INVESTIGATING PETROLOGIC INDICATORS OF MAGMATIC PROCESSES IN VOLCANIC ROCKS

The cooling kinetics of plagioclase feldspar as revealed by electron-microprobe mapping†

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ABSTRACT

In this study, we have used electron-microprobe mapping to investigate plagioclase compositional evolution due to cooling kinetics. We re-analyzed five run-products from a prior study (Iezzi et al. 2011), crystallized by cooling a natural andesitic melt from 1300 to 800 °C at 25, 12.5, 3, 0.5, and 0.125 °C/min under atmospheric pressure and air redox state. As the cooling rate decreases, the texture of large plagioclases changes from skeletal to hollow to nearly equant. In this study, we use X-ray map data to obtain a database of 12275 quantitative chemical analyses. The frequency of An-rich plagioclases showing disequilibrium compositions substantially increases with increasing cooling rate. At 25 and 12.5 °C/min the distribution is single-mode and narrow, at 0.5 and 0.125 °C/min is single-mode but very broad, whereas at the intermediate cooling rate of 3 °C/min two distinct plagioclase populations are present. This intermediate cooling rate is fast enough to cause departure from equilibrium for the crystallization of the An-rich population but also sufficiently slow that An-poor plagioclases nucleate from the residual melt. We interpret our findings in the context of time-temperature-transformation (TTT) diagrams, and infer the crystallization kinetics of plagioclase in the experiments. Compositional trends and our inferences regarding TTT systematics are consistent with two discrete nucleation events that produced separate populations of plagioclase (i.e., An-rich and An-poor populations) at 3 °C/min. Using plagioclase-melt pairs as input data for the thermometric reaction between An and Ab components, we find that plagioclase mirrors very high- (near-liquidus) crystallization temperatures with increasing cooling rate. These results have important implications for the estimate of post-eruptive solidification conditions. Lava flows and intrusive bodies from centimeters to a few meters thick are characterized by a short solidification time and a significant thermal diffusion. Under such circumstances, it is possible to crystallize plagioclases with variable and disequilibrium chemical compositions simply by cooling a homogeneous andesitic melt. X-ray element maps enrich the study of plagioclase compositional variations generated under conditions of rapid cooling.

Keywords: Andesite, plagioclase, EPMA map, cooling, crystallization, thermometer

INTRODUCTION

Plagioclase is the most common mineral in igneous rocks. Over other crystal phases, plagioclase has important advantages in preserving records of the chemical and physical evolution of magmas due to the slow coupled CaAl-NaSi interdiffusion that inhibits the re-equilibration of growing crystals and favors the retention of original element concentrations (Grove et al. 1984; Morse 1984; Liu and Yund 1992; Baschek and Johannes 1995). This ensures that plagioclase chemical and textural zoning can be used for deciphering magmatic events (cf. Putirka 2008) as it is also highlighted by the rare occurrence of compositionally homogeneous plagioclases in nature (Smith and Brown 1988; Liu and Yund 1992; Baschek and Johannes 1995; Deer et al. 2001). Indeed, disequilibrium textures and compositions of plagioclase are frequently studied under natural and laboratory conditions (Hammer 2006; Iezzi et al. 2008, 2011; Brugger and Hammer 2010; Del Gaudio et al. 2010; Mollo et al. 2011a, 2011b, 2012a, 2012b; Lanzafame et al. 2013).

Cooling, crystal settling, convection and mixing in magma chambers allow crystallization of plagioclase phenocrysts with compositions that deviates from equilibrium (Marsh 1988; Singer et al. 1995; Couch et al. 2001; Pietranik et al. 2006). Disequilibrium crystals (microphenocrysts) can also solidify when magmas rise to the surface in response to rapid volatile degassing imposed by decompression paths (Couch et al. 2003; Blundy et al. 2006; Brugger and Hammer 2010; Frey and Lange 2011). In addition, rapidly cooled plagioclases are observed at the margin of small intrusions and the outermost portion of lavas (Ujiike 1982; Loomis 1981; Chistyakova and Latypov 2009; Del Gaudio et al. 2010; Mollo et al. 2012a, 2011b). This latter process has been experimentally investigated for basic magmas (Hammer 2006; Mollo et al. 2011a), but is still poorly unconstrained for andesitic melts where plagioclase is by far the most abundant mineral. Since the cooling rate may dictate the compositional evolution of plagioclase in andesitic lavas (Tamura et al. 2003; Mattioli et al. 2006), it is important to quantify this process for discriminating between pre- and post-eruption solidification conditions.