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Anisotropy of bubble microstructure and gas permeability in sheared magma

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Permeable gas transport through connected gas bubbles (bubble network) in magma is a possible mechanism to induce magma degassing and reduce the explosivity of volcanic eruptions. The gas permeability of magma ascending in volcanic conduits has been investigated by performing decompression and shear deformation experiments for hydrous magma. The gas permeability of experimentally sheared magma shows the anisotropy (Okumura et al., 2009 EPSL). When large shear strain (>8) is applied to magma, the gas permeability parallel to shear direction starts to increase at a vesicularity of 30 vol% and reaches the order of 10^{-13} m^2 at a vesicularity of 50 vol%. On the other hand, the gas permeability perpendicular to shear direction is lower than the order of 10^{-16} m^2 at a vesicularity of <80 vol%. In this study, we investigated bubble microstructure of sheared magma to understand the origin of the anisotropy.

Three dimensional (3D) microstructure of bubbles in experimentally sheared rhyolite was observed using synchrotron radiation X-ray CT (BL20B2, SPring-8). The sheared rhyolites were prepared by performing the torsional deformation experiments at a temperature of 975oC and a rotational rate of 0.5 rpm. The outer parts of columnar run products were used for image analyses (256x256x256 voxels, corresponding to the actual size of 1.1x1.1x1.1 mm). In the 3D images, all bubbles in a sample were counted and their volumes were measured. In addition, electrical current simulation (ECS) was numerically done for networks formed by connected bubbles to investigate the controlling factors of the gas permeability.

With the increase in shear strain, the number of bubble networks which achieve from end to end along shear direction increases at a vesicularity of 9-41 vol%. The networks show tube shape rather than frothy shape. When we assume a tube model ($k = ad^2 / 32$, where k is the permeability;a, porosity ; d, tube diameter), the permeabilities calculated along the tube show similar values with measured permeabilities. On the other hand, no bubble network is percolated along the direction perpendicular to shear at <48 vol% vesicularity and 0-10 rotations. The ECS for the largest bubble network in a sample shows that there are some narrow bottle necks for the current flow perpendicular to shear direction. The bottle necks are located on the side of tube networks, resulting in the increase in the tortuosity for the flow. These results indicate that the anisotropic gas permeability is originated by the formation of tube bubbles which results in the enhancement of the gas permeability toward shear direction but decreases the gas permeability perpendicular to shear direction due to the formation of narrow bottle necks and the increase in the tortuosity.

Keywords: magma, shear deformation, anisotropy, bubble microstructure, gas permeability