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Fracturing of volcanic systems: Experimental insights into pre-eruptive conditions

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ABSTRACT

Conditions for fracturing are a primary control on the behaviour of volcanic systems, especially during the approach to eruption. We here present the results of deformation experiments under simulated volcanic conditions on a porhyritic andesite from ancestral Mount Shasta. Andesite was chosen as a representative material because it is common at subduction-zone volcanoes, among both erupted products and country rock. We deformed the lava in tension and triaxial compression tests at strain rates of 10^{-5} s^{-1}, confining pressures from 0 to 50 MPa and temperatures up to 900 °C. We also concurrently recorded acoustic emissions (AE), in order to monitor cracking activity. The results show that deformation behaviour changes significantly in the temperature range 600–750 °C. Thus, as temperatures increased across this interval, the tensile fracture toughness increased from 2.5 ± 0.5 MPa $m^{1/2}$ to 3.5 ± 1 MPa $m^{1/2}$, the compressive strength decreased from 110 ± 30 MPa to 55 ± 35 MPa (at 900 °C) and the corresponding Young's Modulus decreased from 20 ± 4 GPa to 6 ± 4 GPa. The changes occur when the deformation of the sample changes from elastic–brittle to brittle–ductile behaviour, which we attribute to the blunting of crack tips due to melting of the glass phase and enhanced crystal plasticity at high temperature. AE activity was observed in all experiments, indicating that earthquakes can be generated not only in country rock, but also in hot magma, such as may be found in lava domes and at the margins of magma conduits. In addition, the trends in accelerating AE event rates before sample failure were comparable to those seen in earthquakes before some volcanic eruptions and a minimum in the seismic -value coincided with sample failure. Applied to volcanic systems, the results suggest that (1) andesite strength and elasticity will not be affected by temperature or pressure beyond ~10–100 m from active magma, (2) before eruptions, fractures propagate preferentially through weaker horizons in a mechanically heterogeneous volcano, and (3) volcanic rocks have characteristic seismic -values that are perturbed during the approach to bulk failure. Each of these conditions provides quantitative constraints on models for seismic precursors to eruption or intrusion.

1. I d c

Fractures are a ubiquitous feature of volcanic systems, exerting a Kilburn, 2003; Kilburn and Voight, 1998; Scandone et al., 2007), the stability of domes and volcanic edifices (e.g.,) and the dynics of lava dome growth and flow emplacement (Fink et al., 1990; Kilburn, 1996; Kilburn, 2004; Smith et al., 2001). The rate of fracturing in the volcanic edifice, recorded as earthquakes, can be used to forecast the timing of eruptions or changes in eruption style (Voight, 1988). In a series of papers, Kilburn and his collaborators developed an eruption forecasting model based on the physics of crack growth (Kilburn, 2003; Kilburn and Sammonds, 2005; Kilburn and Voight, 1998), which Smith et al. (2007) applied to the dome eruption of Mount St. Helens.

De mi0213(m)(of [illegible] andesite, with 40 mm long × 20 mm in diameter, which provides a ratio of length to diameter that is too small to measure true compressive strengths (ratios >2.5 are required; Paterson, 1978). The restricted nature of the mechanical data sets means that fracture-related models applied to andesitic–dacitic volcanoes normally have to infer relevant mechanical rock properties by analogy with the behaviour of other compositions (e.g., Dennniger, 1990; Hale and Wadge, 2003; Kilburn, 2003).

Acoustic emissions (AE), which are a laboratory scale analogue to seismic events, can be recorded during laboratory deformation

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the positions labelled “3”, triaxial compression experiments (with 10 MPa and 30 MPa confining pressure, which is equivalent to 0.5 and 1.5 km depth) at 600 °C model material fairly close to the conduit (within 10 s of m) deforming in shear mode under compressive stresses. For the positions labelled “4”, uniaxial and triaxial (10 MPa confining pressure) compression experiments at room temperature and 300 °C represent fracture of shallow rocks (<500 m) that are not heated or are only minimally heated by the presence of magma. For the positions labelled “5”, triaxial compression experiments with confining pressure of 30 and 50 MPa at room temperature and 300 °C represent shear fracture at depths of 1.5 to 2.5 km in mateca630

and acoustic emission patterns, but fast enough for the experimental conditions to be maintained for the duration of the test. Although this

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