Goldschmidt 2000
September 3rd–8th, 2000
Oxford, UK.

Journal of Conference Abstracts
Volume 5(2), 166

Pa-Th-U Constraints on Melting and Material Recycling in Subduction Zones: A Case Study of the Philippine Arcs

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Subduction zones represent the most important setting for material transfer from the mantle to the lithosphere and recycling of lithospheric material back into the convecting mantle. Understanding melting processes in subduction zones is thus crucial in determining crust-mantle mass balance. Although there is agreement on the broad outlines of melting processes in arcs there are a number of disagreements on details, such as the sources of the non-depleted mantle elemental and isotopic signatures. U-series isotope variations in arc magmas may provide important constraints, inasmuch as they consist of elements of diverse geochemical behaviors having half-lives with appropriate time scales for assessing melting and mass transfer.

Here we present Pa-Th-U data for Mayon volcano of the eastern Philippine arc (Bicol arc) and Taal volcano of the western Philippines arc (Luzon arc). Volcanism in the eastern arc is associated with the westward subduction of the Philippine Sea Plate, while volcanism of the western arc is associated with the eastward subduction of the South China Sea Plate and associated sediments. Previous Sr, Nd and Pb isotopic work (Mukasa et al., 1987; Mukasa et al., 1994 and unpublished data) show that lavas from the western Philippine arc have more radiogenic $^{87}Sr/^{86}Sr$ and Pb isotopic ratios and non-radiogenic $^{143}Nd/^{144}Nd$ ratios compared to lavas from the eastern Philippine arc. The isotopic differences between the two arcs were attributed to the availability of continental sediments from Eurasia only to the western arc. The U-series data, while supporting the previous conclusion, provide additional important constraints on timing and the nature of the mantle and sedimentary components.

Lavas from the western arc, typical of many arcs globally, show ^{238}U over ^{230}Th enrichment, ($^{230}Th/^{238}U$) (i.e. activity ratio) = 0.917 -0.951, while lavas from the eastern arc show ^{230}Th over ^{238}U enrichment, ($^{230}Th/^{238}U$) = 1.09 - 1.15. Lavas from both arcs show significant ^{231}Pa over ^{235}U enrichment, ($^{231}Pa/^{235}U$) = 1.31 - 1.51 for the western arc, ($^{231}Pa/^{235}U$) = 1.71 - 1.76 for the eastern arc. The ($^{231}Pa/^{230}Th$) of lavas from both arcs are similar ~ 0.21, indicating that the differences in ($^{230}Th/^{238}U$) and ($^{231}Pa/^{235}U$) are due to variations in the extents of uranium addition during or subsequent to melting. ^{238}U over ^{230}Th and ^{231}Pa over ^{235}U enrichment are positively correlated with $^{143}Nd/^{144}Nd$ (fluid non-mobile element) and negatively correlated with $^{87}Sr/^{86}Sr$ and $^{207}Pb/^{204}Pb$ ratios, while there is no systematic relationship with $^{206}Pb/^{204}Pb$ ratios (carbonate or fluid addition). Thus U addition is most likely due to sediment addition in whole or as melt.

The combined data argue for U over Th and Pa enrichment in the western arc to be due to recent (within the time scale of the half life of ^{231}Pa ~ 32.7 kyr) addition via the addition of bulk clastic sediments or sediment melts. Lavas from the eastern arc have extremely uniform and correlated Sr, Nd and Pb isotopic values, with $^{208}Pb/^{206}Pb$ ratios that are higher than Pacific MORB but close to Indian Ocean MORB. Given these observations, in addition to the large Pa over U and significant Th over U enrichments in the eastern arc lavas, it is unlikely that there has been significant fluid or sediment component addition to the source. Moreover, the source is likely to be an enriched mantle wedge that has had a long-term Th over U, Rb over Sr and LREE enrichment compared to typical MORB source.

The large Pa over U melting enrichments seen in both arcs argue for very small degree of melting or porosities (in the range of bulk DU) and rapid melt transfer through the lithosphere (in time scales of 32.7 kyr, the half life of ^{231}Pa) and similar to those seen in intra-plate mantle melting (Asmerom et al., in press).

Asmerom et al., *Nature*, **in press**, (2000).
Mukasa et al., *Earth Planet. Sci. Lett.*, **84**, 153-164, (1987).
Mukasa et al., *Tectonophysics*, **235**, 205-221, (1994).