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Decoding magmatic intrusion crystallization mechanisms: a microstructural study from the Little Minch Sill Complex, Scotland

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The processes occurring during the crystallization of magmatic intrusions at upper to middle crustal levels depend on the physical behaviour of crystal-bearing magmas. From emplacement to complete solidification, fluid dynamic properties of the magma will determine the final internal architecture of the intrusion. Such properties result from the interplay between a set of different parameters including the temperature of the country rock, magma composition, and the volumetric amount and grain size distribution of the original crystal load.

We argue that microstructural features present in settled accumulations of crystal cargos can be used to decode the fluid dynamical behaviour of the intruded magma. Settled accumulations are typically characterized by a fining-upwards sequence on the intrusion floor. In detail, the structure of fining-upwards sequences can be used to differentiate between gravitational settling from a static magma and from a convecting magma: the former results in a fining-upwards sequence characterised by the complete disappearance of progressively smaller size classes upwards in the accumulation, whereas the latter forms a fining-upwards sequence characterized by the gradual phasing out of each class size.

We present the results of a microstructural case study of olivine accumulations in the highly olivine-phyric basaltic sills of the Palaeogene Little Minch Sill Complex (Isle of Skye, Scotland). We show that combining petrographic observations such as olivine crystal size distributions and plagioclase aspect ratios, together with a consideration of mineral mode (Ol, Pl:Cpx ratio) and thermodynamic modelling, can constrain the details of the solidification history. A consideration of the size of clusters of olivine crystals in the floor accumulation is used to support evidence of synneusis of suspended cargo crystals during convection in the early history of the intrusion. The olivine crystal size distribution and the number of grains per olivine cluster are used to model the relative timing of grain and cluster settling and the upwards propagation of the solidification front on the sill floor.

These findings have important implications for our understanding of the rheological state of volcanic systems and have potential to provide insights into Earth's early differentiation and the crystallization of magma oceans.