Budget of slab-derived water within arc crust: Implications from crust-melt reaction zones and fossil caldera differentiation process

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Water budget in the arc crust is of critical importance for volcanic activities, rheology and energy budget of the arc crust. Based on geochemical analysis of volcanic rocks, mantle xenoliths and hot spring water, and seismic tomography and magnetotelluric imaging, it is revealed that large amount of slab-derived water are supplied to subarc mantle, and hydrous basaltic melt with average ~4wt%H_2O are transported to subarc. However, water budget and distributions within arc crust are not well revealed yet.
According to the geochemical mass balance model, for 1 m along arc distance, 13 t/yr/m H_2O are supplied to sub arc in the form of hydrous melt (Kimura and Nakajima, 2015). In this study, to understand the re-distribution of H_2O within the arc crust, differentiation of H_2O during crust-melt reactions and subsequent ascent in magma chamber were constrained from crust-melt reaction zones in East Antarctica and melt inclusions in fossil calderas in NE Japan.
The granulite-hosted crust-melt reaction zones in Sør Rondane Mountains, East Antarctica, records peridotite–granitic magma reactions under 0.5 GPa, 700°C (Uno et al., 2017). Granitic dykes (0.1–2 m in width) intrude into phlogopite-pargasite-peridotite, and accompanies amphibole–phlogopite reaction zone at the wall rock (10–20 cm). Based on thermodynamic analysis of these reaction zones, it was revealed that activity of H_2O (a_{H2O}) in the granitic dyke reaches 1, whereas it is ~0.7 at the host peridotite (~20 cm from the dyke wall). Therefore, it is suggested that the transport and reaction of H_2O from the granitic dyke to the host rock was limited, and most of the H_2O liberated from the granitic dyke (>65%) was transported as excess fluid toward the upper crust through the dyke-related fractures.
The budget of H_2O transported to upper crust can be estimated from fossil caldera distributed in NE Japan arc. Miocene Shirasawa caldera (10–7 Ma) is one of major fossil caldera in NE Japan. The analyses of melt inclusions in quartz in Shirasawa caldera suggest that its magma chamber existed at the depth of 1–11 km with dacite–rhyolite melt composition, the H_2O content of melt ranges 3–6 wt% and the magma chamber was water saturated at least <6 km depth (Suzuki et al., 2017). Assuming the caldera diameter of 20 km, depth of 10 km, H_2O content of 4 wt% and igneous duration of 3 Myr, the flux of H_2O supplied into Shirasawa caldera is 1.3×10^5 kg/yr, or 6.6 t/yr/m for a unit along arc distance. This is almost same order as the subarc H_2O flux estimated by Kimura and Nakajima (2014).
Based on these analysis, 0^{th} order H_2O budget in the arc crust is as follows: most of H_2O liberated from subarc magma do not react with surrounding crust, and transport upwards to magma chambers in upper crust, and get saturated <~6 km. Further detailed understanding of mass balance of H_2O is needed with better knowledge of evolution of H_2O content with magma differentiation, and crustal lithology, water content, fracture density and permeability.

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