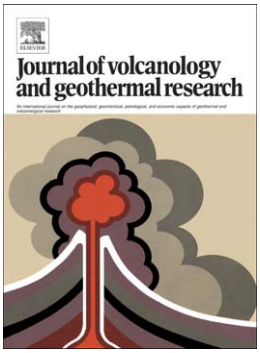

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Magma Wagging and Whirling in Volcanic Conduits

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Abstract

Seismic tremor characterized by 0.5-7 Hz ground oscillations commonly occur before and during eruptions at silicic volcanos with widely ranging vent geometries and edifice structures. The ubiquitous characteristics of this tremor imply that its causes are potentially common to silicic volcanoes. Here we revisit and extend to three dimensions the magma-wagging model for tremor [Jellinek and Bercovici, 2011, Bercovici et al., 2013], wherein a stiff magma column rising in a vertical conduit oscillates against a surrounding foamy annulus of bubbly magma, giving rise to tremor. While prior studies were restricted to two-dimensional lateral oscillations, here we explore three-dimensional motion and additional modes of oscillations. In the absence of viscous damping, the magma column undergoes 'whirling'motion: the center of each horizontal section of the column traces an elliptical trajectory. In the presence of viscous effect we identify new 'coiling'and 'uncoiling'column bending shapes with relatively higher and comparable rates of dissipation to the original two-dimensional magma wagging model. We also calculate the seismic P-wave response of the crustal material around the volcanic conduit to the new whirling motions and propose seismic diagnostics for different wagging patterns using the time-lag between seismic stations. We test our model by analyzing pre-eruptive seismic data from the 2009 eruption of Redoubt Volcano. In addition to suggesting that the occurrence of elliptical whirling motion more than one week before the eruption, our analysis of seismic time-lags also implies that the 2009 eruption was accompanied by qualitative changes in the magma wagging behavior including fluctuations in eccentricity and a reversal in the direction of elliptical whirling motion when the eruption was immediately impending.

Keywords: Volcanic tremor, Magma dynamics, Volcano seismology

1 Introduction

Volcanic tremor is a common feature of explosive volcanism and plays an important role in volcanic hazard monitoring and eruption forecasting. Typically, a tremor emerges with frequencies of 0.5 to 2 Hz several hours to days before the eruption starts. As the volcano's activity intensifies, frequencies can glide up, increasing to 5 to 7Hz [Thompson et al., 2002, Neuberg, 2000, Konstantinou and Schlindwein, 2003, McNutt, 2005, McNutt and Nishimura, 2008, Chouet and Matoza, 2013, K.Unglert and Jellinek, 2017]. An understanding of the origin of volcanic tremor and an explanation for the full range of behaviors of pre-eruptive tremor may consequently be key for forecasting dangerous explosive volcanism.

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