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Geochemistry and petrogenesis of the Fort Portal, Uganda, extrusive carbonatite

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ABSTRACT

The Quaternary Fort Portal volcanic field occurs at the northern end of the Western Rift in Uganda. The eruptive phases consist of (1) early carbonatite tuff cones followed by (2) a blanket carbonatite tuff (the major unit of the field) and finally (3) a small volume of carbonatite lava. Mantle and crustal xenoliths are found in all eruptive phases and melilitite lapilli are found in the blanket tuff. The melilitite lapilli contain carbonate ocelli and abundant lithic fragments. Major and trace element abundances were determined for 37 whole-rock samples from all three eruptive phases plus 10 crustal xenoliths and for the melilitite lapilli matrix, carbonate ocelli, carbonate lapilli, carbonate ash, and inter-lapilli carbonates. The chemistry of the tuffs was modeled using a 3 component system – carbonatite lava, melilitite, and xenolithic silicate material. Average values for the cone-building tuffs are 75% carbonatite lava, 25% xenolithic silicate material, and no melilitite, in agreement with petrographic observations. For the blanket tuffs the mixing model gives 20 to 53% carbonatite lava, 14 to 22% melilitite, and 12 to 55% xenolithic silicate material, also in agreement with petrographic observations. The carbonate ocelli in the melilitite lapilli could represent an immiscible liquid separated from melilitite melt or trapped melt inclusions. However, the trace element data support a model involving the separation of a late-stage CO_2-rich fluid from the crystallizing melilitite. Trace element data support an origin of the carbonate lapilli and carbonatite lava as an immiscible liquid separated from a carbonated melilitite melt at relatively high pressure (~1.0 GPa). The primary magma may have been an olivine melilitite. An important feature of both the carbonatite and melilitite magma is the low absolute abundance of alkalis, a very different situation from that observed for the only currently irruptive carbonatite (natrocarbonatite) volcano – Oldoinyo Lengai. It is proposed that the formation of the immiscible liquid pair occurred simultaneously with the loss of alkalis and eruption.

1. Introduction

Seven percent of the 527 carbonatite occurrences reported by Woolley and Kjarsgaard (2008) are associated with melilite-bearing rocks. However, of the 46 extrusive carbonatite occurrences reported by these authors, 16 (35%) are associated with melilite-bearing rocks. While these associations are relatively rare, they are intrinsically interesting because of the presence of melilite. One of the extrusive carbonatite–melilite associations, the Quaternary Fort Portal volcanic field, is the subject of this paper.

The Quaternary Fort Portal and Kasekere volcanic fields of southwest Uganda (Fig. 1) were first mapped and described by von Knorring and Du Bois (1961). The area is bounded to the west and north by rift faults associated with the western branch of the East African rift system. Fort Portal and Kasekere are part of a larger volcanic province (Fig. 1) characterized by the eruption of K-rich magmas. Extrusive carbonatites (Fort Portal and Kasekere) occur in the northern part of the province, ultrapotassic volcanics occur in the central part (Katwe–Kikorongo and Bunyaraguru), and potassic mafic and felsic volcanics in the southern part.

As determined by ^{14}C dating (Vinogradov et al., 1978; reported in Barker and Nixon, 1989) the extrusive carbonatites at Fort Portal and Kasekere erupted between 6000 and 4000 years ago. The initial phase of volcanic activity at Fort Portal includes carbonatitic tuff cones and craters, many of the latter occupied by lakes, which occur along two ENE trends. This phase was followed by eruption of carbonatitic tuffs that cover some 142 km^2. On average the tuff layer is about 2 m thick and has a total volume of 0.25 km^3. The volcanic activity ended with the eruption of minor volumes of carbonatite lava.

Nixon and Hornung (1973) give petrographic descriptions of the lava and tuffs together with whole-rock analyses of eight samples of lava and 14 of tuff. Barker and Nixon (1989) report chemical data for a number of minerals in the Fort Portal carbonatite and some additional whole-rock chemistry. They noted that plots of Al_2O_3 versus various oxides and elemental abundances formed linear trends between the lava samples and the crustal xenoliths suggesting simple mixing between these end

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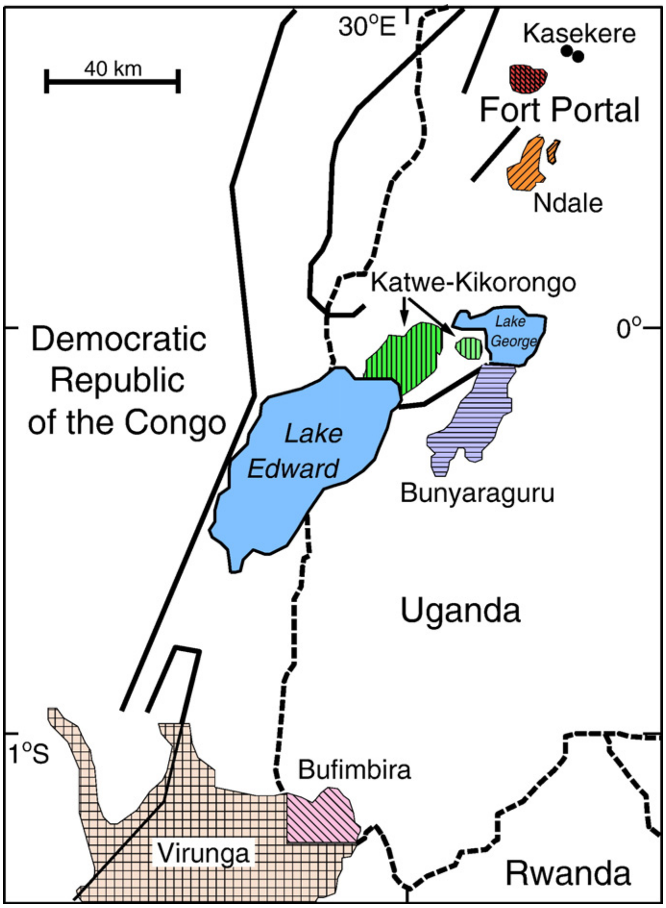

Fig. 1. Locations of the major volcanic fields in the southwest Uganda portion of the western branch of the East African rift system. Fort Portal and Kasekere – calciocarbonatites; Ndale, Katwe–Kikorongo, and Bunyaraguru – kamafugites; Bufumbira (part of the larger Virunga field) – potassic mafic–felsic flows and pyroclastics.

members. Although they considered the possibility that phenocrysts of olivine, titaniferous magnetite, clinopyroxene and phlogopite in the lavas might be mantle-derived, they concluded that it was more probable that they represented disrupted cumulates, possibly coeval with the carbonatite magma. Barker and Nixon (1989) concluded that "No coeval silicate rock was erupted with the Fort Portal carbonatite, making it impossible to construct a petrogenetic model based either on crystal–liquid fractionation or on liquid immiscibility." In a brief discussion of the whole-rock chemistry of extrusive carbonatites, Woolley and Church (2005), using a data set consisting of 26 analyses of lavas and tuffs from Fort Portal, showed in simple plots of SiO2 versus CaO and MgO that the Fort Portal carbonatites do define clear trends that can be explained by contamination with crust (or mantle)-derived silicate material.

The present authors collected samples, including many of the flaggy carbonatitic tuff, during fieldwork in 1999. Subsequent work on this material revealed the presence of rounded, near isotropic, lapilli in some of the tuffs that subsequently proved to be fresh melilitite. A detailed account of the petrography of the melilitite lapilli, including numerous electron microprobe analyses of the mineral phases and glass, was given by Bailey et al. (2005), who emphasized that we had, for the first time, a recognizable silicate fraction coeval with the carbonatite.

In this paper we present an extensive set of new major and trace element data for the carbonatite tuffs, carbonatite lava and xenolithic silicate material, along with scanning electron microscope (SEM), electron microprobe (EMPA) and laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) analyses for the carbonate and silicate fractions of the melilitite lapilli, carbonate lapilli, carbonate ash, and inter-lapilli carbonates. These data allow us to expand on the original work of Barker and Nixon (1989) and are used to construct petrogenetic models for the various phases of the Fort Portal extrusive carbonatite.

2. Petrography of the volcanic products

The extrusive carbonatite at Fort Portal consists of three phases (in order of eruption): cone-building lapilli tuffs, blanket tuffs, and carbonatite lava. The cone-building lapilli tuffs essentially comprise carbonate lapilli and a variety of xenolithic silicate material. The blanket tuffs are similar with the notable exception that melilitite lapilli are found in these tuffs. The carbonatite lava is basically a mixture of essential calcite and spurrite, accessory phases, and xenolithic silicate material.

2.1. Cone-building lapilli tuff

The lapilli tuffs forming the ash cones have been described in detail by Barker and Nixon (1989). The matrix of sparry calcite often supports lapilli of micritic calciocarbonatite. The abundant irregular vesicles and inter-lapilli voids frequently contain zeolite rather than carbonate. From these observations it is inferred that the spar may be juvenile carbonate ash that subsequently recrystallized. Ash-cone lapilli contain tabular carbonate phenocrysts. There are occasional ocelli of coarse carbonate. In addition to the same xenolithic silicate materials (Fig. 2a, b) found in the blanket tuff (see next section for description), garnet and spinel lherzolite have been reported from the Fort Portal Kalyango tuff cone (Kapustin and Polykaov, 1985), while from the same cone Nixon and Hornung (1973) reported eclogite of probable crustal origin. The two lapilli tuff samples reported in this study are from the Kajonjo ash cones in the Kasekere field.

2.2. Blanket tuff

The blanket tuff comprises three principal components: (1) melilitite lapilli (approximately 10–50 modal% of the tuff), (2) carbonate ash- to lapilli-sized globules that nearly always support the melilitite lapilli, and (3) xenolithic silicate material. Representative photomicrographs are given in Figs. 2c–f and 3a–c.

2.2.1. Melilitite lapilli

Melilitite lapilli are irregular and lobate or tend towards ovoid. Ovoid lapilli often enclose a lithic kernel and sometimes show a concentric arrangement of melilite and apatite crystals. The lithic kernel comprises xenolith or xenocryst material, either mantle- or crust-derived. In some cases melilitite lapilli appear broken into angular fragments, indicating that they may have solidified relatively early during entrainment, and before accretion of a carbonate rim. The lapilli are variable in modal content (see Bailey et al., 2005), with glass and melilite both ranging from ~15 to 85%, and may contain groundmass carbonate from <1 to ~75%. An average lapillus is composed of pale-brown to colorless cryptocrystalline glass (~45% modally), which encloses ~30 modal% melilite laths that range in size from ~5 to 120 µm in length. Apatite needles of a similar size to melilite comprise ~10 modal%. Titaniferous magnetite (~5%) is the only abundant phenocryst (average diameter ~100 µm) and also occurs as tiny cuboids (a few microns in diameter) scattered in the groundmass (see also Bailey and Kearns, 2002). Some titaniferous magnetite is probably xenolithic as it has been observed in polymineralic fragments associated with other xenolith minerals, such as biotite and clinopyroxene. Perovskite (<5% of a lapillus) is less common than titaniferous magnetite and rarely forms phenocrysts. Ocelli of coarse mosaic carbonate are found in the melilitite lapilli. Notably, the ocelli are aggregates of apparently coexisting high-Mg