LANDSCAPE EVOLUTION OF THE APURIMAC RIVER DRAINAGE BASIN, SOUTHERN PERU

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SETTING

The northernmost part of the Altiplano in Southern Peru is drained by the river Apurimac and its tributaries. The Altiplano is a region that covers most of the eastern part of the Cordillera Occidental and is bounded in the East by the Cordillera Oriental. The Apurimac River Drainage Basin (ARDB) extends roughly between 13°S and 15°S over 50000 km^2. It mainly occupies the northeastern flank of the Cordillera Occidental and a negligible part of the southwestern flank of the Cordillera Oriental. At the latitude of the Abancay deflection, i.e. 13.5 S; 72.7 W, the Apurimac River abandons the Cordillera Occidental. On its way to the Amazon Basin in the North the Apurimac River drains the Cordillera Oriental and the Sub-Andean Zone (SAZ). The incision by the rivers of the ARDB has created differences in relief of more than 2000 m that contributed to the denudation and exhumation, hence the evolution of the landscape.

The Altiplano sedimentary basin contains an 8 kilometers thick succession of Cenozoic sediments, which it received from the surrounding highs in the West and the East. Its structural framework has been formed by the various tectonic events that struck the Andes and the various pulses of magmatic activity that took place during the Cenozoic. In the western part of the Altiplano Miocene volcanics dominate, whereas in the northeastern part, in the Cusco region, clastic deposits do so. In the region of Abancay, a batholite got emplaced during the mid Tertiary, that extends over few 1000 km2.

PROBLEM

Landscape evolution is an interplay between tectonic and surface processes, like for instance rock uplift and fluvial incision. Another parameter in the creation of topography is the lithologically dependant rockstrength-weatherability.

The key to unravel this interplay is to identify so-called morphotectonic domains. Morphotectonic domains are tectonic units characterized by a typical geomorphological signature in for example relief (Szynkaruk et al, 2004) and by a typical denudation history (Springer 1999).

Difference in denudation history between adjacent morphotectonic domains often coincides with a difference in landform on either side of the domain boundary fault. If not, erosion processes probably have had time enough to wipe out the geomorphological evidence. This illustrates that tectonic and surface processes operate on different time-scales (Burbank 2002, Burbank & Anderson 2001)

METHODOLOGY-APPROACH

To be able to determine the timing of domain bounding fault activity and to establish rates of incision and denudation, Apatite Fission Tracks Analysis (AFTA) is applied in this research. Apatite Fission Track Analysis (Wagner and van den Haute 1992, Andriessen and Zeck 1996 and Ruiz 2002) is a low temperature thermo-chronometer that is used to investigate the time-temperature path for apatite crystals in the upper few kilometers of the crust.
AFTA provides the cooling age of apatite crystals through the 120-60°C apatite partial annealing zone during uplift and denudation. Cooling ages and fission-track lengths for apatite of samples that form a

vertical profile across a valley, are plotted in an age-elevation profile. From such a plot cooling-rates of the sample can be deducted. In order to convert temperature to depth, especially in a tectonically active and complex setting as the Andes, a regional geothermal gradient has to be available.
Otherwise a general upper crustal geothermal gradient of 25-30°C/km is assumed.
Integration of geomorphological and structural analysis on Digital Elevation Models (DEM) is carried out in a GIS (Geographical Information System). High-resolution satellite imagery of Terra-Aster DEM and Terra-Aster VNIR, SWIR and TIR bands are being used in the remote sensing analysis. Further on INGEMMET's digital geological attribute maps at a scale of 1:100000 and a geological map by Carlotto at a scale of 1:400000 make up the geological database in this GIS.
The sampling site selection procedure has taken place in GIS and it became clear that the valleys of the ARDB bear suitable sampling locations for this study. About 180 samples have been collected during two field campaigns in corporation with INGEMMET.
An extensive AFTA is currently being undertaken to provide a framework for the denudation histories across the ARDB. Additionally, like Gunnell (1998) did before, Ahnerts Equation: $D = 0.1535h$ (1970) in which potential denudation D is a function of mean slope or local relief h, is used to calculate future denudation for the ARDB morphotectonic domains. Comparison in GIS of historical and future (potential) denudation values might explain the present state of topography of a morphotectonic domain.

PRELIMINARY RESULTS AND DISCUSSION

The processing of DEM data to slope and relief (Florinsky 1996) has yielded a distribution of landforms and revealed the presence of previously unmapped faults on the ground and on satellite imagery (Sides & Woldai 2000). At least seven morphotectonic domains within the ARDB are identified. To a large extend the boundaries of these domains coincide with regional scale faults. River courses coincide with such faults in most cases but not where they are detoured by geological thresholds.

The results from two sections, analyzed by Dr. Ruiz using AFTA, show that both sections experienced a synchronous denudation phase in the Middle Miocene (~16±1 Ma). This confirms tectonic phase Quechua F3 in the Central Andes (Sebrier et al 1988, Carlotto 1998 and Jaillard et al. 2000). One section originates from the Abancay Batholite of Tertiary age, Cerro del Condor near Tamburque. The other originates from the conglomeratic Formation Anta of Upper Eocene-Lower Oligocene age on the North flank of the Apurimac valley near Tinco, South of Cusco. These two localities are 100 kilometers apart and are situated in two different morphotectonic domains. Within the conglomerate section, cooling ages for apatite of 9±1 Ma (Quechua F4) have been produced while 13 to 11 microns Mean Track Lengths dominate.

Springer (1999) provided a regional geotherm of ± 12.5°C/km from heat-flow data across the Andes in southern Peru. This geothermal gradient implies that cooling through the 120°C occurred at ± 10 km depth. The geothermal setting of the northern Altiplano can be explained by the 8 km thick succession of Cenozoic sediments deposited in the Altiplano Basin. The orogenic root of the Andes reaches a depth of ± 70 km disturbing the isotherm pattern drastically (Beck et al. 1996 and James 1971). If we consider a 12.5°C/km geothermal gradient, this brings for both sections a denudation rate of ± 0.6 km/Ma . In comparison, Ruiz (2002) evidenced denudation rates greater than 2 km/Ma in the Ecuadorian SAZ – while Sebrier et al. (1988) calculated rates of uplift in the order of 1.0 km/Ma for the Central Andes for the period Miocene Quechua F5 event (± 7 Ma) to Recent.

Sebrier et al (1988) also stated that the compressive tectonic phase Quechua F3, is also held responsible for the formation of landforms in the Central Andes. The recognition of additional geomorphological expressions such as terraces, can further contribute to the refinement of the denudation history and hence the landscape evolution of the Apurimac River Drainage Basin.

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