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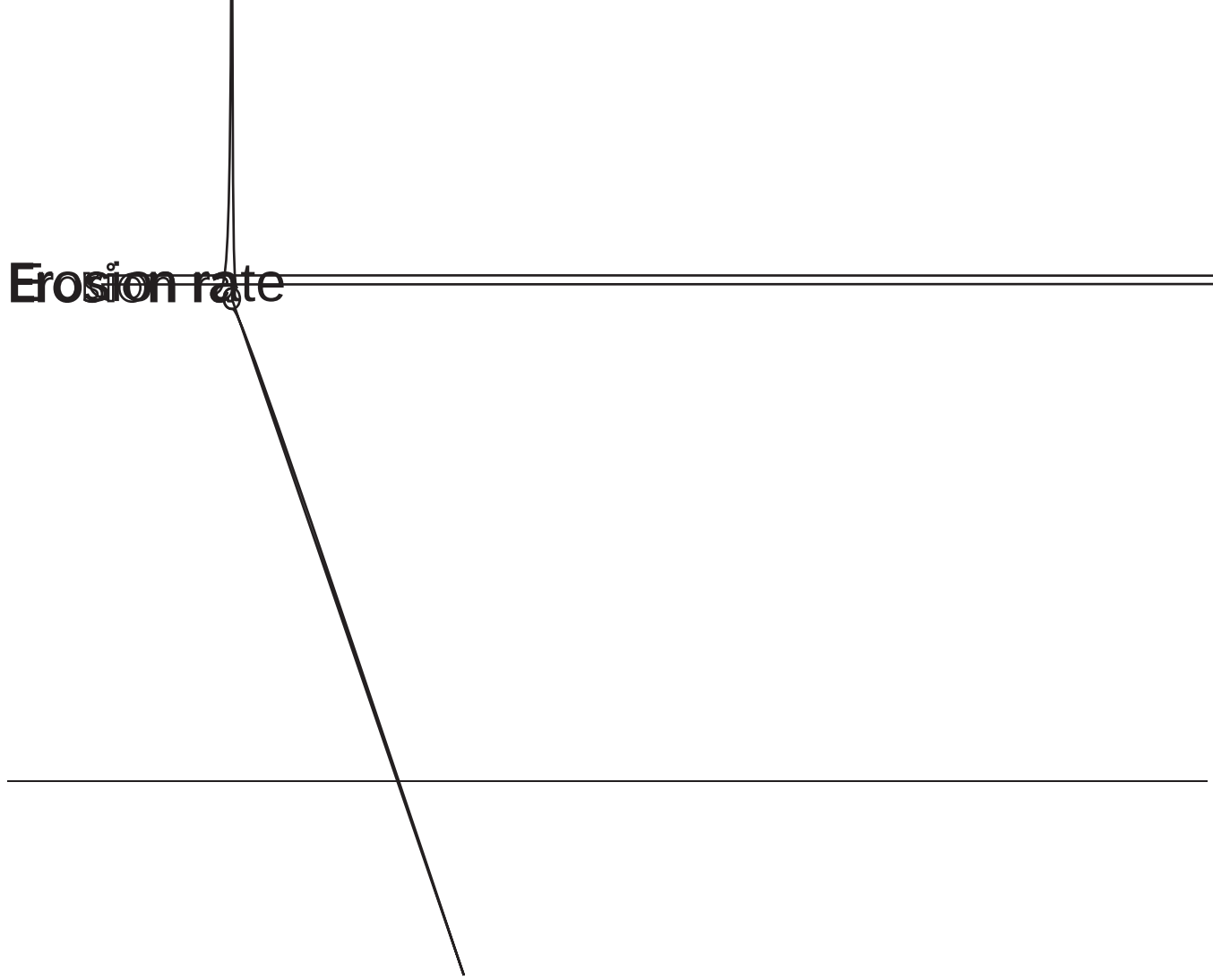
Erosion rate

Setting

Geology

The Andean mountain belt forms a 9000 km long, north–south oriented range along the western edge of South America. The Andean orogen is located above the active subduction of the Farallón Nazca plate beneath the South American plate. This subduction controlled arc magmatism since Jurassic times and uplift at 30 to 25 Ma ago (Isacks, 1988). In Peru and northern Chile, the river catchments draining the Western Escarpment are underlain by a suite of Quaternary sediments and low-grade metasediments of Mesozoic age (metasandstones, limestones, and graywackes) intruded by the Cretaceous to early Tertiary Coastal Batholith (granites and granodiorites). In the headwaters, these rocks are unconformably overlain by a hundreds of metres thick series of Tertiary volcanoclastic deposits (Cobbing et al., 1981; Fernández Dávila, 1993; García and Hérail, 2005) (Figure 1). As synthesized by Wipf (2006), the rock units underlying the volcanoclastic series have experienced four main phases of shortening and deformation since the Mesozoic: (i) the Early Cretaceous Mochica phase, involving large

2D surface area ratios following Norton and Vanacker (2009) using the 90 m resolution Shuttle Radar Topography Mission (SRTM) data. Total ^{10}Be production rates were calculated using a sea level, high latitude ^{10}Be production rate of 5.1 atoms g^{-1}_{qtz} yr^{-1} scaled to altitude and latitude following Dunai (2000), and bedrock density was assumed to be 2.7 g cm^{-3}. No corrections for uplift7 -5513 71.77346y w

to 217 $m^{0.9}$ for normalized channel steepness (Table II). Denudation rates in the catchments vary from ~8 to 185 mm ky^{-1} in the Piura, ~10 to 250 mm ky^{-1} in the Pisco, and ~15 to 29 mm ky^{-1} in the Lluta. Upstream from the knickzones and the escarpment edge, denudation rates are less than 15 mm ky^{-1} in all catchments.

The measured denudation rates plot into two distinct groups with respect to precipitation rates (Figure 3). Denudation rates

The distribution of hillslopes in the three catchments varies considerably (Figure 6a). The Lluta is dominated by low slope angles, whereas the Pisco and Piura show progressive steepening. Valley crosssections through the knickzones in each catchment also show distinct di erences in hillslope morphology (Figure 6b). The Lluta valley in northern Chile, with the lowest precipitation and denudation rates, has a well-formed plateau, and a ~10 km wide valley that displays little dissection

rates (Figure 3). This plateau landscape, characterized by smooth, convex hillslopes, shows no evidence for a tectonic forcing (i.e. faults that offset dated deposits) over the past several millions of years (Zeilinger et al., 2005; Hoke et al., 2007). Our data thus supports the arguments of Ahnert (1970) and data of von Blanckenburg et al. (2004) that in the absence of relative baselevel fall denudation rates do not necessarily increase with higher precipitation rates.

Denudation rates below the escarpment edge are generally an order of magnitude faster than those on the plateau and scale with precipitation (Figure 3). We interpret this to indicate that the knickzones in the studied rivers are eroding into the escarpment edge at a rate that is proportional to stream power; that is, some function of the product of channel gradient and discharge. Given that precipitation controls river discharge, this interpretation implicates climate as an important control on erosion beyond the plateau edge. Accordingly, we attribute to discharge (via precipitation) the notable differences in cross-valley hillslope morphology (Figure 6).

Links between topography and denudation rates

Steep mountain rivers serve as the local base level for hillslope erosion, though ongoing fluvial incision rapidly brings hillslopes to a condition of maximum steepness, determined by rock mass

pre-uplift base level (Kober et al., 2006; Schlunegger et al., 2006; Schildgen et al., 2007). We envisage that surface uplift between 7.5 and 10 Ma (García and Hérail, 2005; von Rotz et al., 2005; Schildgen et al., 2007) created a steepening ramp that promoted stripping of the Tertiary caprocks in the west and knickpoint retreat into the underlying fractured Cretaceous intrusives and Jurassic meta-sedimentary rocks. Knickzones continue to propagate headward via parallel retreat thanks to the presence of the Tertiary caprocks forming the Meseta/Altiplano. The differential erodibility at the escarpment edge helps to maintain steep slopes and impedes propagation of the base level signal that would otherwise lead to channels steepening upstream of the knickzones. Renewed Quaternary uplift (Jordan et al., 2010; Regard et al., 2010) may also be affecting these streams. In particular, the Lluta River is steeper near the coast than would be expected for a graded stream (Figures 1 and 6c).

Spatial differences in how climate affects denudation rates

On the Meseta/Altiplano above the escarpment edge, denudation rates remain uniformly low irrespective of precipitation