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Constraining the impact of earthquakes on mountainous landscapes

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Earthquakes alter the topography of mountain ranges by shortening and thickening the crust, while also causing erosion via co-seismic landsliding. For single large (>Mw7) earthquakes, co-seismic landslide volumes can exceed the volume of rock uplifted by the earthquake. Hence, large earthquakes are hypothesised to generate rock uplift, but minimal (or no) surface uplift. Surface uplift of mountains is affected by existing regolith limiting the amount of bedrock erosion by landslides, rock uplift by small earthquakes (that do not produce landslides), inter-seismic erosion, and a-seismic rock uplift, hence the role of earthquakes in generating surface uplift of mountains is poorly constrained. Observations of a post seismic multi-temporal landslide inventory of the 2008 Wenchuan earthquake demonstrate that landslide deposits are likely to remain within the Longmen Shan for longer than previously assumed. We demonstrate the importance of persistent regolith and aseismic uplift to surface uplift by using a dimensionless seismic volume balance model. Regolith generated by large earthquakes limits exhumation rates over 102-103 years because smaller landslides remobilise existing regolith rather than eroding bedrock, creating a depth-dependent co-seismic landslide regolith production function (CLRPF). Applying this model to the Longmen Shan in China reveals that 42% of the regolith generation is by co-seismic landsliding. We varied the proportion of rock uplift by earthquakes to a-seismic processes, demonstrating that stochastic rock uplift and CLRPF leads to statistically significant differences in the variability of exhumation rates measured across cosmogenic timescales. To test this model result, we analysed a global database of detrital cosmogenic nuclides from a range of tectonic settings, demonstrating that seismically active compressional landscapes have significantly higher variance and skew. The results demonstrate that the influence of earthquakes on the exhumation of mountains extends beyond the timescale of most dating methods (including cosmogenic radionuclide dating) and that average erosion rates calculated by these methods may significantly underestimate erosion rates.