



Timescales of texture development in a cooling lava dome

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Abstract

Crystal growth and crack development in cooling lava domes are both capable of redistributing and mobilizing water. Cracking and hydration decrease the stability of a dome, which may lead to hazards including partial dome collapse and block and ash flows. By examining the distribution of water around crystals and cracks, we identify and confine temperature and timescales of texture development in glassy rocks of volcanic domes. Four generations of textures have been identified: type a: spherulites, type b: cracks associated with spherulite growth, type c: perlitic cracks, and type d: disparate cracks. High-resolution imaging using Fourier Transform Infrared Spectroscopy (FTIR) performed on samples from the Ngongotaha dome, New Zealand, show an increase in H₂O of up to 450% along gradients of around 100 μm up to 300 μm in length from perlitic cracks, spherulitic cracks and in haloes around spherulites. No gradients in water concentrations across the disparate cracks are present. Water diffusion models show potential timescale–temperature couples that coincide with textural observations and previous studies, and allow us to develop a conceptual model of spherulite growth and cracking in a cooling lava dome. Spherulite growth starts around the glass transition temperature (T_g) when the viscous melt cools to a brittle solid and proceeds with cracking related to volume changes at slightly lower temperatures and shorter timescales (days to weeks) compared to spherulite growth. Perlitic cracking happens at $T \ll T_g$, allowing hydration of a permeable network within weeks to months. Low temperature ($\lesssim 50$ °C) cracks could not be hydrated in the time since eruption (≈ 230 ka). Our data show that textures in cooling glass develop during cooling below T_g within days, producing cracks and crystals that create inhomogeneities in the spatial distribution of water. The lengthscales of water diffusion away from spherulites, spherulite cracks, and perlitic cracks suggest that most of the rehydration of melt/glass occurs at relatively high temperatures (>400 °C). Lack of evidence for water diffusion around other cracks suggests minor low-temperature meteoric water rehydration following emplacement.

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1. INTRODUCTION

Crystallization and crack formation during lava dome cooling increases the likelihood that a lava dome will fail (Platz et al., 2012). Crystal formation and cracking of lava can be observed at any volcanic outcrop; however, constraints of timescales and temperatures of these

alteration processes are incomplete. Understanding the behavior of cooling magma is crucial for using volcanic textures as a proxy for volcanic processes and for estimating the weakening of volcanic rocks. During cooling of a melt crystals grow and cracks form (Davis and McPhie, 1996). The formation of cracks decreases the stability and changes the permeability of volcanic structures such as domes, spines and plugs (Mueller et al., 2004; Kennedy et al., 2009; Platz et al., 2012). The formation of anhydrous crystals rehydrates surrounding glass/melt (e.g. Smith et al., 2001; Castro et al., 2008; Taisne and Jaupart, 2008; Watkins et al., 2008; Gardner et al., 2012), whereas cracks

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shorten diffusion paths for degassing and act as channels for water to leave the rock (Cabrera et al., 2010). Most studies focus on the degassing of melt (e.g. Gonnermann and Manga, 2005; Proussevitch and Sahagian, 2005; Taisne and Jaupart, 2008; Cabrera et al., 2010; Castro et al., 2012). Fewer studies discuss the re-hydration of magmatic melts, which can either be just a redistribution of water or an actual increase of the bulk water content of the magma by hydration with meteoric water (Friedman et al., 1966). Sources of water for redistribution into the melt fraction are collapsing bubbles (e.g. Yoshimura and Nakamura, 2010; Watkins et al., 2012) and growing crystals (e.g. Taylor et al., 1983; Sparks, 1997; Stix et al., 1997).

Around the glass transition temperature (T_g), where a viscous melt cools to a brittle glass, supercooled magma allows heterogeneous crystal growth on pre-existing mineral phases (Swanson et al., 1989; Shtukenberg et al., 2012). In silicate glasses, crystals tend to grow as branched needles to form spherulites. Spherulites are fibrous, often radial aggregates of anhydrous, branched crystals such as SiO_2 phases and feldspars (McPhie et al., 1993). During spherulite formation, anhydrous crystal growth enriches the surrounding glass in water, as the water is incompatible in the anhydrous crystal phases (Castro et al., 2008, 2009), resulting in a halo of increased water content (Smith et al., 2001; Castro et al., 2008). The high volume of exsolved volatiles can lead to the formation of lithophysae (i.e. inflated spherulites (McPhie et al., 1993)) when exsolved volatiles form cavities in the center of the spherulite (Swanson et al., 1989). Timescales of spherulite growth in rhyolites typically range from a few tenths to hundredths of a millimeter per day at eruptive temperatures from 650 °C to 850 °C (Castro et al., 2008) and become prohibitively slow at temperatures less than 400 °C (Watkins et al., 2008). Below T_g , no studies on the possible brittle response of the surrounding glass due to volume changes during crystal growth and water exsolution have been presented.

At surface temperatures diffusion coefficients are too low to allow significant hydration of large volumes of volcanic glass post-eruption. Volcanic glasses with very high water contents of several wt.% are usually perlitic. Perlite is the network of hydrated, arcuate cracks that form during cooling in volcanic glasses (McPhie et al., 1993; Denton et al., 2009). Experiments by Morse et al. (1932) indicated that these cracks form due to the volume increase during hydration. Tuffen and Castro (2009) show that this may explain perlitic development in the products of subglacial eruptions. Another possible explanation for perlitic cracks is thermal cracking during fast cooling, although this is thought to produce more aligned cracks (Davis and McPhie, 1996). Depending on solubility and diffusion rates, interconnected cracks that develop from perlitic lead to dehydration or hydration of the cooling magma (Morse et al., 1932; Marshall, 1961). Spherulites are frequently surrounded by cracks comparable to fracturing resulting from growing bubbles (Romano et al., 1996). This radial cracking and the resulting hydration of the surrounding glass have not been previously described in the literature. The dense network of cracks lowers the stability of glassy domes considerably (Lavallée et al., 2008).

In order to understand the alteration of volcanic domes during cooling, a better comprehension of common textures in volcanic glass is needed. In this study, we estimate time and temperature ranges of cooling textures by measuring water contents across common textural features of volcanic glass such as spherulitic crystals and perlitic cracks. Fourier Transform Infrared Spectroscopy (FTIR) imaging is utilized to resolve the distribution of dissolved water around a spherulite. High-resolution images of water distribution identify and quantify the redistribution of water in a cooling glass and within a variety of textural features that occur during cooling of a magma. We present a detailed study of the hydration occurring around common magmatic textures and provide estimates of mechanisms, timescales and temperatures that lead to the formation of cracks and crystals in a cooling lava dome.

2. METHODS

2.1. Sample selection, characterization and preparation

Ngongotaha dome is a rhyolitic, peraluminous dome that erupted 230 ka ago (Ashwell et al., submitted for publication) as part of the Rotorua caldera formation in the Taupo Volcanic Zone, New Zealand. It consists of several lobes of obsidian of homogeneous chemical composition and low initial crystallinity of <5% (Richnow, 1999). A sample (Ng-10-7) with low spherulitization and perlitization with pristine glass was chosen for analysis. X-ray powder diffractometry on a Philips PW1820/1710 of isolated spherulites yielded ≈ 60 wt.% albite and ≈ 40 wt.% cristobalite. X-ray diffraction patterns were collected between 2Θ values of 3–70° with a generator current of 50 kV, a generator potential of 40 mA (using Cu $K\alpha$ radiation) and a scan speed of 0.02° $2\Theta/s$. Peak areas of each identified phase were measured to estimate relative amounts.

The sample was immersed in epoxy resin at atmospheric pressure in order to prevent further cracking during sample preparation. For FTIR measurements, samples were polished on two parallel surfaces to a thickness of 167 μm using silicon carbide and diamond paste of decreasing grain sizes to 0.25 μm to ensure highly polished surfaces. Ethyl cyanoacrylate (superglue) was used to mount the sample on a glass slide, allowing the second side of the sample to be polished. The superglue was completely removed with acetone to free the samples for analysis. No binding agent was present when the sample was viewed under the microscope.

2.2. Calorimetry

The glass transition temperature of 43.05 mg of chips of Ng-10-7 was estimated using a Netzsch Differential Scanning Calorimeter 404 (DSC) similar to Giordano et al. (2005). A sapphire crystal of approximately the same weight as the sample was used for heat capacity calibration and measurements. The specific heat capacity (C_p) was measured at a heating rate of 10 °C/min in a N_2 -purged furnace. In this study, the temperature at the peak in C_p associated with the glass transition measured at 10 °C/min was used to define T_g .

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