Identifying the form of precursory trends before eruptions: reducing uncertainty with rock-physics experiments

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A key goal in forecasting eruptions is to quantify accelerating rates of precursory signals. Exponential and faster-than-exponential (FTE) changes with time are two common forms of acceleration identified from field data, especially for rates of volcano-tectonic (VT) events. Although both types of acceleration have been described by recent theoretical models (Refs. 1 and 2), the noise in field data can introduce ambiguities in identifying the appropriate trend (Ref. 3). The nature of the expected trends can additionally be investigated in the laboratory by deforming and breaking rock under controlled conditions. Most previous experimental studies have focussed on failure in compression. In the field, however, at least local extension must occur for a pathway to open ahead of rising magma. Here we present results on precursory rates of fracturing, using a novel experimental apparatus that recreates rock failure in extension.

To recreate field conditions, we used the fault jog method to generate extensional stress within a background compressional stress field. Two parallel slots, 2 mm wide, were cut at 30° to the vertical axis in cylindrical samples, 40 mm across and 110 mm long. The perpendicular offset between slots was held at 10 mm, but the slot overlap was varied from 0 to 10 mm. Water saturated samples were deformed under triaxial stress at a strain rate of 10^{-5} s^{-1}, 60 MPa confining pressure and 20 MPa pore fluid pressure. Using acoustic emissions (AE) as laboratory analogues of VT events, the number and energy of AE were measured, together with axial and volumetric strain, to investigate the accumulation of crack damage within each sample.

We performed the experiments on samples of alkali baslt from Mt Etna, in Sicily. Our results show that AE rates tend to increase exponentially with time until immediately before bulk failure, when the rate abruptly becomes faster than exponential. The behaviour is well-described by a new theoretical model (Ref. 2) for which the exponential trend is characterised by the energy stored in the atomic structure at absolute temperatures and confining pressures above zero. The characteristic stored energy can be calculated using rock composition, temperature and confining pressure. In our experiments, the exponential trends yield values for the characteristic stored energy of 28-36 MJ m^{-3}. These compare well with the calculated values of 32 (± 20%) MJ m^{-3}. The good agreement suggests that VT precursors in the field are likely to evolve with time from exponential to FTE trends and that the onset of an FTE acceleration may be an essential signal to indicate that an eruption is imminent.

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