28*th* IUGG Conference on Mathematical Geophysics, June 7-11, 2010, Pisa, Italy
Session 1: Geophysical fluid dynamics I - Volcanoes

Amplification of pressure waves in supersaturated bubbly magma

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Keywords: *amplification; bubbly magma; pressure waves; long-period; volcano-seismology*

We study the interaction of acoustic pressure waves with an expanding bubbly magma. The expansion is the result of bubble growth during or following magma decompression and leads to two competing processes that affect pressure waves. On one hand, growth in vesicularity leads to increased damping and decreased wave amplitudes, and on the other hand, a decrease in the effective bulk modulus of the bubbly mixture reduces the wave velocity and leads to wave amplification. Under certain conditions, the amplification is strong enough to account for a significant reduction in damping and may even lead to amplification. Thus, some of the energy released during growth is transformed into acoustic energy. We first examine this phenomenon analytically to identify conditions under which amplification is possible. These conditions are further examined numerically to shed light on the frequency and phase dependencies in relation to the interaction of waves and growing bubbles. Amplification is possible at low frequencies and when the growth rate of bubbles reaches an optimum value for which the wave velocity decreases sufficiently to overcome the increased damping of the vesicular material. We present two amplification phase-dependent effects: 1) a tensile-phase effect in which the inserted wave adds to the process of bubble growth, utilizing the energy of the growing bubble and therefore converting a large proportion of this energy into additional acoustic energy; and 2) a compressive-phase effect in which the pressure wave works against the growing bubbles and dissipates a large amount of the acoustic energy during the first cycle, but later gains enough energy to amplify the second cycle in comparison to the first. The two effects provide additional new mechanisms for the amplification phase seen in Long-Period (LP) and Very-Long-Period (VLP) seismic signals originating in magma-filled cracks. For example, when bubbly magma expands within a crack it builds up pressure. Upon reaching a critical pressure threshold the crack fails, allowing the release of gases through the permeable part of the magma. The resulting collapse of the permeable network allows new supply of magma and further degassing, rebuilding the pressure and initiating the next cycle. Waves emitted during the decompression stage may move freely through the expanding magma due to its lower damping and, in some cases, they may actually be amplified.