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Effect of glacial ice cover on fracturing in critically stressed bedrock

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The natural generation of macroscopic extensional fractures in near-surface rock may be observed through phenomena such as pop-ups, A-tents and exfoliation joints in previously glaciated terrain. Drawing from rock mechanics principles and tunneling experience, we apply a tri-linear failure criterion to model intact rock behavior on natural slopes. Our model indicates that extensional fracturing may develop as a result of high differential stresses in the near surface, in a similar process as spalling on the walls of deep excavations. This process is dependant on both in situ landscape stresses, and on confining stress provided by external loads normal to the rock surface. Such loading may be imposed by fractured rock or soil cover, or by glacial ice, but is reduced to zero when rock is exposed at the ground surface.

The process of spalling is an active form of brittle rock fracture and can produce hazardous rock bursts in tunnels, though typically results in the generation of centimeter to decimeter thick rock slabs or flakes on tunnel walls. Similar rapid development of extensional Mode I fractures has been observed in modified natural environments eg. as 'instantaneous' development of (decameter-scale) pop-ups or rock bursts in open pit quarries. We suggest that the development of such fractures in these modified natural environments may be a result of the removal of overburden from highly stressed underlying rock, leading to a reduction in confining stress, and inducing high in situ differential stresses. Though the stress paths may be different, the final stress state induced through quarrying may be similar to that shown to induce extensional fracture and spalling on tunnel walls. At the same time, the geometries and mode of fracture development within quarries are similar to those of exfoliation joints observed in previously glaciated terrain. Such fractures can therefore provide an important link between our application of the tri-linear failure criterion to naturally induced in situ stresses in Alpine landscapes, and the development of exfoliation fractures in association with glacial processes within these evironments.

Using insights gained from our modelling approach, we illustrate the potential effect of ice or overburden on critically-stressed bedrock, then highlight possible dependencies relating to the development of ice cover, sub-glacial erosion, ongoing tectonics, and potential path dependant behavior of fracture generation beneath accumulating, or downwasting glacial ice.