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Research paper

In situ cosmogenic ^{10}Be production rate in the High Tropical Andes

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ABSTRACT

Continental climate change during the late glacial period has now been widely documented thanks to Cosmic-Ray Exposure (CRE) dating of glacial features. The accuracy of these CRE ages mainly relies on *a priori* knowledge of the production rate of the cosmogenic nuclide that has accumulated in a specific mineral. To produce unequivocal and accurate chronologies of glacier fluctuations during the late glacial period, it is crucial that the cosmogenic nuclide production rates are better constrained, particularly in the high tropics where existing spatial and temporal scaling models show significant discrepancies. Here we report a new production rate established at low latitude (19°S) and high elevation (3800 masl) on the Challapata fan-delta, at the edge of the Paleolake Tauca, on the flank of Cerro Azanaques (Bolivia). Sedimentological evidence for synchronicity with the Tauca Lake highstand along with U–Th and ^{14}C measurements established that the fan-delta is 16.07 ± 0.64 kyr BP old. In situ-produced ^{10}Be concentrations measured in 15 boulders lying on the fan-delta yield a mean ^{10}Be concentration of $4.92 \pm 0.05 \times 10^5$ at g^{-1}. A local in situ ^{10}Be production rate of 30.8 ± 1.3 at g^{-1} yr^{-1} is thus obtained at 3800 masl and 19°S. Application of the "Lal-modified" scaling scheme to this Azanaques production rate, using a standard atmosphere and the Muscheler et al. (2005) geomagnetic reconstruction, leads to a Sea Level High Latitude (SLHL) in situ ^{10}Be production rate of 3.76 ± 0.15 at g^{-1} yr^{-1} (1σ uncertainty). In addition, we propose a reference in situ ^{10}Be calibration dataset for the region that combines the production rates of this study with those of Blard et al. (2013b) and Kelly et al. (2015). This dataset of three calibration sites shows a good consistency and yields a regional in situ ^{10}Be production rate of 3.74 ± 0.09 at g^{-1} yr^{-1} using the same scaling.

1. Introduction

The growing number of studies based on terrestrial cosmogenic nuclides evidence their importance in modern Earth Surface Sciences. This expanding interest can be explained by the wide fields of application of cosmogenic nuclides, including Cosmic-Ray Exposure (CRE) dating, and estimation of burial ages and denudation rates. CRE dating of glacial landscapes has significantly improved our knowledge of glacial chronologies and has provided tight constraints on the evolution of the continental climate since the Last Glacial Maximum in many settings (e.g. Barrows et al., 2011; Blard et al., 2007; Gosse et al., 1995; Jomelli et al., 2014; Licciardi et al., 2009; Smith et al., 2005). This is of particular interest for the tropical Andes since this region is thought to play a key role in the dynamics of the Atlantic Meridional Overturning Circulation (Leduc et al., 2007). The determination of a CRE age relies on *a priori* knowledge of the production rate of the measured cosmogenic nuclide in a specific mineral. This production rate depends on spatial parameters, namely the latitude, altitude and depth of the sample, and also varies with time due to temporal fluctuations in the Earth's magnetic field. Several scaling models have therefore been proposed for converting Sea Level High Latitude (SLHL) production rates into production rates for different sampling locations (Desilets et al., 2006; Dunai, 2001; Lal, 1991;

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Lifton et al., 2005; Stone, 2000). However, discrepancies between the different proposed models are often difficult to assess and biases are introduced that ultimately affect the accuracy of the CRE dating. Even though Lifton et al. (2014) have proposed a new scaling model that aims to reconcile the different published models, the use of production rates calibrated from independently-dated geomorphological surfaces remains necessary. An effective way to overcome scaling discrepancies is to use a "local" calibration site; "local" meaning close, both in space (a few hundreds of km horizontally and less than 1000 m in elevation) and time (a few ka for Pleistocene moraines), to the studied site. In this case, scaling from the Sea Level High Latitude (SLHL) production rate to the local object to be dated is symmetric to the scaling originally used to convert the local production rate to a SLHL production rate (Fig. 1) (Balco et al., 2008; Licciardi et al., 2009). This dramatically reduces the impact of the scaling model on the CRE age.

In this study, we present a new ^{10}Be production rate from a calibration site located at 18.91°S - 66.76°W and 3800 m asl in the tropical Andes, on the Bolivian Altiplano. The motivation for this work is twofold: first, to enrich the worldwide database of production rates and thus improve the accuracy of CRE dating methods, and second, to provide a new local calibration site to chronologically anchor palaeoclimatic and geomorphologic studies in the central Andes. The calibration feature is the Challapata fan-delta, a glaciogenic fan that shows sedimentological evidence for synchronicity between its deposition and the highest level reached by the Paleolake Tauca (Clapperton et al., 1997; Clayton and Clapperton, 1997). Sedimentological evidence and ^{14}C ages constrain this synchronicity and enable emplacement of the fan-delta to be dated. The local in situ ^{10}Be production rate is then derived from measurement of the ^{10}Be concentrations of 15 boulders embedded in the fan. This calibrated local in situ ^{10}Be production rate is then scaled to the Sea Level High Latitude conditions and compared with an updated and homogenized dataset of regional production rates (Blard et al., 2013a; Kelly et al., 2015). The dataset exhibits good internal consistency and can therefore be taken as a reference calibration dataset for in situ ^{10}Be production rates in the High Tropical Andes.

2. Geologic setting of the "Azanaques" calibration site

2.1. The Altiplano and the Paleolake Tauca shorelines

The Altiplano is a wide intermontane plateau, covering an area of 196 000 km^2 and delimited by the eastern and the western Andes cordilleras (Fig. 2). Latitudinally, it spans from 15.5°S (Peru) to 22.5°S (Bolivia), and it ranges in elevation from 3658 masl in the middle of the plateau to 6542 masl at Sajama volcano. Due to its configuration, the Altiplano is an endorheic basin, which is today dry but was covered by large paleolakes (>50 000 km^2) during the wettest periods of the Quaternary (Placzek et al., 2006; Sylvestre et al., 1999).

Of the several lake episodes that have occurred during the last 120 ka, the Lake Tauca episode was the widest and deepest (~120 m) (Placzek et al., 2006). U–Th and ^{14}C dating of the shorelines has enabled the timing of the Tauca cycle to be constrained and the transgression (18–16 ka BP) and regression phases of the lake (14.5–13.5 ka) to be bracketed (Blard et al., 2013b). During its highstand (16–15 ka BP), the level of the lake reached a maximum altitude of 3770 masl and covered a surface of 55 000 km^2. Two shorelines have been unequivocally identified at elevations of 3770 and 3760 masl and accurate dating of these has indicated that the highstand lasted from 15.8 to 14.9 ka BP (Blard et al., 2013b, 2011; Placzek et al., 2006; Sylvestre et al., 1999). These U–Th and ^{14}C ages are used in this study to independently date the cosmogenic ^{10}Be calibration site (Section 3.1).

2.2. Cerro Azanaques and the Challapata fan-delta

Located at mid-latitude on the eastern Altiplano, Cerro Azanaques (19.96°S, 66.70°W) culminates at 5140 masl on the eastern flank of the Poopo basin (Fig. 2). Cerro Azanaques is the summit of a wide granodiorite massif that formed during the upper Oligocene/lower Miocene (Clayton and Clapperton, 1995; K–Ar age of 23.7 ± 1.6 Ma, GEOBOL, 1994). Though not glaciated today, Cerro Azanaques presents clear geomorphic and sedimentological evidence for intense glacial activity during the Quaternary.

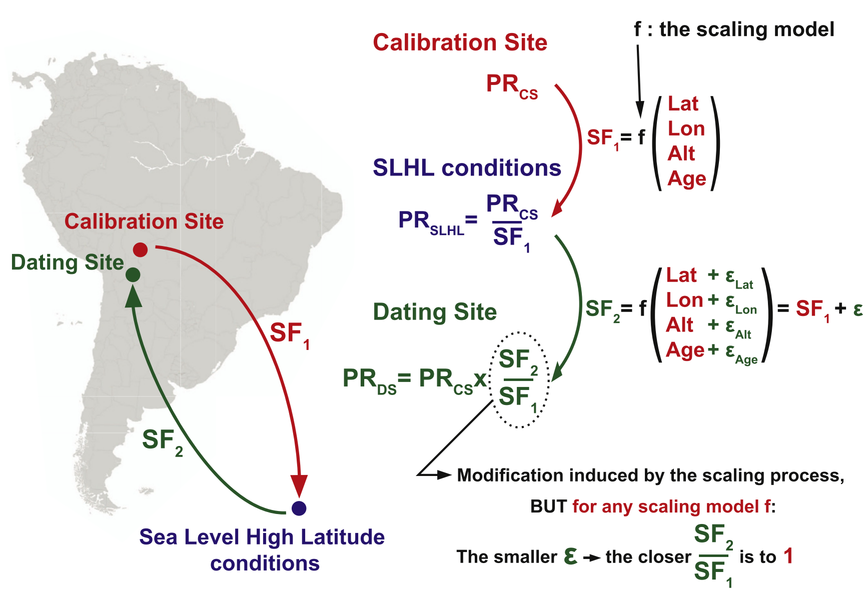

Fig. 1. The benefit of using regional calibration sites. When the calibration site and the site to be dated are close, the SF_1 scaling factor that transforms the production rate determined at the calibration site (PR_{CS}) into a Sea Level High Latitude production rate (PR_{SLHL}) is close to the SF_2 scaling factor that transforms the SLHL production rate into the site to be dated (PR_{DS}). Consequently, the SF_2/SF_1 ratio, which quantifies the modification induced by the scaling process, is close to 1. In this case, small inaccuracies in the scaling factors SF_1 or SF_2 are cancelled-out.