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The thickness of crystal mushy layers on magma chamber floors

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Heat loss through the margins of crustal magma bodies drives crystallization and the development of crystal mushy layers. In small intrusions the bulk composition of the mushy layers is the same as that of the intruded magma, but for larger bodies there is abundant evidence that residual mush liquid is expelled from the mushy layer on the chamber floor, driving fractionation of the bulk magma. There is debate about the precise mechanism(s) by which the residual liquid is expelled, with suggestions ranging from convection within the mushy layer driven by compositionally-controlled changes in density, compaction and collapse of the crystal framework, to diffusion and primary adcumulate growth at a hard-ground. The effective operation of these different mechanisms requires specific values of physical parameters. One of these parameters is the thickness of the mushy layer.

Direct measurement of the crystal mushy layer on the floor of a magma chamber is not possible. Field observations of the effects of block settling and slumping, and downwards percolation of low viscosity dense liquids point to thicknesses of the order of metres, although numerical models of compaction and compositional convection require thicknesses of order 100 m. A new parameter that may be of use in constraining erstwhile mush thickness in fully solidified mafic intrusions is the median dihedral angle subtended at clinopyroxene-plagioclase-plagioclase junctions, Θcpp.

Most gabbroic rocks are not in textural equilibrium, and Θcpp is controlled by the kinetics of crystal growth, resulting in values lower than the equilibrium value of 109°. Θcpp in dolerites is a sensitive function of crystallization rate, rising from 78° in rapidly cooled small sills and dykes to > 100° in the centres of large sills. In fractionated bodies such as layered intrusions, Θcpp falls in the same range as that observed in dolerite sills < 300 m thick, and increases in a step-wise fashion at the arrival of a new liquidus phase. These steps occur regardless of the cumulus mineral mode, the mode and assemblage of intercumulus phases, and the sequence of mineral arrivals: they therefore relate to fundamental physical, rather than compositional, changes.

A first-order observation is that the step-wise changes in Θcpp are sharp, occurring over a few metres of stratigraphy. Regardless of the exact mechanism driving the changes in Θcpp this points to a thin mush zone: formation of all cpx-plag-plag junctions was complete at the base of the step before the arrival of the new cumulus phase. The relationship between crystallization time and Θcpp derived for dolerites can be used to estimate mush thickness by assuming both a constant rate of upwards movement of the magma-mush interface and that the population of cpx-plag-plag junctions is created entirely within the mush zone. The step-wise changes in Θcpp primarily correspond to changes in mush thickness, due to variations of crystal productivity consequent to changes in the liquidus assemblage. For typical solidification rates of order 0.01 m per year, the range of Θcpp in layered intrusions is consistent with mush thickness of 1 – 10 m.