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Surface uplift and convective rainfall along the southern Central Andes (Angastaco Basin, NW Argentina)

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ABSTRACT

Stable-isotopic and sedimentary records from the orogenic Puna Plateau of NW Argentina and adjacent intermontane basins to the east furnish a unique late Cenozoic record of range uplift and ensuing paleoenvironmental change in the south-central Andes. Today, focused precipitation in this region occurs along the eastern, windward flanks of the Eastern Cordillera and Sierras Pampeanas ranges, while the orogen interior constitutes high-elevation regions with increasingly arid conditions in a westward direction. As in many mountain belts, such hydrologic and topographic gradients are commonly mirrored by a systematic relationship between the oxygen and hydrogen stable isotope ratios of meteoric water and elevation. The glass fraction of isotopically datable volcanic ash intercalated in sedimentary sequences constitutes an environmental proxy that retains a signal of the hydrogen-isotopic composition of ancient precipitation. This isotopic composition thus helps to elucidate the combined climatic and tectonic processes associated with topographic growth, which ultimately controls the spatial patterns of precipitation in mountain belts. However, between 25.5 and 27°S present-day river-based hydrogen-isotope lapse rates are very low, possibly due to deep-convective seasonal storms that dominate runoff. If not accounted for, the effects of such conditions on moisture availability in the past may lead to misinterpretations of proxy-records of rainfall. Here, we present hydrogen-isotope data of volcanic glass (δDg), extracted from 34 volcanic ash layers in different sedimentary basins of the Eastern Cordillera and the Sierras Pampeanas. Combined with previously published δDg records and our refined U–Pb and (U–Th)/He zircon geochronology on 17 tuff samples, we demonstrate hydrogen-isotope variations associated with paleoenvironmental change in the Angastaco Basin, which evolved from a contiguous foreland to a fault-bounded intermontane basin during the late Mio–Pliocene. We unravel the environmental impact of Mio–Pliocene topographic growth and associated orographic effects on long-term hydrogen-isotope records of rainfall in the south-central Andes, and potentially identify temporal variations in regional isotopic lapse rates that may also apply to other regions with similar topographic boundary conditions.

1. Introduction

The Andean Altiplano–Puna Plateau constitutes the most important orographic barrier in the southern hemisphere (e.g., Garreaud et al., 2010; Fig. 1A) and causes pronounced east–west rainfall and surface-process gradients (e.g., Bookhagen and Strecker, 2008, 2012). While the eastern plateau flanks are humid with rainfall of up to 3000 mm/yr in NW Argentina, the semi-arid to arid orogen interior transitions westward into one of the driest places on Earth, the Atacama Desert. Various plateau-evolution models have been proposed for the Andes (e.g., Isacks, 1988; Allmendinger et al., 1997), but the timing and style of uplift of the plateau and its flanking ranges remain controversial. For ex-

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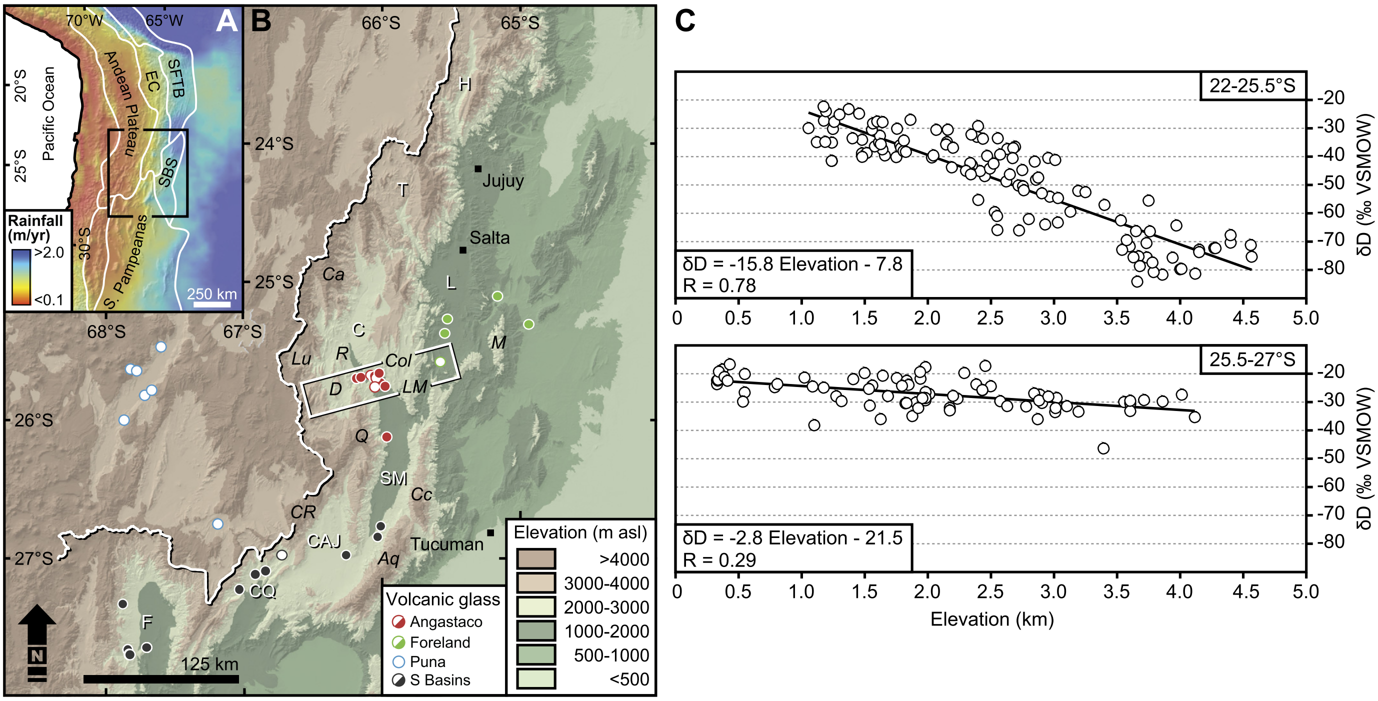

Fig. 1. (A) Morphotectonic map of southern Central Andes showing mean annual rainfall derived from NASA's (National Aeronautics and Space Administration) TRMM mission (Tropical Rainfall Measurement Mission) and extent of Fig. 1B (black box). EC—Eastern Cordillera, SFTB—Subandean fold-and-thrust belt; SBS—Santa Barbara System. (B) Digital elevation model with sample locations of isotopically dated Miocene to Pleistocene volcanic ash samples (filled: this study; open: Canavan et al., 2014; Carrapa et al., 2014) color-coded according to locations in the southern central Andes. White box indicates extent of Fig. 2. White letters denote sedimentary basins: H—Humahuaca; T—Toro; L—Lerma; C—Calchaquí (including the Angastaco Basin); SM—Santa María; CAJ—El Cajón; CQ—Corral Quemado; F—Fiambalá. Black letters indicate mountain ranges related to this study: Ca—Sierra de Cachi-Palermo; Lu—Cumbres de Luracatao; Col—Sierra de los Colorados; LM—Sierra León Muerto; R—Cerro Runno; D—Cerro Durazno; Q—Sierra Quilmes; Cc—Cumbres Calchaquíes; Aq—Sierra Aconquija; CR—Sierra Chango Real. (C) Hydrogen stable-isotope data from modern stream water between 22 and 27°S showing a strong latitudinal dependence of isotopic lapse rates across the eastern margin of the southern Central Andes (data from Rohrmann et al., 2014). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

ample, it is debated whether the southern sector of the plateau (Puna Plateau) has formed by crustal shortening during continuous lateral growth since Paleo–Eocene time (e.g., Reiners et al., 2015) or if this topographic growth had been accomplished by stepwise regional uplift associated with continental lithospheric delamination and the attainment of present-day elevations by ∼36 Ma (Canavan et al., 2014; Quade et al., 2015). In either case, given the meridional orientation of the Andes and the principal trajectories of atmospheric circulation in the southern hemisphere, changes in topography must have fundamentally impacted biotic evolution and the climate and hydrologic systems on the windward and leeward sectors of the evolving orogen (e.g., Hoorn et al., 1995, 2010; Gregory-Wodzicki, 2000; Strecker et al., 2007; Baker et al., 2014).

In addition to classical stratigraphic and paleontological approaches with which to decipher plateau uplift, stable-isotope paleoaltimetry has become an indispensable method for the reconstruction of surface uplift of orogenic plateaus and their flanks (Chamberlain et al., 1999; Garzione et al., 2000; Gébelin et al., 2013; Hoke and Garzione, 2008; Mulch et al., 2008, 2004; Polissar et al., 2009; Quade et al., 2007; Rowley et al., 2001; Saylor and Horton, 2014; Cassel et al., 2014; Mulch, 2016). Typically, proxy-derived oxygen (δ^{18}O) or hydrogen (δD) isotope ratios are compared to present-day isotopic compositions of surface waters or modeled δ-values in precipitation assuming Rayleigh condensation and rainout of an adiabatically ascending air mass (e.g., Poage and Chamberlain, 2001; Rowley et al., 2001; Rowley and Garzione, 2007). However, among the many assumptions required to interpret paleoaltimetry results, a major problem in correctly assessing environmental change due to uplift is the complex interplay between surface uplift, atmospheric circulation, and orographic rainfall (Mulch, 2016). This combination of processes affects δ^{18}O and δD values of precipitation, and hence paleoelevation reconstructions. Moreover, many paleoaltimetry studies have focused on orogen interiors, while comparable analyses in the sedimentary fills adjacent to plateau-bounding ranges have been less common (e.g. Mulch et al., 2006; Hren et al., 2009). As a consequence, isotopic changes induced at orogenic margins (i.e., by topographic growth, atmospheric re-organization, and changes in isotopic lapse rates) may remain undetected in plateau environments or may not be interpreted as such.

Modern δ^{18}O and δD values in surface waters across the eastern Andean flanks between 22 and 28°S suggest that interactions between continental-scale atmospheric circulation and the topographic and thermal characteristics of areally extensive intermontane basins at the eastern plateau margin result in a gradual weakening of isotope-elevation relationships (lower isotopic lapse rates) with increasing latitude (Rohrmann et al., 2014; Fig. 1C). Accordingly, the modern river-based hydrogen isotope lapse rate between 25.5 and 27°S is very low (−2.8‰/km) compared to a pronounced rate north of 25.5°S (−15.8‰/km, Fig. 1C). This difference has been related to non-systematic effects of atmospheric convection characteristic of subtropical regions that interfere with orographic rainout along the eastern Andean flanks (Rohrmann et al., 2014). Evaluating past environmental conditions and paleoelevations under such conditions is challenging and requires understanding of how isotope lapse rates have changed over time.

Here, we present hydrogen stable isotope records from hydrated volcanic glass (δDg) extracted from intercalated volcanic ash-fall deposits in the Angastaco Basin (∼25.7°S) in the Eastern Cordillera, the Lerma Basin in the adjacent broken Andean foreland (∼25.5°S), and additional intermontane basins between