PALEOMAGNETISM OF LATE CENOZOIC ANDEAN BASINS AND COMMENTS ON THE BOLIVIAN OROCLINE HYPOTHESIS

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Resumé

Paleomagnetic data are presented for late Cenozoic high-elevation basins in the Cordillera Oriental of Bolivia. These results suggest negligible rotation at 17° S lat. and significant (17.8 ± 5.1°) clockwise rotation at 22° S. These rotations may be interpreted as (1) local block rotations, or (2) the preferred hypothesis of Neogene oroclinal bending of the Andes.

Resumen

Nuevos datos paleomagneticos son presentados para las cuencas de alta correspondientes al Cenozoico tardío en la Cordillera Oriental de Bolivia. Estos resultados indican una insignificante rotación a los 17° S y una significante rotación (17.8 ± 5.1°) en la dirección de las agujas del reloj a los 22° S. Probablemente, estas rotaciónes representen (1) rotaciónes locales de bloques estructurales, o (2) en la hipótesis preferida, deformación tectonica del oroclinal Boliviano durante el Neógeno.

Key Words: Paleomagnetism, Cenozoic, Andes, Basins, Tectonics, Orocline

Introduction

The high-elevation sedimentary basins of the Cordillera Oriental of Bolivia provide an excellent opportunity to understand the tectonic evolution of the Andes. This paper presents paleomagnetic data from Quebrada Honda and Micana. In conjunction with previous paleomagnetic results from Salla, Bolivia (MacFadden et al., 1985) and the Ocros dyke swarm of Peru (Heki et al., 1985) these data are interpreted relative to possible local rotation versus oroclinal rotation.

Geological Setting

(1) Quebrada Honda, consisting of a 305-m thick section, is located in the southern Altiplano at lat. 22° S. Hoffstetter (1977) described the presence of Friasian land mammals from this locality, and its age is middle Miocene, or about 12 Ma (MacFadden et al., 1990). (2) Micana, consisting of a 205 m thick section, is located in the Cordillera Oriental at lat. 17° S. MacFadden et al. (1990) have determined that this locality is late Miocene, or about 7 Ma. (3) Salla,

Table 1. Paleomagnetic data for late Cenozoic localities from Bolivia (taken from MacFadden et al., 1990). Ns/Nu=number of sites originally sampled/number of sites used for overall mean directions; RES, Resultant (Fisher, 1953); α_{95}, 95% cone of confidence; R, amount of rotation (Beck et al., 1986); Δ R, error in calculation of rotation (Beck et al., 1986).

Locality	Lat. (°S)	Dec. (°)	Inc. (°)	Ns/Nu	RES	α_{95} (°)	K	R (°)	Δ R (°)
Salla	17	353.4	-37.4	104/58	53.7	5.4	13.1	6.6	6.8
Micana	17	355.2	-25.8	39/25	24.0	5.9	24.8	-4.8	6.6
Q. Honda	22	17.8	-40.7	106/79	74.6	3.9	17.9	17.8	5.1

consisting of a 540 m thick section, is located in the eastern Cordillera at lat. 17° S. The age of this locality is late Oligocene to early Miocene, or about 28 to 22 Ma (MacFadden et al., 1985; Naeser et al., 1987). (4) The Neogene Ocros dyke swarm is located in central Peru at 13° S. Heki et al. (1985) present the paleomagnetic results from this locality which are reviewed here in a context of the tectonic development of the Andes.

Paleomagnetic Procedures and Analyses

In all three basins listed above, paleomagnetic sites, or horizons (each consisting of three or more separately oriented samples), were collected throughout the fine-grained deposits and were spaced vertically at intervals averaging about 6 m. This sampling regime, which spans at least 1 myr in each of the sedimentary basins, therefore averages out any possible instantaneous effects of non-dipole components of the ancient geomagnetic field in calculating a mean direction for the each stratigraphic section.

Isothermal remanent magnetization experiments indicate that the magnetic mineralogy is complex and could result from carriers where saturation occurs in low fields or others where saturation does not occur in applied fields up to 3 Tesla (MacFadden et al., 1990). Given this potentially complex magnetization for each site, individual samples were subjected to either stepwise (usually in 4 to 10 increments, or more) treatments using either standard alternating field or thermal demagnetization. Therefore, all sites were treated by both techniques to better isolate characteristic magnetizations. Paleomagnetic samples were measured in a cryogenic magnetometer located in a low-field shielded room at the University of Florida.

Using these laboratory procedures, linear trajectories were isolated for many samples and principal component analysis (Kirschvink, 1980) was used to calculate the least-squares, best-fitting line for determining the characteristic, stable direction, presumably primary in origin. Within sites the individual sample directions were then combined to determine a mean direction for that stratigraphic horizon using Fisher statistics (Fisher, 1953). In order to calculate the overall formational mean directions, only sites whose R-statistic (Resultant in Table 1 here) satisfied Watson's significance point criteria (Irving, 1964) were used. Because the sediments are essentially flat-lying, fold tests to determine stability of remanence were impossible. However, the presence of site means with antipodal normal and reversed populations suggests ancient magnetizations rather than spurious secondary overprints (MacFadden et al., 1990).

The R ± ΔR values for the three sites studied here indicate different amounts of rotation relative to the late Tertiary reference pole for stable South America. Given the associated errors, Salla and Micana have negligible, whereas Quebrada Honda indicates significant (17.8 ± 5.1°) clockwise rotation since time of deposition (no stratigraphic trends in declination anomalies are apparent from any of the three localities).

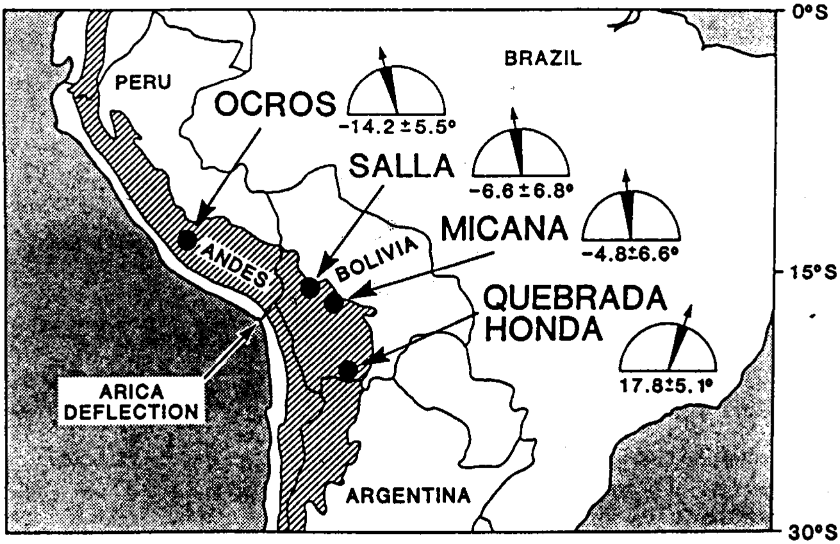

Figure. 1. Map of central part of South America showing general extent of the Andes (shaded) and the sites described in the text. The arrows within the half-circles represent the amount of rotation (R) and the black cones encircling the arrows represent ΔR, the estimated error.

Results and Interpretation

Of the possible structural/tectonic interpretations of rotated terranes (Beck, 1989) two seem plausible. (1) The data above indicate local, small-block rotation. If this is the case, then the scale on which rotated blocks must have occurred would have been greater than 6 km^2, indicating some meso- to large scale tectonic process. (2) These data support the hypothesis of oroclinal bending of the Andean orogen. Carey (1955) proposed the concept of an orocline to describe large scale tectonic bending of mountain ranges such as the Andes, from which the term Bolivian Orocline was proposed (1958). In plan view, the Andes are curved with about 45° of flexure along an axis aligned SW-NE inland along the Arica deflection.

Numerous studies have analyzed the paleomagnetism of volcanic and sedimentary rocks of Mesozoic age (summarized in Beck, 1988; Isacks, 1988) on either limb of the supposed Bolivian Orocline. Isacks (1988) interpret these data to suggest oroclinal bending, but given the available data, the age of bending is only constrained as post-Cretaceous. If the principal phase of oroclinal bending is related to subduction of the Nazca plate and Andean uplift (Isacks, 1988), then this tectonic deformation should have occurred very recently, i. e., during the late Cenozoic. However, there have been few paleomagnetic studies of young rocks in relevant areas. In addition to the data presented in Table 1 here, Heki et al. (1985) reported 14.5 ± 5.5° of counterclockwise rotation for the Neogene Ocros dyke swarm at 13° S lat. in Peru. Thus, these four data sets would suggest counterclockwise rotation at 13° S, negligible rotation at 17° S, and clockwise rotation at 22° S during the late Cenozoic (Fig. 1). The magnitude and sense of these data corroborate the hypothesis of about 10-20° of late Cenozoic oroclinal bending on both the north and south limbs of the presumed orocline, with little bending near the axis (Isacks, 1988; Figs. 1,2 here). This, however, does not account for all the bending necessary to account for the 45° bend at the Arica deflection. As Beck (1988) has suggested (although he does not advocate the oroclinal model), there may have also been an earlier phase of structural deformation.

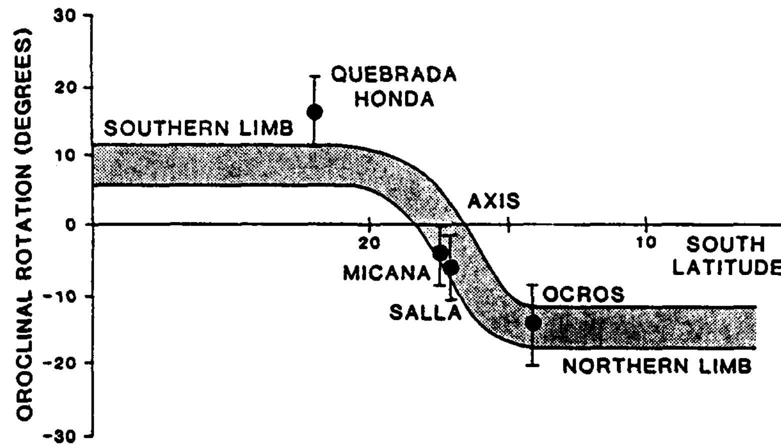

Figure 2. Predicted values (shaded) of oroclinal rotation (Isacks, 1988) and the late Cenozoic paleomagnetic data discussed here. The bars on either side of the calculated rotation (R) represent the estimated error, ΔR.

Conclusion

I prefer the hypothesis of Neogene oroclinal bending because the paleomagnetic data presented here are consistent with Isacks' (1988) model. However, these data could also represent local block rotations. Additional paleomagnetic data points are needed from other rocks in the Andes to further test these two alternate hypotheses.

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