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GLACIAL CHRONOLOGIES FROM NE SECTOR OF NEVADO COROPUNA (PERU): GEOMORPHOLOGICAL AND PALEOCLIMATIC IMPLICATIONS

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Most of the datings of the Last Glacial Maximum on Central Andes were made before the 90's, using ^{14}C. The works had a wide range of results, compiled in previous papers. During the last decade new ages have been performed using techniques of surface exposure dating (SED). The results were widely discussed in Smith et al. (2008). Glacial ages suggest that some andean mountains have remained above the Equilibrium Line Altitude of glaciers (ELA or paleoELA) since the Pliocene, allowing the presence of ice masses, but others have not reached sufficient altitude until late Quaternary. Geomorphological interpretation of SED from Central Andes shows a very prolonged expansion from the Last Glacial Maximum (LGM) to Late Glacial (LG). In addition, there are synchronicities and asynchronies in the beginning of glacial expansion, among valleys of the same region or different regions in Central Andes, as well as in relation to the global glacial timetable. Glacial ages reflect a progressive delay of glaciation towards the South and west of the Central Andes, in the same way that reduces the distance to the source area of the Humboldt current and increases the climate aridity.

Hitherto, only Bromley et al. (2009) and Bromley et al. (2011b) have obtained glacial chronologies in Nevado Coropuna. Their results indicate that the phases of advancing paleoglaciares were lasted from Last Glacial Maximum Local (LLGM), after LGM, until Local Late Glacial (LLG), contemporary to LG. In this paper the acronym LLGM-LLG is used to refer to this long period of glacial advances observed in the Nevado Coropuna. To contribute to the understanding of glacier evolution during Late Pleistocene were estimated SED (^{36}Cl) of boulders in 8 moraines and in one not glaciated lava flow. The volcanic chronology confirms that the Nevado Coropuna is active and the risks must be enough evaluated.

II. STUDY AREA

Nevado Coropuna (15º31'S, 72º39'W, 6377 masl) is on the southern edge of the Altiplano, 150 km to the NW of the city of Arequipa, between the watershed of rivers Ocoña and Majes, to west of Central Andes (figure 1). Volcanoes were built on a huge landslide affecting the southern edge of the altiplano. The stratigraphy culminates to the top with thick layers of early Pliocene ignimbrites. Geomorphological evidence suggests that volcanic activity stopped during the last glaciation and has been recently reactivated. The units which reflect these processes are shown in a map geomorphological (figure 2) and topographic profiles (figure 3).

Three Holocene eruptions caused the emission of ash which cover the proglaciar ramp, on the northern side, and three lava flows which were channeled in glacial valleys, in the west, northwest and southeast. Lava flows were only eroded by ice masses in the Little Ice Age (LIA). Therefore were attributed to Holocene.

The complex Nevado Coropuna consists of a group coalescent stratovolcanoes exceeding 6200 m altitude. Currently the peaks are covered by glaciers that descend to 5200-5600 m. Other authors (Racoviteanu et al., 2007) measured the surface of glaciers and snow cover in an ASTER satellite image (October 2000). The result was 60.8 km^2. More recent work (Úbeda, 2011) has differentiated the ice masses of areas covered exclusively by snow. Two orthophotos (1955-1986) and an ASTER satellite image (2007) were used. The results were: 56.1 km^2 (1955), 54.1 km^2 (1986) and 46.6 km^2 (2007). The comparison of the two time series (1955-1986 and 1986-2007) shows an acceleration of deglaciation, consistent with the global warming trend reports by the Intergovernmental Panel on Climate Change.

On the Nevado Coropuna don't exist weather stations. In 2007 data loggers were installed at different altitudes, in NE sector. Statistical analysis of several tens of thousands of records has revealed that currently the annual isotherm of 0°C is at 5350 masl (Úbeda, 2011). A value of 485 mm for annual precipitation at the same altitude was deduced in the same work. The data used were from the 1965-2003 serie of Andagua (15° 29'S, 72° 20'W, 3587 m), 20 km eastward of the Nevado Coropuna. To asses the precipitation was applied the same altitudinal gradient (0.1 mm / m) used by Klein et al 1999 in a reconstruction of regional snowlines.

ELA and paleoELA rise southward and westward of Central Andes (Clapperton, 1993), in the same way that the climate aridity increase. Because of this regional trend, the ELAs and paleoELAs are considerably higher in Nevado Coropuna than in other mountains north and eastward of the altiplano, as the Cordillera Blanca and eastern ranges of Peru and Bolivia.

Dornbusch (2002) estimated the values of the current ELA and the paleoELA at LGM (5558 m and 4750 m), in SW sector of Nevado Coropuna. Bromley et al. (2011a) studied numerous valleys around the volcanic complex. They found 4663 ± 232 and 5200 ± 68 m (present), 5319 ± 139 and 5757 ± 52 m (LLG) and 4663 ± 232 and 5200 ± 88 m (LLGM), depending on the slope orientation. Úbeda (2011) used statistical methods to reconstruct ELAs and paleoELAs in two tens of valleys, on NE and SE sectors. Their results indicated the following pairs of values for both flanks (NE / SE): 5968/5862 m (2007), 5929/5853 m (1986), 5923/5787 m (1955), 5886/5776 m (LIA) and 5179 / 4951 m (LLGM-LLG).

III. METODOLOGY

Research methods were based on a geomorphological mapping (figure 2) developed in a Geographic Information System, differentiating volcanic and glacial units. Following the criteria proposed by Zreda and Phillips, (2000) were selected boulder surfaces that could be assumed that retained its original location, were not affected by erosion too intense and had not been covered by sediments.

Samples analysis allowed to determine the amount of atoms ^{36}Cl, using the procedures described in Zreda et al. (1999) and Phillips (2003). SEDs were estimated by treating the results obtained in the laboratory in the online tool CRONUS CALCULATOR (http://www.cronuscalculators.nmt.edu/cl-36/). First, exposure ages were calculated using the five scale models included in CRONUS (LSI, LSD, DAZ, LFT and DUN). Then the averages of these chronologies were considered the best and most statistically representative estimates.

To cope with the discussion of the results and their regional interpretation a paleoclimatic diagram was generated using the millennial average of sea surface paleo-temperatures in Galapagos Islands and the percentage (%) of freshwater plankton in sediments from Lake Titicaca.

IV. CONCLUSIONS

Eight ^{36}Cl SED from moraines indicate that the last maximum advances of ice masses in NE sector of Nevado Coropuna have occurred at 22 ka before present, and were followed by new maximums lasting up 11 ka. This interpretation is consistent with the results of previous publications that used ^{3}He (Bromley et al., 2009; Bromley et al., 2011b).

The evolution of surface sea paleo-temperature in Galapagos Islands (Lea et al., 2006) shows a rise since 18 ka, consistent with global warming during Holocene. However, freshwater plankton in sediments from Lake Titicaca (Fritz et al., 2007) suggests that the environmental conditions in the southern Central Andes (wetter than nowadays) continued to favor the glacier expansion up to 9 ka.

Nevado Coropuna glacial ages differ of datings from Eastern Central Andes, which also show considerable internal discrepancies. In some cases these asynchronies can be justified with paleoclimatic arguments, but must be assumed that during the late Pleistocene the LLGM gradually moved south and west of Central Andes, due to the progressive increase in the humid of climate of this currently dry regions.

In other cases, glacial SED asynchronies only be explained by geomorphological processes, because the datings reflect several successive advances, that deposited polygenic moraines or have eroded pre-existing landforms.

Our hypothesis is that increased in precipitation caused several maxima between LLGM and LLG (at Pleistocene-Holocene transition).

The discussion of these results with new evidences should help to confirm or reject this hypotheses.

REFERENCES

BROMLEY, R.M., SCHAEFER, J.M., WINCKELER, G., HALL, B.L., TODD, C.E., RADEMAKER, K.M. (2011a): «Late Pleistocene snowline fluctuations at Nevado Coropuna (15°S), southern Peruvian Andes». *Journal of Quaternary Science*, 26 (3): 305-317.

BROMLEY, R.M., HALL, B.L., SCHAEFER, J.M., WINCKELER, G., TODD, C.E., RADEMAKER, K.M. (2011b): «Glacier fluctuations in the southern Peruvian Andes during the late-glacial period, constrained with cosmogenic ^{3}He». *Journal of Quaternary Science*, 26 (1): 37-43.

BROMLEY, R.M., HALL, B.L., SCHAEFER, J.M., WINCKELER, G., TODD, C.E., RADEMAKER, K.M. (2009): «Relative timing of last glacial maximum and late-glacial events in the central tropical Andes». *Quaternary Science Reviews*, 1-13.

CLAPPERTON, C. (1993): *Quaternary Geology and Geomorphology of South America*. Elsevier, Amsterdam (Holanda).

DORNBUSCH, U. (2002): «Pleistocene and present day snowlines rise in the Cordillera Ampato, Western Cordillera, southern Peru». *Neues Jahrbuch für Geologie und Paläeontologie Abhandlungen*, 225: 103-126.

FRITZ, S.C., BAKER, P.A., SELTZER, G.O., BALLANTYNE, A., TAPIA, P., CHENG, H., EDWARDS, R.L. (2007): *Lake Titicaca 370KYr LT01-2B Sediment Database, Lake Titicaca 370KYr LT01-2B Sediment Data. IGBP PAGES/World Data Center-A for Paleoclimatology Data Contribution Series # 92-008*. NOAA/NGDC Paleoclimatology Program. Boulder (EEUU).

LEA, D.W., PAK, D.K., BELANGER, C.L., SPERO, H.J., HALL. M.A., SHACKELTON, N.J. (2006): *Galápagos TR163-22 Foraminiferal $\delta^{18}O$ and Mg/Ca Data and SST Reconstruction. IGBP PAGES/World Data Center for Paleoclimatology Data Contribution Series # 2006-090*. NOAA/NCDC Paleoclimatology Program, Boulder (EEUU).

PHILLIPS, F.M. (2003): «Cosmogenic ^{36}Cl ages of Quaternary basalt flows in the Mojave Desert, California, USA». *Geomorpholog*y, 53: 199-208.

RACOVITEANU, A. MANLEY, W.F., ARNAUD, Y., MARK, W.W. (2007): «Evaluating Digital Elevation Models for Glaciologic Applications. An example from Nevado Coropuna, Peruvian Andes». *Global and Planetary Change*, 59: 110-125.

SMITH, J.A., MARK, B.G., RODBELL, D.T. (2008): «The timing and magnitude of mountain glaciation in the tropical Andes». *Joumal of Quaternary Science*, 23: 609-634.

ÚBEDA, J. (2011): *El impacto del cambio climático en los glaciares del complejo volcánico Nevado Coropuna (cordillera Occidental de los Andes, Sur del Perú)*. Tesis Doctoral. Departamento de Análisis Geográfico Regional y Geografía Física. Universidad Complutense de Madrid, Madrid (España). 558 pp. Disponible online en el enlace: http://eprints.ucm.es/12076/ .

ZREDA, M.G., PHILLIPS, F.M. (2000): «Cosmogenic Nuclide Buildup in Surficial Materials. Quaternary Geochronology, Methods and Applications». En STRATON NOLLER, SOWERS, J.M., LETTIS, W.R. (Eds.). *Americal Geophysical Union*: 61-76. Washington (EEUU).

ZREDA, M., ENGLAND, J., PHILLIPS, F.M., ELMORE, D., SHARMA, P. (1999): «Unblocking of the Nares Strait by Greenland and Ellesmere ice-sheet retreat 10,000 years ago». *Nature*, 398: 139-142.