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Research paper

A locally calibrated, late glacial ^{10}Be production rate from a low-latitude, high-altitude site in the Peruvian Andes

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ABSTRACT

Well-dated records of tropical glacier fluctuations are essential for developing hypotheses and testing proposed mechanisms for past climate changes. Since organic material for radiocarbon dating is typically scarce in low-latitude, high-altitude environments, surface exposure-age dating, based on the measurement of in situ produced cosmogenic nuclides, provides much of the chronologic information on tropical glacier moraines. Here, we present a locally calibrated ^{10}Be production rate for a low-latitude, high-altitude site near Quelccaya Ice Cap (~13.95°S, 70.89°W, 4857 m asl) in the southeastern Peruvian Andes. Using an independent age (12.35 +0.2, −0.02 ka) of the late glacial Huancané IIa moraines based on thirty-four bracketing radiocarbon ages and twelve ^{10}Be concentrations of boulders on the moraines, we determine a local production rate of 43.28 ± 2.69 atoms gram^{-1} year^{-1} (at g^{-1} yr^{-1}). Reference ^{10}Be production rates (i.e., production rates by neutron spallation appropriate for sea-level, high-latitude sites) range from 3.97 ± 0.09 to 3.78 ± 0.09 at g^{-1} yr^{-1}, determined using scaling after Lal (1991) and Stone (2000) and depending on our assumed boulder surface erosion rate. Since our boulder surface erosion rate estimate is a minimum value, these reference production rates are also minimum values. A secondary control site on the Huancané IIIb moraines suggests that the ^{10}Be production rates are at least as low as, or possibly lower than, those derived from the Huancané IIa moraines. These sea-level, high-latitude production rates are at least 11–15% lower than values derived using the traditional global calibration dataset, and they are also lower than those derived from the late glacial Breque moraine in the Cordillera Blanca of Peru. However, our sea-level, high-latitude production rates agree well with recently published, locally calibrated production rates from the Arctic, New Zealand, and Patagonia. The production rates presented here should be used to calculate ^{10}Be exposure ages in low-latitude, high-altitude locations, particularly in the tropical Andes, and should improve the ability to compare the results of studies using ^{10}Be exposure-age dating with other chronological data.

1. Introduction

Paleoclimate data from tropical glaciers provide valuable information on tropical cooling during the Last Glacial Maximum (e.g., Clapperton, 1983; Rind and Peteet, 1985; Klein et al., 1999; Porter, 2001; Benn et al., 2005; Smith et al., 2005a, 2005b), rapid climate changes during the last glacial–interglacial transition (e.g., Clapperton et al., 1997; Rodbell and Seltzer, 2000; Bromley et al., 2011; Kelly et al., 2012), and Holocene climate (e.g., Solomina et al., 2007; Rabatel et al., 2008; Licciardi et al., 2009; Jomelli et al., 2009, 2011). Although many studies have developed paleoclimate records from tropical glacier extents, there are few precisely dated glacial landforms in the tropics. This situation is mainly

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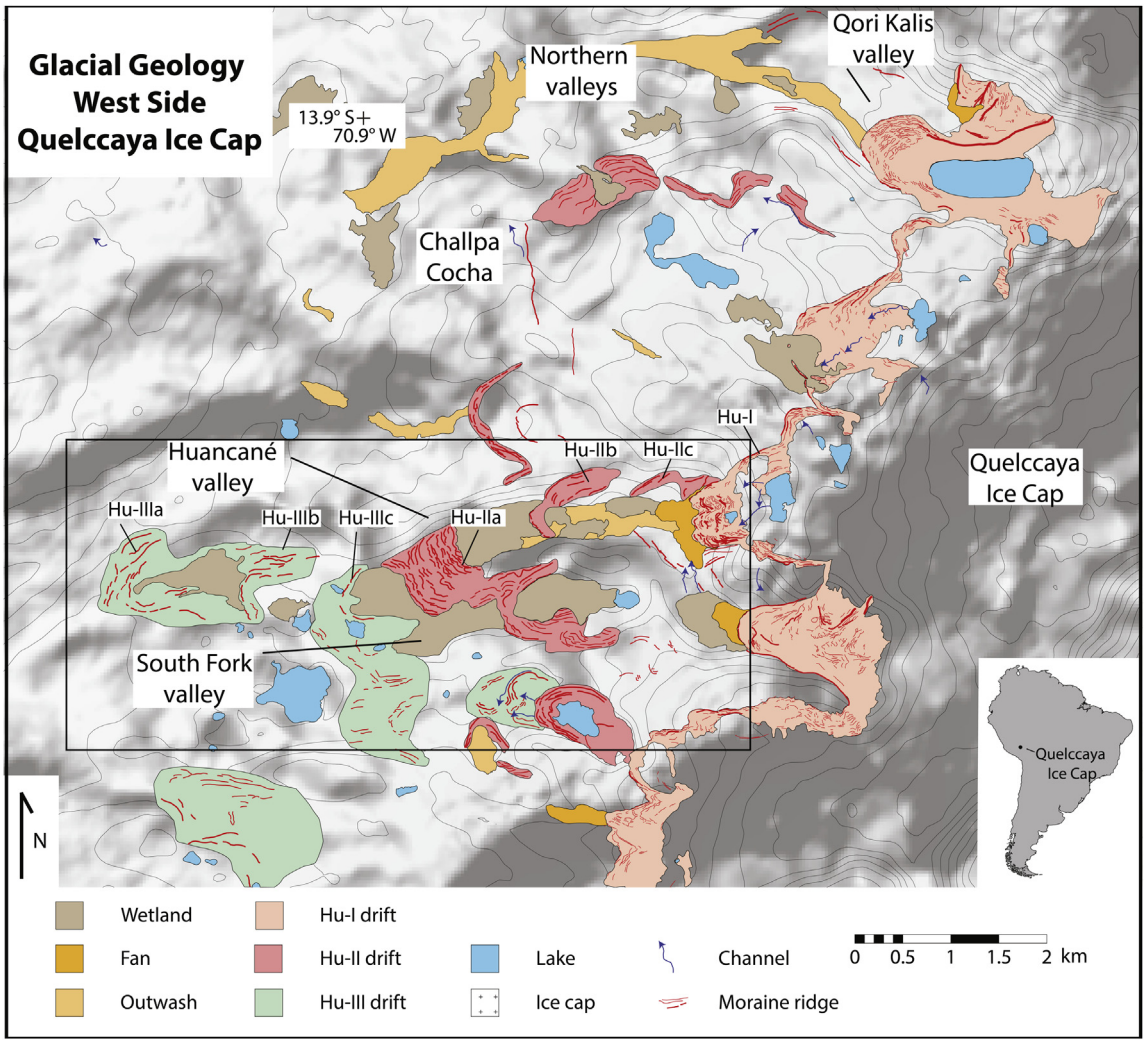

Fig. 1. Glacial geologic map of valleys west of Quelccaya showing locations of the major moraine sets, the Huancané III, II and I moraines, and subdivisions of these moraines (e.g., Huancané IIIa, IIIb and IIIc moraines)(Mercer and Palacios, 1977; Kelly et al., 2012). "Huancané" is abbreviated as "Hu-". The black rectangle shows the location of Fig. 2.

due to the scarcity of organic material associated with tropical glacial deposits, since many tropical glaciers occur in high-altitude, arid environments. Surface exposure-age dating using the cosmogenic nuclides ^{10}Be, ^{26}Al, ^{36}Cl and ^{3}He provides a means to date glacial landforms directly, but accurate surface exposure ages depend on well-known nuclide production rates (e.g., Glasser et al., 2009). While several studies have estimated ^{10}Be production rates from measurements at middle- and high-latitude locations (Balco et al., 2009; Putnam et al., 2010; Kaplan et al., 2011; Fenton et al., 2011; Young et al., 2013), few production-rate estimates have been obtained from low-latitude, high-altitude locations (Farber et al., 2005). Locally calibrated production rates at low-latitude, high-altitude locations provide the opportunity for studies applying surface exposure-age dating in these locations to minimize the uncertainties associated with scaling production rates determined at very different latitudes and altitudes (Balco, 2011).

To facilitate the application of surface exposure-age dating in low-latitude, high-altitude regions, we determine a locally calibrated ^{10}Be production rate from the Huancané II moraines deposited by the Quelccaya Ice Cap in Peru using a precise, independent, radiocarbon dating-based determination of the moraine's age and ^{10}Be concentrations of moraine boulders (Kelly et al., 2012). This site is suitable for a ^{10}Be calibration site because of the abundant organic material beneath, within and upvalley from the moraines and the occurrence of quartz-rich boulders atop moraine crests. Below, we present the age of the late glacial Huancané II moraines based on thirty-four maximum- (ice advance) and minimum- (ice recession) limiting radiocarbon ages from stratigraphic sections and lake cores in two adjacent valleys west of Quelccaya Ice Cap (Figs. 1 and 2). We then use this age and the ^{10}Be concentrations of twelve boulder surfaces atop the moraines to calculate a local, spallogenic, ^{10}Be production rate at ~13.95°S, 70.89°W and 4857 m asl. We compare this ^{10}Be production rate to the production rate at a nearby secondary control site on the Huancané III moraines that is based on four minimum-limiting radiocarbon ages from a lake sediment core and ^{10}Be concentrations of five boulder surfaces atop the moraines.

2. Geological setting

2.1. Quelccaya Ice Cap

Quelccaya Ice Cap (~55 km^2), the largest ice mass in the tropics, is located in the Cordillera Oriental of the Central Andes, southeastern Peru (Fig. 1). Quelccaya is situated atop a relatively flat plateau of ignimbritic bedrock which slopes from northeast to southwest (Audebaud, 1973). The west-to-east width of the ice cap varies between 3.8 and 1.2 km with sizable embayments atop