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Rockfalls on limestone coastal cliffs

Matt Westoby (1), Michael Lim (2), Michelle Hogg (3), Lesley Dunlop (1), Matthew Pound (1), and John Woodward ()

(1) Geography and Environmental Sciences, Northumbria University, Newcastle upon Tyne, United Kingdom (matt.westoby@northumbria.ac.uk), (2) Mechanical and Construction Engineering, Northumbria University, Newcastle upon Tyne, United Kingdom, (3) South Tyneside Council, South Shields, United Kingdom

We use terrestrial laser scanning and surface differencing to quantify rockfall generation across a 0.6 km-long (15.3 $\times$ 10^3 m2) section of hard rock cliff at Marsden Bay, on the north-east coast of the UK, and explore spatiotemporal variability between different geologies (dolomitic, secondary and concretionary brecciated limestones). A total of 37,070 failures were detected, covering 12% of the exposed cliff face. Erosion activity was characterised by a dominance of small rockfalls, interspersed with episodic large (>10 m3) failures, some of which show evidence of progressive instability prior to failure. The largest detected failure was 104.3 m3, producing a mean local erosion rate which exceeded the site-wide rate (0.032 m-1 a-1) by over an order of magnitude. Mean rockfall depth (0.142 m) and volume (0.024 m3) differed by <0.01 m and <0.01 m3 respectively between geologies. Rockfalls <0.1 m3 accounted for 98% of events, whilst rockfalls >0.1 m3 accounted for 89% of the total eroded volume. We observed complex patterns of erosion cycling, including areas which experience intense and short-lived periods of activity adjacent to areas with a more balanced distribution of failure periodicity and volume. The dolomitic and secondary limestones generated rockfalls more or less synchronously, whereas the timing of erosion in the brecciated limestone concentrated in the period March-May 2016. The spatiotemporal distribution of rockfalls varied considerably between geologies; dolomitic limestones showed little variability in rates of erosion, whilst in the secondary limestone we observed increased erosion rates toward the cliff top and cliff base, perhaps reflecting preferential erosion by processes such as surface runoff and wave action, respectively. The highest erosion rates in all geologies occurred in winter months at almost all cliff elevations. Our results highlight the inherent complexity of rockfall generation across coastal cliffs and expand the body of research into the evolution of these environments over spatial and temporal scales which are relevant for coastal managers and hazard practitioners.