

RESTORATION IN MAP VIEW OF THE PAMPEAN RANGES PROVINCE, SOUTHERN EDGE OF THE PUNA PLATEAU, ARGENTINA.

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RESUMEN : En el Noroeste Argentino (27°S), el límite meridional de la Puna es una zona transpresiva dextral : la zona de transición de Tucumán. Las estructuras regionales neógenas se desarrollaron como consecuencia de las variaciones de la intensidad de deformación continental entre dos segmentos corticales. En el sector Norte (Puna), el accortamiento neógeno y el espesor cortical son importantes. Al Sur, en las Sierras Pampeanas, la deformación continental es menor. Un método numérico de reconstrucción en mapa nos permite estimar los desplazamientos y el campo de deformación producidos por la tectónica neógena a través de la zona.

INTRODUCTION :

The Sierras Pampeanas of Argentina are located in the Central Andes at the southern edge of the Altiplano-Puna (27°S). The boundary between the high plateau and the northernmost Pampean Ranges is a major dextral transpressional zone : the Tucumán transfer zone (Jordan et al., 1983; Urreiztieta et al., 1996). A variation in the style of deformation within the foreland occurs across this transition zone (Allmendinger et al., 1983). The Sub-Andes are affected by thin-skinned deformation whereas the Pampean Ranges, located further South, are characterized by thick-skinned deformation. Deformation within the Pampean Ranges involves faulting and basement uplifts associated with block rotations about vertical axes. The study area consists of alternating Neogene compressional basins and ranges of Pre-Mesozoic crystalline basement. Ramp basins and basement uplifts are bounded by high angle thrusts and result from the bulk subhorizontal shortening and crustal thickening of the area since Miocene times (Gonzalez Bonorino, 1950). The Neogene detrital cover lies unconformably on an erosional surface which is exhumed on the tops of most crystalline basement ranges. This interface is easily identified both on the ranges (via topography and satellite images) and at the base of the basins (via seismic profiles). This plane of reference and the regional fault pattern were used to estimate the overlaps along major faults and to draw a mosaic of fault-bounded blocks throughout the Pampean Ranges area (Fig. 1). We have restored the crustal rigid block geometry using a numerical method of reconstruction in map view in order to compute the field of finite displacements associated with the fault network. We compare the numerical results with previous interpretations based on structural and paleomagnetic studies and discuss the regional tectonic patterns across the Pampean Ranges.

PRINCIPLE OF THE METHOD

To estimate the Neogene kinematics within the Pampean Ranges we used a numerical restoration method applicable in map view to non cylindrical compressional structures (Rouby *et al.*,

Figure 1.

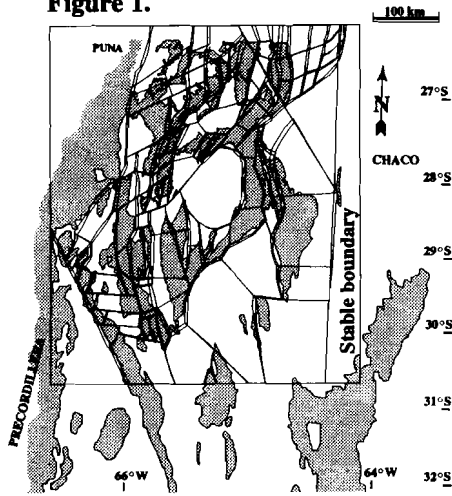


Figure 2.

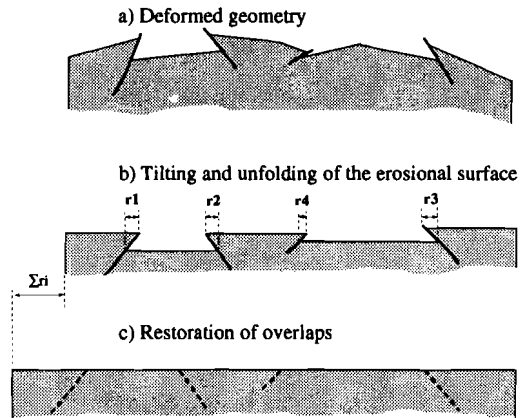


Figure 3.

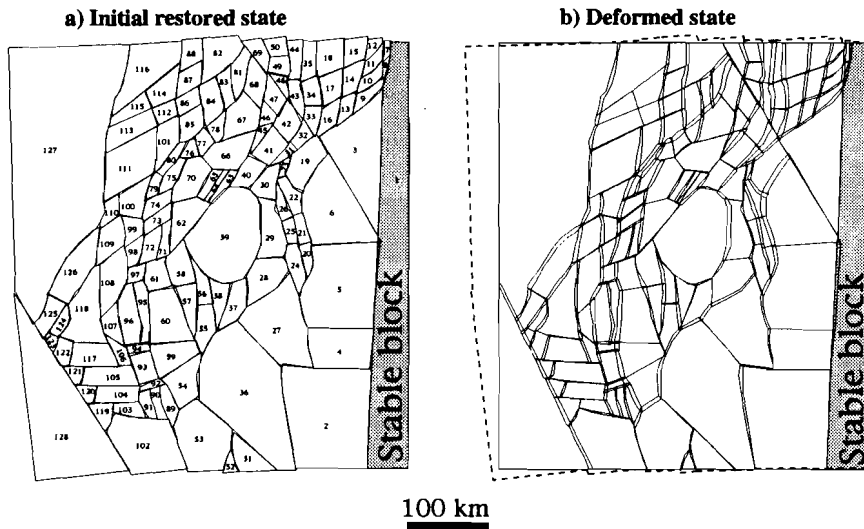
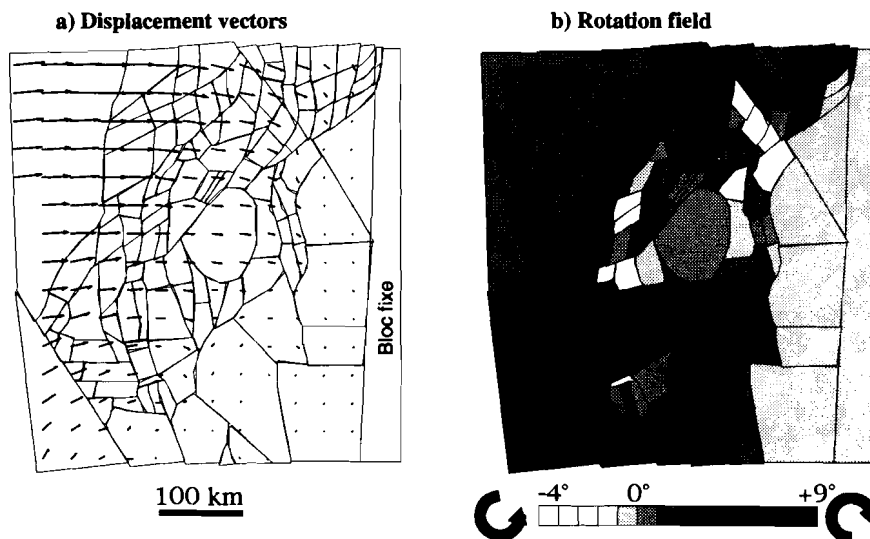


Figure 4.



1993; Bourgeois, 1994). The principle of restoration is to compute the initial undeformed state of an horizontal reference surface, assuming that displacement on the faults is achieved by rigid translations and rotations of the fault blocks. The initial data is a mosaic of fault bounded blocks overlapping each other along compressional structures (Fig. 1). The width of the overlaps is equal to the horizontal component of the amount of overthrusting corrected by the folding and tilting of the reference surface (Fig. 2). The displacement on the fault is inverted by minimizing gaps and overlaps at block boundaries using a series of rigid body translations and rotations about vertical axes centered at the block centroids. In doing so, we assume that internal strain of blocks is negligible with respect to the displacement along faults. The comparison between restored and deformed states gives the fields of finite displacements, finite block rotations and finite strain.

RECONSTRUCTION OF THE PAMPEAN RANGES

For the study area, the reference plane is the erosional surface (interface between Neogene cover and crystalline basement). We assume that it was horizontal before deposition of the Neogene cover. The carving of the area into 128 fault-bounded blocks fits the regional fault pattern (Fig.1). The dip of fault planes is arbitrarily chosen at 45°. The amount of overthrusting along regional faults is estimated using field observations and seismic surveys and corrected by untilting and unfolding of the reference surface (Fig. 2). The blocks are adjusted against the stable easternmost boundary (equivalent to the Andean foreland; Fig. 1). After numerical fitting, gaps and overlaps between rigid blocks remain but they are negligible with respect to the overall area.

FIELDS OF FINITE DISPLACEMENTS, ROTATIONS AND STRAIN

Displacement vectors are the finite displacements of points of a regular grid attached to the block mosaic between the initial and final stages (Fig. 3). Displacements increase away from the stationary boundary (Fig. 4a). Furthermore, displacements increase from the South towards the Northwest, defining two sectors limited by a NE-SW trending strip (equivalent to the Tucumán transition zone). This pattern suggests that the absolute motion of the blocks towards the East is greater in the Puna. Rigid blocks in the vicinity of the plateau were translated twenty kilometers towards the NE. This finite displacement field (Fig. 4a) and the geometry of the regional fault pattern are compatible with a dextral component along the NE-SW trending Tucumán transfer zone (TTZ).

Individual rigid block rotations calculated by the reconstruction are mostly clockwise (Fig. 4b). Rotations reach maximal values (9°) within the TTZ, where *en échelon* blocks bound the plateau. This pattern of bulk clockwise rotations is compatible with a regional component of dextral wrenching along the southeastern edge of the Puna. The clockwise block rotations are consistent with paleomagnetic measurements along the southeastern edge of the Puna (Roperch et al., 1996). Paleomagnetic results within Cretaceous to Pliocene sequences also confirm the bulk clockwise pattern of block rotations (up to 29° within the TTZ). The magnitudes of rotations calculated by the restoration are smaller than the measured paleomagnetic rotations. This suggests that we have probably under-estimated the strike-slip components along major faults.

The finite element analysis of the displacement field gives the orientations of the principal shortening and stretching axes within each cell of a regular grid. We have compared the orientations of the principal axes of deformation with the orientations of axes obtained from the analysis of fault populations measured at 72 localities in the field (Fig. 5). The fault population analysis shows that the shortening directions are sub-horizontal at most localities and are therefore comparable with the horizontal shortening directions obtained by restoration. Both methods show a substantial scattering of the orientations of shortening axes throughout the area (Fig. 5). There is a good consistency between both sets of results (Fig. 5). Two main shortening directions are represented. The first shortening orientation is widespread and trends roughly E-W. The second shortening orientation is locally observed in the vicinity of the Puna within the TTZ and strikes NW-SE. Furthermore, unlike field observations, restoration estimates the amount of dextral wrenching parallel to the TTZ (Fig. 6). The dextral component along the southern edge of the Puna appears to be significant (bulk dextral shearing is about $\gamma = 0,20$.) It is combined with a NW-SE regional shortening of 10%.

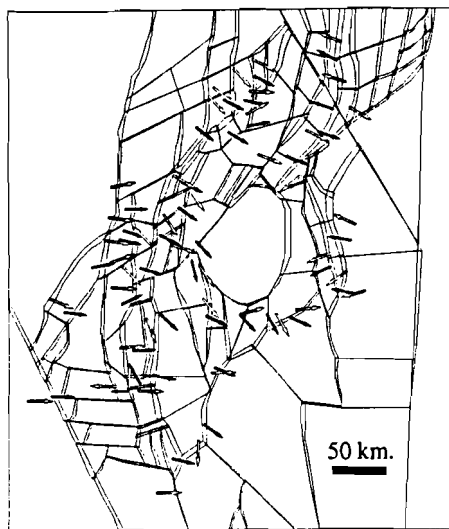



Figure 5.

 Shortening axes from fault kinematics
 Shortening axes from restoration

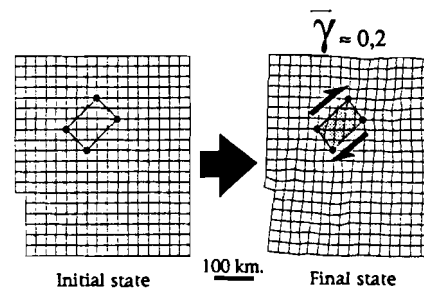


Figure 6.

CONCLUSIONS

The finite displacement, rotation and strain fields calculated by restoration are consistent with the results of (1) the fault populations analysis, and (2) the paleomagnetic study.

The displacement field confirms a dextral component along faults parallel to the TTZ and indicates an overall dextral motion along the TTZ of 20 km. The clockwise rotations associated with the motion along regional faults are maximal within the TTZ. Furthermore, we confirm that the NW-SE regional shortening across the TTZ is at least 15 km. Fault population analysis and restoration show a strong consistency. The scattering of shortening directions measured in the field is also shown by the numerical restoration. Across the Tucumán Transfer Zone, results of both methods reflect the superimposition of two main deformation fields: (1) a ENE-WSW to E-W subhorizontal shortening probably related to bulk convergence between Nazca and South America plates, and (2) a NW-SE subhorizontal shortening consistent with dextral wrenching along the TTZ and with southeastward expansion of the high plateau. The resulting bulk strain is locally of constrictional type, with subvertical principal extension.

The finite displacement and strain field calculated by the reconstruction method does not take into account the history of deformation. However, the remarkable correlation between the results of this numerical method and other independent methods suggests that the complex strain field accumulated in the area probably results from a progressive deformation.

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