Modeling Compressibility and Pressure Changes in a Magma Chamber prior to the 2006 eruption of Augustine Volcano, Alaska

Wasser[1], V.K., Lopez[1], T.M., Izbekov[1], P.E., Freymueller[1], J. T., Anderson[2], K. R.
[1]Geophysical Institute, University of Alaska Fairbanks, USA
[2] CalVO, USGS, Menlo Park, California, USA

Geodesy is an integral part of volcano monitoring; however, volume estimates based on volcano deformation usually underestimate the volume of erupted material. Specifically, in the case of the Augustine 2006 eruption, the dense rock equivalent (DRE) of the erupted volume was three times larger than the modeled volume based on the deflation signal. The discrepancy is thought to be caused to a significant degree by magma compressibility.

Magma compressibility describes how a given mass of material changes volume as a function of pressure; compressible magma will occupy less volume at higher pressures. Magma compressibility is strongly dependent on the amount of exsolved gas present within the chamber, and also influenced by the relatively poorly constrained chamber compressibility.

The goals of this study are: (1) to calculate the magma compressibility, the chamber compressibility and the exsolved gas volume for the Augustine 2006 eruption based on existing geodetic, gas emission, and petrology data; and (2) finding an upper limit for the pressure increase caused by magma recharge prior to the eruption.

Here we use the following equations from Mastin et al. (2008) and Mastin (2002) to model the magma compressibility at Augustine volcano:

$$\frac{V_{DRE}}{deformation} = 1 + \frac{\beta_{magma}}{\beta_{chamber}} \tag{1}$$

And

$$\beta_{magma} = \beta_{gas} \times \mathcal{V}_{gas} + \beta_{melt} \times \mathcal{V}_{melt} + \beta_{crystals} \times \mathcal{V}_{crystals} \tag{2}$$

Where β stands for the compressibility of the magma and chamber, V_{DRE} for the volume of erupted material, and $\mathcal{V}$ for the volume fraction of gas, melt and crystals. Deformation was defined here as the volume of deflation that was measured during the eruption.

We conducted three different model iterations to solve for one of the key parameters using existing constraints on the other two parameters:

a) magma compressibility (β_{magma}) based on estimates of an exsolved gas volume and the compressibility of the chamber ($\beta_{chamber}$).

b) chamber compressibility ($\beta_{chamber}$) based on estimates for an exsolved gas volume and melt compressibility (β_{melt}).

c) exsolved gas volume based on previous estimates from the literature for the values of the melt and chamber compressibilities ($\beta_{chamber}$, β_{melt}).

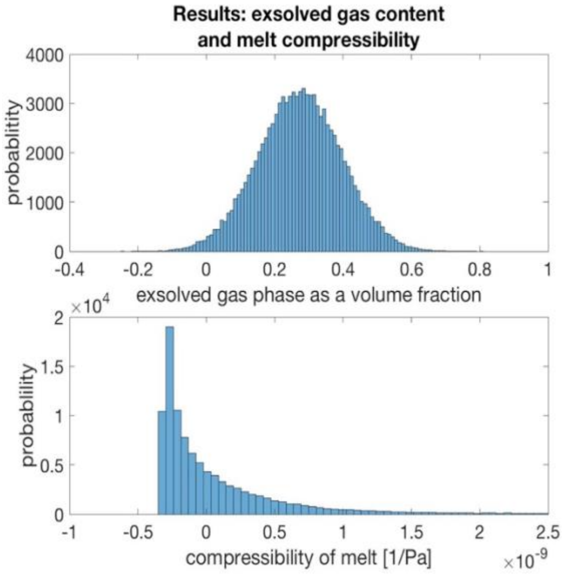

Fig. 1. Resulting probability distribution function of a) the exsolved gas phase (volume fraction) and b) compressibility of the melt calculated with model iteration one.

We used geodetic data of Cervelli et al. (2010), petrology data of Larsen et al. (2010) and erupted volume estimates of Coombs et al. (2010). For iteration a) and b), we additionally used petrology data of Webster et al. (2010) and gas emission data of McGee et al. (2010).

The results from our model (Fig. 1) show a discrepancy between what are thought to be reasonable values for the exsolved gas volume fraction (~30%) and the chamber compressibility as can be seen from the negative compressibility values. Two possible explanations for this discrepancy are that (1) existing estimates of chamber compressibility or volume of the exsolved gas phase are inaccurate, or (2) degassing of a significant quantity of unerupted magma occurred during the Augustine eruption. Scenario 2 could indicate that there may be a large volume of magma underneath Augustine.

Pressure Changes

Fifty representative plagioclase crystals from one high-silica andesite tephra sample from the 2006 Augustine eruption were analyzed using the JEOL JXA-8530F electron microprobe at the Advanced Instrumental Laboratory at UAF. The primary goal of this work is to find dissolution surfaces and associated increases in anorthite contents that are thought to be caused by magma recharge.

Anorthite content of plagioclase crystals is a function of pressure, temperature, and melt composition. We assume that in a large magma body only crystals proximal to a fresh mafic injection will be significantly affected by a temperature increase and a possible change of melt composition, whereas all of the crystals will be affected by a pressure increase. We focus on large oscillatory-zoned plagioclases, which experienced less or no P-T-x_{melt} disturbances as compared to all other populations of plagioclases. Based on our assumptions, the outermost dissolution surface followed by a subtle rim-ward increase of anorthite content in the outermost zone of oscillatory zoned plagioclases may be associated with the last pressure buildup caused by a mafic recharge. The pressure buildup alone can cause the unthawing of a water-saturated magma and the partial dissolution of plagioclase crystals, forming the dissolution surface. The eruption triggered by the mafic recharge will suddenly decrease pressure and cause plagioclase growth again. Importantly, the difference of plagioclase composition before and after the pressure build up is directly related to the amplitude of pressure increase. In this work we use subtle changes in plagioclase composition as a pressure gauge to quantify the pressure build up prior to the 2006 Augustine eruption.

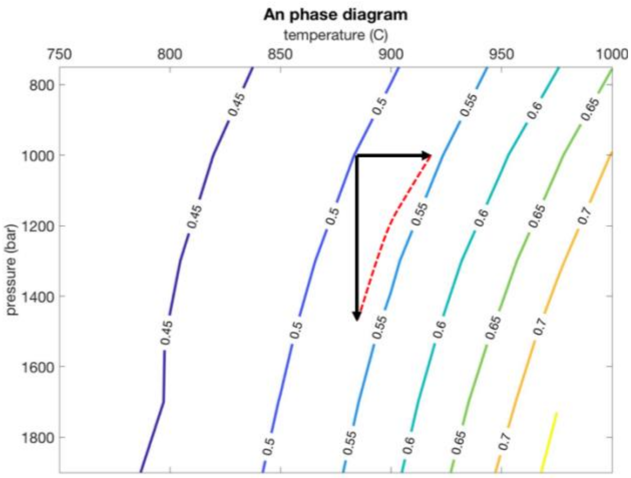

Fig. 2. Model of pressure increase in the magma chamber based on MELTS program and plagioclase data (Ghiorso and Gualda, 2015; Gualda et al. 2012). The contour lines indicate the An content of plagioclase crystals. The red line marks the range of possible conditions after the magma recharge.

Rhyolite MELTS was used to identify potential correlations between the anorthite content and the pressure/temperature changes (Ghiorso and Gualda, 2015; Gualda et al. 2012). Preliminary results show that the difference in anorthite content across the dissolution surface is between 4-25 mol%. This change in plagioclase composition is consistent with a pressure increase of ca. 500 bars prior to the 2006 eruption of Augustine Volcano. This pressure increase is affecting the compressibility of the magma calculated in the first part. In this presentation we discuss these preliminary results and future work related to this project.

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