KECK GEOLOGY CONSORTIUM

PROCEEDINGS OF THE TWENTY-FIFTH ANNUAL KECK RESEARCH SYMPOSIUM IN GEOLOGY

April 2012
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JESSICA TRÉANTON, Colorado College
Research Advisor: Donald T. Rodbell

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HOLOCENE CLIMATE CHANGE AND GLACIAL EVOLUTION OF THE CENTRAL PERUVIAN ANDES: LACUSTRINE RECORD FROM THE PROGLACIAL LAKE JAICO

JESSICA TRÉANTON, Colorado College
Research Advisor: Donald T. Rodbell

INTRODUCTION

Glacial ice fluctuations are considered as proxies for climatic conditions due to the impact of precipitation, temperature, and solar radiation on their mass balance (Stansell et al., 2005). This approach was initially proposed by Karlén when he used proglacial lake sediment as a record for up-valley glacial evolution (Karlén, 1988). Furthermore, alpine glaciers in general and tropical ones especially so, have high activity ratios and are therefore extremely reactive to changing conditions (Rodbell et al., 2008).

While Holocene glacial history is well documented in the Northern Hemisphere, that of South American low latitudes remains more enigmatic. Furthermore, the naturally low carbon content of alpine environments limits the opportunities for ^{14}C studies and consequently limits the use of traditional clastic sediment flux proxies. However, glacial sediments differ in many respects including sedimentological, geochemical and physical ones, which constitutes the foundation for multi-proxy approaches to glacier activity reconstructions (Bakke et al., 2010). Using several records allows for more nuanced interpretations due to the differing variables represented such as temperature or humidity (Stansell et al., 2010). This research aims to use the multi-proxy approach in a glacial reconstruction.

OBJECTIVES

The primary objective of this research is to contribute to the sparse and variable South American Holocene glacial history by examining sedimentological records obtained from the proglacial Laguna Jaico located in the Central Peruvian Andes. In order to do so, I will study a 268 cm-long core from Laguna Jaico for sedimentological, geochemical and physical properties in order to compare obtained records with others from proximal locations. This will allow me to determine ages of glacial advance and retreat, climate change events, and finally to assess the accuracy of proxies used.

STUDY SITE

Laguna Jaico (4478 m elevation) is located on the western side of the Central Peruvian Andes at the southern base of the currently glaciated Peak Nevado Huaguruncho (5723 masl). The catchment includes both the 65m deep Laguna Jaico as well as a second lake, Laguna Yanacocha (Fig. 1). On site, the only visible lithology consisted of Triassic-Jurassic granodioritic rocks.

METHODS

In June 2011, we used a percussion coring system to collect three overlapping cores (A-11, B-11, and C-11) in order to avoid record gaps (Stansell et al. 2005). The top 30cm were extruded at 0.25cm intervals in the field and placed in baggies to avoid mixing of the non-consolidated upper portion of core A-11. They were then photographed, described and split at Ohio State University. Compiled depth, established based on extrusion depths and recovery lengths, yielded a total of 268 cm. Cores were then sampled for 1cc of sediment every 2cm, freeze dried, and measured for dry bulk density. XRF analyzes were conducted at the University of Minnesota. Samples mailed to Colorado College were analyzed for carbon and nitrogen content.

Carbon and nitrogen content analysis was conducted using a ThermoFisher NC2100 CHNS elemental analyzer. Samples were combusted at 1000°C in an oxidized atmosphere that separated the gaseous products by chromatography. In this manner, elemental content was determined in weight %. C/N atomic

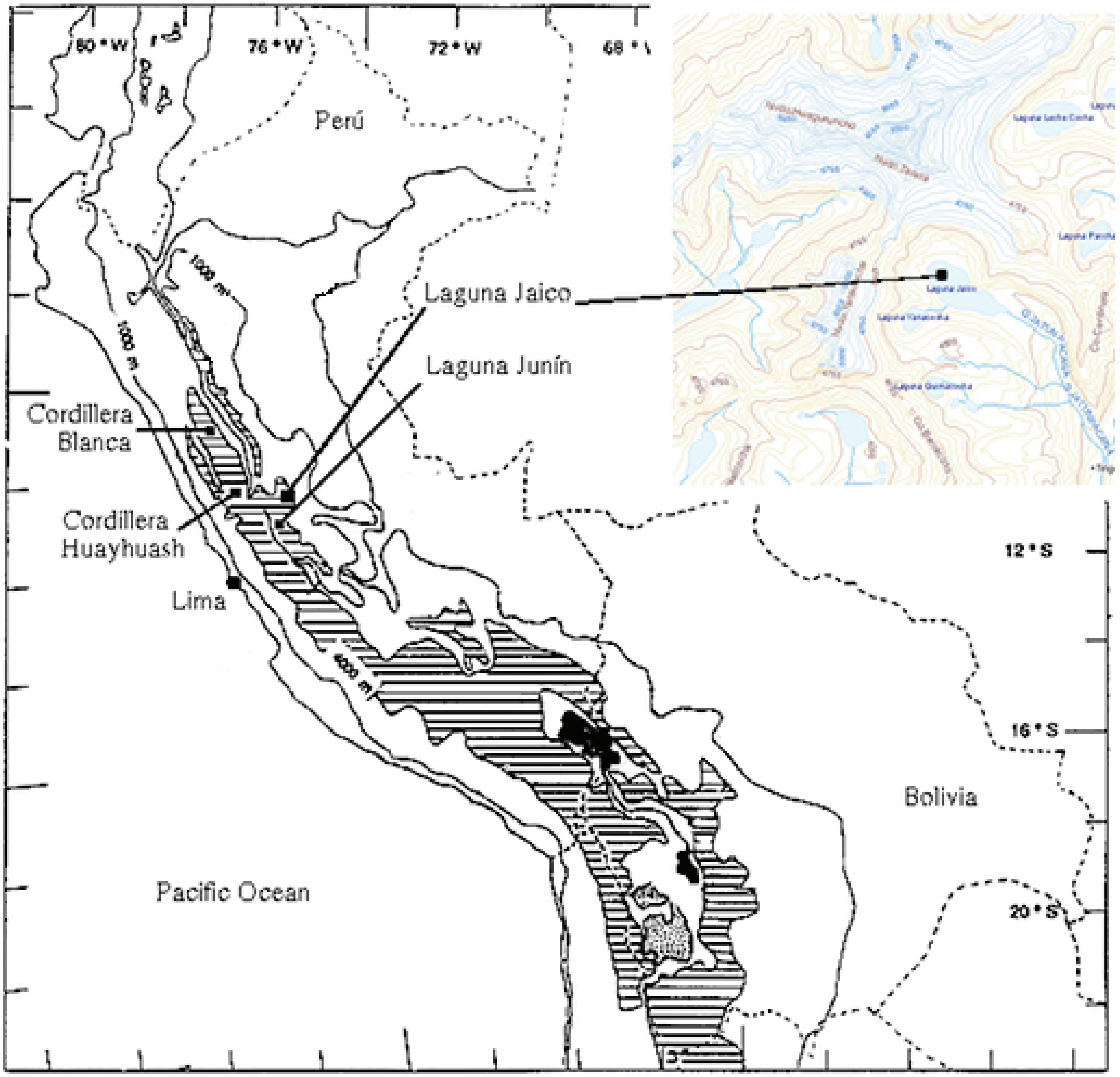

Figure 1. Map of South America showing the location of Laguna Jaico relative to other locations mentioned (modified from Seltzer, 1990). In addition, a topographical map of the valley shows the location of Laguna Jaico relative to Peak Nevado Huaguruncho, and Laguna Yanacocha.

ratios were determined from elemental ones with the following equation: C/Natomic = C/Nmass*1.167. Geochemical proxies were obtained through ITRAX scanning XRF at 1 mm spacing resolution. Results are in counts per second (cps) and therefore only semi-quantitative.

While ^{14}C analyses were performed on Laguna Jaico cores, results were inconclusive. The age-depth model used was therefore based on one determined for Laguna Yanacocha which is located in the same watershed (Fig. 1). Nine charcoal and aquatic macrofossil samples were extracted from the core at varying depths and dated at the UC-Irvine Keck Carbon Cycle AMS Facility. Calendar year results were determined based on the median distribution of true age results obtained during the analysis. Radiocarbon results are presented in B.P. which refers to calendar years before present, and assumes the present in 1950.

DATA AND INTERPRETATION

An age-depth model determined for Laguna Yanacocha indicates that the 268cm-long core obtained from Laguna Jaico contains lacustrine sediment deposited in between ~ 6845 B.P. and the present. The model applied to convert compiled core depths to age was a linear relationship given by the following formula: $y = (x*25.939) - 61$. However, evidence of landslides was visible in the field with moraines wasting into Laguna Jaico. The addition of this younger slump material into the lake would translate into artificially older ages for deeper portions of the core.

BIOLOGICAL PROXIES

Total organic carbon content (TOC) is a product of both primary productivity and the degree of dilution by other sediment constituents such as clastic material (Burnett et al., 2011). While total carbon was measured, it is considered representative of TOC due to the lack of visible carbonate units in the valley. Carbon to nitrogen atomic ratios (C/N) reveal the relative contributions of aquatic and/or terrestrial sources to TOC (Stansell et al., 2010). Si/Ti reflects biogenic silica, and therefore constitutes a proxy of aquatic primary production (Rothwell, 2006).

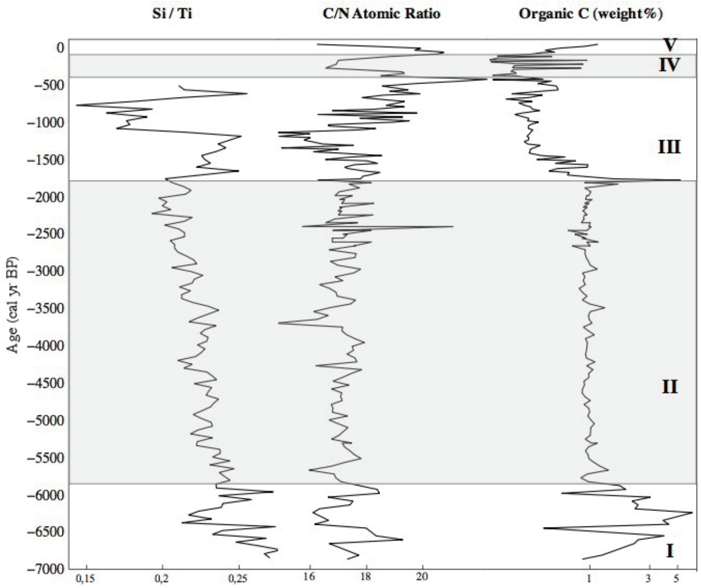

Figure 2. Plots of silicon to titanium ratio, carbon to nitrogen atomic ratio, and total organic carbon content. These three proxies reflect biogenic processes that occurred in Laguna Jaico. Gray shading denotes inferred episodes of glacial advance, and the roman numerals label five independent climatic periods.

TOC declines from ~6% to >1% in three general steps circa 5800, 1800, 400, but increases starting 100 B.P. These dates bound periods I, II, III, IV, and V later referenced (Fig. 2). Peak variability occurred during period I, and II was marked by abrupt change with average values decreasing by ~50%. Similarly, Si/Ti reaches its maximum in period I, and declines smoothly during II (Fig. 2). Circa 1800 B.P., variability resumes with an increase until 1250 B.P. and subsequently decreases. Whole core C/N values are comprised in between 14-22% indicating that organic matter was of both aquatic and terrestrial origin, with a larger contribution by the former (Fig. 2). C/N inversely reflect Si/Ti, with the exception of period II which is characterized by stable values.

SEDIMENT PROPERTIES AND PROVENANCE

Dry bulk density (DBD) indicates up-valley glacier mass balance changes and especially useful in high alpine environments with low organic carbon content. It is based on the relationship in between glacier mass-balance and volume of meltwater flowing down-valley which impacts clastic sediment contributions to proglacial lakes. DBD therefore reflects differing proportions of organic and clastic components within the total sediment. Glaciofluvial sediment typically has higher DBD values due to smaller grain size and lower water content than organic-rich sediment (Bakke et al., 2005).

Si content indicates clastic sediment input (Bakke et al., 2010). Therefore, in conjunction with TOC, it should reflect trends similar to those of the DBD record. Ti/Rb is proportional to the heavy resistate clastic material content (Rothwell, 2006). High values represent weathered material and hence correlate with glacial episodes. Due to differential fractionation effects, Fe/Ti traces grain size (Rothwell, 2006). Low values are expected during glacial episodes due to an increased content of glacial flour.

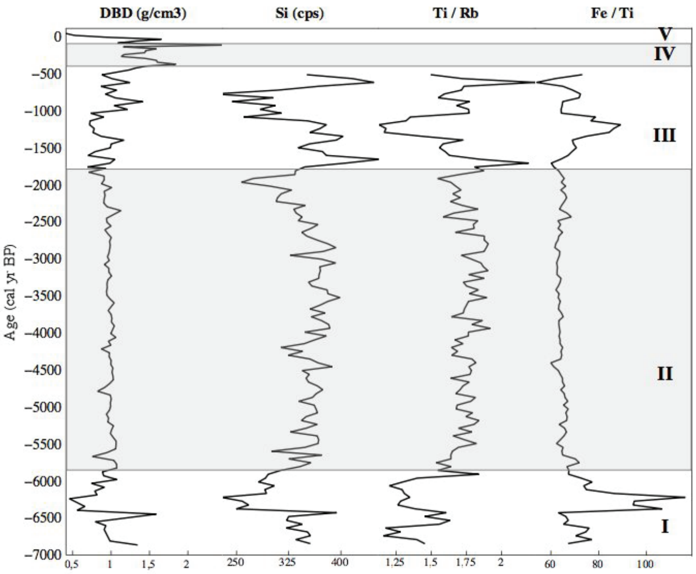

Figure 3. Plots of dry bulk density, silicon content, titanium to rubidium ratio, and iron to titanium ratio. These proxies reflect variations in sediment properties which in turn track changes in transport mechanisms or provenance. Gray shading denotes inferred episodes of glacial advance, and the roman numerals label five independent climatic periods.

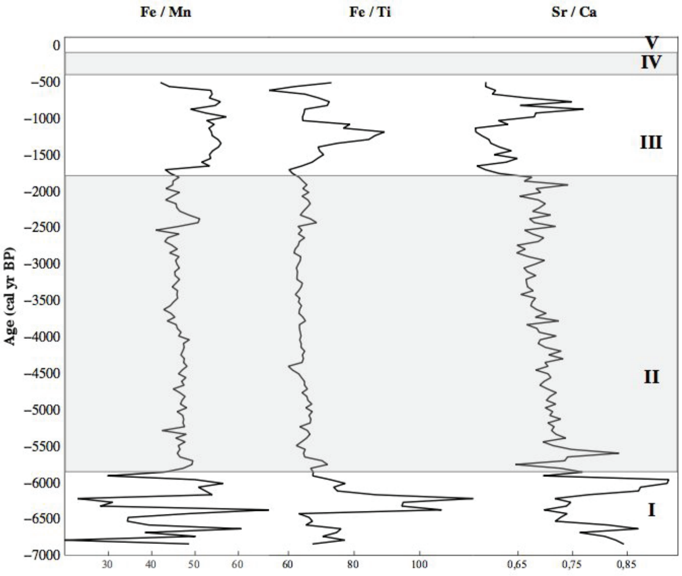

Figure 4. Plots of iron to manganese, iron to titanium, and strontium to calcium ratios. These proxies trace changing lacustrine conditions including relative changes in chemocline depth, reducing conditions, and water levels respectively. Gray shading denotes inferred episodes of glacial advance, and the roman numerals label five independent climatic periods.

All proxies related to sediment characteristics and provenance have similar trends in terms of variability with large ranges during period I, stable values during period II, and large ranges again during periods III, IV, and V (Fig. 3). DBD respective average values of 0.91, 0.97, 0.94, 1.47, and 0.63 g/cm3 reflect glacial variations with highest values interpreted as glacial advances. Ti/Rb mirrors this trend with higher values during glacial episodes reflecting the increased content of glacially reworked sediment (Fig. 3). Fe/Ti is inversely related and shows larger grain sizes during the inter-glacial episodes I and III than during the glacial II.

LAKE PROPERTIES

Elemental metal content such as Fe or Mn provides information about the changing lacustrine redox conditions based on the differing solubility of elements in reducing or oxidizing environments. In an oxidizing event related to a lowering of lake level or increased mixing, the chemocline depth increases and allows for the precipitation of Fe and Mn at greater depths. Because Ti is primarily contributed by clastic sediment, normalizing Fe to Ti removes the effect of dilution from the iron precipitation signal. In addition, due to slight differences in oxidation mechanisms of Fe and Mn, their ratio should decrease as a function of increasing distance from the chemocline (Brown et al., 2000). Finally, Sr/Ca ratios reflect the presence of high-Sr aragonite which requires a shallow water source to form (Rothwell, 2006). In this manner, both elemental metal and high-Sr aragonite content should parallel each other with high values reflecting lake shoaling, and low ones reflecting lake deepening.

All proxies have the largest range during period I, and reach their core maximum circa 6000 B.P. (Fig. 4). An abrupt decrease ~5800 B.P. marks the transition into period II with both Fe/Mn and Fe/Ti remaining stable at intermediate values and Sr/Ca decreases steadily. Similarly to period I, III is characterized by large ranges. However, while Sr/Ca is marked by low values for the first half of III and transitions to higher ones circa 1000 B.P., Fe/Ti has an opposite trend, and Fe/Mn has generally high stable values bracketed before and after by significantly lower ones (Fig. 4).

GLACIAL HISTORY BASED ON THE LAGUNA JAICO RECORD

Based on moraine dates, ice cores, lake records, and lichenometry, studies have been able to document the patterns of Holocene glaciation in the Central Andes. According to Abbott et al. (2003), early Holocene aridity resulted in widespread deglaciation from 10,000 to 6,000 B.P. and glacial advance occurred during the middle Holocene ~5200 B.P. Similarly, Hall et al. (2009) noted that the early Holocene was characterized by a fluctuating climate with intermittent droughts and volatile lake levels. While glacial readvance took place ~8.7 ka to ~5 ka due to an increase in relative humidity, lake levels did not stabilize until 5000 B.P. Rodbell et al. (2008) found glacial re-advance dates of 5000-3500 B.P. for the eastern side of the Cordillera Huayhuash (Fig. 1). Furthermore, Solomina et al. (2007) determined that peak LIA advances in the Cordillera Blanca (Fig. 1) occurred 360-230 B.P. and were associated with cooler temperatures. Finally, Kaser (1999) characterized the recent Holocene glaciation when he concluded that several localized ice expansions and retreats took place during the 1900's, and final deglaciation in the Cordillera Blanca occurred in the 1980's AD (Fig. 1).

The Laguna Jaico record confirms Early-Holocene regional findings with glacial recessions reflected in low DBD values and resistate content, and large grain size of the sediment during period I (6845-5800 B.P.). Aridity is visible in the redox paleotracers, which show a deep chemocline and large amounts of oxidized metals interpreted as a shoaling of lake level due to the positive correlation with high Sr-aragonite content. Clastic input during this period is low which could reflect decreased erosion and deposition due to aridity. Finally, fluctuating climatic conditions are visible in the maximum variability of proxies during this time-span. More specifically, the full range of the chemocline depth proxy occurs in ~ 500 years circa 6500 B.P.

The record also corroborates a mid-Holocene glacial re-advance ~5800-1800 B.P. The onset is slightly earlier than the findings of Abbott et al. (2003) and Rodbell et al. (2008), but well within the 8700-5000 B.P. range given by Hall et al. (2009). Glacial conditions are reflected in smaller grain sizes, an increased presence of heavy resistates, and higher DBD values of the sediment. Water level proxies trace the more humid climate with increasing water levels, an intermediate chemocline depth, more reducing conditions, and a subsequent decrease of biogenic silica. Finally, climate stabilization is visible in the reduced range of most proxies and especially so in the stabilization of TOC, and lake level tracers.

A glacial retreat episode (1800 - 400 B.P.) is recorded by a decrease in TOC and resistate minerals, an increased variability in clastic content and carbon contributors, and an increase in grain size. From 1800-1000 B.P., an increase in water level correlates with increasingly oxidizing conditions at the sediment-water interface and a deepening of the chemocline. Conversely, from 1000-500 B.P., a lowering of lake level co-varies with increasingly reducing conditions for a similar chemocline depth. In order to record similar chemocline depths for varying water levels, the degree of mixing must be implicated. Therefore, these relationships most likely reflect an event of increased mixing linked to higher water levels, and a subsequent shoaling resulting in decreased mixing. The LIA is recorded in Laguna Jaico from 400-100 B.P. This glacial episode is visible in the fleeting decrease of DBD, C/N, and TOC values. While the onset is slightly older, and the duration longer than the LIA recorded in the Cordillera Blanca, such disparities are regionally more the norm than the exception. Final glacial retreat is dated circa 100 B.P. or 1850 AD. High variability in the recent Holocene glacial history of the region renders comparison of this age difficult due to the short time-frame of the event.

CONCLUSION

Sediment cores extruded from Laguna Jaico located in the Cordillera Oriental of the Central Peruvian Andes allowed for a glacial history reconstruction based on multi-proxy analyses. Climatic events and up-valley glacial evolution were identified on the basis of dry bulk density, organic carbon, and Si content which reflected the contributions of clastic sediment into the lake relative to the organic matter content. Geochemical proxies provided further information such as chemocline depth, water level fluctuations, redox conditions at the time of deposition, and information pertaining to sediment characteristics. Laguna Jaico cores reflected an early Holocene arid episode of glacial retreat (6845-5800 B.P.), mid-Holocene glacial advance (5800-1800 B.P.) and subsequent deglaciation (1800-400 B.P.), the LIA (400-100 B.P.), and final recent deglaciation (100 B.P.-present). These dates adhere to the regional record which is characterized by large variability. Slight timing discrepancies do arise which some suggest is related to the role of topography (Hall et al., 2009), or to the unequal sensitivity of glaciers to solar variability. It is important to note the source of error contributed by the potential presence of recent slump material to the age-model ,which would artificially age interpreted events.

Having a more precise understanding of past climatic and glacial events is regionally significant due to the freshwater source that glaciers represent for human populations in Peru. Knowledge of past glacial evolution could help predict future stream discharge required for industrial and agricultural purposes (Abbott et al., 2003). Secondly, the tropics are the 'heat engine' of the planet. Constructing a more complete Holocene record of these regions will allow us to better understand climatic mechanisms and feedback systems on a global scale (Mark, 2006; Stansell et al., 2010).

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