Spatial and temporal constraints on Neogene tectonics of the Peruvian Altiplano from new paleomagnetic and geochronologic data

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INTRODUCTION

The Andean Cordillera spans the entire Pacific margin of the South American continent, forming one of the Earth's longest and highest mountain belts. Between 15°S and 22°S, the orogen displays its greatest width (more than 700 km), thickest crust (up to ~70 km), and the earth's second largest high plateau, the Altiplano. This region is also characterized by a progressive reorientation in geologic strike that parallels the curved shape of the margin. The systematic change in strike, is mimicked by a progressive change in the sense of paleomagnetic rotations, going from mainly clockwise south of the bend to counterclockwise north of it (Randall, 1998; Beck, 1998; Roperch et al., 2000; Lamb, 2001; Richards et al., 2004). The origin and mechanism that caused such a pattern remain unclear; however, most workers agree that the structural evolution of the Bolivian Orocline can be better understood by mapping paleomagnetic rotations in space and time.

Central to the way vertical-axis paleomagnetic rotations can be used to constrain the tectonic history of the Andes is by knowing when they occurred and the size of the block that was rotated. Proposed kinematic block models range from large-scale oroclinal bending, with wholesale rotation of the two limbs to a series of smaller scale block models. Recent block models concerning the tectonic evolution of the Bolivian Orocline mostly invoke the existence of broad regions that experienced homogeneous rotations, bounded by narrow regions that facilitated enhanced deformation with rotations of local origin, uncorrelated to the broad regions around them (Kley et al., 1999; Roperch et al., 2000; Lamb, 2001; Richards et al., 2004).

However, although most of these block models make predictions about how the northern (Peruvian) part of the Bolivian Orocline deformed in time and space, this region is completely void of relevant paleomagnetic data for the period when most workers agree that deformation was most active, e.g., since ~25 Ma. Indeed, only one study reports a reliable Cenozoic paleomagnetic pole (ca. 55 Ma) for the entire Peruvian Altiplano (see Richards et al., 2004).

Therefore, to better constrain the Neogene deformation history of the Peruvian Altiplano and test available models, we combined $^{40}Ar/^{39}Ar$ radiometric dating with an extensive paleomagnetic study of Miocene strata from the Peruvian Altiplano and adjacent areas. Paleomagnetic samples were collected in the Huaccochullo basin over a region spanning ~5000 km^2 west of Lake Titicaca and in the Ayaviri (15°S, 289.4°E) and Descanso (14.5°S, 288.7°E) basins, which lie closer to the Eastern Cordillera. Paleomagnetic samples were also collected from the Subandean belt near Pilcopata (12.7°S, 288.64°E) (Figure 1).

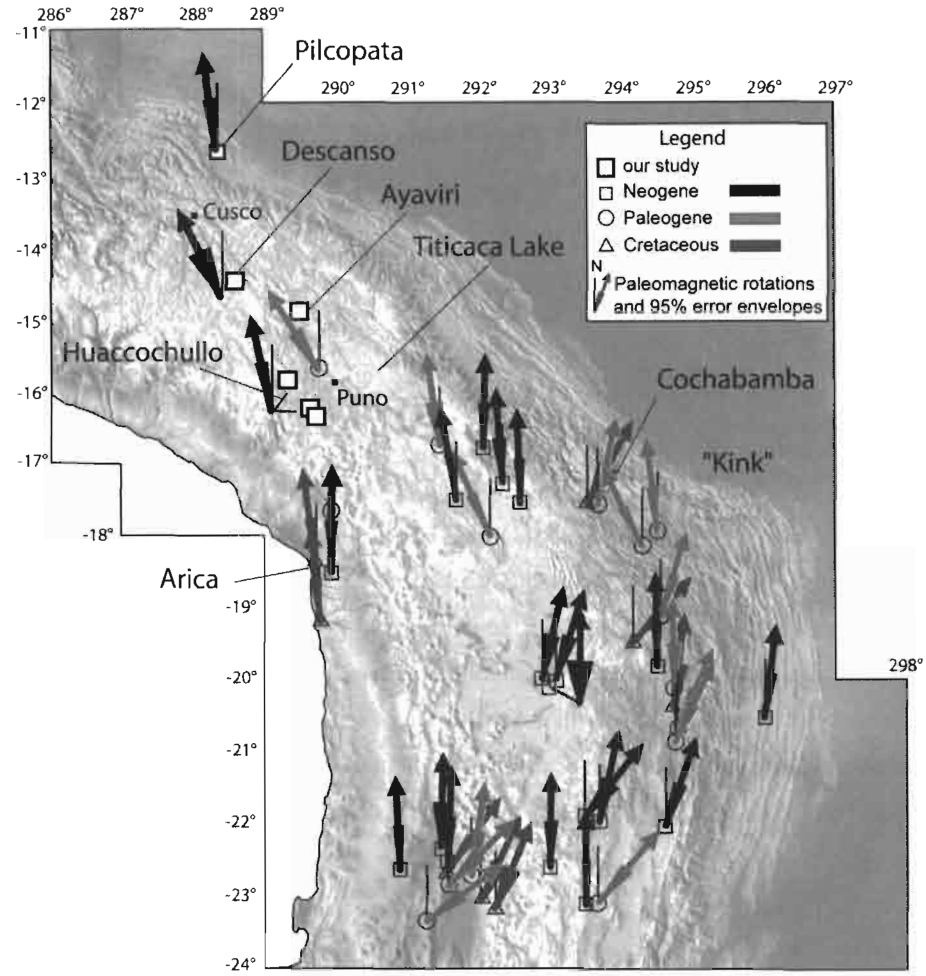

Figure 1 : Topographic map of the Bolivian Orocline with non-exhaustive compilation of the paleomagnetic rotations from the Cretaceous to the Neogene. (After Rousse, 2002; Richards et al., 2004). Filled squares show the localities from this study.

Ar/Ar DATING COMBINED WITH PALEOMAGNETIC RESULTS

Paleomagnetic vertical-axis rotations were calculated for each locality from the overall reliable mean poles from this study and compared to the reference poles derived from the synthetic South American apparent polar wander path (APWP) (Besse and Courtillot, 2002) in order to derive tectonic inferences. For the Altiplano basins, $^{40}Ar/^{39}Ar$ dating has precisely defined the age of the sampled strata, and hence allows us to compare against the reference pole of the appropriate age. For Ipururo Formation from the Subandean belt the age is broadly constrained as Miocene, yet older than 9 Ma (Campbell et al., 2001). Based on positive fold and reversal tests, pre-folding, primary magnetizations were isolated at the Huaccochullo, Descanso, and Pilcopata localities. For the Ayaviri basin, the magnetic remanence was acquired either after folding and represents a recent field direction or during progressive sedimentation, deformation and rotation.

$^{40}Ar/^{39}Ar$ dating in the Huaccochullo basin defines two distinct populations, with older ages in the northwestern part of the basin (26.5-24.0 Ma; samples 970815-1, 981005-1(2)) and younger ones in the southeast (13-12 Ma; Samples 011019-7(8)). The overall tilt-corrected mean paleomagnetic directions of the two are identical at the 95% significance level (Ds= 169.2°, Is= 20.7°, α_{95}= 17.2°, N= 3 versus Ds= 165.5°, Is= 27.3°, α_{95}= 7.8°, N= 10). We thus combined the two populations. Comparing the overall mean pole (76.6°S, 28.9°E, A_{95}= 6.1°) against the 20 Ma reference pole (84.7°S, 313.8°E, A_{95}= 2.7°) suggests that the Huaccochullo basin experienced a significant counterclockwise rotation of 11.3°±5.4°.

For the Descanso basin, the $^{40}Ar/^{39}Ar$ data brackets the age of the sampled strata between 18.5 and 12.5 Ma (Samples 970823-2 (3,5), 970829-3). Six sites from this basin pass the fold and reversals tests and likely possess primary remanent magnetizations. Despite this, one site lies far from the rest and adds a few degrees of uncertainty to the result. We thus omitted this site when calculating an overall mean pole for the Descanso basin (57.6°S, 8.4°E, A_{95}= 12.2°, N= 5), which yields a 31.0°±10.2° counterclockwise rotation versus the 20 Ma reference pole for stable South America.

In the Subandean belt, the overall mean pole based on seven sites (79.5°S, 21.0°E, A_{95}= 5.7°) compared to the 10 Ma reference pole (85.9°S, 331°E, A_{95}= 2.0°) implies a counterclockwise rotation of 7.8°±4.8°. The rotation magnitude does not change significantly when compared against the 20 Ma pole (8.3°±5.1° counterclockwise). This amount of rotation is similar to, yet slightly less than, that of the Huaccochullo basin some 300 km to the south, on the other side of the Eastern Cordillera.

CONCLUSIONS

Our paleomagnetic results of 28 over 36 sites (315 samples) of Neogene strata from the Peruvian Altiplano and adjacent Subandean belt (Pilcopata area), combined with $^{40}Ar/^{39}Ar$ dating of 13 volcanic flows and one lava neck, places new constraints on the Cenozoic tectonic history of the northern Bolivian Orocline. Our new $^{40}Ar/^{39}Ar$ dates bracket the age of the sampled strata from the Altiplano between ~26 to 12 Ma for the Huaccochullo basin, ~18.5 to 12.5 Ma for the Descanso basin and ~17.2 to 15.8 Ma for the Ayaviri basin. The data indicate that the Huaccochullo and Descanso basins and the Subandean Zone at Pilcopata experienced significant counterclockwise vertical axis block rotations of 11.3°±5.4°, 31.0°±10.2° and 7.8°±4.8°, respectively. The pattern of rotations together with mapped structures suggests that deformation was partitioned into (1) large regions experiencing little rotation that absorbed large amounts of margin-parallel shortening and (2) smaller, isolated basins exhibiting high-amplitude counterclockwise rotations that lie in major left-lateral shear zones. Our new results imply significant deformation occurred throughout the Peruvian Altiplano in the last 12 Ma, likely coeval with deformation in the sub-Andes.

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