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

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Keck Geology Consortium: Projects 2011-2012
Short Contributions— Peruvian Glaciers Project

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TROPICAL HOLOCENE CLIMATIC INSIGHTS FROM RECORDS OF VARIABILITY IN ANDEAN PALEOGLACIERS

DONALD T. RODBELL, Union College
NATHAN STANSELL, Byrd Polar Research Center, Ohio State University

INTRODUCTION

The overarching goal of the larger project is to generate continuous, centennial to millennial-scale records of mountain glaciation in Peru (Fig. 1) spanning the Holocene (~12 ka to present) that can be used to test hypotheses concerning the causes of abrupt climate change in the tropics.

Mountain glaciers are one of the best recorders of atmospheric change over the continents, and numerous workers have highlighted the importance of glacial deposits in tropical paleoclimate studies (Porter, 2001; Mark and Seltzer, 2005; Polissar et al., 2006b; Rodbell et al., 2009; Hastenrath, 2009; Licciardi et al., 2009). Glaciers are also an important water resource in the tropics, and documenting the timing and causes of past variability is needed to predict future runoff changes (Mark and McKenzie, 2007). Studies of ice volume change in the tropics, the heat engine of Earth, provide useful information about past shifts in atmospheric water vapor content (Broecker, 1997), and such studies are important for understanding the role of the low latitude hydrologic cycle in modulating global temperature and moisture-balance fluctuations (Seager et al., 2000). However, these studies are currently confounded by a discontinuous record of Holocene glacial variability in the tropical Andes, one that is only broadly defined: restricted ice cover early in the Holocene, followed by a regionally complicated glacial history during the middle and late Holocene (e.g., Rodbell et al., 2009).

Figure 1. Location of western and eastern study sites in central Peru.

While there are no current studies on modern sediment yields in glaciated catchments in the tropical Andes, climate and topographic conditions suggest that rates could be relatively high and closely related to climate-mediated glacier mass balance changes. Given a homogeneous temperature regime, tropical glaciers are highly sensitive to moisture related fluxes and variables such as accumulation, albedo, cloudiness, atmospheric long wave emission, and sublimation (Kaser et al., 2003; Vuille et al., 2008). Tropical Andean glaciers are warm-based, have strong vertical mass balance gradients, and are marked by year-round ablation (Kaser, 2001). Seasonally, maximum rates of ablation are coincident with maximum accumulation, as melt rates increase 30% in the wet season (Kaser et al., 1990). With high annual precipitation, mass turnover is sizeable and glaciers have short response times to changes in net balance, as demonstrated by the synchrony of hydrologically-derived mass balance with observations of terminus positions (Kaser et al., 2003). Variations in glacial flour flux should, therefore, closely correspond to variations in ice extent with a lag time of less than a few years.

There is evidence of multiple glacial advances and retreats in the southern tropical Andes during the Holocene (Röthlisberger, 1986; Seltzer, 1990; Seltzer, 1992; Rodbell, 1993), but well-dated records of Holocene mountain glaciation from this region are still few and far between. Most catchments in the Central Andes were ice free for much of the early Holocene (10,000 to 6,000 cal yr BP), and many workers have attributed this to widespread early Holocene aridity (Abbott et al., 2003). However, the early Holocene may not have been entirely devoid of glacial activity. Rodbell (1993) reported minimum-limiting radiocarbon ages for moraines near cirques in central Peru between 9000 and 7000 cal yr BP, and Seltzer (1992) reported similar minimum ages for moraines in northern Bolivia. Without corresponding maximum-bracketing ages, however, it is not known whether these minimum-limiting ages are simply young minima for Late Glacial moraines or truly date early Holocene advance(s). It is important to note that the early Holocene globally has been a time interval that has prompted much debate among glacial geologists (e.g., Porter, 2000) as there is a dearth of moraines anywhere that have been sufficiently dated to demonstrably show that they both post date the Late Glacial and predate the Neoglacial. The increasing application of cosmogenic radionuclide (CRN) dating to moraines

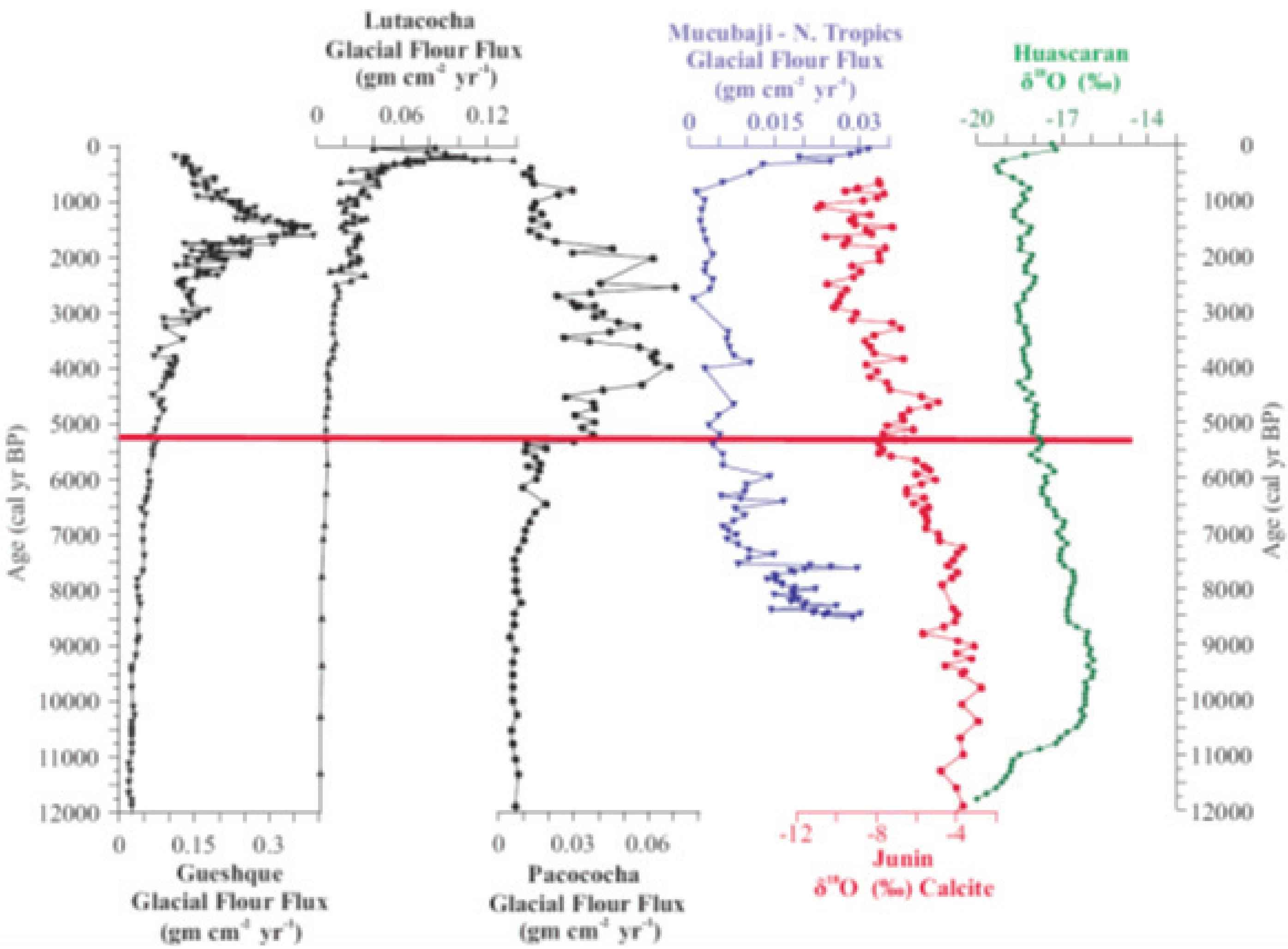

Figure 2. Downcore variations in glacial flour flux from tropical Andean glacier lakes plotted versus the Lake Junin (Fig. 1) record of moisture-balance change and the Huascaran oxygen isotope record. The Mucubaji data are from the Northern tropical Andes of Venezuela (data from Stansell et al., 2005). The red line marks the onset of neoglaciation in the Central Andes that likely coincides with increased moisture availability (more depleted isotope values in Lake Junin). The northern tropical record (Mucubaji) shows a markedly greater flour flux during the early Holocene than any of the Peruvian records. The Holocene pattern of glaciation in the Peruvian records was likely driven mostly by increased moisture flux, punctuated by millennial-scale periods of colder conditions. The varied response among the Peruvian records may reflect the location of the lakes in question along the existing steep moisture gradients, which predisposed the glaciers at these sites to be either more or less sensitive to changes in moisture balance.

in the tropical Andes has provided more evidence for a far more complex early Holocene than previously envisaged (Licciardi et al., 2009; Hall et al., 2010). A prinicpal aim of this project is to couple high-resolution sediment cores (e.g., Fig. 2) with CRN dating of Holocene moraines. This approach should yield both a continuous sediment archive of glaciation and sediment yield with clear temporal and spatial evidence of paleoglacier extent.

PROJECT OVERVIEW

A prime goal of this year's project was to develop coupled lake sediment core and CRN-dated moraine records from glaciated sites at both ends of the steep NE-SW moisture gradient of the central Peruvian Andes (Fig. 1). We spent approximately 2 weeks at each site. The eastern (wet) site is located at the foot of Nevado Huaguruncho (5723 masl; Fig. 3) in the Cordillera Oriental, and the western (dry) site is located on the eastern flank of Nevado Tunshu (5730 masl; Fig. 4) in the Cordillera Occidental. Bedrock in the eastern site is Triassic-Jurassic granodiorite, and that at the western site is Cretaceous red mudstone, carbonates, and conglomerate, and, at the highest elevations, Paleocene granodiorite, and metamorphic rocks. No prior work had been done at either site, but we know from other regional studies (e.g., Smith et al., 2005; Rodbell et al., 2008) that deglaciation commenced about 21 ka, and so the cirques and valley floors in which we worked became ice-free after this date.

At each site we mapped moraines, sampled several dozen glacial erratics for CRN dating, and cored lakes and wetlands. CRN samples were obtained with hammer and chisel, and students mapped moraines by walking moraines crests with hand-held GPS receivers. Lake cores were obtained from inflatable rubber rafts using either a Livingstone square piston corer for lakes with less than about 15 m of water, and a Nesje-style percussion corer for deeper lakes. Bogs and wetlands were cored with the Livingstone square-rod piston corer. In total we cored four lakes and five bogs, and obtained nearly 100 samples for CRN dating. We were quite a sight at the Lima airport as we had several hundred pounds of excess baggage to check in for our return flight home. All cores were split, described, and sampled either at Union College or Ohio State University. Samples for radiocarbon dating were obtained from all cores and submitted to the Keck AMS Radiocarbon Facility at the University of California, Irvine. Select cores were transported to the University of Minnesota Duluth for analyses using the ITRAX scanning X-Ray Fluorescence instrument. While all students participated in all aspects of the research, each student selected one or more of the sediment cores to analyze in their home institutions.

Figure 3. Nevado Huaguruncho (5723 masl) in the eastern cordillera of the Peruvian Andes with Laguna Jaico in the foreground. Note recently deglaciated bedrock and twin moraine ridges (probable late Holocene) that wrap across the valley just below the exposed bedrock.

Figure 4. Nevado Tunshu (5730 masl) in the western cordillera of the Peruvian Andes with Laguna Shiurococha in the foreground.

Emma Coronado (St. Lawrence) has been working on fingerprinting the sediment in a core from Laguna Shiurococha, located at the western site. The idea here is that with progressive ice retreat from the coring site during deglaciation, a decreasing fraction of the sediment would have been derived from the main cirque (crystalline rocks) and an increasing proportion of the sediment would derived from the Cretaceous red beds that surround the lake. In contrast, with the onset of neoglaciation during the late Holocene a reversal in this trend might be expected. Thankfully, Emma'a thesis advisor, Prof. Alexander Stewart from St. Lawrence, joined us in the field and played a major role in coring Laguna Shiurococha. Emma's work has shown that indeed the two end-members of sediment provenance can be distinguished based on x-ray diffraction, and the expected deglacial shift is seen. Sasha Rothenberg (Union College) focused on the sedimentology and radiocarbon dating of all the bog and wetland cores obtained from both sites, and on one of the sediment cores obtained from Laguna Yanacocha. Her work reveals that at the eastern site, the lowest-elevation basins became ice-free more than 14,000 years ago, and that glacial readvances during the Holocene were of very limited extent. This is contrasted markedly by the chronology of ice front retreat documented at the western site. There, the bog and lake cores suggest a significantly greater late Holocene ice extent than noted at the eastern site.

Chris Sedlak (Ohio State) worked on sediment records from the deep basin in Yanacocha. His results are similar to Sasha's and document that the watershed was deglaciated well before 14000 years ago. The results from Chris' core samples tentatively suggest that glaciers advanced during the early Holocene, but more work involving the CRN samples is needed to document the presence of ice at that time. His data also suggest that most of the remaining Holocene was a period of restricted, or absent, ice cover until the very late Holocene (last ~1000 years). Perhaps one of the more interesting results of Chris' work is evidence in the lake sediments of pronounced aridity in the region during the mid-Holocene. These records from Yanacocha provide us with valuable insight into the timing and causes of Holocene glaciation in the Peruvian Andes.

Jessica Treanton (Colorado College) focused on sediment cores from Laguna Jaico (Fig. 3), in the basin that sits just below Yanacocha. Like Yanacocha, Jaico documents evidence of reduced ice cover during much of the mid-Holocene, followed by renewed glaciation during the last ~1000 years. Jessica also performed detailed mineralogical studies on the Jaico samples, and these results provide interesting information about changes in weathering of clay minerals in the watershed at times of shifting climate during the Holocene. Combined with Yanacocha, the Jaico record provides new paleoclimate information for a mountain range in Peru that, until now, has been mostly unstudied.

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