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Dependence of glacial erosion rates on the spacing of fractures in alpine landscapes

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Crystalline plutons in the Sierra Nevada, California, show distinct variations in the spacing of fractures across the mountain range. Wide and medium fracture spacing in Yosemite National Park contrast with very closely-spaced fractures on the eastside of the Sierran drainage divide. These differences in fracturing profoundly influence the surface morphology, with massive, intact valley walls and smoothly-polished bedrock domes in areas where the fracture spacing is wide and highly eroded, rough hillslopes in areas with narrow fracture spacing. In this study we explore the relationship between bedrock fracture spacing and the erosion of this alpine landscape during the last glacial cycle. We are in particular interested in exploring the control of the degree of bedrock fracture spacing on the two glacial erosion mechanisms: quarrying of blocks and abrasion of bedrock surfaces.

In order to document glacial cycle average erosion rates, we sampled glacially-polished bedrock surfaces for cosmogenic 10Be concentrations along a 94-km longitudinal transect in the Tuolumne drainage basin west of the Sierran divide, and along two 10-km long transects on the east side in Bloody and Lee Vining Canyons. The sampling domain stretches from the drainage divide to the LGM glacier termini and includes granitic and granodioritic units that display strong differences in joint spacing. In addition, we systematically measured the fracture spacing as proxies for relative erodibility at each cosmogenic sampling site.

Our 10Be results show that the depth of glacial erosion during one glacial cycle is dominantly controlled by the fracture spacing. Joint spacing differs markedly across the divide. In the Tuolumne catchment draining toward the west, sample sites in one particular intrusive unit display anomalously high 10Be concentrations, implying an erosion depth of less than 2-3 m. These sites have an average fracture spacing of 2.7 m. Samples in the other intrusive units yield 10Be concentrations that can be best explained as reflecting solely postglacial nuclide accumulation; at these sites more than 3 m of rock were eroded during the last glaciation effectively removing all 10Be inventory from the rock. These reset sample sites have average fracture spacings of about 0.7 m. Fracture data from our eastern sample sites show that bedrock is significantly more fractured compared to the west side; the average spacing is 0.3 m, presumably reflecting proximity to the active normal fault that bounds the eastern Sierras.

We interpret our results as indicating that rock type and in particular joint spacing strongly governs the susceptibility of a rock to glacial erosion. The broader the spacing, the lower are the rates at which a glacier can quarry blocks from its bed. That some of the major granitic intrusions of Yosemite are so poorly jointed, itself reflective of both intrusive mechanisms and gentle exhumation, results in a landscape that is less prone to glacial quarrying and that displays beautiful polish that reflects dominance of glacial abrasion.