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Cyclic pressurisation of Mount St Helens dacites and basalt. Laboratory results and implications for lava dome monitoring

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Lava domes are frequently subjected to cyclic heating and pressurisation, which may weaken the dome rocks, leading to renewed extrusion, explosions or collapse. These heating and loading cycles can be recreated in the laboratory, allowing the level of crack damage caused by these cycles to be established through analysing elastic moduli. Acoustic emissions (AEs) indicate the timing of cracking, and can also be used to interpret precursory seismicity for eruption prediction.

Experiment samples are from Mount St. Helens, USA: 3 dacites from the Pine Creek eruptive period (2.9-2.55 ka), a Castle Creek age basalt (2.55-1.895 ka), and 4 dacites from the 2004-2008 eruption. Each sample was cut into several cylindrical cores (25 mm diameter and 62.5-70 mm long). Some samples were then heated and cooled at 1˚C/ minute to a target temperature of 600o C or 900o C, and held for 2 hours to achieve thermal equilibrium. This heating can cause cracking due to contrasts in thermal expansion of different minerals. Dynamic elastic moduli were calculated for each sample using ultrasonic wave velocity, density and porosity for later comparison to static elastic moduli gathered during deformation. One core of each sample was loaded to failure in uniaxial compression in order to [U+FB01]nd the short term strength of the sample. For all cyclic loading tests, conducted on pre-heated and unheated cores, samples were loaded at $10-5$ s^{-1} strain rate then unloaded to 5MPa. Subsequent cycles had an increasing peak load. Most had the same rate for unloading, with a few samples unloaded instantaneously. Axial, radial and volumetric strain were determined from the recorded displacement throughout the experiment and used with the axial stress measurements to calculate static elastic moduli.

Samples loaded to failure with no cycling generally failed at higher stresses than their cyclically loaded counter-parts, whilst rapid unloading increased their strength. Failure stresses of the dacite lava dome rocks ranged from 18 MPa for a sample from the Pine Creek age to 100 MPa for samples extruded later in the 2004-2008 eruption, whilst basalt samples failed at strengths of up to 198 MPa. Static Young's modulus and Poisson's ratio were comparable to the calculated dynamic elastic moduli. With each successive cycle, Poisson's ratio increased (total increase of factor of 1.25-3), while the peak Young's Modulus decreased (total decrease of 20-44%). However, the pre-heated samples had comparable strength and elastic moduli to their unheated counterparts. The amount of AE increased for stronger samples and during successive loading cycles, though there was often more AE in the penultimate loading cycle than the [U+FB01]nal one.

Reduction in Young's modulus during successive cycles is attributed to the nucleation, propagation and coalescence of microcracks, whilst the increase in Poisson's ratio in successive cycles is attributed to the closure of radially aligned cracks. The lower strength of Pine Creek dacite compared with modern dacites could be due to weakening over time, potentially due to stress cycling; whilst the higher strength and Youngs modulus of the basalt re[U+FB02]ects typical differences between these rock types. The increase of strength for samples that were rapidly unloaded is possibly due to the rock being held under stress for a shorter amount of time. The decreasing Young's modulus and strength with subsequent loading cycles indicate that in subsequent cycles of lava dome pressurisation, similar amounts of in[U+FB02]ation may indicate less pressurisation, but the dome rocks being closer to failure. A greater amount of AE in the penultimate burst indicates that a seismic swarm resulting in a lava dome collapse or eruption may be smaller than the swarm preceding it.