

## Geology

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Paul A. Baker, Mark Bush, Sherilyn Fritz, Catherine A. Rigsby, Geoffrey Seltzer and Miles Silman

*Geology* 2003;31:e26-e27

doi: 10.1130/0091-7613-31.1.e26

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#### Notes

## Last Glacial Maximum in an Andean cloud forest environment (Eastern Cordillera, Bolivia): Comment and Reply

### COMMENT

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Whether the climate of tropical South America during the Last Glacial Maximum (LGM) was colder and drier or colder and wetter than present day has been widely debated. It is accepted, however, that the LGM in tropical South America was 2–9 °C colder than today (e.g., Betts and Ridgway, 1992; Bush et al., 2001). Without debating the merits of the following choices, if we assume a lapse rate in the LGM similar to the modern one of  $\sim 0.6$  °C·100 m<sup>-1</sup>, then an intermediate cooling of 5 °C would lower the boundary between montane cloud forest and the overlying puna grasslands by  $\sim 800$  or 900 m. Palynologists on both sides of the wet/dry debate have come to similar conclusions about forest-boundary lowering due to temperature decrease (reviewed by Flenley, 1998). In the Eastern Cordillera of Bolivia the modern puna–cloud forest boundary lies  $\sim 3400$  m above sea level (masl). Ignoring any other environmental changes, LGM cooling would have lowered this boundary to 2500 or 2600 masl.

Mourguiart and Ledru (2003) presented an interesting pollen diagram from a late Quaternary sedimentary sequence from a peat bog near Siberia, Bolivia. The site (2920 masl) is located within the modern cloud forest. Based on cooling alone during the LGM, it is expected that their site would have been well above cloud forest, and therefore well within the puna vegetation zone. Mourguiart and Ledru (2003) indeed observed just such an expected change at their site: the full glacial had lower representation by cloud forest taxa (e.g., *Podocarpus* and *Myrtaceae*) and higher representation by puna taxa (e.g., *Poaceae*). Although not referenced by Mourguiart and Ledru (2003), it should be mentioned that two previously published pollen records from sites within 40 km of Siberia at 2700 masl (Cala Conto) and 2720 masl (Wasamayu) show continuous moist-forest taxa throughout the LGM (Graf, 1989, 1992). We were thus surprised that Mourguiart and Ledru (2003, p. 195) concluded that their pollen record indicates a “drastic decrease of the Amazonian moisture source,” rather than that the upper cloud forest boundary had simply migrated to elevations well below their site due to cooling. Indeed, we see nothing in the pollen or algal record to support inferences of wide-spread aridity.

To corroborate their interpretation from Siberia, Mourguiart and Ledru (2003) present data from a second coring site at <19 m water

depth in Lago Huiñaimarca, a shallow arm of Lake Titicaca (3810 masl). From changes in the abundance of *Isoetes*, *Pediastrum*, and *Botryococcus* in this core, they conclude that Lago Huiñaimarca was shallower during the LGM than before or afterward. Although lake-level change may be one mechanism to account for the observed patterns in Lago Huiñaimarca, there are other possible explanations for these data (e.g., changes in temperature, nutrient availability, or water clarity; Jankovska and Komarek, 2000) that are fully consistent with the hypothesis of a cold and wet LGM, as suggested by other paleoecological studies from the Altiplano. Based on data from multiple proxies (diatoms, pollen, stable isotopes, inorganic and organic carbon) in many sediment cores that we recovered from multiple locations in the main part of Lake Titicaca as well as in Lago Huiñaimarca, we have shown that the main basin of Lake Titicaca was a deep, freshwater lake during the LGM and that it overflowed via its outlet on Lago Huiñaimarca (Baker et al., 2001a; Seltzer et al., 2002; Tapia et al., 2003; Paduano et al., 2003). In fact, the greatly enhanced discharge from the lake via the Río Desaguadero (Cross et al., 2001) contributed to the flooding of the central Altiplano and the formation of a large and deep paleolake that existed throughout the LGM from ca. 25,000 to 16,000 cal. yr B.P. (Baker et al., 2001b). Thus, Lago Huiñaimarca was filled to its present-day (shallow) depth at the LGM. Indeed, as long as the outlet of Lake Titicaca was at its present-day depth, it could hardly have been otherwise.

A parsimonious explanation for all available data is that the Altiplano was cold and wet during the LGM, not a dry environment as Mourguiart and Ledru (2003) concluded. Furthermore, given the clear pacing of wet-dry cycles at precessional frequencies in regional records and the absence of evidence for LGM aridity at the Siberia site, we do not feel that it is necessary to revise our well-supported conclusions (Baker et al., 2001a, 2001b) about the contributory causes of increased precipitation on the Altiplano during the LGM.

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## REPLY

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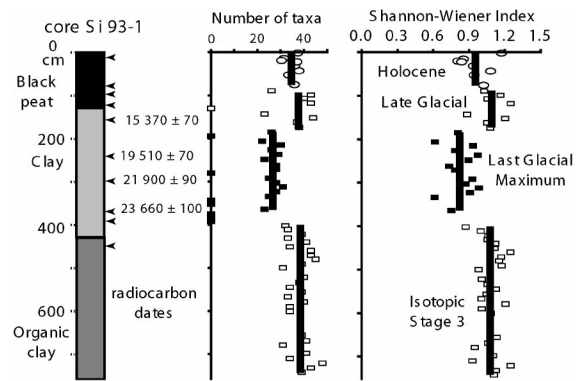
Baker et al. (2001) suggested that variations in solar insolation as a consequence of precession might play an essential role in the intensity and displacements of the monsoon systems. In order to verify this hypothesis, it is crucial to accurately define tropical paleoenvironments in the context of glacial-interglacial cycles. Whether or not the South American climate of the Last Glacial Maximum (LGM) was dry or wet has been a topic of debate for many years. The aim of our paper (Mourguiart and Ledru, 2003) was to provide new evidence for a dry LGM in Bolivian highlands. Our interpretation is supported by the analysis of the specific diversity represented by the number of identified taxa in each sample and the Shannon-Wiener index (Fig. 1). Samples associated with the LGM interval exhibit low indices compared to other biozones. We believe that colder conditions alone could not explain such a spectacular response, and that it is thus necessary to invoke drier conditions as well (see Arroyo et al., 1988). In their comment, Baker et al. disagree with this conclusion, suggesting we misinterpreted our palynological records. Their statements are based on several points that merit consideration.

1. Contrary to what Baker et al. state about vegetation changes at the Siberia location during the LGM, we consider absence of taxa such as *Botryococcus* or *Isoetes* indicative of locally dry conditions. Furthermore, the absence in pollen spectra of taxa such as *Polylepis*, a tree that presently grows on Nevado Sajama up to 5100 m (Lieberman Cruz et al., 1997), and a decline in plant diversity both suggest regionally drier conditions. Moreover, a shift in pollen diversity and abundance is also observed at that time in records at Lake Titicaca (Paduano et al., 2003).

2. Baker et al. correctly note that factors such as temperature, water clarity, or nutrient availability could explain changes in taxa distribution during the LGM. However, in Lake Huiñaimarca, high sedimentation rates during the LGM (Mourguiart and Ledru, 2003) are not indicative of ultra- to oligotrophic lakes (Pouchet et al., 1995) or lacustrine profundal zones (Pouchet et al., 1994).

3. The validity of the diatom study by Tapia et al. (2003) is questionable for not taking the published modern database into account. Moreover, the study suffers from a lack of rigorous statistical analysis. One way or another, the well-known mid-Holocene dry phase was unquestionably characterized by *Cyclotella meneghiniana*, a taxum found presently in lacustrine macrophyte and in relatively high percentages

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**Figure 1. Evolution of plant taxa diversity (richness and Shannon-Wiener index) at Siberia (Eastern Cordillera, Bolivia).**

during the LGM. So, we do not agree with Baker et al.'s assumption that Lake Titicaca was overflowing throughout the LGM. Their own data seem to demonstrate the reverse!

4. Furthermore, Baker et al. refer to studies by Graf (e.g., 1992) in the Valles of Cochabamba. Strahl (1998), in reference to a new pollen diagram, concluded that the LGM environments in this part of Bolivia were much drier than the Graf interpretations, according to previous conclusions drawn by Purper and Pinto (1980) on ostracode ecology. In the Bolivian lowlands, at Laguna Bella Vista and Laguna Chaplin, the same picture was observed (Mayle et al., 2000).

In conclusion, there is growing evidence that the signal of drier-than-present (but also drier than before and afterward) conditions at the LGM is not wholly an artifact of temperature depletion, and, therefore, insolation (precessional cycles) cannot be invoked to explain this situation.

## ACKNOWLEDGMENTS

The manuscript was improved by the suggestions of Mike Burn, University College London.

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