# Excitation of acoustic waves by bubble rupture in a crystal-bearing magma: A laboratory investigation

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Acoustic measurements at volcanoes are commonly conducted to monitor and characterize their activity (Johnson and Ripepe, 2011, Fee and Matoza, 2013). The observed acoustic waveforms are diverse, and we still have limited understanding of their origin. Several laboratory experiments have been previously conducted to better understand the acoustics generated by the rupturing bubble (e.g., Divoux et al., 2008; Kobayashi et al. 2010; Lyons et al, 2013). However the effect of the **magma crystallinity** on the rupturing process and acoustic waves has not been addressed. Here we conduct a series of laboratory experiments which model the bubble rupturing in a crystal-bearing basaltic magma. In the experiments we vary the volumetric fraction of particles $\phi$ in the fluid, as well as the bubble volume and the height surface of the fluid in the conduit. We analyze the acoustic waveforms and high-speed images, to understand the mechanism of acoustic excitation.

To model the crystal-bearing magma, we use an index-matched mixture of silicone oil and silicone powder, which allows us to **visualize** the bubble rising beneath the surface of the fluid. $\phi$ of the particles ranges from $\phi = 0 - 0.5$. From the rheology measurements, we find that the viscosity and the yield stress increase with $\phi$, and that the fluid becomes increasingly shear thinning with $\phi$, a feature common with a crystal-bearing magma. For $\phi = 0.5$ fluid, the bubble did not ascend, and accordingly its acoustics is not measured.

From our experiments, we find that there are three excitation mechanisms (see Kobayashi et al (2010) for a brief review). First is the **vibration of a bubble film** covering the over-pressurized gas inside the bubble. The characteristic frequency is inversely proportional to the bubble radius. Second is the **Helmholtz resonance** of the ruptured air bubble. A bubble with an aperture forms a resonator whose frequency is proportional to the aperture radius and inversely proportional to the bubble volume (Spiel, 1992). Third is the **resonance of the air column** in the conduit above the surface of the fluid (Kobayashi et al., 2010). The resonance frequency is inversely proportional to the air column length. When the free surface of the fluid is low, we find from spectral analyses, that the acoustic waves are excited simultaneously by the Helmholtz resonance of a bubble as well as by air column resonance.

At $\phi = 0$, bubble rupturing occurs after the bubble forms a hemispherical dome at the surface of the fluid. The characteristic frequency of the acoustic wave is around 20 kHz, which is consistent with that of the film vibration. It seems that Helmholtz resonance in the bubble is not excited because the aperture growth is fast. On the other hand, for $\phi = 0.4$ fluid, the waveform indicates a damped oscillation, with a characteristic frequency close to that of Helmholtz resonance. In addition, a long period pressure fluctuation follows after the resonance, which seems to originate from the air flow rising from the ruptured bubble.

Our experiments indicate an acute sensitivity of acoustic waveform to the particle content $\phi$ of the fluid, which affects the **timing of rupturing** and **aperture growth velocity**. The experiments also indicate that identifying different frequency components is important to separately constrain the **bubble volume**, **rheology** and the **height of the conduit** above the surface of magma.

Keywords: bubble, magma, crystals, acoustics, resonance

 