Estimating Magma Decompression Rates of the 3600 yr. BP Plinian Eruption of Cerro Machin Volcano, Colombia

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Introduction

Magma decompression rates are an important control on volcanic eruptive style. In dacitic magma, decompression rates over ~0.001 MPa s^{-1} typically erupt explosively, while dacitic magmas with decompression rates lower than ~0.001 MPa s^{-1} typically erupt effusively (Cassidy,2018). As a result, scientists have found that higher dacitic magma decompression rates correlate with more explosive eruptions. Despite being one of the most explosive eruptions on Earth, few magma decompression rates of dacitic Plinian eruptions have been observed using modern scientific instrumentation. With this study, I seek to examine the rock record to quantify dacitic magma decompression rates at Cerro Machin Volcano during the 3600 yr. BP Plinian eruption. This will allow for a better understanding of Cerro Machin Volcano eruption patterns and potential hazards the future eruptions may pose.

Hypotheses

Hypothesis 1: Magma decompression rates of Cerro Machin's 3600 yr. BP eruption will decrease throughout the eruption due to the eruption waning over time.

Null hypothesis: Magma decompression rates show no significant change as the eruption evolves.

Hypothesis 2 : Bubble Number Density of Cerro Machin 3600 yr. BP eruption will record lower for the inside of pumice clasts compared to the outside of the pumice clast leading to magma decompression rate appearing lower.

Null hypothesis: There will be no significant difference between BND rates at the edges and the centers of the pumices leading to no significant change in magma decompression rates.

Geological Setting

Cerro Machin Volcano is a stratovolcano located in Colombia, South America. Cerro Machin is considered to be one of Colombia's most dangerous volcanoes because of its vicinity to densely populated cities and its demonstrated ability to bring about major explosive eruptions (Laeger et al.,2013). Within the last 5000 years, Cerro Machin has produced at least six large dacitic eruptions which included four Plinian, one Sub-Plinian and one Vulcanian. If an eruption were to happen today, it would effect nearly 1 million people (Cortes,2001). While there have been studies examining Cerro Machin Volcano, there has yet to be a study done to estimate magma decompression rates. The 3600 yr. BP eruption of Cerro Machin is recorded to be one of the four Plinian eruptions based on its pyroclastic deposits (Rueda, 2005). Quantifying magma decompression rates throughout one of Cerro Machin's major volcanic eruptions would hold great significance in understanding the destructive patterns of the volcano.

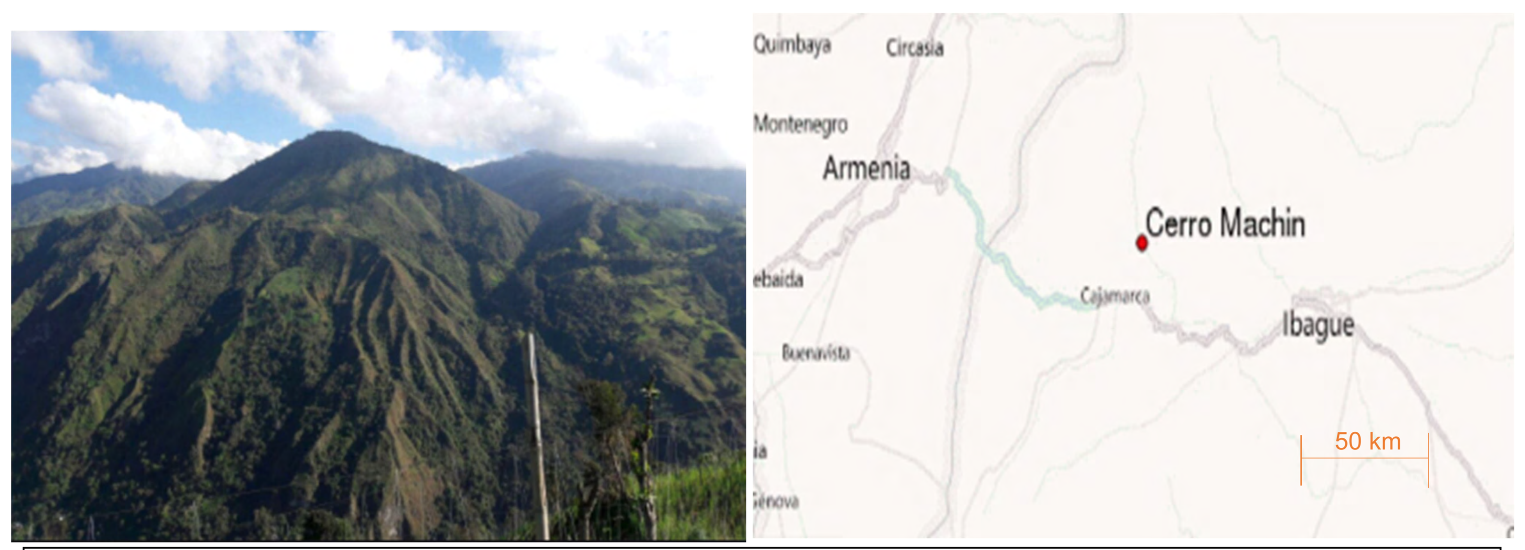


Figure 1a and 1b : Picture of Cerro Machin Volcano, Colombia (Cortes, 2001). Right picture is the map of surrounding area near Cerro Machin Volcano, Colombia (Cortes,2001). Nearby capital cities such as Ibague and Armenia are shown.

Methods

To estimate magma decompression rates, I used the technique of examining Bubble Number Density (BND) of pumice from Cerro Machin's 3600 yr. BP volcanic eruption. During a volcanic eruption, nucleation of bubbles occur due to pressure decreasing as magma rises to the surface. Rapid magma decompression leads to volatile supersaturation in the melt, encouraging the nucleation of many tiny bubbles, leading to high BND. However, slow magma decompression allows bubbles to nucleate and grow at lower degrees of volatile supersaturation, producing magma with low BND. To quantify magma decompression rates from BND, Toramuru (2006), developed a decompression rate-meter equation. While studies have used BND to estimate decompression rates, it still has uncertainties. One uncertainty is the extent to which bubbles in the centers of large pumice clasts are affected by post-eruptive bubble growth. By separately calculating decompression rates from the inside and outside of Cerro Machin's pumice clast, I can examine my results to see if they are affected by post-eruptive bubble growth.

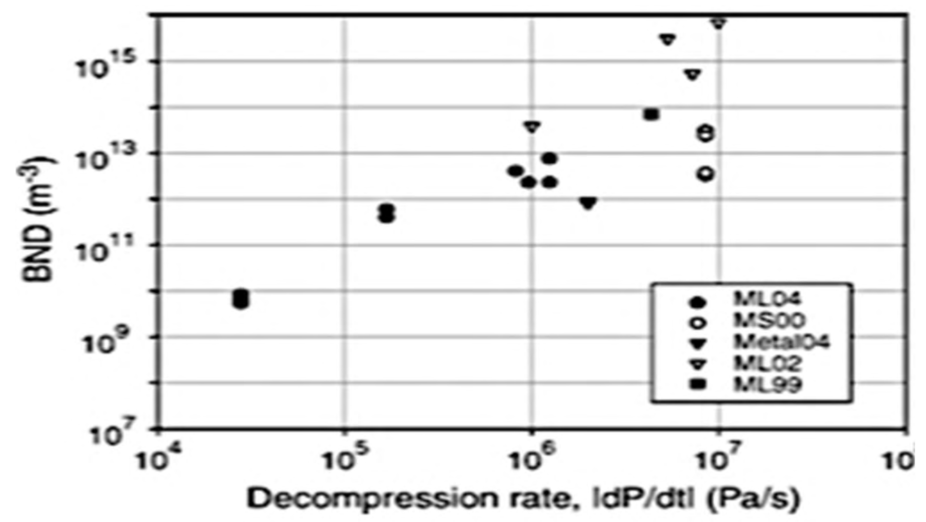


Figure 2: BND versus magma decompression rate of experimentally decompressed magmas (Toramaru 2006). Experimental data show a strong positive correlation between BND and magma decompression rate. The data in this figure is used by Toramaru (2006) to calibrate a BND decompression rate meter that can be applied to natural samples of pumice with unknown decompression histories.

Figure 3a and 3b: Pumice clasts were sampled from the 3600 yr. BP fall deposit (left picture), scale is in centimeters. The fall deposit was split up into three phases based on Rueda (2005). In this study, I examined a 1 cm pumice clast (right picture) from the middle phase of the volcanic eruption.

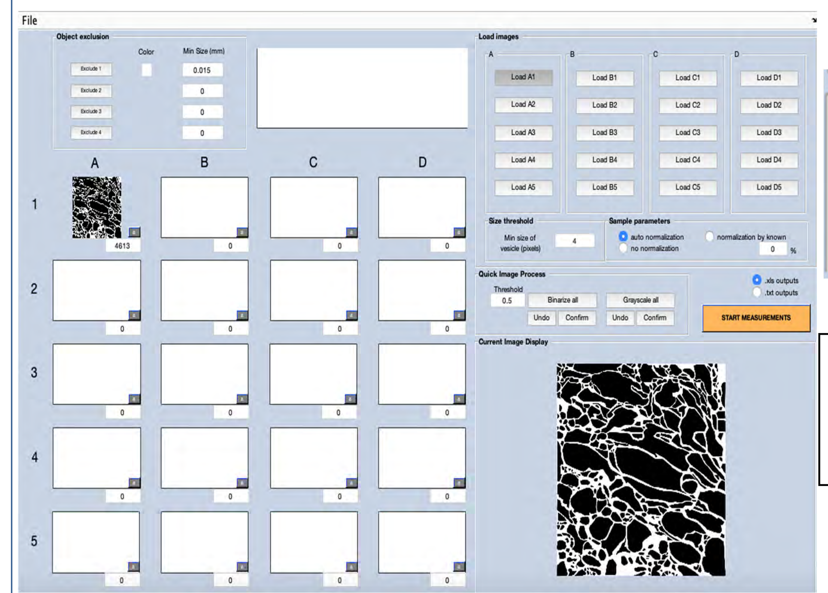
To calculate BND,I used a MATLAB application called FOAMS. FOAMS is an image acquisition application, that uses 2-D images of bubbles to calculate 3-D vesicles. Two images of the inside of the pumice and two images of the outside of the pumice were taken using a JEOL JXA-8900R Scanning Electron Probe in the Backscattered Electron setting. The images were edited in Adobe Photoshop and Illustrator using Shea et. al (2010) methods. The images were then inputted into FOAMS to obtain BND for three different experiments. For the first experiment, all images were inputted one at a time to get four plausible BNDs for the middle of the volcanic eruption. The second experiment found BND from two images at the outside of the pumice and the third experiment found BND from inputting two images from the inside of the pumice.

Inside Images

Outside Images

Figure 4 : Edited images of Cerro Machin pumice. Inside images were taken 5 mm inside of the pumice and outside images were taken at the outside natural edge of the pumice. Inside and outside images were taken at both 250x magnification (right image) and 450x magnification (left image).

Methods



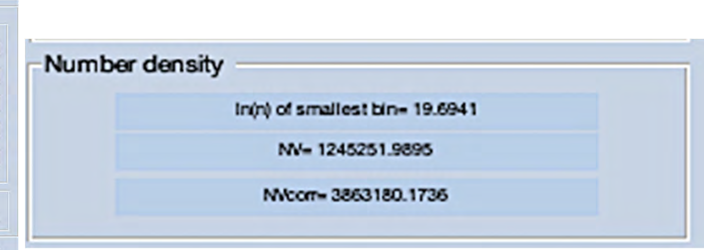


Figure 5a and 5b: Picture to the left shows an example of FOAMS processing screen for image four. Right picture shows FOAMS output of corrected BND, Nvcorr= 3.9 x 10^6 mm^{-3}.

After obtaining BND, magma decompression rates were calculated using Toramaru (2006) decompression rate meter equation.

$$\left|\frac{dP}{dt}\right| = a \cdot D \cdot \sigma^2 \cdot P_W^{-1/3} \cdot T^{-1/2} \cdot N^{2/3}$$

Figure 6: Toramaru (2006) decompression rate meter equation. *N* represents BND. Laeger (2013) tested the conditions of crystallization of amphiboles in Cerro Machin's 900 yr. BP eruption and found pressure (*P*) of water during the eruption to be 3.6 x 10^8 Pa and temperature (*T*) to be 1243 Kelvin. The interfacial tension variable o^2 was assumed to be 0.025 N m^{-1} for heterogenous nucleation (Shea, 2017). The diffusivity of H2O (*D*) was calculated using Zhang (2007) diffusivity equation to be 9.2 x $10^{-14} m^2 s^{-1}$ and *a* represents the constant 3.5 x 10^{14}.

Discussion

Experiment 1

	Bubble Number Density	Decompression Rates	AVERAGE Decompression Rate
1st IMAGE	4.0 x 10^5 mm^-3	1.7 x 10^5 Pa/s	4.0 x 10^5 Pa/s
2nd IMAGE	2.1 x 10^5 mm^-3	1.1 x 10^5 Pa/s	
3rd IMAGE	2.2 x 10^6 mm^-3	5.4 x 10^5 Pa/s	
4th IMAGE	3.9 x 10^6 mm^-3	7.9 x 10^5 Pa/s	

Experiment 2

Outside	Bubble Number Density	Decompression Rates
2 IMAGES	3.5 x 10^6 mm^-3	7.4 x 10^5 Pa/s

Experiment 3

Inside	Bubble Number Density	Decompression Rates
2 IMAGES	1.7 x 10^6 mm^-3	4.5 x 10^5 Pa/s

Figure 7: Tables show calculated magma decompression rates for Cerro Machin 3600 yr. BP eruption.

The goal of this study was to determine bubble number density of Cerro Machin's pumice from its 3600 yr. BP eruption in order to calculate magma decompression dates. From our analysis of Cerro Machin pumice, we have started to understand the magma decompression rates of the 3600 yr. BP eruption. For the outside of the pumice clast I got 3.5 x 10^6 mm^{-3} for BND. For the inside I got 1.7 x 10^6 mm^{-3}. These numbers are not significantly different. This is in support of my null hypothesis that there is no significant difference of BND between the inside and outside of the pumice. This has lead to no significant change in magma decompression rates leading to the idea that this Cerro Machin pumice clast was not affected by post-eruptive bubble growth . With more data from Cerro Machin pumice, I can conclude my findings. From my first experiment, I got an overall magma decompression rate of the middle phase of Cerro Machin's 3600 yr. BP eruption. This magma decompression rate recorded to be 4.0 x 10^5 Pa s^{-1}. This magma decompression is closely related to other Plinian eruptions such as the eruption of Mount. Vesuvius in 512 A.D. Pumice clasts from Mount Vesuvius' eruption recorded a magma decompression rate of 4.7 x 10^6 Pa s^{-1} (Shea, 2017).

References

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