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Long-term time-dependent rock deformation at constant stress: a mechanism for accelerated deformation preceding volcanic eruptions.

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Time-dependent brittle rock deformation is of first-order importance for understanding the long-term behaviour of the Earth's brittle crust. In particular, the mechanism of stress corrosion enables cracks to propagate in rocks at stresses far below their short-term failure stress. The crack growth is highly non-linear and accelerates towards dynamic failure over extended periods of time, even at constant applied stress. In volcanic systems, this type of behaviour is commonly manifested as accelerating deformation (fault slip and ground tilt) and accelerating seismicity over periods of days to months preceding eruptions. Such accelerations are often attributed to increases in the pressure exerted by a magma body on the surrounding country rock. An alternative interpretation is that short and medium-term precursors are controlled by brittle creep and so accelerate at a rate determined by rock weakening under a virtually constant stress.

Interpretation of results from traditional laboratory experiments of brittle creep have generally been in terms of three individual creep phases; primary (decelerating), secondary (quasi-steady-state) and tertiary (accelerating or unstable). The deformation may be distributed during the first two, but localizes onto a fault plane during phase three. More recently, models have been proposed that explain this trimodal shape of creep curves in terms of the competition between a weakening mechanism and a strengthening mechanism, with the weakening mechanism eventually dominating and leading to localized failure. However, a major problem is that it is very difficult

to distinguish between these competing mechanisms and models given the lower limit of strain rates achievable in laboratory experiments over practicable time scales. This is important because the interplay between mechanisms controls the timescale over which seismic and deformation precursors accelerate to eruption.

A new project has been developed to investigate long-term rock fracturing and deformation at very low strain rates through experiments conducted in a deep-sea laboratory in the Ionian Sea. A prototype deformation apparatus (CREEP) has been designed and built for the project, within which the confining pressure is provided by the ambient water pressure (approx. 22 MPa), and the constant axial stress is provided by an actuator that amplifies this pressure. Measurement transducers and a data acquisition system are sealed internally, with power provided for up to 6 months by an internal battery pack. The great advantage of operating in the deep sea in this way is that the system is essentially passive, has few moving parts, and requires no maintenance. The apparatus is held in place by a disposable cast-iron anchor and supported above the seabed by a deep-sea buoyage system. On completion of each experiment, an acoustic release detaches from the anchor and allows the apparatus to float to the surface to be recovered by an oceanographic research vessel.

The prototype apparatus has been deployed for periods from 3 days to 6 months, since March 2003. Results from a 4-month deployment show a rapid increase in sample strain during deployment as the apparatus sinks to 2100 m water depth, which takes about 15 minutes. The sample then creeps under constant applied differential stress for approximately 100 days before the onset of accelerating creep instability. The average creep strain rate during the main phase of deployment was approximately 5 x 10^{-11} s^{-1}, some two orders of magnitude lower than achieved in earlier laboratory experiments.