

Diffusive growth of water bubbles in rhyolitic melts

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Rates of volatiles exsolution and bubble growth are important in determining the nature of volcanic eruptions. Bubbles grow by diffusive flux of volatiles from the supersaturated melt into the bubble, and by expansion, in response to pressure release. Here we report the results of experimental and numerical investigation of diffusive growth of water bubbles at constant pressure.

Experimental procedure

Rhyolitic obsidian containing less than 1% microlites of Fe-Ti oxides was hydrated at 150 MPa and 780–850°C. After saturation was reached (5.3–5.5 wt% water), pressure was dropped rapidly and held at a new lower value (15–145 MPa), and bubbles were allowed to nucleate and grow from the supersaturated melt for variable amounts of time. Finally, samples were quenched by dropping them into the pre-cooled zone of the pressure vessel. This rapid quenching and the high viscosity of the melt prevented significant shrinkage of bubbles. Calculations predict that bubble volume decreased by less than 5%. The quenched vesiculated glasses were polished and the number density and size of the bubbles were measured in the bulk of the sample under a microscope.

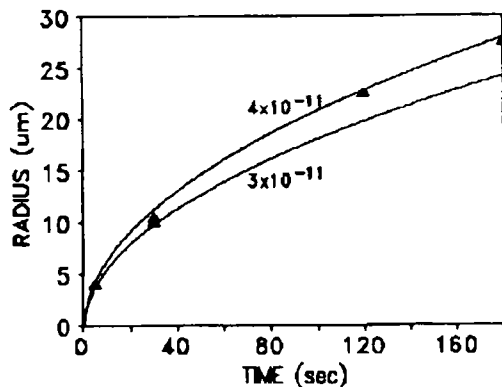


FIG. 1. The growth of bubble radius with time. Triangle - experiments, curves - modelling with $D = 3 \times 10^{-11}$ m²/sec and 4×10^{-11} m²/sec.

Experimental results

The number density of bubbles depends strongly on the availability of nucleation sites (Hurwitz and Navon, 1994). This dependence leads to variation of up to five orders of magnitude in number density of bubbles between runs where microlites were still present, and high temperature runs where they were fully dissolved. As a result, the spatial separation between neighboring bubbles varies by about two orders of magnitude. Bubble size in individual samples is relatively uniform. In most samples standard deviations from the average radius are less than 20%. The average bubble radius varies between 2–160 μm, and is controlled mainly by the final pressure, the time spent at that pressure, and the separation between bubbles. In a series of experiments, that were held at $P_{\text{final}} = 120$ MPa for different lengths of time, and where the average separation between bubbles is large compared to their radius ($S > 5R$), we found linear correlation with the square root of time ($R \propto t^{1/2}$).

The numerical model

A numerical model based on the general scheme of Proussevitch *et al.* (1993) was constructed to simulate bubble growth in a viscous melt under constant pressure. Each bubble is surrounded by a

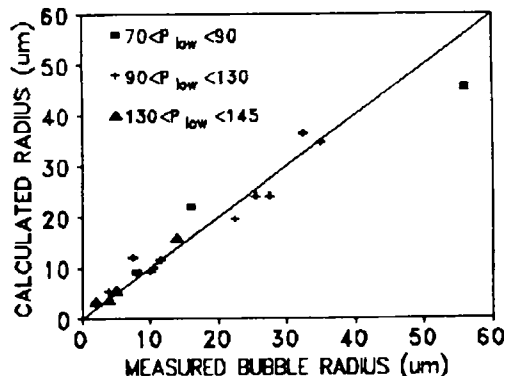


FIG. 2. Comparison of average bubble radii determined experimentally with those calculated by numerical simulation of the experimental condition.

concentric shell of melt with a finite separation. Concentration gradients between the supersaturated melt in the shell and the equilibrated melt at the bubble wall lead to water diffusion into the bubble. The radius of the simulated bubble grows with time from $R_0 = 2R_{\text{critical}}$ up to a final size which corresponds to the duration of the experiment. For pressure drops of $5 < \Delta P < 80$ MPa, the characteristic time for diffusion, R^2/D_{water} , is much shorter than the characteristic time for viscous flow $R/(dR/dt)$ and a quasi-static analytical solution was used for the water concentration around the bubble. The diffusion coefficient and melt viscosity were assumed to be constant. These assumptions are justified because in most of our experiments, concentration gradients are relatively small.

Under the above conditions, the solution is insensitive to variations in surface tension ($0.01 < \sigma < 0.1$ Nm) or viscosity ($10^5 < \eta < 10^6$ Pa sec). At higher viscosities, growth is delayed for the first few seconds, but follows a square root relation at later times. The most important controlling parameter is the diffusion coefficient. Figure 1 presents the effect of diffusion on bubble radius (using $\eta = 10^6$ Pas sec, $\sigma = 0.06$ Nm, and $P_{\text{final}} = 120$ MPa). Comparison of the calculated growth curve with the experimental results shows that a reasonable fit is achieved for $D_{\text{water}} = 3-4 \times 10^{-11}$ m²/sec. Fig. 2 demonstrates that using $D_{\text{water}} = 3 \times 10^{-11}$ m²/sec, yields close fits for experiments with a wide range of decompressions (ΔP) or separations (S).

Discussion

The value we used for D_{water} is higher by a factor of seven compared with values calculated by extrapolating the results of Zhang *et al.* (1991) to high water contents. This higher value suggests that the dependence of water diffusion on water content of the melt is significant, and cannot be fully explained by the fast equilibration between molecular water and hydroxyl alone (Zhang *et al.*, 1991). Rather, the diffusivity of either molecular water or hydroxyl groups is enhanced in heavily hydrated melts.

Our results indicate that water diffusion is fast enough to allow diffusive growth of bubbles over time scales of 100–1000 seconds after nucleation. For slow ascent rates, e.g. during convection in the magma chamber or during dome formation, the change in pressure during 100–1000 seconds is not significant, and our experiments and numerical model may be used to simulate bubble growth. Nucleation may delay the initiation of growth, but once bubbles nucleate, degassing proceeds under quasi-equilibrium conditions.

References

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