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Insights into hydrothermal sealing from physical properties of volcanic bombs

EMILY MICK[1], MICHAEL J HEAP[1], GEOFFROY AVARD[2], THIERRY REUSCHLÉ[1], CLAIRE HARNETT[3], THOMAS R WALTER[4] AND VALENTIN R TROLL[5]

[1]University of Strasbourg
[2]Universidad Nacional
[3]University College Dublin
[4]GFZ Helmholtz Centre for Geosciences
[5]Uppsala University

Understanding hydrothermal sealing is crucial for mitigating the risks associated with phreatic and phreatomagmatic eruptions. Poás, Turrialba, and Rincón de la Vieja volcanoes (Costa Rica), host active hydrothermal systems and exhibit eruptive activity ranging from phreatic to phreatomagmatic, making them ideal natural laboratories for investigating hydrothermal sealing processes. In such systems, rock physical and mechanical properties vary dramatically in response to hydrothermal alteration, exerting strong controls on fluid migration, pressurization, and seal development. In this study, we characterize the physical and mechanical properties of volcanic bombs from these three systems, including porosity, P-wave velocity, permeability, thermal properties, and tensile strength. Our objective is to constrain the rock properties most relevant for modelling hydrothermal systems at depth. To this end, we also examine how these properties evolve with increasing confining pressure, providing insight into subsurface conditions associated with hydrothermal seal formation. Our results show that hydrothermal sealing and associated alteration produce highly heterogeneous rock frameworks with strongly contrasting physical properties. Although alteration can reduce primary porosity, it may also generate secondary pore networks, leading to complex, and sometimes opposing, effects on permeability. As a result, both the spatial distribution of permeability barriers and the magnitude of permeability evolution with alteration and pressure are of first-order importance in the development of hydrothermal seals. Using the pore collapse critical pressure, we constrain the maximum pressures, and corresponding depths, sustained by these rocks prior to eruption, providing new insight into the depth extent and pressurization conditions associated with hydrothermal sealing. The pronounced heterogeneity in permeability and mechanical strength indicates that sealing promotes localized overpressure accumulation and highlights the importance of accounting for spatial variability in seal properties when modelling hydrothermal systems. Overall, our findings demonstrate that variability in alteration and rock properties fundamentally controls fluid pressurization and eruption dynamics, underscoring the value of detailed physical property characterization for improving models and forecasts of hydrothermal unrest and associated volcanic hazards.