Using U-Series Isotopes to Investigate the Effects of Thick Continental Crust on Arc Volcanics: Insights from Reventador Volcano, Ecuador

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Background:

In oceanic arc settings, U-series measurements coupled with other isotopic and chemical constraints provide important information on the time scales of melting processes and help to identify the various components contributing to arc volcanics. In continental arcs, where magma ascent through and storage in the crust can significantly influence lava compositions, these methods could potentially measure the timescales of processes such as assimilation and fractional crystallization. To test this hypothesis we have measured U-series isotopes, Nd and Sr isotopes (plus Hf and Pb), and major and trace element concentrations in samples from Reventador Volcano, Ecuador (Figure 1). In addition to furthering our knowledge of the processes occurring in continental arcs, our research will also improve understanding of volcanic hazards associated with Reventador, a highly active and potentially dangerous volcano.

Figure 1. Reventador erupting at night. Copyright Jeff Cundith 2013

Figure 2. Arial photo with location of Reventador (REV), Quito (Q) and other major Quaternary volcanic centers (ALT = El Altar, ANT = Antisana, CAY = Cayambe, CMB = Chimborazo, CTX = Cotopaxi, ILZ = Illiniza, IMB = Imbabura, M-F = Mojanda-Fuya Fuya, PCH = Pichincha, SGY = Sangay)

Geologic Setting:

- Northern Volcanic Zone of the Andes
- In Ecuador the arc is broad (~120 km), and can be divided into four distinct zones: the Western Cordillera, Interandean Valley, Eastern Cordillera and Back Arc (Hall et al., 2008)
- Reventador is located in the Eastern Cordillera, ~100 km of Quito (Figure 2)
- The crust is >50 km thick (Guillier et al., 2001)
- Paleozoic-Mesozoic igneous and metamorphic basement (Aspden et al., 1992)

General traits of Reventador Lavas:

- 17 samples from the current edifice: 3 historical (1944-1977), 14 from the current eruptive phase (2002-2008)
- 1 sample from the Old Volcanic Edifice (OVE)
- Basaltic andesite-andesite, mid-high K (Figure 3A) (Matthews, 2012)
- Adakite-like residual garnet signature (Figure 3B), similar to other Ecuadorian volcanos (Monzier et al., 1999, Bourdon et al., 2002, Samaniego et al., 2005, Bryant et al., 2006, Garrison et al., 2006, Hidalgo et al., 2012)

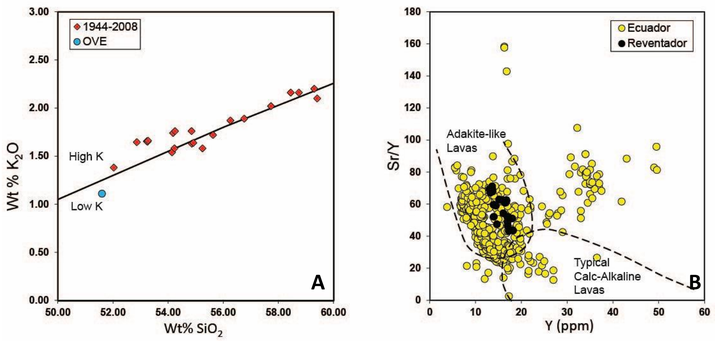

Figure 3. Geochemical Traits of Reventador lavas. A: Wt % K2O vs. SiO2. OVE = Old Volcanic Edifice, 1944-2008 = Lavas erupted 1944-2008. Division between High K and Medium K after Peccerillo and Taylor, 1976. B: Sr/Y vs. Y. Adakite-like and Typical Calk-Alkaline fields after Defant et al., 1991. Ecuador dataset compiled by Hidalgo et al., 2012

Origins of ($^{238}U/^{230}Th$) disequilibria:

- Of 14 historical and modern lavas, eight have ($^{230}Th/^{238}U$) > 1. For the OVE, ($^{230}Th/^{238}U$) = 1.083 ±0.023 (Figure 4) (Matthews, 2012)
- ($^{230}Th/^{238}U$) > 1 in continental arc settings can be generated via partial melting in the mantle with residual garnet or assimilation of ^{230}Th enriched melts
- Although unusual for arc lavas, these values are consistent with ($^{230}Th/^{238}U$) values from Cotopaxi (Garrison et al., 2006) and trace element trends
- ($^{230}Th/^{238}U$) is negatively correlated with measures of differentiation and fluid addition (Figure 5), suggesting that these processes lowered ^{230}Th excesses in some samples, brought others into within error of equilibrium, and created ^{238}U excesses in others

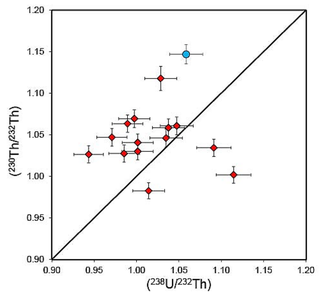

Figure 4. ($^{230}Th/^{232}Th$) vs ($^{238}U/^{232}Th$), most samples have (^{230}Th) excess

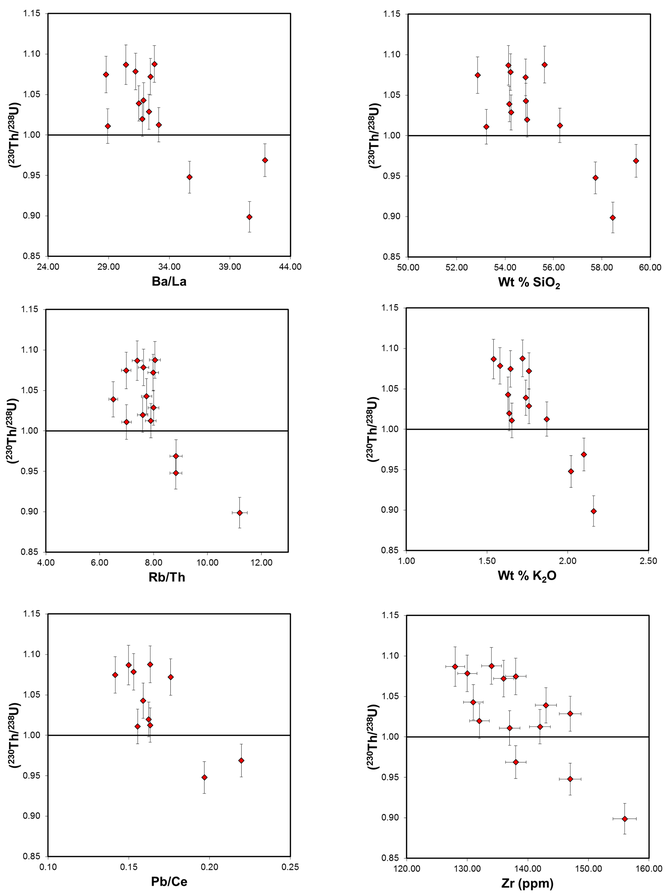

Figure 5. ($^{230}Th/^{238}U$) is negatively correlated with Ba/La, Rb/Th, Pb/Ce, SiO_2, K_2O, and Zr

Age of the Old Volcanic Edifice:

- ^{230}Th excess observed in the OVE, indicating that OVE is younger than 350 Ka (Figure 4) (Matthews, 2012)
- Suggests that a K/Ar date of 348 Ka (Ridolfi et al., 2008) may be incorrect, especially if ^{230}Th excess was initially established in the mantle (Matthews, 2012), and that eruption rates are faster than previously thought

Volcanic Hazards:

- Reventador is Spanish for "The Exploder"
- The current eruptive phase began in November 2002. The initial VEI 3 eruption resulted in 1-2 mm of ash in Quito and closure of the airport
- Pyroclastic flows and lahars have damaged main highway between Quito and the oil producing regions of the Amazon Basin and oil pipelines.
- Although rare, large debris avalanches associated with flank collapse and possibly caldera forming eruptions have occurred in the past (IGPEN Hazards Map)

Isotopic Evidence for Crustal Assimilation:

- The role of crustal assimilation is unclear, and may be more important in some volcanic centers (Bourdon et al., 2002, Samaniego et al., 2005, Bryant et al., 2006, Garrison et al., 2006)
- May be more important further from the trench: $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ ratios of Eastern Cordillera lavas are more crust-like (Hidalgo et al., 2012)
- Reventador lavas have the highest $^{86}Sr/^{87}Sr$ observed in Ecuador and low $^{143}Nd/^{144}Nd$ comparable with other Eastern Cordillera lavas (Figure 6).
- Suggests a larger contribution from the continental crust at Reventador

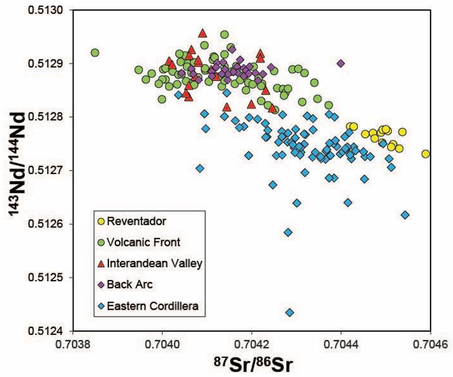

Figure 6. $^{143}Nd/^{144}Nd$ vs. $^{86}Sr/^{87}Sr$. Reventador lavas have among the most crust-like Sr and Nd isotopic compositions observed in Ecuador. Ecuador dataset compiled by Hidalgo et al., 2012

Future Research:

- Determine the composition of the crustal basement so that we can quantitatively evaluate crustal input
- Detailed study of the OVE to constrain its age and learn more about changes through time and the time scales of collapse
- Collect post 2008 flows to expand our dataset

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