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Brittle creep in rocks: from laboratory to crustal time scales.

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Earthquake rupture and volcanic eruptions are the most spectacular manifestations of dynamic failure of critically stressed crust, but these are actually rare events in both space and time. Most of the crust spends most of its time in a highly-stressed but sub-critical state. Furthermore, water is ubiquitous in the crust and water-rock chemical reactions can lead to time-dependent deformation that allows rocks to fail over extended periods of time at stresses far below their short-term failure strength; a phenomenon known as “sub-critical crack growth”.

Quantifying sub-critical crack growth and brittle creep is therefore crucial to understanding the evolution and dynamics of the brittle crust. The presence of cracks allows the crust to store and transport fluids, and even modest changes in crack size, density or linkage can produce major changes in fluid transport properties. Time-dependent rock deformation therefore has both a scientific and a socio-economic impact since it controls the precursory phase of important geohazards such as earthquake rupture and volcanic eruptions, and also influences effective recovery of hydrocarbon and geothermal energy resources, and the integrity of long-term storage facilities for hazardous waste.

Most importantly, this mechanism allows rock to deform even under a constant applied stress over extended periods of time; a phenomenon known as brittle creep. This style of deformation has usually been described empirically as exhibiting a trimodal behaviour when axial strain is plotted against time (commonly known as a creep curve). The three stages of the creep curve have conventionally been described as; (1) primary or decelerating creep, (2) secondary or steady-state creep, and (3) tertiary or accelerating creep. Deformation may be distributed and stable during primary and secondary creep, but generally becomes localized and unstable during tertiary creep. Eventually, the deformation accelerates to failure producing a localized fault plane.

Since it is not possible to perform laboratory rock deformation experiments over the time scales relevant to large scale tectonic deformation, we are forced to rely on theoretical models to extrapolate laboratory creep data to natural strain rates. However, it is currently not possible to discriminate between competing models based on the restricted range of strain rates achievable in normal laboratory experiments. We are therefore left with two major questions which form the basis of this presentation: (1) is secondary creep genuinely steady state and, if so, over what time scales can steady state deformation be achieved; and (2) how can we extend the range of achievable strain rates in deformation experiments to bridge the gap between laboratory and natural strain rates?

We address the first question by considering the first and second derivatives of strain against time, and find the process to be steady-rate rather than steady-state. We address the second question by using the stable environment of the deep sea to allow us to perform ultra-long-term brittle creep experiments at strain rates that bridge the gap between laboratory and tectonic rates.