Lake and bog sediment records of Holocene climate and glacier variability in the Cordillera Vilcabamba of southern Peru (PP31D-1889)

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1. PROJECT SUMMARY

- Detailed studies of lake and bog sediments that preserve continuous records of environmental change significantly improve our knowledge of the timing and extent of glaciation.
- The main objectives of this project are to:
  1. **reassess the interpretation** that increased clastic sediment flux reflects the advance of local glacier ice in the Peruvian Andes (Figure 2; Rodbell et al., 2008; Stansell et al., 2013),
  2. **develop the first continuous sedimentary archives** of glacier and climate variability in the Cordillera Vilcabamba (13°20'S) of southern Peru,
  3. **supplement the existing ^{10}Be moraine chronology** (Licciardi et al., 2009, 2013) with minimum-limiting basal radiocarbon ages,
  4. **determine if Holocene climate shifts** in the field area are coeval with regional oscillations.
- The close correlation between peaks in clastic flux and composite ^{10}Be chronology in the Vilcabamba range supports that clastic sediment flux can be used as a proxy indicator of regional ice cover.
- Clastic flux records reveal late Holocene glacier advances not preserved in the moraine record.
- Vilcabamba sediment records are consistent with regional paleoclimate oscillations across the Peruvian Andes.
- A cryptotephra dated to 1660 cal yr BP (300 C.E.) present in 5 separate cores is a newly discovered tephra in southern Peru and serves as a chronostratigraphic marker.

Figure 1. Map showing the location of the Cordillera Vilcabamba, along with nearby lake sediment records in the Peruvian Andes and Ecuador (see selected references).

2. BACKGROUND & STUDY LOCATION

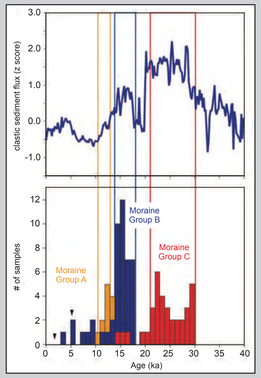


Figure 2. Comparison of stacked record of clastic flux (blue line) with distribution of CRN ages from 3 moraine groups in Peru and Bolivia. Figure from Rodbell et al. (2008).

- No single drainage in the Vilcabamba contains geomorphic evidence for all 5 glacial culminations, reflecting the inherently discontinuous nature of moraine records (Figure 3).
- Records of clastic yield are developed in two separate valleys, and allows the potential to detect regional glacier activity, rather than local or valley-specific climate effects.
- Both valleys offer opportunities to exploit the combination of intercalated bog sediments and moraine sequences.
- Previous lake sediment studies in the tropical Andes have demonstrated the potential for using clastic flux as a proxy indicator of the extent of regional ice cover (Figure 2; e.g., Rodbell et al., 2008; Stansell et al., 2013).
- These studies suggest that times of high clastic yield reflect periods of enhanced erosion by growing glaciers, whereas a decrease in clasticsediment flux reflects ice margin retreat and lower erosion rates (Harbor and Warburton, 1992).
- The work presented here is the first comparison between bog sediment records of clastic sediment flux and precisely-dated moraine positions (Licciardi et al., 2009, 2013) conducted in the same valley system.
- The composite ^{10}Be chronology comprising 115 exposure ages indicates at least 5 discrete glacial culminations during the Lateglacial, early Holocene, Neoglacial, and Little Ice Age throughout the Vilcabamba range (Licciardi et al., 2009, 2013).

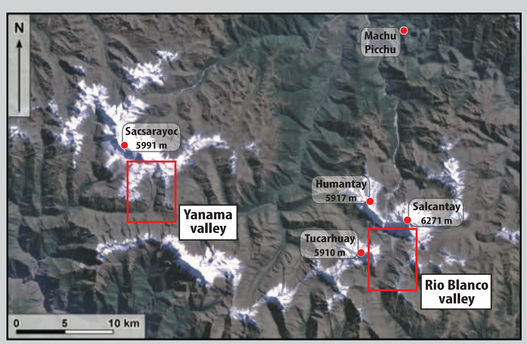


Figure 3. Landsat composite image acquired on June 23, 2000 illustrating the central highlands of the Cordillera Vilcabamba. Red boxes indicate locations of the Yanama and Rio Blanco valley field sites. The four highest peaks and the Machu Picchu sanctuary are labeled with corresponding elevation.

3. FIELD SITES

RIO BLANCO VALLEY

- The Q'enqo Huaylla and Huaylla Pampa bogs are in direct stratigraphic contact with moraines.

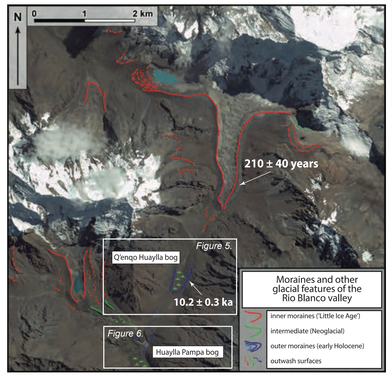


Figure 4. Geomorphic map of the Rio Blanco valley field site with Q'enqo Huaylla and Huaylla Pampa bogs. Solid lines represent moraines mapped and dated by Licciardi et al. (2009, 2013).

Q'enqo Huaylla bog

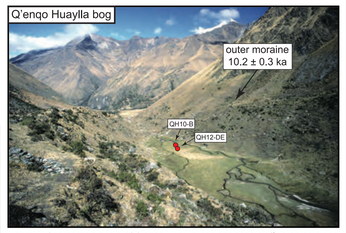


Figure 5. Geomorphic photo of Q'enqo Huaylla bog enclosed by ^{10}Be-dated outer moraine in the Rio Blanco valley. View is looking downvalley. Red circles indicate locations of cores QH10-B and QH12-DE.

Huaylla Pampa bog

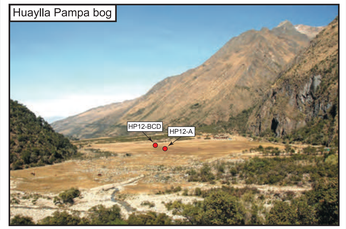
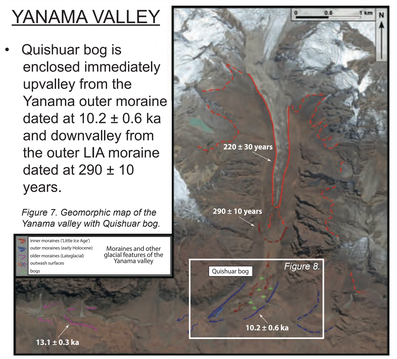


Figure 6. Geomorphic photo of Huaylla Pampa bog located downvalley from an as-yet undated moraine in the Rio Blanco valley. View is looking downvalley. Red circles indicate locations of core HP12-BCD.

YANAMA VALLEY

- Quishuar bog is enclosed immediately upvalley from the Yanama outer moraine dated at 10.2 ± 0.6 ka and downvalley from the outer LIA moraine dated at 290 ± 10 years.

Figure 7. Geomorphic map of the Yanama valley with Quishuar bog.



Quishuar bog

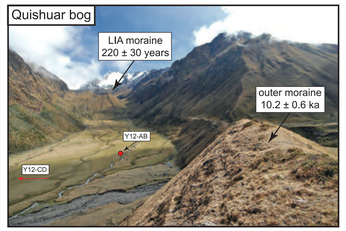


Figure 8. Geomorphic photo of Quishuar bog enclosed by ^{10}Be-dated outer moraine in the Yanama valley. View is looking upvalley towards the LIA moraine. Red circles indicate locations of cores Y12-AB and Y12-CD.

4. METHODS

Figure 9. Extraction of bog cores from Huaylla Pampa bog using a portable modified Livingston coring system.

- Age control is derived from radiocarbon dating of clean charcoal grains. 37 radiocarbon dates were obtained from cores in this study.
- Age-depth models were constructed by fitting the radiocarbon ages and the tephra age with spline functions using the *CLAM v2* code (Blaauw, 2010).
- Carbon measurements, bulk sedimentation rate, biogenic silica, and dry-bulk density are used to calculate clastic sediment flux:

$$Flux_{clastic} = SR * (BD - ((BD*TOM) + (BD*TCC) + (BD*BSiO_2)))$$

SR = bulk sedimentation rate (cm yr^{-1}), BD is the dry-bulk density (g cm^{-3}), TOM is the weight fraction organic matter, TIC is the weight fraction authigenic calcite, and BSiO2 is the weight fraction biogenic silica.

5. RESULTS

CRYPTOTEPHRA

- Prominent peaks in MS profiles (> 30 SI) in 5 cores correspond to the same disseminated cryptotephra across both valley systems.
- An age of 1660 cal yr BP (300 C.E.) was derived from linear interpolation between three pairs of bracketing radiocarbon ages that resulted in the same age (± 20 years) from 3 separate cores.

Figure 10. SEM images of tephra grains from the Rio Blanco valley reveal cuspate and conchoidal features.

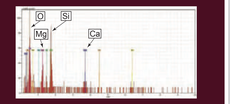


Figure 11. Preliminary EDS data reveals that the dominant compositional elements are Si, O, Ca, and Mg.

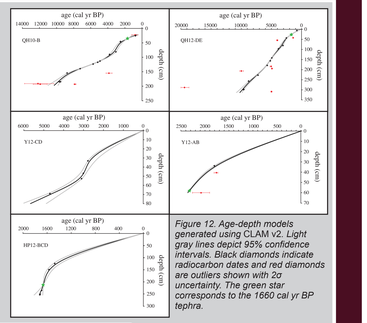
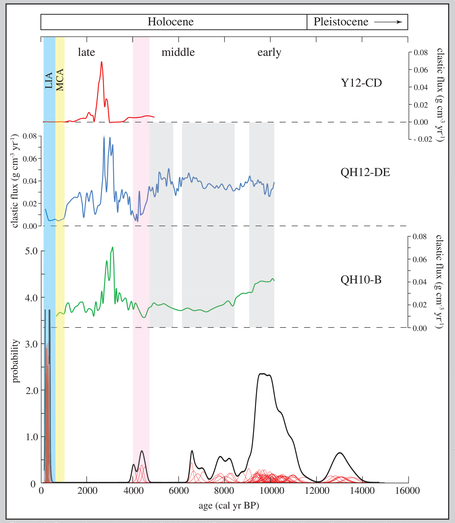


Figure 12. Age-depth models generated using CLAM v2. *Light gray lines depict 95% confidence intervals. Black diamonds indicate radiocarbon dates and red diamonds are outliers shown with 2σ uncertainty. The green star corresponds to the 1660 cal yr BP tephra.*



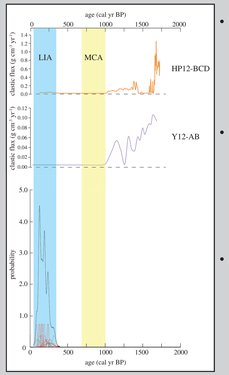


Figure 13. Comparison between the Vilcabamba ^{10}Be chronology (excluding outliers) and sediment core data from Y12-CD, QH12-DE, and QH10-B (top panel) and HP12-BCD and Y12-AB (right panel). Exposure ages are recalculated using a reference ^{10}Be production rate of 3.97 ± 0.09 g^{-1} quartz yr^{-1} (SLHL sea level high latitude production rate of Kelly et al., 2014) and time-invariant St scaling (Lal, 1991; Stone, 2000). 'Camel plots' constructed using MATLAB code of Balco et al. (2011). The Medieval Climate Anomaly (MCA; 1.0 - 0.7 ka) and LIA (0.6 - 0.1 ka) are represented by the yellow and blue panels, respectively.

- Elevated clastic flux concurrent with, or prior to dated moraine positions reflect increased erosion by advancing glaciers (gray panels).
- Abrupt decreases in clastic flux occur following moraine depostion and glacier retreat indicating paraglacial sedimentation is not the primary control on clastic sediment flux.
- Consistent with regional paleoclimate records, clastic flux minima coincide with exceedingly arid conditions ~4.5 to 4.0 ka in the tropical Andes (pink panel).
- The interval of high clastic flux values from ~4.0 - 1.0 ka in both valleys represents a late Holocene advance not preserved in the moraine record.
- Waning clastic input until ~1.0 ka reflects ice retreat at the end of the Neoglacial. All records exhibit near-zero values of clastic flux coincident with warm and dry conditions during the MCA.
- The expression of the LIA is modest in the sediment record, suggesting that basin-specific factors influenced clastic input values during this episode.

6. CONCLUSIONS

- The close correlation that exists between peaks in clastic sediment flux and the composite ^{10}Be chronology indicate that changes in the extent of local glacier ice represent the the primary control on clastic sedimentation. Small offsets in timing of clastic flux in different valleys likely reflects natural geomorphic variability (i.e., glacier and catchment hypsometry, catchment size, bog surface structures) and age control uncertainites.
- The continuous sedimentary archives developed here are the first in the Vilcabamba range and reveal late Holocene glacier advances (~4.0 - 1.0 ka) not preserved in the moraine record.
- A cryptotephra dated to 1660 cal yr BP (300 C.E.) represents a newly discovered tephra layer that has the potential to serve as a regional chronostratigraphic marker across southern Peru. Future work includes SEM imaging and electron microprobe analyses to charcterize the morphology, minerology, and geochemistry, which may help to ultimately identify the source volcano.

7. SELECTED REFERENCES

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