Along-stream variations in valley flank erosion rates measured using 10Be concentrations in colluvial deposits from Atacama canyons: implications for valley widening

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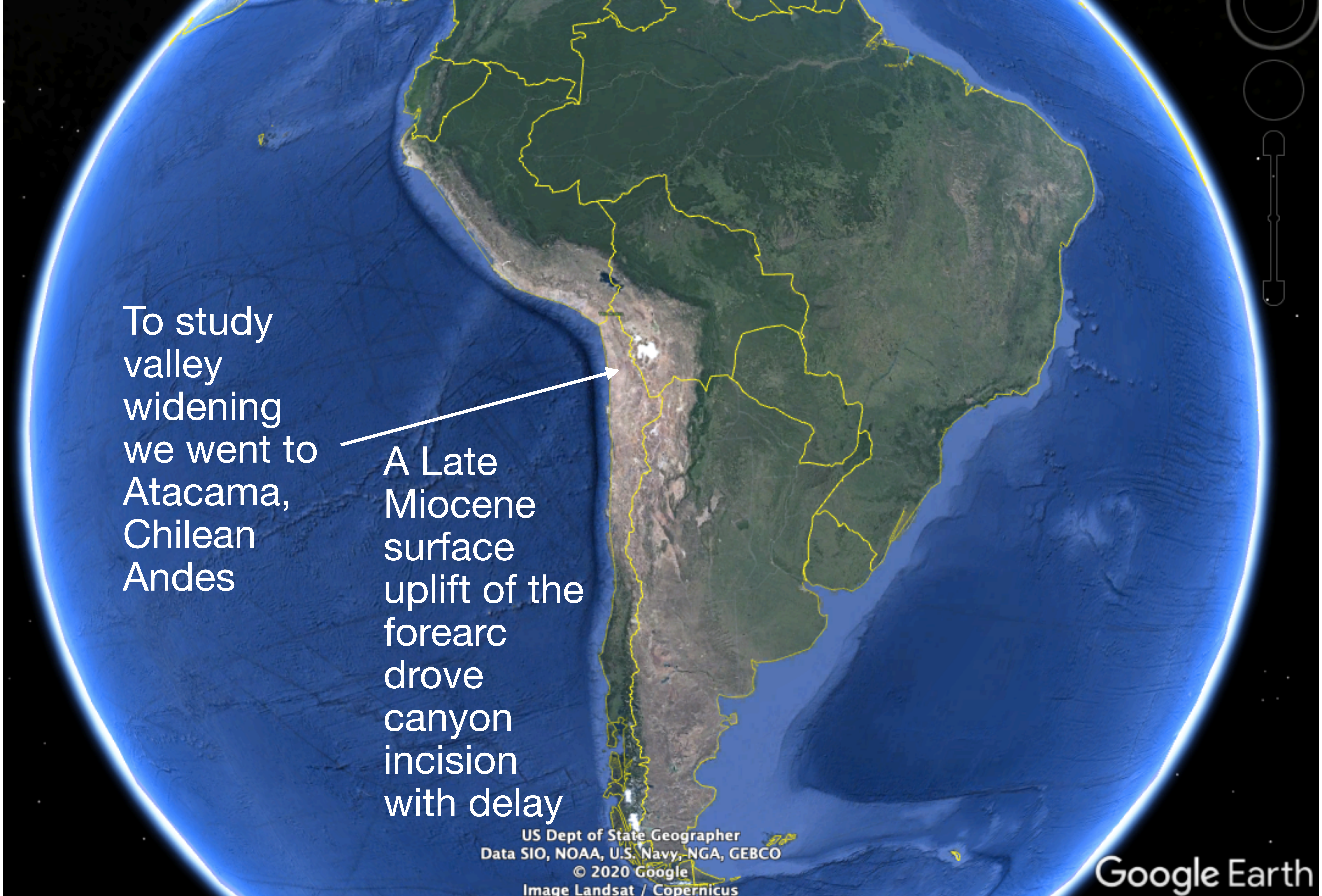
The Pyrenees in front of Toulouse, France

A common feature of river landscapes is the widening of valleys downstream (= floodplains). A large literature has explored controls on river width (e.g. Finnegan et. al., Geology, 2006), but different processes can control valley widening. Lithology and downstream variations in river hydraulic geometry have been invoked (e.g. Brocard and van der Beek, GSASP, 2006; Langston and Temme, GRL, 2019). However, very little is known about valley widening. Landscape evolution models lack field-based law for lateral erosion, which limits our ability to model terraces and landscape responses to tectonic and climatic variations (Hancock and Anderson, GSAB, 2002). The main challenge is to quantify lateral erosion rates on millennial time scales representative of valley widening.


To study valley widening we went to Atacama, Chilean Andes
A Late Miocene surface uplift of the forearc drove canyon incision with delay
US Dept of State Geographer
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
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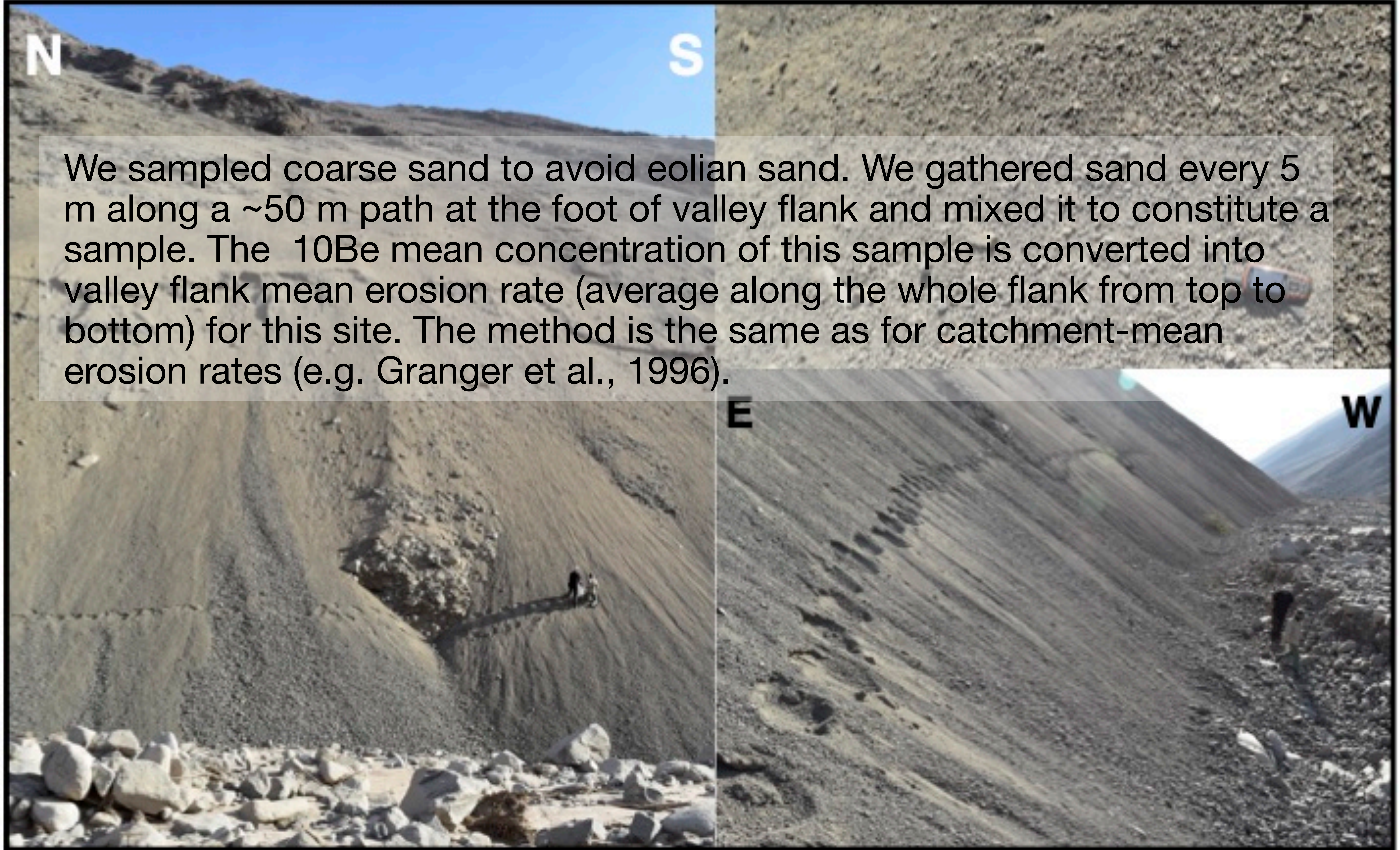
We studied two simple canyons cutting into the Pampa and draining water falling mainly on the Altiplano. These canyons are similar to experimental flumes.

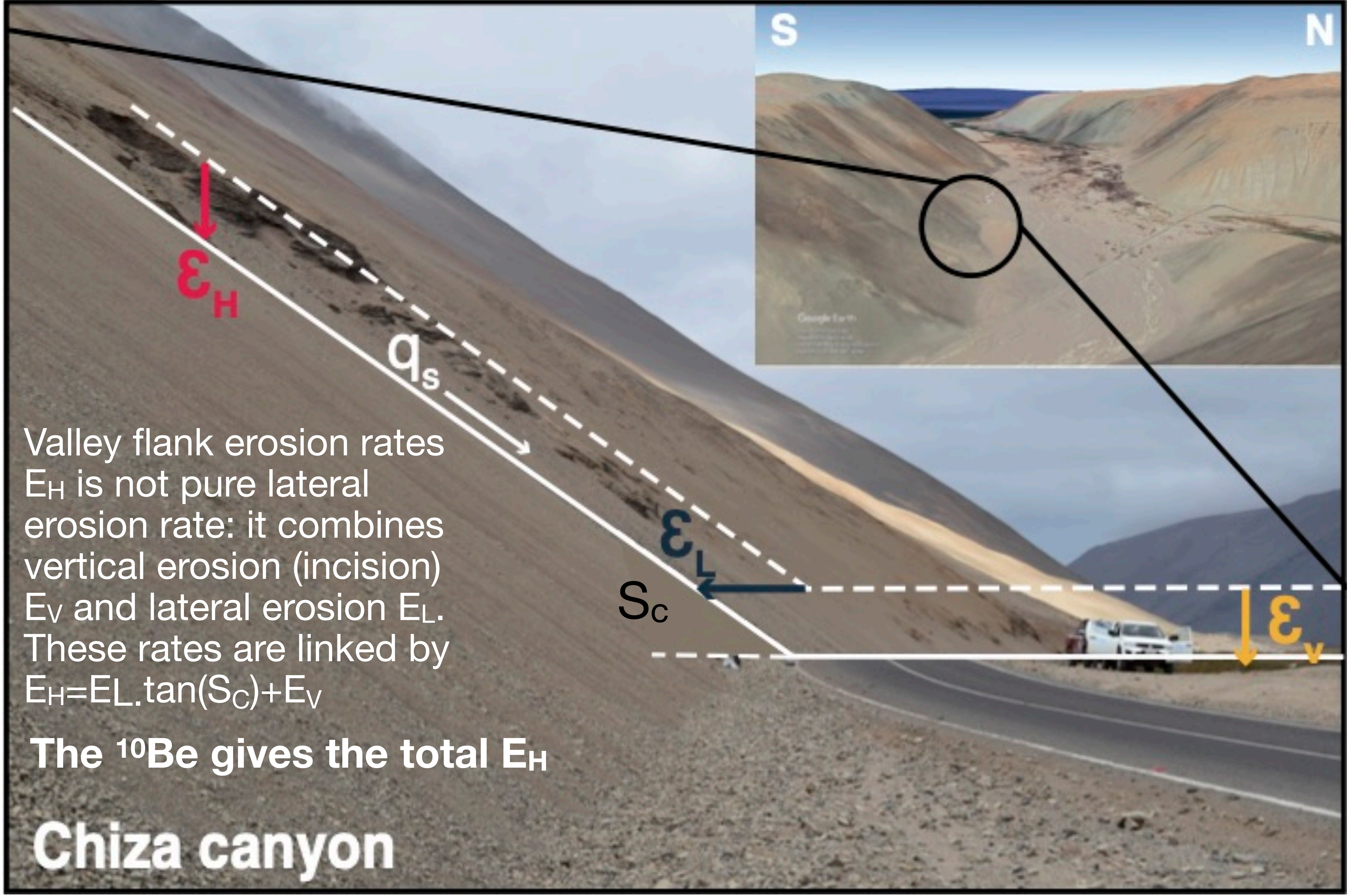
They have transient incising profiles and Tana is less advanced than Chiza.


Altiplano
View to the west on the Tana knickzone
Pampa
(Late MioPliocene surface)
Image © 2020 CNES / Airbus

In Tana, downstream the knickzone, the valley widens rapidly and valley flanks are covered by regolith and have nearly constant slopes ~35 deg. There is no sharp slope difference at lithological transition



We sampled coarse sand to avoid eolian sand. We gathered sand every 5 m along a ~50 m path at the foot of valley flank and mixed it to constitute a sample. The 10Be mean concentration of this sample is converted into valley flank mean erosion rate (average along the whole flank from top to bottom) for this site. The method is the same as for catchment-mean erosion rates (e.g. Granger et al., 1996).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Valley flank erosion rates E_H is not pure lateral erosion rate: it combines vertical erosion (incision) E_V and lateral erosion E_L. These rates are linked by $E_H=E_L.\tan(S_C)+E_V$
The ^{10}Be gives the total E_H
Chiza canyon

Key points of the next slide

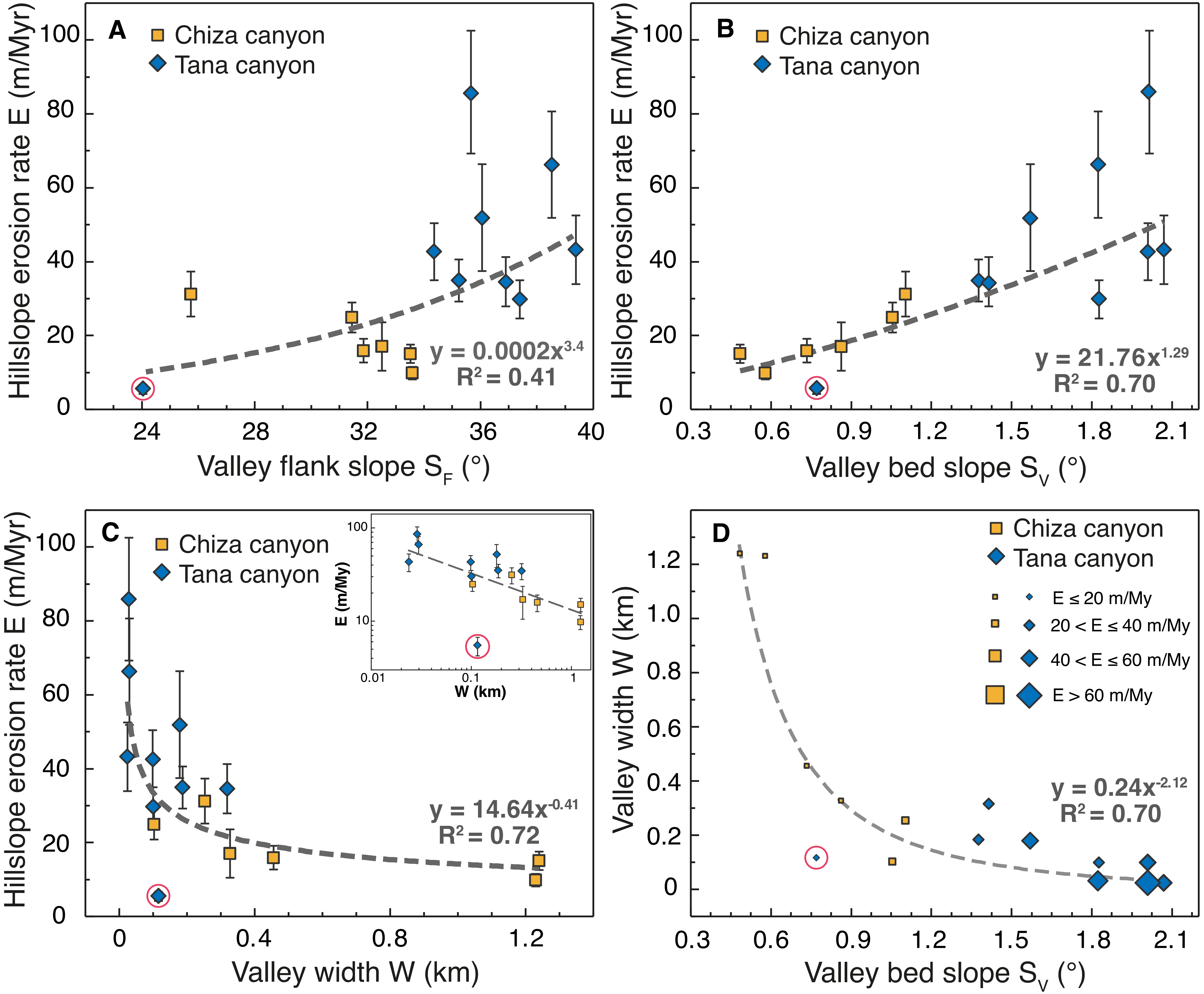
- River long profiles display 5-10 km wide knickzones
- Hillslopes are ~35 deg downstream the knickzone and are more gentle upstream
- Valley width decreases upstream as ~distance$^{-[0.5,-0.9]}$
- Valley flank erosion rate increases upstream (Chiza profile) and then decreases upstream the knick zone (Tana profile) to a lower value than at outlet

A. Chiza canyon
B. Tana canyon
Elevation (km)
Slope valley bed S_v (°)
knickzone
Valley width W (km)
Slope valley flank S_F (°)
Flank N
Flank S
$y = 3.9x^{-0.98}$
$R^2 = 0.44$
$y = 0.27x^{-0.52}$
$R^2 = 0.33$
Erosion rate E_H (m/Myr)
Distance to mouth (km)

Key points of the next slide

- Data from both valleys put together follow consistent trends
- Valley flank erosion rate increases with valley flank slope (A)
- Valley flank erosion rate increases with valley floor slope (B)
- Valley flank erosion rate decreases with valley width as $E \sim W^{-0.4}$, but the point above the knickzone in Tana is an outlier (C). Note that ~110 m of post-LGM sea level rise may artificially increase the valley width near outlet by a maximum of ~150 m.
- Valley width decreases with valley floor slope (D)

Point above the Tana knick zone



Outcomes

The rate of erosion valley side E_H is the result of vertical incision and lateral erosion. Near the outlets, the vertical incision is minor and the rate of lateral erosion is close to E_H. Within knickzones, vertical erosion dominates. Upstream, both work.

The studied valleys are drained by multiple channels. In the field, we observed that the channels in contact with a border of the valleys eroded laterally and activated shallow landslides on the flank. The lateral mobility of the channels is the key process in widening the valley here, not the downstream increase in water flow, as the water flow should be almost constant along these canyons (rainfall only on the Altiplano). The downstream variation in the rate of lateral erosion depends mainly on the width of the valley (the wider the valley, the less likely it is that the channels will be in contact with the edges of the valley) and on the factors that control the mobility of the canals. Channel mobility should depend on the total sediment flux (e.g. Bufe et. al., Nature Geoscience, 2016). Sediment flow increases downstream because valleys incise on long time scales. The downstream widening and lateral mobility caused by sediment flux act as competing agents on the rate of lateral erosion, which explains the downstream valley widening despite downstream constant water flow, and the higher erosion rates E_H near the Tana outlet compared to the upstream value of the knickzone.

These data provide a unique data set for testing lateral erosion models. This application of 10Be could be carried out in other valleys to document valley widening in other contexts.