Using Water Concentration Gradients in Quartz to Determine Magma Decompression Rate

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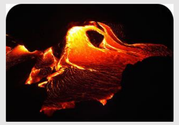
Introduction

- Volcanic eruptions are inherently dangerous. Explosive eruptions produce hot pyroclastic flows and widespread ash deposits, which can ruin plants and crops and sometimes result in the deaths of people and animals.



- Effusive volcanic eruption on left.- Lava flow, Hawaii,(Jan. 26, 2011). Credit: Paul Bica
- Explosive volcanic eruption, Mt Etna volcano on right Credit: Wanted in Rome (March 4, 2021).

- Effusive eruptions are usually less hazardous, but their associated lava flows can sometimes have the same effects as explosive eruptions.
- The eruptive style of a volcano is thought to depend on the magma decompression rate. In this study, we mapped water concentration gradients in quartz crystals to calculate the decompression rate as well as the magma ascent rate of Cerro Machin Volcano.
- Cerro Machin Volcano is situated in the central cordillera of Colombia, South America. The quartz crystals were collected from the eruption that occurred 3600 years ago which is the largest known eruption of Cerro Machin.

- Location on Cerro Machin Volcano on the map. Google Image.

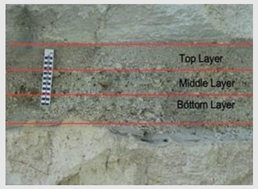
- Aerial view of Cerro Machin volcano (16 November 2011). Picture retrieved from the Smithsonian Institution Global Volcanism Program database. Courtesy of INGEOMINAS.

Hypotheses

- Hypothesis: Water Concentration at the edge of the crystal is different from the center because water diffuses out of the crystal as it moves up the conduit. If the quartz crystals are zoned in water concentration, the gradient can be used to calculate the magma ascent rate.
- Alternative Hypothesis: The quartz crystals are not zoned with respect to water and therefore cannot be used to calculate the magma ascent rate

Methods

A



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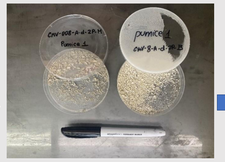

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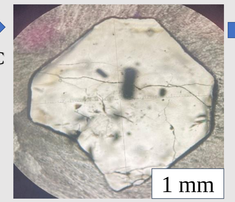

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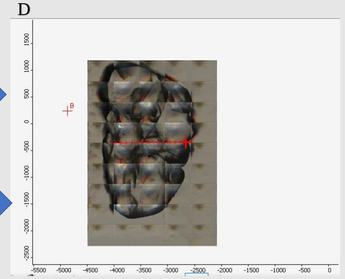
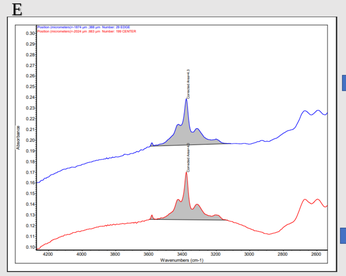


- A- Layers from which the quartz crystals were picked. The red lines show the boundaries of the top, middle and bottom layers. Scale is in cm.
- B- The crushed samples collected from the middle and bottom layers.
- C- The polished surface of one quartz crystal collected from the bottom layer.
- D- Mosaic of the quartz crystal from the lower layer of the deposition with points picked for measurements.
- The point B marks the background set to eliminate the atmospheric CO_2 and water vapor.
- The red line across the crystal shows the points chosen going from E-W. The points chosen on this crystal goes from 0 µm to 1300 µm (one edge to the other edge).
- This process is done using the Nicolet iN10 MX Fourier Transform Infrared spectrometer (FTIR) used to map the water gradients in the crystals

Results

E



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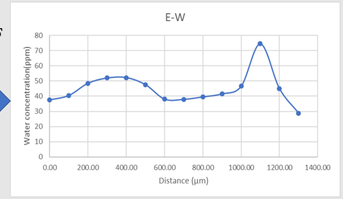

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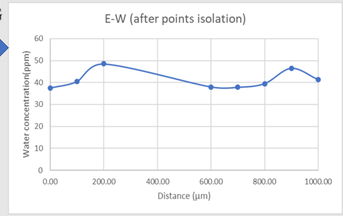
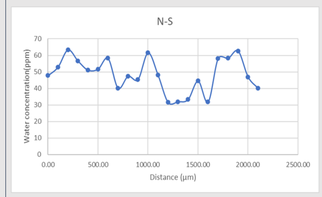
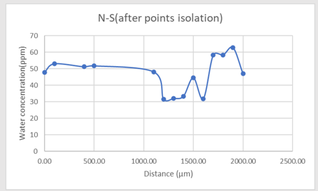


- E- Area shaded under curve correlates with water concentration with the blue curve representing the edge (area under blue curve= 4.3) and red curve representing the center (area= 4.0).
- The red and blue curves both have a starting absorbance point which is at 0.10 micrometers, and they are offset to see the difference between the area under the curves.
- F- Plot of the water concentration (ppm) against all the points chosen (µm) including the points with the anomalies on the crystal in the E-W direction(0 µm to 1300 µm).
- G- Plot of the water concentration(ppm) against the points without contaminations (µm) in the E-W direction.
- The water concentrations in ppm were calculated using the modified Beer–Lambert law $c = \frac{A_{tot} * M_i}{\varepsilon_i * \rho * t}$ retrieved from Hencz et al. (2021)



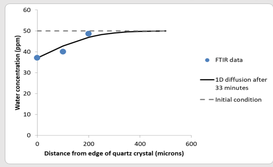
- H- Plot of the water concentration (ppm) against all the points chosen (µm) including the points with the anomalies on the crystal in the N-S direction.



- I- Plot of the water concentration(ppm) against the points without contaminations (µm) in the N-S direction.

- The calculated water concentration using the along the E-W direction of the crystal when oriented along the c-axis is ~44 ppm (with a range of 28-74 ppm) and along the N-S direction is ~48 ppm (with a range of 31-60 ppm).

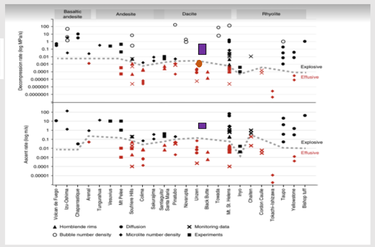
Results and Discussion



- J- An analytical solution of the 1D diffusion equation; $log_{10}D_0 + \frac{-E_a}{2.303RT}$ (Jollands et al. 2020) was applied to the first three points at the edge of the crystal from the east to west measurements to calculate the magma ascent rate.
- Preliminary estimate of magma ascent rate is ~33 minutes.

	Pressure	Pressure	Decompression Rate	Acceleration of Gravity	Magma Depth	Magma Speed
	MPa	N/m²	(MPa/s)	(m/s²)	(m)	(m/s)
Minimum	100	100000000	0.0505	9.8	3580.37	1.808
Maximum	500	500000000	0.2225	9.8	17901.9	9.041

- For the calculation of the magma depth and speed, in the table above the ascent time was converted to be 1980 seconds from 33 minutes, and the lithostatic gradient (crustal density) was assumed to be 2850 kg/m^3 according to Ferguson et el., 2016.
- K- Plot collects ascent and decompression rate data from a range of different techniques, including bubble number density, experiments, hornblende rims, extrusion rate and diffusion rates. Courtesy of Cassidy et al., 2018.



- Cerro Machin magma was stored at a pressure range of ~100 – 500 MPa (based on melt inclusion and amphibole barometry by S. Castilla). This pressure range corresponds to a depth of ~17 km using the equation h=P/(p*g).
- My decompression rate estimate for Cerro Machin falls between ~0.05 MPa/s and ~0.3 MPa/s as indicated with the purple box. This is similar to other diffusion-based estimates of magma decompression rate.
- As observed in other studies, our water diffusion-based estimate is lower than decompression rate estimates from bubble number density in pumice (which is about 6.5 MPa/s as calculated by Makayla Etheredge). This may be because bubble number densities record magma decompression at the top of the conduit, but water diffusion begins deep in the conduit where the magma is decompressing more slowly.
- This range also falls above the effusive-explosive line, as expected for this highly explosive Plinian eruption of Cerro Machin Volcano.

References

- Bica, P. (2011) Lava Flow. https://commons.wikimedia.org/wiki/File:Flickr_-_paul_bica_-_flowing_rock.jpg
- Cassidy, M., Manga, M., Cashman, K., and Bachmann, O. (2018). Controls on explosive effusive volcanic eruption styles. Nature Communications, 9(1), 1–7. https://doi.org/10.1038/s41467-018-05293-3
- Ferguson, D. J., Gonnermann, H. M., Ruprecht, P., Plank, T., Hauri, E. H., Houghton, B. F., & Swanson, D. A. (2016). Magma decompression rates during explosive eruptions of Kilauea volcano, Hawaii, recorded by melt embayments. Bulletin of Volcanology, 78(10), 1-12. https://link.springer.com/article/10.1007/s00445-016-1064-x
- Global Volcanism Program, 2012. Report on Machin (Colombia) (Herrick, J.A., and Wunderman, R., eds.). Bulletin of the Global Volcanism Network, 37:11. Smithsonian Institution. https://doi.org/10.5479/si.GVP.BGVN201211-351040
- Hencz, M., Biró, T., Kovács, I. J., Stalder, R., Németh, K., Szakács, A., Pálos, Z., Pécskay, Z., & Karátson, D. (2021). Uniform "water" content in quartz phenocrysts from silicic pyroclastic fallout deposits – implications on pre-eruptive conditions. European Journal of Mineralogy, 33(5), 571–589. https://doi.org/10.5194/ejm-33-571-2021
- Jollands, M. C., Ellis, B., Tollan, P. M., & Müntener, O. (2020). An eruption chronometer based on experimentally determined H-Li and H-Na diffusion in quartz applied to the Bishop Tuff. Earth and Planetary Science Letters, 551, 116560. https://www.sciencedirect.com/science/article/pii/S0012821X20305045
- Wanted in Rome (2021). Italy: Mount Etna Emits 12 km High Ash Plume into Sky. Accessed April 24 https://www.wantedinrome.com/news/italy-mount-etna-emits-12-km-high-ash-plume-into-sky.html