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Genesis and crystallization of ultramafic alkaline carbonatite magmas of Siberia: ore potential, mantle sources, and relationship with plume activity

N.V. Vladykin *

A.P. Vinogradov Institute of Geochemistry, Siberian Branch of the Russian Academy of Sciences, ul. Favorskogo 1a, Irkutsk, 664033, Russia

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Abstract

This paper discusses the genesis of large Siberian alkaline massifs hosting major ore deposits. These reference massifs are grouped based on the predominance of alkalies (K or Na) and their agpaitic index (miaskitic and agpaitic). We proposed new emplacement schemes for the Tomtor, Murun, Burpala, Synnyr, and Bilibino massifs supported by petrochemical and geochemical data, as well as new age estimates. Types of their ore potential and genesis of rare-metal mineralization are discussed. The formational types of carbonatites as the main ore-bearing rocks are given. The depth of magma generation and types of mantle sources are determined using isotopic data from previous studies. A model of plume-related generation of ultramafic alkaline magmas is proposed.

Keywords: petrology of alkaline rocks; ore potential; trace element and isotope geochemistry; mantle sources; magma genesis model

Introduction

Alkaline rocks are a unique set of rocks hosting important rare-metal mineralization of Nb, Ta, Zr, Y, REE, Cu, and P as well as an abundance of semiprecious stone deposits of charoite, Cr-diopside, dianite. Since the discovery of diamond-bearing lamproites in Australia, the complex processes of their formation have been, and remain, a matter of hot debate. The advent of new analytical methods considerably enhances our understanding of the composition of these rock complexes and the results of isotope geochemistry confirm a mantle origin for the alkaline massifs. Observations of mineral assemblages and genesis of alkaline rocks provide clues for deciphering dynamic processes in the deep Earth.

The alkaline complexes are commonly interpreted to be associated with large composite plutons made up of alkaline-ultramafic rocks of the K–Na series and agpaitic alkaline granitic complexes.

The parental magmas of many alkaline-ultramafic complexes were derived from deep (mantle) or plume sources. Such magmas were emplaced along ring fractures to form central-type ring complexes made up of multiple magmatic phases with vertical contacts. Most of the ring complexes contain both volcanic and plutonic rocks that appear genetically related in a single volcanoplutonic complex.

The various types of alkaline rocks can be distinguished using a geochemical indicator called the agpaitic index (K_a, the molar ratio (Na + K)/Al). The agpaitic index is greater than 1 for the agpaitic rocks and less than 1 for the miaskitic rocks. Alkaline massifs are known from a variety of locations worldwide (Fig. 1).

Examples of large ore-bearing alkaline massifs

Alkaline rocks are generally considered to be relatively rare in nature, but this is not correct. This is clearly seen in Fig. 1 showing only a portion of all known occurrences of alkaline igneous rocks of the world (Woolley, 2001). In addition, some of the largest intrusions of alkaline rocks may range in size from 100 to 500–1000 km^2 and more. These are the Pocos de Caldas and Itatiaia massifs in Brazil, Pilanesberg in South Africa, Khibina and Lovozero on the Kola Peninsula (Russia), Guli and Tomtor on the Anabar Shield, and Synnur in the northern Baikal region. The unique massifs in terms of their mineralization are the Murun and Bilibino massifs (each 150 km^2 in extent) on the Aldan Shield, Burpala massif

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* Corresponding author.
E-mail address: vlad@igc.irk.ru (N.V. Vladykin)

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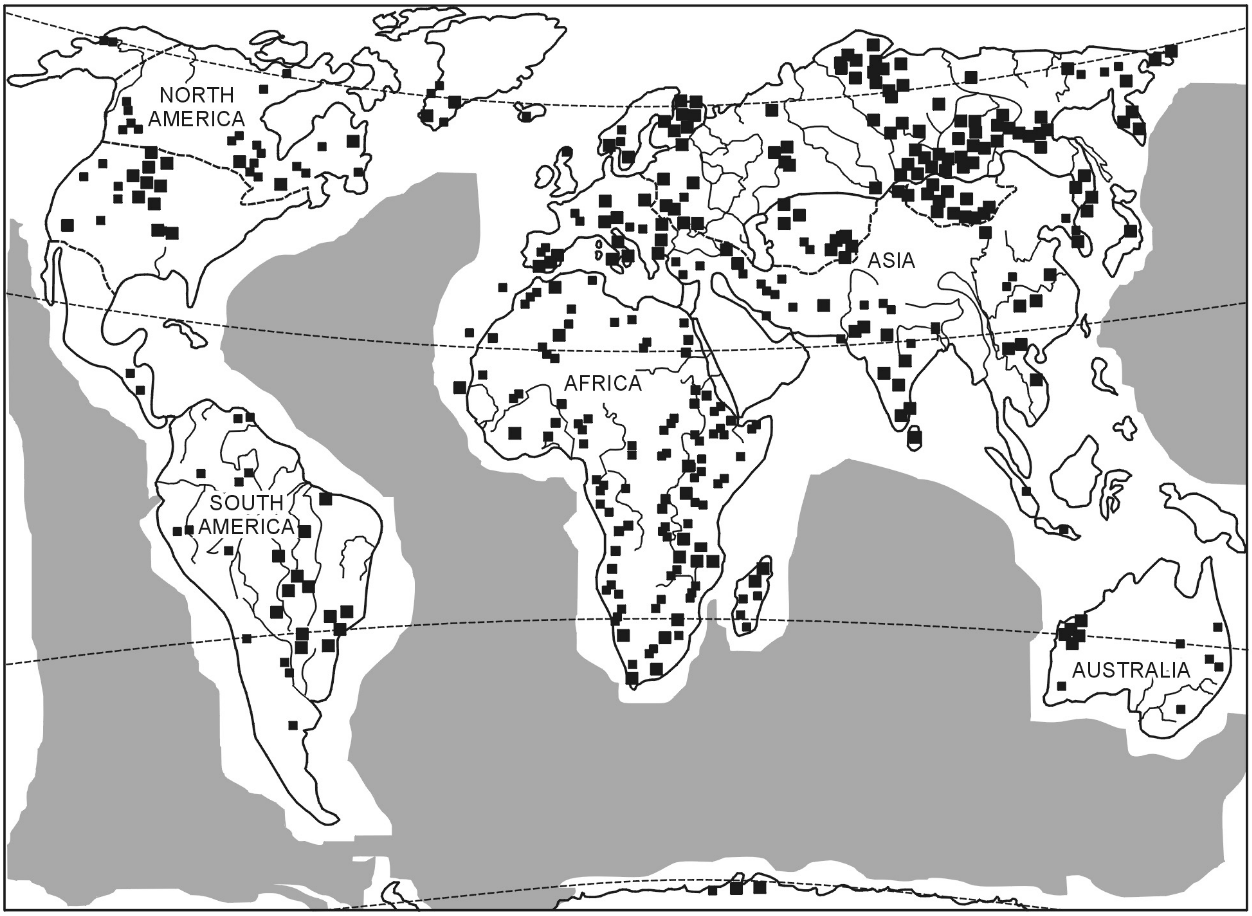

Fig. 1. Distribution of alkaline rocks in the world, compiled after Woolley (2001).

(250 km^2) in the northern Baikal region, Khan-Bogdo massif (over 1000 km^2) in Mongolia (Vladykin, 2013) and others.

The alkaline massifs have proved as major hosts of many rare-metal deposits of Ta, Nb, Zr, REE, Y, Be, Sr, Ba and others, which are used in a range of modern technologies. Based on their large size, these massifs can be also regraded as a potential source of economic rare-metal deposits. Below, we provide a brief characterization of the alkaline massifs of Siberia, which are subdivided into high-K and high-Na types on the basis of our own data.

Na-rich alkaline massifs

The Burpala massif is a central-type intrusion, some 250 km^2 in extent, located in the northern Baikal region (Fig. 2). It is a unique complex of alkaline affinity hosting an economic rare-metal deposit. New U–Pb zircon ages of 283 ± 1 Ma for syenites (main magmatic stage) and 294 ± 1 Ma for rare metal-bearing pegmatites (Kotov et al., 2013) confirm a genetic link between the alkaline massif and mineralized pegmatites. Comparison of the new ages of the Burpala massif with previously published age of the Synnyr massif (300 Ma) defines a single cycle of the Paleozoic alkaline magmatism. We propose a new emplacement sequence of the Burpala massif (from the early to late stage): shonkinite → nepheline syenite → alkaline syenite → quartz syenite → vein rock (nepheline-sodalite syenite → rare-metal pegmatite → apatite-fluorite rock → carbonatite → alaskite and alkaline granite) (Vladykin et al., 2014a).

The main stage rock types are miaskitic while the latest veins are agpaitic. Mica, amphibole, and pyroxene are the most common constituents in the alkaline silicate rocks. These rocks contain about 100 minerals, most of which are hosts to rare metal mineralization (Sotnikova, 2009).

Rare-metal syenites and pegmatites are emplaced along fractures at contact zones in the southwestern and central parts of the massif. These are mostly fine-, medium- and, rarely, coarse-grained rocks consisting of microcline, albite, pyroxene, amphibole, and rare-metal minerals (up to 30%). The rare-metal mineralization in alkaline syenitic rocks is contained in a variety of Zr-silicates (zircon, eudialyte, lavenite, Ti-lavenite, wöhlerite, burpalite, seidozerite, Ca-seidozerite, rosenbuschite, vlasovite, catapleite, Ca-catapleite), Ti-minerals (titanite, astrophyllite, ramsayite, loparite, metaloparite, rinkolite, Mn-neptunite, bafertisite, chevkinite, Mn-ilmenite, pyrophanite, Sr-perrierite, landauite, rutile, anatase, bookite), REE minerals (loparite, metaloparite, britholite, rinkolite, melanocerite, bastnäsite, parisite, fluocerite, ancylite, monazite, REE-