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

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KECK GEOLOGY CONSORTIUM
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Keck Geology Consortium: Projects 2014-2015
Short Contributions— Paleoclimate Change from Peruvian Lake Deposits Project

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BIOGEOCHEMISTRY AND SEDIMENT TRANSPORT THROUGH A TROPICAL ANDEAN PATERNOSTER LAKE SYSTEM: A MODERN CALIBRATION PROXY FOR LIMNOLOGICALLY-BASED PALEOCLIMATE RECONSTRUCTIONS
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Research Advisor: Nathan Stansell

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NICHOLAS WEIDHAAS, Union College
Research Advisors: Donald Rodbell and David Gillikin

INTRODUCTION

Glaciation and melt water dynamics in the Cordillera Blanca

Tropical mountain glaciers, such as those of the Peruvian Andes, serve as an especially useful indicator of paleoclimate change due to their high sensitivity to small-scale climatic fluctuations (Rodbell et al., 2008; Licciardi et al., 2009). Therefore, accurate chronologies of glaciation in the Peruvian Andes are imperative in paleoclimate reconstruction and understanding modern climate change, with focus primarily on the effects of fluctuations of temperature and precipitation. Peru holds the highest concentration (70%) of the world's tropical glaciers (Vuille et al., 2008), with the majority in the Cordillera Blanca. This large concentration of climatically sensitive glaciers plays an essential role in water supply dynamics for the human population (~267,000) of the Cordillera Blanca (Mark et al., 2010). Glacial meltwater is a crucial buffer to the highly seasonal precipitation patterns of the central Andes (Vuille et al., 2008), with >80% of all precipitation falling between the months of May and October (Mark et al., 2010). In the past century alone, temperatures have risen in the area by ~0.1°C each decade, and this small increase in temperature is having distressing effects on the extent of glacial ice cover (Vuille et al., 2008). The Cordillera Blanca has lost >30% of its glacier area since the maximum reaches of the 19th century (Vuille et al. 2008). The protection of these water resources and the mitigation of the effects of their decrease hinges, in part, on understanding past glacial activity of the Cordillera Blanca.

Glacial sediment analysis

Terrestrial glacial sediment deposits are inherently incomplete in nature due to their destruction with subsequent glacial advances. A reliable collector of glacially-derived sediment is a proglacial lake, with its conception occurring as ice retreats up-valley. To accurately understand patterns of glacial activity, it is necessary to decipher trends in sediment characteristics, and correlate these to the extent of glaciation. Studies analyzing glacial lake sediment cores (Rodbell et al., 2008; Stansell et al., 2013), moraine dating (Licciardi et al., 2009; Smith and Rodbell, 2010), and compilations of various sources (Rodbell et al., 2009) have provided in-depth reviews of late Quaternary glaciation of the Cordillera Blanca. A principal method used for reconstructing glaciation records is the analysis of clastic sediment flux within cores, as the extent of ice cover and flux exhibit a strong, directly proportional relationship (Rodbell et al., 2008). Other prevalent inorganic proxies include magnetic susceptibility, bulk density, and various indicators based on elemental geochemistry, such as the composition of Sr, Ti, Zr, and Ca (Stansell et al., 2013). These proxies are interpreted as functions of erosion rates and therefore extent of glacial cover.

Modern comparative analysis

A problem with many paleoclimate reconstructions from glacial lake sediment cores is that modern sediment dynamics are often overlooked, and assumptions are made regarding the reliability of proxies, such as magnetic susceptibility, Sr, and Ti, to accurately record past extents of glaciation. These proxies can be perturbed by factors such as multiple bedrock lithologies, secondary inflows, hillslope failure from high shoreline relief, and increase in distance from the glacier itself. Therefore, the understanding of modern variability in sedimentary processes is vital in groundtruthing sediment core glacial proxy records. This analysis is rarely done, and yet a keystone of geology is that "The present is the key to the past" (Lyell, 1830). This statement can be modified to assert that the "past is the key to the future," which is the principal basis on which many studies on climate change are founded.

The objectives of this study are to expand the current understanding of Cordillera Blanca glaciation through modern limnological, biogeochemical, and sedimentological data analysis, with the aim of providing a modern proxy calibration to aid in paleoclimate reconstruction, and future climate prediction and the implications for the modern hydrological cycle in regards to local water supply.

Study area

This study analyzes biogeochemistry and sediment transport through a paternoster lake system in the glaciated Queshque Valley in the western Peruvian Cordillera Blanca. Queshque Valley is approximately 8.7 km in length from the glacier toe to the outflow of the lowermost of its four paternoster lakes and has a watershed headwall elevation of ~5600 m.a.s.l. (Fig. 1). Bedrock lithology is comprised of granodiorites and metasediments, and during glacial advance, granodiorites are increasingly overridden (Stansell et al., 2013). New Lake is the most ice-proximal of the four and exhibits characteristic pastel blue glacial flour pigmentation. Its drainage basin contains very limited grass cover, and the lake itself is devoid of any visible algae or aquatic plants. The drainage basin is dominated by large outcrops of exposed bedrock and high-relief slopes consisting of large angular boulders. Using lichenometry, the damming moraine was dated to the Little Ice Age (Rodbell, 1991). A ~4.5 km stream connects New Lake to Upper Lake and travels through many bogs during its course. Upper Lake is far more biologically productive than New Lake, containing plethoric macrophytes of varying sizes and species. Vegetation is dominated by short grasses due to burning by locals and livestock grazing. Its end moraine was ^{10}Be-dated to be late glacial (~12.5 ka) in age (Faber et al., 2005). A ~400 m stream connects Upper Lake to Lower Lake. which appears similar to Upper Lake in biological activity and drainage basin vegetation. Shoreline relief is much greater than that of Upper Lake, with many scarps evidencing hillslope failure. There is at least one secondary inflow coming from the east. Lower Lake was likely formed following the last glacial maximum. A short stream connects Lower Lake to Small Lake, which could be considered as a simple widening in the stream due to its shallowness.

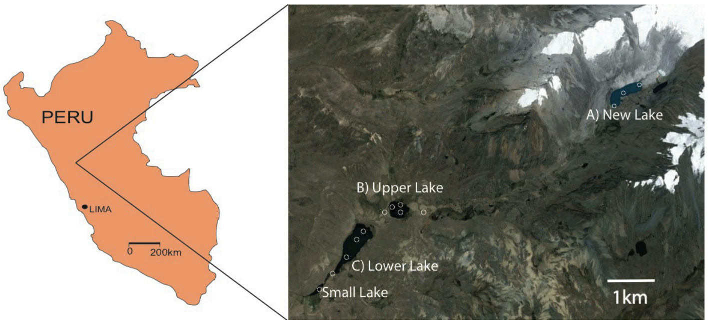

Figure 1. Queshque Valley, Cordillera Blanca, Peru location map with open circles representing water sample sites (from Google Earth).

METHODS

Water Samples

Twenty-eight water samples were collected at surface and depth from New Lake, Upper Lake, Lower Lake, Small Lake and all connecting streams. In the stream connecting Upper and Lower Lakes, samples were taken every four hours over a 24-hour period. Water samples were analyzed for temperature, pH, total alkalinity (TA), specific conductivity (SpC), dissolved oxygen, turbidity, and total suspended material (TSM). Dissolved inorganic carbon (DIC) and $p\mathrm{CO}_2$ were calculated using temperature, pH, and total alkalinity (Robbins et al., 2010). $\delta^{13}\mathrm{C}_{\mathrm{DIC}}$ and $\delta^{18}\mathrm{O}$ were determined in Union College's IRMS laboratory.

Surface Sediment

Surface sediment samples were collected using an Eckman box sampler at 12 locations throughout both Upper Lake Lower Lake, for 24 total samples. Samples were analyzed for organic/inorganic carbon content, magnetic susceptibility, grain size, biogenic silica ($bSiO_2$), and elemental composition, and percent clastics was calculated.

RESULTS & DISCUSSION

Water Chemistry

Water chemistry data present contradictory evidence on the accepted convention that the glacier is the dominant sediment supplier to the system. TA increases with distance away from the glacier, suggesting that the glacier is not the dominant source, however these values are overall very low (average 0.056 ±0.037 mmol/L). It is likely that there is TA production elsewhere in the basin, suggesting input from secondary inflows to the system. TSM values are highly variable (average 1.102 ± 0.581 mg/L) with distance from the glacier, which suggests an influx of organic material or a non-glacial inorganic sediment source. There is a decrease in specific conductivity with increasing distance from the glacier (from 0.088 to 0.062 mS/cm), indicating a glacier-dominated source of dissolved material. The 24-hour diurnal cycle data also suggest a glacial sediment source. A correlative sinusoidal trend of temperature and TSM was recorded, suggesting higher temperatures cause increased glacial melting and subsequent sediment yield (Fig. 2). An opposite trend is seen in the diurnal SpC data, which is likely due to dilution during times of increased melting. Increased TSM values during daylight hours indicate that there is a short residence time in the system.

Surface Sediment

Surface sediment grain size does not show the expected correlation to the distance from the main inflow of each lake (*D)*. Grain size should decrease with increased *D*, however, there is no significant trend in either Upper or Lower Lake (R^2=0.349;0.487). Therefore, there must be another source entering the system that alters the signal, illustrating the import of secondary inflows.

Surface sediment elemental compositions, with regard to those that are known to track glacial activity in the basin, specifically Sr and Zr, tell a different story. Sr and Zr are proven proxies for extent of glacial cover in Queshque Valley, with increased glacier cover resulting in more erosion of granodiorites (Stansell et al., 2013). Both Upper and Lower Lake provide paleoclimate records from the early Holocene through the Medieval Climate Anomaly (MCA) and the Little Ice Age (LIA) (Stansell et al., 2013; Rodbell, 1991). A glacial sediment source was recorded even though Upper and Lower Lakes were ~5 km from the glacier toe, which was likely near the modern outflow of

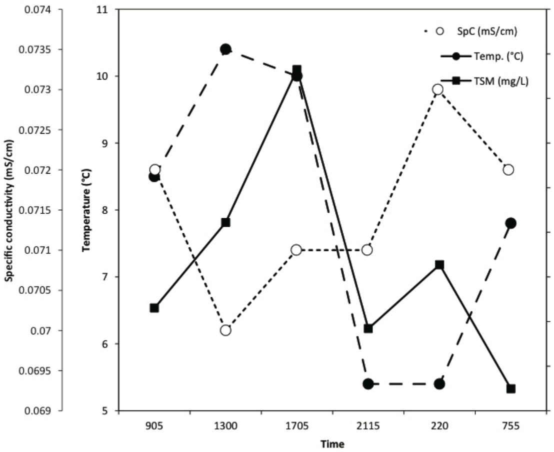

Figure 2. Temperature (°C), SpC (mS/cm), and TSM (mg/L) over a 24-hr period in the stream connecting Upper and Lower Lakes, illustrating glacial influence to the system.

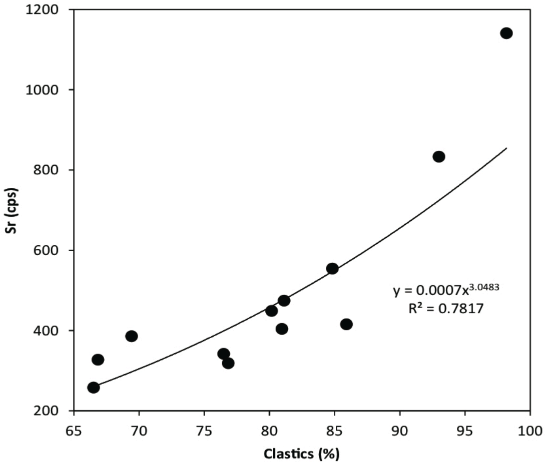

Figure 3. Surface sediment Sr abundance (cps) vs. % Clastics in Upper Lake, suggesting Sr is an adequate indicator of non-biogenic sediment.

New Lake, at the time of deposition during the LIA. However, modern depositional signature in these lakes may not be entirely glacial in origin. Sr correlates to percent clastics in Upper Lake (R^2=0.748) (Fig. 3), but not Lower Lake (R^2=0.029). This relationship indicates that Sr is representative of the non-biogenic sediment that is purely erosional in nature. Thus, Sr currently records a glacial sediment signature in Upper Lake, but not Lower Lake. The relationship between Sr and *D* suggests the same scenario. Sr decreases with distance from the main inflow in Upper Lake (R^2=0.637) (Fig. 4a), but a strong glacial Sr signal is not seen in Lower Lake, with no correlation between Sr and *D* (R^2=0.182) (Fig. 4b).

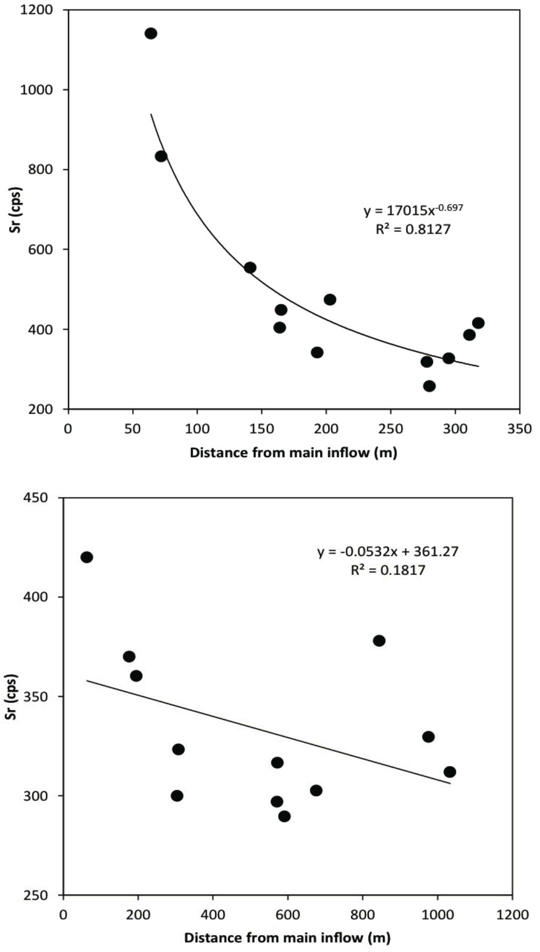

Figure 4. Surface sediment Sr abundance (cps) vs. Distance from main inflow (m) in (a) Upper Lake and (b) Lower Lake, indicating a modern dominant glacial sediment source to Upper Lake, but not Lower Lake.

The same correlations are observed for Zr as well, except the relationship to percent clastics in both lakes is significant, and Zr abundance increases with increased *D* in Lower Lake (R^2=0.729). These data indicate that a glacial sediment source is no longer dominant to Lower Lake, and therefore glacial activity is likely no longer recorded its sedimentary record. Since the LIA is observed in paleoclimate records from Lower Lake, the shut-off of glacially-dominated sediment must have happened within the most recent ~250 years.

There are three possible explanations for this occurrence, and the ultimate explanation could well be the combination of all three. (1) Extent of glacial cover has simply decreased to the degree where not enough Sr is input to the system by granodiorite erosion to reach Lower Lake, yet it still reaches Upper Lake. (2) Hillslope instability of Lower Lake's high-relief shorelines has increased in the recent past due to burning by local residents for livestock grazing. This would cause a dilution of the glacial sediment signature. (3) Possibly the most likely explanation is that the formation of New Lake during the post-LIA glacial retreat resulted in an effective sediment trap, allowing much less sediment to be introduced to the paternoster system downstream of New Lake.

CONCLUSIONS

Upper Lake and Lower Lake have effectively recorded Holocene paleoclimate change through the MCA and LIA. Since the LIA, dynamics of the paternoster system have been altered in a way that causes Lower Lake to no longer be a reliable recorder of glacial activity. This change is discernable through the non-glacial trends of known trace element proxies in the surface sediments of both lakes. The formation of New Lake post-LIA, which now serves as a sediment trap, is the likely causal factor in the reduction of glacial signature that reaches Lower Lake.

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