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Imaging the intrusion of a magmatic sill beneath the town of Pozzuoli (2012-2013)

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Campi Flegrei caldera (Southern Italy) is among the areas with the highest volcanic risk in the world. The megacity of Naples, hosting more than 1 million inhabitants, lies across the caldera borders. In recent years Campi Flegrei caldera has experienced an accelerating uplift rate of the ground deformation. In particular, during the April 2012 - January 2013 time interval the caldera has shown a rapid uplift of about 6 cm with a peak rate of about 3 cm/month in December 2012. This event led the Italian Civil Protection to raise the alert level of the volcano from green to yellow. We exploited the displacement time series obtained by processing 90 SAR images acquired from the COSMO-SkyMed sensor constellation along ascending orbits via the well-known DInSAR algorithm referred to as SBAS algorithm, and the measurements provided by 14 continuous GPS stations deployed within the caldera and belonging to the permanent INGV-OV monitoring network. To study the detail of the intrusion process we have applied novel geodetic imaging technique to determine the spatial and temporal kinematics of the ground deformation source in the selected period. The retrieved temporal pattern of the source geometry reflects that of a growing sill which, at the end of the considered period, has a roughly elliptical geometry with an extension of about 6 km in the EW direction and about 4 km in the NS one. The maximum aperture of the sill is of about 30 cm at its center. To understand the dynamics of this phenomenon we used a recently developed numerical model of the emplacement of a magmatic sill, to fit the retrieved geometry. The parameters to be determined are: the average magma viscosity, the amount of magma already present in the sill before the 2012-2013 episode and the magma injection rate. Results show that the most likely value for the viscosity is between $10^3 - 10^4 Pa \cdot s$ and that to justify the observed deformation pattern it is required that the reservoir should have contained at least $10^{10} kg$ of liquid magma before 2012. The injection rate has two main peaks on September and December 2012, and a smaller one on March 2013. The first two peaks have a value of about 400 kg/s and duration of 3-4 months. The total amount of injected magma is of about $8.2 \cdot 10^{10} kg$. The magma viscosity value is compatible with that of the most common magmas erupted in the past 40 ky: phonolites, while the total inferred amount of liquid magma is of the same order of magnitude of small-size eruptions (VEI 2-3) occurred in the caldera during the last 15 ky. The first injection peak is associated with a seismic swarm, located beneath the town of Pozzuoli. The swarm consisted in about 200 earthquakes (maximum magnitude 1.8) occurring within an interval of about 1.5 hours. The hypocenters were located outside the area usually affected by microearthquakes in the previous years. Using finite element structural mechanical modeling we show that the inferred source caused a marked increase in the maximum shear stress along the rim of the sill. In fact hypocenters were located very close to the northern edge of the growing magmatic reservoir. Our findings suggest a key to interpret the caldera unrest that, started about 60 years ago, has led to a maximum uplift in the area of more than 3 m. Consequently, the observed uplift phenomenon could be interpreted in terms of injection of limited magma batches feeding the growth of a shallow magmatic reservoir. Similar mechanisms have been inferred for other calderas, where the repeated emplacement of magmatic sills has been recognized having an important role in the evolution of the volcano. Accordingly, the observation of short evolution of volcanic precursory phenomena as well as the development of innovative real-time analysis techniques should be taken into account for an effective surveillance of the Campi Flegrei caldera.
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