TECTONIC AND GLACIAL FORCING OF MOTION ALONG AN ACTIVE DETACHMENT FAULT

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The Cordillera Blanca of central Peru forms the highest topography of Peru and contains the tallest Andean peak north of 32° S. The range is bounded on the west by the spectacular ~200 km long Cordillera Blanca Detachment Fault (CBDF) and widespread tectonic indicators for extension in this portion of the Andes have led a number of authors to cite the CBDF as a type example of gravitational collapse of high topography(Dalmayrac and Molnar, 1981; Richardson and Coblentz, 1994). Exposures of 5-8 Ma granodiorite with ~4 Ma apatite fission track ages at ~7000 m in the footwall of the CBDF, document extremely rapid exhumation of the range(McNulty and Farber, 2002; Perry and Garver, 2004). This exhumation has been interpreted as rapid Miocene – Pliocene surface uplift, leading to the apparent paradox of extensional lowering of the topography with significant topographic uplift. In order to understand the nature of the CBDF we have determined the rates of Quaternary motion along the fault and modeled the isostatic effects of the dissection of the footwall.

The broad regions of accordant summits at 4200 to 4300 m.a.s.l. extending for ~100 km east of the northern Cordillera Blanca are the remnants of the now partially dissected Puna plateau(Cobbing et al., 1981; Wilson et al., 1995). To the west across the Callejon de Huaylas, the crest of the Cordillera Negra is a partly-dissected northward extension of the Puna plateau(McLaughlin, 1924) (at ~4400 to 5000 m.a.s.) that truncates Tertiary volcanic and folded Mesozoic sedimentary rocks. Along ~150 km of north-south transects, the topography of the Cordillera Negra summits and the high elevations of the plateau east of the Cordillera Blanca are nearly identical (Fig. 2) suggesting that the present topography represents a formerly continuous northward extension of the Puna plateau.

To calculate slip rates along the CBDF, we have measured topographic profiles and the ages of offset moraines and tectonically-generated fluvial terraces(Bierman et al., 1995; Van der Woerd et al., 2000) at four locations along the CBDF, from north to south: Huaytapallana, Cojup, Queroccocha and Tuco. The vertical slip rates decrease monotonically from north to south, and are 5.1±0.8 mm/yr at Huaytapallana, 2.9±0.3 mm/yr Cojup, 0.77±0.1 mm/yr at Queroccocha, and 0.59±0.2 mm/yr at Tuco. Both the maximum elevation and the relief of the Cordillera Blanca are strongly correlated with offset rates along the CBDF. Maximum elevations decrease from ~6700 m (Huaytapallana) to ~6200 m (Cojup) and ~5600 m (Queroccocha), and maximum relief decreases from ~2900 m to ~1000 m, reflecting the diminishing depth of glacial erosion in the south. Assuming the initial topography of the Puna surface was at an elevation of ~4500 m prior to onset of the CBDF motion, these maximum elevations provide minimum estimates of footwall uplift of ~2000 m, ~1600 m, and ~1000 m at Huaytapallana, Cojup, and Queroccocha. This is however, a lower bound, as an unknown amount of material may have been exhumed from top of the present peaks since the initiation of fault motion.

In the northern and central part of the Callejon de Huaylas, a distinct, gently rolling paleovalley floor incised by the Rio Santa is preserved on the hanging wall of the CBDF. The modern slope of this paleovalley parallels that of the Rio Santa (Fig. 2) suggesting little downward to the north tilting of the paleovalley deposits and, therefore, of the hanging wall of the CBDF. Thus, the concordance of the thermochronologic data taken from the footwall block together with our Quaternary offset rates and the correlation between the uplift rates and range geomorphology, suggests that relative to sea level, motion along the CBDF is largely confined to the footwall.

To quantify the relative contributions of tectonics and erosional unloading to generation of the topography, we have calculated the isostatic component of the uplift by estimating the mass removed and the resulting flexural-isostatic response since onset of motion along CBDF. To do so, we have used the continuity of the Puna plateau across the region now occupied by the Cordillera Blanca as an initial condition of the topography prior to onset of motion along the CBDF. The calculated flexurally-driven uplift patterns predict the present elevation of much of the plateau remnants, with the exception being the crest of the Cordillera Blanca. There, peaks extend to elevations well in excess of that predicted by the model thus requiring a significant additional tectonic forcing.

The localization of the excess topography along the CBDF, together with the correlation of the excess topography with the relief and slip rates along the CBDF suggests that much of this uplift is accommodated through tectonically driven footwall motion. Our calculations imply that tectonically driven extensional footwall uplift along the CBDF is substantial, generating 60% to 70% of the total uplift since fault initiation. However, at least a portion of the more rapid fault motion in the north is plausibly generated by extensive glacial erosion allowed by the higher topography. Indeed, this growing topography likely facilitated the growth of larger and more erosive glaciers, accelerating the rate of footwall uplift in the north by isostatically-driven footwall uplift superposed on the tectonically-driven fault motion.

The style of deformation we document along the CBDF has important tectonic implications. The increase in mean elevation (relative to the initial plateau topography) requires a mechanism other than erosional unloading or extension and crustal thinning accommodated by the CBDF, both of which would produce an overall lowering of the mean topography. Thus, the previously proposed(Dalmayrac and Molnar, 1981; Richardson and Coblentz, 1994) models calling on gravitational collapse of high topography to account for the presence of extension in this portion of the high Andes cannot explain our observations. We consider the most likely explanation to be additions of material at the base of the lithospheric section. The location of the Cordillera Blanca directly above the Peruvian flat slab section suggests that this may indeed be the case. In central Peru, the onset of flat slab subduction since ~5 Ma likely accommodated replacement of dense lithospheric material beneath the Cordillera Blanca with the buoyant oceanic slab, increasing the thickness of the crustal section below central Peru(Gutscher et al., 2000). In contrast to the Altiplano section studied by Ghosh et al. (Ghosh et al., 2006) where uplift was largely complete by 5 Ma, in this portion of the Andes, topography has not yet reached steady state and is likely still increasing today.

REFERENCES

Bierman, P.R., Gillespie, A.R., and Caffee, M.W. 1995. Cosmogenic Ages For Earthquake Recurrence Intervals And Debris Flow Fan Deposition, Owens-Valley, California: Science, v. 270, p. 447-450.

Cobbing, E., Pitcher, W., Wilson, J., Baldock, J., Taylor, W., McCourt, W., and Snelling, N. 1981. The geology of the Western Cordillera of northern Peru: London.

Dalmayrac, B., and Molnar, P. 1981. Parallel Thrust And Normal Faulting In Peru And Constraints On The State Of Stress: Earth And Planetary Science Letters, v. 55, p. 473-481.

Ghosh, P., Garzione, C.N., and Eiler, J.M. 2006. Rapid uplift of the Altiplano revealed through C-13-O-18 bonds in paleosol carbonates: Science, v. 311, p. 511-515.

Gutscher, M.A., Spakman, W., Bijwaard, H., and Engdahl, E.R. 2000. Geodynamics of flat subduction: Seismicity and tomographic constraints from the Andean margin: Tectonics, v. 19, p. 814-833.

McLaughlin, D.H. 1924. Geology and physiography of the Peruvian Cordillera, Departments of Junin and Lima: Bulletin of the Geological Society of America, v. 35, p. 591-632.

McNulty, B., and Farber, D. 2002. Active detachment faulting above the Peruvian flat slab: Geology, v. 30, p. 567-570.

Perry, S.E., and Garver, J.I. 2004. Onset of tectonic exhumation of the Cordillera Blanca, northern Peru based on fission-track and U+Th/He dating of zircon: Abstracts with Programs - Geological Society of America, v. 36.

Richardson, R.M., and Coblentz, D.D. 1994. Stress Modeling In The Andes - Constraints On The South-American Intraplate Stress Magnitudes: Journal Of Geophysical Research-Solid Earth, v. 99, p. 22015-22025.

Van der Woerd, J., Ryerson, F.J., Tapponnier, P., Meriaux, A.S., Gaudemer, Y., Meyer, B., Finkel, R.C., Caffee, M.W., Zhao, G.G., and Xu, Z.Q. 2000. Uniform Slip-Rate along the Kunlun Fault: Implications for seismic behaviour and large-scale tectonics: Geophysical Research Letters, v. 27, p. 2353-2356.

Wilson, J., Reyes, L., and Garayar, J. 1995. Geologia de quadrangulos de Pallasca, Tayabamba, Corongo, Pomabamba, Carhuaz, and Huari: Lima, Insituto Geologico and Minero y Metalurgico.