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Forecasting the brittle failure of heterogeneous, porous geomaterials

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Heterogeneity develops in magmas during ascent and is dominated by the development of crystal and importantly, bubble populations or pore-network clusters which grow, interact, localize, coalesce, outgas and resorb. Pore-scale heterogeneity is also ubiquitous in sedimentary basin fill during diagenesis. As a first step, we construct numerical simulations in 3D in which randomly generated heterogeneous and polydisperse spheres are placed in volumes and which are permitted to overlap with one another, designed to represent the random growth and interaction of bubbles in a liquid volume. We use these simulated geometries to show that statistical predictions of the inter-bubble lengthscales and evolving bubble surface area or cluster densities can be made based on fundamental percolation theory. As a second step, we take a range of well constrained random heterogeneous rock samples including sandstones, andesites, synthetic partially sintered glass bead samples, and intact glass samples and subject them to a variety of stress loading conditions at a range of temperatures until failure. We record in real time the evolution of the number of acoustic events that precede failure and show that in all scenarios, the acoustic event rate accelerates toward failure, consistent with previous findings. Applying tools designed to forecast the failure time based on these precursory signals, we constrain the absolute error on the forecast time. We find that for all sample types, the error associated with an accurate forecast of failure scales non-linearly with the lengthscale between the pore clusters in the material. Moreover, using a simple micromechanical model for the deformation of porous elastic bodies, we show that the ratio between the equilibrium sub-critical crack length emanating from the pore clusters relative to the inter-pore lengthscale, provides a scaling for the error on forecast accuracy. Thus for the first time we provide a potential quantitative correction for forecasting the failure of porous brittle solids that build the Earth's crust.