Reconstructions of past sediment and water discharges from fluvial-fill terraces in the southern Central Andes of NW Argentina

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Introduction

Alluvial river long profiles continually adjust to their water discharge (Q_w) and sediment supply (Q_s). Q_w and Q_s are in turn functions of local climatic and tectonic conditions. Hence, changes in the prevailing tectonic or climatic conditions will trigger adjustments to channel long profiles, either by channel incision into previously deposited sediments or by sediment deposition (Fig. 1). Cyclic phases of sediment deposition and channel incision can form alluvial terrace sequences (Fig. 2). Because terrace surfaces are abandoned floodplains that preserve ancient river elevation profiles formed from past Q_s and Q_w, they store information on past climatic or tectonic conditions.

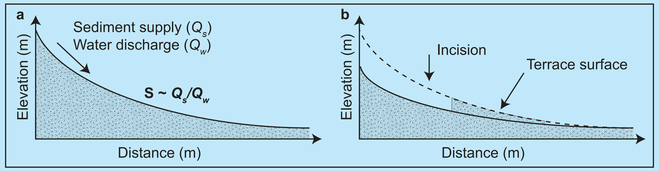


Fig. 1 Longitudinal river profile of alluvial rivers. (a) The river slope is a function of upstream sediment supply (Q_s) and water discharge (Q_w). (b) Changes in Q_w or Q_s can trigger river incision and slope adjustments.

Question:

What can we learn about past environmental conditions from alluvial terraces?

Study site

Fig. 2 Study location. (a) Topographic map of South America with the Toro Basin located within the Eastern Cordillera of the southern Central Andes. (b) Photo of the alluvial terrace sequence preserved in the center of the Toro Basin.

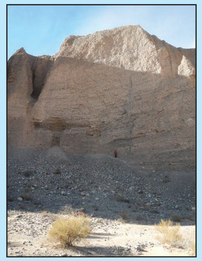
The Toro Basin is an intermontane basin located within the Eastern Cordillera of the southern Central Andes. In the center of the Toro Basin sits a several hundred meter thick fluvial fill terrace sequence. The terraces have been dated and began to form ca. 500 ka (Tofelde et al., 2017).

Approach

Sediment composition → Past sediment supply (Q_s)

Terrace geometry → Past water discharge (Q_w)

Past sediment supply (Q_s)



Q_s = mean erosion rate (L/T) * Area (L^2)

Cosmogenic ^{10}Be concentrations in dated terrace sediments

Derived from DEM

Fig. 3 Sampling location of terrace sediments to derive past erosion rates from cosmogenic ^{10}Be. Person for scale.

Past water discharge (Q_w)

$$Q_w = \frac{1}{k_{Qs}\, I} \frac{Q_s}{S^{7/6}} \quad \text{(equation 1)}$$

Following equation 1 of Wickert and Schildgen (2019), water discharge (Q_w) is a function of sediment supply (Q_s), slope (S), the sediment discharge coefficient (k_{Qs}) and intermittency (I).

Both, k_{Qs} *and* I are unknown constants, which precludes the possibility to simply calculate past Q_w, even if Q_s and S were known.

Instead, we use modern Q_w from a gauging station, modern S from a DEM, and modern Q_s from detrital cosmogenic ^{10}Be (Tofelde et al., 2018, Fig. 4) for a calibration. Then, past Q_s from ^{10}Be concentrations in terrace sediments and past channel S from terrace surfaces together with the calibrated model can be used to reconstruct past Q_w.

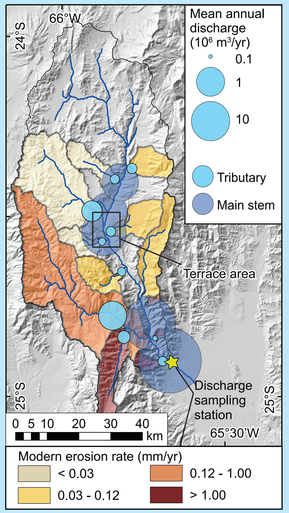


Fig. 4 Modern erosion rates, from which modern sediment supply (Q_s) can be estimated, and modern water discharge (Q_w).

Past sediment and water discharge

Past erosion rate (Q_s)

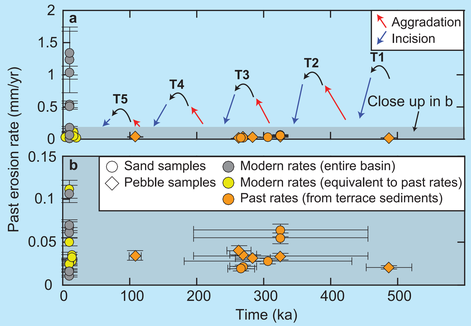


Fig. 5 Past erosion rates derived from ^{10}Be concentrations in dated terrace sediments. Yellow circles are the modern equivalents to past erosion rates (orange). (a) Data from the entire Toro Basin and (b) close up of low erosion rate samples only. Red and blue arrows indicate times of river aggradation and incision after Tofelde et al. (2017). T1 to T5 are the individual terraces.

Past water discharge (Q_w)

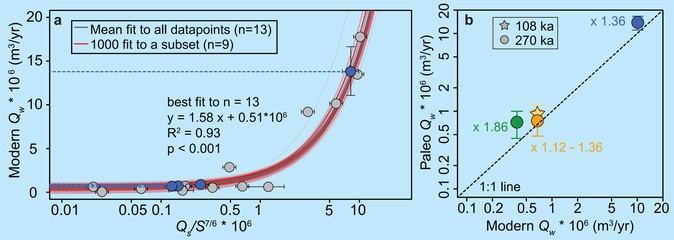


Fig. 6 Past water discharge. (a) Calibration of the relationship between Q_w and the ratio of Q_s over S with modern data from figure 4 (grey circles). Red curves show 1000 linear regressions to a random subset of 9 out of 13 modern data points. Grey curve is the mean of 1000 fits. Blue circles are the Q_s-S ratios of terraces, from which past Q_w is reconstructed based on the equation describing the grey curve. (b) Past water discharge at times of terrace formation (onset of incision) is between 12 and 86 % higher compared to modern water discharge.

Q_s: Erosion rates over the past ~500 ka varied by a factor of ~2, but were fairly constant compred to the modern spread in erosion rates (Fig. 5).

Q_w: Higher discharge during terrace formation (onset of incision) compared to today (Fig. 6).

Conclusion

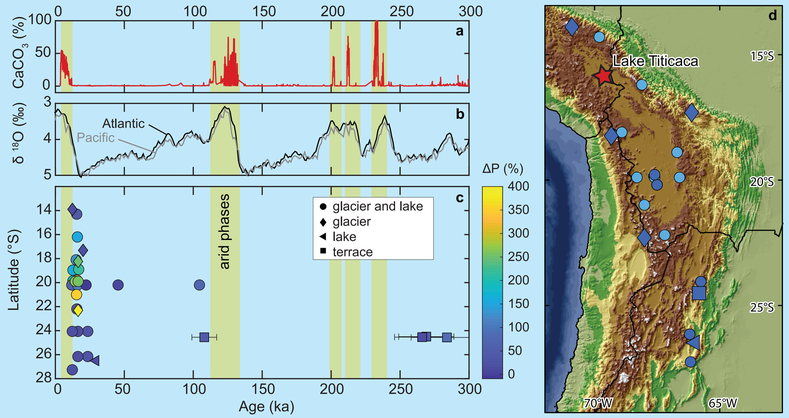


Fig. 7 Past climate reconstructions compared to a compilation of quantitative past hydrological reconstructions for the Andes. (a) $CaCO_3$ concentration in Lake Titicaca (Fritz et al., 2007). (b) Benthic oxygen isotope values for Atlantic and Pacific (Lisiecki & Raymo, 2009). (c) Differences in precipitation (P) or discharge between the past and today for locations throughout the Andes as indicated in d.

Past Q_w reconstrcutions from terraces indicate that it has been between 12 and 86% wetter during the onset of river incision. Temporal comparison to past climate data confirms that river incision occured during regional wetter phases (Tofelde et al., 2017).

The magnitude of difference between modern and past Q_w as reconstructed from terraces is similar to other quantitative hydrological reconstructions for the same latitude (Fig. 7). However, compared to more established records (glacier or lake deposits), alluvial terraces are older and, thus, have the potential to expand the environmental records of the Andes further back in time.

References

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