Long magma residence times at an island arc volcano (Soufriere, St. Vincent) in the Lesser Antilles: evidence from ^{238}U-^{230}Th isochron dating

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Establishing the time-scales of melt production, transport, storage, crystallisation and shallow-level degassing of magmas is critical for understanding magmatic systems and assessing volcanic hazards. High precision (TIMS) measurements of U and Th isotope concentrations have been determined on whole rocks and mineral separates from Soufriere volcano on St. Vincent in the Lesser Antilles island arc. The whole rocks display relatively constant U/Th ratios (~ 0.5), and are characterised by excess ^{238}U relative to ^{230}Th which is attributed to the addition of U-rich fluids from the subducting slab to the mantle source of the magmas. Mineral isochrons for four recently erupted (< 4 ka) rocks yield ages of 46–77 ka and the combined data have an age of 58 ± 7 ka with an initial ($^{230}Th/^{230}Th$) ratio of 1.054 (Fig. 1).

A combination of petrographic and geochemical data can be used to argue that mixing of young magmas, or magma-cumulate mixing are unlikely to be responsible for these isochronous relationships (e.g. Fig. 2). Contamination of young, phenocrystic magmas with previously crystallised magma could produce the isochrons, in which case the ages provide maximum and minimum ages, respectively, for these magmas. However, no lavas with ($^{230}Th/^{230}Th$) ratios of 1.054 have been found (see Fig. 1) and there is no petrographic evidence for mixing or phenocryst-magma disequilibrium (Heath *et al.*, 1998).

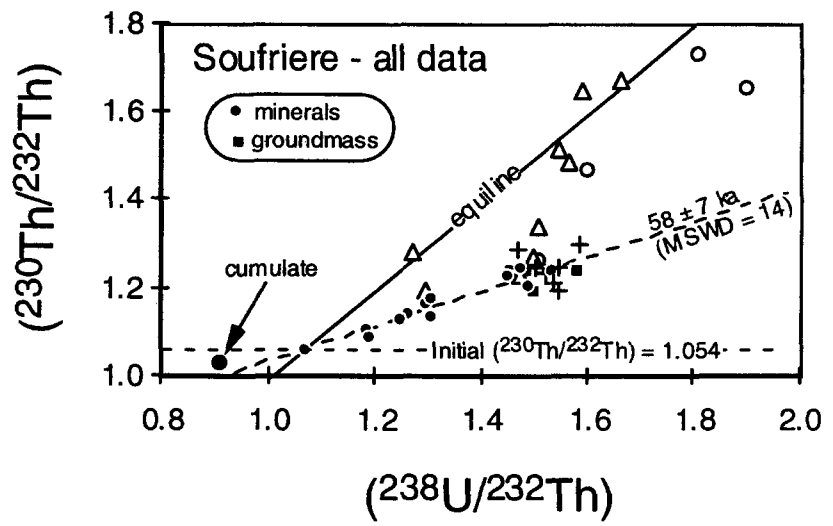

FIG. 1. An isochron through the combined mineral and whole rock data from the four Soufriere rocks. Also plotted are the other whole rock data (open symbols) showing that no lavas lie below the isochron(s) or have ($^{230}Th/^{232}Th$) ratios similar to the initial ratios of the isochrons. Note that the cumulate lies close to the low ($^{238}U/^{232}Th$) end of the isochron.

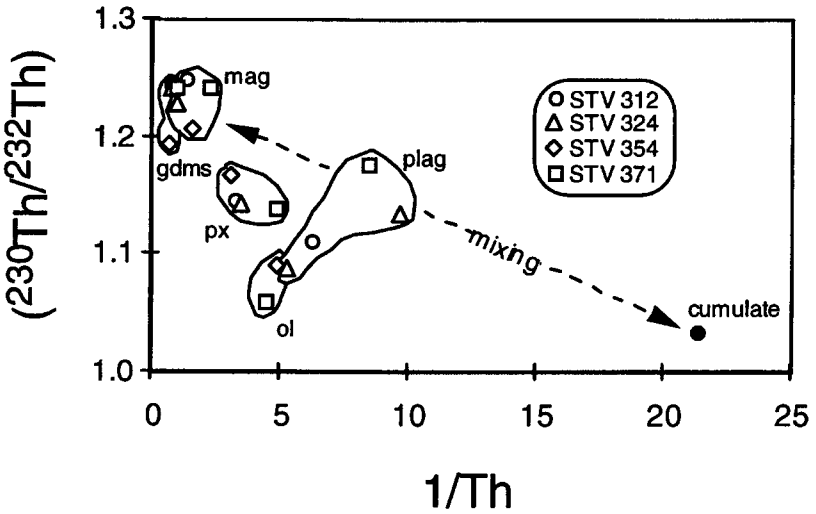

FIG. 2. The minerals do not form a straight line array between the groundmass points and the cumulate on a (^{230}Th/^{232}Th) *vs* 1/Th diagram suggesting that the isochrons did not result from cumulate–magma mixing.

Our preferred interpretation is that the isochrons reflect long magma residence times within the arc crust. Following initial crystallisation, due to heat loss to the wall rocks, the magmas were maintained at a temperature close to their liquidus while ^{230}Th-ingrowth occurred in both the magma and the crystals. Maintenance of a relatively constant temperature requires good insulation by cumulate layers and probably heating from below by influxes of fresh magma which either did not mix with the resident magma or else had an essentially indistinguishable composition.

Subtraction of the residence times from the ~90 ka inferred to have elapsed since fluid addition to the mantle wedge beneath the Lesser Antilles island arc (Turner *et al.*, 1996) leaves ~30 kyr for transfer through the wedge, similar to that inferred in several other arcs (e.g. Elliott *et al.*, 1997; Hawkesworth *et al.*, 1997; Turner and Hawkesworth, 1997; Turner *et al.*, 1997). It is postulated that long residence times may typify more evolved lavas that develop in thicker arc crust whereas tholeiitic arc lavas are inferred to have trivial crustal residence times but similar transfer times through the mantle wedge (Elliott *et al.*, 1997; Turner and Hawkesworth, 1997; Turner *et al.*, 1997).

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