

Machine Learning in Volcanology: Addressing Epistemological Challenges and Deciphering Pre- Eruptive Dynamics in Antarctic and Italian Volcanoes

MÓNICA ÁGREDÁ LÓPEZ AND MAURIZIO PETRELLI

University of Perugia

Machine learning (ML) is emerging as a powerful tool in volcanology and petrology, offering new ways to analyse and interpret magmatic processes. However, its use raises key epistemological questions regarding model interpretability, transparency, and reproducibility. These concerns become particularly relevant in volcanic hazard assessment, where ML-driven predictions may influence risk mitigation strategies and decision-making.

In this study, we explore the opportunities and limitations of ML applications in volcanology, specifically focusing on igneous petrology and pre-eruptive dynamics. We combined traditional petrological investigations, advanced analytical techniques, and supervised and unsupervised ML approaches to infer magma storage, crystallisation depths and reservoir evolution using the crystal cargo of volcanic eruptions.

To refine our reconstruction of magmatic systems, we integrate single-spot trace element data and high-resolution chemical mapping of clinopyroxene crystals. This multi-modal approach enables a detailed assessment of magma reservoir dynamics, linking geochemical signatures to eruptive behaviour in Antarctic and Italian volcanoes. Our findings highlight the potential of ML-driven methodologies to improve the understanding of pre-eruptive dynamics.

This work reinforces the importance of interdisciplinary strategies in advancing volcanology and provides a framework for integrating ML techniques into the study of magmatic systems across diverse geological settings.