U-Th-Ra disequilibrium applied to Ardoukoba tholeiitic basalts (Asal rift): timescales of magmatic crystallisation

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The ^{238}U decay-series can be used to study the processes and timescales of magma generation, crystallisation and migration. In particular, U/Th and Ra/Th fractionate during mantle melting, which results in disequilibria in ^{230}Th-^{238}U and ^{226}Ra-^{230}Th in the magma. If the magma then evolves as a closed system, these disequilibria tend to diminish with time. The relatively short half-life of ^{226}Ra (1600 y) is of particular interest for determining the magma residence time in a chamber. For that purpose, we analysed a series of lava flows from Ardoukoba volcano, which were emitted within a single week in 1978, in the central zone of the Asal rift (Djibouti). These lavas are tholeiitic basalts, slightly enriched in K, and very rich in megacrysts of bytownite (An_{83}), olivine (Fo_{80}), and clinopyroxene (Augite $En_{47}Fs_{8}Wo_{45}$).

Results

U, Th, Ba and ^{226}Ra concentrations were determined by isotope dilution on 0.1–0.5 g samples. Trace elements were measured by INAA, and major elements by X-ray-fluorescence. $^{230}Th/^{232}Th$ isotopic ratios were measured by TIMS with a 0.7% uncertainty at the 2σ level.

Th concentrations range from 0.9 ppm for the first erupted lavas to 0.4 ppm for the last erupted ones, and Ra concentrations from 180 $fg.g^{-1}$ to 85 $fg.g^{-1}$. Incompatible elements when plotted versus Th, which is considered as the most incompatible element (Joron *et al.*, 1980) show positive linear trends going through the origin. The very first magma to erupt is distinct from all the others in major and compatible elements like Sr, Sc and Ni. All the basalts exhibit similar ($^{230}Th/^{232}Th$), corresponding to a (Th/U) = 2.7 in the mantle source, which is typical of a slightly enriched MORB source (Allègre and Condomines, 1982). The samples plotted in a $^{226}Ra/Ba$-$^{230}Th/Ba$ diagram show a vertical trend associated with a slight decrease in Th/Ba. The corresponding ($^{226}Ra/^{230}Th$) disequilibrium show a linear inverse correlation with incompatible trace elements such as Th or Ta.

Discussion

The linear correlations between Th and other incompatible elements reflect a fractional crystallisation of 65%, if D_{Th} is assumed to be ≈ 0. As the first lava to erupt is the most differentiated, and the last one the most primitive, the Ardoukoba tholeiites could have erupted from a zoned magmatic reservoir. Sr, Sc and Ni *vs* Th trends can be modeled by fractional crystallization of 45% plagioclase, 15% clinopyroxene, 40% olivine and minor accumulation of bytownites and olivine (1 to 6%) in the upper part of the magmatic reservoir. This accumulation could result from flotation of plagioclase phenocrysts (Clocchiatti, 1993). The homogeneous ($^{230}Th/^{232}Th$) activity ratios and (Th/U) ratios for all the basalts indicate that the lavas are derived from geochemically similar parental magmas. As ($^{226}Ra/^{230}Th$) correlates with the degree of differentiation, the vertical trend in the $^{226}Ra/Ba$-$^{230}Th/Ba$ diagram must be produced during magma crystallisation. Nevertheless it cannot be explained solely by fractionation of plagioclase because the corresponding Ba/Th fractionation (19%) is too restricted compared to the $^{226}Ra/^{230}Th$ fractionation (48%). In addition, as Ra is usually considered to be at least as incompatible as Ba (Blundy and Wood, 1995), plagioclase fractionation should have for this system a limited influence on ($^{226}Ra/^{230}Th$) ratio. As a consequence, we infer that the magma chamber must have been fed with repeated inputs of magmas with similar composition. (Joron *et* *al.*, 1980, Demange *et al.*, 1980). The range in ($^{226}Ra/^{230}Th$) permits to calculate residence times in the chamber for the erupted magmas (550-800 y). These times, combined with indices of differentiation, can be interpreted in terms of crystallisation times for these magmas.

References

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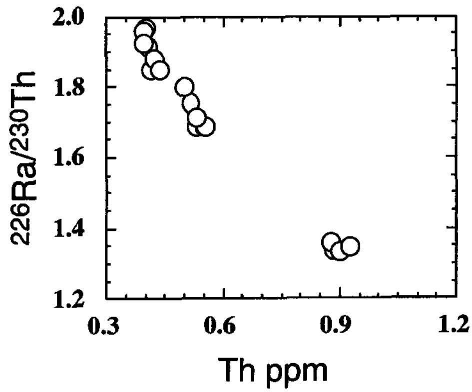

FIG. 1.