Estimation of surface tension of hydrous rhyolitic melts based on decompression-induced vesiculation experiments and classical nucleation theory

*Mizuki Nishiwaki[1]

1. Department of Earth and Planetary Sciences, Graduate School of Sciences, Kyushu University

{Background}
Vesiculation of magma is one of the elementary processes that compose volcanic eruption phenomena. Volatile components, such as H_2O and CO_2, supersaturated in silicate melts due to decompression, nucleate as bubbles, and grow, expand, coalesce, split, deform, and before reaching the ground surface, fracture the melts and crystals. An essential physical quantity for understanding these processes is surface tension between melt and vapor [N/m]. Bagdassarov et al. (2000) succeeded in measuring surface tension between granitic melt and water vapor in situ at high temperature and high pressure using the sessile drop method (solid line in Figure).
On the other hand, surface tensions have been calculated in a series of recent studies on laboratory decompression-induced vesiculation experiments of magma focusing on the nucleation process (cited papers in Figure). In specific, the value of surface tension included in the theoretical equation of nucleation rate [number m^{-3} s^{-1}] was determined to match the bubble number density [number m^{-3}] obtained by microscopic observation and image analysis of the bubble texture. Shea (2017) considered the variations of the physical parameters used in the calculations in each paper as the problem and recalculated them in a unified manner using the theoretical equation of Hirth et al. (1970) (dashed line in Figure).

{Main subject}
Hajimirza et al. (2022) conducted a large number of rapid decompression experiments using hydrous rhyolitic melts under six different temperature and hydration pressure conditions (Suite 1-6) by changing post-decompression annealing time by a few seconds. From the results of the bubble number density measurements of these samples, the time evolution of the nucleation rate, which had been poorly resolved, was clarified. In this study, we substituted this result into the theoretical equation of nucleation rate of Toramaru and Miwa (2008) to obtain surface tension. The improvements from the previous method are (1) direct comparison of the theoretical equation with the accurately obtained value of the nucleation rate, and (2) inclusion of Poynting correction, which takes into account the effect of the compressibility of the liquid on the equilibrium vapor pressure in the bubble when the liquid pressure around the bubble nucleus changes (Blander and Katz, 1975), in the exponential term of the theoretical equation. The figure is a modified version of Fig. 1 in Hajimirza (2019), where the vertical axis is surface tension and the horizontal axis is pressure. The color in the symbols corresponds to temperature. Decompression experiments are replotted with the values recalculated by Shea (2017) (dashed grid lines of symbols). The star plots of Suite 1-6 in Hajimirza et al. (2022) are approximately linearly aligned, and the first-order approximation is {surface tension N/m} = -2.76 E-4 {saturation pressure MPa} +0.127. While the approximation by Shea (2017) (dashed line) had a very weak pressure dependence, the one in this study (dotted line) shows a large pressure dependence trend similar to the directly measured value (solid line) of Bagdassarov et al. (2000). The fact that surface tension increases significantly with decreasing pressure means that bubble nucleation becomes relatively more difficult as magma decompression proceeds and the time in which supersaturation is not easily resolved becomes longer. Since surface tension is a very

sensitive parameter that exponentially controls the nucleation rate, we consider that the Poynting correction is important for the quantitative discussion of vesiculation of magma.

This work was supported by JSPS KAKENHI Grant Number JP20J20188.

Keywords: surface tension, decompression-induced vesiculation experiment, bubble number density, nucleation rate, rhyolitic melt, water