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Modeling of porous reactive flow in cooling igneous sills: the role of near solidus melt segregation in magmatic differentiation

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Basic-ultrabasic sills present a unique opportunity to study processes controlling the differentiation of natural silicate magmas. The detailed geochemical study of the Golden Valley Sill Complex (GVSC) shows a wide range of compositions and fractional crystallization trends. Vertical compositional variations detected by the Mg-number in the GVSC reveal I-, S-, and D- and even C-shaped profiles. Such profile patterns are typical for tholeiitic sills, and we show here that different profiles may develop in different parts of a single saucer-shaped sill. Here we present a new numerical model aimed at identifying the conditions that lead to the development of different profiles.

The traditional approach to resolve magmatic differentiation is based on the Bowen's concept of fractional crystallization, suggesting the crystal segregation from the melts and gravitational ordering of the convecting magma as a mechanism of magmatic differentiation. Our observations show that the processes operating in a thin sill are probably different from those which control segregation in convecting magma, which leads us to reexamine segregation process in relatively thin sheet-like intrusions. In a search for possible new explanations we study the processes possibly taking place after the end of convection and formation of crystalline skeleton. We study porous flow of remaining melt and resulting compositional evolution. Basically, instead of segregating crystals from convecting magma at fluid-like stages of magmatic evolution, we study melt segregation from solid skeleton at later solid-like stages of magma cooling

and crystallization.

We have rederived the governing system of equations. This thermodynamically consistent model describes balance of stresses, strains, energy and equilibrium between two-phase media in a multi-component system. In order to simulate the cooling processes in tholeiitic sills we had to include several mineral phases, crystallization, and compaction. The numerical code “DreamT” based on the finite-element method was designed to solve the system of equations and applied to describe evolution of relatively thin (ca. 100 m) sills. Our study shows that fractionation in tholeiitic sills may develop under near-solidus conditions. Under such conditions flow of near equilibrium melt seems to be the most efficient segregation process. Thus, we have modeled in detail the porous flow and evolution of porosity in thin sills and investigate the influence of these parameters on the process of segregation. The results of the numerical modeling have been compared with field observations and chemical data on the GVSC.