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# Cosmogenic $^{10}$Be denudation rates and geomorphometric analysis in the Ambato range (28°–29°S), Sierras Pampeanas, Argentina

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ABSTRACT

Quantifying denudation rates along orogenic systems is crucial to understand how tectonics and climate interact with each other to create topography. Long-term mean denudation rates estimated from geologic data in the Ambato range (Sierras Pampeanas) is 0.34 mm/yr. When compared with short-term denudation rates from other studies northward and southward along the Argentine South Central Andes foreland, our results are similar to those found in regions with higher mean annual precipitation. Here we utilize concentrations of $^{10}$Be cosmogenic radionuclide (CRN) in river sediments from catchments along the eastern slope of the Ambato range to understand the relationship among short-term ($10^2$–$10^4$ yrs) catchment-wide denudation rates and long-term denudation rates estimated from geologic data. CRN denudation rates range between ~0.038 and ~0.12 mm/yr. The relationship between geomorphometric parameters (local relief, slope, hypsometric integral, and catchment mean channel steepness index, $K_{sn}$) and CRN denudation rates shows linear behavior. The best correlation concerned $K_{sn}$ indicating a strong connection in the Ambato range between tectonics and denudation. When analyzed together with denudation rates from other studies northward and southward along the South Central Andes foreland, our results are similar to those found in more arid regions and suggest that bedrock strength variations should be contemplated in a regional analysis as well as climate.



## 1. Introduction

Mountain building is a complex process that results of the interaction between tectonics, geomorphological processes and climate (Burbank and Pinter, 1999; Willett et al., 2006). Denudation acts during these interactions mainly by reducing elevations, which are partially recovered by isostatic rebound (Bishop and Brown, 1992; Bishop, 2007). Denudation is also a proxy of uplift because the higher a relief the higher denudation is, under similar climatic conditions (e.g., England and Molnar, 1990). Therefore, understanding how topographic morphology and denudation rates correlate, not only assist on the comprehension of the landscape evolution along a mountain belt, like the Andes, but also of the controls on mountain building. Although different studies have examined these relationships in different settings (e.g., Montgomery and Brandon, 2002; von Blanckenburg, 2005, and references therein), general conclusions have not been reached. In this contribution we examine the relationship between denudation rates and morphometric indexes, particularly the channel steepness index ($K_{sn}$), to account for a more reliable metric of denudation rates in tectonically active landscapes. The denudation rates were calculated using in situ-produced cosmogenic nuclides ($^{10}$Be), which provides a measurement of the rate at which erosional debris has accumulated in a sedimentary deposit (e.g., Reneau et al., 1989; Granger et al., 1996).

We selected as case study a mountain belt located in the Argentine broken foreland (or basement foreland province) of the Andes, known as the Ambato range. This region preserves remnants of an Upper Miocene–Pliocene continuous foreland basin fill, the Aconquija Fm. (González Bonorino, 1950; Nasif et al., 2007; Dávila et al., 2012) tilted and exhumed during the main Andean deformation occurred in the Pliocene (Sobel and Strecker, 2003). On the base of stratigraphic relationships (see Dávila et al., 2012; Aconquija Fm. thickness ~1.7 km) and low-temperature cooling ages (Sobel and Strecker, 2003; main exhumation at ~5 Ma), Nóbile (2013) estimated a long–term denudation rate of ~0.34 mm/yr. These mean values, however, do not show a clear correlation with other denudation rates estimated on in situ-produced cosmogenic radio nuclides (CRN) on

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fluvial sediments along the South Central Andes (Fig. 1A–C). Between 23° and 27°S, in the NW Argentina, CRN denudation rates differ between 0.01 and 8 mm/yr, with values of ~1 mm/yr in the eastern slope of the Aconquija range to the north of our study region (Bookhagen and Strecker, 2012, Fig. 1), i.e., an order of magnitude higher than in the Ambato range. To the south, between 31° and 33°S, in the Argentine Precordillera, CRN denudation rates are remarkably lower and vary between 0.04 and 0.12 mm/yr (Walcek and Hoke, 2012; Siame et al., 2015, Fig. 1). Although these Andean examples, north and south of Ambato, started to uplift as well in the Pliocene, they show different climatic conditions and substrate lithologies. It is important to notice that Neogene to present shortening estimations from north to south do not vary significantly (Fig. 1C; Hilley and Coutand, 2010). While mean annual rainfall is >700 mm/yr and substrate lithologies are sedimentary Paleozoic and Mesozoic to the north in the NW Argentina, in the Precordillera, to the south, precipitation is <200 mm/yr and lithologies are dominated by Paleozoic strata. Crystalline basement rocks, in contrast, dominate our study region, and rainfall is ~650 mm/yr (see Section 2). When we compared the stratigraphic-cooling age mean denudation rate estimations in the Ambato with the CRN denudation rates along the south Central Andes, we noticed that correlations only occurs with those areas where precipitation is much higher (~1000 mm/yr). This preliminary comparison suggests that climate would not be the primary control or that after the Miocene the foreland basin was exhumed, basement was exposed and consequently rates would have decreased.

In order to have a similar method to compare with other regions, here we estimated denudation using the concentrations of $^{10}Be$ in river sediments on fluvial sands within the Ambato range. Our results were correlated with different morphometric indexes to explore the relationship between morphology and denudation rates.

## 2. Study region

The Sierras Pampeanas (Fig. 1A) are the easternmost elevations of the South Central Andean foreland also known as the Argentine broken foreland (González Bonorino, 1950; Jordan et al., 1983). An extensive Proterozoic-Paleozoic igneous and metamorphic basement is exposed along basement thrusts and then cover by Cenozoic sedimentary rocks (Jordan and Allmendinger, 1986; Dávila and Astini, 2003). Deep Neogene intermontane basins have developed between the major ranges. According to stratigraphic relationships supported by low-temperature thermochronology (Sobel and Strecker, 2003; Strecker et al., 2009; Dávila et al., 2012; Dávila and Carter, 2013) the basement uplift and last major tilting (of the Upper Miocene strata) took place at ~5 Ma. Plio-Pleistocene strata are subhorizontal indicating no major tectonic rotations (Dávila et al., 2012), but they are strongly incised by fluvial canyons indicating change in base level. The Ambato range (Fig. 2A) is located in the northeastern Sierras Pampeanas, between 28°–29° S. Within this range, we focused on its eastern slope (Fig. 2B).

The Ambato range is bounded to the west by a west-vergent thrust that involved crystalline basement (Fig. 2B) and has internally developed six basement-thrust sheets with strong asymmetrical profiles (Fig. 2C). The range is bounded to the west by the Pipanaco Basin and to the east by the Tucuman Basin. The highest summit is the Cerro El Manchao (4550 masl.), whereas the lowest elevation are located at the intermontane tectonic valleys (<400 masl). The thrust sheets are composed of unweathered Paleozoic medium-to-high grade metamorphic rocks (>90% of granulites, migmatites, gneisses and <10% of schists and phyllites; Caminos, 1979; Toselli et al., 1986; Pankhurst and Rapela, 1998; Chew et al., 2007; Ramos, 2008; among others) intruded by Ordovician to Carboniferous granitoids (Grosse et al., 2009; Dahlquist et al., 2010, 2013; Fig. 2B). Neogene alluvial beds crop out along the internal north–south oriented tectonic valleys that are bounded by six basement-thrust sheets (Fig. 2B and C). To the

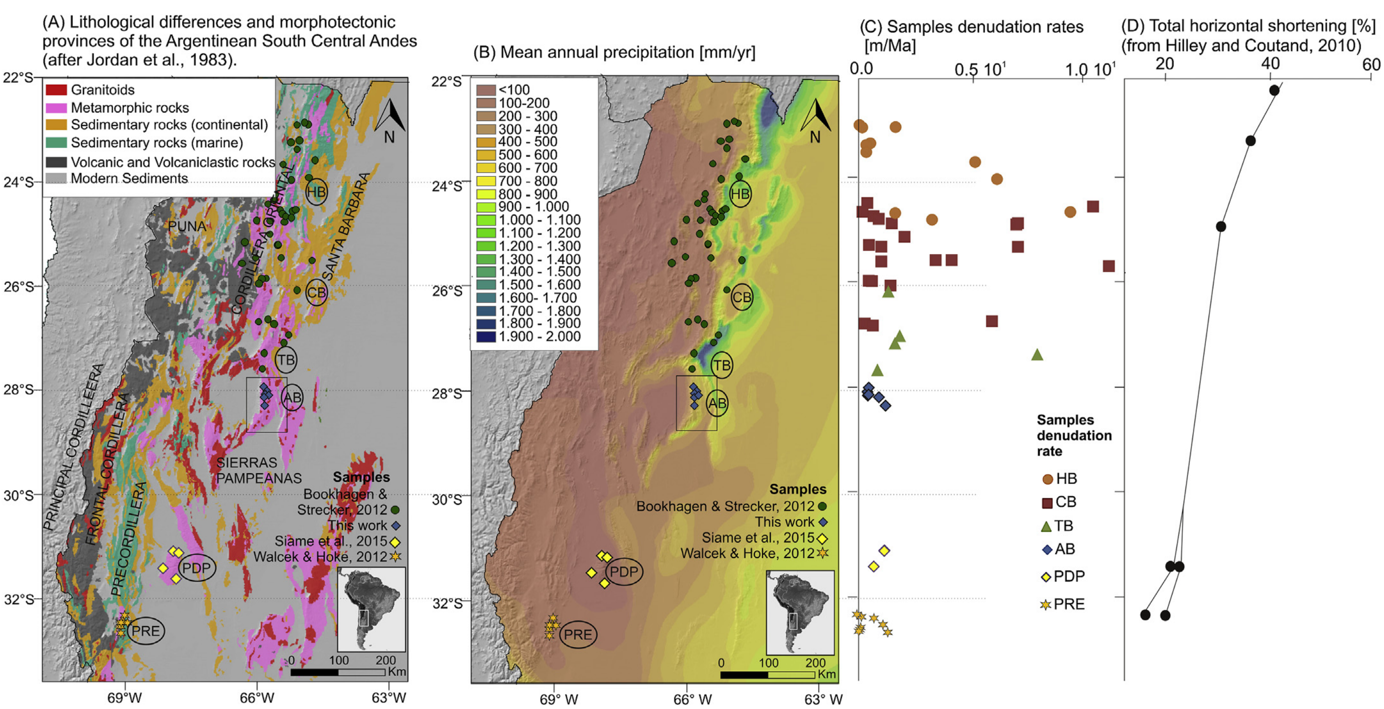


**Fig. 1.** Relief map of the Argentine Central Andes backarc area between 22°S and 33°S showing all cosmogenic radionuclide catchment-wide denudation rates samples (A) lithological differences and structural domains and (B) mean annual precipitation (mm/yr, from Bianchi and Cravero, 2010); TB, Tucumán Basin; CB, Calchaquíes basin; AB, Ambato range (see Fig. 2); PRE, Precordillera range; PDP, Pie de Palo range; (C) cosmogenic radionuclide catchment-wide denudation rates along strike, from Bookhagen and Strecker (2012), Walcek and Hoke (2012), Siame et al. (2015) and this study; (D) total horizontal shortening (L/Lo) × 100) with Lo, initial length and L, total displacement (from Hilley and Coutand, 2010).

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