Geophysical Research Abstracts, Vol. 8, 05980, 2006
SRef-ID: 1607-7962/gra/EGU06-A-05980

Exposure dating in the Central Andes: paleoclimatic implications of asynchronous glacial advances

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The Central Andes in South America are a key region for the reconstruction of paleoclimatic conditions during the Late Quaternary, because they mark the transition zone between the tropical and the extratropical atmospheric circulation system. Any changes in the position and intensity of the westerlies, as well as changes of the South American Summer Monsoon (SASM), should therefore be recorded in paleoclimate archives. As glaciers are sensitive to temperature and precipitation, moraines may provide valuable information about past climate conditions. The establishment of reliable glacial chronologies has, however, been difficult up to now due to the lack of organic material for radiocarbon dating.

We applied surface exposure dating on moraines along a N-S transect from Bolivia ($\sim$15˚S) to the Chilean Lake District ($\sim$40˚S), in order to determine timing and extent of the last glaciation: In the Cordillera Real and the Cordillera Cochabamba, Bolivia, the glacio-morphological conditions are highly complex and characterized by multiple moraine sequences. Nevertheless, preliminary results point to glacial (re-)advances at $\sim$20, 16, 12, 10 and 8 ka BP. Comparison with northern hemispheric temperature records indicates that reduced temperatures probably played an important role in triggering the glacial advances (during the LGM, the Heinrich 1 event, the Late Glacial, the Preboreal and the 8.2 ka event). Glacier-climate-modelling corroborates that temperature depressions were substantial. Simultaneous precipitation increases may also have occurred, as predicted by increased meridional sea surface temperature gradients in the tropical Atlantic and the resulting strengthening of the SASM.

Exposure ages from northern Chile at $\sim$30˚S indicate that glaciers reached their maximum extents at $\sim$30 ka BP and again during the Late-Glacial (14-12 ka BP). Appar-

ently, precipitation at these latitudes was insufficient for a substantial glacial advance during the LGM. Instead, increased moisture availability at 30 ka BP and during the Late Glacial exerted the dominant control for the Late Quaternary glaciation. Although further exposure ages are certainly required in order to determine the regional occurrence of the respective glacial advances (i.e. especially along the N-S gradient), we propose to consider a significant intensification and/or south-ward shift of the tropical circulation system during the Late Glacial. Appropriate paleoclimatic conditions have previously been inferred from δ^{18}O speleothem data in SE Brazil and from lake sediments on the Altiplano. Accordingly, increased influence of the Atlantic moisture source might have triggered lateglacial advances (14-12 ka) as far south as 30˚S, although, at present, most precipitation is advected with the westerlies from the Pacific. Up to now, insufficient data are available to evaluate paleohumidity and glacial responses south of 30˚S.

In contrast, significant glacier extents at around 30 ka BP could be documented as far south as $\sim$39˚S (Valle Rucachoroi, Argentina). This may point to different atmospheric conditions, i.e. especially moisture advection, at that time.

Ongoing research is currently focussing on the search and direct dating of LGM moraines between 40 and 30˚S. Maximum glacial advances should have occurred at that time, if the wide-spread assumption of a northward shift of the moisture-bearing westerlies is correct. Apart from the hitherto limited number of exposure ages and the tentativeness of the paleoclimatic conclusions, one should be aware of the current limitations of surface exposure dating: Systematic uncertainties due to altitude and latitude scaling and uncertainties due to variations of the geomagnetic field need to be addressed in further studies. Local calibrations would be very desirable.