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Magmatic processes in the crust revealed from modeling magma dynamics combined with U-series disequilibria: A progress report on Volcán Quizapu, southern Chile

Philipp Ruprecht, George W. Bergantz, & Kari M. Cooper

Dept. of Earth and Space Sciences; Box 351310; University of Washington; Seattle, WA 98195-1310; USA (ruprecht@u.washington.edu)

Two approaches have traditionally been used to address the diversity of magmatic processes typical of many arc systems, including Andean systems: analog or numerical modeling of magma chambers (e.g. Bergantz, 2000, Bergantz and Breidenthal 2001; Couch et al 2001; Jaupart and Tait 1995) or geochemical characterization either at the bulk rock or single crystal scale (Singer et al. 1995, Davidson and Tepley 1997). These approaches usually resolve different time and space scales of the processes that produce petrological diversity, and rarely have been combined in a way that allows for them to be mutually constraining. For example, while numerical models typically resolve the meso-to-macro scales of magma dynamics (heat and mass balance), the geochemical approach can resolve a greater density of data, such as the crystal-size heterogeneities. Our aim is to explicitly combine modeling with observations within the context of a single, young magmatic system. The integration of observational and modeling technologies has tremendous potential to reveal the templates (i.e., the fundamental styles of magma-magma and liquid-crystal interactions) that produce the compositional diversity commonly observed both at the macroscopic and crystal scale.

Simplified Geologic Map of Volcán Quizapu and Vicinity

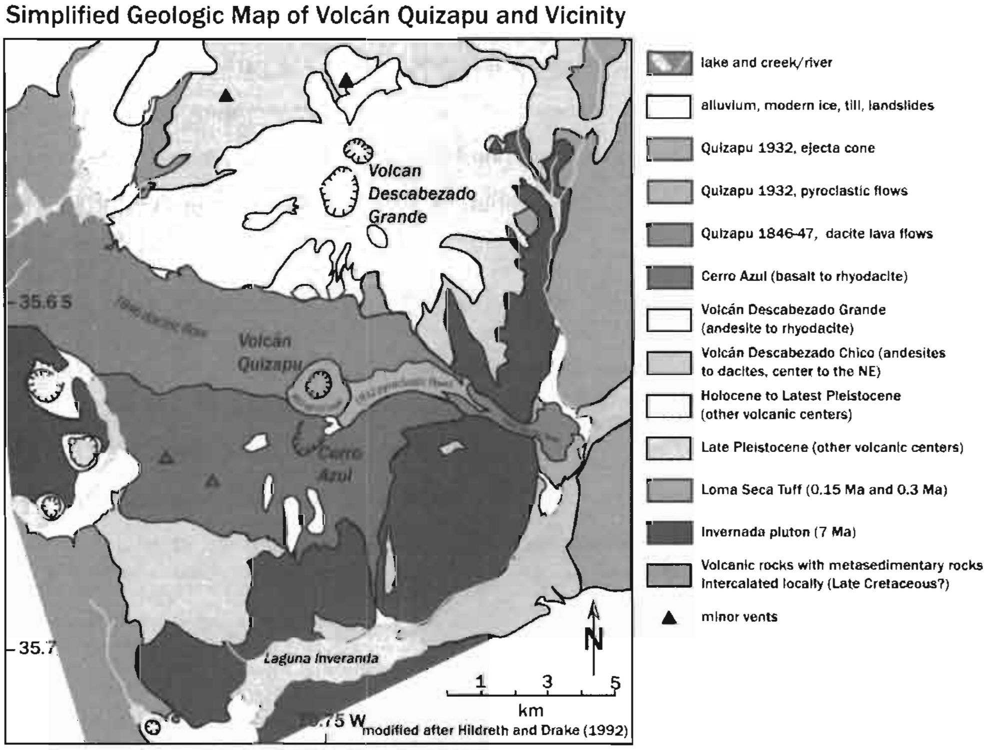

Fig. 1. Geological Map of Volcán Quizapu area

The initial application of this approach requires an especially simple natural example. Volcán Quizapu, part of Cerro Azul (35.653°S, 70.761°W) in the Southern Volcanic Zone of the Andes (Fig. 1), is an excellent natural laboratory for a study of this kind. This system had two historic, large (~ 4-5 km^3) dacitic eruptions, one in 1846-1847 and one in 1932. Much of what is known is the result of work by Hildreth and Drake (1992). While the hornblende-dacite magma from 1846 was erupted effusively from Quizapu, the same vent was the center for a plinian eruption of compositionally very similar dacitic magma (both 67-68 wt.% SiO_2). Both eruptions are virtually identical in terms of the concentrations and ratios of incompatible trace elements. In addition, they resemble each other in their crystallinity (15-19 %), their relative abundances of phenocrysts (plag > opx ~ hbl > titanomagnetite > ilmenite ~ cpx > apatite > sulfide blebs), and their phenocryst compositions. The plinian eruption was accompanied by volumetrically minor andesite scoria, and small volumes of rhyodacite pumice were erupted throughout the plinian phase. Hildreth and Drake (1992) concluded that the co-erupted mafic magmas did not indicate a zoned magma chamber, but rather, the entrainment of adjacent magma bodies that were disrupted during the plinian eruption.

Unlike most Andean magmatic systems (e.g. Volcán San Pedro; Costa and Singer 2002), the Quizapu phenocryst assemblage appears to contain only trace amounts of 'antecrysts' or crystalline material that has been recycled from mushy subjacent portions of the magma system. Hence whatever variations in compositional character one can document in the crystals largely represents processes associated with the current magma chamber. This provides a 'benchmark' of the variability one might expect in the simplest of systems. It allows one to identify the expected range in magmatic intensive variables prior to over-printing by open-system processes or by recycling of magmatic materials.

We also view this as an opportunity to understand magmatic processes in a system of transitional size, as it is big enough to potentially have a variety of convective and multiphase transport processes. This provides a window into some of the controls on homogenization at the largest scale, which is of importance in the evolution of the Andes as displayed by large ignimbrites (e.g., Francis et al. 1983, Grunder and Mahood 1988). Of these time scales three are thought to be the most important: system residence time, duration and style of fractionation and homogenization time.

In an attempt to better understand the interplay of these time scales, we have a program of numerical models. Our modeling approach is a modification of the Eulerian-Eulerian multiphase solidification approach of Ni and Incropera (1995a, 1995b). We use their methodology to calculate the distribution of the intensive and transport 'field variables' and properties of the magma chamber, and into these insert 'smart' Lagrangian tracers that can act as probes of the evolving thermal and compositional character of the magma. In a sense this is equivalent to creating synthetic crystal zoning as well as CSD's, but constrained by the actual dynamics of the system. This will allow us to better understand what magmatic events are recorded by zoned crystals and their gathering and dispersal during chamber activity.

Estimates of these time scales have emerged from a growing catalog of high-precision crystal-chemical and U-series age dating. Due to a short time gap of less than a 100 years between the two major eruptions at Volcán Quizapu we can employ the entire suite of trace element diffusion (e.g., Zellmer et al. 2003, Costa et al. 2003) as well as ^{238}U-^{230}Th and ^{230}Th-^{226}Ra disequilibria dating methods (Cooper and Reid 2003) on plagioclase and hornblende, to be used as an independent constraint on the geological fidelity of dynamic models.

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