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Glacial evolution of the Ampato Volcanic Complex (Peru)

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Ice masses on the Western range of the Central Andes are a main source of water resources and act as a geoindicator of variations in the climate of the tropics (Mark, 2008). The study of their evolution is of particular interest since they are situated in the transition zone between the tropical and mid-latitude circulation areas of the atmosphere (Zech et al., 2007). The function of this transition area is currently under debate, and understanding it is essential for the development of global climate models (Kull et al, 2008; Mark, 2008). However our understanding of the evolution of glaciers and their paleoclimatic factors for this sector of the Central Andes is still at a very basic level.

This paper presents initial results of a study on the glacial evolution of the Ampato volcanic complex (15º24´- 15º 51´ S, 71º 51´ - 73º W; 6288 m a.s.l.) located in the Western Range of the Central Andes in Southern Peru, 70 km NW of the city of Arequipa. The main objectives are to identify the number of glacial phases the complex has undergone using geomorphological criteria to define a time frame for each phase, based on cosmogenic ^{36}Cl dating of a sequence of moraine deposits; and to estimate the glacier Equilibrium Line Altitude (ELA) of each phase. The Ampato volcanic complex is formed by 3 great andesitic stratovolcanoes, the Nevados HualcaHualca-Sabancaya-Ampato, which started forming between the late Miocene and early Quaternary (Bulmer et al., 1999), aligned N-S and with summits covered with glaciers. The Sabancaya volcano is fully active, with its latest eruption occurring in 2001.

Glacial landforms were identified and mapped using photointerpretation of vertical aerial photographs from 1955 (1:35,000 scale, National Geographic Institute of Peru), oblique photographs from 1943 (Aerophotographical Service of Peru), and a geo-referenced high-resolution Mrsid satellite image from 2000 (NASA). This cartography was corrected and improved through fieldwork. It was then digitized in a Geographical Information System (GIS) using the existing 1:100,000 maps (National Geographical Institute of Peru) as a topographical base.

Once the geomorphological maps had been analyzed, we decided to focus on the glacial evolution of a representative section of the Ampato Complex, specifically the Huayuray valley, located north of the HualcaHualca volcano. According to the altitudinal position and the degree of conservation of the moraines along the Quebrada, glacial phases of the Last Glacial Maximum (LGM), the Neoglacial and the Little Ice Age (LIA) were identified. The GIS was then used to delimit and calculate the ice surface area of each one. The same was also done for the years 1955 and 2000 AD, based on the interpretation of aerial photographs and satellite images from those years. Next, the ELA was calculated using the Altitude Area (AA) method (Osmaston, 2005) using GIS and the glacier paleotopography was reconstructed using geomorphological evidence (Carr, S & Coleman, C, 2007). To obtain numerical ages of moraine boulders and glacially abraded bedrock we applied cosmogenic^{36}Cl surface exposure dating (Gosse & Phillips, 2001), which is the best method for volcanic rocks with no quartz content. Samples were collected from stable boulders located at the crests of moraine ridges and over 1 m in height. They were analyzed following procedures by Zreda et al. (1999) and Phillips (2003); physical analyses were undertaken at Universidad Complutense in Spain and physic-chemical analyses at the PRIME laboratory (Purdue University).

LGM moraine forms always occupy the lowest altitude position, forming well-defined moraine arcs and ridges, with large dimensions and well preserved. During this phase, the climate was colder and damper than is currently the case in the Central Andes. Calculations show mean temperature during this period to have been 4 - 6ºC below present values, and with more abundant precipitation (Seltzer et al., 2002). Under these climatic conditions, glaciers

expanded and their fronts descended to a minimum altitude of 3900 m a.s.l. in the Huayuray valley. The ELA was at 4980 m a.s.l., implying an ELA depression of 900 m compared to the situation in 2000 AD. The age obtained for the Ampato Volcanic Complex using cosmogenic methods is 16,500 $\pm$ 0.37 y. AP, similar to the dates proposed by Clapperton (1993) – around 18,800 y. BP-, and far away from those proposed by Seltzer (2002) -30,000 y. BP- or by Smith et al. (2005) -21,000 y. BP-, although there is no certainty that the samples represent the oldest ridges of this period.

Several records exist of Neoglacial advances, mainly well preserved moraines located in the glacial valleys immediately behind LGM moraines. One of these reached a minimum altitude of 4300 m a.s.l., with the ELA at 5240 m a.s.l., which implies an ELA depression of 560 m compared to the 2000 AD situation. ^{36}Cl dating indicates that this Neoglacial advance occurred in 11,400 $\pm$ 0.21 y. BP. Two main glacial readvancement events due to climatic conditions have been noted in the Central Andes: The first between 15,000 and 13,000 yr. BP and the second at 12,000-10,000 yr. BP (Clapperton, 1993; Zech, et al., 2007). The latter has been dated with sufficient precision on the Chimborazo (Ecuador), the Junin Plains (Peru), and the Quelccaya Glacier (Peru) (Clapperton, 1993; Seltzer, 1990 and Smith et al. 2005) and corresponds to the described event in the Ampato Complex.

There is limited data on the Little Ice Age for the Central Andes. This phase is represented by small moraines, located at high altitudes, very near the current glacial fronts. Ice cores extracted from some Central Andean glaciers, such as the Quelccaya Glacier (Peru), show a cooling episode between 1500 and 1820 AD, which corresponds to the LIA (Seltzer, 1990). During this recent global cold event, the minimum altitude of glaciers on the Ampato Volcanic Complex reached 5400 m a.s.l., 250 m below their 2000 position. The ELA is estimated at 5770 m a.s.l., with a depression of 110 m compared to 2000 AD.

Existing ice masses on the Ampato are currently experiencing a substantial retreat. In 1955 the surface area they covered in the Huayuray valley was 2.45 km^2, with an estimated ELA of 5800 m a.s.l., whereas by 2000 the area had been reduced to 1.45 km^2 and the ELA climbed to 5887 m a.s.l.. In only 45 years, the glaciers have shrunk $\sim$1 km^2 and the ELA has raised 90 m. If the current trend continues, glaciers will have disappeared from this tropical mountain in approximately 65 years time.

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