Paired ^{1}Be–^{2}Al dating of an extreme debris-flow: resolving timing and inheritance in the Caraz fan (Cordillera Blanca, Peru)

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Abstract

Rapid cryosphere degradation is increasing the frequency of cascading hazards in high-mountain environments, yet rare high-magnitude events remain poorly constrained due to limited historical records. Long-lived depositional archives recording slope responses during past glacial retreat provide critical insights into such extreme processes and might serve as analogues current and future situation.
Here we investigate the Caraz debris fan (_˜200–300 Mm^3) in the Cordillera Blanca (Peru), one of the most glacial-hazard-prone tropical mountain regions. Geomorphological and sedimentological characteristics-including a smooth 3-km-wide radial morphology, abundant granodioritic boulders up to 20 m in diameter, compact and poorly-sorted deposit (20-40m thick), jigsaw-fractured clasts, and run-up features-indicate rapid emplacement by a high-energy flow with exceptional transport capacity.

We apply paired in-situ cosmogenic ^{1}Be–^{2}Al exposure dating (n = 22) to constrain the timing and exposure history of the deposit. Results yield a consistent emplacement age of 9.6 ± 1.6 ka (Early Holocene). A subset of samples shows ^{2}Al/^{1}Be ratios of _˜4–5, indicating inheritance and suggesting that some clasts were previously exposed and stored in the upper catchment before incorporation into the event. Possible source elevations are evaluated by comparing production-rate scaling and inherited cosmogenic components.
These results support emplacement during a single extreme event and highlight the necessity of using paired cosmogenic nuclides to discard apparent-ages and resolve complex exposure histories in large mass-flow deposits. Combined with geomorphic constraints, the data favor a cascading scenario involving a rock–ice avalanche, glacial lake outburst, and downstream debris flow propagation.

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