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Deep magma degassing and volatile fluxes through volcanic hydrothermal systems in Iceland

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Volcanic hydrothermal systems (VHSs) act as conduits for volatiles between degassing magmatic intrusions and the surface. Quiescent outgassing at VHSs could account for a significant portion of mantle-to-atmosphere volatile fluxes, potentially outsizing eruptive volatile emissions over long timescales. However, recognizing and quantifying magmatic volatiles in hydrothermal fluids sampled at the surface is complicated because primary magmatic signals are typically masked by volatiles from crustal sources and/or seawater, and modifications from shallow-level hydrothermal processes.

Here, we present new compositional and isotopic (δD-$\delta^{18}O$-$^3He/^4He$-$\delta^{13}C$-$\Delta^{33}S$-$\delta^{34}S$) data for hydrothermal waters and fumarole gases from VHSs associated with the Askja and Kverkfjöll volcanoes in central Iceland. The two VHSs are ideal for distinguishing magmatic volatile signals, as they are far from the sea, the crust is igneous (and volatile-poor), and the primary magmatic volatile characteristics well-constrained. We use the data together with magma degassing models and mass balance calculations to assess the role of intrusive magmatism to the volcanic volatile emission budgets in Iceland.

The CO_2/S_{tot} (10-30), $^3He/^4He$ (8.3–10.5 R_A; $^3He/^4He$ relative to air), $\delta^{13}C$-CO_2 (–4.1 to –0.2 ‰) and $\Delta^{33}S$-$\delta^{34}S$-H_2S (–0.031 to 0.003 ‰ and –1.5 to +3.6 ‰) values in high-gas flux fumaroles (CO_2 > 10 mmol/mol) are consistent with an intrusive magmatic origin for CO_2 and S.

We demonstrate that deep (~2-18 km) decompression degassing of basaltic intrusions is sufficient to account for the estimated CO_2 flux of Icelandic VHSs (3365–6730 kt/yr), and a large part of the VHS S flux (220–440 kt/yr). Secondary, crystallization-driven degassing from maturing intrusions and leaching of crustal rocks are suggested as additional sources of S. Only a minor proportion of the mantle flux of Cl is channeled via VHSs, whereas the H_2O flux remains poorly constrained, because magmatic signals in Icelandic VHSs are masked by a dominant meteoric water component. These results suggest that the bulk of the mantle CO_2 and S flux to the surface in Iceland is supplied by intrusive, not eruptive magmatism, and is largely vented through hydrothermal fields.