Lithos 210–211 (2014) 260–277

Contents lists available at ScienceDirect

Lithos

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

Sr–Nd–Pb isotope systematics and clinopyroxene-host disequilibrium in ultra-potassic magmas from Toro-Ankole and Virunga, East-African Rift: Implications for magma mixing and source heterogeneity

N.S. Muravyeva [a,*], B.V. Belyatsky [b], V.G. Senin [a], A.V. Ivanov [c]

[a] Vernadsky Institute of Geochemistry and Analytical Chemistry RAS, Kosygin st. 19, Moscow, 119991 Russia
[b] VNIIOkeangeologia, Antarctic Geology Department, St. Petersburg, Russia
[c] Institute of the Earth's Crust RAS, Siberian Branch, Lermontova St., 128, Irkutsk, 664033, Russia

ARTICLE INFO

Article history:
Received 11 March 2014
Accepted 13 September 2014
Available online 4 November 2014

Keywords:
Isotope composition
Mantle source heterogeneity
East African Rift
Clinopyroxene
Magma mixing

ABSTRACT

Nd, Pb and Sr isotope ratios have been determined for kamafugite lava and clinopyroxene phenocrysts from Bunyaruguru (Toro-Ankole) and Virunga volcanic fields of the East African Rift. The whole rock Sr–Nd isotopic signatures of kamafugites ($^{87}Sr/^{86}Sr$: 0.70463–0.70536; $^{143}Nd/^{144}Nd$: 0.51249–0.51255) suggest derivation from an EM1-type mantle source. In contrast, Pb isotopic compositions of the same samples ($^{206}Pb/^{204}Pb$: 19.00–19.57; $^{207}Pb/^{204}Pb$: 15.69–15.74; $^{208}Pb/^{204}Pb$: 39.30–40.26) reveal a similarity to EM2-type mantle. New Nd, Pb and Sr isotopic data for clinopyroxene ($^{87}Sr/^{86}Sr$: 0.70473–0.70503; $^{143}Nd/^{144}Nd$: 0.51250–0.51254; $^{206}Pb/^{204}Pb$: 18.04–18.17; $^{207}Pb/^{204}Pb$: 15.58–15.60; $^{208}Pb/^{204}Pb$: 38.09–38.23) suggest derivation from an EM1-like source, and indicate Sr and Pb isotope disequilibrium between clinopyroxene and corresponding host rock. Moreover, clinopyroxenes exhibiting a greater degree of isotopic disequilibrium with their host rock are more sodic in composition. The isotopic disequilibrium is corroborated by the presence of chemical zoning within clinopyroxene, which suggests rapid magma ascent rates preventing melt homogenization. The Pb isotopic ratios for both mineral and corresponding whole rock, together with published data on East African rift-related alkaline centers, define a trend interpreted to represent a mixing line for melts derived from sources such as EM1 and as HIMU. The similar isotopic compositions for clinopyroxene from the different volcanic rocks within the East African Rift suggest the existence of a common, older mantle source for their parental melts. The origin of these melts can be attributed to an enrichment event ~400–500 Ma, i.e., significantly prior the younger ultrapotassic magmatism. Our preferred interpretation for the results reported here involves the mixing of melts derived from EM1- and HIMU-like sources, which were rapidly transported to the Earth's surface. The primary magmas formed as the result of melting of a heterogeneous (on kilometer scale) mantle source consisting of peridotite and pyroxenite.

1. Introduction

Clinopyroxene and olivine formed during the early crystallization stage of mantle-derived magmas carry important information about the parental melt composition and hence its source. These minerals can serve as capsules preserving the Sr and Nd isotopic signature of magmas from which they have crystallized. They provide important insights into the range of mantle heterogeneities sampled by a single lava flow, and ultimately degree of the mantle source heterogeneity sampled by rift volcanoes. The investigation of the isotopic relationships between clinopyroxene and their host lavas provides significant insight into the fundamental nature of the mantle source (e.g. Simonetti and Bell, 1993, 1994, 1995; Bryce and DePaolo, 2004; Ramos and Reidy, 2005; Jackson et al., 2009).

The Western Branch of the East African Rift is a region with classic occurrences of ultra-potassic magmatism (Bailey, 1974; Eby et al., 2003; Foley et al., 1987; Rosenthal et al., 2009). The trace element geochemistry of these ultrapotassic rocks indicates derivation from an enriched mantle source (e.g. Eby et al., 2003). The great diversity in the modal and chemical composition of the volcanic rocks within a limited geographic region is a reflection of upper mantle heterogeneity at the kilometer scale. For example, the mantle source of the ultrapotassic rocks is thought to be lherzolite (harzburgite?) characterized by numerous veins and interlayers of phlogopite-bearing pyroxenite (Lloyd et al., 1999).

This paper focuses on an investigation of kamafugites from the Toro-Ankole and Virunga provinces in the northern part of the Western Branch of the East African Rift (Fig. 1). Sr, Nd and Pb isotopic data are available for the kamafugite rocks (Davies and Lloyd, 1989; Rosenthal et al., 2009) but there is a paucity of isotopic compositions for constituent minerals. Isotope data for minerals and xenoliths contained in kamafugite from Katwe-Kikorongo were first reported by Davies and

* Corresponding author. Tel.: +7 499 9397027; fax: +7 495 938 20 54.
E-mail address: nmur@mail.ru (N.S. Muravyeva).

http://dx.doi.org/10.1016/j.lithos.2014.09.011
0024-4937/

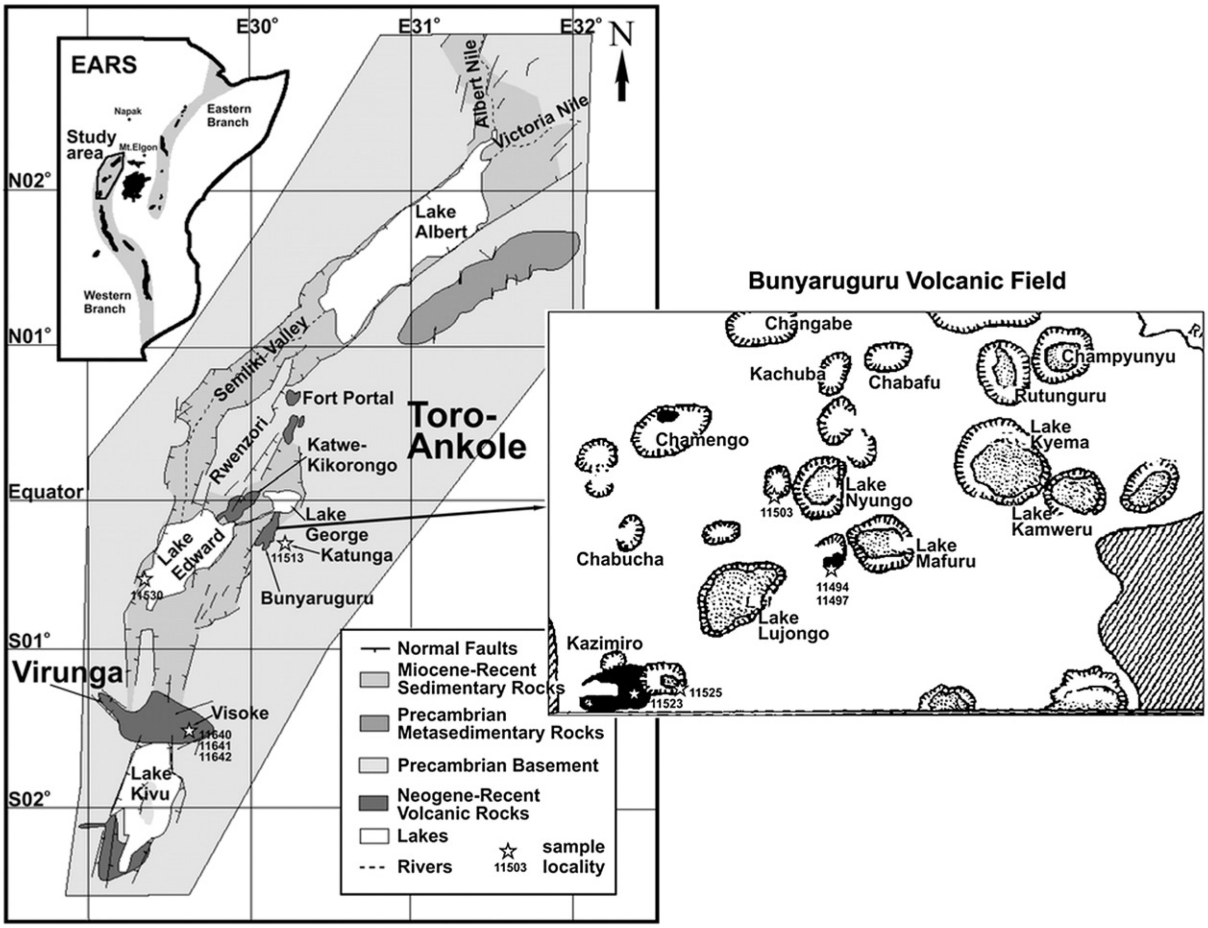

Fig. 1. Simplified map showing the Kivu–Edward–Albert–West Nile rift zone of the East African Rift System. Insert map shows parts of East Africa, with the location of the two rift branches, and the location of the rift zone (after Lærdal and Talbot, 2002). Inset shows sketch-map of Bunyaruguru volcanic field, showing the explosion craters and lava occurrences that are illustrated at 11.6 × 6 km (after Holmes, 1942). Numbers in the figure indicate places, where studied specimens were sampled.

Lloyd (1989). Subsequent studies were undertaken on nephelinite lavas from Napak and Mount Elgon volcanoes, eastern Uganda-western Kenya (Simonetti and Bell, 1993, 1995). The objectives of the present work are to (1) elucidate the mantle source composition on the basis of Nd, Pb and Sr isotope composition of rock-forming minerals, (2) document the isotopic relationships between minerals and their host rocks, and (3) assess the isotopic evolution of the kamafugite magmas. This approach will help enhance understanding of the nature and degree of lithosphere–asthenosphere interaction in areas of continental rifting.

2. Geological setting and sample localities

The Toro Ankole volcanic field is the northernmost expression of rift-related magmatism in the Western Branch of the East African Rift. Geological study of this region was first conducted in 1929 by Wayland and Combe (Combe, 1930, 1937) and Holmes (e.g. Holmes, 1942, 1950); subsequent researchers include Gerasimovskiy and Polyakov (1974).

Volcanism in the Western Rift is limited to four main regions in addition to isolated small areas where volcanic intrusions are present; from north to south these are Toro-Ankole, Virunga, South Kivu and Rungwe. In general, the volcanics form spatially isolated rock units that occur in conjunction with the rift grabens. Western Rift volcanism in the Virunga Province approximately 12 million years ago and is still active today. In the Kivu province, basaltic–trachyte volcanism has been active from 8 million ago till the mid-Pleistocene (Logatchev et al., 1972), and appears to predate the beginning of volcanic activity within the Rungwe province in southern Tanzania. Volcanism in the Toro-Ankole province at the northern end of the Western Rift appears to be restricted to the past 1 million years (Ebinger, 1989; Nyablade and Brazier, 2002). K-Ar and $^{40}Ar/^{39}Ar$ ages indicate that volcanism is at most 50,000 years old (Boven et al., 1998). The explosive eruptions that occurred within this region continued until about 4000 years ago (Logatchev et al., 1972).

The Toro-Ankole province consists of three volcanic fields: Fort Portal, Katwe-Kikorongo and Bunyaruguru. The Bunyaruguru volcanic field – which forms the focus of this research – is located south of Lake George and east of Lake Edward (Fig. 1). It consists of numerous, closely spaced Late Pleistocene–Quaternary explosion craters, many of which presently have crater lakes. Most of the volcanics are tuffs; lavas are scarce. The magmatism of the Bunyaruguru field is generally similar to that of neighboring Katwe-Kikorongo, but the volcanic rocks are characterized by higher Mg# [$Mg\# = Mg/(Mg + Fe^{2+})$ in moles, with $Fe^{2+} = 0.85$ total Fe] and a wider distribution of olivine phenocrysts (Eby et al., 2003). Samples of ugandite and mafurite used in this study were collected from the Bunyaruguru volcanic field (Kazimiro, Mafuru and Nyungu craters; Fig. 1). Katunga, an isolated undissected tuff cone with associated lava flows located east of the Bunyaruguru field, is the southernmost feature of an N–S-trending chain of high-potassic foiditic volcanism (Fig. 1). Katunga (the type locality for katungite, an olivine-melilitite) is located directly atop the metamorphic basement rocks and contains a freshwater lake in its summit crater. Two lava flows occurred to the NE of vents on the northern and NE flanks. The sample of katungite reported here is from the crater on the left bank of NE section of Katunga Lake. The age of the cone is uncertain, but it is contemporaneous with Late Pleistocene to Recent tuff cones in the Bunyaruguru area, and the undissected condition of the tuff cone and associated lava flows implies a young age (Combe, 1937; Holmes, 1950).