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Cosmogenic in-situ 14C reveals rapid soil erosion with the onset of agro-pastoralism on the Andean Altiplano

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The profound impact of modern human land use on surface erosion and sediment dynamics is undisputed. Although many landscapes have been under intense cultivation and modification by humans for millennia, quantifying the impact of land use on erosion dynamics is challenging. Previous research on prehistoric soil loss has mostly relied on indirect proxies such as floodplain sediments or lake deposits. However, these records can be biased due to ineffective source-to-sink coupling. Here, we quantify soil loss directly on eroded hilltops and in fluvial sediments with a multi-nuclide approach involving in-situ produced cosmogenic 14C, 10Be, and 26Al. Our approach exploits the nuclides' differing half-lives, which yield disequilibrium relationships in response to landscape transience.

We measured 14C-10Be-26Al on bedrock, soil-mantled hilltops, and in river sands in a catchment on the Andean Altiplano. The high Andes, despite today's comparatively low population density and rural development, represents a highly modified landscape recording more than 12 kyr of human occupation and adaptation. Our analyses show a pronounced offset between 14C and the longer-lived 10Be and 26Al nuclides, which is defined by a strongly reduced 14C concentration. In contrast, concordant results were obtained for the 10Be-26Al pair suggesting long-term steady-state conditions. We interpret these results to indicate a major erosional perturbation over recent, millennial timescales relative to the long-term (pre-human) rates of soil erosion (up to 100 kyr). To identify the potential causes of the deviation in the 14C-10Be data, we test two limit case scenarios using Markov chain Monte Carlo (MCMC) inversion modelling based on two hypotheses: 1) a simple, one-step change in erosion rate, and 2) an abrupt pulse of erosion over a constant background erosion rate. Preliminary results for the 'step-change model' indicate a 58-109-fold acceleration in hilltop erosion rates between 4.5 and 1.1 ka (modelled interquartile ranges, IQR). Preliminary results for the 'spike model' suggest an erosion pulse causing hilltop surface lowering of ~1.1-1.9 m between 2.6 and 1.2 ka (IQR). These results are corroborated by independently dated floodplain sediments that indicate rapid valley-floor alluviation consistent with major landscape perturbation from ~3.4 to 1.2 cal ka BP [1].

The timing of the proposed drastic change in erosion dynamics coincides with a shift to more humid climate conditions at ~4.5 ka, which set the stage for the adoption of rainfed agriculture and pastoralism in the region around 3.5 ka [2]. We propose that this transformation from hunter-gatherer societies to agro-pastoral economies and the expanding human population brought large-scale transformation of hillslopes and valley soils that largely outpaced the impact of climate change on the landscape. This is supported by the large amplitude of the erosional perturbation and the close temporal correspondence of soil loss with the onset of agriculture. Although central Andean civilizations of the last millennium (i.e. Inka and hispanic) may have continued to degrade soils, we suggest they inherited a resource that was already severely depleted.

[1] Hippe et al., 2018 – Earth Surf Proc Land: doi: 10.1002/esp.4529
[2] Binford et al., 1997 – Quaternary Res 47: 235–248