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Thermal influences on macroscale rock damage

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Fracture processes in rock have widespread implications in the geohazard, geomorphologic, and civil and mining engineering communities. Propagation of fractures reduces overall rock mass strength, can lead to large-scale gravitational instabilities, and can cause significant hazard and damage to infrastructure. The potential for critical fracture in the form of rock falls and rock bursts are often the primary driver for scientific investigations, civil work project planning, and mining investment outlays. However, slower subcritical fracture from long-term monotonic and/or cyclic stress perturbations often control the eventual more rapid (and more catastrophic) response of rock. These slower damage mechanisms may result from existing or perturbed tectonic stresses, stress relief from exhumation or excavation, or long-term environmental stressors such as thermal cycling and frost cracking.

Here we investigate the role of thermal cycling in generating subcritical stresses to which virtually all rock cliffs worldwide are exposed. Our hypothesis – that diurnal and seasonal cycles of temperature can lead to substantial subcritical fracture propagation and eventual critical fracture – has led us to design several field and laboratory experiments to measure both the deformations and the stresses associated with environmental thermal forcing in rock. Our studies focus on granitic exfoliation environments, common in many mountainous regions of the world, where relatively thin (centimeters to decimeters) exfoliation sheets are able to undergo a full thickness thermal response, and where exfoliation-related rock falls are common and in some places, well-documented.

In cliff environments located in Yosemite National Park (California, USA), our field studies using in-situ measurements (i.e., crackmeters and temperature sensors) have shown that diurnal and seasonal thermal cycles lead to cyclic stresses in the subcritical range, with resultant cumulative and seemingly permanent rock deformation outwards from the main cliff surface. Additional field studies using thermal IRT (InfraRed Thermography) imaging identify the locations of rock bridges that likely serve as focal points for these thermally-induced stress concentrations. Although we did not measure the critical fracture conditions that would result in a rock fall, we did, fortuitously, capture the deformation signals leading up to explosive fracture of a nearby granitic 100-m-

diameter exfoliation dome during peak temperatures at the site (located ~60 km northwest from Yosemite), thereby proving the efficacy of thermal stresses in driving both long term – and catastrophic – rock damage. These field studies are substantiated by analytical fracture mechanics solutions which show how rock may eventually fail under these conditions. These studies therefore serve as proxies for understanding how some rock falls eventually occur under subcritical thermally-induced cyclic stress conditions, but also more generally for how thermal-stress conditions may affect rock damage in a multitude of environments.