Rates and timescales of melt generation and differentiation in the Teide-Pico Viejo Complex, Tenerife, inferred from U-series isotopes

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U-Th-Ra disequilibria can be used to constrain the rates and timescales of melt generation, differentiation and crustal residence prior to eruption. Ocean island basalts (OIB) provide important windows into the compositional variations in the Earth's mantle, and they are therefore widely used to evaluate models for mantle convection and evolution (McKenzie and O'Nions, 1995). However, the effects of melt generation and migration remain controversial, as do the depths of the source regions sampled by OIB. This study presents new mass spectrometric U-Th-Ra isotope analyses of well characterised samples from the Teide-Pico Viejo complex on Tenerife in the Canary Islands, to investigate the effects and timescales of shallow level basalt-phonolite differentiation, and the conditions of melt generation. The Canary Islands provide an excellent area to observe U-Th-Ra isotope disequilibrium in historic lavas because they are underlain by a region of relatively low buoyancy flux, and so there is sufficient time to develop U-Th-Ra disequilibria during melting (Chabaux and Allegre, 1994). This is in contrast to areas like Hawaii where the faster mantle upwelling rates (Sleep, 1990), and associated melt generation rates, inhibit such isotope disequilibria.

The geology and geochemistry of the Teide-Pico Viejo complex, Tenerife

The Teide-Pico Viejo complex of Tenerife has formed in the caldera of the Las Cañadas volcano since 175 Ka. The vent system of Teide, Pico Viejo and Montaña Blanca forms a large stratovolcano complex with high volume eruptions tapping 2 distinct basanite to phonolite lineages (Ablay *et al.*, 1998) from different segments of the volcano's plumbing system. There are believed to be a number of underlying magma chambers at different depths beneath the complex, with lavas ranging from basanite to phonolite, with $SiO_2 = 42.2-59.9\%$, MgO $= 0.34-11.26\%$, Ni and Cr $= 0.5-227$ ppm and $0-483$ ppm respectively. The Teide-Pico Viejo complex is divided up into a number of units on the basis of geochemistry (Ablay *et al.*, 1998). The group comprising of the caldera floor lavas and the latest historic eruptions are mafic ranging from basanite to trachy-basalt in composition, with the highest MgO (>6 %) Ni and Cr and lowest alkalis and Zr abundances of the samples analysed. The Teide Series comprises of the products of Pico Teide, the oldest parts of Pico Viejo and Montaña Blanca. This suite ranges in composition from plagioclase basanite to phonolite, showing a considerable range in major and trace elements. The youngest Pico Teide and the Teide flank eruptions tend to be the most evolved. Finally the Pico Viejo Series consists of the youngest Pico Viejo and Montaña Blanca rocks, again ranging in composition from plagioclase basanite to phonolite, with the youngest Pico Viejo lavas having more intermediate compositions, while the Montaña Blanca are the most evolved phonolites in the complex. This series show Ba enrichment relative to the Pico Teide series and the Mafic series, despite similarities in most of the other major and trace elements.

U-Th-Ra isotopes

The lavas analysed range in age from ~ 175 Ka to the most recent eruption in 1909 and the vast majority exhibit ^{230}Th-^{238}U disequilibrium with $(^{230}Th/^{238}U) = 1.004-1.39$ (Fig. 1). In addition one cumulate has been analysed and that has excess ^{238}U and $(^{230}Th/^{238}U) = 0.90$.

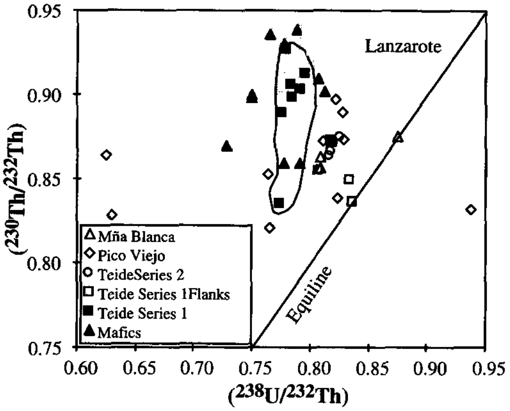

FIG. 1. ($^{238}U/^{232}Th$ *vs* $^{230}Th/^{232}Th$).

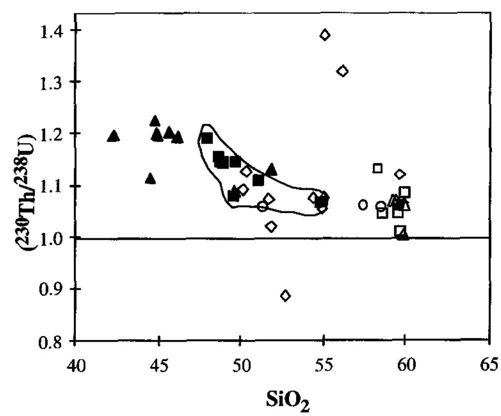

FIG. 2. ($^{230}Th/^{238}U$) *vs* SiO_2.

In detail the basanites have ($^{230}Th/^{238}U$) = 1.09–1.23, and the phonolites have ($^{230}Th/^{238}U$) = 1.004–1.09, and so there is a general decrease in the degree of ^{230}Th-^{238}U disequilibrium with increasing SiO_2 (Fig. 2). This might reflect progressive contamination with crustal material that was in or close to isotope equilibrium, but there is no systematic increase in, for example, Sr isotopes with increasing SiO_2. This suggests that contamination with crustal material is unlikely, unless the contaminant was recently crystallised magma from the same system. Alternatively the overall decrease in ($^{230}Th/^{238}U$) with increasing silica might be an indication of the average time for differentiation to phonolite.

This can be seen in more detail in the Older Teide Series which includes the earliest Teide and the earliest Pico Viejo rocks, in which silica = 47.8–54.9 %, but U/Th and Sr and Nd isotopes are constant. ($^{230}Th/^{238}U$) decreases from 1.16 to 1.07 with increasing silica. This suggests basalt to phonolite differentiation took ~200 Ka, even though these magmas were erupted in 50–100 Ka. The magma chambers beneath Tenerife are thought to undergo cyclic removal of magma and refill. A possible scenario may have been that the magma evolved in a chamber and some erupted, whilst the rest underwent mixing with newly generated magma and perhaps remelting of more silicic wall rocks, which would have similar Sr and Nd isotopes. This more evolved composition then undergoes further fractionation and decay. The timescale of 200 Ka is significant from a geological and volcanological perspective, since it is the approximate length of time that occurs between the major cycles in the Upper group of the caldera wall, and hence the Las Cañadas volcano.

A residence time of 87 Ka has been determined (Allègre and Condomines, 1976) from the 1492 Teide eruption, consistent with the more rapid stratigraphic evolution of the Teide succession to an evolved intermediate composition which may be parental to the Teide phonolite. The phonolites seem to have separated from the main body of evolving intermediate magmas relatively early on, and were erupted halfway up the succession. Hence we can assume an age of approximately half to a third of the evolution of Teide-Pico Viejo complex (60–90 kys). Furthermore ($^{230}Th/^{238}U$) decreases in cycles as the lavas increase in age throughout the Teide-Pico Viejo sequence. Some of these cycles are close to vertical on an equiline diagram allowing observation of decay through time, whilst the higher ($^{230}Th/^{238}U$) range gives information about conditions of melt generation and mixing.

The mafic compositions (basanite to alkali basalt) in the Teide-Pico Viejo complex can be compared with similar compositions in the historic lavas of Lanzarote (Fig. 1). The range of ($^{238}U/^{232}Th$) in the Lanzarote lavas is similar to that in Tenerife, but the ($^{230}Th/^{232}Th$) in Lanzarote tends to be higher than many of the Tenerife mafics (Thomas *et al.*, 1998). The range in ($^{230}Th/^{238}U$) in Lanzarote is attributed to mixing between different melt fractions generated at different depths in the melting zone in the presence of residual garnet, using a constant melt rate of 0.125×10^{-3} kg.m^{-3}.yr^{-1} and varying the matrix transfer time.

$^{226}Ra/^{230}Th$ disequilibrium is present in rocks younger than 8,000 years. A preliminary whole rock isochron gives an age of 2.3 Ka for the Montaña Blanca 2020 b.p. eruption, indicating (^{226}Ra-^{230}Th) fractionation into feldspar just prior to eruption.