Experimental study of plagioclase rim growth around anorthite seed crystals in rhyodacitic melt

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ABSTRACT

The purpose of this study was to replicate experimentally the growth of new rims around highly anorthitic plagioclase "core" phenocrysts, analogous to the incorporation of xenocrysts into a silicic magma body through magma mixing. Aniakchak rhyodacite forms the bulk starting composition, and phase-equilibria experiments constrained the pre-eruption magma conditions to be ~110 MPa and 870–880 °C. The experimental runs were seeded with Great Sitkin anorthite (An$_{91-95}$) crystals. New rim growth of An$_{28-38}$ plagioclase occurred at rates between 3.5 (±0.3) × 10$^{-10}$ to 60.6 (±20.0) × 10$^{-10}$ cm/s at pressures and temperatures from 50 to 150 MPa and 825 to 880 °C. The values in parentheses are ±1σ standard deviation. Microlite crystallization (An$_{27-41}$) occurred in all experiments within the plagioclase stability field, and their growth rates varied from 4.4 (±1.3) × 10$^{-10}$ to 65.7 (±10.1) × 10$^{-10}$ cm/s. The rim and microlite growth rates are similar to one another within each experiment, and microlite number density ($N_v$) is correlated approximately inversely with rim growth rates. Microlite crystallinities increased from 4.2 to 49.7 vol% as a function of increasing Δ$T_{eff}$ up to 95 °C. The results indicate growth-dominated crystallization at low Δ$T_{eff}$, and nucleation dominated crystallization at high Δ$T_{eff}$, in agreement with previous studies. Assuming the experiments apply to nature, the rim growth rates can provide a minimum estimate on how fast magma mixing can occur. Rims that are 10 to 100 μm wide can grow in ~10 days to 4 months, recording fast mixing timescales as long as eruption occurs shortly after mixing. The growth rate estimates presented here generally agree with those derived from sodic rims growing around anorthite cores after mixing between basalt and andesite prior to the 1996 eruption of Karymsky volcano, Kamchatka.

INTRODUCTION

Plagioclase phenocrysts commonly contain dissolution and growth features that track pressure, temperature, and/or compositional changes that occurred in their host magma bodies, or in response to ascent or magma-mixing processes perturbing the system (e.g., Vance 1962, 1965; Kuo and Kirkpatrick 1982; Pearce et al. 1987; Singer et al. 1995; Davidson and Tepley 1997; Tepley et al. 2000; Davidson et al. 2001; Costa et al. 2003). Previous constraints on plagioclase growth rates ($Y$) have resulted in a wide range of estimates from ~10$^{-2}$ to ~10$^{-12}$ cm/s, depending upon the degree of experimental undercooling, compositions of the plagioclase and surrounding melt, temperature, pressure, experimental configuration, or on how the analysis of crystals in the volcanic rock samples was conducted (Kirkpatrick 1976, 1977; Kirkpatrick et al. 1976; Swanson 1977; Dowty 1980; Lasaga 1982; Muncill and Lasaga 1987, 1988; Cashman 1990, 1992; Hammer and Rutherford 2002). For example, rim growth rates derived from Sr and K concentration gradients in the outermost portion of plagioclase phenocrysts yield estimates of ~10$^{-9}$ cm/s, for growth under highly disequilibrium conditions during magmatic ascent (Singer et al. 1995). In contrast, Sr isotopic stratigraphy studies, combined with observed eruption timescales at El Chichón, provide minimum estimates on plagioclase growth rates of ~10$^{-12}$ cm/s (Davidson and Tepley 1997).

A relatively common feature of arc magmas is the presence of highly anorthitic plagioclase xenocrysts, occurring as calcic cores that are rimmed with more sodic plagioclase exteriors (e.g., Izbekov et al. 2002). The presence of significantly lower An content rims around those xenocrystic cores indicates reequilibration in a more silicic magma prior to eruption. Indeed, Izbekov et al. (2002) concluded that basaltic replenishment of the andesitic Karymsky magma prior to the 1996 eruption resulted in overgrowth of more sodic rims around the highly anorthitic cores that resided in the replenishing basalt, and used this to examine magma mixing timescales. Experimental studies of plagioclase growth around seed crystals (e.g., Muncill and Lasaga 1987, 1988) could also be used to help constrain magma mixing timescales, in comparison with natural samples.

The focus of this study was to provide new estimates on plagioclase rim growth rates in rhyodacite magmas. Growth of plagioclase rims (An$_{28-38}$) around anorthite (An$_{91-95}$) seed crystals was examined at various pressures and temperatures constrained by the phase equilibria of the natural rhyodacite from Aniakchak caldera. The bulk and seed crystal compositions were selected because of the compositional contrast between plagioclase stable in the rhyodacite and the highly anorthitic seed crystals. This model artificially replicates a situation where a significant change in ambient magma composition would initiate growth of plagioclase rims with a lower An content around anorthite xenocrysts. This study resulted in plagioclase growth rates that vary by ~1 order of magnitude across differences in temperature of 80