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The influence of hydrothermal alteration on volcano stability: a case study of La Soufrière de Guadeloupe (France)

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Volcanoes are inherently unstable structures that spread and frequently experience mass wasting events (such as slope failure, rockfalls, and debris flows). Hydrothermal alteration, common to many volcanoes, is often invoked as a mechanism that contributes significantly to volcano instability. We present here a study that combines laboratory deformation experiments, geophysical data, and large-scale numerical modelling to better understand the influence of hydrothermal alteration on volcano stability. La Soufrière de Guadeloupe (France) is a hazardous andesitic volcano that hosts a large hydrothermal system and therefore represents an ideal natural laboratory for our study. Uniaxial and triaxial deformation experiments were performed on samples prepared from 17 variably-altered (alteration minerals include quartz, cristobalite, tridymite, hematite, pyrite, alunite, natro-alunite, gypsum, kaolinite, and talc) blocks collected from La Soufrière de Guadeloupe. Our uniaxial compressive strength experiments show that strength and Young's modulus decrease as a function of increasing porosity and increasing alteration. Triaxial deformation experiments show that cohesion decreases as a function of increasing alteration, but that the angle of internal friction does not change systematically. We first combined recent muon tomography data with our laboratory data to create a 3D strength map of La Soufrière de Guadeloupe. The low-strength zone beneath the southern flank of the volcano exposed by our 3D strength map is coincident with the hydrothermal system. We then assigned laboratory-scale and upscaled mechanical properties (e.g., Young's modulus, cohesion, and angle of internal friction) to zones identified by a recent electrical survey of the dome of La Soufrière de Guadeloupe. Numerical modelling (using the software LaMEM) was then performed on a cross-section of the volcano informed by the recent electrical data, and on a cross-section in which we artificially increased the size of the hydrothermally altered zone. Our modelling shows (1) the importance of using upscaled values in large-scale models and (2) that hydrothermal alteration significantly increases the surface velocity and strain rate of the volcanic slope. We therefore

conclude, using models informed by experimental data, that hydrothermal alteration decreases volcano stability and thus expedites volcano spreading and increases the likelihood of mass wasting events and associated volcanic hazards. Hydrothermal alteration, and its evolution, should therefore be monitored at active volcanoes worldwide.