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Brittle creep, damage and time to failure in rocks

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We first review published data of time to failure, t_f, of rocks under creep conditions. We compare exponential and power-law relationship between t_f and the applied stress for tests performed on different types of rock and various environmental

conditions. This data shows that the time to failure changes by several orders of magnitude when varying the confining pressure, the temperature or the water saturation. We then use this time-to-failure relation as input for a numerical model based on progressive damage. This model reproduces the primary and tertiary creep regimes observed experimentally for rocks. During primary creep, the strain rate, the energy rate, and the rate of damage events decay with time as a power-law with an exponent of 0.8. The tertiary creep is characterized by a power-law acceleration of damage with an exponent of 0.8 for the event rate, and 1.3 for strain and energy rates. We derive analytical solutions for a simplified version of the model, which explain qualitatively these results. The distribution of damage event sizes is a power law when integrated over all the simulation. The temporal evolution of this distribution shows an increase of the mean event size before failure. During primary creep, damage is relatively uniform in space. Damage localization occurs at the transition between primary and tertiary creep, when damage rate starts accelerating. The final state of the simulation shows highly damaged bands, similar to shear bands observed during laboratory experiments. The thickness and the orientation of these bands depend on the applied stress. This model shows that a complex global behavior (primary and tertiary creep regimes, power-law distribution of event sizes, and damage localization) can emerge from a simple elementary behavior, based on progressive damage and experimentally established time-to-failure law.