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Short Paper

Recently exposed vegetation reveals Holocene changes in the extent of the Quelccaya Ice Cap, Peru

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ABSTRACT

Radiocarbon dating of well-preserved, in-place vegetation exposed by the retreating Quelccaya Ice Cap of southeastern Peru constrains the last time the ice cap's extent was smaller than at present. Seventeen plant samples from two sites along the central western margin collectively date to 4700 and 5100 cal yr BP and strongly indicate that current ice cap retreat is unprecedented over the past ~5 millennia. Seventeen vegetation samples interbedded in a nearby clastic sedimentary sequence suggest ice-free conditions at this site from ~5200 to at least ~7000 cal yr BP, and place minimum constraint on early- to mid-Holocene ice cap extent.

Introduction

Anthropogenic greenhouse gas emissions very likely account for much of the observed increase in globally-averaged temperatures since the mid-20th century (Hegerl et al., 2007). Some of the more visible effects of this warming trend have been large changes in the planet's cryosphere (e.g., snow cover, river and lake ice, sea ice, glaciers, ice caps, ice sheets and ice shelves) and, increasingly, these changes are contributing to sea level rise (Lemke et al., 2007). In particular, glaciers and ice caps (GIC; this excludes the Greenland and Antarctic ice sheets) contributed an estimated 0.77 ± 0.22 mm/yr in sea level rise from 1991 to 2004 (Lemke et al., 2007). It has been estimated that GIC account for approximately 60% of the new-water contribution to present-day eustatic sea level rise, with a projected 0.1 to 0.25 m contribution from GIC alone expected by the end of the 21st century (Meier et al., 2007). Furthermore, ice loss potentially bears substantial local- to regional-scale consequence, especially at lower latitudes where precipitation exhibits a strong seasonal distribution, as glacier meltwater augments agricultural, hydroelectric and other municipal water supplies (e.g., Mark and Seltzer, 2003; Mark et al., 2005; Juen et al., 2007, and references therein). A critical step, however, towards understanding modern cryospheric change, and indeed all aspects of recent climate change, is to place such change in a context of past variability.

Beginning in 2002 and continuing with annual field expeditions between 2004 and 2007, remarkably well-preserved, in-place, soft-bodied plant deposits were discovered at sites along the recently deglaciated central western margin of the Quelccaya Ice Cap (QIC), southeastern Peru (Fig. 1). Accelerator mass spectrometry (AMS) ^{14}C dating of these deposits is employed to examine changes in areal extent of the QIC during the Holocene, as well as to illustrate that the modern extent of the ice cap is unprecedented over the last 5 millennia.

Setting

A marked feature of the Central Andes is a broad, high-elevation plateau, situated roughly between 14°S and 22°S, referred to as the Altiplano. With an areal extent of ~200,000 km^2 and average elevation of ~4000 m above sea level (masl), the Altiplano is the second highest plateau after the Tibetan Plateau (Wirrmann and de Oliveira Almeida, 1987). The QIC, Earth's largest tropical ice cap, is located in the eastern bounding range of the Peruvian Altiplano in the Cordillera Oriental (13°56′S, 70°50′W; ~55 km^2; Thompson et al., 1985).

Precipitation over the Altiplano exhibits a clear seasonal cycle with more than 80% of the annual total amount falling between

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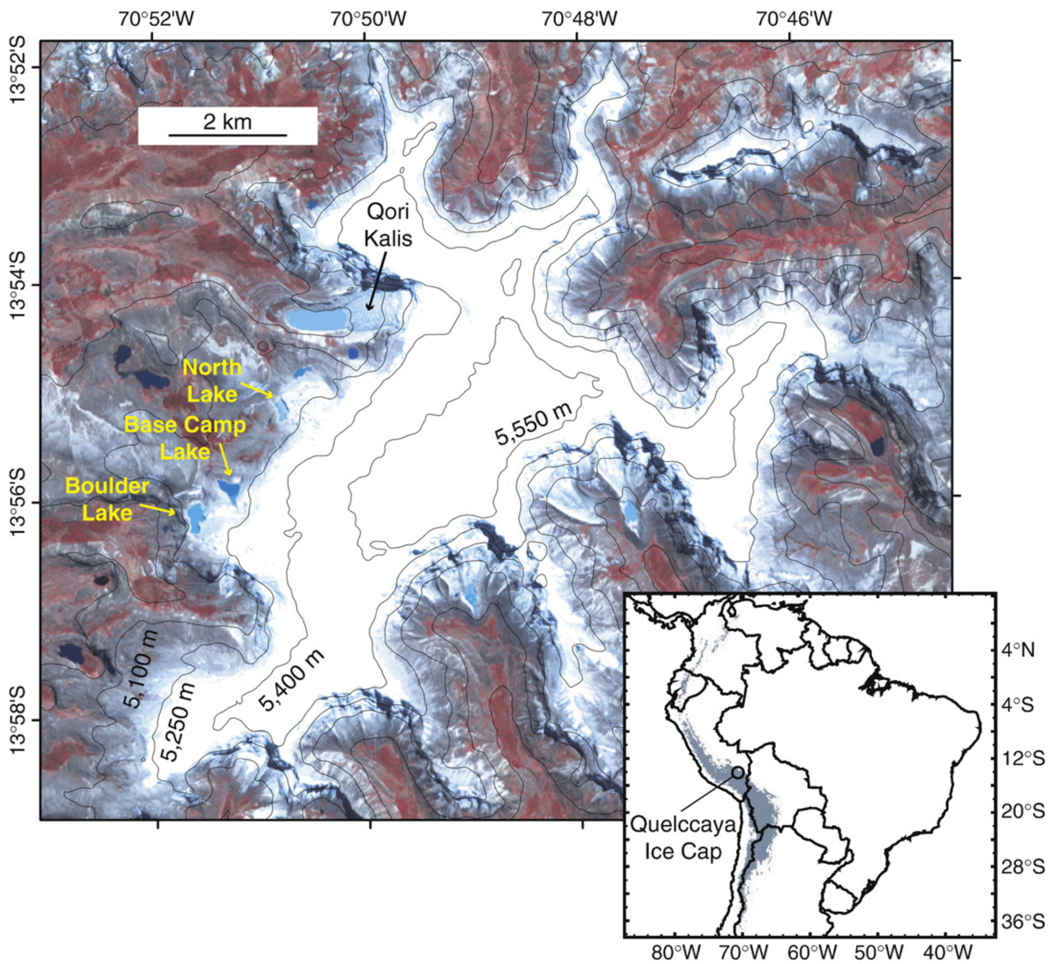

Figure 1. Map showing location of the Quelccaya Ice Cap, southeastern Peru and ASTER false-color image of the ice cap, from June 3, 2004, with the Boulder Lake, Base Camp Lake and North Lake noted. The elevation contour interval is 150 m.

December and February (Aceituno, 1988; Garreaud et al., 2003). Despite its location on the far western edge of the South American continent, the dominant moisture source for the Altiplano is ultimately the tropical and subtropical Atlantic Ocean (Taljaard, 1972). Moisture is transported by northeasterly trade winds over the Amazon Basin, where much of it is recycled during the wet season, and eventually precipitated over the Andes (Salati et al., 1979; Grootes et al., 1989). Movement of moist air from the nearby Pacific onto the Altiplano is inhibited both laterally, by coastal topography, and vertically, by a strong and persistent temperature inversion (~800 masl) maintained by cool waters offshore and large-scale subsidence over the southeastern Pacific (Rutllant and Ulriksen, 1979).

Mean annual temperature at the QIC's 5670 masl summit, based on hourly automated weather station (AWS) measurements from July, 2005 through June, 2007, is −4.2°C (Hardy, D.R., personal communication, 2008). Assuming a constant environmental lapse rate of 6.5°C/km, the summit AWS measurements can be adjusted to approximate temperature along the central western margin of the QIC. This produces a mean dry season (June–August) temperature of −3.3°C, with an average daily minimum and maximum of −6.3 and 0.9°C, respectively, and a mean wet season (November–March) temperature of −0.5°C, with an average daily minimum and maximum of −3.1 and 2.9°C, respectively (Hardy, D.R., personal communication, 2008; Hardy, 2008).

The QIC is particularly well suited to study the effects of climate change as its broad dome of ice rests atop a relatively flat ignimbrite plateau (Mercer and Palacios, 1977). Consequently, a small increase in the mean elevation of the 0° isotherm will affect a greater relative area of the QIC surface than for more steeply inclined alpine glaciers. Retreat of the QIC's largest outlet glacier, Qori Kalis, has been well documented since 1963 using areal and terrestrial photogrammetric techniques (Thompson et al., 2000, 2006). Qori Kalis has experienced a 10-fold increase in its rate of retreat between 1991 and 2005 (~60 m/yr) relative to the initial measurement period from 1963 to 1978 (~6 m/yr; Thompson et al., 2006).

Plant deposits recently exposed at the bedrock surface have been discovered at two sites (Base Camp Lake and North Lake; BCL and NL; ~5200 m), ~2 km apart, along the central western margin of the QIC. Additionally, an exposed clastic sedimentary deposit, hereafter the Boulder Lake Sequence (BLS; ~5100 m), is located ~1 km southwest of BCL at Boulder Lake (Fig. 1). All three sites are characterized by bedrock depressions along the upper margins of the plateau where small lakes have formed subsequent to recent ice retreat. These lakes are presently bounded by the ice cap on their upslope ends and all discovered plants, as well as the BLS, occupy portions of the ice-free downslope margins (Fig. 2).

Collection and dating methods

To obtain the most recent samples possible, only the upper portions of individual vegetation deposits at BCL and NL were collected for dating purposes. Vegetation sampled from the BLS was

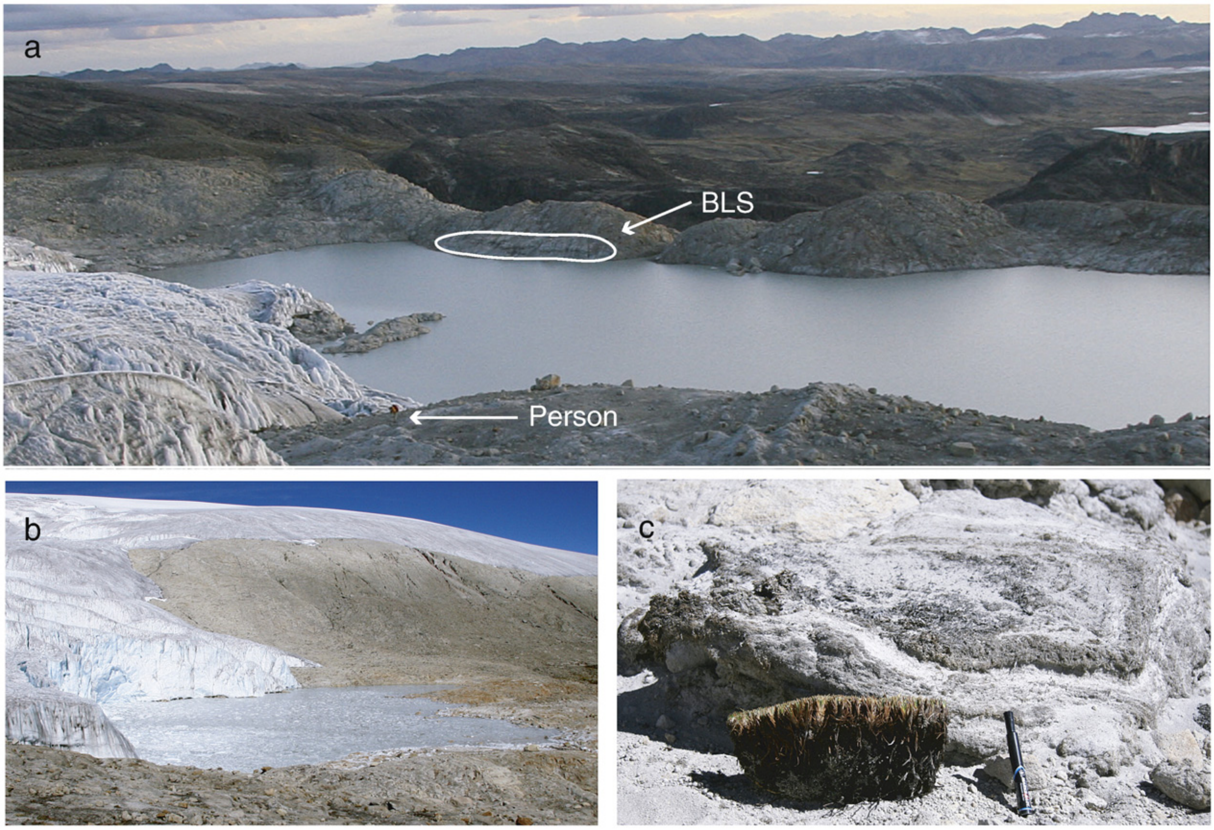

Figure 2. (a) Boulder Lake with the BLS noted and a person for scale. Approximate height of the BLS is 6 m. (b) The North Lake collection site. All plants at this site were discovered along the lake's western margin (right side in photograph). (c) An extremely well-preserved, recently exposed *D. muscoides* deposit at the Base Camp Lake site with a modern *D. muscoides* specimen from a nearby valley (~100 m lower in elevation) placed alongside for comparison. The marker (~16 cm in length) is for scale.

retrieved after removing and discarding the weathered, outermost ~10 cm of material. No macroscopic, modern vegetation was observed growing on any of the sampled surfaces.

Samples were dated using AMS radiocarbon techniques at either the Center for Accelerator Mass Spectrometry (CAMS) at the Lawrence Livermore National Laboratory or the National Ocean Sciences Accelerator Mass Spectrometry Facility (NOSAMS) of the Woods Hole Oceanographic Institution. If sufficient material was available, samples were dated multiple times at one or both facilities. The ^{14}C ages were calibrated using the Calib 5.0.1 radiocarbon calibration program with the Southern Hemisphere calibration dataset SHCal04 (Stuiver and Reimer, 1993; McCormac et al., 2004). Composite ages were calculated for suites of surface samples from the BCL and NL sites using the 'C_Combine' function of the OxCal4 calibration program (Bronk Ramsey, 1995). When a sample was dated multiple times, a combined age was calculated using the OxCal4 'R_Combine' function and weighted as a single sample in the composite site average (Bronk Ramsey, 1995; McCormac et al., 2004).

Results

Base Camp Lake and North Lake surface samples

All sampled specimens represent exposed surface plants observed to be rooted and in original growth orientation, thus strongly suggesting that their positions have not been altered by glacier advance (Fig. 2c). The specimens were identified as *Distichia muscoides* (Juncaceae), a dioecious, cushion-forming plant that is well adapted to the diurnal freeze–thaw cycles of the Altiplano climate. The deposits were excellently preserved and retained their overall cushion shape as well as finer detail (see Thompson et al., 2006). The modern-day altitudinal limit of *D. muscoides* at the QIC, based on our field observations, is ~5100 masl. In contrast, the recently exposed specimens are found above 5200 masl.

Vegetation exposed by recent glacier retreat provides a useful tool for constraining the timing of glacial inception as well-preserved, in-place, surface deposits are indicative of continuous, protective ice-cover since burial (e.g., Anderson et al. 2008). The composite age ranges (1σ) of 6 discrete BCL and 11 discrete NL samples are 5101–5146 and 4738–4758 cal yr BP, respectively (Table 1). These ages thus identify when these sites were last free of glacial ice cover.

The Boulder Lake Sequence

The BLS is ~100 m long and ~6 m high at its thickest section (Figs. 2, 3 and 4). The basal 20 cm consist of a massive diamict characterized by large, subangular and subrounded cobbles supported by a matrix of fines (clay and silt) and coarser grains. These sediments cannot be strictly identified as a till as it was not possible to discern striations on grains. The diamict is conformably overlain by 85 cm of massive fines interspersed with plant fragments that may represent deposition in a lacustrine environment. It is unknown if this vegetation represents *in situ* plant growth or fluvially transported material, though eolian transport can likely be discounted given the relatively large size (up to 2 cm) of the fragments.

A thin layer of massive, rounded and subrounded gravel in a matrix of fines and sands interrupts these sediments between 55 and 60 cm above the base of the sequence, possibly representing a subaqueous debris flow. Ice rafting is an unlikely explanation for this layer given

Table 1
AMS ^{14}C ages of surficially exposed plants from the Base Camp Lake and North Lake sites.

Sample name	Lat. (S)	Long. (W)	Elev. (masl)	^{14}C age ± 1σ (^{14}C yr BP)	Calibrated 1σ age range (cal yr BP)	Laboratory	Receipt No.
Base Camp Lake							
2002 Sample 1-Run 1	13°55.76'	70°51.09'	5210	4470 ± 60	4868–5053 (4961)	CAMS	89195
2002 Sample 1-Run 2	"	"	"	4525 ± 40	5164–5279 (5222)	CAMS	89196
2002 Sample 1	"	"	"	4530 ± 45	5162–5282 (5222)	NOSAMS	35784
2002 Sample 2-Run 1	"	"	"	4530 ± 45	5162–5282 (5222)	CAMS	89197
2002 Sample 2-Run 2	"	"	"	4465 ± 40	4947–5043 (4995)	CAMS	89198
2002 Sample 2	"	"	"	4510 ± 40	5167–5276 (5222)	NOSAMS	35785
Sample 7 (Plant 1)	"	"	"	4570 ± 45	5055–5188 (5122)	NOSAMS	50084
Sample 3 (Plant 2)	"	"	"	4440 ± 45	4866–4979 (4923)	NOSAMS	50082
Quel 5 (Plant 3)-Run 1	"	"	"	4520 ± 35	5166–5277 (5222)	CAMS	118268
Quel 5 (Plant 3)-Run 2	"	"	"	4525 ± 35	5165–5278 (5222)	CAMS	118277
QIC-07 Plant	13°55.78'	70°51.15'	5200	4510 ± 45	5166–5277 (5222)	NOSAMS	60780
North Lake							
2004 Sample 4	13°54.95'	70°50.71'	5208	4370 ± 45	4837–4892 (4865)	NOSAMS	44574
2004 Sample 5	13°54.90'	70°50.72'	5208	4100 ± 25	4440–4486 (4463)	NOSAMS	44575
2004 Sample 5-Run 1	"	"	"	4160 ± 30	4528–4628 (4578)	CAMS	111484
2004 Sample 5-Run 2	"	"	"	4185 ± 30	4573–4653 (4613)	CAMS	111486
Sample 8 (Plant 4)	13°54.88'	70°50.70'	5204	4430 ± 40	4866–4974 (4870)	NOSAMS	50085
Quel 4 (Plant 5)-Run 1	"	"	"	4480 ± 35	4953–5052 (5003)	CAMS	118267
Quel 4 (Plant 5)-Run 2	"	"	"	4505 ± 35	4972–5067 (5020)	CAMS	118276
Quel 10 (Plant X)-Run 1	13°55.06'	70°50.70'	5200	4165 ± 35	4566–4645 (4606)	CAMS	118269
Quel 10 (Plant X)-Run 2	"	"	"	4180 ± 35	4569–4653 (4611)	CAMS	118278
Quel 11 (Plant Y)-Run 1	"	"	"	4315 ± 35	4820–4865 (4843)	CAMS	118270
Quel 11 (Plant Y)-Run 2	"	"	"	4325 ± 35	4821–4871 (4846)	CAMS	118279
Sample 6 (Plant 2)	"	"	"	4240 ± 45	4689–4762 (4726)	NOSAMS	50083
Quel 12 (1A)-Run 1	13°54.94'	70°50.72'	5208	4185 ± 35	4572–4654 (4613)	CAMS	118271
Quel 12 (1A)-Run 2	"	"	"	4145 ± 35	4521–4628 (4575)	CAMS	118280
Quel 13 (1B)	"	"	"	4110 ± 40	4498–4581 (4540)	CAMS	118272
Quel 1 (1C)*	"	"	"	4150 ± 35	4524–4628 (4576)	CAMS	118266
Quel 14 (1C)-Run 1*	"	"	"	4065 ± 35	4462–4520 (4491)	CAMS	118273
Quel 14 (1C)-Run 2*	"	"	"	4100 ± 35	4497–4570 (4534)	CAMS	118281
Quel 18 (1E)-Run 1	"	"	"	4150 ± 35	4524–4628 (4576)	CAMS	118275
Quel 18 (1E)-Run 2	"	"	"	4130 ± 35	4516–4622 (4569)	CAMS	118283

Calibrated ages are given in years before present (cal yr BP), where the origin on the radiocarbon calibration timescale is placed at 1950 AD. The calibrations were carried out using Calib 5.0.1 (Stuiver and Reimer, 1993; McCormac et al., 2004). Identical samples are noted by *.

the observed rounding and lack of larger grains. The absence of ice rafted debris in the sections of massive fines suggests that this was not a proglacial lacustrine environment. Root structures are observable in the upper 5–10 cm of these fines.

Immediately above is a ~1.25-m section of planar cross-stratified sands interbedded with horizontal, discontinuous laminae of sands, fines or vegetation. The consolidated nature of the vegetation in this section—vegetation is not dispersed as discrete fragments, but is instead preserved as laminae—would suggest *in situ* growth. This section is erosively overlain by ~1.6 m of planar and trough cross-stratified gravels, likely indicative of deposition in a braided stream environment. Again, vegetation is confined to discontinuous horizontal lenses, possibly representing vegetated bars. Continuing upsection are two ~1 m massive diamicts containing subrounded and subangular boulders supported by a matrix of fines and coarser grains.

The uppermost diamict is the most recently deposited by the QIC. Ice advance at this time seems to have been variable as the two diamicts are separated by 15 cm of planar and trough cross-stratified gravels with discontinuous horizontal lenses of vegetation, again interpreted as deposition in a braided stream environment.

The use of recently exposed surface vegetation to reconstruct glacial chronology is limited as ages of these samples reflect only the most recent glacial inception, not the duration of ice-free conditions. However, a minimum temporal constraint for when the BLS site was not glaciated can be deduced from seventeen discrete plant samples retrieved from the exposure that date roughly between 5200 and 7000 cal yr BP, with some variability within the chronology possibly due to fluvial reworking of material (Table 2). The older limiting age of ~7000 cal yr BP must be viewed as a minimum date for ice-free conditions as a depositional hiatus between the basal fines and diamict cannot be dismissed. The upper bounding age of 5200 cal yr BP, however, is likely a robust estimate for the most recent glacial inception given its similarity to the composite ages of recently exposed surface vegetation at the BCL and NL sites.

Discussion

Although the ages of recently exposed vegetation presented here reflect past changes in ice cap extent at only three sites along the present-day western margin of the QIC, we believe that the glacial history of these sites is likely a good approximation for that of the QIC as a whole. This argument rests on two points: (1) the ice that bounds the BCL, NL and NLS sites is not that of steep, lower elevation outlet glaciers but of the QIC itself, and (2) the QIC is a relatively flat ice cap resting on a broad, flat plateau. Consequently, small changes in the mean elevation of the equilibrium line affect relatively large portions of the ice cap, and our sites are well positioned to reflect a response in the QIC's areal extent.

The mid-Holocene

Collectively, the ages of recently exposed BCL, NL and BLS vegetation provide evidence for a less extensive QIC from ~5000 to at least 7000 cal yr BP. In concert with the increase in the paleo-altitudinal extent of *D. muscoides*, these findings suggest warmer and drier climatic conditions in the Central Andes during the early to mid-Holocene. A wide array of multiproxy paleoclimate data support this conclusion (e.g., Thompson et al., 1995, 2000; Seltzer et al., 1998;

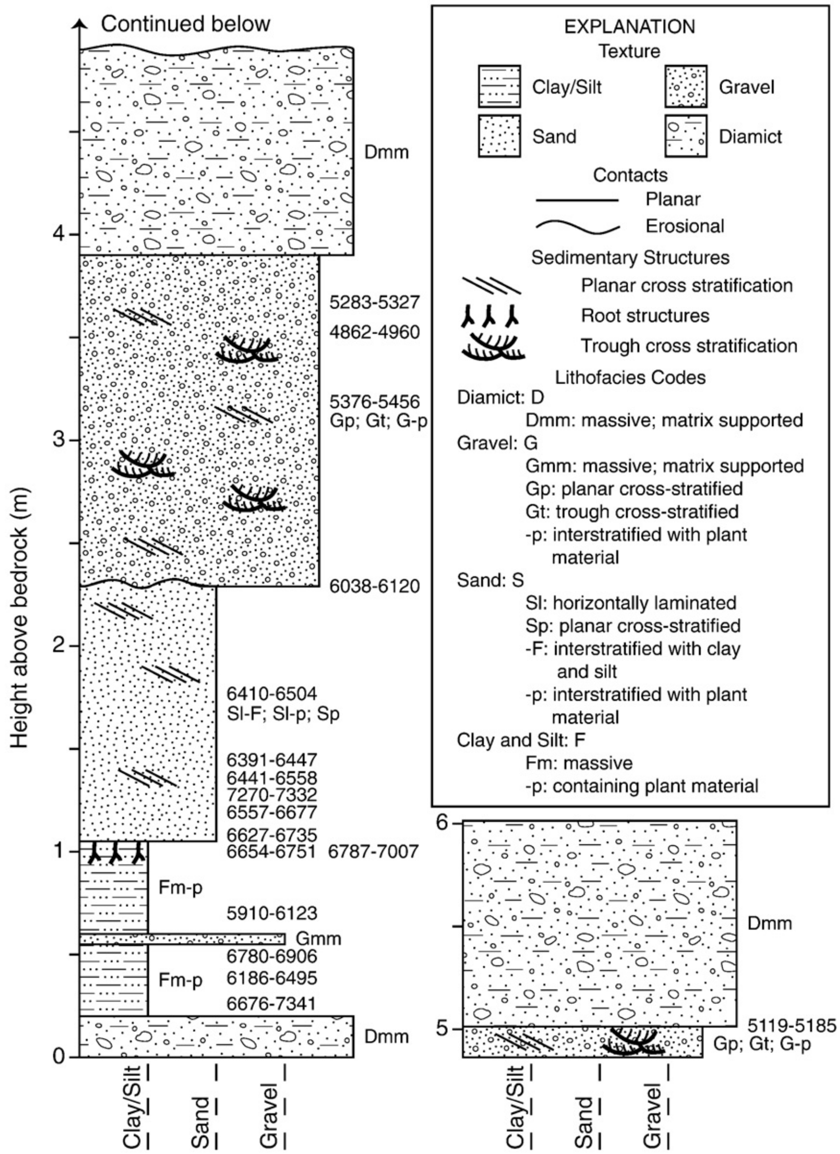

Figure 3. Stratigraphic column of the BLS. Calibrated ^{14}C 1σ age ranges (cal yr BP) of sampled vegetation are noted (Table 2). Lithofacies codes are modified from Eyles et al. (1983) and Miall (1985).

Baker et al., 2001; Paduano et al., 2003; Weng et al., 2006; Grosjean et al., 2007), although the coverage and consistency of drought conditions is still debated (Betancourt et al., 2000; Grosjean, 2001; Grosjean et al., 2003).

The growth of the QIC ~5000 yr ago reflects the return of cooler and/or wetter conditions. Independent evidence for QIC advance at this time comes from an abrupt increase in the clastic sediment flux—a proxy for advancing ice—to the nearby Laguna Pacococha, which receives direct meltwater input from the QIC (Rodbell et al., 2008). A reduced flux between ~5000 and ~12,000 cal yr BP indicates that the QIC was not advancing during this period, and suggests that the ~2000-yr period of smaller-than-present ice extent inferred from the BLS vegetation may underestimate the actual duration of these conditions. In the adjacent Cordillera Vilcanota, the earliest Holocene age of moraine-cored peat dates to 5045 cal yr BP, providing additional evidence for regional ice advance at this time (Mark et al., 2002).

That the QIC region appears to have undergone a climatic transition ~5000 yr ago is notable in light of an accumulating body of evidence, from an extensive geographic distribution of paleoclimate records, for abrupt, interhemispheric climate change ~5000 to 5500 yr ago (e.g., Magny and Haas, 2004; Thompson et al., 2006; Magny et al., 2006 and references therein). For example, cooler and wetter conditions in eastern equatorial Africa, inferred from the Kilimanjaro ice cores and lake levels in the Ziway-Shala basin, ended abruptly ~5200 yr ago (Street-Perrott and Perrott, 1990; Gasse, 2001; Thompson et al., 2002). In the eastern Mediterranean region, cooling at ~5200 yr ago is reflected by a large $\delta^{18}O$ enrichment in the Soreq Cave speleothem record (Bar-Matthews et al., 1999). These events are also roughly synchronous with the drying of the Saharan desert at the end of the African Humid Period ~5500 yr ago (deMenocal et al., 2000a,b).

Such changes were not confined to the Tropics. North Atlantic marine sediment cores document maximum Holocene reduction in meridional overturning circulation and increased drift ice ~5000 yr ago (Bond et al., 2001; Oppo et al., 2003). Evidence for an abrupt shift to cooler and wetter conditions in central Europe comes from the rapid rise of Lake Constance in the Swiss Alps at 5320 cal yr BP (Magny et al., 2006) and glacier advance in the Tyrolean Alps which quickly buried, and preserved until recently, the "Tyrolean Iceman" 5050–5300 cal yr BP (Baroni and Orombelli, 1996; Rollo et al., 2000). The

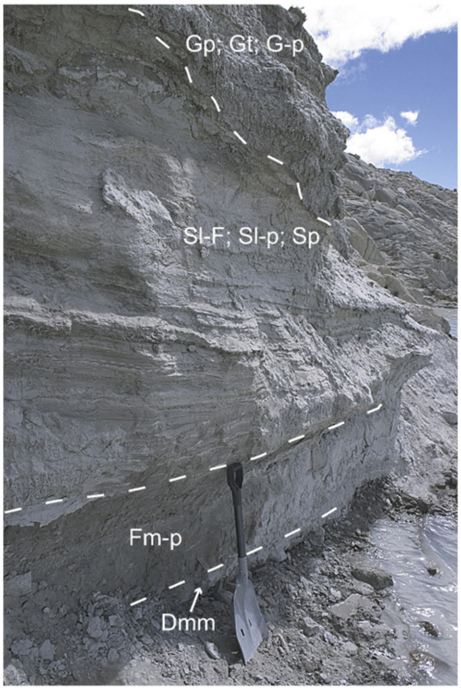

Figure 4. Photograph of the bottom ~3.5 m of the BLS. Fm-p represents both sections of fines (Fig. 3). The ~5 cm Gmm layer within these Fm-P sections is not visible. Note shovel for scale.

marked transition to a wetter climate in southern Patagonia at 5500 cal yr BP is recorded in a peat core from the Rio Rubens Bog (Huber and Markgraf, 2003). In the South Atlantic sector of the Southern Ocean, Hodell et al. (2001) note an abrupt cooling of surface waters and expansion of sea ice ~5000 yr ago. Collectively, these observations provide a framework of evidence, although circumstantial, for a large and abrupt climatic event in the mid-Holocene, the interhemispheric character and synchronicity of which may point to a tropical origin (Cane, 1998).

A perspective on the recent retreat of the QIC

The recent exposure of ~5000-yr-old surface vegetation along the QIC margin places the modern retreat of the ice cap in a millennial-scale context. It is very likely that the BCL and NL plant deposits were covered by the ice cap for the last ~5000 yr, thereby preserving the vegetation from decay and erosion. Modern changes in the planet's cryosphere, including the near global-scale retreat of glaciers, are expected responses to the recent increase in Earth's globally-averaged temperature, due in part to increased anthropogenic greenhouse gas emissions. In this context, the recent retreat of the QIC suggests that modern human influences on the global atmosphere are likely shifting the climate system toward a state that is unprecedented over the last 5 millennia.

Summary

Recent retreat of the Quelccaya Ice Cap, southeastern Peru has exposed well-preserved, in-place vegetation deposits that have been continuously protected by ice-cover since burial. AMS ^{14}C ages of samples from two sites along the central western margin of the ice cap collectively date to 5101–5146 and 4738–4758 cal yr BP, and reveal when these sites were last ice-free. Dating of vegetation interbedded in a nearby recently exposed clastic sedimentary sequence provides evidence for ice-free conditions from roughly 5200 to at least 7000 cal yr BP and places a new minimum constraint on early to mid-Holocene ice cap extent. The advance of the QIC at ~5000 yr ago reflects a regional climate change to cooler and/or wetter conditions and adds to a growing body of paleoclimatic evidence for interhemispheric abrupt climate change ~5000 to 5500 yr ago. Additionally, the ages of these deposits provide millennial-scale context for the modern retreat of the ice cap and suggest that the reduced areal extent of the QIC is unprecedented over the past ~5 millennia.

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Table 2
AMS ^{14}C ages of plants collected from the Boulder Lake sediment sequence.

Sample name	Height above bedrock (m)	Lat. (S)	Long. (W)	Elev. (masl)	^{14}C age ± 1σ (^{14}C yr BP)	Calibrated 1σ age range (cal yr BP)	Laboratory	Receipt no.
QIC-06 BS-15	4.90–5.05	13°56.01'	70°51.54'	5143	4610 ± 45	5119–5185 (5152)	NOSAMS	55141
QIC-06 BS-14	3.59–3.75	"	"		4650 ± 40	5283–5327 (5305)	NOSAMS	55140
QIC-06 BS-13	3.52	"	"		4410 ± 35	4862–4960 (4911)	NOSAMS	55139
QIC-06 BS-12	3.14	"	"		4690 ± 40	5376–5456 (5416)	NOSAMS	55138
QIC-06 BS-11	2.29	"	"		5350 ± 40	6038–6120 (6079)	NOSAMS	55137
QIC-06 BS-10	1.69	"	"		5750 ± 35	6410–6504 (6457)	NOSAMS	55136
QIC-06 BS-9	1.42–1.45	"	"		5680 ± 40	6391–6447 (6419)	NOSAMS	55135
QIC-06 BS-8	1.36–1.39	"	"		5770 ± 35	6441–6558 (6500)	NOSAMS	55134
QIC-06 BS-7	1.27–1.28	"	"		6450 ± 45	7270–7332 (7301)	NOSAMS	55133
QIC-06 BS-6	1.19–1.21	"	"		5880 ± 40	6557–6677 (6617)	NOSAMS	55132
QIC-06 BS-5	1.05–1.09	"	"		5900 ± 45	6627–6735 (6681)	NOSAMS	55131
QIC-07 BS-3	0.95–1.05	"	"		6110 ± 80	6787–7007 (6897)	NOSAMS	60783
QIC-06 BS-4	0.90–1.05	"	"		5940 ± 45	6654–6751 (6703)	NOSAMS	55130
QIC-06 BS-3	0.72	"	"		5290 ± 100	5910–6123 (6017)	NOSAMS	55129
QIC-07 BS-2	0.45–0.55	"	"		6060 ± 45	6780–6906 (6843)	NOSAMS	60782
QIC-06 BS-2^	0.50	"	"		5600 ± 140	6186–6495 (6341)	NOSAMS	55128
QIC-06 BS-1^	0.27							
QIC-07 BS-1	0.20–0.30	"	"		6220 ± 350	6676–7341 (7009)	NOSAMS	60781

Samples noted with ^ were combined at the laboratory noted prior to analysis in order to attain sufficient material for dating. Calibrated ages are given in years before present (cal yr BP), where the origin on the radiocarbon calibration timescale is placed at 1950 AD. The calibrations were carried out using Calib 5.0.1 (Stuiver and Reimer, 1993; McCormac et al., 2004).

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