A quantitative model for trace element behavior during crystal settling and reequilibration in high-silica magma chambers.

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The chemical evolution of magmas is governed by crystallization induced by a decrease in temperature and the removal of the crystals from the melt due to their density difference. If the melt and crystals remain in perfect chemical equilibrium with each other, the melt composition evolves along an equilibrium crystallization path. In contrast, if crystals are completely prevented from reacting with the melt by settling, the melt composition evolves along a fractional crystallization path. These two models form useful end-members amongst crystallization mechanisms. In nature, however, the chemical evolution of magmas is more complicated due to the thermal structures in the chambers. In the past few decades, petrological, experimental and theoretical studies have demonstrated that a magma chamber solidifies through the formation of a mushy boundary layer along the chamber walls. In the interior of the chamber, the magma is hotter and the crystals settling from the upper boundary layer should partially melt and re-crystallize there. This implies that disequilibration and reequilibration occur simultaneously in the chambers. However, the compositional evolution that occurs due to such a process remains poorly understood. The purpose of this study is to propose a quantitative model of the compositional evolution due to crystal settling followed by partial resorption and renewed growth.

The high-silica ash-flow tuffs that erupted instantaneously from the zoned magma chambers provide ample evidence that crystals have sunk and reacted with the surrounding melts. In the Bishop Tuff (California, USA), for example, melt inclusion gas-saturation pressure increases from the phenocryst core to the rim, which suggests crystal settling (Anderson et al., 2000). Bulk trace element studies of the Bishop Tuff have also suggested crystal settling (Michael, 1983; Cameron, 1984). Petrological study of melt and magnetite inclusions and zoned phenocrysts has suggested that some phenocrysts continued to crystallize as they sank several kilometers through progressively less differentiated melts (Anderson et al., 2000). The present paper develops a model for trace element behavior during crystal settling and reequilibration in high-silica magma chambers and discusses the implications of the model for our understanding of the origin of zoned magma chambers observed in many silicic magma systems.

A unique and important feature of this model is the temporal variation of liquid lines of descent. Previous crystallization models such as fractional and equilibrium crystallization have assumed that a melt with a single composition evolves along a single liquid line of descent with increasing degree of solidification. In the present model, however, melts of various compositions exist within the chamber at a given time, and the liquid line of descent itself changes with time. The chemical evolution expected from crystal settling and reequilibration is consistent with the data from the Bishop Tuff high-silica magma chamber and may account for some of the characteristic patterns of chemical zonation observed in high-silica magma chambers.