Modelling caldera dynamics: Insights from physical experiments and geophysical data.

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Résumé

Caldera collapse and resurgence dynamics arise from complex interactions among geological and mechanical parameters, which influence surface deformation patterns, internal fault development, and structural transitions. Understanding these processes is crucial not only for advancing volcanological knowledge but also for improving hazard assessment and the monitoring of active volcanic systems. In this study, we investigate the dynamics of caldera collapse and resurgence through analogue experiments combined with high-resolution laboratory-scale physical measurements, offering new insights into the relationship between internal fault evolution and surface morphology.

The experimental setup simulate a magma chamber using a cylindrical reservoir filled with a high-viscosity analogue fluid (Polyglycerine-3), located beneath a layered sand pack that simulates brittle crustal overburden. Collapse is initiated by draining the fluid at a constant rate, inducing deformation within the overlying granular medium. After collapse, magma intrusion is simulated by reinjecting the same fluid at a constant flux. A high-resolution pressure sensor, positioned at the interface between the fluid chamber and the granular material, continuously records pressure variations throughout both the collapse and injection phases. Simultaneously, photogrammetry, PIV, and structural mapping are employed to document the three-dimensional evolution of surface and internal structures.

The results reveal a well-defined structural evolution. Initially, outward-dipping reverse faults nucleate at the chamber edges and propagate upwards. These are followed by inward-dipping normal faults that accommodate vertical subsidence, producing a characteristic caldera fault architecture. These faulting stages correspond to distinct pressure regimes: pressure peaks occur during reverse fault formation, followed by a drop and subsequent rise during the development of normal faults. As the deformation stabilizes, pressure fluctuations are primarily associated with minor faulting and rim collapse events. This observed transition from compressive to dilatational stress regimes directly affects fault kinematics and caldera morphology.

By integrating physical modelling with internal geophysical monitoring, this approach provides a robust framework for analyzing caldera dynamics. Our findings help bridge the gap between laboratory experiments and natural systems, improving the interpretation of geophysical data in volcanic regions and contributing to more accurate hazard assessments-particularly in caldera systems such as Campi Flegrei, Italy.

Mots-Clés: caldera collapse, volcano, physics, granular material

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