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Origin of kamafugite magmas in the East African Rift of western Uganda

Anja Rosenthal[1,2], Stephen F. Foley[1,2], D. Graham Pearson[3], Geoff M. Nowell[3] and Sebastian Tappe[1,4]

[1]*Institute of Geoscienes, University of Mainz, Becherweg 21, 550099 Mainz, Germany*
[2]*Research School of Earth Sciences, The Australian National University, Canberra ACT 0200, Australia*
[3]*Department of Earth Sciences,Durham University, Durham, England*
[4]*Department of Earth and Atmospheric Sciences, University of Alberta,Edmonton, Alberta, Canada*

Introduction

Kamafugites of the Toro Ankole volcanic field in and adjacent to the western branch of the East African Rift provide an excellent opportunity to study the spatial and temporal variation of magma compositions within a major continental rift underlain by a Palaeo-proterozoic-Archean basement complex (Tanzanian and Congo cratons; Fig. 1). Here, we present Sr,Nd, Hf and Os isotope data for the Ugandan kamafugites, and use them to constrain their source characteristics and petrogenesis.

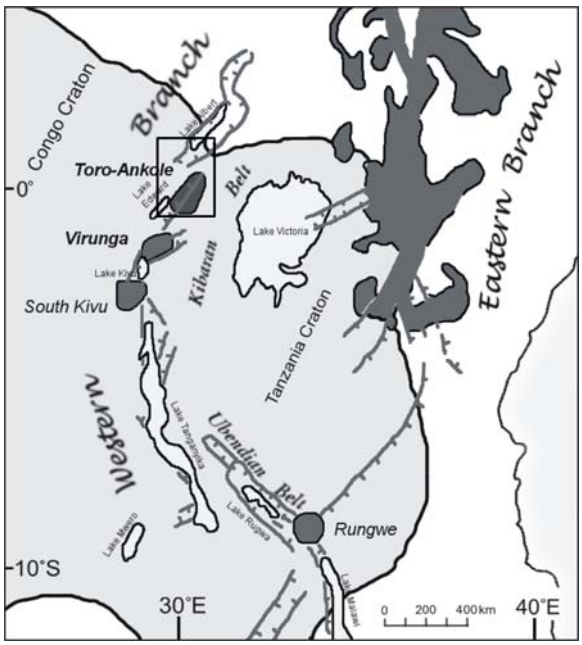

Fig. 1 Simplified map of the equatorial part of the western and eastern branches of the East African Rift.

Major elements and compatible trace elements

The archetypal Ugandan kamafugites are rare silica-undersaturated, calcium-rich igneous rocks. Their acronym refers to old local petrographically defined names such as katungite, mafurite and ugandite (Sahama, 1974). The presence of modal kalsilite, leucite and perovskite in the volatile-rich, potassic to ultrapotassic kamafugitic magmas is an expression of low contents of silica (SiO_2 = 31.8 – 41.8 wt%; Fig. 2), low Al_2O_3 (< 8.0 wt%), and high CaO contents (≤ 16.6 wt%). They have high MgO (≤ 22 wt%), Ni, Cr and Os concentrations, and high Mg#. Rarer nephelinites are more evolved with lower Mg#.

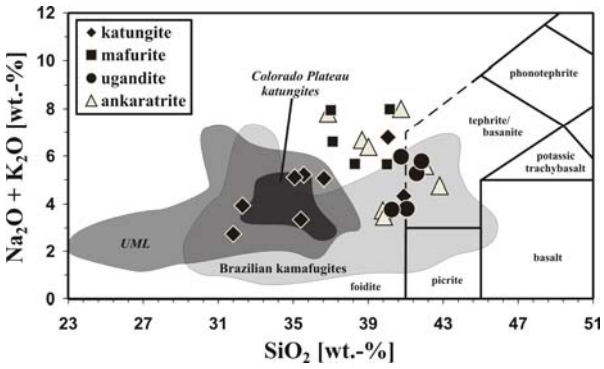

Fig. 2. Total alkali – silica classification diagram of Toro Ankole kamafugites (solid symbols) and ankaratrites (open symbols).

As illustrated in Figure 2, katungites resemble most Colorado and Brazilian kamafugites as well as ultramafic lamprophyres in composition. The high alkali content Ugandan kamafugites is due to potassium enrichment.

Incompatible trace elements

The extreme and similar enrichments of incompatible trace elements in Ugandan, Colorado and Brazilian kamafugites is striking, with LREE, HFSE and LILE being most enriched and the HREE least enriched (Fig. 3). However, their prominent negative K and P anomalies contrast with their significant K_2O and P_2O_5 enrichment, indicating exceptional enrichment in incompatible trace elements.

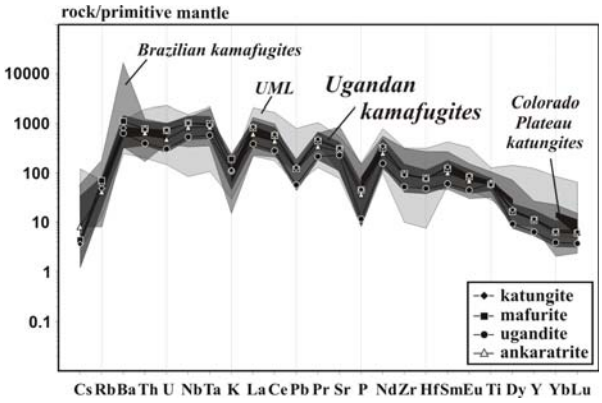

Fig. 3 Average trace element abundances in Ugandan kamafugites normalized to primitive mantle values.

Isotope analyses show that crustal contamination did not play a major role. The latter is demonstrated by a horizontal array on a plot of $^{87}Sr/^{86}Sr$ vs. Mg#, and by negative Pb troughs in trace element patterns (Fig. 3). This contrasts with positive Pb in kamafugites which has been shown to originate from sources involving the crust (Prelevic et al., 2005; Prelevic & Foley, 2007).

Constraints from Sr-Nd-Hf isotopic compositions

The correlation of enriched Nd and Hf isotopic compositions (ε_{Nd} = 0.08 to -4.70 and ε_{Hf} = 3.64 to -8.84) indicate time-integrated enrichment of the source, which is attributed to carbonate-rich melt infiltration (Fig. 4).

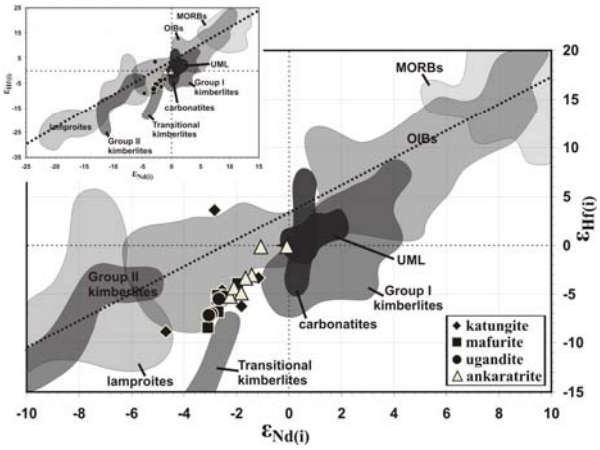

Fig. 4 ε_{Hf} versus ε_{Nd}. Hf isotopic compositions of Toro-Ankole kamafugites show a much wider range than Nd, distributed along the lower edge of the OIB field, and mainly below the mantle regression line. The latter characteristic is analogous to some lamproites, kimberlites, alkaline basalts and garnet pyroxenites. (e.g. Nowell et al., 2004; 2008; Janney et al., 2002; Pearson & Nowell, 2004; Tappe et al., 2007). Data from Nowell et al. (2008) are not displayed in this figure.

In contrast, the restricted range of $^{87}Sr/^{86}Sr$ (0.704599 to 0.705402) of the lavas – intermediate between those of the enriched Virunga province and the more isotopically depleted South Kivu province – indicate recent enrichment of potassium (Fig. 5). Hence, the formation of phlogopite in the source, which is required by the potassic chemistry of the kamafugites, must have occurred shortly before eruption, otherwise more marked growth of $^{87}Sr/^{86}Sr$ would have occurred.

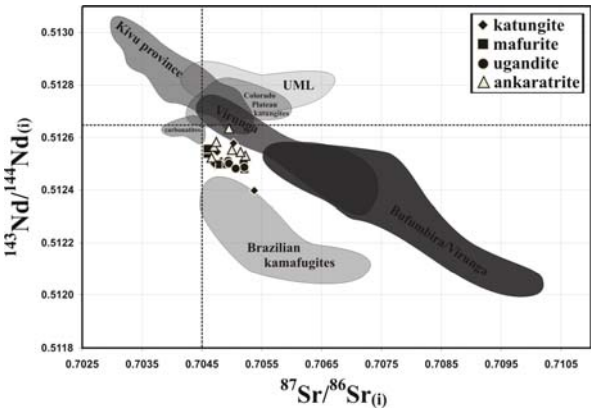

Fig. 5 $^{143}Nd/^{144}Nd$ versus $^{87}Sr/^{86}Sr$. Toro-Ankole kamafugites and ankaratrites lie well below the array defined by other western rift volcanics.

The mantle source of Ugandan kamafugites

Isotopes and trace elements are consistent with mixed source components, favouring discrete vein assemblages over enrichment of the mantle lithosphere by pervasive metasomatism. The carbonatitic and alkaline silicate (phlogopite pyroxenite) vein assemblages melted and reacted with peridotitic mantle. This is evident from mixing-curves on plots of γ_{Os} vs. $^{87}Sr/^{86}Sr$, γ_{Os} vs. Os content (Fig. 6), and also γ_{Os} vs. Ni and MgO content. High Os concentrations and low γ_{Os} of perditotite contrast with low Os content but high γ_{Os} of the end-member derived from the ultramafic veins.
In addition, the well-defined inverse curves of radiogenic Os isotopic composition versus Os (Fig. 6; and also of γ_{Os} vs. Ni, MgO content) suggest also mixing between peridotite and an enriched end-member in refractory elements.

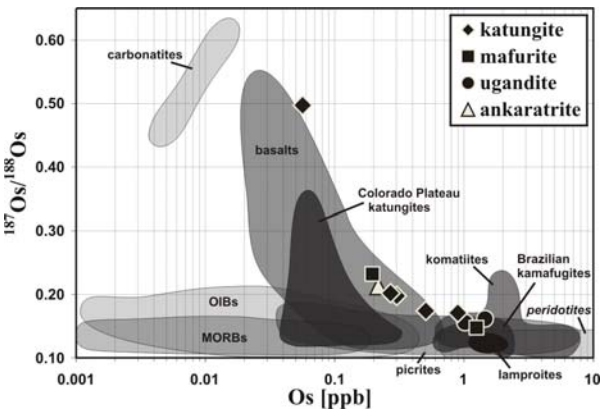

Fig. 6 $^{187}Os/^{188}Os$ versus Os content.

Such suprachondritic Os isotopic composition as well as elevated Os, Ni and MgO concentrations in the Ugandan kamafugites cannot be derived from the convecting mantle. The radiogenic γ_{Os} require time-integrated elevated Re/Os ratios known to be formed by partial melts of peridotitic mantle material.

However, the trends seen in the volcanic rock data cannot be fit by mixing curves between two fixed end-members, but good fits result if petrologically reasonable variation within each of these end-members is permitted. Isotope modeling indicates that the bulk of the melt composition originates in the pyroxenite veins, with a lesser contribution from the peridotite; this is also consistent with curved trends on plots of Os concentrations against Ni and MgO.

Two-stage enrichment of silicate melts and carbonate melts at approximately 120-180 km depth within the lithosphere is also known from geochemically similar ultramafic lamprophyres (Tappe et al., 2007). Both magma types, the Ugandan kamafugites and ultramafic lamprophyres, represent the earliest and deepest-derived magmatic products of rifts through thick continental lithosphere.

References

The complete reference list for the data in the figures is available on request from anja.rosenthal@anu.edu.au.

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