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Reservoir architecture, trigger mechanisms, and timescales of shallow magma transfer preceding eruptions at Campi Flegrei caldera, Italy

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Since 2005, Campi Flegrei (Italy) has experienced persistent volcanic unrest marked by earthquake swarms reaching magnitudes up to 4.6 and ground uplift rates of 10-30 mm per month, totalling approximately 160 cm. With 500,000 residents living within the designated red zone, accurately assessing how this crisis may evolve and identifying potential eruption-triggering mechanisms is of critical importance for public safety. In this study, we apply machine-learning clinopyroxene-only thermobarometry [1] to pyroclastic samples from diverse eruptions across the caldera to reconstruct its magmatic plumbing system.

Clinopyroxenes from opening and upper units display comparable Mg# values, though upper units exhibit more homogeneous distributions. Thermobarometric estimates indicate that all eruptions were preceded by magma storage at shallow depths of 1-2 kbar (~4 km). Except for Monte Nuovo and Agnano Monte Spina, opening units also record the extraction of hot magma (1100° C) from depths exceeding 2.5 kbar (>8 km). High-intensity eruptions, such as the Neapolitan Yellow Tuff, show bimodal crystallization temperature distributions separated by a clear gap at 900-1000° C. Only Agnano Monte Spina and Monte Nuovo exhibit petrological evidence for eruptions triggered by external processes, such as elastic crustal weakening [2]. The Campanian Ignimbrite displays continuous temperature estimates similar to low-intensity eruptions (e.g., Solfatara, Averno 1), suggesting that reservoir configuration alone does not control eruption magnitude and that surface deformation, governed by shallow plumbing dynamics, may not directly correlate with future eruption size.

The shallowest magma emplacement depths align with the current source of seismicity and ground deformation, while deeper storage levels match those imaged by recent seismic and magnetotelluric surveys [3]. We infer that the volume of eruptible magma stored within the mid-lower crustal reservoir is a key parameter for estimating future eruption intensity. Thermal and statistical modelling suggests that eruptions can be preceded by multidecadal unrest periods. This study provides new constraints on preferred magma pathways and plausible eruptive scenarios – essential for volcanic hazard assessment and risk mitigation.

[1] Ágreda-López et al., (2024) Computers & Geosciences, 193
[2] Kilburn et al., (2023) Commun Earth Environ 4, 190
[3] Isaia et al., (2025) Commun Earth Environ 6, 213