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Insights into lava dome and spine extrusion using analogue sandbox experiments

Edgar Zorn[1], Thomas Walter[1], Michael Heap[2], and Ulrich Kueppers[3]
[1]Deutsches Geoforschungszentrum GFZ, 2.1 Physics of Earthquakes and Volcanoes, Potsdam, Germany
[2]Géophysique Expérimentale, Institut de Physique de Globe de Strasbourg, Strasbourg, France
[3]Department of Earth and Environmental Sciences, Ludwig-Maximilians-Universität München, Munich, Germany

Lava dome formation is a common process at stratovolcanoes involving the shallow intrusion or extrusion of viscous lava and may lead to the rise of spines. Spines are protrusions observed to extrude episodically during lava dome growth, yet the structural and mechanical factors controlling their formation are only partially understood. Here, we provide new, detailed insight into lava dome growth and the production of spines using a novel set of analogue experiments extruding sand-plaster mixtures from a fixed-diameter conduit under isothermal conditions. We trace displacement and strain with photogrammetric methods for precise and detailed monitoring of the extrusion process. Results show initial dome growth forming a steep-sided and flat-topped shape through extrusion of new material, leading to slumping of oversteepening slopes, forming a talus. Spines are found to protrude at a later stage through the dome surface along discrete circular faults that originate from the conduit walls, starting a cycle of spine growth and collapse. As our spines only appear after prolonged extrusion, we relate their appearance to the compaction and strengthening of material within the conduit. We find that spine diameter, height and volume are positively correlated with increasing cohesion and therefore material strength. The spine diameter was also observed to be smaller or equal to the diameter of the underlying conduit, as shear extrusion occurs along vertical to outward-dipping fault planes. For natural domes, our findings imply that spine growth may be the consequence of compaction and densification via porosity loss, shearing and/or outgassing of conduit magma during ascent. More efficient compaction will yield wider and taller spines as a result of increasing rock strength. Our study further highlights the relevance of analogue experiments in the study of lava domes and spines, which remain one of the most hazardous and unpredictable features at dome-forming volcanoes worldwide.