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Increasing rock-avalanche frequency correlates with increasing seismic moment release in New Zealand's Southern Alps

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The occurrence rate of large, spontaneous rock avalanches in New Zealand's Southern Alps has increasing over the last 50 years. The rate has been about 20 events per decade for the last 10 years, whereas for the period 1976-1999, it was 4 per decade. Allen et al. 2011 and Allen and Huggel, 2013 link the increase to alpine permafrost decay due to anthropogenic global warming, similar to the increased occurrence rate in the European Alps which is attributed to this cause. We however suggest a different primary cause, linking the increase to tectonic strain, which has been shown to also affect valley-bottom hot springs in the region.

The altitudes from which these landslides have fallen are coincident with the region's topographically protruding slopes which favour stress concentration and failure, and many, but not all, failures have been from already highly fractured rock masses, for which an explanation of the fracturing is called for. Also, the earliest documented spontaneous rock avalanche in the Southern Alps occurred in 1873 and fell from a similar altitude on the same face of the same mountain as the most recent event in 2014.

Cox et al. (2014) shows that valley-bottom hot springs in the Southern Alps respond to distant strong earthquakes in a manner suggesting weak local ground deformation and increased bedrock permeability. We suggest that the surrounding slopes respond to the same stimuli. We find that the observed occurrence-rate increase has occurred simultaneously with a seismic-moment-release increase in New Zealand, which follows the trend of global seismic moment release. It may also be associated with the accumulating slope deformations since about 1717 AD, when a great earthquake triggered much slope collapse in the region.

In support of this link, Barff (1873) which reports the 1873 landslide from Aoraki/Mount Cook, also reports a seemingly associated but unexplained shift of hot springs in the area. The timing of both coincides with a distant series of moderate earthquakes west of North Island, New Zealand, which was felt widely in North Island.

The New Zealand seismological record is complete enough since 1969 for earthquake magnitudes $\geq$4.0 to enable determination of seismic moment release. We applied an exponential distance attenuation to the accumulating moment release with an empirical decay constant of 2093 km to obtain closely matching trends between our two data sets. Such a relatively slow decay with distance may imply that ong-wavelength surface waves are affecting the slopes. On the other hand, the increasing landslide frequency sometimes leads the increasing seismic moment, suggesting that the two may be driven by a third process such as accumulating regional crustal strain in the South Pacific.

An earthquake of M>8.0 occurred over 290 years ago (ca. 1717 AD) on the Alpine fault with no major release of regional crustal strain there since that time. This earthquake is expected to have triggered widespread landsliding in the central Southern Alps. Since that regional release of elastic crustal strain, the underlying rock mass of the S. Alps has been accumulating elastic strain beneath a relatively thin skin of semi-detached, brittle and closely jointed rock. The estimated mean recurrence time of ruptures on the Alpine fault is about 330 years, and so, the expected misfits between the deforming intact rock and the overlying dilated granular masses of potential landslides can be expected to be approaching average levels not present since before 1717 AD. Perhaps this is the reason why more of the semi-detached masses are completing the detachment process and falling off.

We do not discount an additional link with permafrost decay, which is a mechanism with potential to lower the cohesion in granular rock masses in the permafrost zone of the higher Southern Alps. But permafrost decay does not create granular rock masses.