Deformation and failure of single- and multi-phase silicate liquids: seismic precursors and mechanical work

Jeremie Vasseur[1], Yan Lavallée[2], Fabian Wadsworth[1], Kai-Uwe Hess[1], Joachim Wassermann[1], Donald B. Dingwell[1]

[1]Earth and Environmental Sciences, University of Munich, Germany, [2]Earth, Ocean and Ecological Sciences, University of Liverpool, UK

E-mail: jeremie.vasseur@min.uni-muenchen.de

Along with many other material failure phenomena, volcanic explosion is regarded as a catastrophic one and is often preceded by diverse precursory signals. Although a volcanic system intrinsically behaves in a non-linear and stochastic way, these precursors sometimes display systematic trends leading to eruptions. During dome growth, the seismic activity displays a (supra-)exponential acceleration prior to an explosive eruption – a precursory signal similarly observed prior to failure of magma under controlled laboratory experiments. In laboratory experiments, acoustic emissions (AE) are commonly used to monitor fracture initiation and propagation at a decimetric sample scale. Here, we investigate the mechanical work involved in the failure of magma and assess the ability of AE to be used as a failure forecast proxy. The method has been applied to high-temperature (around the glass transition temperature of the material) deformation experiments in compression with synthesised glass samples (0 to 30% porosity). The technique has also been applied to samples from the dome of Volcán de Colima, Mexico, with a similar porosity range. We observe that the failure of more dense (porosity below 10%) glasses is achieved at large compressive stress (greater than 200 MPa) and thus requires a significant accumulation of strain, suggesting the importance of pervasive microfracturing. Less dense glasses as well as volcanic samples (porosity above 10%) need much lower applied stress (less than 100 MPa) and deformation to fail, as fractures are nucleating, propagating and coalescing into localized large-scale cracks, taking the advantage of the existence of numerous defects (pores in glasses, pores and crystals in volcanic rocks). These observations demonstrate that the mechanical work done through cracking is efficiently distributed inside more homogeneous samples, as underlined by the overall larger AE energy released during experiments. In contrast, the quicker AE energy released during the loading of heterogeneous samples shows that the mechanical work tends to rapidly concentrate in specific weak zones facilitating dynamical failure of the material through dissipation of the accumulated strain energy. Applying a statistical Global Linearization Method (GLM) in multi-phase silicate liquids samples leads to a maximum likelihood power-law fit of the accelerating rate of released AEs. The calculated α exponent of the famous empirical Failure Forecast Method (FFM) tends to decrease from 2 towards 1 with increasing porosity, suggesting a shift towards an idealized exponential-like acceleration. Single-phase silicate liquids behave more elastically during deformation without much cracking and suddenly releasing their accumulated strain energy at failure, implying less clear trends in monitored AEs. In a predictive prospective, these results support the fact that failure forecasting power is enhanced by the presence of heterogeneities inside a material.