KECK GEOLOGY CONSORTIUM

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

April 2012
Amherst College, Amherst, MA

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ISSN# 1528-7491

The Consortium Colleges The National Science Foundation ExxonMobil Corporation

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Funding Provided by:
Keck Geology Consortium Member Institutions
The National Science Foundation Grant NSF-REU 1005122
ExxonMobil Corporation

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GLACIAL LACUSTRINE RECORDS OF CLIMATE VARIATION IN THE TROPICAL PERUVIAN ANDES

SASHA ROTHENBERG, Union College
Research Advisor: Donald Rodbell

INTRODUCTION

Glaciers respond to climatic changes that affect their mass balance by either increasing or decreasing ice accumulation. Because of this, past glaciation has commonly been used as a record of regional and global climate patterns. Glacial erosion processes produce large amounts of fine-grained sediments that can be deposited in lakes. Therefore, sediment cores taken from glacial lakes offer important records of climate variation because they can provide a continuous record of glaciation (Stansell et al., 2005; Polissar et al., 2006; Rodbell et al., 2008). Alpine glaciers are especially sensitive to changes in precipitation and temperature so they make excellent proxies for climate reconstruction (Hall et al, 2009).
It can be difficult to find lakes with fast sedimentation rates that can produce high-resolution cores but the intermontane basins in the Peruvian Andes have potential to provide a long continuous record (Hooghiemstra and Sarmiento, 1991). Another complication in using lacustrine sediment from glacial lakes as a record of climate variability is that alpine glaciers respond closely to both temperature and precipitation variation, which do not always fluctuate together (Luckman, 2000). The reconstruction of past climates requires a differentiation between changes in these two variables affecting glaciation. Although early climate change research focused on the Northern Hemisphere because of its driving forces in global circulation, recent studies have found the tropics to also play a significant role (Fritz et al., 2004; Rodbell et al., 2009). In particular, the tropical hydrologic cycle has been found to affect atmospheric trace gases and global climate change and the South American tropics are important to the tropical climate system (Seltzer et al., 2000). Owing to steep east-to-west moisture gradients across the Andes, glaciers in the eastern cordillera are more sensitive to changes in temperature whereas those in the drier, western, cordillera are more sensitive to changes in precipitation (Rodbell et al. 2009). This study focuses on the tropical Peruvian Andes and uses sediment cores to interpret changes in glacial extent.

OBJECTIVES

The objective of this study is to delineate a continuous record of Holocene glaciation in the tropical Andes across a moisture gradient to differentiate between changes in precipitation and temperature. Glaciation is interpreted by measuring three sedimentologic properties: magnetic susceptibility, bulk density, and organic carbon content. The sedimentologic records are compared to stable oxygen isotope records from the region to further interpret relative changes in precipitation and temperature.

METHODS

Multiple lacustrine sediment cores were taken from two sites in the central Peruvian Andes in June 2011 using a Livingstone piston corer: one in the wet, eastern cordillera and one in the dry, western cordillera. All of the cores were split, digitally photographed, and physically described at Union College in Schenectady, NY. They were then measured for magnetic susceptibility (MS) using a Bartington MS2 meter, then sampled, at least every 5 cm, or more depending on stratigraphy, and freeze dried to measure dry bulk density.

To calculate total organic carbon (TOC), samples were run first through a CM 2500 Autosampler Furnace, measuring total carbon (TC) by combustion at 1000^{o}C to convert all forms of carbon into carbon dioxide that was then measured with a UIC coulometer. Samples were then run through a CM 5230 TIC to measure total inorganic carbon by measuring carbon dioxide released after acidification (TIC). TOC was then calculated by subtracting TIC from TC. All MS, bulk density, and TOC data were plotted using DeltaGraph.

To date the records, organic materials (mostly charcoal) were sampled from cores and rinsed. These samples were then radiocarbon dated at the Keck Carbon Cycle AMS Facility, UC Irvine. The radiocarbon ages were converted to calibrated calendar years using CALIB 4.0, reporting ages in years before present (BP) where present is 1950 AD. An age-depth model was created for Laguna Yanacocha.

DATA AND INTERPRETATION

Between the two sites sediment cores were extracted from five bogs and one lake. In the eastern cordillera, Laguna Yanacocha (10.558°S, 75.927°W; 4358 m asl) yielded an ~2.6 meter-long sediment core with a minimum age of 13733 (+189,-173) BP. The MS plots show two significant declines indicating a two-step deglaciation: the first from 14,000-13,000 BP and the second from 8000 BP-present (Fig. 1). The bulk density drops while TOC increases at the same time as the second decline in MS. This shows that after the second deglaciation there has been little ice advance and the lake is undergoing eutrophication in the absence of clastic sediment input (Rodbell, 2009). Since Laguna Yanacocha was the best dated core, its sedimentologic record was compared to the $\delta^{18}O_{precipitation}$ record obtained from authogenic calcite preserved in nearby Laguna Pumacocha (Fig. 1) (Bird et al., 2011). The $\delta^{18}O_{precip}$ record shows a period of rapidly increasing aridity or temperature from 11000-10000 BP, followed by a very gradual increase in precipitation/decrease in temperature through the rest of the Holocene (Bird et al, 2011). The period of either drier or warmer conditions peaks roughly 1000 years before the final deglaciation shown in Laguna Yanacocha, indicating a lagged glacial response, but still a

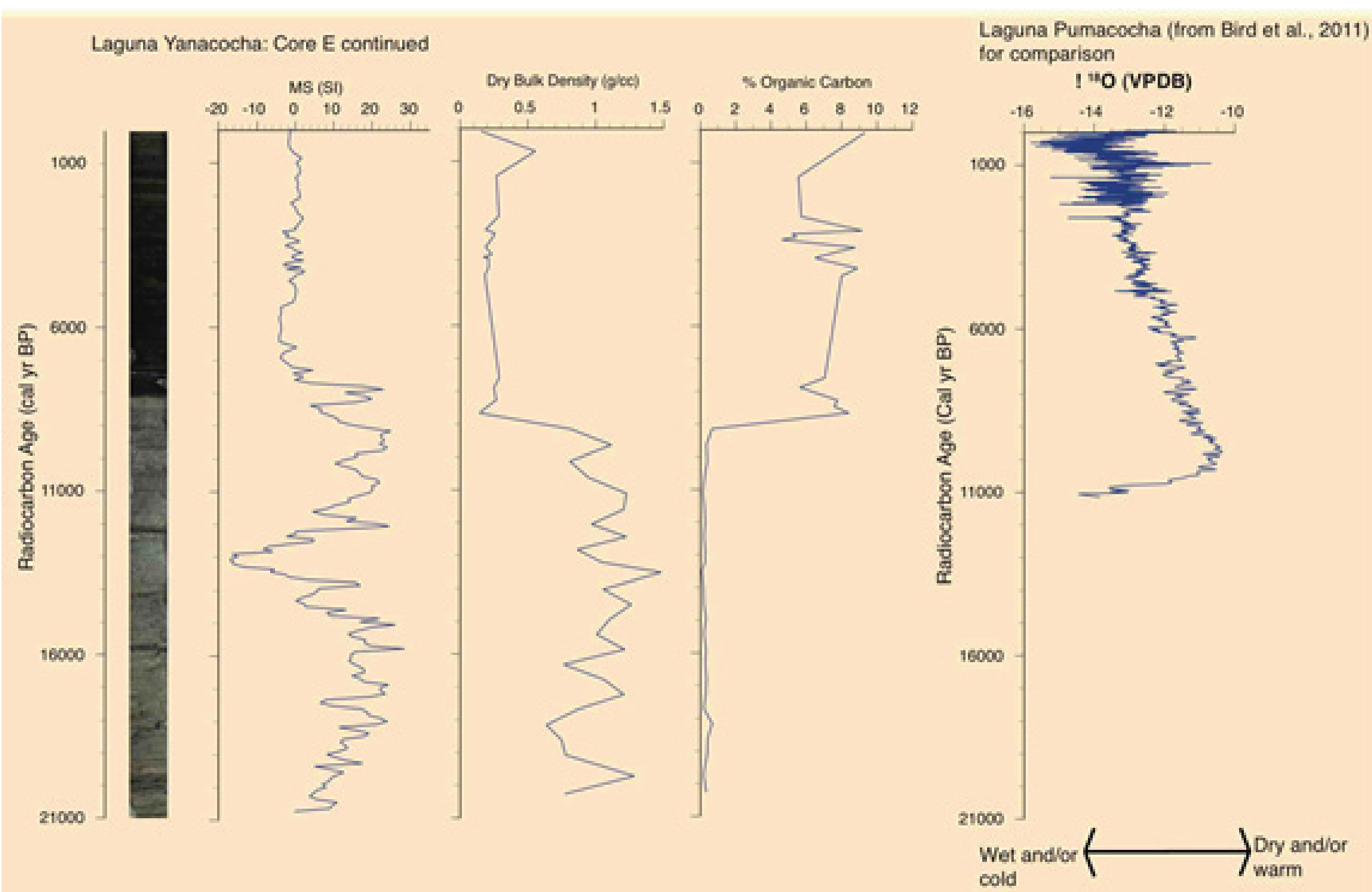

Figure 1. Digital photograph and downcore plot of radiocarbon age versus magnetic susceptibility, dry bulk density, and TOC(%) of the core extracted from Laguna Yanacocha. For comparison $\delta^{18}O_{precip}$ from authogenic calcite preserved in Laguna Pumacocha are plotted on the same radiocarbon age scale.

response to this change in conditions.

Two ~4.8 meter-long cores were taken from Jaico Bog revealed an age of 10336 (+48,-67) BP and little significant variation in MS, bulk density, or TOC. The old basal age of this bog spans the entire Holocene suggesting little glacial advance in the region and an old minimum age of deglaciation. Two cores from Yanacocha Bog show a gradual downcore increase in MS and bulk density as well as decrease in TOC and had a minimum age of 2870 (+53,-64).

In the western cordillera an ~6.7 meter-long core was taken from the upper end of Laguna Shiurococha (11.905°S, 75.960°W; 4585 m asl) that records more than 3550 years of sedimentation. This core reveals a sharp decline in glacigenic sedimentation around 3550 BP, with very little glacial input thereafter. The Side Valley Bog cores show a minimum age of deglaciation to be 2995 (+69,-45) BP. The two bogs are up valley from each other so the close timing of the formation of the Side Valley Bog and the cut off of glacigenic sediment from Shiurococha Upper End Bog suggests a large glacial retreat at this time. The North Side Valley Bog is on the opposite side of Laguna Shiurococha and has received little to no glacial input for at least 10213 (+13,-13) BP.

The large range in basal ages of these cores, from both the eastern and western cordillera, has been correlated to the head wall elevation of the inputting glacier (Fig. 2). The plotting of this relationship shows the minimum age of deglaciation at low-elevation sites to be between 14000-10000 BP, while it is only 3500-2500 for high elevation sites. This not only reveals a late Holocene neoglaciation of higher elevation glaciers in both cordillera, but also suggests an early to middle Holocene interval of dry and/or warm conditions that caused reduced ice cover.

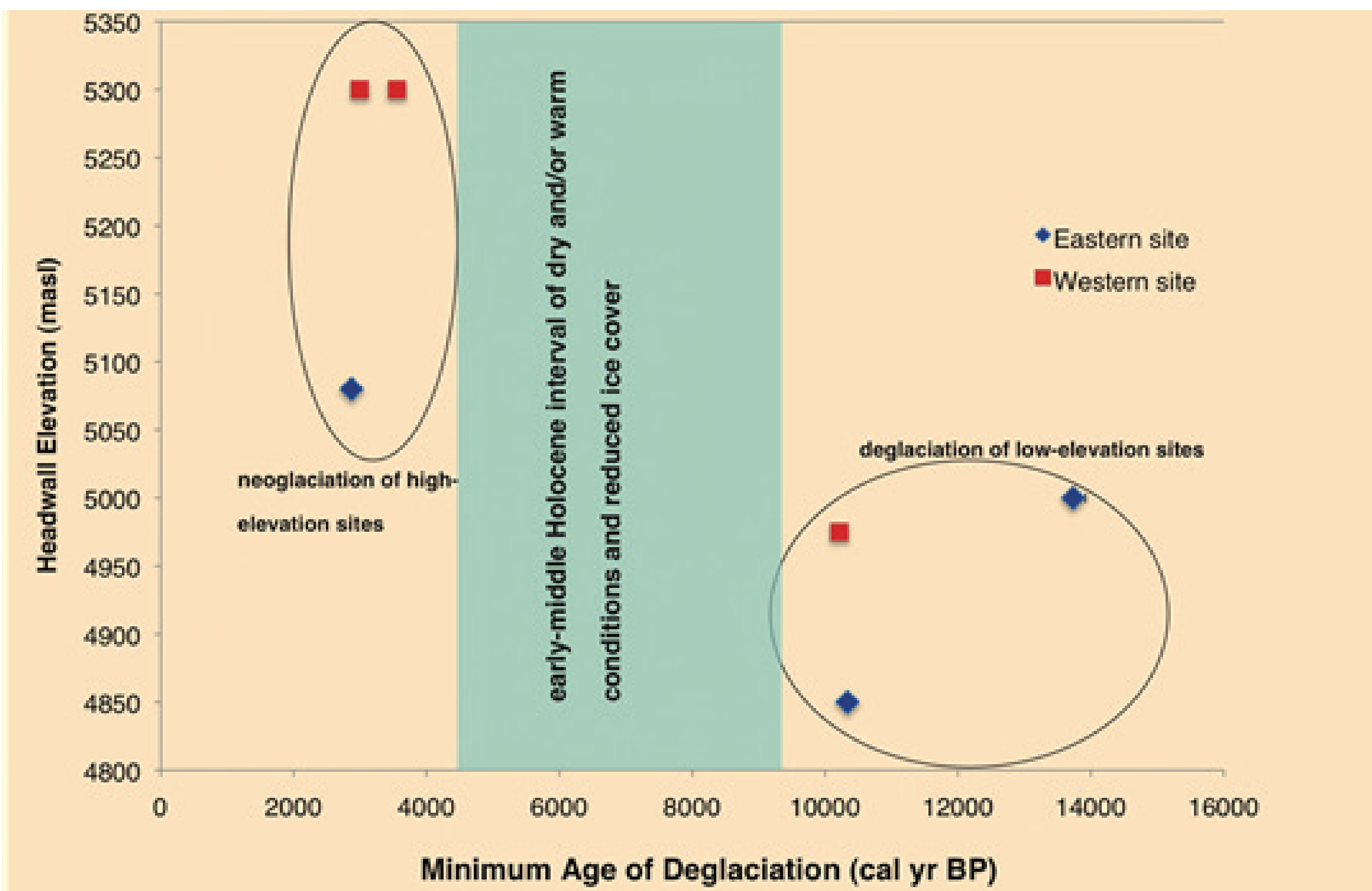

Figure 2. Plot of minimum age for deglaciation from lakes and wetlands in both study sites versus glacier headwall elevation. Data suggests an interval of reduced ice extent during the early-middle Holocene.

Laguna Yanacocha, which showed little glacial input throughout the Holocene, is less than 1.0 km horizontally from the modern ice limit. This indicates that any Holocene ice advance in the eastern site must have been minimal. Shiurococha Upper End Bog sits more than 2.0 km horizontally from the modern ice limit and was receiving significant glacial input in the late Holocene. Although there is evidence of neoglaciation at both sites, a comparison of its magnitude on the eastern versus the western cordillera shows a much greater ice advance in the western cordillera. Since this region is generally much drier, its glaciers are highly sensitive to increases in precipitation because it is the main restricting factor. Therefore, this difference in ice extent during late Holocene glaciation suggests that it was caused by an increase in precipitation. This hypotheses is also be supported by the depleted $\delta^{18}O_{precip}$ values from Laguna Pumacocha.

CONCLUSION

The results of this study have supported previous evidence that the central Peruvian Andes experienced a dry and/or warm period in the early Holocene causing glacial retreat in both the eastern and western cordillera. The lack of glaciation throughout the entire region during the middle Holocene suggests a period of minimum ice cover followed by a neoglaciation. This glacier expansion must have been brought on by an onset of cooler temperatures or increased precipitation, which is also shown in the gradual depletion of $\delta^{18}O_{precip}$ values from Laguna Pumacocha. Since the ice extent was much greater during glacier advance on the western cordillera compared to the eastern cordillera, the climatic forcing was most likely due to an increase in precipitation.

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