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# Delayed earthquake-volcano interactions at Campi Flegrei Caledra, Italy

Matteo Lupi (1), Marcel Frehner (1), Erik H. Saenger (2), Nicola Tisato (3), Philipp Weis (1), Sebastian Geiger (4), Giovanni Chiodini (5), and Thomas Driesner (1)

(1) ETH Zürich, Geological Institute, Zürich, Switzerland, (2) Hochschule Bochum, Bochum, Germany, (3) University of Toronto Department of Civil Engineering, Toronto, Canada , (4) Heriot-Watt University, Institute of Petroleum Engineering, Edinburgh, United Kingdom, (5) Osservatorio Vesuviano, Instituto Nazionale di Geofisica e Vulcanologia, Naples, Italy

The Campi Flegrei Caldera near Naples, Italy, is arguably one of the world's prime examples of volcanic hazard in a heavily populated area. Over the last centuries the ground of the caldera went through cyclical phases of inflation and deflation. The inflation phase consists of rapid vertical ground movements associated with the emission of volcanic gases marked by a strong magmatic component. Such deformations are suggested to be caused by pulses of $CO_2$-rich fluids injected into the caldera's shallow hydrothermal system or by the intrusion of magmatic bodies at shallow depths.

We show that since 1945 the uplift crises occurring at the Campi Flegrei Caldera are caused by large regional earthquakes. Our results point out that maximum uplift rates in the caldera take place about three years after the occurrence of large earthquakes that imposed a $\log_{10}(\mathrm{PGA}[\mathrm{cm\ s}^{-2}])$ greater than 0.18. These observations are supported by forward seismic simulations and with a semi-quantitative statistical analysis of ground surface displacements and Peak Ground Accelerations (PGA).

Our proposed geomechanical model integrates and simplifies previous empirical concepts of upwelling fluids that pressurize the region beneath the Campi Flegrei causing ground surface uplift. Numerical simulations indicate that passing seismic body waves impose high dynamic strains at the upper boundary of the deep magma reservoir as well as at the brittle/ductile transition at about 3 km depth. Such dynamic strains induce short-lived brittle failure in nominally ductile regions causing the release of magmatic fluids. The approximately 3-years time lag between the earthquake and maximum surface uplift reflects the time during which the lithostatically pressured fluids ascend through hot, nominally ductile lithologies without expanding. After passing the brittle/ductile transition at $\sim$3 km depth the $H_2O$-$CO_2$ mixture can expand and phase-separate, pressurizing the subsurface. This leads to a rapid ground uplift coupled with increasing magmatic gas concentrations in fumarole discharges. The self-consistent mechanistic explanation of the time lag may have strong implications in the predictive aspects of volcanic hazard assessment in the Neapolitan region contributing to the understanding of unrest-related precursors of large dormant calderas.

To date, clear triggering correlations could only be established for quasi-immediate earthquake-volcano interactions (i.e., from seconds to days) with the underlying mechanisms remaining elusive. Here we provide strong evidence for a much longer time window implying that earthquake-volcano interactions may be much more common processes than presently thought.