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Canyon incision, volcanic fill, and re-incision rates in southwest Peru: proxies for quantifying uplift in the Central Andes

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Using zircon and apatite fission tracks and apatite (U–Th)/He to constrain 26 rock cooling histories of Cretaceous diorites and 40Ar-39Ar to date 45 Neogene ignimbrites and lavas, we have estimated incision and topographic uplift rates of the Western Cordillera in southwest Peru. Rock cooling patterns confirm that continental denudation declined rapidly during the early Cenozoic. Topographic paleoelevations provided by 24.5 Ma forearc marine sediments now occurring at 1.8 km a.s.l. indicate that the Andean orogenic plateau did not begin to rise before Miocene time. A suite of marker horizons consisting of Huaylillas ignimbrite (14.3–12.7 Ma) on the plateau, and of Sencca ignimbrite (3.8 Ma) and Barroso lavas (2.27 Ma) near the Rio Cotahuasi and Rio Ocoña valley floors, respectively, have helped to bracket accelerated uplift between 13 Ma and 3.8–2.27 Ma.

In-canyon (U–Th)/He bedrock cooling ages decrease upstream from ∼13 Ma to 2–4 Ma, implying that uplift-driven valley incision began after 14 Ma and that downcutting was neither steady nor uniform along the 209 km-long canyon system. Whereas ∼9 Ma Caraveli ignimbrites filled broad, shallow valleys, V-shaped downcutting occurred after 9-6 Ma. Argon-dated in-canyon lava flows and ignimbrites reveal three pulses of bedrock incision: 8.8–5.8 Ma, 5.8–3.6 Ma, 3.6–1.36 Ma, followed by post-1.36 Ma re-incision into unconsolidated valley fill. Accordingly, ample variations belie the 14 Myr-averaged incision rate of 170 m Myr–1: 130–190 m Myr–1 between 13 and 9 Ma, rising to 250–400 m/Myr–1 between 9 and 3.8 Ma and to >1000 m Myr–1 of reincision after 1.36 Ma. Rapid bedrock incision ended before 3.76 Ma in the upper, and before 2.27 Ma in the lower canyon reaches. The 3.76 to 1.36 Ma pyroclastic and mass-flow deposits filled the valley to ∼75% and ∼60% of its height in its upper and lower reaches, respectively. Post-1.36 Ma re-incision removed 75% of these deposits, thus exhuming most of the bedrock paleocanyon. The upper canyon system is still adjusting its course through large Pleistocene debris-avalanche deposits.

Three knickzones occur along the length of the canyon. Upstream, V-shaped bedrock gorges of Cotahuasi give way to a ∼1 km-wide braided channel of Ocoña, confirming asynchronous incision. Successive waves of knickpoint migration can be evidenced by breaks in slope when reconstructing Pliocene longitudinal valley profiles, when the 4.9–3.6 Ma Sencca ignimbrites filled the canyon. Longitudinal incision and lateral slope processes collaborated to shape distinct canyon reaches. No volcanic rocks older than some 2.27 Ma valley-floor lava flows have been preserved on the steep walls of the lower Rio Ocoña valley. In contrast, in the upper reaches of the Ocoña and Cotahuasi, two Sencca ignimbrites, 4.9–3.6 and 2.34–1.6 Ma old, cap two sets of rock plat-forms cut in slopes 400–600 m above the present-day channel.

The 3390 km2 canyon catchment area has undergone 0.2 km3 Myr–1 of averaged bulk erosion since 13 Ma. This relatively low rate for an active orogen can be explained by the long-term prevalence of arid climatic conditions. Runoff and erosion were nevertheless enhanced after 6 Ma by bedrock being driven through increasingly higher altitudinal belts, eventually permitting glacier-fed runoff after 2 Ma. Erosion has been intermittent, alternately enhanced or hindered by slope instability. Large debris avalanches and mass flows caused ponding and subsequent lake-breakout debris flows, which slowed down the successive waves of knickpoint propagation. Clastic fill having repeatedly altered local relief in the canyon, the mass balance of valley incision has thus been more complex than any impression of a steady removal of bedrock in response to crustal uplift might suggest.