Earth and Planetary Science Letters 482 (2018) 160–170

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

www.elsevier.com/locate/epsl

# Tectonic control of erosion in the southern Central Andes

Pedro Val[a,b,*], Agostina L. Venerdini[c], William Ouimet[d], Patricia Alvarado[c], Gregory D. Hoke[a]

[a] 204 Heroy Geology Laboratory, Syracuse University, Syracuse NY, 13244, USA
[b] Scripps Institution of Oceanography – Earth Division, University of California, San Diego, La Jolla, CA, 92093, USA
[c] CIGEOBIO, Conicet – Dept. Geofísica y Astronomía, Universidad Nacional de San Juan, San Juan, Argentina
[d] Dept. of Geography and Center for Integrative Geosciences, University of Connecticut, Storrs, CT, 06269, USA

ARTICLE INFO

*Article history:*
Received 2 February 2017
Received in revised form 25 September 2017
Accepted 1 November 2017
Available online xxxx
Editor: A. Yin

*Keywords:*
erosion rate
tectonics
crustal seismicity
precipitation
Andes
landscape evolution

ABSTRACT

Landscape evolution modeling and global compilations of exhumation data indicate that a wetter climate, mainly through orographic rainfall, can govern the spatial distribution of erosion rates and crustal strain across an orogenic wedge. However, detecting this link is not straightforward since these relationships can be modulated by tectonic forcing and/or obscured by heavy-tailed frequencies of catchment discharge. This study combines new and published along-strike average rates of catchment erosion constrained by $^{10}$Be and river-gauge data in the Central Andes between 28°S and 36°S. These data reveal a nearly identical latitudinal pattern in erosion rates on both sides of the range, reaching a maximum of 0.27 mm/a near 34°S. Collectively, data on topographic and fluvial relief, variability of rainfall and discharge, and crustal seismicity suggest that the along-strike pattern of erosion rates in the southern Central Andes is largely independent of climate, but closely relates to the N–S distribution of shallow crustal seismicity and diachronous surface uplift. The consistently high erosion rates on either side of the orogen near 34°S imply that climate plays a secondary role in the mass flux through an orogenic wedge where the perturbation to base level is similar on both sides.


## 1. Introduction

Global compilations suggest that climate exerts a significant control on exhumation of rocks in active orogens (e.g. Herman et al., 2013; Yanites and Kesler, 2015). In non-glaciated landscapes, the premise for climatic influence on erosion is straightforward: more precipitation increases river discharge and therefore stream power, which leads to increased rates of fluvial incision (e.g. Ferrier et al., 2013). Moreover, heavy rainfall can lower the threshold hillslope gradient by increasing pore pressure and causing mass-wasting processes and relief reduction (Bookhagen et al., 2005; Gabet et al., 2004; Trauth et al., 2000). In contrast, hyperaridity can bring erosion to a halt and lead to greater surface uplift and topographic growth if tectonic uplift is ongoing (Jordan et al., 2014; Kober et al., 2007). Thus, when mountain ranges grow tall enough to develop orographic precipitation and rain shadows, the climatic patterns can enhance exhumation in the prevailing wind direction and induce an asymmetric mass flux and crustal strain rate, controlling topographic form (e.g. Willett, 1999; Whipple, 2009) and the position of the orogenic thrust front (e.g. Lease et al., 2016; Norton and Schlunegger, 2011).

Despite straightforward predictions by the numerical models (Willett, 1999; Whipple, 2009), explicit field evidence supporting the link between climatically driven erosion and the evolution of mountain ranges has been difficult to consistently identify. The climatic influence on erosion in compressional orogens is often clouded by tectonic deformation because of its control of topographic relief through increased rock and/or surface uplift and the local base level (e.g. Balco et al., 2013; Gasparini and Whipple, 2014; Godard et al., 2014). Also, erosion thresholds and discharge variability will exert a strong influence on the style of erosion and make landscapes less sensitive to increases in runoff (e.g. DiBiase and Whipple, 2011). In these locations, decreasing trends in erosion rates can sometimes be observed in the direction of an increasing precipitation gradient (e.g. Balco et al., 2013; Carretier et al., 2013). Thus, the hypothesis that orographic precipitation in compressional orogens causes greater exhumation needs to be tested in a region where climatic, tectonic, topographic, and erosion rate data are available.

We contribute to this debate by comparing along-strike erosion rates in the Central Andes between 28°S and 36°S, where

* Corresponding author at: Scripps Institution of Oceanography – Earth Division, University of California, San Diego, La Jolla, CA, 92093, USA.
*E-mail address:* pedroval07@gmail.com (P. Val).

https://doi.org/10.1016/j.epsl.2017.11.004
0012-821X/

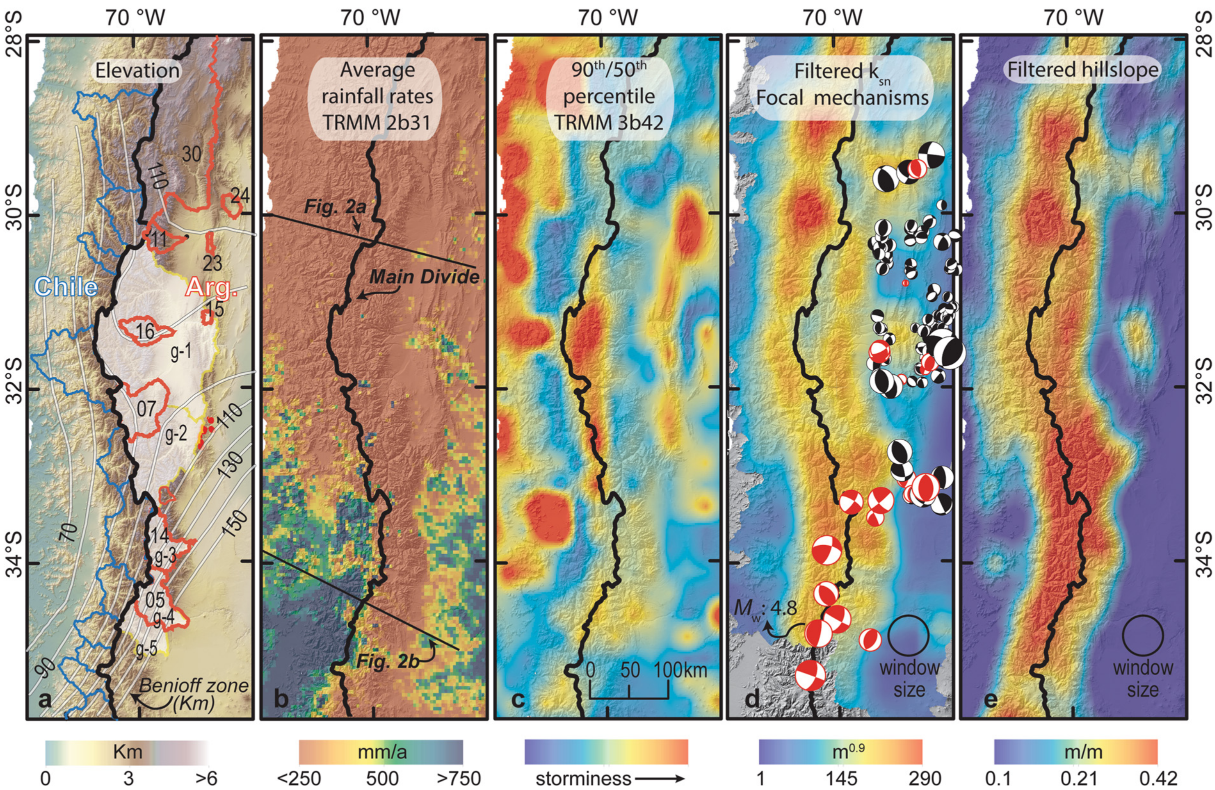


**Fig. 1.** Southern Central Andes. **(a)** Topography (SRTM, 90 m). Eastern Andean catchments sampled for CRN are outlined in red; catchments used for gauge data are outlined in yellow with white shading and labeled with the prefix "g". Western Andean catchments are shown in blue and correspond to Carretier et al. (2013). Depths to Wadati–Benioff zone are shown (white contours) after Anderson et al. (2007). **(b)** 12-year average precipitation from Tropical Rainfall Measuring Mission (TRMM) after Bookhagen and Strecker (2008). **(c)** interpolated 90th/50th percentile of daily rainfall using TRMM 3b42 (30 km resolution) from 1998 through 2014 (http://gcmd.gsfc.nasa.gov). Higher values reflect heavy-tailed frequency distribution of rainfall rates. **(d)** Beach ball diagrams showing solutions of compiled and new focal mechanism data (red outline: focal depth <20 km). An earthquake of $M_w$ 4.8 is labeled for scale (see Fig. S1 for solutions outside of map area). Background map: interpolated and filtered fluvial steepness ($k_{sn}$-normalized steepness index). Discrete $k_{sn}$ values were computed in batch using Stream Profiler (geomorphtools.org) for channels with drainage areas $>50^6$ m$^2$, normalized to a reference concavity index of 0.45, and filtered through a 50 km wide low-pass Gaussian moving-window chosen to capture broad, long-wavelength patterns for a qualitative view. **(e)** Hillslope angles filtered as in **d.** Note the steepest hillslope and $k_{sn}$ areas between 32°S–34°S. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

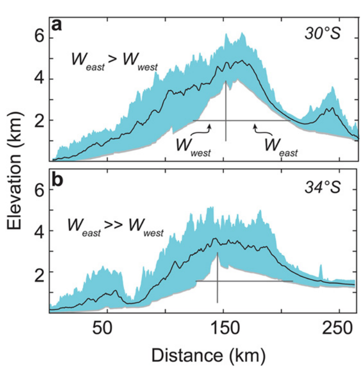


**Fig. 2.** Elevation swath cross-sections (50 km wide) of the southern Central Andes at 30°S and 34°S (centerlines in Fig. 1b). The shaded region shows the domain between elevation minima and maxima, and the black line shows the mean elevation. The horizontal line shows the half-peak width of the orogen under the drainage divide (vertical line). Note higher asymmetry near 34°S where orographic precipitation is strong (see Fig. 1b).

an orographic rainfall gradient with a three-fold variation in precipitation exists across strike (Fig. 1a, b). This region is ideal to test the predictions of orographic rainfall controls on erosion rates and ultimately orogenic evolution for three main reasons: (1) the mountain range is asymmetric where the orographic effect is strongest (~34°S; Fig. 2); (2) the N–S gradients in curvature, catchment hypsometry, slopes, drainage density, further suggest a climatic influence on topographic form (Carretier et al., 2013; Rehak et al., 2010); (3) the range of precipitation (<0.25 m/a to >0.75 m/a) and runoff (<0.1 m/a to >0.8 mm/a), are at the transition where landscapes are most sensitive to precipitation and discharge amounts and variability (e.g. DiBiase and Whipple, 2011). Thus, this setting provides a test of the orographic effect hypothesis: erosion rates should be systematically higher in the western Andes south of ~33.5°S (i.e. asymmetric) where it rains 3 to 4 times more than the eastern Andes. In contrast, a tectonic control should reveal symmetric patterns of erosion rates on both sides. From here forward, we refer to the regions east and west of the main drainage divide as eastern and western Andes, respectively (Fig. 1).

In this study, we provide new erosion rate data from the eastern Andes and compile previously published data from both the western and eastern flanks (Carretier et al., 2013; Pepin et al., 2013; Walcek and Hoke, 2012). We pair these data with an assessment of along-strike seismicity, catchment-average topographic and fluvial relief, annual rainfall and runoff, and rainfall and river discharge variability. Our results reveal relationships between erosion rates and hillslope gradient, fluvial relief, and river runoff that have important implications for understanding the evolution of mountain ranges struck by orographic precipitation and rain shadows.

## 2. The Andes between 28°S and 36°S

Between 28°S and 36°S, the width of the Andes narrows from ~400 km in the Puna plateau to ~250 km south of it, reaching