A SIMPLE COOLING MODEL FOR IGNEOUS ROCKS. J.W. Minear, NASA Johnson Space Center, Houston, TX 77058, C.R. Fletcher, Lockheed Electronics Company, Houston, TX 77058.

The manner in which a layer of silicate melt crystallizes is of fundamental importance to several first-order lunar and planetary problems. Two examples illustrate this importance. First, given the mineralogy and texture of a basalt sample, the thickness of the flow from which it came can be estimated if the relation of these parameters to cooling is known. Second, a generally accepted implication of the returned sample and seismic data is that the Moon had a thick initially molten outer layer. Petrologic implications of such a magma ocean are generally arrived at by analogy with relatively thin terrestrial layered intrusive complexes. Models that incorporate the effects of crystallization, gravity settling and convective transport offer a useful tool in evaluating the existence of such oceans and contributing to the understanding of differentiation within thick intrusive complexes.

Because of the sparsity of data on layering within the Moon and the lack of reliable models that incorporate the phenomena that influence differentiation and crystallization, we have begun with a simple model that is applicable to basalt flow cooling. The model is structured to allow later inclusion of phenomena that are active in the cooling of planetary scale magma oceans or of large bodies of silicate melt within a planet. The objective is to provide output that is directly interpretable in terms of the observable parameters such as texture, mineralogy and cooling rate.

The model is based on the two-dimensional conservation of energy equation which is solved numerically. Thermal conductivity and density are assumed to be functions of the composition. Specific heat is assumed to vary with temperature only. Thermal conductivity includes a lattice conductivity term dependent on the mean atomic weight and the density (1) and a radiative term proportional to the cube of the temperature and to the iron content. Liquid densities are computed by the method of Bottinga and Weill (2). Latent heat of fusion is computed from a weighted average of the mineral phases crystallizing at a particular time. Composition is specified by the mineral phases fayalite, forsterite, enstatite, ferrosilite, wollastonite, anorthite, and albite. The phases can be broken down into oxides for physical property calculations that merit such an approach (liquid density, viscosity, and radiative conductivity) or used directly for others (lattice conductivity, latent heat, solid density, nucleation rate, growth rate).

Liquid viscosity is computed from the oxide fractions by the method of Shaw (3). The logarithm of viscosity is assumed to have an inverse temperature dependence. Crystal effects are included by assuming that the viscosity of a liquid-crystal mush depends exponentially on the crystal fraction; an assumption that is reasonable for crystal fractions less than about 0.5.

The major effects of crystallization on the cooling of a silicate melt layer are the release of latent heat of fusion and the interference with magma migration at large crystal/melt ratios which in turn may decrease the effective convective heat transport. Latent heat effects of crystallization can be simulated by various techniques that are independent of crystallization kinetics (4, 5). However, texture and the effects of crystal settling which are
both observables can be modeled only by directly incorporating crystal nucleation and growth in the thermal model. Although the present lack of data on nucleation and growth rates is recognized, this approach is fundamental and offers the only avenue of providing model textural and mineralogic predictions.

The general form and dependence of the growth and nucleation rates are known (6), but many of the physical parameters are poorly known. We have assumed some simple forms for these rates in order to test their effect on our model. The simplest model is of a single phase composition and assumes that the nucleation and growth rates are constant. Nucleation is initiated and terminated at specified undercoolings. Growth may continue after nucleation ceases. The effects of different thermal diffusivities (a compositional dependence) on the cooling rate and on the total crystal fraction can be significant. For example, at large thermal diffusivities, the rate of undercooling is large so that total crystal growth is diminished. Crystal size-frequency curves are used to illustrate the effects of conductivity and nucleation and growth rate parameters.

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