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Modelling Seismological Observables Associated With The Dynamics of Hydrothermal Systems

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Once subjected to pressure instabilities, subsurface fluids of either magmatic or hydrothermal origin can be the source of seismo-volcanic signals such as Long-Period (LP) events and Tremor. Frequency and damping of these signals may thus be diagnostic of the type and physical state of fluids involved into the resonant source process. On the other hand, density changes of fluids hosted by porous/fractured rocks alter the bulk elastic properties of the propagation medium, thus being potentially detectable via accurate measurements of seismic velocities. In this work we use TOUGH2 (Pruess, 1991) models of fluid circulation beneath the Solfatara crater (Campi Flegrei Caldera, Italy), to derive composition and physical properties of hydrothermal fluids throughout an unrest episode. From these data, we derive the space- and time-varying sound speed and densities of the multi-phase, multi-component hydrothermal mixtures. These pieces of information are converted to two seismological observables, i.e. (1) The dominant frequency and quality factor of LP events potentially accompanying the unrest, according to the resonating-crack model (Chouet, 1988), and (2) The travel-time changes for seismic ray-paths crossing the hydrothermal system. The ultimate goal is twofold: (1) to characterise possible LP signals associated with the hydrothermal system throughout an unrest episode, and (2) to verify whether hydrothermal circulation can be probed through examination of LP waveforms and/or accurate travel-time measurements of either passive or active seismological data. In TOUGH2 models, the hydrothermal system is parameterised as a porous (0.2%) medium filled with a 2-phase mixture of liquid water and water/CO2 gases. Circulation is fed by a hot mixture of H2O and CO2 of magmatic origin. Unrest events are periods of higher flow rate and CO2 content at the source. These simulations output the spatial and temporal variations of pressure, temperature, gas volume fraction and density of the multiphase mixture, that we use for deriving sound speed values. From these data, we follow Ferrazzini and Aki (1987) and Chouet's (1988) model to define ranges of the acoustical properties of LP signals potentially originating in the region under study. Source wavelets having dominant frequency and attenuation defined this way are propagated in a realistic, heterogeneous 2-D medium using a finite-difference wave simulator, thus obtaining a set of synthetic waveforms tracking the dynamic evolution of the hydrothermal system. The same data are used for a separate evaluation of how changes in hydrothermal fluid properties affect the compressional wave-speed of the propagation medium. Results indicate that, in principle, the hydrothermal dynamics could be probed by both types of analysis. Frequency and damping estimates are however severely biased by the marked path and site effects which affect wave propagation throughout the heterogeneous volcanic terrains. The predicted velocity changes are very consistent, well within the sensitivity range offered by analysis of scattered waves from time-repeating artificial sources or studies of noise correlation functions.

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