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

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Dr. Robert J. Varga, Editor
Director, Keck Geology Consortium
Pomona College

Dr. Holli Frey
Symposium Convener
Union College

Carol Morgan
Keck Geology Consortium Administrative Assistant

Christina Kelly
Symposium Proceedings Layout & Design
Office of Communication & Marketing
Scripps College

Keck Geology Consortium
Geology Department, Pomona College
185 E. 6th St., Claremont, CA 91711
(909) 607-0651, keckgeology@pomona.edu, keckgeology.org

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Robert J. Varga
Editor and Keck Director
Pomona College

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Christina Kelly
Proceedings Layout & Design
Scripps College

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Research Advisors: Kelly MacGregor, Macalester College

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Research Advisor: Nathan Stansell

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GLACIAL VARIABILITY IN THE PERUVIAN ANDES AS RECORDED IN LAKE SEDIMENTS

ALIA PAYNE, Macalester College
Research Advisors: Kelly MacGregor, Macalester College

INTRODUCTION

Glaciers are sensitive indicators of climate, responding to changes in precipitation and temperature regimes with changing mass balance and terminus position. Tropical glaciers respond differently to climate than do temperate glaciers (Kaser et al, 2003), and tropical hydrologic cycles play a key role in global climate change (Seltzer, 2000), further meriting the study of glaciers in tropical latitudes. Peru is an ideal study location, as it is home to 71% of the world's tropical glaciers (Kaser and Osmaston, 2002). By studying tropical glaciers, it is possible to gain insight into broader atmospheric trends in the past, and better predict glacier response to future climate change.

Peruvian glaciers are an important source of water for agriculture, potable water supplies and hydroelectricity to dependent populations throughout Peru. A 2003 hydrologic study focused on the Río Santa, one of the largest rivers in Peru that supplies water for multiple hydroelectric plants, mines, villages, and cities. The study found that of the water discharging from glacial watersheds during one year, a minimum of one third was due to glacial melt (Mark and Seltzer, 2003). Glaciers also act as important storage for precipitation in such an arid climate, buffering the water flow differences between wet and dry season (Mark and Seltzer, 2003). Reduction of glacial melt water and ice storage as a result of shrinking glaciers would have drastic affects on those reliant on the resource.

Past studies of tropical glaciers in the Andes have focused on inherently discontinuous moraine chronologies to reconstruct glacial conditions (Rodbell et al., 2009; Licciardi et al., 2009.) Lake sediment records are now being used in tandem with moraines to provide a more continuous record of upvalley glacial extent. Clastic sediment flux and total organic carbon content are used as a proxy for glacial erosion taking place up valley. Advancing glaciers typically erode bedrock at greater rates than retreating glaciers, washing the sediment into down valley lakes and leaving a clastic-rich, organic-poor record (Rodbell et al., 2008). Lake sediment records can misrepresent glaciation events when sediment input is affected by heavy precipitation, seismic activity (Stansell et al., 2014), anthropogenic activities (Rodbell et al., 2008), landslides, etc. However, the method has become more widely used, and techniques have been developed to identify and "remove" non-glacial signals of clastic sediment that may otherwise confuse the record (Stansell, 2014; Rodbell, 2008; Rodbell, 2009).

OBJECTIVES

The objective of this study is to reconstruct climatic and glacial history during the Holocene in Queshque Valley, Peru using geologic evidence from lake cores taken from three paternoster proglacial lakes throughout the valley. Clastic sedimentation and organic content of the core are the primary means through which to reconstruct glacial extent. The sediment records are compared to climate proxies from the region, which provide constraints on timing of environmental and geomorphic change.

METHODS

Lacustrine sediment cores were collected from three lakes in Queshque Valley, in the Cordillera Blanca of the Peruvian Andes in July 2014. All of the lakes were connected by a stream running downward from the glacier at the head of the valley. One core was taken from New Lake, the highest lake right beneath the modern glacier (9.7988˚ S, 77.25993˚ W; 4687 masl), five from Upper Queshque, the next lake down valley from New Lake (9.81947˚ S, 77.30122˚ W; 4284 masl), and two from Lower Queshque, the furthest down-valley lake we sampled (9.82910˚ S, 77.31148˚ W; 4255 mas).

The lakes were accessed using inflatable rubber rafts, and cores were taken using a Livingstone square-rod piston corer. In total, we took eight cores from three lakes, ranging in length from 22.3 to 127 cm. Several cores that were deemed too liquid to transport well were partially extruded in the field into WhirlPac bags, labeled and sealed in the field. Cores were sealed and shipped back to Union College in Schenectady NY. In the Union Lab, cores were split, described, and digitally photographed. One half was used as an archive core, and was scanned for magnetic susceptibility using a Bartington MS2 Meter and scanned for elemental composition using an Bruker portable scanning XRF. The other half was used as a working core, and was sampled volumetrically (1 cm^3) every centimeter. The samples were then weighed and freeze dried in order to measure dry bulk density.

Select cores were sent to Macalester College to measure percent total organic carbon (%TOC), while the rest were processed at Union College. Total carbon (TC) was determined by combusting samples at 1000°C in an autosampler furnace and measuring the resultant CO_2 by coulometery. Total inorganic carbon (TIC; $CaCO_3$) was measured by acidifying samples in 0.1 N H_3PO_4, and measuring the resultant CO_2 by coulometry. TOC was calculated from TOC=TC-TIC. Total inorganic carbon (TIC) was measured in approximately every third sample.

Two cores from upper Laguna Queshque (Cores A and E) were sampled for basal radiocarbon ages, and one core from upper Laguna Queshque was sampled for ^{210}Pb dating. Radiocarbon samples were obtained by obtaining ~2g of core core material obtained from an ~1cm interval. These samples were then sieved through a 250 µm sieve. Charcoal that did not pass through the 250µm sieve was picked with either tweezers or via pipette in a laminar flow hood to reduce the likelihood of contamination. Charcoal samples were then submitted to the Keck Carbon Cycle AMS Facility, at UC Irvine. The radiocarbon ages were converted to calibrated calendar years using CALIB 4.0. An age-depth model was created for each core. Once ^{210}Pb dating is complete, the radiocarbon and ^{210}Pb results will be combined to generate an age-depth model for upper Laguna Queshque that will be applicable to all cores from that lake.

DATA AND INTERPRETATION

In the six cores for which we have TOC data, there was no TIC presence and TC ended up being the same as TOC. Percent TOC values ranged from 10.9

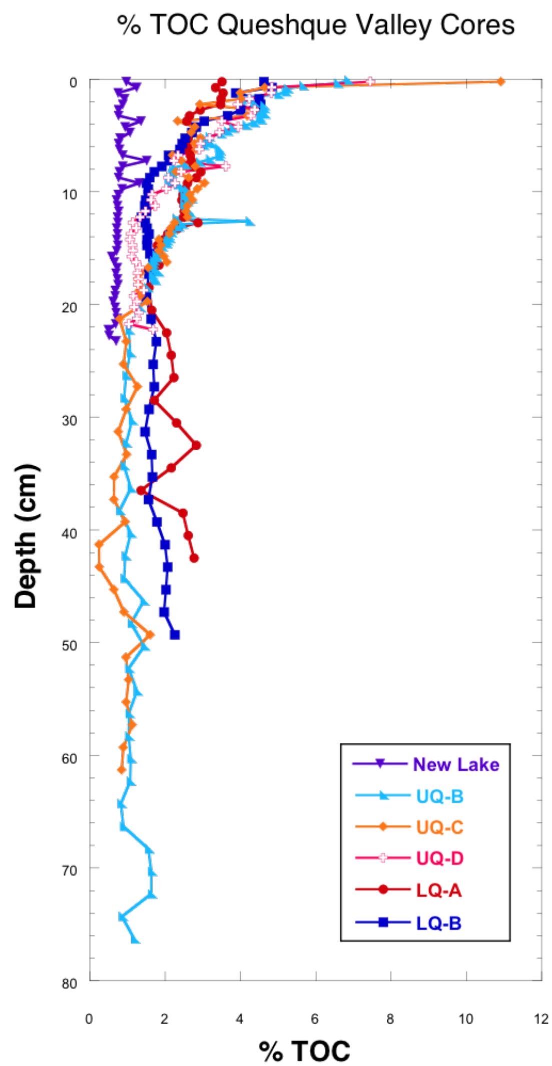

Figure 1. Percentage total organic carbon (TOC) plotted against depth for all cores with TOC data. New Lake shows little variation and a lower overall %TOC, whereas lower Laguna Queshque (LQ) core reveal the highest TOC levels likely reflecting lower average clastic sedimentation rates than either of the two upvalley lakes.

to 0.03%, with the majority falling between 0.5 to 2.5% (Fig.1). The %TOC pattern in Upper and Lower Queshque Lakes are very similar, with all four cores showing a significant rise in %TOC in the top ~15 cm, moving from about 2% to about 6% TOC in that time span (Fig. 2). While we do not yet have an age model, the similarity in %TOC profiles between lakes suggests that the sedimentation rates of Upper and Lower Queshque are approximately the same and are reacting to the same events, likely a change in glacial extent. New Lake, the most upvalley lake in our sequence, had %TOC values just below 1%, with no trends or change over time compared to the other lakes. This is likely because its location proximal to the glacier and at the top of the valley, which would allow for maximum input of clastic sediment eroded directly by the glacier. Organic material may also be less likely to accumulate in New Lake, as its catchment basin is smaller than the down valley lakes and so not as much organic material will be funneled into its record. New Lake did not show the same increase in %TOC in the top ~15cm as the other cores did.

It is important to note, however, that the TOC signal from Lower and Upper Queshque is not simply controlled by the flux of organic matter to the lake bottom, but rather it is a ratio of total organic carbon to other material (probably mostly clastic sediment). This drastic rise in %TOC can then mean either an increase in organic sediment input, a decrease in clastic sediment input, or both, as they are often correlated (Karlen, 1981; Rodbell, 2008). This strong signal, if taken as an indication of decreasing clastic input, would signify glacial retreat. This matches general patterns that others have observed in the recent Holocene (Stansell et al., 2013).

The fact that New Lake does not as clearly record this increase in %TOC in the upper 10cm may be interpreted in several ways. New Lake is situated at a higher elevation (4687 masl) than the lower lakes in the Queshque basin (4284 and 4255 masl), it receives meltwater directly from the retreating ice margin, and New Lake is surrounded by unvegetated till in contrast to the dense tussock grasses and thick (>20 cm thick) surface A horizons that mantle the landscape surrounding the lower lakes. The lack of organic matter on the landscape surrounding New Lake means that when sedimentation shifts from direct glacial meltwater input to sediment derived from the surrounding landscape, the sediment that accumulates in New Lake will not show an increase in organic matter, whereas cores from the lower lakes will record such a shift. In addition, the water column of New Lake is not as organically productive as the lower lakes in the Queshque drainage basin due to higher suspended sediment content and lower resultant light transmisivity. This lower productivity further precludes New Lake from generating sediment with even modest TOC levels.

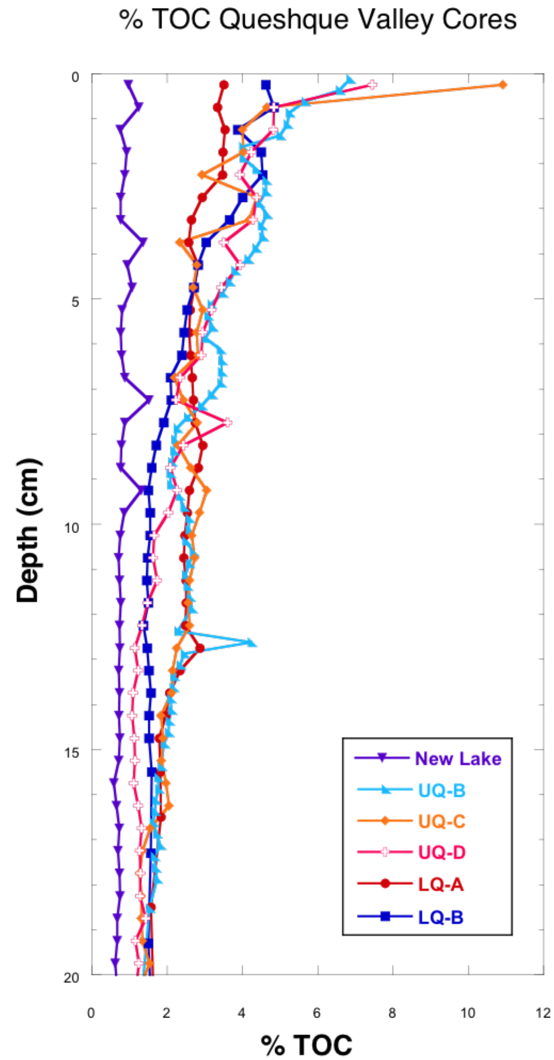

Figure 2. Percentage total organic carbon (TOC) plotted against depth for the upper 20 cm of all cores with TOC data. The top 20 cm of these cores highlight an upcore increase in %TOC for all cores except New Lake, suggesting glacial retreat and reduction in clastic sediment input.

The four cores with magnetics data came from Upper and Lower Queshque, but not New Lake since the core was extruded in the field. The magnetic susceptibility plot (Fig. 3) shows a clear delineation between Upper and Lower Queshque. Upper Laguna Queshque has a

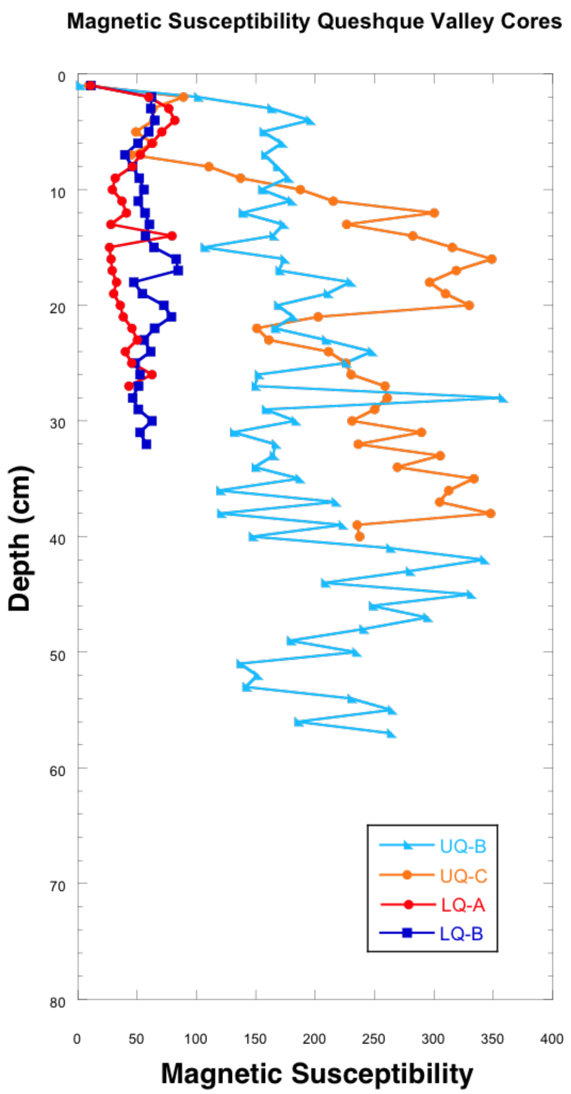

Figure 3. Magnetic Susceptibility (SI, volume) can be used as a rough proxy for clastic sediment content, often correlating inversely with %TOC. Upper (UQ) and Lower Queshque (LQ) reveal different magnetic signals, with Upper Queshque displaying a higher overall and more variable magnetic signal than Lower Queshque, which likely records the effect of clastic sediment being trapped in Upper Queshque.

higher overall average, centering around 200 SI units, about 4x the average value for, Lower Queshque. The Lower Queshque cores also appear to be much less variable in MS value than the Upper Queshque cores. This may be a function of basin topography, or may be a filtering effect whereby Upper Queshque is receiving stronger glacial signals, but trapping much of the sediment from moving downstream to Lower Queshque. The fact that Lower Queshque shows much lower susceptibility overall does support this hypothesis, suggesting the clastic sediment is trapped in upvalley lakes, with less and less showing up downstream.

CONCLUSION

The results of this study support previous evidence that in the recent Holocene, there has been glacial retreat in the tropical Andes. The comparison of data between lakes indicates that there is a much weaker organic signal in the highest lake directly beneath the glacier, whereas the other lakes are mostly aligned in their broad trends, but with slightly different signals in each lake as the movement of sediment changes downstream. Once an age-depth model is developed, it will be possible to compare the data to previous cores, moraines, and other paleoclimate indicators to better understand the timing of changes in the extent of ice cover, and the climatic shifts that drove those changes.

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