Orbitally-driven climate changes recorded by cut-and-fill terrace sequences at the Pacific coast, Pisco valley, Peru

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The climate in the central Andes is characterized by strong north-south and east-west precipitation gradients, has experienced orbital changes in precipitation regimes as documented by variations in lake level highstands on the Altiplano (Fritz et al., 2004), and has likewise been affected by shifts in the Andean jet in response to the rise of Altiplano. Here, we focus on the Pisco valley at lat. 13°S that covers an area of 4300 km^2 and extends c. 200 km in an east-west direction. Mapping shows that this valley hosts three terrace sequences that can be traced along the entire stream. We explore these terraces for three questions: (i) Have they formed in response to orbitally driven-climate changes? (ii) Did sediment accumulation occur due to changes in hillslope erosion? (iii) Was fast hillslope erosion related to a more humid climate, and if this was the case: to what extent has this palaeoclimate contrasted to the modern desertic conditions?

We addressed the first scope using optically stimulated luminescence dating techniques (OSL) and collected approximately 35 OSL samples from the terrace sediments along the Pisco valley (Steffen et al., 2009). The ages show that the terraces were formed in response to at least two different stages of sediment accumulation and erosion, where the main phase of sediment aggradation occurred between c. 54–38 ka. The ages also show that sediment accumulation was contemporaneous with the time intervals of the Minchin (47.8–36 ka) and Tauca (26–14.9 ka) palaeolakes on the Altiplano (Fritz et al., 2004), where the headwaters of the Pisco River are located. In addition, the occurrence of debris flow deposits embedded in the terrace sequences suggests that enhanced precipitation not only occurred in the headwaters on the Altiplano, but also along the middle part of the Pisco drainage basin close to the Pacific Ocean. In this lower reach, high rainfall rates resulted in increased erosion and transport of sediment from the

hillslopes into the channel network by debris flows processes. Related sediment flux has been quantified through in-situ ^{10}Be-based sediment budgets for the terrace sequences in this valley, in which context we then addressed the second question outlined above. We found that the Minchin period c. 47.8–36 ka ago was characterized by an erosional pulse along the Pacific coast where in-situ ^{10}Be-based palaeo-denudation rates reached values as high as 600±80 mm/ka for a relatively short time interval lasting a few thousands of years (Bekaddour et al., 2014). This contrasts to the younger pluvial periods and particularly to the modern situation where ^{10}Be-based sediment budgets register nearly zero erosion along the Pacific coast. It thus appears that during Minchin times, the fast erosion on the hillslopes bordering the Pisco valley and the large sediment supply to the Pisco stream resulted in a sediment flux that was larger than the sediment transport capacity of the receiving stream. We use these mechanisms, together with a decreasing stream gradient and larger channel width in the downstream direction, to explain the deposition of sediment on the valley floor c. 40 ka ago (Norton et al., 2016).

As a final third question, we aimed at quantifying the contrasts in climate conditions between the modern situation and the Minchin times (Litty et al., 2016). We proceeded by combining data about in-situ ^{10}Be-based sediment flux, gauging records, channel geometries and grain size measurements, to quantitatively assess sediment and water discharge values during Minchin times in relation to present-day conditions. In particular, we found that the D_{50} grain size percentiles vary between 0.8 and 3.6 cm for the modern sediments, and between 1.9 and 3.7 cm for the Minchin deposits. Contrariwise, the D_{96} varies between 4.5 and 9.5 cm for the present material, and 8.7 and 18.4 cm for the past deposits. At all sites, the ancient material is coarser for the two percentiles than the present material. We used the grain size data and ^{10}Be-based sediment flux data (Bekaddour et al., 2014) to solve the Bagnold formulation for bedload sediment transport that yields information on water discharge required to transport the supplied bedload material. We found that the water discharge of the paleo-Pisco River, during the Minchin pluvial period approximately 40 ka ago, was c. 7–8 times greater than the runoff of the modern Pisco River if values for the mean and the maximum water discharge are considered. It thus appears that the past was characterized by a climate with a higher frequency of high-magnitude precipitation events, which yielded in more powerful floods in the past, but which also initiated multiple debris flows along the lower reaches of the Pisco valley close to the Pacific coast, thereby supplying large quantities of sediment to the Pisco trunk stream.

References

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