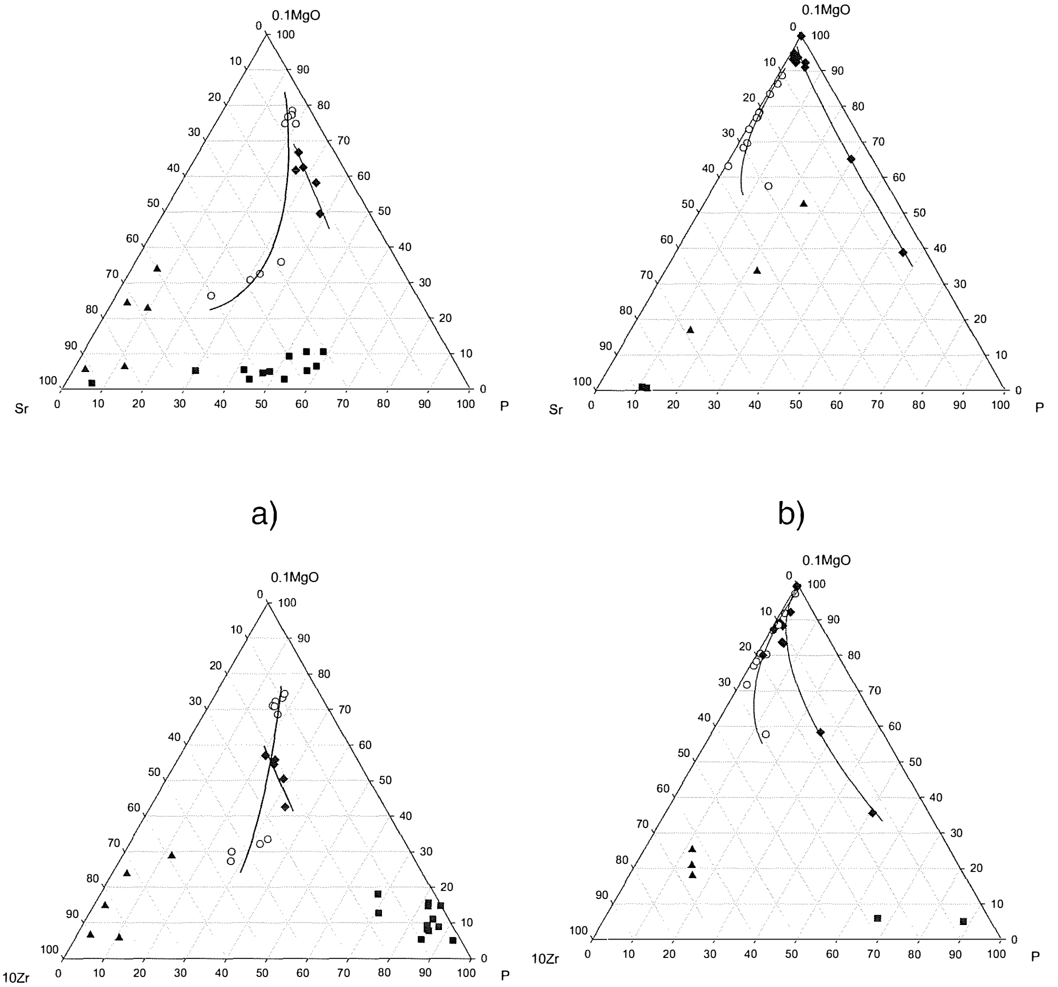


Fig. 2 – Fractionation of Sr, P and Zr: (a) in Kaiserstuhl essexite-tephrite (diamonds) and melilite-bearing (circles) series, phonolites (triangles) and carbonatites (squares); (b) in Odikhincha melilite-free (diamonds) and melilite-bearing (circles) series, nepheline syenites (triangles) and carbonatites (squares).

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