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Chemical diffusion during isobaric degassing of magma

Felix W. von Aulock (1), Ben M. Kennedy (2), Yan Lavallée (1), Sarah Henton-de Angelis (1), Christopher Oze (2), Daniel J. Morgan (3), and Steve Clesham (1)

(1) University of Liverpool, Liverpool, United Kingdom (f.von-aulock@liverpool.ac.uk), (2) University of Canterbury, Christchurch, New Zealand, (3) University of Leeds, Leeds, United Kingdom

During ascent of magma, volatiles exsolve and bubbles form. Volatiles can either escape through a permeable network of bubbles in an open system or be trapped in non-connected pores during closed system degassing. Geochemical studies have shown that in most cases both- open system and closed system degassing take place at the same time. During cooling of the melt, diffusion slows down and eventually diffusional gradients get frozen in, preserving a history of degassing and rehydration during bubble growth, bubble collapse and crystal growth.

We present data from experiments in which natural obsidian was degassed at atmospheric pressures at 950ºC over timescales of 3-24h. During bubble growth, a skin formed, at the outer edge of the sample, effectively prohibiting any degassing of its interior. Diffusion gradients were measured across the glass surrounding vesicles, and across this impermeable skin. Water contents were analyzed with synchrotron sourced Fourier transform infrared spectroscopy and several major, minor and trace elements were mapped using synchrotron sourced X-ray fluorescence spectroscopy.

The samples show a dimpled surface, as well as signs of oxidation and growth of submicroscopic crystals. Water contents around bubbles decrease in simple heating experiments (from ∼0.13 wt. % down to ∼0.1 wt. %), whereas slight rehydration of the vesicle wall can be observed when a second, cooler step at 850ºC follows the initial 950ºC. Water gradients towards the outside of the sample decrease linearly to a minimum of ∼0.045 wt. %, far below the solubility of water in melts at these temperatures. We mapped the distribution of K, Ca, Fe, Ti, Mn, Rb, Sr, Y and Zr. Especially the trace elements show a decrease towards the outside of the sample, whereas K, Fe, Ca and Ti generally do not show significant partitioning between melt and gas/crystal phase. Several effects could attribute to the distribution of these elements, such as the crystal growth and exchange with atmospheric oxygen, and detailed models of the diffusion of these elements will have to verify the mechanisms of elemental partitioning during degassing

Our experiments show that even on a small scale, open system and closed system degassing inherently coexist. This manifests itself in different elemental distribution in the quenched glass. Water distribution gradients can be explained with diffusion during exsolution and rehydration during cooling, however, the surface of the sample is undersaturated in water. Some trace elements follow the same pattern, even though they might not be considered as volatile. Therefore we suggest that chemical gradients may be partially induced by the growth of sub-microscopic crystals and by exchange with the atmosphere. Crystal rich, volatile poor outer skins, as produced in the experiments of this study, have locally drastically increased viscosities and can therefore withstand higher pressures during foaming of the interior of the sample. This self sealing of magma could be an important process on different scales of magma degassing, from bread crust bombs to rising magma in conduits.