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Crustal assimilation at intra-oceanic arc volcanoes: implications for timescales of magmatic differentiation

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Intra-oceanic arc volcanoes are often selected for petrogenetic studies because modification of mantle-derived magma through interaction with the crust is assumed to be limited. However, the degree of interaction is poorly constrained and may be difficult to detect due to the potentially similar compositional nature of both the arc crust and ascending magma using standard discriminating tools (Sr and O isotopes and trace element ratios). Failure to identify crustal contamination can result in overestimation of differentiation timescales using disequilibria studies of U, Th and Ra isotopes of the Uranium-series, which are highly sensitive to crustal contamination. Overestimation of magmatic crustal residence times may have drastic consequences for determination of volcano eruptive periodicity and, therefore, has significant implications for volcanic hazard assessment.

Despite relatively homogeneous Sr-Nd isotopic compositions (cf. other Vanuatu lavas) of high-MgO basalts and differentiates erupted over the last 100 years at Lopevi volcano, Vanuatu (intra-oceanic arc SW Pacific), the rock suite displays a strong negative correlation between $^{87}Sr/^{86}Sr$ isotope ratio and indices of differentiation (e.g. SiO_2). This presents compelling evidence for the interaction of rising mafic magmas with 'primitive' sub-arc crust and provides an excellent framework within which to investigate and ascertain timescales of crustal interaction using U-series data. Quantitative geochemical modelling of whole-rock trace element ratios, $^{87}Sr/^{86}Sr$ isotope compositions and U-series data shows that assimilation of a relatively small-degree partial melt of "old" (i.e. $>$380 Ka) mafic oceanic crust during fractional crystallisation of magma exerts major control on ($^{230}Th/^{232}Th$) and ($^{226}Ra/^{230}Th$) activity ratios of the lavas. The incorporation of higher ($^{230}Th/^{232}Th$) and lower ($^{226}Ra/^{230}Th$) assimilated material draws the samples much closer towards secular equilibrium than that of simple closed-system differentiation, reducing calculated apparent timescales of closed-system differentiation from Th isotope composition (10^4-10^5) by orders of magnitude. Modelling suggests that assimilation occurs extremely rapidly at Lopevi with maximum timescales for magma generation, differentiation and eruption in the order of 10^2 years.

Magma residence timescales at intra-oceanic arc volcanoes are commonly calculated assuming differentiation by closed-system fractional crystallisation. We show that U-series isotopes are extremely sensitive to assimilation of "old" crustal material, even in intra-oceanic arcs where magma rises rapidly. We suggest that the early stage of magmatic differentiation in intra-oceanic arcs may be characterised by assimilation of 'primitive' oceanic crust during fractional crystallisation. Subsequently, it is proposed that crustal contamination processes at intra-oceanic arcs may be more common than previously detected, and may have been significantly overlooked in settings where the crust is compositionally similar to the magma itself, e.g. immature intra-oceanic arcs and volcanoes residing on older volcanic material.