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In-situ cosmogenic ^{10}Be production rate at Lago Argentino, Patagonia: Implications for late-glacial climate chronology

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ABSTRACT

When calculated with the commonly accepted average Northern Hemisphere production rate, ^{10}Be dates of surface boulders on moraines in the Lago Argentino area of Patagonia are younger than minimum-limiting ^{14}C ages for the same landforms. This disagreement could result from the lack of a regional ^{10}Be production-rate calibration site. To assess this possibility, we here present high-precision measurements of ^{10}Be in samples collected from surface boulders on the Herminita and Puerto Bandera moraine complexes deposited alongside Lago Argentino on the eastern flank of the Andes at 50°S in Patagonia. Together with maximum- and minimum-limiting ^{14}C ages for the two moraine systems, these measurements confine the local ^{10}Be production rate to between 3.60 and 3.82 atoms/g/yr (midpoint = 3.71 ± 0.11 atoms/g/yr) when using a time-dependent scaling method that incorporates a high-resolution geomagnetic model. This range includes upper and lower error bounds of acceptable production rates derived from both the Herminita and the Puerto Bandera sites. The upper limit of this range is more than 12% below the average Northern Hemisphere production rate, as calculated using the same scaling method, given in Balco et al. [Quat. Geochron 3 (2008) 174–195]. Other scaling models yield production rates with similarly large offsets from the Balco et al. (2008) rate. On the other hand, the range of acceptable production rate values determined from Patagonia overlaps at 1σ with, and encompasses, the production rate recently derived in Macaulay valley in the Southern Alps of New Zealand [A. Putnam et al., Quat. Geochron. 5 (2010a) 392–409]. Within uncertainties (i.e., overlap at 1 sigma) this Patagonian production rate range also agrees with a recently determined production rate from low-elevation sites in northeastern North America and northern Norway. When the Macaulay production rate is used to calculate Patagonian exposure dates, ^{14}C and ^{10}Be chronologies are mutually compatible for late-glacial moraine systems. Both chronologies then indicate that outlet glaciers of the Southern Patagonian Icefield achieved a late-glacial maximum in the western reaches of Lago Argentino at 13,000 cal. yr BP at the end of the Antarctic Cold Reversal (14,500–12,900 cal. yr BP). Outlet glaciers subsequently receded to near present-day ice margins during the Younger Dryas stadial (12,900–11,700 cal. yr BP). This general retreat was interrupted about 12,200 cal. yr BP when Upsala Glacier constructed an interlobate complex of moraine ridges on Herminita Peninsula. Mountain glaciers in Patagonia and New Zealand, on both sides of the South Pacific Ocean, exhibited a coherent pattern of late-glacial ice-margin fluctuations.

1. Introduction

Climate changes in the Southern Hemisphere during the last transition from glacial to interglacial conditions remain poorly understood. Ice cores at high southern latitudes register the Antarctic Cold Reversal (ACR, 14,500 to 12,900 cal. yr BP) as a plateau or a reversal in temperature and in atmospheric CO_2 concentration (Blunier et al., 1997; EPICA, 2004; Jouzel et al., 2001; Stenni et al., 2011). Antarctic temperature and atmospheric CO_2 then increased (Blunier et al., 1997; EPICA, 2004) during the Younger Dryas stadial (YD, 12,900 to 11,700 cal. yr BP) of the North Atlantic region. In the Southern Alps of New Zealand in middle latitudes, glacier expansion occurred during the ACR and recession

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during the YD (Alloway et al., 2007; Kaplan et al., 2010; Putnam et al., 2010b). An outstanding question is whether the timing of glacier advance and retreat observed in New Zealand is evident in enough other areas of the middle latitudes to imply a coherent pattern of late-glacial climate change over the southern half of the Southern Hemisphere.

Whether glaciers in South America advanced or retreated during the ACR and the YD is a matter of debate (Ackert et al., 2008; Kaplan et al., 2008; Mercer, 1976; Moreno et al., 2009; Strelin and Denton, 2005; Sugden et al., 2005). For example, Ackert et al. (2008) produced a large and internally consistent set of ^{10}Be and ^{36}Cl exposure ages for a moraine ridge of the classic late-glacial Puerto Bandera landform sequence alongside Lago Argentino (50°S). The data set obtained by Ackert et al. (2008) was taken to mean that at least one of the Puerto Bandera lobes deposited moraines in earliest Holocene/latest YD time, in contrast to the older age for Puerto Bandera moraines inferred from ^{14}C dating (Mercer, 1976; Strelin et al., in press; Strelin and Denton, 2005; Strelin and Malagnino, 2000). This chronological discrepancy may reflect the lack of a local production rate for determining accurate ^{10}Be surface-exposure dates. Therefore, we investigate here the ^{10}Be production rate in Patagonia and discuss the implications for late-glacial climate changes.

Two primary methods are used here to date glacial deposits in Patagonia, ^{14}C and cosmogenic exposure dating. Prior to the late CE1990s, only ^{14}C ages on organic matter afforded mainly minimum-limiting values for glacial tills and/or landforms. However, over the last 15 years, cosmogenic nuclide measurements of samples from surface boulders have been used to determine the exposure age of moraine systems (e.g., Ackert et al., 2008; Jackofsky et al., 1999; Kaplan et al., 2008; McCulloch et al., 2005; Moreno et al., 2009). Such cosmogenic ages should pinpoint when a boulder was deposited on a moraine ridge. But an accurate cosmogenic nuclide age for the boulder under question requires knowledge of the in-situ accumulation rate of ^{10}Be atoms near the upper rock surface.

At present, the production rate of ^{10}Be at different latitudes and elevations is debated (e.g., Balco et al., 2008; 2009; Fenton et al., in press; Putnam et al., 2010a). In the middle-to-high latitudes of the Southern Hemisphere, there is only a single ^{10}Be production-rate calibration site, situated in Macaulay valley of the Southern Alps of New Zealand (Putnam et al., 2010a). The Macaulay ^{10}Be production rate is 12–14% lower than the widely used Northern Hemisphere "average" value (Balco et al., 2008), which is based on all geological ^{10}Be calibration sites employed before CE2008. However, recently published ^{10}Be production-rate values from the Northern Hemisphere, one from northeastern North America (Balco et al., 2009) and another from northern Norway (Fenton et al., in press), are consistent with the Macaulay rate, within stated uncertainties. In southern South America, a local ^{10}Be calibration site is not yet available. Therefore, whether the ^{10}Be production rate commonly used in the Northern Hemisphere (Balco et al., 2008) or that obtained in Macaulay valley of New Zealand, or neither, should be employed in Patagonia remains unresolved.

Here, we test what production rate should be used to calculate ^{10}Be surface-exposure ages in Patagonia. To accomplish this test, we measure ^{10}Be concentrations in boulders on moraines with independent limiting ^{14}C ages in the Lago Argentino area of Patagonia. We document at two different localities that ^{14}C- and ^{10}Be-based chronologies for moraine formation are mutually compatible only if the Macaulay production rate is employed in the exposure-age calculations. After demonstrating the appropriate production rate to be used in Patagonia, we show that both the ^{14}C and the ^{10}Be techniques afford consistent ages for glacier fluctuations, together indicating expansion during ACR and contraction during YD times.

2. Background

2.1. Setting and climate

The southern Andes support the 16,800 km^2 Southern Patagonian Icefield (SPI). Outlet glaciers that drain the SPI include the Perito Moreno, Upsala, Grande, and Dickson Glaciers (Fig. 1A). These glaciers terminate near the western reaches of Lago Argentino (50°S, 72°W), the second largest lake in Patagonia. The eastern end of the main body

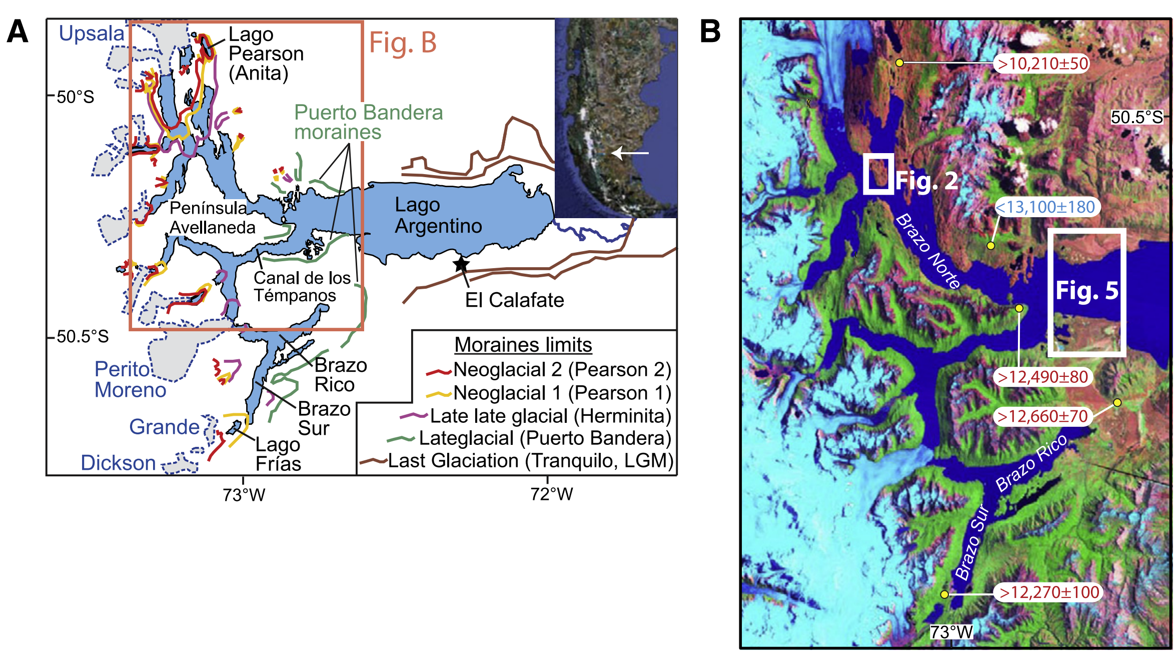

Fig. 1. A) Map of the Lago Argentino area with places mentioned in the text and the major moraine systems drawn schematically (Mercer, 1968, 1976; Strelin and Malagnino, 2000; and references therein); B) A satellite image that shows the Lago Argentino area, including the setting of the Herminita Peninsula (Fig. 2) and outlet glaciers of the SPI. Minimum-limiting calendar-year converted ^{14}C ages are shown in red at Península Avellaneda, Brazo Rico spillways, Lago Pearson (Anita) and Lago Frías (see Table 1). Maximum-limiting calendar-year converted ^{14}C age for the Puerto Bandera moraines is shown in blue. ^{14}C dates are from Strelin and Denton (2005), Strelin et al. (2008), and Strelin et al. (in press). Ages reported as cal. yr before present (BP). For production rate calculations (Table 3), 57 or 58 years are added to these calendar-year converted ^{14}C ages, so they are relative to CE2007 and CE2008 (the year in which samples for ^{10}Be analyses were collected).