Magma chamber evolution as revealed by ^{226}Ra-^{230}Th disequilibrium at Longonot volcano, Kenya

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The rates at which magmatic processes operate are seldom determined, yet they offer powerful tests of competing physical models of magmatic evolution. U-series disequilibria have the potential to place constraints on the rates of geological processes and highlight significant differences in magmatic timescales. Recent advances in thermal ionisation mass spectrometry have made it possible to detect small variations in ^{226}Ra-^{230}Th disequilibria and here we apply these techniques to a suite of peralkaline trachytes from Longonot volcano in Kenya to evaluate the timescales of closed system magma chamber fractionation.

Longonot volcano is situated in central Kenya in the vicinity of Lake Naivasha and has erupted both pyroclastic material and lava flows of almost exclusively trachyte composition for about 10,000 years. The latest phase of activity started around 5650 ± 120 y BP with the cessation of pyroclastic eruptions and the production of a sequence of trachyte lava flows. The earliest eruptions in this lava pile are mixed peralkaline trachytes and hawaiites and were followed by successive lava flows of peralkaline trachyte which terminated at 3280 ± 120 y with the eruption of a large (2 km^3) ash horizon. The lava pile stage is estimated to have a total volume of 18–20 km^3 (Scott 1980) of which the main trachyte sequence accounts for 16 km^3.

The lava pile shows minimal variation in major elements (61.4–62.2% SiO_2) and radiogenic isotopes (average ^{206}Pb/^{204}Pb: 19.65 ± 0.02, n = 17; ^{143}Nd/^{144}Nd: 0.51262 ± 1.8×10^{-5}, n = 21). By contrast, incompatible elements increase dramatically (e.g. Th: 12.5–23.6 ppm; Zr: 576–1126 ppm) whereas Ba, which is compatible in sanidine, the major fractionating phase, decreases rapidly from 198–4.7 ppm (Fig. 1). It is well established that Zr behaves as an incompatible element in F-rich silicic peralkaline systems (Leat, 1984), and the strong linear trend shown by Th and Zr can be modeled as the result of ~50% closed system sanidine fractionation ($D_{Th} \sim D_{Zr} < 0.01$). Similarly the rapid decrease in the concentration of Ba (Fig. 1) is consistent with its compatibility in K-feldspar. In detail two trends can be distinguished on Fig. 1, and the most clearly defined can be modeled assuming a D-value of 8, based on ion-probe determinations of coexisting glass and sanidine. The subordinate trend, with lower Ba at a given Th concentration, is defined by flows that interfinger with the oldest lavas of the main trend.

The marked fractionation of Ba from Th suggests that Ra will also be fractionated from its parent ^{230}Th and results of ^{226}Ra and ^{230}Th analyses are summarised in Fig. 2. The whole rock data define a strikingly linear array, the slope of which corresponds to an age of 2640 yrs ± 150 yrs BP (2σ error). This age is significantly younger than the ^{14}C age of 3280 yrs ± 120 y BP, the minimum age for the uppermost flow, suggesting either that the ^{14}C age is incorrect or that the linear trend in Fig. 2 is not an isochron. The latter case could occur if the ^{226}Ra/Ba is also fractionated by the same process that fractionates Th from Ba. Extrapolation of experimentally determined D-values of divalent elements between alkali feldspar and silicate melt imply the $D_{Ra} > D_{Ba}$ and that it has a value of ~12. Fig. 2 shows how the initial ^{226}Ra/Ba ratio is reduced by fractionation if $D_{Ra} = 12$ and consequently how the ages calculated from the measured ^{226}Ra/Ba ratios are likely to be greater than that calculated assuming the linear array represents an isochron.

Applying this model to the data from Longonot yields a number of results. Firstly, all the data points now give distinct model ages that are greater then 3 000 y and are therefore consistent with the ^{14}C ages. Secondly, the calculated ages of Ra/Th fractionation decrease as the amount of fractionation increases. Thus the two least evolved samples have ages of ~9000 y because they lie close to the equiline,

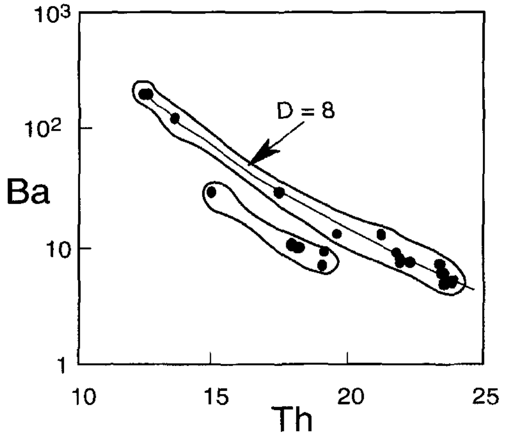

FIG. 1. Ba and Th variation in Longonot lavas showing two trends and a model fractional crystallisation trend in which $D_{Ba} = 8$ and $D_{Th} = 0.01$.

whereas the more evolved lavas give model ages between 6000 and 3000 y. Significantly, the two least evolved samples also lie on the subordinate fractionation trend in Fig. 1 and it is suggested that these are samples of a distinct magma batch that was evacuated from the magma chamber early in the development of the main group of lavas. The more evolved lavas clearly have a distinct parent and it is suggested that between 9 and 6 ka, the chamber was replenished with a new batch of trachytic magma which underwent fractionation over the next ~3ka. The Th/Ba variation can be modeled as the result of ~10% sanidine fractionation and, assuming that the volume of the lava pile (16 km^3) represents a minimum volume for the magma chamber, this figure translates into the accumulation of ~1.6 km^3 of sanidine in 3000 y.

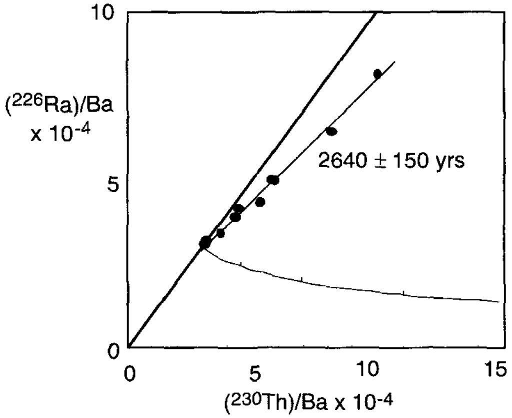

FIG. 2 $^{226}Ra/^{230}Th$ analyses of lavas from Longonot volcano define a linear trend with an age of ~2640 y. The curve illustrates the (instantaneous) effect of 18% sanidine fractionation on the $^{230}Th/Ba$ and $^{226}Ra/Ba$ ratios starting with ratios of 3×10^{-4}. Tick marks at 5% increments.

References

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