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Vesiculation of rhyolite magma in the IDDP-1 borehole at Krafla, Iceland

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In 2009 the IDDP-1 borehole at Krafla, Iceland unexpectedly intersected rhyolitic magma at 2.1 km depth [1,2], providing unprecedented opportunities to investigate silicic melt formation and storage, and potential for powerful geothermal energy production. A key objective is to constrain the nature of the rhyolitic melt and its response to drilling. As no intact core was extracted, evidence is fragmental - from glassy rhyolitic clasts retrieved from the cuttings. These exhibit a range of glass colours, vesicularities and phenocryst contents [1,2].

Here we use benchtop infra-red spectroscopy and petrological microscopy to characterise the H_2O concentrations and bubble number densities within diverse glassy clasts, complemented by 1 Atm bubble growth experiments with a heated stage to investigate vesicle growth. Juvenile glassy clasts were divided into three categories (brown>banded>very dark glass). H_2O concentrations within clasts showed some spatial variability, with enrichment towards bubble-rich areas that may be resorption-related but could not be adequately characterised with a benchtop source. However, mean values ranged from 1.41-1.68 wt %, with no statistically significant difference between clast types. This is broadly consistent with previous studies [1,2].

Bubble growth rates in all clast types were determined during isothermal dwells at 600, 650 and 700 °C, for which bubbles grew at 0.03-0.09, 0.11-0.31, and 0.46-0.82 μm s-1 respectively. The highest growth rates were measured for the most water-rich clast analysed - a banded clast with mean H_2O of 1.68 wt %, and initially-larger bubbles also grew more rapidly. Measured bubble number densities (BNDs) range from 10[11.7] m-3 in banded clasts to 10[13.1] m-3 in very dark clasts, corresponding to decompression rates of ~0.1-1 MPa/s [3], although experimentation on IDDP-1 magma is needed to properly calibrate BNDs as a decompression rate meter. Nonetheless, such decompression rates suggest nucleation occurred over tens-hundreds of seconds, as pressure dropped from magmastatic towards lower borehole values.

The duration of vesicle growth was roughly estimated from measured bubble sizes, which range from ~5 μm in very dark clasts to ~30 μm in banded clasts, and extrapolated bubble growth rates at magmatic temperature (900 °C) and appropriate pressure. Results suggest only brief pre-quenching growth occurred, over ~seconds. We therefore propose that magma adjacent to the drill head experienced decompression prior to interception, leading to a brief period of bubble nucleation and a briefer period of growth prior to fragmentation and quenching. The high bubble strain, low bubble number density and largest bubble sizes in banded clasts all point towards slower decompression and more protracted viscous flow in this part of the rhyolitic magma. However, better temporal constraints are required on the extraction of distinct clast types to determine how magma response evolved through time, and better piece together this enigmatic magmatic jigsaw.

1. Elders WA et al. 2011 Geology 39, 231-234.
2. Zierenberg RA et al. 2013 Cont. Mineral. Petrol. 165:327-347.
3. Hamada M et al 2010 Bull. Volcanol., 72, 735–746.