Morphology and dynamics of explosive vents through cohesive rock formations

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Shallow explosive volcanic processes, such as kimberlite volcanism, phreatomagmatic and phreatic activity, produce volcanic vents exhibiting a wide variety of morphologies, including vertical pipes and V-shaped vents. In this study we report on experimental and numerical models designed to capture a range of vent morphologies in an eruptive system (Galland et al., 2014). Using dimensional analysis, we identified key governing dimensionless parameters, in particular the gravitational stress-to-fluid pressure ratio ($\Pi_2 = \frac{P}{\rho gh}$), and the fluid pressure-to-host rock strength ratio ($\Pi_3 = \frac{P}{C}$). We used combined experimental and numerical models to test the effects of these parameters. The experiments were used to test the effect of $\Pi_2$ on vent morphology and dynamics. A phase diagram demonstrates a separation between two distinct morphologies, with vertical structures occurring at high values of $\Pi_2$, and diagonal ones at low values of $\Pi_2$. The numerical simulations were used to test the effect of $\Pi_3$ on vent morphology and dynamics. In the numerical models we see three distinct morphologies: vertical pipes are produced at high values of $\Pi_3$, diagonal pipes at low values of $\Pi_3$, while horizontal sills are produced for intermediate values of $\Pi_3$. Our results show that vertical pipes form by plasticity-dominated yielding for high-energy systems (high $\Pi_2$ and $\Pi_3$), whereas diagonal and horizontal vents dominantly form by fracturing for lower-energy systems (low $\Pi_2$ and $\Pi_3$). Although our models are 2-dimensional, they suggest that circular pipes result from plastic yielding of the host rock in a high-energy regime, whereas V-shaped volcanic vents result from fracturing of the host rock in lower-energy systems.