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ABSTRACT:

Stochastic Prediction of Lava Flow Extent via Rheology and Morphology

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Accurately forecasting the terminal extent of lava flows is essential for effective volcanic hazard mitigation and for advancing our understanding of planetary surface evolution. Conventional operational models predominantly employ deterministic power-law relationships that correlate final flow length with eruption parameters such as effusion rate, yielding single-value predictions. These approaches, however, fail to account for the intrinsic stochasticity of eruptive processes and the complex rheological and morphological dynamics governing lava emplacement. The ultimate runout of a lava flow is primarily controlled by its time-dependent rheology which dictates internal resistance to deformation. A recent study [1] have demonstrated that the morphological complexity of lava flows, quantified via the prefractal dimension, emerges as a predictable function of yield strength. This geometric complexity exerts a significant influence on flow resistance and, consequently, on the final propagation distance.

This study addresses a critical limitation in existing methodologies by introducing a probabilistic forecasting framework that transcends deterministic paradigms. By integrating the stochastic variability of eruptive inputs with advanced physical models of lava rheology and morphology, we aim to generate probabilistic forecasts that capture the full spectrum of plausible flow outcomes. This framework will provide a quantitative basis for hazard assessment on Earth and enable comparative analyses of lava flow dynamics across planetary bodies, including Mars.

[1] Miguel, A.F. (2025) Fractal complexity and symmetry in lava flow emplacement. Symmetry 17, 1502