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Predicting the timescales of catastrophic stratovolcano collapse – A model based on Mt. Taranaki, New Zealand.

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Andesitic stratovolcanoes or composite volcanoes are constructed in short, but rapid growth-rate eruption episodes to form steep, unstable edifices made of alternating layers of lavas, pyroclastic and epiclastic breccias. Stratovolcanoes regularly collapse catastrophically, producing highly destructive volcanic debris avalanches that present the extreme hazard scenario at all major continental volcanic arcs on Earth. However, models to forecast their likelihood and size are rare, typically because of poor age and volume constraints on their deposits in the geological record at any one volcano.

Here we use one of the best-exposed long-term records of both volcanic sedimentation and geochemical evolution from a typical calc-alkaline andesitic volcano to develop a steady-state growth and volume-controlled model for the probability of catastrophic volcanic edifice collapse. The >130 kyrs history of Mt. Taranaki (2518 m) in New Zealand's North Island is punctuated by at least 14 catastrophic edifice failures. These involved all sectors of the volcano and produced debris avalanche deposits of >1 to >7.5 km3 with recurrence intervals of 2.5-15 kyrs. The largest of these sudden events removed as much as one third of the upper present-day equivalent cone. Individual debris avalanche units show similar sedimentary and geomorphic characteristics, suggesting that the nature of proto-edifices, failure trigger mechanisms and runout path conditions were similar for each event. Each collapse was followed by sustained renewed volcanism and cone regrowth, although there are no matching stepwise geochemical changes in the magma erupted. Instead a stable, slowly evolving magmatic system has prevailed, producing similar eruption styles and frequency throughout the volcanic history. The strong climate variations and extreme conditions during the Last Glacial are also uncorrelated with the timing or magnitudes of edifice collapse. These similar internal and external conditions resulted in the observed long-term balance between the rates of edifice destruction and reconstruction, characterised by regular, predictable collapse and subsequent restoration of the pre-failure state.

Our data demonstrates that if the magmatic composition erupted from stratovolcanoes is constant and basement geology conditions are stable, the frequency of large-scale edifice collapse and the generation of catastrophic debris avalanches will be governed by the magma-supply rate. Using a mass balance approach, a steady-state volume-frequency model can be applied to forecasting both the probable timing and volume of future failures of such stratovolcanoes. In the Mt. Taranaki case, the maximum potential size of a present collapse is estimated to be 7.9 km3, while the maximum interval before the next collapse is <16.2 kyrs. The current annual collapse probability is around 0.00018 with the most likely event being a small one (<2 km3).