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Formation of sheeting joints in Yosemite National Park, California

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The formation of sheeting joints (i.e., "exfoliation joints"), opening mode fractures subparallel to the Earth's surface, has been a classic unresolved problem in geology. Diverse new observations and analyses support the hypothesis that sheeting joints develop in response to a near-surface tension induced by compressive stresses parallel to a convex slope (hypothesis 1) rather than the conventional explanation that the joints form as a result of removal of overburden by erosion (hypothesis 2). The opening mode displacements across the joints together with the absence of mineral precipitates within the joints mean that sheeting joints open in response to a near-surface tension normal to the surface (N) rather than a pressurized fluid. An absolute tension must arise in the shallow subsurface if a plot of N as a function of depth normal to the surface (z) has a positive slope at the surface (z=0). The differential equations of static equilibrium require that this slope (derivative) equals k_2 P_{22} + k_3 P_{33} - ρg cosβ, where k_2 and k_3 are the principal curvatures of the surface, P_{22} and P_{33} are the respective surface-parallel normal stresses along the principal curvatures, ρ is the material density, g is gravitational acceleration, and β is the slope. This derivative will be positive and sheeting joints can open if the surface-parallel stress in at least one direction is sufficiently compressive (negative) and the curvature in that direction is sufficiently convex (negative).

Hypotheses 1 and 2 are being tested using geologic mapping and aerial LIDAR data from Yosemite National Park, California. The abundance of sheeting joints on convex ridges there, where erosion is a local minimum, coupled with their scarcity in the adjacent concave valleys, where erosion is a local maximum, is consistent with hypothesis 1 but inconsistent with hypothesis 2. At several sites with sheeting joints, measurements of the current topographic curvatures and the current surface-parallel stresses, typically about -10 MPa, meet the requirement above. In apparent violation of hypothesis 1, however, sheeting joints occur locally at the bottom of Tenaya Canyon, one of the park's deepest glaciated, U-shaped (concave) canyons in Yosemite. The sheeting joints occur only where the canyon is convex in the downstream direction though, and that is the approximate direction of the most compressive stress based on nearby stress measurements. Apparently the effect of the least compressive stress acting across the valley, which acts to close the joints, is overcome by the effect of the most compressive stress acting along the down-valley convex curvature, which promotes the opening of the joints.