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Multi-scale heterogeneity in rhyolitic lava at Hrafntinnuhryggur, Krafla, Iceland

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Small-volume rhyolitic lava flows and domes erupted through thin ice at Hrafntinnuhryggur, Krafla, Iceland[1] display remarkable textural heterogeneity over a range of spatial scales from microns to metres. As textures in the exposed feeder dyke are uniform and the aphyric magma was originally compositionally homogeneous, this heterogeneity must have emerged through strong spatial variations in deformation, vesiculation and crystallization within the lava bodies themselves.

Metre-scale textural zonations occur between the margin and the interior of lava bodies. Spherulitic lava interiors are enveloped by concentric zones of lithophysae-rich obsidian, coarsely-vesicular obsidian in various stages of collapse and flow-banded, faulted obsidian[1]. These zonations reflect divergent pathways of lava evolution at different background cooling rates, which allow differing extents of late-stage crystallization and secondary vesiculation. The liberation of latent heat during spherulite crystallization[2] is an example of a feedback that can magnify the resultant textural diversity, as heat release can trigger both accelerated crystallization and vesiculation of the lava.

Striking textural heterogeneities also occur on much smaller spatial scales within the lava. The flow-banded obsidian displays a broad spectrum of colours on a millimetre scale and different-coloured bands have distinct magnetic properties. This indicates that contrasting populations of sub-micron magnetite, haematite and clinoferrosilite grains are present in adjacent flow bands. Some flow bands contain remnants of now-collapsed vesicles, indicating that heterogeneous degassing may have led to highly-localised melt dehydration, redox conditions and resultant crystal nucleation. Strain localization is another feedback that can play a major role in emphasizing differences between neighbouring flow bands.

Two other types of textural heterogeneity occur on still-smaller spatial scales. Firstly, individual spherulites are surrounded by a sub-millimetre halo of glass that is enriched in OH-groups due to their expulsion during crystal growth[3]. Ferric iron within this zone is reduced, which is attributed to hydrogen diffusion and demonstrates that late-stage crystallization can result in micro-scale redox disequilibrium within glassy lavas. Secondly, in some instances micron-scale magnetite and clinoferrosilite crystals have nucleated exclusively on the walls of partially or totally-collapsed vesicles. This has created films of crystal enrichment whose form records the three-dimensional geometry of late-stage foams and their subsequent deformation. Subtle compositional heterogeneities also exist, which point towards limited major-element mobility during lava evolution. Calcium depletion in melt adjacent to zones of late-stage vesiculation may indicate scavenging by a sulphur-rich fluid phase.

The textures at Hrafntinnuhryggur illustrate how numerous interrelated processes can lead to the spontaneous generation of heterogeneity within rhyolitic lava. Distinct trajectories of textural evolution are controlled by boundary conditions (e.g. strain rate and background cooling rate), initiated by thresholds (e.g. brittle or ductile behaviour, conditions for bubble and crystal nucleation) and amplified by positive feedbacks related to the mutual triggering of crystal and bubble growth.

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[2]Tuffen, H., Castro, J.M., Wilson L. The thermal effects of spherulite growth in rhyolitic lava. Earth. Planet. Sci. Lett., in revision.

[3]Castro, J.M., Cottrell, E., Tuffen, H., Logan, A., Kelley, K.A. (2009) Spherulite crystallization induces Fe-redox redistribution in silicic melt. Chem. Geol. 268, 167–179.