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Compositional time-series from tephra and the temporal evolution of Grímsvötn's magma chamber

Olgeir Sigmarsson (1,2), Bergrun Arna Óladóttir (1,2), and Guðrún Larsen (2)

(1) Laboratoire Magmas et Volcans, C.N.R.S.-Université Blaise Pascal, Clermont-Ferrand, France (olgeir@raunvis.hi.is), (2) Institute of Earth Sciences, University of Iceland, 101 Reykjavík, Iceland

Improved understanding of magma chambers and the related plumbing system is needed for active volcanoes. Their architecture, size and location determine the magma dynamics from source to surface, and the rate of magma transfer is in part controlled by variable sizes and forms of magma chambers. Since these are not constant features but evolve with time, only detailed studies of fine-tuned time-series allow quantitative assessment of their physical evolution, such as their volume.

The subglacial volcano Grímsvötn is the most active of all Icelandic volcanoes. Interaction between the hot basaltic magma and glacier melt-water results in tephra formation during each eruption. Careful soil inspection around the Vatnajökull ice-cap has revealed an eruption frequency, higher than 7 eruptions per century. A compositional record of major- and trace element concentrations has been obtained by electron microprobe and laser ablation ICP-MS measurements of tephra glasses for the last 7600 years. We combine these results with more precise data from isotope-dilution mass-spectrometry on historical tephra from the Vatnajökull glacier.

The Holcene basalts from Grímsvötn clearly form two distinct compositional groups, G-1 and G2. The group G-1 is characterized by Mg#> 47, K2O< 0.4 wt% and Th< 0.9 ppm, whereas the G-2 magma has more evolved composition. Simple fractional crystallization readily explains the compositional variations within group G-1, while the G-2 magmas have suffered from additional crustal contamination (through AFC). The Holocene tephra record reveals that both magma types are erupted contemporaneously, and even during the same eruption such as produced during the last eruption in 2004. This clearly indicates a polybaric origin of the emitted basalts, and eliminates the possibility of a single well-mixed, steady-state magma chamber beneath Grímsvötn. After the large fissure eruption of Laki (1783-84), which is on the same volcanic system, the composition of Grímsvötn tephra has shown a subtle but significant increase in incompatible element concentration such as that of Th.

The subglacial nature of Grímsvötn volcano gives access to information of the heat emitted from magma at depth towards surface, if all the heat is consumed in glacier melting. The heat that melted ice above the sub-glacier lake at Grímsvötn between 1922 and 1998 is estimated close to 10^{19} J (Björnsson and Gudmundsson, 1993) and could be generated by magma cooling from its liquidus to solidus (delta T= 200°C) which corresponds to 7 km^3 of solidified magma. The proportion of the magma chamber that froze during the same period can be calculated, using the Rayleigh distillation law, from increasing concentration of trace elements that are excluded from crystals and concentrated in the liquid. The increase in Th concentration from 1.20 ppm in 1922 tephra to 1.52 ppm in the 1998 tephra, yields 20% decrease in the liquid fraction of the magma chamber. The increasing Th concentrations in Grímsvötn tephra with time during the last two centuries is best explained by eruptions of a progressively fractionating magma chamber, which volume has decreased from 12 km^3 at the time of the Laki 1783-84 volcano-tectonic event in South-Iceland to the actual 9 km^3.