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Climatic and Tectonic forcing on alluvial fans in the Southern Central Andes

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ABSTRACT

Mountainous regions and their forelands commonly support a suite of landforms sensitive to climate change and tectonics. Alluvial fans in particular, are prominent geomorphological features in arid and semiarid regions which provide record for landscape, climate, and tectonic evolution. We applied ^{10}Be surface exposure dating on moraines and associated fan terraces of the Ansilta range (31.6°S - 69.8°W) in the Southern Central Andes with the aim of comparing both chronologies and examining the nature of alluvial fan development. The alluvial fans yield minimum ages of 19 ± 1 (T1), 120 ± 9 (T2), 185 ± 9 (T3), 389 ± 22 (T4) and 768 ± 35 (T5) ka. Minimum ages derived from moraines are 18 ± 1 (M1), 27 ± 1 (M2), 279 ± 23 (M3) and 410 ± 28 (M4) ka. M1-T1 and M4-T4 seem to be geomorphic counterparts during MIS2 and MIS11-12. Combining our glacial and alluvial database with that available from other published studies, we recognized further glacial-alluvial counterparts. The distinct phases of alluvial fan aggradation mainly correlate with moraines or have a regional extension and fall into local cold and wet times, so that climate seems to be the main forcing of alluvial fan formation at our study site, even being a region with proofed neotectonic activity. We interpret the presence of at least six cold and humid periods of alluvial aggradation which correlate with global MIS 2, 3, 5d-e, 8, 12 and 18–20. Based on these results, alluvial fans may allow landscape and climate reconstructions back to ~750 ka in our study region.

1. Introduction

Climate is a key factor in the evolution of landscapes. Understanding how it has changed in the past has direct paleoenvironmental implications at different time and spatial scales, which in turn may directly affect the interaction nature – human being. The current climate distribution of South America is defined among other factors by the topography of the Andes. The Cenozoic uplift of the Southern Central Andes created not only the relief needed for glaciers to occur at mid latitudes, but also determined a new circulation pattern, resulting in an arid to semiarid climate regime (Ehlers and Poulsen, 2009). The so called Arid Diagonal located ~18–27° S works as an interference zone between the tropical and extratropical precipitation regimes, the South American Summer Monsoon (SASM) from the north and the Westerlies from the south (Fig. 1a). Glaciations in the Southern Central Andes are moisture limited, so that they record not only past temperatures, but are particularly sensitive to periods of increased moisture availability due to shifts of these two main atmospheric circulation systems (Valero-Garcés et al., 2005; Zech et al., 2006). However, very little is known yet about the Pleistocene climate history for this region. Glaciers are key as indicators of climate and hydrologic change, but absolute glacial ages are still limited. Moreover, most of the studies referred to the very Late Pleistocene (global LGM) to Holocene times, in part because of the low preservation potential of the glacial deposits.

Periods of enhanced or lower precipitation should have impacted not only glaciations but also river aggradation–incision cycles, so that geochronological studies on alluvial fans may provide valuable information on paleoenvironmental change and landscape evolution too. Moreover, because of their higher preservation potential, they might allow us to go further back in time than moraines.

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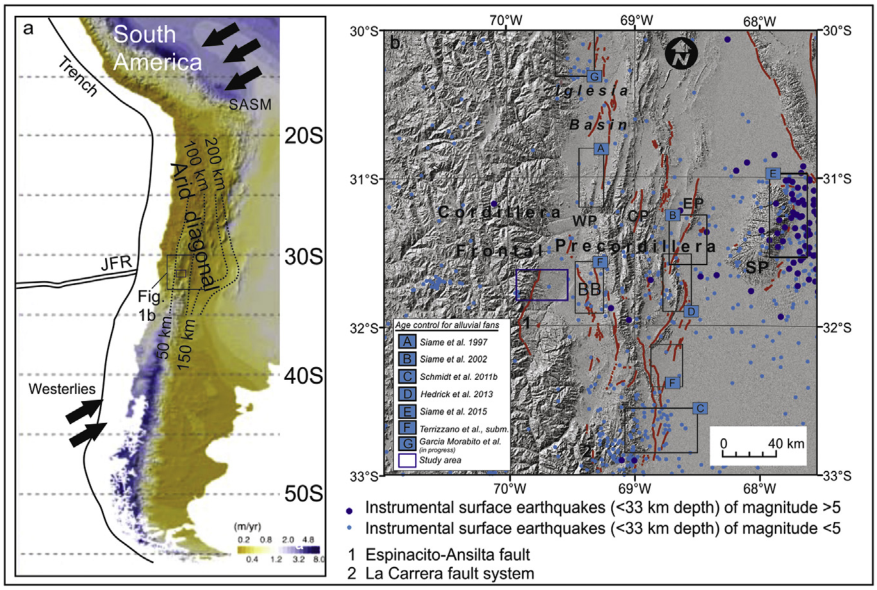

Fig. 1. Regional setting and location of the study zone. a) Precipitation regimen over South America (from Montgomery et al., 2001) and location of the current arid diagonal. Dotted black lines indicate slab depth contours between 25° and 35°S of the Wadati-Benioff zone of the Nazca plate beneath South America, showing the Pampean flat slab subduction segment due to the subduction of the Juan Fernández ridge (JFR), black arrows indicate the main atmospheric circulation systems, the South American Summer Monsoon (SASM) from the North and the Westerlies from the South, blue rectangle shows the study location, b) Local setting and location of the main morphotectonic units at the Southern Central Andes between 30° and 33°S, red lines show faults and folds with Quaternary activity (modified from Casa et al., 2014 plus own observations), BB: Barreal block, WP: Western Precordillera, CP: Central Precordillera, EP: Eastern Precordillera, SP: Sierras Pampeanas, blue dots: instrumental surface earthquakes (<33 km depth) of magnitude >5, light blue dots: instrumental surface earthquakes (<33 km depth) of 3 < M < 5 Magnitude (www.earthquake.usg.gov). Rectangles in black indicate areas with age constrains on alluvial fans, blue rectangle indicates the study area. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

In arid and semiarid regions, alluvial fans are built up by short violent or moderate flows governed primarily by precipitation. Aggradation has been attributed to peak global glacials or to transition to global glacials to interstadials (Pan et al., 2003; Kober et al., 2013; Bull, 2013; Owen et al., 2014) and dissection either to the transition to interglacials (Pan et al., 2003; Kober et al., 2013) or to peak interglacials (Molnar et al., 1994). In the classical literature, dissection of alluvial fans (formation of terraces) is attributed to increased precipitation whereas aggradation occurs in periods of less precipitation (e.g. Blissenbach, 1954), but exceptions have been reported, where aggradation has been associated to enhanced precipitation (Bull, 2013; Dey et al., 2016). Furthermore, although tectonic activity also helps providing conditions suitable for alluvial fan development (accommodation space, high amounts of sediments), controversy exists over its potential role on landscape evolution. Terrace exposure dating on strath and fan terraces in the Southern Central Andes foothills suggests that their formation agrees with events of global climate change when compared to marine isotope stages (MIS) (Hedrick et al., 2013), and that deposition occurred during glaciations and ended during interglacials (Siame et al., 1997; Baker et al., 2009). A landscape in which tectonic controls are more significant that climate, however, has been highlighted for the Chilean Andean slope at 32°-34.5°S based on mass transport studies on landslides (Antinao and Gosse, 2009). Yet, ages and forcing controls on alluvial fan formation in the Southern Central Andes are not fully understood, so that more studies are still needed to clarify the forcing modelling the landscape.

The Ansilta range and its foreland provide a perfect setting to study the link between climate versus tectonic evolution and landscape response (Fig. 1). First, due to the extreme aridity, particularly good preserved glacial deposits document past periods of lower temperatures and increased precipitation and reach down to a series of huge and complex alluvial fan systems. Second, the region is tectonically active and the Ansilta mountain front has been suggested to be controlled by faults. Third, its location is ideal as it lies in the transition zone between atmospheric circulation patterns, the SASM and the Westerlies, so that it should record variation in the position of these winds.

We applied ^{10}Be surface exposure dating to establish robust and precise ages of both, the glacial deposits and related alluvial terraces. Comparing chronologies of fan terraces in the Cordillera Frontal and its foreland (the Precordillera) and exploring for the first time their relationship with glacial chronologies and the paleoclimate context can thus be expected to provide valuable new insights into the Quaternary landscape and climate history of the Southern Central Andes. This might also help to better predict regional geomorphological and hydrological consequences of today's climate change in a region where water resources become a central issue for sustainable development.

2. General geographic setting

The Ansilta range is located at ~32° S in the Southern Central Andes of Argentina (Fig. 1). Only 25 km^2 are occupied today by glaciers on the highest summits (~5000 m a.s.l.) (ING, 2015). Present annual mean precipitation is < 100 mm yr^{-1} (data for Barreal, 1965–1987, from PNEL, 2009) making moisture supply clearly a limiting factor for glacial advances nowadays.

Today, the so-called ‘Arid Diagonal’ (De Martonne, 1935; Bruniard, 1982) crosses the Central Andes between ~18° and 27°S and is characterized by the lack of glaciers even at altitudes higher than 6000 m a.s.l. South of the Arid Diagonal precipitation mainly falls in austral winter and is related to the Westerlies, which advect moisture from the Pacific. The northernmost modern influence of the Westerlies in an interannual scale occurs at ~30°S, although their maximum lies at ~50°S (Moy et al., 2009; Garreaud et al., 2013). North of the Arid Diagonal precipitation