PALEOGENE-LOWER MIOCENE LOCAL CLOCKWISE VERTICAL AXIS TECTONIC ROTATIONS IN THE NORTHERN ARGENTINA PUNA: NEW DATA

Claudia Prezzi[1*], Pablo Caffe[2], María Paula Iglesia Llanos[1*]

[1] CONICET, Universidad de Buenos Aires. IGEBA, Dpto. de Cs. Geológicas, FCEyN, Universidad de Buenos Aires. Ciudad Universitaria, Pabellón 2, 1428, Buenos Aires, Argentina. Tel/Fax: +54-11-4788-3439. prezzi@gl.fcen.uba.ar

[2] CONICET – Instituto de Geología y Minería, Universidad Nacional de Jujuy. Avda, Bolivia 1661, S. S. de Jujuy, Argentina.

Resumen

En los Andes Centrales se ha identificado un patrón de rotaciones tectónicas (PRAC) según ejes verticales a través de estudios paleomagnéticos. Diferentes hipótesis han sido propuestas tratando de explicar el PRAC, sin embargo el debate continúa. Recientemente, distintos autores han sugerido la existencia de distintos dominios rotacionales con diferentes características. En particular, las rocas paleógenas del norte de Chile y de la Cordillera Oriental habrían registrado rotaciones grandes. Aparentemente existiría una estrecha correlación entre el patrón espacial y temporal de deformación y la magnitud de las rotaciones según ejes verticales. Con el objetivo de profundizar en la investigación de dicha correlación se han llevado a cabo nuevos estudios paleomagnéticos en rocas paleógenas – miocenas inferiores aflorantes en la Puna Norte. Los resultados obtenidos indican que mientras una de las localidades muestreadas no ha sufrido rotaciones según ejes verticales significativas, las otras dos localidades han registrado rotaciones según ejes verticales en sentido horario mayores a los 30°. Estos resultados sugieren que las rotaciones detectadas serían de tipo local, e indicarían que mientras las rocas más antiguas que 17 Ma han sufrido rotaciones horarias de gran magnitud, las rocas suprayacentes no han sido afectadas por deformación rotacional.

Abstract

Along the Central Andes a pattern of vertical axis tectonic rotations has been paleomagnetically identified. Such rotations are counterclockwise north of Arica Deflection (~19° S) and clockwise to the south. Different hypothesis and models have been proposed to explain the Central Andean Rotation Pattern (CARP). However, the CARP is a subject of ongoing debate. Recently, different authors have proposed the possible existence of different rotational domains with distinct characteristics. Particularly, paleogene rocks cropping out in northern Chile and in the Eastern Cordillera would have registered large rotations. A close correlation would exist between the style and the temporal and spatial pattern of deformation and the amount of recorded vertical axis rotations in the Southern Central Andes. In order to further investigate such relationship, new paleomagnetic studies were carried out in Paleogene – Lower Miocene rocks of the northern Argentine Puna. Our results indicate that while one of the sampled localities did not undergo significant vertical axis tectonic rotations, the other two registered clockwise vertical axis tectonic rotations larger than 30°. These results suggest that rotations are of local character, and would indicate that while rocks older than 17 Ma underwent large magnitude vertical axis rotations, the overlying rocks were not affected by rotational deformation.

Introduction

Along the Central Andes a pattern of vertical axis tectonic rotations has been paleomagnetically identified (*e.g.* Isacks, 1988; Beck, 1988). This Central Andean Rotation Pattern (CARP, Somoza *et al.,* 1996) is characterized by counterclockwise block rotations north of Arica Deflection (~19° S) and clockwise rotations to the south. Different hypothesis and models have been proposed to explain the CARP. Isacks (1988) presented a regional oroclinal model, suggesting that an ancient curvature of the margin was enhanced to accommodate along- strike gradient of neogene horizontal-shortening in the eastern part of the Central Andes. Alternatively, models suggesting the existence of local block rotations in response to distributed shear have also been proposed (*e.g.* Beck, 1988; Somoza *et al.,* 1996). In such models, the Arica Deflection is considered a primary feature of the Andean chain. Some authors (*e g.* Butler *et al.,* 1995) developed models which combine oroclinal bending and local block rotations. Domino-style models that relate the rotations detected in northern Chile to observable faults in the forearc have also been published (*e.g.* Abels and Bischoff, 1999). However, Arriagada *et al.* (2003) found clockwise tectonic rotations of up to 65° within the forearc domain (Antofagasta region), which would have occurred mainly during the Incaic orogenic event of Eocene-early Oligocene age. Taylor *et al.* (2005) also noted that many of the rotations detected in the forearc of northern Chile are particularly large and appear to record a rotational event older than those observed elsewhere in the Central Andes. They argued that such data define a domain marked by large clockwise crustal rotations related to late paleocene–early eocene highly oblique convergence.

Most of the models developed to explain the CARP are of regional character (*e.g.* Isacks, 1988; Beck, 1988; Butler *et al.,* 1995) and do not consider the possible existence of different rotational domains in the Central Andes. Local models have also been proposed, but they are focused in the forearc (*e.g.* Abels and Bischoff, 1999; Arriagada *et al*., 2003; Taylor *et al*., 2005). Recently, the quantity, quality, and geographic distribution of paleomagnetic data have expanded greatly (*e. g.* Maffione *et al*., 2009). The increased paleomagnetic data set has been accompanied by an increase in the current knowledge of the deformation periods in the Andes (*e.g.* Oncken *et al.,* 2006; Barnes and Ehlers, 2009), allowing a more detailed analysis of the temporal and spatial distribution of the detected rotations. Prezzi (2011) and Iglesia Llanos and Prezzi (this volume) highlighted that paleogene rocks cropping out in northern Chile and in the Eastern Cordillera would have registered large rotations. These authors suggested that a close correlation would exist between the style and the temporal and spatial pattern of deformation and the amount of recorded vertical axis rotations in the Southern Central Andes. In order to further investigate such relationship, new paleomagnetic studies were carried out in Paleogene – Lower Miocene rocks of the northern Argentine Puna. Our results indicate that while one of the sampled localities did not undergo significant vertical axis tectonic rotations, the other two registered clockwise vertical axis tectonic rotations larger than 30°.

Geologic and tectonic setting

Our work is focused on the paleomagnetic study of some of the oldest deposits from the San Juan de Oro basin, stranded in the transition between the northern Puna and southernmost Bolivian Altiplano (22º–22.5º S). The San Juan de Oro basin (SJOB) is the broadest Neogene basin in northern Puna (Fig.1), covering a large area whose basement is represented by Ordovician rocks and thin Cretaceous to Paleocene rocks from the Salta Group (Coira *et al*., 2004). The first sedimentary record corresponds to the Paleogene to Lower Miocene thick fluviatile redbed deposits from the Peña Colorada (Coira *et al*., 2004), San Vicente (Fornari *et al*., 1993) and Esmoruco (Garcia, 1997) Formations. One of the main characteristics of early Neogene Puna basins shared by the SJOB, is the intercalation of sediments with volcanic products (Caffe and Coira, 2002), which in the southern San Juan de Oro basin is represented by the the Middle Miocene (15-12 Ma) Tiomayo Fm. (see Prezzi *et al*., 2004). However, in the northern part of the basin there are several other volcanosedimentary units older than Tiomayo, as the Cabrería Fm. and Torrelaire Tuffs that usually mantle redbed deposits and are recording some of the first volcanic pulses in the region. Since the Upper Miocene, the infilling has been even more volcanic, almost exclusively composed by ignimbritic successions erupted from large caldera structures (Figs. 1 and 2).

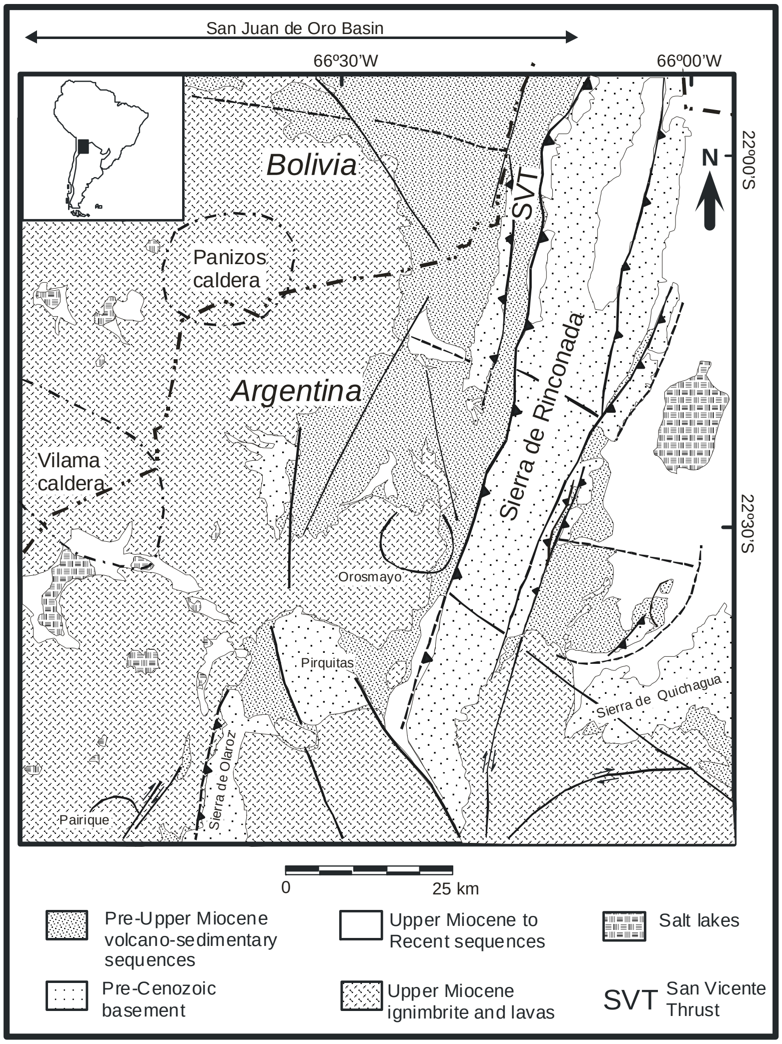

Figure 1: Simplified geologic map of the San Juan de Oro basin (Modified from Prezzi et al., 2004).

Argentine localities: Casa Colorada and Paicone localities – Peña Colorada Formation:
This unit is of fluvial origin. It is mainly composed by reddish conglomerates and sandstones. Two members were identified: the Lower Villa María Member and the Upper San Isidro Member (Coira *et al.,* 2004). The transition between both members is defined by the progressive disappearance of conglomerates and the increasing presence of volcaniclasts and gypsum. An angular unconformity is observed between Peña Colorada Fm and the Ordovician basement (Fig. 2). In Casa Colorada locality (Fig. 2), Peña Colorada Fm is gently folded in a symmetric anticline (10 km wave-length), whose eastern limb was sampled. On the other hand, in Paicone locality (Fig. 2) this unit has a subhorizontal attitude, with shallow inclination to the west. The Lower Villa María Member is mainly composed by conglomerates and medium to coarse gray, red and yellow sandstones. In Casa Colorada locality, the total thickness of this Member is of 35 m, and material of volcanic origin is totally absent. Considering its lithology, this portion of Peña Colorada Fm could be correlated to the San Vicente Fm in Bolivia (Fornari *et al.*, 1993). The San Isidro Member is thicker than the Villa María Member, is mostly of red color, and the presence of conglomerates is very scarce. In Casa Colorada locality, its total thickness is of 210 m and

it is predominantly composed of medium to coarse sandstones. Some of them are white, yellow or green carbonatic or ferruginous. Red, massive mudstones, frequently with gypsum-calcite-aragonite veins and nodules are intercalated in the sequence. The outcrops sampled in Paicone locality, with a total thickness of 75 m, would be part of the San Isidro Member.

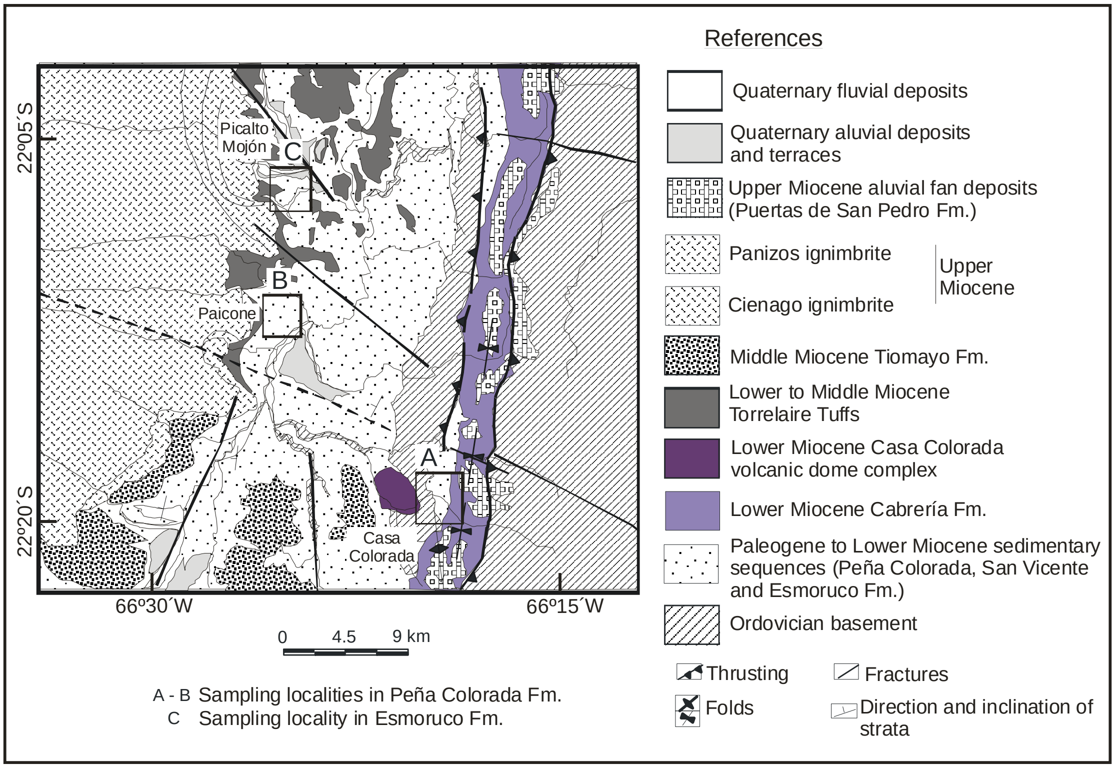

Figure 2: Geologic map of the principal units cropping out in the northern San Juan de Oro basin. The location of the sampled localities is shown.

Peña Colorada Fm age is not well defined, being assigned to the Paleogene – Upper Lower Miocene. In the Bolivia – Argentina border, Peña Colorada Fm overlies in angular unconformity the Santa Bárbara Subgroup (Paleocene-Eocene). In Casa Colorada locality it is covered by Cabrería Fm (17.4 ± 0.8 Ma) (Caffe and Coira, 2002) and by a block and ash deposit from Casa Colorada Volcanic Complex (17.3 ± 0.7 Ma) (Coira *et al.*, 2004).

Bolivian locality: Picalto – Mojón locality: Esmoruco Formation:
This fluviatile-lacustrine unit (García, 1996), is equivalent to part of Peña Colorada Fm. In Picalto Mayu, Esmoruco Fm overlies the Upper Oligocene San Vicente Fm (García, 1997). It is mainly composed by beds of massive white and red sandstones and mudstones with thicknesses of 1 to 3 m. Sandstones are in part carbonatic and gypsiferous and contain volcanic material. The total thickness of the sampled sequence in Picalto-Mojon locality is ~80 m. In the studied locality Esmoruco Fm is overlain by Tobas Torrelaire 1, dated at 17.1 ± 0.6 Ma (García, 1997). The lithological and geochronological similarities between Tobas Torrelaire 1 and Cabrería Fm, and the presence of volcanic material and gypsum nodules allow the correlation of Esmoruco Fm with the Upper San Isidro Member of Peña Colorada Fm.

Paleomagnetic sampling, methods, analysis and results

Samples were collected using a portable field drill and oriented using magnetic and solar compasses. In Casa Colorada locality (Fig. 2) the lower Peña Colorada Formation (Villa María Member) was sampled in 10 sites. In Paicone locality (Fig. 2) the upper Peña Colorada Formation (San Isidro Member) was sampled in 7 sites. North of Paicone locality, in Picalto - Mojón locality (Bolivia) the Esmoruco Formation was sampled in 5 sites (Fig. 2). A total of 121 oriented samples were obtained.
Magnetization was measured using a 2G Enterprises cryogenic magnetometer. Detailed thermal demagnetization techniques were applied. 18 steps up to temperatures of 700 ◦C were performed using a Schonstedt TSD-1furnace. The bulk magnetic susceptibility was measured after each heating step in order to monitor possible magnetic mineral changes.
The corresponding components of natural remanent magnetization (NRM) were determined using principal components analysis (Kirschvink, 1980) when linear trends of vector end points were identified. Site-mean directions were determined applying Fisher's (1953) statistics. The correspondent rotations, inclination flattening and their confidence intervals were calculated in direction space (Demarest, 1983). The site-mean directions have positive and negative inclinations, so the reversal test (McFadden and McElhinny, 1990) was performed. In Picalto-Mojón and Casa Colorada localities the test was successful with classification C. In Paicone locality there was only one site with reverse polarity, and the isolated observation reversal test was Indeterminate. The positive reversal tests support the idea that there is no bias due to inappropriate analysis or deficient demagnetization and that site-mean directions fully average secular variations and reflect an axial dipole field. The fold test (McFadden, 1990) was also performed, but it was indeterminate, probably due to the low inclination (less than 15°) and very similar attitude of the beds sampled in the different sites. The following rotation values were calculated for each one of the sampled localities: Casa Colorada: $R \pm \Delta R = 37.5° \pm 7.7°$; Paicone: $R \pm \Delta R = -1.4° \pm 10.3°$; Picalto-Mojón: $R \pm \Delta R = 32.2° \pm 13.5°$.

Discussion and conclusions

Prezzi *et al.* (2004) showed the existence of very low, statistically insignificant rotation in middle Miocene rocks from Tiomayo Fm which overlie the Peña Colorada Fm sampled in this work. Upper Miocene (10 Ma and younger) ignimbrites, which overlie these middle Miocene rocks, are unrotated (Somoza *et al.*, 1996). On the other hand, our results show that Paleogene – Lower Miocene rocks recorded local clockwise rotations larger than 30º. The main fault in the study area, the west vergent San Vicente Thrust (Figs. 1 and 2), was active during late Oligocene–early Miocene times (Müller *et al.*, 2002). Undeformed, ca.17 Ma ignimbrites that cover this thrust and associated sedimentary deposits in the Bolivian sector indicate end of fault motion by the late early Miocene (Müller *et al.*, 2002). Likewise, on the basis of a local unconformity observed in the northern Puna, Caffe and Coira (2002) suggested that the motion of this fault stopped between 18 and 15 Ma. Then, major activity in the San Vicente Thrust could have occurred simultaneously with or subsequently to the deposition of the units paleomagnetically studied in this work, but previously to the deposition of Tiomayo Fm and the Upper Miocene ignimbrites.
These results would support the existence of the close correlation between the style and the temporal and spatial pattern of deformation and the amount of recorded vertical axis rotations in the Southern Central Andes proposed by Prezzi (2011) and Iglesia Llanos and Prezzi (this volume).

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