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Exfoliation-type rock fall triggering from thermally-induced cyclic deformation

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The driving factors and rates of rock fracture formation leading to subsequent rock falls are in many cases, poorly constrained. Yosemite National Park, California, USA provides an ideal research laboratory for investigating rock fracture mechanics where exfoliation plays a primary role in cliff evolution. In Yosemite, numerous mechanisms are inferred to trigger rock falls; nevertheless, many rock falls have no recognized triggers. As a result, several potential, but as yet unquantified, triggering mechanisms have been proposed. One of these, thermally-induced flexure, by which cyclic temperature variations drive deformation of partially detached exfoliation sheets of rock may explain several recent rock falls in Yosemite.

We present work aimed at investigating this hypothesis through the use of a nearly two-year-long continuous record of 5-minute-interval, crack-aperture measurements taken at three locations behind a near-vertical, partially detached exfoliation sheet of rock in Yosemite. The sheet of rock or "flake" is 14 m tall, 4 m wide, 12 cm thick. It is attached to the cliff face at its bottom and top, but is detached at its sides and middle section by a 10 cm wide crack on one side, tapering to a 1 cm wide crack on the opposite side. We combine the crack-aperture data with a simultaneous record of near-surface air temperatures both on the face and behind the rock flake to establish a direct empirical correlation between flake deformation and temperature variation. The flake receives direct sun exposure during most of the day and we further correlate temperature with solar radiation through light sensor measurements.

Our data indicate the flake undergoes maximum deformation at mid-span between attachment points and deforms from both diurnal and seasonal temperature fluctuations. Recorded maximum diurnal deformation measured perpendicular to crack orientation is approximately 1 cm. Since monitoring began in May 2010, maximum cumulative (temporary) inward and outward deformation has been 1.5 cm and 0.9 cm, respectively. High-resolution lidar data verify the measured deformations and further show the three-dimensional pattern of deformation is consistent with expectations for a simple end-pinned column. Temperature and light data indicate a direct link to flake deformation, with peak expansion (crack opening) in late-afternoon, within four hours of peak solar radiation and within two hours after peak temperatures (up to 56°C). Likewise, peak contraction (crack closing) occurs in mid-morning at opposite diurnal cycle, synchronous with low solar radiation and air temperature (down to -7°C). We interpret the lag between solar radiation, temperature and deformation to be caused by the response time needed for thermal propagation through the granitic flake itself.

We use deformation mechanics analysis to verify that the amount of measured flexure is coincident with what has been measured. Further, we identify two potential modes for eventual failure of the rock flake: (1) cumulative outward overall deformation leading to increased overturning moment and tensile failure, and (2) cumulative subcritical crack growth at the crack tips leading to eventual critical crack growth and detachment. The data and analyses provide an explanation for many exfoliation-type rock falls occurring in Yosemite and elsewhere.