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Fracturing of volcanic edifices and dyking during magma ascent

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During periods of volcanic unrest, magma is transported to the surface by swarms of dykes, which must overcome the strength of the country rock in order to propagate. Field and theoretical studies have shown that the majority of dykes are arrested long before they actually get to the surface. As such, the importance on understanding dyke propagation through field, theoretical and experimental means is of wide importance in hazard mitigation, both directly due to eruption and also indirectly due to edifice stability. However, to date, there exists a paucity of laboratory information to compliment the field and analytical hypotheses on dyke movement, in particular in terms of how pressurised conduits and dykes interact with the surrounding country rock in order to overcome its tensile strength and hence, propagate to the surface (or otherwise).

Previous hydrofracture data has largely concentrated on the pressurization of a central conduit at ambient (room temperature) conditions through the use of a low viscosity pressurisation fluid. Although useful for examining general physical processes, such experiments cannot reveal details due to the temperature of the pressurising fluid (magma) or interaction between melt and the simulated country rock. Conversely, rock mechanics experiments at high temperature have previously been performed at representative temperatures, but without considering a fluid filled conduit; instead relying on mechanical means to fracture the sample, and thus allow the tensile strength and/or critical stress intensity factor (K1c) to be calculated. Therefore, we present a new set of experiments in which a two 'phase' (conduit/shell) system is examined under conditions similar to magma ascent, and that subsequently lead to dyking and fracturing due to the overpressurised fluid (conduit).

The experiments are conducted in a uniaxial press at temperatures of 828°C, 867°C and 914°C and under strain rates approximating 10-5 s-1. In our experiments we pressurise a crystal-poor granitic melt (obsidian from cougar creek, Yellowstone national park, USA within a cylindrical shell of basalt from Mt. Etna volcano, Italy. Pressurization of the melt, with a known temperature-dependence of viscosity, is used to impose a force on the inner wall of the shell in a manner essentially analogous to dyke pressurisation and movement. As the conduit is incompressible, the force provided by the loading ram can be directly used to calculate an imposed stress and thus conduit pressure. Importantly, to simulate as precisely as possible the cyclical nature of volcanic pressurisation, a strain rate was imposed in a series of strain steps. Eventually, the outer shell fractures under the stress. For each temperature tested, shell failure is confirmed through a peak in acoustic emission energy, at which point the conduit pressure falls to zero. Our results show that a prominent stress relaxation response accompanies each period of decrease in strain rate. temperature controls the rate of stress relaxation. Samples at lower temperatures (and thus higher viscosity) take longer to relax compared to higher temperatures. We observe a noticeable dependence of peak stress upon temperature; conduit pressures at fracture of approximately 44 MPa, 18 MPa and 15 MPa measured for sample temperatures of 828°C, 867°C and 914°C respectively (corresponding to conduit viscosities of 9.5, 9.0 and 8.0 log unit respectively. Finally, we present a simple model for (a) calculating the simple tensile strength based on sample geometry and conduit pressure, and (b), determining conduit properties (viscosity) based on the measured stress relaxation data.