Characteristic Dimensions and Times for Dynamic Crystallization

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Abstract

This study focusses on the role of the crystallization kinetics. We describe the evolution of crystallization in natural conditions and make a dimensional analysis of the problem. Given characteristic values for the rates of nucleation and crystal growth, I and Y, the crystallization time-scale τ is $(I.Y^3)^{-1/4}$. The thickness of the crystallization interval, i.e. the moving region where magma is partially crystallized, is equal to $\{\kappa.\tau\}^{1/2}$. This gives the thickness of the crystal mush which lies at the chamber bottom. The crystal size is equal to $\{Y/I\}^{1/4}$ and is sensitive to the temperature regime. These scaling laws show that the crystallization parameters are weakly sensitive to the values of the kinetic rates. Disturbing the normal crystallization regime acts to perturb the crystal size over a distance equal to a few times the thickness of the crystallization interval. These theoretical predictions can be checked against petrological observations. Crystal size data from dike margins are used to constrain the peak rates of nucleation and growth to be about 1 $cm^{-3}.sec^{-1}$ and 10^{-7} $cm.sec^{-1}$ respectively. For conditions prevailing in the deep interior of magma chambers, the rates of nucleation and growth are much smaller than these values. A constraint is provided by the mean crystal size which is always close to 1 mm. We suggest values of 10^{-5} $cm^{-3}.sec^{-1}$ and 10^{-9} $cm.sec^{-1}$ for the rates of nucleation and growth respectively. For these, the crystal mush has a thickness of a few metres. Also, the crystallization time-scale is about 10^8s. This is similar to values for the cooling time of a kilometre-sized chamber, which shows that crystallizing magma has time to record the effects of convective processes which operate in the chamber interior. This explains why the igneous structures of large intrusions are more complex than those of sills and dikes.

in « Origins of Igneous Layering », NATO ASI Series, Vol 196, Ian Parsons (Ed.), Reidel Publishing Company, pp. 613-639, 1987.