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OLIVINE CHEMISTRY OF EXCEPTIONALLY YOUNG (HOLOCENE) KIMBERLITE OF THE IGWISI HILLS VOLCANO, TANZANIA

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INTRODUCTION

The Igwisi Hills Volcano (IHV) comprises three small, asymmetric, cratered pyroclastic cones and lies along a NE-SW tending line. It is situated on the western edge of the Tanzanian Archean Craton, Tanzania (Figure 1). The volcano has produced small volume pahoehoe lavas and a coulee. The pyroclastic deposits and lava are the youngest magmatic rocks on the Tanzanian Craton, consisting of the unusual combination of small olivine-dominated upper-mantle peridotite xenoliths within a carbonate rich igneous matrix. Xenoliths of basement are found in the lavas and pyroclastic deposits (Dawson 1994 and Brown *in press*). The IHV contains igneous minerals such as olivine, Cr-spinel, titanomagnetite, perovskite, monticellite, apatite, phlogopite (including the Ba-rich variety; kinoshitalite) and calcite; a mineral assemblage typical of kimberlites (Mitchell 1986 and Sparks 2009). The IHV is a unique example of extrusive kimberlite volcanism that was first dated by perovskite U-Pb giving an imprecise age of 0 ± 29 Ma (Batumike 2008). A more precise age of 10.2 ± 3.0 ka has recently established by cosmogenic ^{3}He dating of olivine crystals from lavas making them the youngest kimberlite volcanoes on Earth (Brown *in press*). Until recently, work on this volcano had been restricted to samples from the lava flow on the NE flank of the NE-volcano (Dawson 1994 and Reid 1975).

The unaltered Igwisi olivine and the presence of both lava and pyroclastic deposits, gives a unique opportunity to identify different olivine populations and elucidate their origin in two different cooling regimes. From the mineral chemistry and elemental X-ray mapping three types of olivines are recognised. Evidence from petrographic and mineral analysis of the olivine, implies a period of stagnation (eg. a failed dyke) followed by a second pulse that successfully reaches the surface.
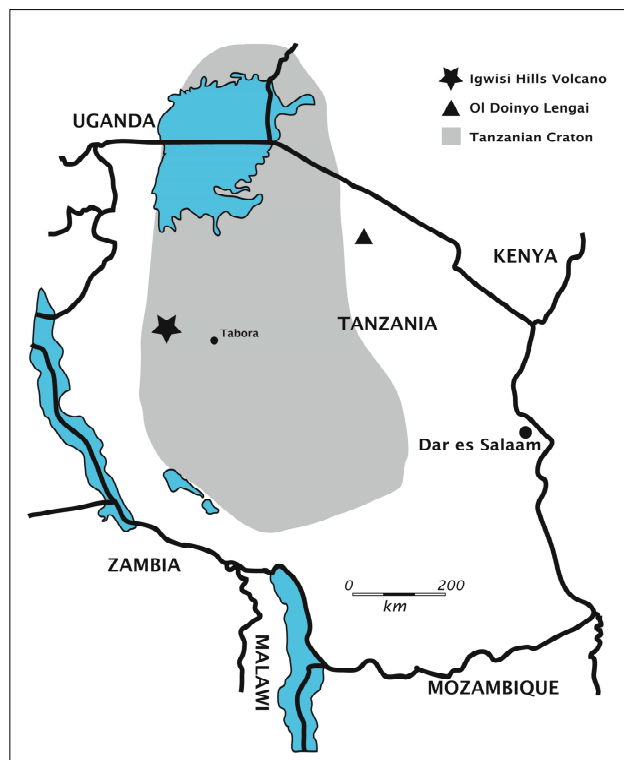

Figure 1: The location of the Igwisi Hills Volcano (IHV, depicted by a star) on the western edge of the Tanzanian Craton.

OLIVINE CHEMISTRY

Igwisi olivines are either completely fresh or have localised minor serpentinisation. They are forsterite rich with a limited compositional range (Fo_{88} to Fo_{92}) and very Al_2O_3 poor (<0.01 wt%). We recognise three types of olivines on the basis of crystal shape, crystal size, zoning

patterns and associated minerals. One type of olivine (type-Ia) corresponds to the micro-xenolith population that consist of large (10 - 30 mm), typically polycrystalline aggregates that are ellipsoidal, rounded crystals with a narrow compositional range (Fo_{89-91}). They commonly contain inclusions such as garnet, opx and Cr-spinel with some type-Ia grains mantled by zones of perovskite and Mg-Al-spinel. These type-Ia olivines are considered to be micro- xenoliths of mantle origin. A second type-I olivine is recognised (type-Ib), which at smaller (0.3 to 10 mm) and contains an unzoned core similar in composition to type-Ia grains. The type-Ib cores are mantled by zoned overgrowth rims. Type-II olivine are smaller (<300 μm), unstrained and subhedral grains set in the groundmass. Chemical analysis demonstrates a chemical similarity between type-Ib overgrowth rims and type-II olivines. The final group (type-III) of olivine are found as inclusions in titanomagnetite host crystals and as polycrystalline intergrowths of titanomagnetite and olivine intergrowths. The chemical composition of type-III olivine falls into two sub-groups for inter-growths and inclusions.

Phosphorous Zoning

P-zoning has been found to be widespread in olivines from different environments including terrestrial basalts, andesites, dacites, komatiites and martian meteorites (Milman-Barris 2008). P- zoning is produced during rapid growth, when the P in the melt is in excess of equilibrium partitioning. Therefore, this zoning reflects the crystal-growth-rate variations within these zoning patterns. In the study by Milman-Barris (2008), a positive correlation was observed between P, Cr and Al suggesting coupled substitution between these elements. The zoning of P, Cr and Al, however, was shown to be independent of Fe/Mg zoning. The P-zoning is believed to be preserved due to the high charge of the P^{5+} cation, which would diffuse the slowest compared to di- and tri-valent cations like Mg, Fe and Cr.

Igwisi type-Ib and type-II olivines show prevalent P-zoning with a positive correlation between Cr and P. The P-zoning is limited to the overgrowth rims in type-Ib olivines but is seen in the whole type-II olivine grain. The presence of P-zoning in type-II olivines and type-Ib overgrowth rims demonstrate that the olivine crystallised from the melt as it grew and cooled rapidly during magma ascent and indicates qualitatively higher temperatures prior to eruption.

NiO Zoning

NiO exhibits two distinct zoning patterns in type-Ib olivine: normal zoning and "relic-normal-zoning". The latter zoning feature sees an initial decrease in NiO-content from the centre towards the core/rim interface (normal zoning) followed by a rapid increase (reverse zoning) to the maximum NiO concentration in the profile where the zoning returns to normal zoning resulting in a 'hump' known as 'relic normal zoning' (Kohn 1989). The one type of profile is not restricted to just one sample, but rather an olivine with a normal zoning feature can be found next to another olivine exhibiting the relic-normal-zoning pattern within the same sample.

The 'relic' feature allows for the calculation of the duration of re-equilibration. The poor constraint of kimberlite magma temperatures prompted the use of a range of temperatures (850-1350 °C) for this calculation. The minimum temperature is based on the presence of biotite-bearing basement gneiss clasts in the central lava (Brown *in press*) which should have broken down if heated >850 °C (Brown 1970). The higher temperature estimate is chosen from experimental studies on model carbonated lherzolite (Gudfinnsson 2005). Calculated residence times in this temperature interval range from a couple of years (at 1350 °C) to centuries (850 °C).

Water Content

The water content in type-Ia and Ib olivine from both pyroclastic deposits and lava was measured using both SIMS and FTIR methods. Olivine crystals from pyroclastic deposits show relatively homogenous water content of <35 ppm and <80 ppm by SIMS and FTIR respectively. Olivine xenocrysts in lava show a large water variation, with the water concentration decreasing markedly from the core (>100 ppm) to the rim (<20 ppm). FTIR on type-Ib olivine demonstrates that this change in water concentration is accompanied by a change in H incorporation mechanism that is linked to the composition change in the olivine.

CONCLUSION

The study of the olivine chemistry in detail (phosphorous zoning in olivine proposed to crystallise from the melt, water and NiO profiles in type-Ib olivine) has allowed for a preliminary petrogenetic model to be proposed for IHV.

Water rich kimberlite arrives at mid mantle lithosphere depths (110 km and 850 °C) where the magma stalls (recorded in NiO profiles to last from a few years to centuries). Here, the magma disrupts the mantle to mix in xenocrystal olivine which is dry and mixes in these xenocrysts/microxenocrysts thoroughly for a period of time. The olivine absorbs the water from the wet kimberlite allowing for the olivine to reach such high water concentrations. The kimberlite then ascends rapidly (as evidenced by phosphorous zoning) with its wet olivine cargo and progressively degasses during ascent forming the low water rims by diffusion.

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