Analyzing Water in Plagioclase to Estimate Pre-Eruptive Relative Storage Depths of Mount Spurr Magma

By: Sami Toibero GEOL394 Advisor: Dr. Megan Newcombe

University of Maryland Department of Geology

Introduction

This study used water-in-plagioclase hygrometry to estimate magma storage depth prior to the September 1992 eruption of Mount Spurr, Alaska. Five hand-picked crystals from the eruption were polished on two parallel faces and analyzed using Fourier Transform Infrared Spectroscopy (FTIR) with unpolarized infrared light to determine their water concentrations. Structural OH^- bonds absorb infrared light going through crystal wafers, and the FTIR produces spectra with a broad OH^- absorbance peak between 2600 cm^{-1} to 3600 cm^{-1}. The area of this absorbance peak is proportional to water concentration. One crystal was hand-picked and cut in half to produce two perpendicular wafers that were used to obtain the water concentration by summing the absorbance in three perpendicular directions using polarized infrared light.

Hypotheses

Null Hypothesis: Depths estimated from water in plagioclase are the same as estimates from amphibole equilibria.

Alternative Hypothesis: Depths estimated from water in plagioclase are not in agreement with estimates from amphibole equilibria

Methods

Choose grains

Method 1: Doubly Polish → Clean → Array Detector → Depth Calculations

Method 2: Wire Saw → Polish Halves → Clean → Cooled MCT Detector → Add Absorbances → Depth Calculations

Fig. 1: A step-by step representation of the methods from choosing a grain, cutting it in half, polishing it, analysis, and calculations that yield the depth for each sample.

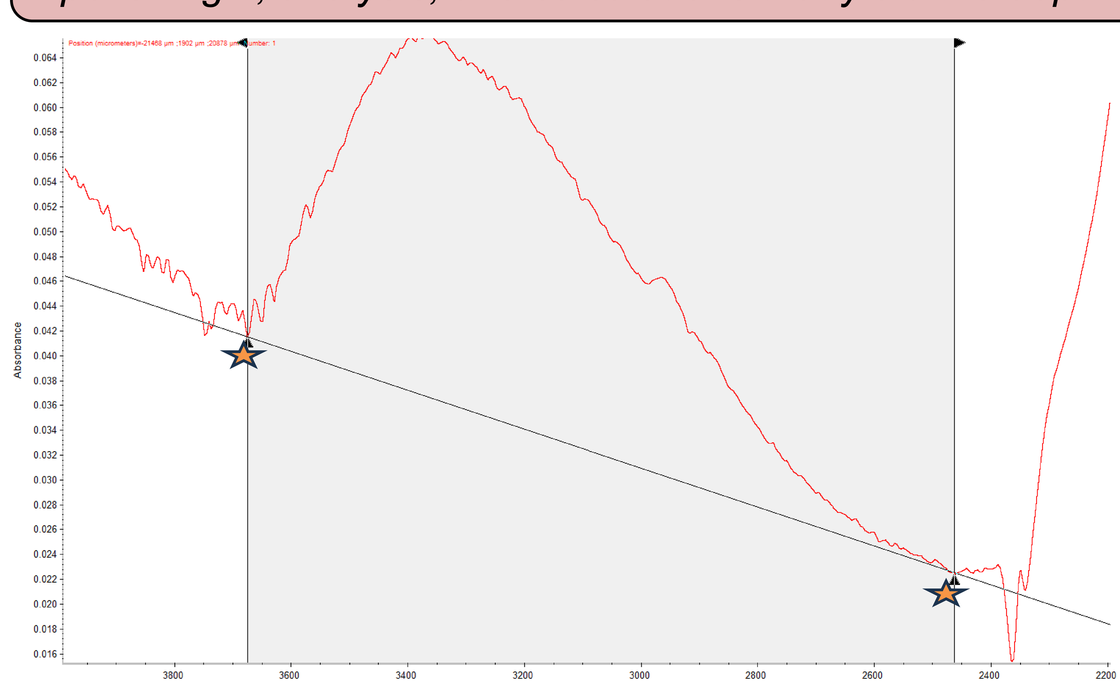

Fig. 2: Example image of the FTIR output spectra of the OH- absorbance peak using OMNIC Picta software. Orange stars with a black outline are used to highlight the two ends of the baselines. The area under the peak is proportional to the water concentration in the sample.

Results

In total, six plagioclase grains from the September 1992 eruption were successfully analyzed. Of these, one was cut and polished using Method 2 and the other five were doubly polished on parallel sides (Method 1). A contour map of each crystal was made with the FTIR and ten points per crystal were extracted from this map and used to measure the OH- absorbance peak. These ten points were averaged to estimate the total absorbance of water within the crystal.

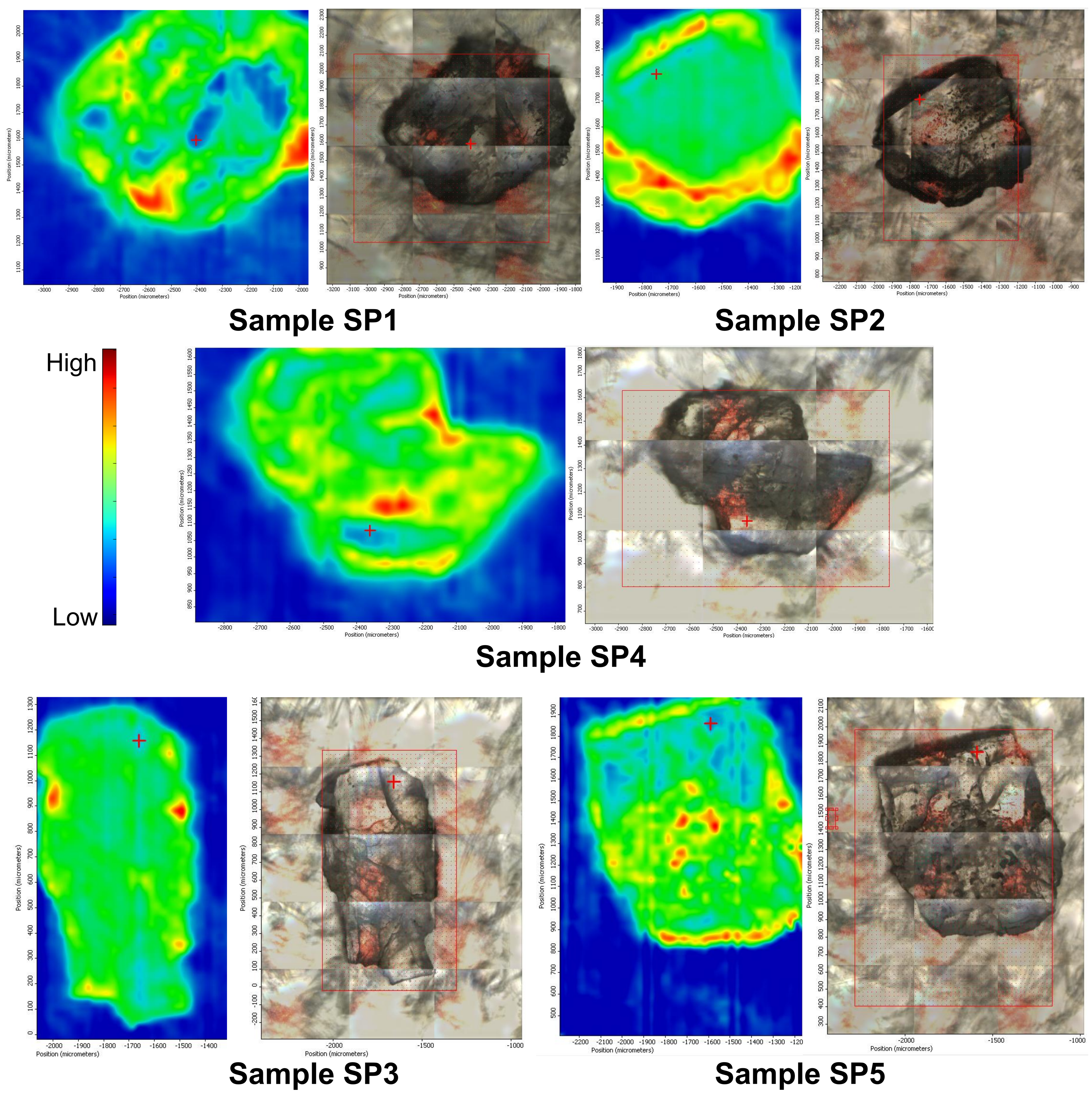

Fig. 3: The contour map on the left shows the OH absorbance of the area map of sample SP1 on the right. The x and y-axis are both the position in micrometers. Blue regions indicate lower absorbance while red regions indicate high absorbance. The red cross towards the center of the contour map represents an example of one of the collected data points. Data points were confined to blue regions of the contour map to avoid fluid or melt inclusions that do not represent structurally bound OH and therefore cannot be used to estimate magmatic water concentrations by applying a plagioclase-melt partition coefficient.

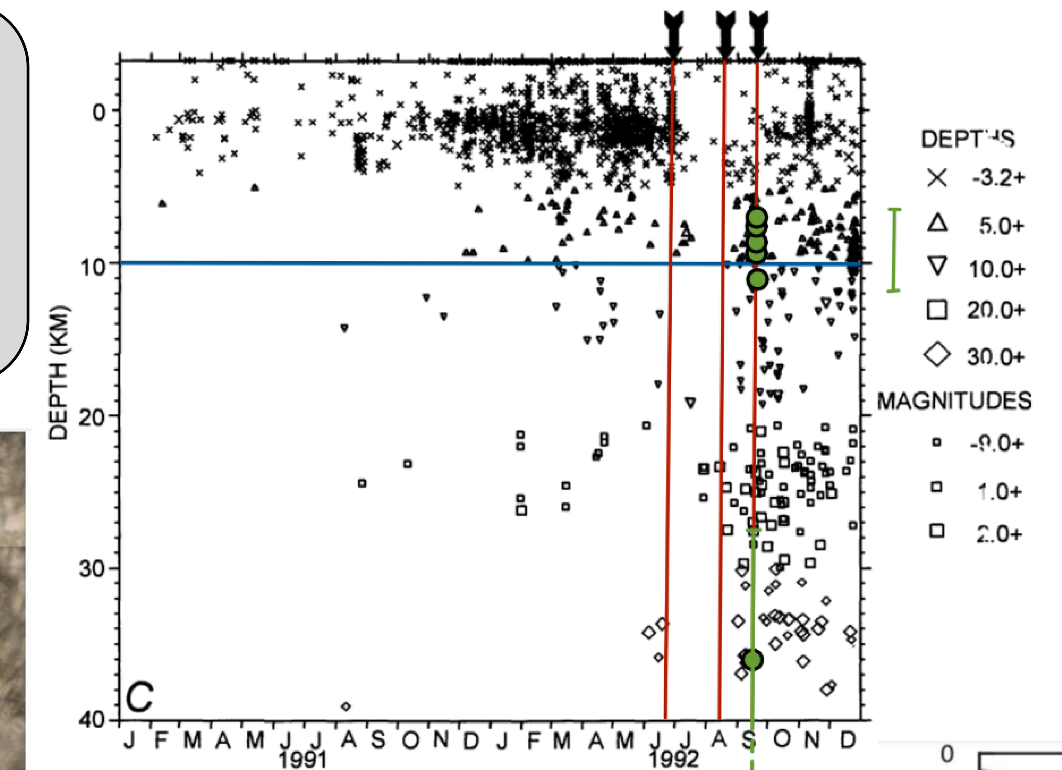

Fig. 4: Depths and associated error bars for each sample superimposed onto the Power et al. (1995) seismicity graph as green circles. The vertical green line on the right represents the average error. Sample SP6 is an exception and has its respective error bar. The horizontal blue line is indicative of the ≥ 10 km depth from Roman and Cashman (2018).

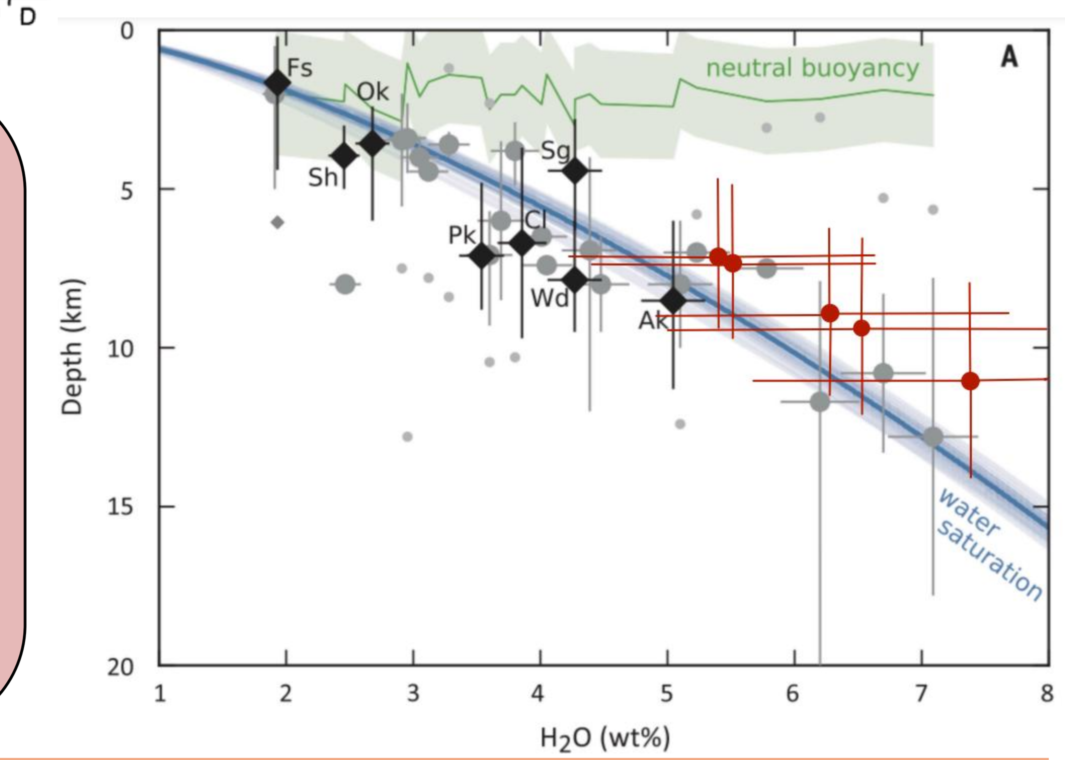

Fig. 5: Depths for samples SP1 through SP5 are plotted as red circles with their respective error bars on the saturation curve by Rasmussen et al. (2020). It should be noted that sample SP2 extends to the wt. % of 9.1 on the x-axis. Sample SP6 cannot be plotted on this graph due to its high wt. % and greater depth. The black and gray dots refer to the other Aleutian Arc volcanoes.

Sample Name	Peak Area (cm^{-1})	C_{H2O} Plag (ppm)	C_{H2O} Melt (wt. %)	Pressure (bars)	Depth (km)
SP1	53.265	131 ± 13	6.5 ± 1.5	2580 ± 770	9.3 ± 2.8
SP2	42.341	149 ± 16	7.4 ± 1.7	3000 ± 850	11 ± 3.1
SP3	37.380	110 ± 11	5.5 ± 1.1	2030 ± 650	7.3 ± 2.4
SP4	47.472	126 ± 13	6.3 ± 1.4	2460 ± 790	8.9 ± 2.7
SP5	36.841	107 ± 11	5.4 ± 1.2	1960 ± 630	7.1 ± 2.3
SP6	59.95, 83.15, 248.3	405 ± 41	20 ± 4.5	10000	36.0 ± 8.5

Tbl. 1: Walk-through of the calculations needed to go from measured peak area to depth. The third column refers to the concentration of water in plagioclase and the fourth column refers to the concentration of water in an equilibrium silicate melt. The greater water concentration in melt for SP6 is due to the likelihood that this crystal was contaminated by melt/fluid. If we assume no contamination, this crystal would have an implied crystallization pressure ~1 GPa.

Conclusion/Discussion

The method developed by Kovács et al. (2008) was applied to determine pre-eruptive depths from doubly polished samples. Calculated depths were relatively close to each other, ranging from ~7-11 km deep with sample SP6 as an outlier. When plotted alongside the calculated depths for amphibole from Roman and Cashman (2018), these results show they are located slightly shallower than expected but still broadly consistent. This could be due to amphibole naturally forming deeper than plagioclase, or it could show that the minimum depth is actually shallower than the study found.

References

Kovács, I., Hermann, J., O'Neill, H. S. C., Gerald, J. F., Sambridge, M., & Horváth, G. (2008). Quantitative absorbance spectroscopy with unpolarized light: Part II. Experimental evaluation and development of a protocol for quantitative analysis of mineral IR spectra. American Mineralogist, 93(5-6), 765-778.

Roman, D. C., & Cashman, K. V. (2018). Top–down precursory volcanic seismicity: Implications for 'stealth' magma ascent and long-term eruption forecasting. Frontiers in Earth Science, 6, 124.

Power, J. A., Jolly, A. D., Page, R. A., & McNutt, S. R. (1995). Seismicity and forecasting of the 1992 eruptions of Crater Peak vent, Mount Spurr Volcano, Alaska: An overview. US Geol. Surv. Bull, 2139, 149.

Rasmussen, D. J., Plank, T. A., Roman, D. C., & Zimmer, M. M. (2022). Magmatic water content controls the pre-eruptive depth of arc magmas. Science, 375(6585), 1169-1172.