Plagioclase growth and nucleation rates in an anhydrous arc basaltic andesite

Melvyn BILLON 1*, Jacqueline VANDER AUWERA 1, Olivier NAMUR 2, François FAURE 3, Bernard CHARLIER 1

1 Department of Geology, Université de Liège, Belgium. 2 Department of Earth and Environmental Sciences, KU Leuven, Belgium. 3 CRPG, Université de Lorraine, France

Crystallization in magmas, marked by chemical and textural changes, is responsible for the transition from a silicate melt to a completely solidified rock by two main processes: nucleation (J), which corresponds to the formation of initial crystals, and growth (G) of these nuclei that increases the mineral/melt proportion (Cashman, 1990). Numerous experimental studies have been realized to constrain these two processes using different crystallization paths (cooling, decompression, or isothermal crystallization) (Brugger & Hammer, 2010b; Shea & Hammer, 2013), a range of initial compositions (basalt, dacite, trachyte) (Brugger & Hammer, 2010b; Pupier et al., 2008), and focusing on several phases (plagioclase, pyroxene, olivine). However, only a few studies were performed on a basaltic andesite, a common rock in arc volcanic zones.

Here, plagioclase nucleation and growth rates have been experimentally investigated in a basaltic andesite from Osorno volcano (Central Southern Volcanic Zone, Chile). A series of experiments were performed at 1 atm under anhydrous conditions at the Ni-NiO oxygen buffer and with low cooling rates (1°C/h, 3°C/h, 9°C/h). After an initial equilibration at 1190°C (10 °C above the liquidus) for 24 hours, the samples were cooled at different rates and finally quenched at various temperatures from 1165°C to 1000°C. Contrary to many studies, no high-temperature pre-heating was applied in order to preserve some pre-existing plagioclase seeds and to avoid nucleation delay. The main objective was to constrain the plagioclase nucleation and growth rates in these conditions and to compare growth results with literature data to identify the experimental parameters controlling crystal growth. Nucleation and growth rates were calculated considering various methods: Batch (characteristic size obtained as a ratio between the proportion of crystals and their number in the sample), lmax (average size of the 10 biggest crystals), and CSD (proportion of crystals per size ranges) methods.

Despite strong variability of the 2D aspect ratio in the same run, the crystal shape and size are correlated during their growth, with the smallest (< 10 µm) and biggest crystals (> 30 µm) displaying respectively an equant/elongated and tabular/bladed 3D shape. Plagioclase shape varied also with the cooling rate, from 2D tabular/elongated crystals at 1 and 3°C/h to hopper and swallowtail aspect at 9°C/h, suggesting a transition from interface- to diffusion-controlled growth. The nucleation and growth rates respectively comprised between 10+01-10+04 cm-3/s and 10-07-10-09 cm/s, show both a maximum close to the liquidus followed by a general decrease with cooling. This decrease becomes minimal at slow cooling rates, resulting in nearly constant G over time (after about 20 hours of cooling).

The growth rate values estimated in this study are similar to those of (Kohut & Nielsen, 2004; Shea & Hammer, 2013) with basaltic/andesitic composition, but two orders of magnitude higher than data obtained for dacitic composition (e.g. Brugger & Hammer, 2010b). It appears that the growth rate values

mainly depend on the crystallization path followed (e.g. cooling/decompression rate, superheating), and the calculation method considered (lmax VS Batch methods).

Cashman, K.V. (1990) Chapter 10. Textural constrains on the kinetics of crystallization of igneous rocks. In: Nicholls, J., Russel, J.K. (Eds.), Modern Methods of Igneous Petrology: Understanding Magmatic Processes. Rev. Mineral 24: 259–314. ; Brugger, C.R., Hammer, J.E. (2010b) Crystallization kinetics in continuous decompression experiments: implications for interpreting natural magma ascent processes. Journal of Petrology 51: 1941–1965. ; Shea, T., Hammer, J.E. (2013) Kinetics of cooling- and decompression-induced crystallization in hydrous mafic-intermediate magmas. Journal of Volcanology and Geothermal Research 260: 127–145. ; Pupier, E., Duchene, S., Toplis, M.J. (2008) Experimental quantification of plagioclase crystal size distribution during cooling of a basaltic liquid. Contributions to Mineralogy and Petrology 155: 555–570. ; Kohut, E., Nielsen, R.L. (2004) Melt inclusion formation mechanisms and compositional effects in high-An feldspar and high-Fo olivine in anhydrous mafic silicate liquids. Contributions to Mineralogy and Petrology 147: 684–704.