Veined pyroxenite xenoliths from the kamafugites in the Toro-Ankole region of western Uganda: a window to a rift-related mantle

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Introduction

Xenoliths in the silica- poor alkaline eruptives of the Western Rift of the East African Rift System from the Toro- Ankole- Field in Uganda mainly consist of clinopyroxene, phlogopite, titanite, perovskite, apatite and titanomagnetite in different proportions. Typically, they lack orthopyroxene and olivine. Their genesis and relation to their host lavas is still a matter of debate.

The unusual kamafugitic host lavas (potassic olivine melilitites, olivine- pyroxene kalsilitites, olivine-kalsilite leucitites and potassic nephelinites) are strongly enriched in K, Ca, CO_2, Sr and other trace elements. Besides this they are also characterized by primitive signatures that express themselves for example in high Mg#, high Cr and Ni concentrations and low $^{87}Sr/^{86}Sr$. Taken together, isotopes and trace elements of the lava indicate that more than one mineral assemblage must have been involved as separate sources. Nd, Hf and Os isotopes indicate mixing between metasomatically influenced peridotite and probably pyroxenite as sources (Rosenthal et al., 2008). Major crustal assimilation processes were not important.

In earlier studies the pyroxenite nodules were considered either as samples of highly pervasive metasomatised peridotite mantle (Lloyd et al., 1987; Lloyd & Bailey, 1975) or as distinct paragenesis occurring as veins within the peridotitic mantle (Irving, 1980; Foley, 1992). In either case the xenoliths may represent mantle material that was at least partly involved as sources for the kamafugite melts. Lloyd (1985) even claimed that kamafugites are plain partial melts of this nodule material.

A third possibility is that they represent "simple" cumulates of the exposed lavas. In any case, the nodules could provide important information not only for understanding the generation of ultrapotassic lavas but also for characterizing the rift-related lithosphere mantle as part of a complex initial continental rift process.

In this study, we present the results of our investigation of pyroxene rich nodules collected during fieldwork in the Toro-Ankole volcanic fields. We are able to distinguish between at least two different generations of mineral growth. The older assemblage consists mainly of pale diopside with high Mg/Fe ratios and phlogopite. The younger paragenesis is made up of green clinopyroxene with significantly lower Mg#, titanite, perovskite, Ti-phlogopite and apatite. Special attention was given to veins preserved in some samples which comprise both mineral paragenesis (Fig.1). These samples enable "in situ" study of the reaction between the older matrix pyroxenite and the younger high Ti melt. As far as we know, these veins have not been described in these nodules before. It is reasonable that the veins formed from a Ti, Ca, Fe and trace element-rich magmatic event which must be younger than the generation of the original diopside rich assemblage and older then the volcanics that brought the pyroxenite nodules to the surface.

Fig. 1 veined xenolith

Petrography

The xenoliths are built up of anhedral clinopyroxene with relict pale cores and green pleochroitic rims. The grain sizes vary strongly and often show signs of recrystallization processes. These clinopyroxenes represent the oldest mineral generation in the samples. Contemporarily to the younger green rims smaller and intensely green granular neoblastic clinopyroxenes appear as minerals of the second generation. Furthermore, a third paragenesis is built up of intensely green cpx, titanite, apatite and occasionally perovskite. Minerals of this latest paragenesis are usually larger than the previous ones and euhedral to subhedral. Titanite, clinopyroxene and sometimes apatite appear in equal proportions. Perovskite and titanomagnetite, where present, are subordinate. Dark brown phlogopite with strongly varying grain size is found in all but the very oldest parageneses. Because of the occasionally very coarse grained structure of the youngest mineral assemblage they can be referred to as pegmatitic textures appearing as veins in the older parageneses. The preserved contacts between the earlier and the youngest assemblages are pronounced. But within the older paragenesis the amount of green clinopyroxene increases noticeably, green rims of the older clinopyroxenes grow at the expense of the transparent cores and small Ti-minerals grow in interstices and element exchanges in older minerals are observed close to the border. Thin sections and computer tomography images of xenoliths with these pegmatitic veins illustrate extensive infiltration of melt into the surrounding wallrock.

Mineral chemistry of the rock-forming minerals

Clinopyroxene

The pale cores of the old clinopyroxenes are characterized by high Mg# (>80) and a moderate SiO_2 content around 50-52%. Their Al_2O_3 and TiO_2 contents can vary but are generally very low compared to the the rims and in the younger clinopyroxenes. In core regions the sodium (Jd-Ac) component is below 2%. Altogether the colourless cores clearly plot in the diopside field of the Wo–En–Fs ternary classification diagram. The chemical composition changes in the green rims and the younger green clinopyroxenes. The Mg# decreases to 65-70 and the Al contents clearly increase. But in the green rims, which are not related to the youngest mineral assemblage (Cpx+ Ti+ Ap± Per± Titanomagnetite) the Ti concentration does not rise. Clinopyroxenes or parts of them which are associated with the youngest mineral assemblage have low Mg# (70-55), high Al and increasing Ti-contents.

The SiO_2 contents decrease with rising Al contents indicating that some of the Al is substituting for tetrahedrally coordinated Si. The sodium (Jd-Ac) component can reach up to 6% even though it does not necessarily increase towards the rims or in younger clinopyroxenes.

The REE contents can be seen in PRIMA-normalized diagrams (Fig.2A). It is noteworthy that the pale, colorless cores of different samples show differing patterns with varying trace element contents. All cores have low HFSE (Nb, Ta, Hf, Zr). One group of samples has pale cores with rather low REE and low La/Lu, negative Ti, Sr anomalies but relatively high amounts of heavy REEs. Relict cpx in other samples are richer in REE with higher La/Lu, are not as depleted in Ti and have 10 x higher Sr. In contrast to the first samples they have sub-PRIMA Lu values that scatter strongly.

In contrast to the old cores, the green pleochroitic rims and clinopyroxenes associated with the pegmatitic magma show homogeneous trends in all samples (Fig.2B). They are enriched in light and middle REE and depleted in HREE. High La/Lu describes the steep trend. Principally they are strongly enriched in Zr, Hf and Ti.

Regarding the concentrations of transition metal elements, significant differences can be observed between the cpx of the first generation and those belonging to the pegmatitic event. Similar to the other trace elements there is no uniform trend within the cores of different samples. The ones with high LREE and high La/Lu are strongly enriched in Cr and Ni compared to the others but both have low V, Mn, and Zn. The young cpx have very low Cr and hardly any Ni but considerably higher V, Mn and Zn values. It is significant that the high La/Lu cores and the younger Cpx have similar Sr values which could be a sign for diffusion processes. Rb varies strongly and is mostly sub-PRIMA. In most cases it correlates with Ba indicating the influence of phlogopite in sources or as magmatic phase.

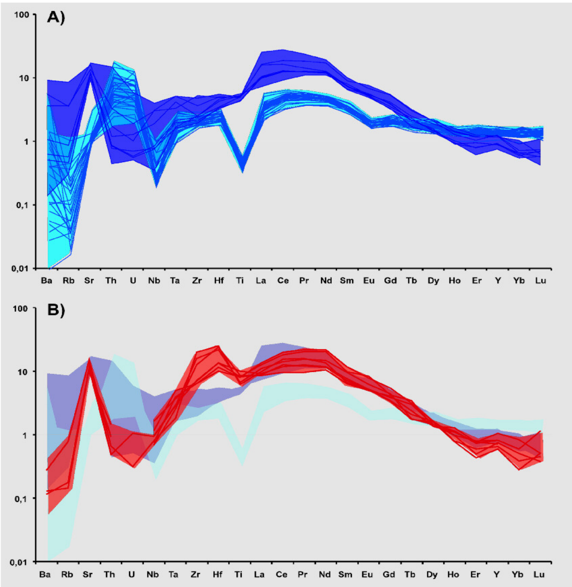

Fig. 2 A) PRIMA normalized Trace elements of Cpx- cores; B) and of pegmatitic Cpx

Micas

The dark micas are titaniferous phlogopite-biotites with Mg# between 65 and 71. The Al_2O_3 content (13- 14 wt%) is generally high compared to most micas of mafic magmatic origin. Within some samples microstructures indicate two generations of Bt. Considering the major elements except Al and Ti hardly any differences are observed, whereas the elder Bt show lower Nb, Ta, LREE and higher Ba (Fig.3).

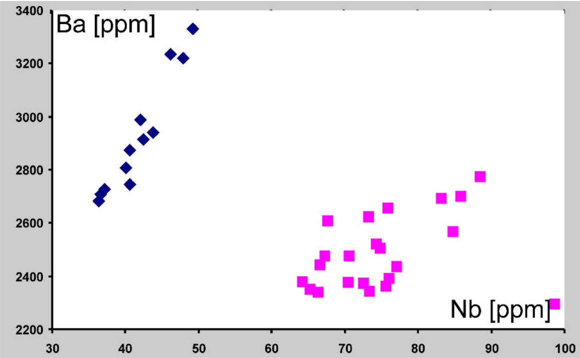

Fig. 3 Ba vs Nb of different mica generations in one sample. (blue: old); (pink: young generation)

Perovskites and Titanites

The titanites contain > 1% REE oxides. The pattern in the chondrite normalized spidergram has a steep slope and a maximum in the MREE (Pr and Nd).

Perovskites have up to 3wt % REEs and are add-itionally characterized by high Sr (~0,5wt%) contents. The elements frequently show oscillating zoning patterns, probably of magmatic origin. Perovskites are 10 times more strongly enriched in LREE than the coexisting titanites and have a steeper slope.

Conclusions

The microscopic observations and the chemical analyses indicate that most nodules have a multiphase history. The oldest observed minerals are the pale to colorless cpx- cores. A second event causes green rims and green neoblastic clinopyroxenes. Part of the mica is cogenetic to this event. During a later (third) event an unusually composed magma with high concentrations in Fe, Ca, Ti, P and trace elements infiltrated the protoliths. It resulted in the assemblages of coarse grained euhedral to subhedral titanite, cpx, apatite, titanomagnetite, mica, and/ or perovskite. It also infiltrates pervasively the wallrock and locally enriches older cpx with Fe, Al, Ti and REE. The Ti enrichment distinguishes the rims and young clinopyroxenes related to this magmatic event from the rims caused by the elder metasomatic event which only show Al enrichment. It seems that the Al and Ti concentrations of the micas support the imprint of two different events younger than the high Mg diospide cores.

The trace element contents as well as the major elements do not support the idea of these nodules representing pervasively metasomatized overprinted mantle. All samples lack relict peridotitic minerals. The old cpx cores with the highest Mg# do not show any clear relation to peridotitic cpx; their Cr, Ni and too high Fe contents are too low. They show a trend towards higher Fe which can be explained by crystal fractionation, in accordance with the increasing amounts of incompatible elements such as Ti and REE accompanying decreasing Mg#. Therefore, it is likely that the relict parts of the xenoliths crystallized from different and older magmas with variable trace element patterns indicating different genesis.

The younger metasomatic event traced in the nodules, resulting also in the pegmatitic veins are found in all samples. Thus the older magmas have undergone the same metasomatic history at a later stage. This indicates that the latest pegmatitic event influenced parts of the lithosphere throughout the Toro Ankole volcanic field. It is reasonable that the veins represent a Ti, Ca, Fe and trace element-rich highly evolved residual melt which is not observed in this form on the surface. This melt infiltration event was younger than the pale cpx but older then the kamafugites. The open question is the nodules' role in the genesis of the kamafugitic lavas.

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