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A U-Th-Pa-Ra Isotope Constraints on Element Transfer Time Scales beneath the Tonga-Kermadec Island Arc

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U-series disequilibria can be used to constrain the time scales and processes of fluid transfer, partial melting, magma ascent and magma differentiation beneath island arcs. However, maximum information is provided by studies involving more than one parent-daughter pair. Here we present mass spectrometric Ra measurements of Tonga-Kermadec arc lavas to complete the first detailed U-Th-Pa-Ra study of island arc lavas. Ra-Th activity ratios in Tonga-Kermadec lavas range from ~1 to 6.2, and they are negatively correlated with silica constraining the time scale for differentiation from basalt to dacite and rhyolite to be < 6000 years. The largest ^{226}Ra-excesses occur in the most depleted rocks which have the highest Ba/Th ratios indicating that the ^{226}Ra-excesses result from fluid addition within the last few 1000 years. Yet U-Th and Pa-Th data from Tonga both record U addition by fluids ~60 000 years ago. A simplified two-stage dehydration model is developed to reconcile these data. Unlike U, Ra lost to the mantle wedge during initial dehydration is replenished in the subducting altered oceanic crust by in-growth from residual Th. Whereas the U budget was dominated by the first fluid flux, the Ra-excesses record the continued addition of fluid to the mantle wedge, probably up until less than 1000 years ago. The observation of nearly ubiquitous large Ra-excesses in the primitive lavas indicates that neither fluids or melts were produced in the presence of significant amounts of residual amphibole and places tight constraints on the time permitted for melt generation, segregation and ascent.