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Carbonate–silicate immiscibility and extremely peralkaline silicate glasses from Nasira cone and recent eruptions at Oldoinyo Lengai Volcano, Tanzania

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ABSTRACT

Phenocrysts of garnet, pyroxene and nepheline in peralkaline nephelinite from the Nasira parasitic cones at Oldoinyo Lengai contain quenched immiscible silicate (peralkalinity = 2–13) and Na–Ca-carbonate melts. Their bulk compositions further define the limits of liquid immiscibility for peralkaline carbonated nephelinite magmas and confirm this process was operative at Oldoinyo Lengai during older stages of activity. Groundmass glasses in Nasira nephelinites are peralkaline (peralkalinity = 5.5–9.5) but less evolved than melt inclusion glasses (peralkalinity = 8–13) in nepheline phenocrysts, implying that these magmas are hybrids formed by magma mixing. Groundmass glass in diverse peralkaline combeite nephelinite ash clasts with and without melilite and/or wollastonite formed in the January–June 2008 eruptions of Oldoinyo Lengai are also exceptionally peralkaline. Two trends in their compositions are evident: (1) increasing peralkalinity from 6 to 10 with SiO_2 decreasing from 42 to 33 wt.%; (2) increasing peralkalinity from 6 to 16 with SiO_2 decreasing from 45 to 40 wt.%. All recent glasses are considered to be more evolved than groundmass glass in Nasira combeite nephelinite. These data indicate that several varieties of nephelinite exist at Oldoinyo Lengai. Their parental magmas are considered to have been initially enriched in alkalis during partial melting of their metasomatized asthenospheric sources and further by subsequent assimilation, or re-solution, of previously exsolved natrocarbonatite melt in the magma chamber(s) underlying Oldoinyo Lengai. On this basis, none of the bulk compositions of peralkaline stage II lavas at Oldoinyo Lengai, including Nasira, are considered to represent those of liquids as their compositions are determined by rheological factors (phenocryst accumulation; cumulate disruption) and assimilation processes. The formation of combeite is considered to be a consequence of natrocarbonatite melt assimilation.

1. Introduction

The silicate lavas extruded from the active natrocarbonatite volcano, Oldoinyo Lengai, Tanzania (2°45′S, 35°54′E) consist principally of nephelinites and phonolites. Although, lavas are rare and the bulk of the volcano is composed of pyroclastic material, they occur as interbedded flows, cognate blocks (Dawson and Hill, 1998) and small late-stage extrusions (Dawson, 1962). Compositional data for these lavas has been provided by Dawson (1998), Donaldson et al. (1987) and Klaudius and Keller (2006). The lavas are all phenocryst-rich (10–40 vol.%: nepheline, pyroxene, Ti-andradite) and contain significant amounts of similar "xenocrystal" material derived from genetically-related disaggregated ijolites (Donaldson et al., 1987). Hence, it is important to note that the bulk composition of the lavas does not actually represent that of liquids. Regardless, petrological evolution is considered to be from early weakly peralkaline phonolites to late strongly peralkaline combeite nephelinites (Dawson, 1998; Kjarsgaard et al., 1995, Klaudius and Keller, 2006, Peterson, 1989a, 1989b).

Knowledge of the composition of the magma present at the time of change in the character of the activity at Oldoinyo Lengai from natrocarbonatite lava during much of the 1980s, 1990s and the first 10 years of the 21st century to highly explosive silicate pyroclastics in September 2007 (Mitchell and Dawson, 2007) is important. Dawson et al. (1992, 1995, 1996), Mitchell (2009) and Mitchell and Dawson (2007) have suggested that the pyroclastic activity in 1966–67 and 2007–08 is driven by decarbonation reactions between natrocarbonatite (either solid or liquid) and new batches of hot silicate (? nephelinitic) magma. Because the natrocarbonatites decompose rapidly on weathering, it is as yet unclear whether or not natrocarbonatites have been erupted through the life of the volcano, and the age of partially-decomposed natrocarbonatite lava interbedded with nephelinite tuffs in the summit area (Dawson et al., 1987) is not known. However, melt inclusions in silicate phases are unaffected by such processes and can provide data on the potential presence of natrocarbonates in older eruptions. In addition estimates of the compositions of

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silicate liquids can be made by the analysis of glass inclusions in primary liquidus phases and of glasses forming the matrix of ash particles.

In this work data are provided on the composition of glass and carbonate inclusions in phenocrysts from the nephelinitic south parasitic Nasira scoria cone and associated lava flow located on north side of the main Oldoinyo Lengai volcano, together with groundmass glass occurring in ash clasts formed during the January to July 2008 pyroclastic eruptions at the northern summit of Oldoinyo Lengai. These data are relevant to both the proposed formation of the natrocarbonatites by liquid immiscibility (Guzmics et al., 2011; Kjarsgaard et al., 1995; Mitchell, 2009) and to evolution and differentiation of the Oldoinyo Lengai magmatic system (Keller et al., 2006).

2. Analytical methods

All silicate glasses and quenched carbonate compositions were determined by quantitative energy dispersive X-ray spectrometry using a JEOL-JSM5900 scanning electron microscope equipped with a LINK ISIS 300 analytical system incorporating a Super ATW light element detector (133 eV FwHm Mn*K*). Raw EDS spectra of rastered areas were acquired for 120 s (live time) with an accelerating voltage of 20 kV and 1 μm diameter beam with a current of 0.475 nA on a Ni standard. The spectra were processed with the LINK ISIS SEMQUANT quantitative software package with full ZAF corrections applied. The following well-characterized mineral and synthetic standards were used: jadeite BM 1913–451 (Na, Al); wollastonite (Ca, Si); orthoclase (K); ilmenite (Fe, Ti); periclase (Mg); Mn-hortonolite (Mn); apatite BM 1926–665 (P); barite (Ba and S); $SrTiO_3$ (Sr); and KCl (Cl). Ba and Sr contents were below the limits of detection (<0.3 wt.%). Fluorine was not analyzed because of significant spectral interferences on the F analytical line.

The relatively large size of the inclusions (10–20 μm) coupled with the low beam currents employed for analysis is considered to preclude contributions to their bulk compositions from host crystals. Following the conventional interpretation of the significance of glass inclusions in primary liquidus phases (Frezzotti, 2001; Schiano, 2003) they are considered to reflect the approximate composition of the magma from which they formed. The absence of crystalline phases in the silicate glass inclusions and lack of re-equilibration with host crystals support this contention. The carbonate segregations in the silicate glass inclusions do not quench to a glass and consist primarily of very fine grained aggregates of Na–Ca-carbonates. Analysis of this material using a rastered beam is considered to provide a reliable estimate of their bulk composition (Mitchell, 2009). The compositions of the silicate glasses forming the groundmass of the nephelinites were determined by rastered analysis of large areas (up to 10^4 μm^2) free from groundmass minerals, and are considered not to have experienced any volatilization of Na during analysis.

3. Nephelinite, Nasira cones

The Nasira cones (Dawson, 1998; Keller et al., 2006) consist of three small north–south orientated Strombolian vents located on the lower northern slope of Oldoinyo Lengai. A short lava flow was emitted from the middle cone. Keller et al. (2006) consider that the activity belongs to the combeite wollastonite nephelinite group of Lengai stage II. The age of the eruptions is not known but is younger than 10 ka; the time of major sector collapse of the main cone. The activity certainly predates significantly the 20th–21st century natrocarbonatite eruptions. Thus, our recognition of preserved immiscible "natrocarbonatite" melt inclusions in the Nasira nephelinites is considered to provide evidence for an earlier period of natrocarbonatite activity at Oldoinyo Lengai.

The Nasira cones consist principally of combeite nephelinites with, in some examples, accessory melilitite and/or wollastonite. Keller et al. (2006) consider that the north Nasira cone evolved from combeite wollastonite nephelinite to melilitite-bearing varieties. The Nasira nephelinites investigated in this work consist of macrocrysts and/or phenocrysts of anhedral-to-subhedral clinopyroxene, subhedral-to-euhedral titanian andradite, macrocrystal wollastonite (commonly resorbed), phenocrystal euhedral-to-subhedral nepheline, two generations of phenocrystal combeite (coexisting altered and fresh) set in a matrix of second generation euhedral nepheline, combeite, Ti-magnetite, apatite, and glass (Fig. 1a, b). The petrography suggests that the rocks consist of a mixture of disaggregated cumulate material, several distinct batches of phenocrysts, and primary liquidus phases. None of the bulk compositions as determined by Keller et al. (2006) can represent liquids. However, the groundmass silicate glass does represent the liquid carrying this assorted assemblage of crystals but it is possibly only in equilibrium with the late-forming groundmass phases. Melt inclusions consisting of silicate glass or silicate glass with quenched carbonate globules are found in phenocrystal nepheline (but not groundmass nepheline), garnet and clinopyroxene. There is no evidence for the presence of a former gas bubble. Groundmass glass also contains very small (<1 μm) Na–Ca carbonate globules. Dawson (1998) has given limited compositional data for silicate interstitial glass in Nasira nepheliites, but this has very low Na_2O (10–14 wt.%) and very high Al_2O_3 (c. 22 wt.%) contents compared with all groundmass glass analyzed in this work; this may result from different analytical methods with low Na contents possibly reflecting Na loss during analysis even with a rastered 10 nA beam current and high Al from excitation of occult nepheline.

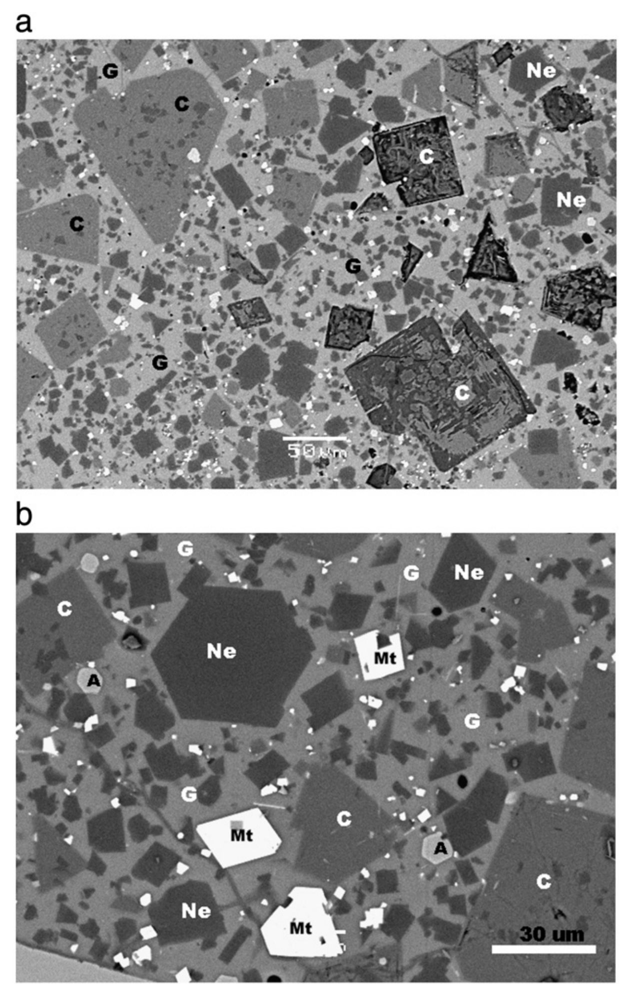

Fig. 1. Representative back-scattered electron images of: (A) hyalo-combeite nephelinite from Nasira with nepheline (Ne) and two generations of combeite (C) set in uniform groundmass glass; (B) Groundmass of combeite nephelinite illustrating late-stage nepheline (Ne), combeite (C), Ti-magnetite (Mt), apatite (A) and abundant glass (G).