Report for the Joint Use/Research of the Institute for Planetary Materials, Okayama University for FY2023

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Category: ☑International Joint Research ☐General Joint Research ☐Joint Use of Facility ☐Workshop

Name of the research project: The effect of the bubble on the viscosity changes and the structural changes of magma

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Collaborator

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Research report:

1) Please write the research report with free format, but include followings: research purpose, actually conducted research, and research outcomes. If necessary, you can add another page.

1. Introduction

This project aims to explore the distribution of bubbles in rhyolitic melts and its effect on the viscosity changes and the structural changes of rhyolitic magma. The explosiveness of volcanic eruption is dependent on the viscosity of magma and the amount of volatiles in the magma. During the upwelling of magma, the solubility of volatile species decreases with decreasing pressure, and the solubility drop causes bubbles to form in magma. The formation of bubbles affects the viscosity of magma as well due to the changes in volatile contents in magma. The distribution and the size of bubbles in magma are essential for understanding the bubble formation in magma and its effect on volcanic eruption.

Mt. Baekdu, one of the biggest volcanoes located in the northernmost part of Korea, is believed to be an explosive volcano. The composition of the upper part of Mt. Baekdu is rhyolitic. The rhyolitic magma has high viscosity and can dissolve >10 wt% of H_2O which can make the eruption of rhyolitic magma explosive. To understand the eruption behavior of Mt. Baekdu, we use hydrous albite glasses as a model system of rhyolitic magma.

The research is conducted at the Institute for Planetary Materials (IPM), Okayama University. During their visit in FY2023, Dr. Kim and Ms. Jeon synthesized six samples using a piston cylinder in IPM with the aid of Prof. Yoshino. See section 2 conducted research in IPM for details. For the data analysis, data from samples made in Bayerisches Geoinstitut, University Bayreuth in Germany are used together with the data from samples made in IPM.

2. Conducted research in IPM

In the research application form, Dr. Kim planned to conduct two sets of experiments: one set for the effect of temperature on the distribution of bubbles in hydrous albite glasses at 0.5 and 1 GPa using the same amount of water (13 wt%) and the other set for the experiments at 0.3 GPa with varying temperature.

For the experiments, albite glasses were synthesized from the oxide powders Na_2CO_3, Al_2O_3, and SiO_2. Oxide powders were dried in the oven at 300 °C overnight to remove moisture and ground in agate mortar with stoichiometry. The sample was decarbonated at 800 °C for 1 hr and then melted at 1500 °C for 30 min using a Pt crucible. After quenching the sample by putting the bottom of the Pt crucible into distilled water, the sample was ground and melted at 1500 °C for 30 min again to make a homogeneous glass.

The actual experiments conducted in IPM are as follows in Table 1. The albite glass powders were loaded into a Pt tube with distilled H_2O. The input of H_2O was calculated by subtracting the weight of a Pt tube and a sample before welding from its weight after welding. Except for PC1128, welded samples were in the oven at 125 °C for 1 hr to ensure that the input amount of H_2O was equally distributed in the Pt tube as the diffusion of H_2O in albite melts is low ($0.6\text{-}11\times10^{-11}$ m^2s^{-1}) (Behrens & Nowak, 1997). For PC1128, the welded sample was in the same condition for 10 min. The samples were loaded into 3/4” inch piston cylinder and the heated at 1000-1200 °C at 0.5 GPa (46-47 bar) for 1 hr. The samples were quenched by turning off the electrical power and pressure during the quenching was adjusted to maintain isobaric condition by pushing the hand pump. Table 1 shows the experimental conditions for all runs performed at IPM during the visit.

3. Research outcomes

Figure 1 shows optical microscopic images of run products of PC1123 (Fig. 1a) and PC1125 (Fig. 1b). The run product of PC1123 showed the blackish color. For the other samples, the run product showed a typical appearance of bubble-bearing glasses, transluscent whitish color with micrometer-scale bubbles. While bubble-free glasses are transparent, bubble-bearing glasses are transluscent or whitish due to the scattering of light by bubbles in glass matrix. The successfulness of the formation of bubble-bearing glasses can be identified by its color and the presence of bubbles under microscope.

Figure 2 showed the X-ray diffraction patterns of PC1123, PC1125, and PC1126. While the transluscent samples like Fig. 1b showed XRD patterns of Pt metal and broad peaks from albite composition glasses, XRD patterns of PC1123 showed broad peak from albite composition glasses and patterns from albite crystals. While it is not clear the presence of graphite from the XRD patterns as all the XRD patterns of graphite are overlapped with those of albite, Raman spectra of PC1123 (Fig. 3, bottom) showed two peaks at ~1360 and ~1600 cm^{-1}, which can be assigned as D and G peak of disordered graphite (Ferrari, 2007; Hanfland et al., 1989). As graphite was not included as a input source, it seems that some carbon from heater diffused into Pt tube during the heating.

Figure 3 showed Raman spectra of hydrous albite glass with H_2O bubbles (three spectra from the top) and mixtures of albite crystals, glasses, and graphite (the bottom-most spectrum) synthesized at 0.5 GPa and at 1000 °C. The sample with 13.5 wt% of H_2O was synthesized at BGI. The sample with no water (0 wt%) showed the vibrational mode of fully-polymerized albite glasses, with a peak at ~500, 800, and 1100 cm^{-1}. The peaks at ~1360 and ~1600 cm^{-1} are from graphite, as mentioned above. Compared with the sample with no water, hydrous albite glasses showed the emergence of new peaks at ~900 and ~1000 cm^{-1}, with peaks from H_2O in the range of ~3000-3700 cm^{-1}. This is because the presence of H_2O in albite glasses depolymerizes the network structure, and transforms Q^4 species (~1100 cm^{-1}) into Q^3 (~1000 cm^{-1}) and Q^2 (~900 cm^{-1}) species, respectively.

Figure 4 showed Raman spectra of hydrous albite glass with H_2O bubbles synthesized at 0.5 GPa and at 1200 °C. With increasing water content in the system, the peak intensity at ~1000 cm^{-1} increases. While the detailed peak deconvolution is needed, the increase of peak at ~1000 cm^{-1} can be related to the depolymerization of network structure with increasing the water content in the system.

Figure 5 showed the Raman spectra of hydrous albite glasses with 13.6-14.0 wt% of H_2O with varying temperature. Compared with the samples synthesized at 1000 °C (Fig. 5), the samples at 1200 °C showed higher peak intensity at ~1000 cm^{-1} and lower peak intensity at ~900 and in the range of 3000-3700 cm^{-1}. The deconvolution of Raman spectra of hydrous albite glasses in the range of 800-1200 cm^{-1} showed that the peak intensity of Q^2 species decreases from 21.4% at 1000 °C to 15.6% at 1200 °C and that of Q^3 species increases from 28.3% at 1000 °C to 34.4% at 1200 °C. The peak intensity of Q^4 species was almost identical (50.3% at 1000 °C to 50.1% at 1200 °C). The calculated NBO/T ratio decreases from 0.178 at 1000 °C to 0.164 at 1200 °C. The peak intensity for water was calculated based on the peak area. The peak intensity for water in the sample synthesized at 1200 °C has 1.25 times lower intensity for H_2O (3000-3700 cm^{-1}) than that at 1000 °C. The relative ratio between H_2O and OH remains constant with increasing pressure. The changes in Q^n species and water contents in hydrous albite glasses indicate that the increase in sample synthesis temperature lowers the solubility of water in albite melts, increasing the degree of polymerization of albite melts.

Figure 6 showed the back-scattered images and binary images of hydrous albite glasses synthesized at 0.5 GPa at 1000 °C and 1200 °C. The numbers and the size of bubbles were analyzed by ImageJ program and the results are plotted in Figure 7 and Table 2. The sample synthesized at 1000 °C showed less bubbles than that at 1200 °C. While the distribution of bubbles at 1200 °C showed normal distribution, that at 1000 °C showed large numbers of small bubbles (smaller than 5 μm in diameter) in the presence of a few number of big bubbles (bigger than 10 μm). The total area of bubbles is almost twice larger at 1200 °C than at 1000 °C.

This is the currently obtained data from bubble-bearing hydrous albite glasses. The obtained data will be compared with 3D X-ray tomography (CT) data once the data analysis of 3D CT is finished. The 2D and 3D data are now under collection for samples synthesized at IPM. The analyzed data for distribution of bubbles and structure of hydrous glasses will be considered together to understand the distribution of bubbles in rhyolitic magma and its effect on the upwelling behavior of magma.

Table 1. Experimental conditions

Run No.	Pressure (GPa)	Temperature (°C)	H_2O content (wt%)
PC1123	0.5	1000	0
PC1125	0.5	1000	9.5
PC1126	0.5	1200	6.1
PC1127	0.5	1200	7.5
PC1128	0.5	1000	14.6
PC1129	0.5	1000	10.6

Table 2. The number and the size of bubbles and the relative area of bubbles to the glasses analyzed by ImageJ. The samples were synthesized at 0.5 GPa at 1000 °C with 13.6 wt% H_2O (Ab1000) and 1200 °C with 14 wt% of H_2O (Ab1200).

Sample	Label	Count	Average size (μm)	Area (%)
Ab1000	a	824	4.42	5.03
	b	1032	6.43	5.86
	c	751	4.44	5.10
	total	2607	5.53	5.52
Ab1200	d	1515	4.87	10.08
	e	1245	5.35	10.15
	f	1463	5.16	10.98
	total	4223	5.11	10.40

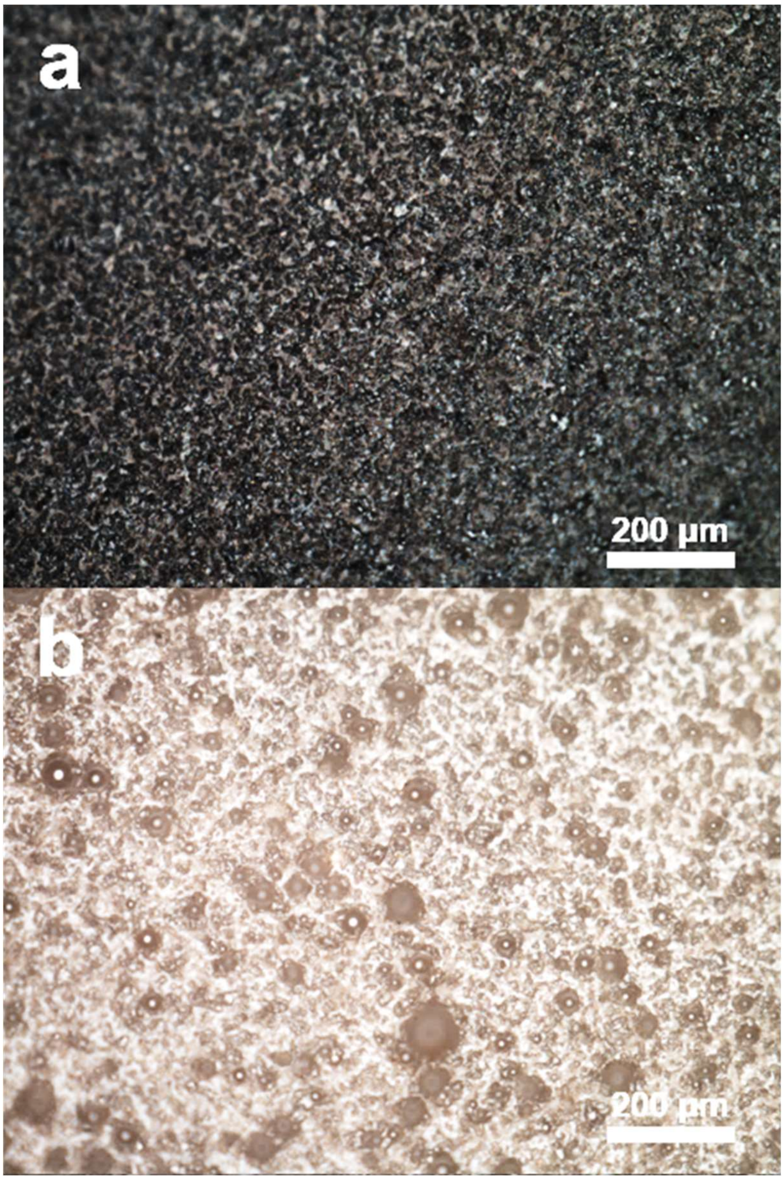

Figure 1. Optical microscopic images of run products: a) PC1123 and b) PC1125.

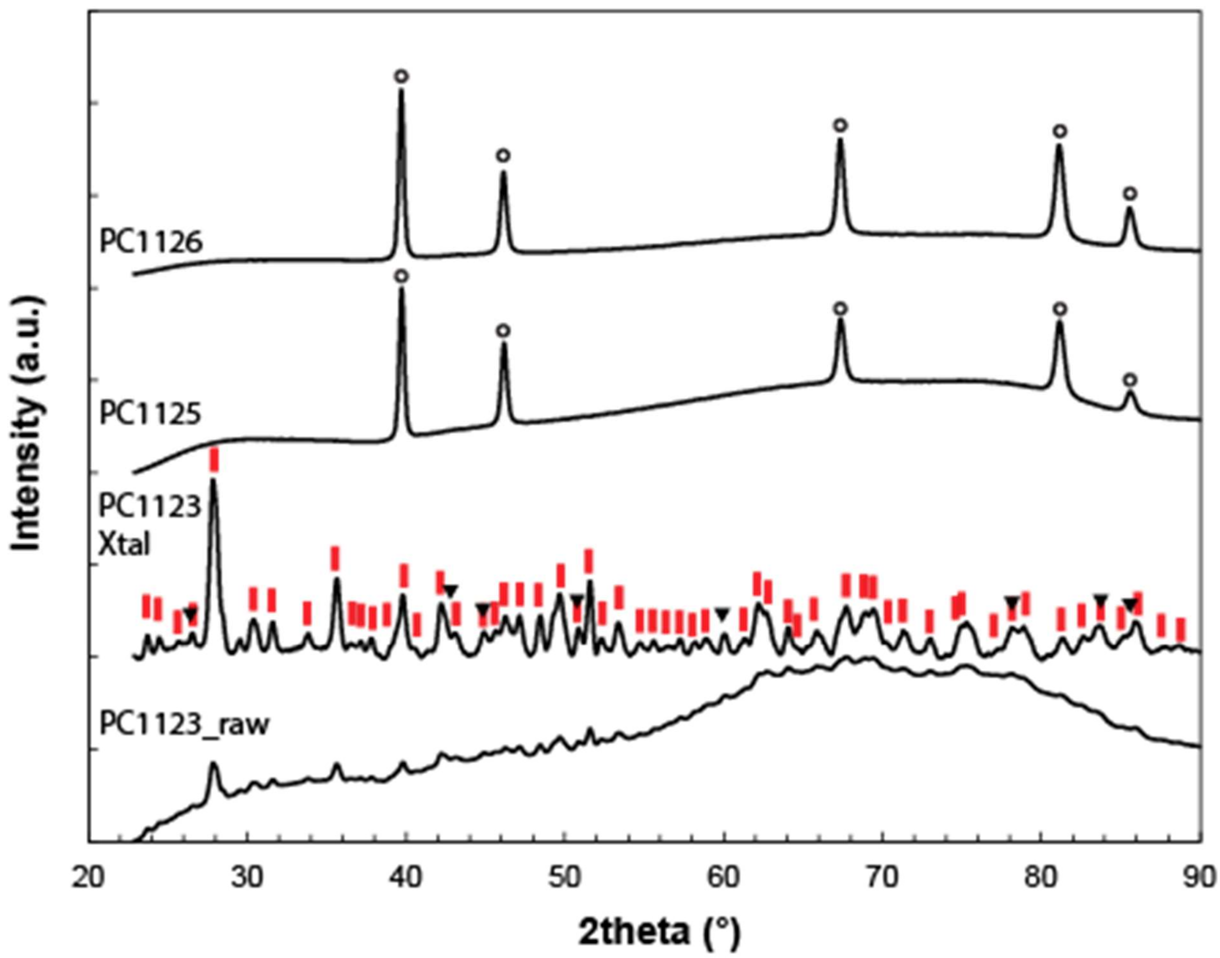

Figure 2. XRD patterns of run products of PC1123, PC1125 and PC1126. PC1123 Xtal refer to the background subtracted XRD patterns of PC1123. Red rectangles, black triangles, and circles represent XRD patterns of albite, graphite, and Pt metal, respectively.

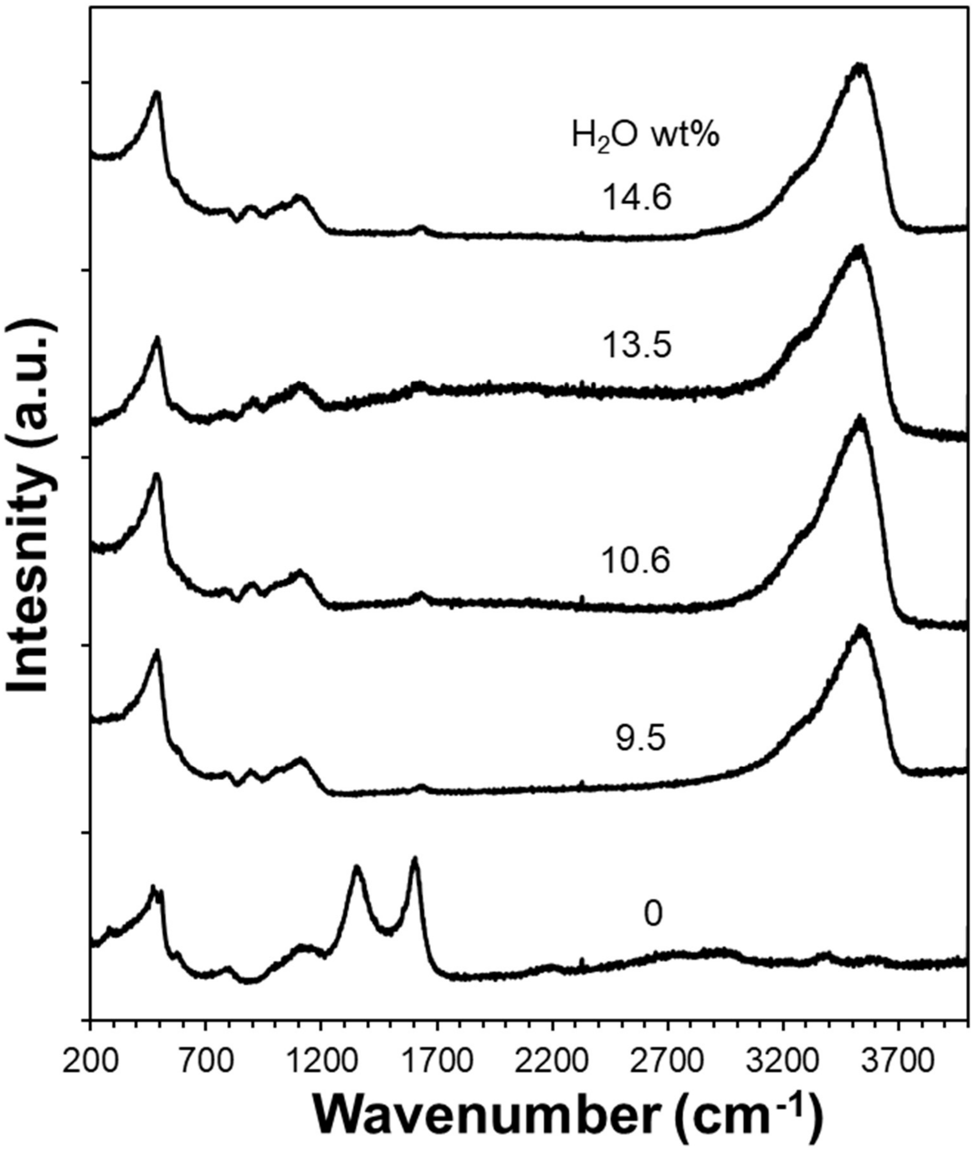

Figure 3. Raman spectra of hydrous albite glass with H_2O bubbles synthesized at 0.5 GPa and at 1000 °C. The numbers above each spectrum represent the input amount of water added in the system. The sample with 13.5 wt% of H_2O was synthesized at BGI. A small sharp peak at ~2350 cm^{-1} is a spectral noise from charge-coupled device (CCD) in the Raman spectroscopy (a central spike from CCD).

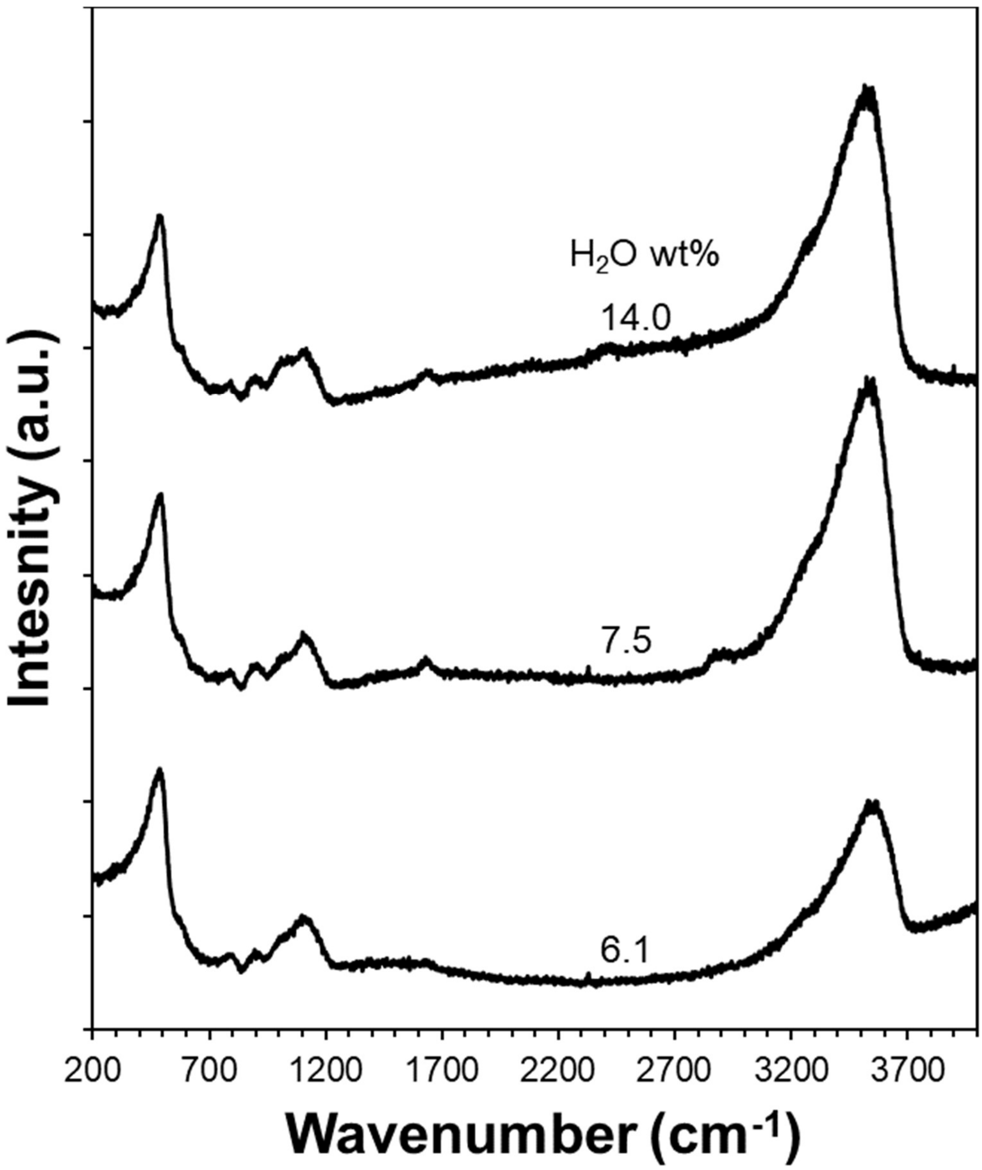

Figure 4. Raman spectra of hydrous albite glass with H_2O bubbles synthesized at 0.5 GPa and at 1200 °C. The numbers above each spectrum represent the input amount of water added in the system. The sample with 14.0 wt% of H_2O was synthesized at BGI. A small sharp peak at ~2350 cm^{-1} is a spectral noise from charge-coupled device (CCD) in the Raman spectroscopy (a central spike from CCD).

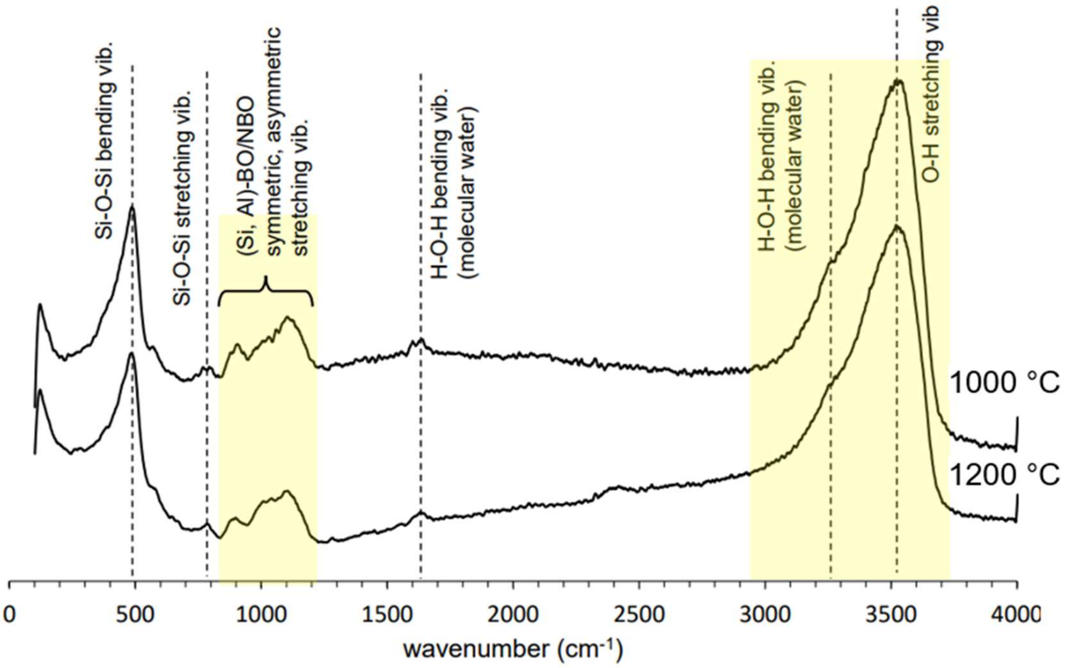

Figure 5. Raman spectra of hydrous albite glass with H_2O bubbles synthesized at 0.5 GPa and 1000 °C with 13.6 wt% of H_2O and glasses at 1200 °C with 14 wt% of H_2O. These samples were synthesized at BGI.

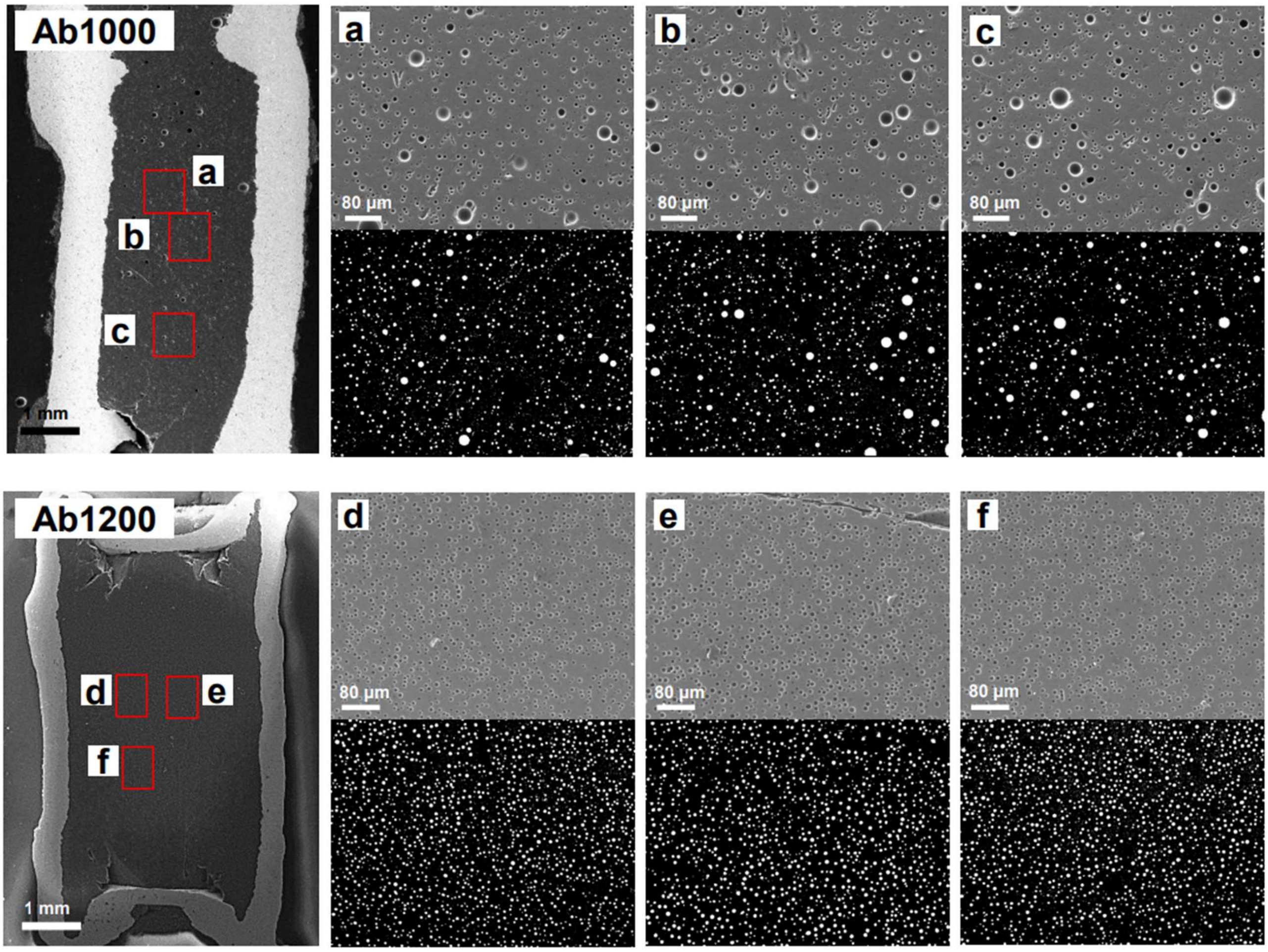

Figure 6. (Left) Back-scattered images of hydrous albite glasses synthesized at 0.5 GPa and 1000 °C (Ab1000) and at 1200 °C (Ab1200). a-f in the left figures are positions of back-scattered images in right side. Binary images in black and white color are the imaged used in ImageJ program to calculate the distribution and the numbers of bubbles in the samples. These samples were synthesized at BGI.

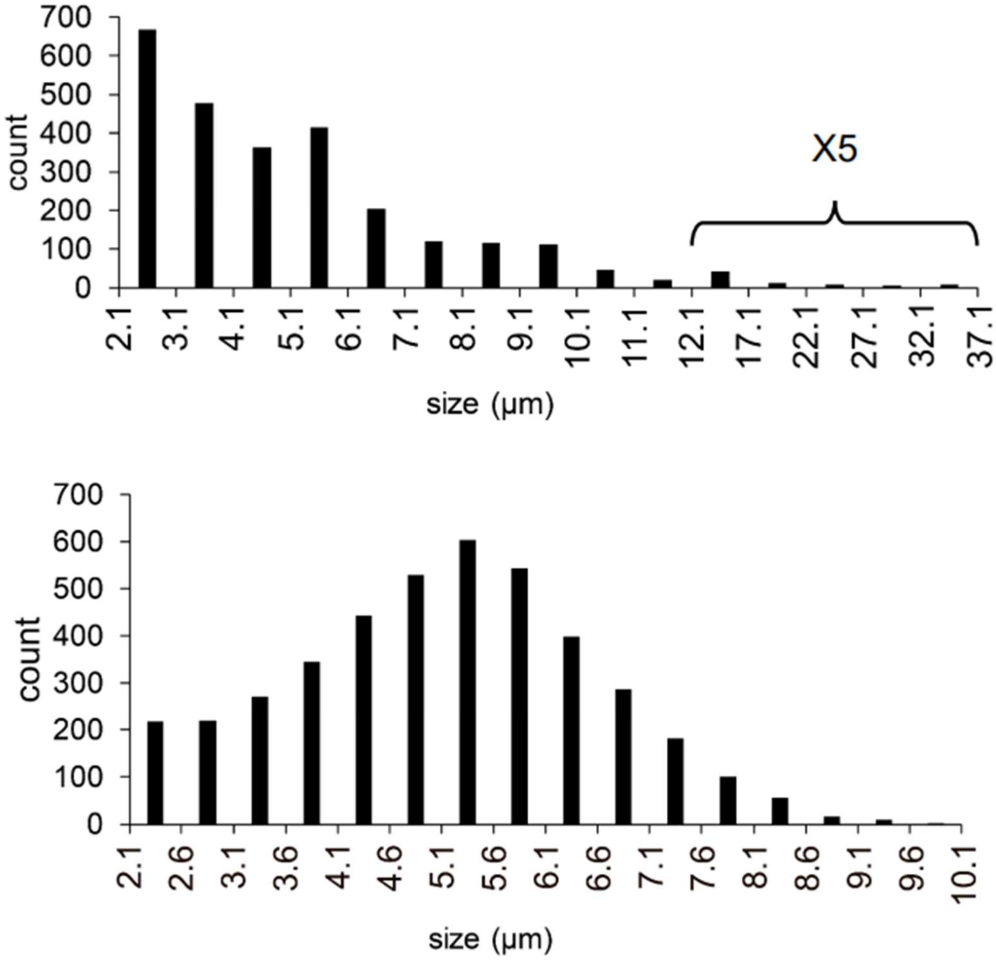

Figure 7. Histograms of bubble size for hydrous albite glasses synthesized at 0.5 GPa and 1000 °C (left) and at 1200 °C (right). These samples were synthesized at BGI.

References

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Hanfland, M., Beister, H., & Syassen, K. (1989). Graphite under pressure: Equation of state and first-order Raman modes. *Physical Review B*, *39*(17), 12598-12603.