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Factors governing fragmentation of submarine lava - mechanism of hyaloclastite formation

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Hyaoclastite is produced by fragmentation of lava when stress accumulates on solid lava faster than it relaxes and ultimately reaches the mechanical strength of the lava. Thermal stress, shear stress and tensile stress acculumating on the lava crust are relaxed by viscous flow of lava, which is governed by viscosity. Therefore, fuidal basalt lava tends to form coherent flows without fragmentation, whereas viscous lava such as andesite and dacite tends to form hyaloclastite. Hyaloclastite with a wide compositional range spanning from andesite to rhyolite is associated with pillow flows and dikes in the Eocene submarine volcanic strata on Chichijima, Ogasawara Archipelago (Umino and Nakano, 2007). These volcanic ejecta are ideal to assess the effect of varying lava composition on the factors that govern the fragmentation of lava.

Quenched glass from chilled margins of pillow and hyaloclastite were collected and analyzed by EPMA for major elements and by SIMS and FTIR for water contents. The amount of primary, magmatic water was discerned from secondary hydration by differential thermal analysis. Eruption temperatures were estimated by the clinopyroxene-liquid geothermometer of Putirka (1999). Crystal number densities of groundmass plagioclase and clinopyroxene were determined on COMPO images and modal abundance of constituent minerals was determined on elemental distribution maps of EPMA. Bulk viscosity of lava was estimated by the methods of Giordano et al. (2008) and Pinkerton and Stevenson (1992).

Andesite consists of clinopyroxene, orthopyroxene, plagioclase and magnetite as phenocrysts set in a groundmass of clinopyroxene and plagioclase microlites, magnetite and glass. In Nagasaki, pillow lava coexists with hyalcoastite. In transition zones from pillow lava to hyaloclastite, pillow lobes are scattered in hyaloclastite. Hyaloclastite is higher in crystal number density, mode of groundmass plagioclase and vesicle number density than the associated pillow lava. Hyaloclastite glass is lower in Al_2O_3 than associated pillow glass, indicating plagioclase fractionation. However, the cpx-saturated melt temperatures show little difference between pillow lava and hyaloclastite. Water contents in glass were determined by using FTIR, which are almost identical in pillow and hyaloclastite. However, primary water contents estimated by differential thermal analysis are lower in pillow lava than in hyaloclastite. Therefore, degassing either within the conduit or during flowage through lava tubes induced plagioclase crystallization that raised the bulk viscosity of lava and stress relaxation time, resulted in the formation of hyaloclastite. However, higher water contents in hyaloclastite suggest that the hyaloclastite was formed by spalling off of chilled margin glass from pillows.

Dacite has phenocrysts of clinopyroxene, orthopyroxene, plagioclase and magnetite in the groundmass of clinopyroxene and plagioclase microlites, magnetite and elongate or spherical vesicles. The dacite shows little difference in melt composition, eruption temperature, crystal number density between pillow lava and hyaloclastite. In Ogamiyama and north of Manjumisaki, lower water contents in hyaloclastite indicate fragmentation occurred due to degassing and increase in bulk viscosity. On the other hand, in Zonahanasaki and Sakaiura, dacite pillow lava has lower water contents than the associated hyaloclastite, which may have formed by spalling off of chilled margins or by fragmentation of pillow lava crust due to higher shear stress.

Keywords: hyaloclastite, viscosity, submarine lava, the Bonin Islands Chichijima