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The samples flowed before the experimentalist: A failure criterion for porous, volcanic material

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Lava domes are complex mounds of silicic material with highly variable crystal (0-100%) and porosity (~<40%) fractions. When subjected to deformation, lava responds by localising strain which can then, under the right conditions, lead to failure. The dimensionless Deborah number, ***De***, can be calculated via the ratio between the relaxation time of a fluid (here, silicate melts) and the timescale of deformation; thus, incorporating the materials' viscosity and the applied stain rate (i.e., the inverse of observation timescale). For silicate melts, it has been shown that they rupture at $\boldsymbol{De} > 10^{-3}$ (known as the critical Deborah number, $\boldsymbol{De}_c$). However, the presence of crystals and bubbles in volcanic materials will influence $\boldsymbol{De}_c$, thus, a method which incorporates these phases needs to be defined. Using uniaxial testing, we characterised the Deborah number of variably porous (0-30%), variably altered, highly crystalline (~75%) dome lavas from the 1991-1995 eruption of Mt. Unzen, Japan. This can then be used to define the macroscopic failure of heterogeneous materials. Experiments were carried out at a range of strain rates (10^{-6}-10^{-1} s^{-1}) at high (900 °C) and room temperature. All ambient temperature experiments resulted in brittle behaviour and the following characteristics were noted:

1. Peak stress decreased with increasing pore volume.
2. Orientation of pore anisotropy had no discerning control over the strength of the rock.
3. Thermal stressing did not affect the strength of rocks within the conditions tested (< 400 °C and 4 °C.min^{-1}).
4. The presence of alteration in some rocks did not result in weakening; in some cases, altered rocks were stronger.
5. Samples deformed at a faster rate typically fail at higher stresses.

At high temperature the response of the samples was variable:

1. At strain rates below 10^{-5} s^{-1}, samples deformed primarily viscously. Their viscosities decreased with strain rate (shear thinning), and did not vary with porosity.
2. At strain rates of 10^{-4} s^{-1}, samples behaved in an increasingly brittle manner (than at low deformation rate).
3. At strain rates above 10^{-3} s^{-1}, samples failed brittlely, with peak stress decreasing with porosity. These samples were stronger than those tested at equivalent strain rates, but ambient temperature.

These conclusions were used to find a relation of the Deborah number as a function of porosity. For the dome lavas of Mt. Unzen tested, we found that $\boldsymbol{De}_c$ scales with porosity according to the linear relationship $\boldsymbol{De}_c$ = -5.1x$10^{-4}\phi$+2.11x10^{-4}. We will discuss how the continued physico-chemical evolution of magmas during ascent leads to a transient failure criterion, whereby the fragmentation threshold decreases by ~2 orders of magnitude as the microstructures evolve.