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Geochronological constraints on tectonics and uplift of the Western Cordillera in southern Peru

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Introduction

Although the Andes represent the classical and largest non-collisional orogen in the world, the nature of tectonism in this region is poorly understood and much debated. A wide range of mechanisms have been employed to explain the uplift of the Western Cordillera and evolution of the Western Andean Escarpment (WAE) in the Central Andes. These include (but are not limited to) monocline tilting from underthrusting of the Brazilian Shield (e.g., Isacks 1988, Allmendinger and Gubbels, 1996) and/or lower crustal flow (e.g., Hindle et al., 2005), alternating periods of thrusting and extension (e.g., Sebrier and Soler, 1991), crustal shortening accommodated by thrust faulting (e.g., Victor, 2004), and later modifications to the morphology such as from landsliding (Wörner et al., 2002). Our goal is to constrain the timing and rate of uplift in the Western Cordillera of southern Peru, and to determine the most probable mechanisms of uplift based on field mapping and the spatial variation in total exhumation today.

We apply geochronometric techniques to measure incision rates in the Colca and Cotahuasi Canyons of southern Peru as a proxy for uplift of the Western Cordillera. Previous and ongoing work (e.g., Thouret et al., 2003) has revealed changing incision rates averaged over differing time periods, which can be interpreted to result from changes in uplift rates, and possibly changes in the mechanisms accommodating uplift. Limitations involving the assumptions inherent to different techniques to measure incision will be minimized through corroborating results with a number of different geochronometers. Thermochronology of bedrock samples collected along the valley bottoms give exhumation rates and the spatial pattern of uplift perpendicular to the WAE, which can be an important constraint on the types of mechanisms which have accommodated uplift. Crystalization ages of volcanic bracketing units (deformed or undeformed) provide constraints on both canyon incision rates and the timing of movement of different faults mapped in the field area.

Morphology and Geology of Field Area

The western margin of the Central Andes marks an abrupt transition from the low coastal forearc region to the high topography of the Altiplano. However, the morphology of the WAE varies dramatically along strike within southern Peru, revealing a ramp-like morphology near the Cotahuasi drainage, and a much sharper rise in elevation 75 km to the SE near the Colca drainage (Figure 1). Because there appear to be no significant differences between the erosional processes affecting the range front in the two regions, we believe the differences in morphology may arise from differences in tectonism.

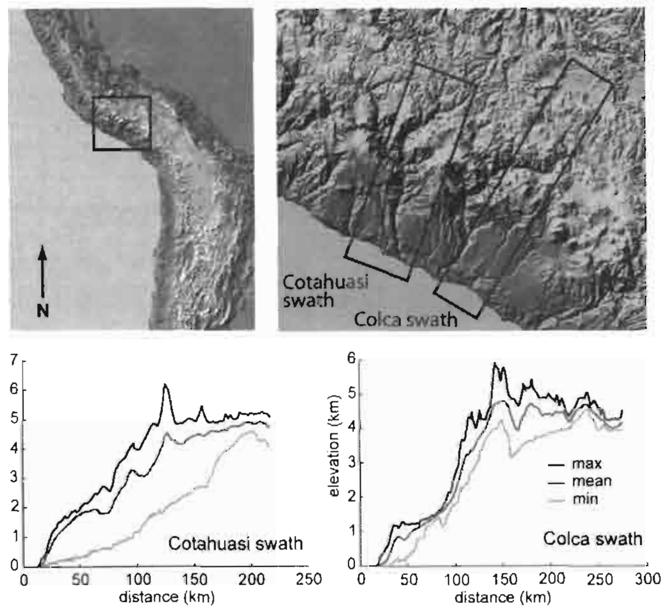

Figure 1. Topographic swath profiles of the range front at two locations (boxed region on map) in southern Peru illustrating topographic changes along strike. The profile near Colca Canyon shows the morphology of the region where we see strongest evidence of significant normal fault displacement. This differs markedly from the profile near the Cotahuasi Canyon which has a ramp-like morphology from the coast up to the plateau. These suggest different processes may be acting on the plateau margin to create the escarpment at these two locations.

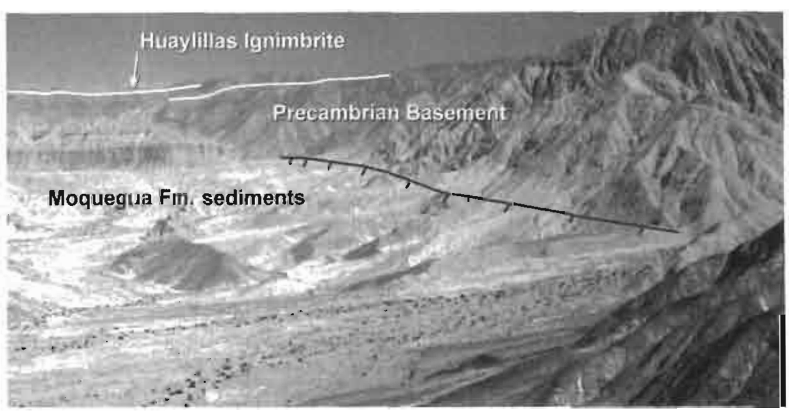

Figure 2. Colca Canyon range front near town of Aplao. Moquegua sediments have been tilted back toward the front on what we interpret as the hanging wall of a normally-faulted block. The Huaylillas Ignimbrite drapes over the fault zone, potentially providing an important constraint on timing of movement.

Sediments deposited along the WAE provide an important record of changes in the morphology and tectonism of the range front through time. The Moquegua Fm. is a sedimentary unit formed by SW-directed deposition into the Central Andean forearc starting in the Eocene-Oligocene (Sempere et al., 2004). Our preliminary field mapping shows that this sedimentary unit presently dips back toward the range front ~4° in the Colca region, and Sempere et al. (2004) also describe normal faults in the unit in southern Peru showing SW-directed offset. The Huaylillas Ignimbrite blankets the region above the tilted sediments and the range front (Figure 2). The character of the ignimbrite in the range front region will show whether or not movement between the Moquegua and the Precambrian basement rocks to the northeast continued after deposition of the Huaylillas. Critical in our future study will be not only mapping the structures and bracketing the timing of movement, but also constraining the amount of offset accommodated along faults.

Present Constraints on Incision Rates and Fault Movement

Thouret et al. (2003) have dated a number of valley-filling ignimbrites in Cotahuasi Canyon which show canyon incision rates to be between 0.2 and 0.3 mm/yr from ~15 to 3.8 Ma, and 0.05 mm/yr from 3.8 Ma to today. We have found similar results from one valley-filling flow in Colca Canyon, which constrains incision to ~0.04 mm/yr since 2 Ma.

The age of an offset volcanic unit within the Moquegua formation east of Colca Canyon shows that normal fault movement occurred after 14.39 ± 0.12 Ma based on $^{40}Ar/^{39}Ar$ single-grain biotite total-fusion analyses (weighted average of 10 grains), or after 14.11 ± 0.05 Ma, based single-grain sanidine total-fusion analyses (weighted average of 10 grains). Total offset has not been estimated in that region, but the tilted sedimentary beds of the Moquegua Fm. 35 km to the west near Colca Canyon suggest post-depositional offset of ~700 m based on an original depositional angle of less than 1° to the SW, and present angle of ~4° to the NE. Further evidence for normal faulting in the region comes from the epicenters of recent earthquakes in southern Peru southeast of Colca Canyon, which show increasing depths from NE to SW (David et al., 2004), suggesting that there may be a SW-dipping structure accommodating recent movement along the western margin.

Data in Progress

Incision rates derived from valley-filling lava flows and ash flow tuffs can be difficult to relate to uplift rates. For example, the flows may not have reached the bottom of the valleys, and the flows may have slowed later incision. Additional incision rate estimates that do not suffer from these potential problems include incision rates derived from cosmogenic exposure age modeling on abandoned strath terraces, and low-temperature bedrock thermochronology.

Apatite U-Th/He ages collected in a vertical transect can reveal canyon incision rates in the deepest reaches of the canyons (Figure 3). Material that is deeper than the initial position of the closure temperature isotherm (prior to canyon incision) will cool below its closure temperature progressively as the valley incises deeper and depresses isotherms. Assuming a geothermal gradient of 30°C/km and a closure temperature of 70°C, this requires greater than 2.3 km of incision to reach material that whose age-elevation slope will represent canyon incision rates. The age-elevation plot of material above 2.3 km depth will reveal the exhumation rate of the surrounding plateau. Initial results will be presented at the meeting.

Bedrock thermochronology can also reveal spatial patterns in total exhumation. Samples collected along valley bottoms will show the changes in exhumation perpendicular to the WAE, which may reveal whether the spatial change in exhumation is gradual, as would be expected along a monoclinal warped margin, or the change is sharp, as would be expected if discrete faults have accommodated uplift. $^{40}Ar/^{39}Ar$ dating of micas is best suited for this purpose since datable material is abundant, the relatively high closure temperature isotherm is unlikely to be significantly perturbed by short-wavelengh changes in topography, and very precise dates ($<1\%$ 2σ error) can easily be measured on samples.

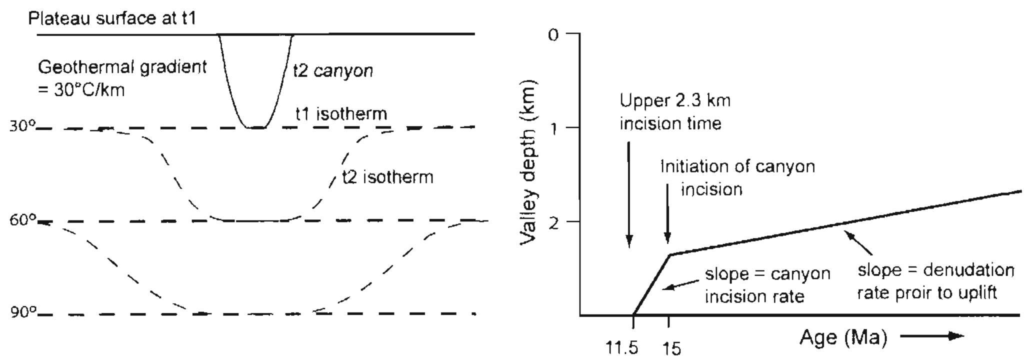

Figure 3. Cartoon illustration of expected age-elevation plots from vertical transects using a low-temperature thermochronometer. In this scenario, we assume plateau uplift at 15 Ma, a closure temperature of 70°C, an incision rate of 0.2 mm/yr, and very slow plateau denudation prior to and after uplift.

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