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Collaborative Research: Timing and Structure of the Last Glacial Maximum and Termination in Southern Peru: Implications for the Role of the Tropics in Climate Change

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Preview of Award 1003471 - Final Project Report

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Cover

Federal Agency and Organization Element to Which Report is Submitted:	4900
Federal Grant or Other Identifying Number Assigned by Agency:	1003471
Project Title:	Collaborative Research: Timing and structure of the last glacial maximum and termination in southern Peru: Implications for the role of the tropics in climate change
PD/PI Name:	Brenda L Hall, Principal Investigator
Recipient Organization:	University of Maine
Project/Grant Period:	10/01/2010 - 09/30/2014
Reporting Period:	10/01/2013 - 09/30/2014
Submitting Official (if other than PD\PI):	Brenda L Hall Principal Investigator
Submission Date:	10/27/2014
Signature of Submitting Official (signature shall be submitted in accordance with agency specific instructions)	Brenda L Hall

Accomplishments

* What are the major goals of the project?

The role of the tropics in abrupt climate change and ice-age cycles, remains poorly understood. The goal of this project was to develop a well-dated chronology of glacial fluctuations from the last glacial maximum (LGM) through the

deglacial period in the eastern and western Cordillera in southern Peru. We then used this chronology to assess the relationships between tropical climate and locations elsewhere in the world to gain insight into the mechanisms behind climate change. Our work consisted of detailed glacial geologic mapping of moraine sets at a scale of 1:50,000 or better; precise cosmogenic surface-exposure age dating (^3He and ^{10}Be) of carefully selected boulders from moraine crests and drift edges across bedrock surfaces; and calculation of former snowline depression.

*** What was accomplished under these goals (you must provide information for at least one of the 4 categories below)?**

Major Activities:

Over the course of this investigation, we have conducted detailed field mapping of glacial deposits and landforms at three main locations: Nevado Coropuna (Western Cordillera); Laguna Aricoma (Eastern Cordillera); and Minas Tira (Eastern Cordillera). This work has then formed the basis for making snowline reconstructions and high-resolution moraine chronologies for each site, in order to (i) determine the timing and magnitude of late Quaternary climate change in the tropical Andes and (ii) compare and contrast glacier/climate response to these events in starkly different (arid vs. humid) environments. Specifically, we have collected a large number of samples for surface-exposure dating, including 120 for ^{10}Be and upward of 500 for ^3He . We have also sampled approximately 20 sediment cores and sections for stratigraphy and radiocarbon dating, in order to augment the surface-exposure chronologies. While the principal focus of this chronologic work has been and remains the period from the LGM to the onset of the Holocene, we also investigated earlier (e.g., MIS-6) and later (Holocene) sections of the record with a view to developing further palaeoclimate research.

As a key component of this project, we have reconstructed LGM snowlines for the Nevado Coropuna (Western Cordillera) region and the Aricoma (Eastern Cordillera) region. Following the LGM, we have also made reconstructions for the tropical termination in order to assess patterns, rates, and magnitudes of climate warming during the end of the last ice age. In addition to glacier chronology, our project has involved the pursuit of high-altitude, low-latitude production-rate calibration sites for cosmogenic nuclides. We continue to develop such a site at Mina Arcata, a late-glacial lava flow located at ~4500 m elevation and approximately 70 km north of Nevado Coropuna. Moreover, this investigation has spurred the refinement of the cosmogenic ^3He surface-exposure method at Lamont-Doherty Earth Observatory (LDEO), resulting in a new procedure for sample preparation that was published in *Quaternary Geochronology* earlier this year.

Five undergraduate and graduate students, from both UMaine and Pacific Lutheran University, have been directly involved in fieldwork associated with this project. In addition, we have forged an ongoing collaboration with Peruvian NGO "AEDES" (Asociación Especializada para el Desarrollo Sostenible), resulting in joint field seasons, data sharing, and collaborative pursuit of common scientific objectives. For example, in 2012 we submitted a successful joint proposal with AEDES to the USAID-NSF "PEER" program, while more recently, project postdoc Bromley has developed new research in association with AEDES. As described in the original proposal, our palaeoclimate work is closely related to the ongoing archaeological investigation into the peopling of the high Andes during the terminal Pleistocene. That relationship continues and resulted recently in the production of an outreach video developed through LDEO (<http://www.ldeo.columbia.edu/news-events/climate-peruvian-andes-early-humans-modern-challenges>). Other outreach activities have included the posting of research blogs (e.g., <http://blogs.ei.columbia.edu/2011/06/17/to-the-tip-of-the-andes/>), public presentations in Peru and Colombia, and the incorporation of research and findings into classes at UMaine, PLU, and LDEO, science programs at regional schools

(e.g., Maine School of Science and Mathematics), and both Belfast and Penobscot Senior Colleges.

Specific Objectives: Our investigation has resulted in one of the highest-resolution glacier chronologies for the tropical latitudes. Furthermore, it has led to the refinement of the ^3He surface-exposure method, which will be of considerable benefit to future users of this approach. **Significant Results:** Specific findings of the project include:

- At least three glacial cycles are represented by the stratigraphic record at Nevado Coropuna, while the distribution of respective deposits suggests regional snowline has become progressively higher over the course of these events.
- The LGM was achieved simultaneously in both the arid Western Cordillera and humid Eastern Cordillera and was synchronous with global events, not anomalously early or late as has been suggested. Moreover, the magnitude of LGM cooling relative to the late Holocene was broadly consistent with global values for snowline depression, indicating a potentially fundamental role for greenhouse gases and/or tropical ocean temperatures in driving globally uniform ice ages.
- Our deglacial chronology indicates that in both arid and humid tropical sites, the termination began shortly after ~19,000 yrs and that major deglaciation subsequently coincided with Heinrich Stadial 1 and the rise of large palaeolakes on the Peruvian-Bolivian Altiplano. Thus, tropical glaciers in starkly different environments are most responsive to temperature, then as now. Our chronology also indicates that glaciers in both regions had lost approximately half of their ice-age extent by ~16,000 yrs, whereupon the first of two late-glacial advances occurred. The second readvance to interrupt deglaciation occurred ~14,000 yrs. The widespread nature of this pattern is indicated by its occurrence both in the Western and Eastern Cordilleras.
- The addition of an HF-leaching step to the preparation of pyroxenes for ^3He surface-exposure dating significantly improves the method. Owing to the removal of impurities by this step, signal-to-weight ratios improve considerably resulting in more realistic age determinations. Furthermore, acid digestion of the outer layers of phenocrysts removes considerable amounts of injected ^4He (a product of U-Th decay) that otherwise can complicate corrections for magmatic helium and undermine precision. Our new procedure also streamlines the preparation process, resulting in greater sample yields in less time.

Key outcomes or
Other achievements:

*** What opportunities for training and professional development has the project provided?**

This work provided opportunities for five undergraduate students, a graduate student, and a postdoc to gain field experience in Peru. This work also provided substantial postdoctoral mentoring on skills, such as planning and executing a field and laboratory program, applying for regular faculty positions, and writing papers and grant proposals.

*** How have the results been disseminated to communities of interest?**

Results have been disseminated both to the international scientific community (i.e., at meetings such as GSA, Comer Abrupt Climate Change Conference), to students and faculty at universities (i.e., talks at Colby College and Woods Hole Oceanographic Institute), and local scientists and NGOs in Peru (i.e., AEDES: Asociación Especializada para el Desarrollo Sostenible in Ariquepa, Peru).

Products

Books

Book Chapters

Rademaker, K., Reid, D.A., Bromley, G.R.M. (2012). Connecting the Dots: Least-Cost Analysis, Paleogeography, and the Search for Palaeoindian Sites in Southern Highland Peru.. *Least Cost Analysis of Social Landscapes: Archaeological Case Studies* D.A. White and S. Surface-Evans (eds.). University of Utah. . Status = PUBLISHED; Acknowledgement of Federal Support = Yes ; Peer Reviewed = Yes

Conference Papers and Presentations

Bromley, G., Joerg M. Schaefer, Gisela Winckler, Brenda L. Hall, Claire E. Todd, Kurt M. Rademaker (2012). *A glacial record of the last termination in the southern tropical Andes [abstract]*. American Geophysical Union. San Francisco. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Bromley, G., Hall, B., Schaefer, J., Winckler, G., Rademaker, K., Todd, C. (2010). *A late-glacial advance in the arid tropical Andes: Cosmogenic He-3 data from Nevado Coropuna, Peru. [abstract]*. Geological Society of America Annual Meeting. Denver, Colorado.. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Inventions

Journals

Bromley, G.R.M., Hall, B.L., Rademaker, K.M., Todd, C.E., Racoviteanu, A.E. (2011). Late Pleistocene snowline fluctuations at Nevado Coropuna (15°S), southern Peruvian Andes.. *Journal of Quaternary Science*. 26 305. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Bromley, G.R.M., Hall, B.L., Schaefer, J.M., Winckler, G., Todd, C.E., Rademaker, K.M. (2011). Glacier fluctuations in the southern Peruvian Andes during the late-glacial period, constrained with cosmogenic ³He.. *Journal of Quaternary Science*. 26 37. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Bromley, G.R.M., Winckler, G., Schaefer, J.M., Kaplan, M., Licht, K., Hall, B.L. (2014). Pyroxene separation by HF leaching and its impact on helium surface-exposure dating.. *Quaternary Geochronology*. 23 1. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Licenses

Other Products

Databases.

Pointers to the data from this project can be found in the Global Change Master Directory:

EntryID: Nevado_Coropuna_Surface_Exposure_Age_Data

http://gcmd.nasa.gov/getdif.htm?Nevado_Coropuna_Surface_Exposure_Age_Data

and

EntryID: Nevado_Coropuna_Glacial_Maps

http://gcmd.nasa.gov/getdif.htm?Nevado_Coropuna_Glacial_Maps

These data also can be found on our website:

<http://umaine.edu/earthclimate/faculty-staff/faculty-and-staff/brenda-hall/glacial-geology-and-geochronology-research-group/data/>

Other Publications

Patents**Technologies or Techniques****Thesis/Dissertations****Websites****Participants/Organizations****What individuals have worked on the project?**

Name	Most Senior Project Role	Nearest Person Month Worked
Hall, Brenda	PD/PI	1
Bromley, Gordon	Postdoctoral (scholar, fellow or other postdoctoral position)	12
Braddock, Scott	Graduate Student (research assistant)	1
Hegland, Matthew	Undergraduate Student	1
Koehler, Matthew	Undergraduate Student	1
Reid, David	Undergraduate Student	1
Schmitt, Matt	Undergraduate Student	1
Strand, Peter	Undergraduate Student	1

Full details of individuals who have worked on the project:**Brenda L Hall****Email:** Brendah@Maine.Edu**Most Senior Project Role:** PD/PI**Nearest Person Month Worked:** 1

Contribution to the Project: Hall mentored postdoctoral researcher Bromley and oversaw the completion of the project. She also participated in preparation of manuscripts.

Funding Support: 1 mo. NSF support

International Collaboration: No

International Travel: No

Gordon Bromley**Email:** gordon.r.bromley1@maine.edu**Most Senior Project Role:** Postdoctoral (scholar, fellow or other postdoctoral position)**Nearest Person Month Worked:** 12

Contribution to the Project: Gordon is the postdoc on this project. He has carried out field work, prepared

samples for cosmogenic dating, interpreted and written up results, and mentored graduate students.

Funding Support: Gordon was funded for 18 months on this grant, with the remainder being funded by a research fellowship at Columbia University.

International Collaboration: Yes, Peru

International Travel: Yes, Peru - 0 years, 4 months, 0 days

Scott Braddock

Email: scott.braddock@maine.edu

Most Senior Project Role: Graduate Student (research assistant)

Nearest Person Month Worked: 1

Contribution to the Project: Scott participated in field work and will be helping to prepare samples for cosmogenic dating.

Funding Support: Internal grant, non-NSF

International Collaboration: No

International Travel: Yes, Peru - 0 years, 1 months, 0 days

Matthew Hegland

Email: heglanmk@plu.edu

Most Senior Project Role: Undergraduate Student

Nearest Person Month Worked: 1

Contribution to the Project: Matthew participated in field work.

Funding Support: Funding from Pacific Lutheran University

International Collaboration: No

International Travel: Yes, Peru - 0 years, 1 months, 0 days

Matthew Koehler

Email: matthew.koehler@maine.edu

Most Senior Project Role: Undergraduate Student

Nearest Person Month Worked: 1

Contribution to the Project: Matthew Koehler participated in field work.

Funding Support: Internal funding, non-NSF.

International Collaboration: No

International Travel: Yes, Peru - 0 years, 1 months, 0 days

David Reid

Email: dreid5@uic.edu

Most Senior Project Role: Undergraduate Student

Nearest Person Month Worked: 1

Contribution to the Project: David Reid participated in field work.

Funding Support: Internal grant, non-NSF.

International Collaboration: No

International Travel: Yes, Peru - 0 years, 1 months, 0 days

Matt Schmitt

Email: schmittm@plu.edu

Most Senior Project Role: Undergraduate Student

Nearest Person Month Worked: 1

Contribution to the Project: Matt participated in field work.

Funding Support: Pacific Lutheran University

International Collaboration: No

International Travel: Yes, Peru - 0 years, 1 months, 0 days

Peter Strand

Email: Peter.strand@maine.edu

Most Senior Project Role: Undergraduate Student

Nearest Person Month Worked: 1

Contribution to the Project: This person participated in field work.

Funding Support: This grant.

International Collaboration: No

International Travel: Yes, Peru - 0 years, 1 months, 0 days

What other organizations have been involved as partners?

Name	Type of Partner Organization	Location
Asociación Especializada Para El Desarrol Sostenible	Other Nonprofits	Arequipa, Peru
Autoridad Nacional del Agua (ANA), Lima, Peru: Jose Ubeda.	State or Local Government	Lima, Peru
Lamont-Doherty Earth Observatory	Academic Institution	New York
Pacific Lutheran University	Academic Institution	Tacoma, WA

Full details of organizations that have been involved as partners:

Asociación Especializada Para El Desarrol Sostenible

Organization Type: Other Nonprofits

Organization Location: Arequipa, Peru

Partner's Contribution to the Project:

Facilities

Collaborative Research

More Detail on Partner and Contribution: We are collaborating with AEDES (Asociación Especializada Para El Desarrollo Sostenible), a not-for-profit organisation working to assess the impacts of climate change on land use and hydrology in the Coropuna region and to develop viable mitigation/adaptation strategies for highland communities (<http://www.aedes.com.pe/>). AEDES glaciologist, Tomás Quispe, joined us in the field for the second year running to (i) participate in our field work and (ii) prepare jointly a proposal for future funding aimed at assessing effects of ongoing climate change on water-resource viability in southern Peru.

Autoridad Nacional del Agua (ANA), Lima, Peru: Jose Ubeda.

Organization Type: State or Local Government

Organization Location: Lima, Peru

Partner's Contribution to the Project:

In-Kind Support

Collaborative Research

More Detail on Partner and Contribution:

Lamont-Doherty Earth Observatory

Organization Type: Academic Institution

Organization Location: New York

Partner's Contribution to the Project:

In-Kind Support

Facilities

Collaborative Research

More Detail on Partner and Contribution: This is a collaborative proposal with Lamont. They are producing and helping to interpret the cosmogenic dates.

Pacific Lutheran University

Organization Type: Academic Institution

Organization Location: Tacoma, WA

Partner's Contribution to the Project:

Collaborative Research

More Detail on Partner and Contribution: Claire Todd and her students have participated both in field and lab work related to this project.

What other collaborators or contacts have been involved?

NO

Impacts

What is the impact on the development of the principal discipline(s) of the project?

Our investigation in the Andes of southern Peru has sought to provide robust geologic constraint of the full capacity of the tropical climate for change, focusing on the single greatest natural climate event of the last ~100,000 yrs: the last glacial-interglacial transition. Our work at Nevado Coropuna, Laguna Aricoma, and Minas Tira has demonstrated (i) that the tropics have experienced high-magnitude ice-age cycles in step with global events and (ii) that short-lived, potentially abrupt perturbations are an inherent characteristic of tropical regions, as they are of higher latitudes. Together with the absence of significant insolation variability at these latitudes, our findings suggest that either greenhouse gases or tropical ocean temperatures play a driving role in tropical climate on all timescales.

What is the impact on other disciplines?

The tropics comprise almost 50% of the Earth's surface, and are home to more than a third of the global population as well as much of its biodiversity. As the energetic powerhouse of the globe, the tropics are the principal source of both heat energy and water vapour for the climate system, and thus play a potentially key role in propagating climate perturbations. Our work has contributed to a better understanding to the pattern and mechanisms behind tropical climate change, which has implications for a wide range of disciplines, particularly ecology. Moreover, our work contributed to an understanding of glacial history in the Coropuna region, which provide important background information for a recent study published in Science on the peopling of the High Andes in late Pleistocene time.

What is the impact on the development of human resources?

This work resulted in the training of students and of a postdoctoral researcher. Several of the undergraduate students have continued on to graduate work. The postdoctoral researcher is a sabbatical replacement at present and is interviewing for full-time academic positions.

What is the impact on physical resources that form infrastructure?

Nothing to report.

What is the impact on institutional resources that form infrastructure?

Nothing to report.

What is the impact on information resources that form infrastructure?

Nothing to report.

What is the impact on technology transfer?

This work led to the development of a new method of cleaning pyroxene that results in more accurate ^3He age analyses. This method is likely to come into widespread use in the future.

What is the impact on society beyond science and technology?

The tropics comprise almost 50% of the Earth's surface, and are home to more than a third of the global population. Tropical glaciers, particularly in the Andes, afford a significant source of water for drinking, irrigation, and hydropower. An understanding of the mechanisms behind tropical glacier fluctuations has significance for future predictions of water resources.

Changes/Problems

Changes in approach and reason for change

Nothing to report.

Actual or Anticipated problems or delays and actions or plans to resolve them

Nothing to report.

Changes that have a significant impact on expenditures

Nothing to report.

Significant changes in use or care of human subjects

Nothing to report.

Significant changes in use or care of vertebrate animals

Nothing to report.

Significant changes in use or care of biohazards

Nothing to report.