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Along-arc U-Th-Ra Disequilibria in the Aleutians: Rapid Timescales of Fluid Transfer

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The Aleutian arc straddles both continental and oceanic crust as the Pacific plate subducts beneath the American plate to the north. This arc provides us with a rare opportunity to establish links between eruption rate, changing along-arc tectonic variables (the orientation and rate of plate convergence, the conditions of the mantle wedge), and the rates of transfer of subducted components to the mantle wedge. In order to address these issues, we have analysed U-Th-Ra isotopes on a suite of historic lavas spanning the 2500 km length of the arc, from Buzzard Creek in the east to Kiska in the west. They reveal consistent geochemical and isotopic along-arc variations which change in sympathy with large-scale tectonic variables. Our data also suggest that fluid transfer events took place relatively recently (<10 ka ago) in comparison with other arcs, where 30-60ka between fluid addition and eruption is a more commonplace time scale. This places unique constraints on models based on U-Th disequilibria because the oceanic Aleutian lavas form a horizontal array on an equiline diagram. This effectively rules out the possibility that such arrays could in fact be artefacts due to variable mantle wedge U/Th composition and/or because the fluid contains some Th, both of which remain a possibility in the interpretation of inclined arrays on equiline diagrams. Overall, U-series disequilibria extend from modest Th excesses of 30% to larger, 75% U excesses (Figure 1). A distinct horizontal array is formed by lavas erupted from volcanoes lying on oceanic crust. Several continental lavas from the volcanoes of Westdahl and Redoubt also fall on this oceanic array. Most importantly, the restricted Th activity ratios in these lavas closely match the composition of oceanic sediment being subducted (($^{230}Th/^{232}Th$) ~1.3; Plank and Langmuir, 1998). This provides an estimate of the initial Th isotope ratio, for those lavas in U/Th disequilibrium, independent of the intersection of the horizontal array with the equiline, with two important implications:

(1) The tendency for arc lavas to form inclined arrays on isochron diagrams is increasingly taken to represent the time elapsed between U-additions by fluids released from the subducting slab, and eruption. Whilst these arrays typically permit 30-60 ka to have passed since U-influxes in many oceanic arcs (e.g. Elliott et al. 1997; Turner et al. 1997), the possibility remains that inclined arrays have no time significance, and instead reflect mixing processes or variable U/Th ratios in the fluid/mantle components contributing to melting. Since the majority of the oceanic lavas from the Aleutians lie on a flat array which intersects the Th isotopic composition of the subducting sediments on Figure 1, the effects of variable U/Th ratios in the mantle wedge are effectively ruled out. Thus, we can be confident that the horizontal array indicates very recent (<10 kyr) fluid addition to the mantle wedge.

(2) If the sediment component was added as a partial melt, sediment melting must have occurred less than 10 kyr ago, or alternatively it did not result in fractionation of U/Th (cf. Elliott et al. 1997). Class et al. (2000) have recently suggested that some sediment components identified in Aleutian lavas were added by a fluid phase. With respect to this it is of interest that there is a preliminary positive correlation between 10 Be and U excesses in Aleutian lavas (Turner et al. 1998) suggesting that some sediment components were transferred by a fluid phase very recently (< 10 kyr).