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Plinian vs. phreatomagmatic eruptions at Grímsvötn volcano, Iceland

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Grímsvötn is a subglacial central volcano located under the Vatnajökull ice cap, above the assumed centre of the Iceland mantle plume. Historical explosive eruptions are mostly of phreatomagmatic character whereas pure magmatic behaviour may characterize the largest eruptions. What causes this different eruption behaviour is uncertain. Here, we report petrological estimates of crystallization depth and volatile degassing as recorded by sulfur concentrations in melt inclusions (MI) hosted by ferromagnesian minerals and the groundmass glass. Tephra from four eruptions, AD 1823, 1873, 2004 and 2011, were selected. The 2011 and 1873 are the largest known historical eruptions, whereas the 2004 eruption is probably amongst the smallest. The repose time preceding those eruptions is surprisingly similar, or 6 to 7 years, and the major-element compositions are uniform.
Plagioclase, clinopyroxene (cpx) and olivine are the three coexisting phases at the liquidus in the quartz-tholeiites of Grímsvötn. The cpx-melt geothermobarometer (Putirka 2008) applied to the 2011 tephra reveals that cpx crystallized over a large range of P from 60 to 640 MPa (depth range: 1.7-18km) and T between 1060 and 1175°C before the Plinian eruption, therefore mobilizing the entire crustal magma system. In contrast, the phreatomagmatic tephra do not record the shallowest crystallization but interestingly all four tephra have identical median entrapment pressure of approximately 400 MPa. Therefore, the depth from which the magma bodies are derived, does not explain the difference in explosivity between those eruptions nor the variable magma volume (V) produced.
Sulfur concentrations in MI are only slightly higher in the Plinian products, the difference (10%) being insufficient to explain the different eruption regimes. The ΔS, the difference between the maximum S concentrations in MI and the mean of the groundmass glass for a given eruption, is higher in the Plinian tephra. Based on literature data for the VDRE of 2004, 2011 and Laki eruptions, a semi-log correlation with R2 = 0.92 was obtained. From $\Delta S = 1094 + 262 \log V$, we calculate DRE volumes of 0.02 and 0.3 km3 for the 1823 and 1873 eruptions, respectively. The latter volume is similar to estimates from Thorarinsson (1974), whereas little is known about the relatively small 1823 eruption. This simple method allows volume assessments of older historical eruptions and, thus, the magma flux of Grímsvötn volcano over the centuries. Here, we apply the volume estimates for the five eruptions in question to evaluate the degassing efficiency of these explosive basaltic eruptions. An excellent correlation between residual S concentrations in the groundmass glass and the logarithm of the magma volume emitted (R2 = 0.98) reveals that tephra from the small phreatomagmatic eruptions in 2004 and 1823 are only partially outgassed whereas those of the Plinian 1873 and 2011 are largely outgassed, with the subaerial Laki products being almost completely outgassed. The efficiency of volatile degassing is thus correlated with the eruption size that in turn is most likely controlled by deeper-seated processes.