Geologica Acta, Vol.5, Nº 4, 2007, 287-294
Available online at www.geologica-acta.com



# A paleomagnetic analysis of the Patagonian Orocline

A.E. RAPALINI

INGEODAV, Depto. Cs. Geológicas, F.C.E. y N., Universidad de Buenos Aires
Pabellón 2, Ciudad Universitaria, C1428EHA, Buenos Aires, Argentina. E-mail: rapalini@gl.fcen.uba.ar

ABSTRACT

The dramatic change in the structural trend of the Andean orogen in southernmost Patagonia has long been considered a possible example of a true orocline. Paleomagnetism has proved a powerful tool to determine whether a curved orogen acquired its shape as a secondary feature. Paleomagnetic data obtained so far in the southern Patagonian and Fuegian Andes are reviewed in order to test the origin of the Patagonian orocline. Systematic counterclockwise (ccw) rotations along the arc are suggested by widespread ccw deflections of paleomagnetic declinations, which may be compatible with some secondary curvature of the orogen. Larger values of declination anomalies in the outer arc are consistent with some oroclinal bending related to mid-Cretaceous closure of the Late Jurassic – Early Cretaceous Rocas Verdes marginal basin. However, a thorough paleomagnetic test of the origin of the Patagonian Orocline is hampered by several problems that affect most results. These include scarce and unevenly distributed studied localities, low quality paleomagnetic data, lack of paleohorizontal control and uncertainty in magnetization ages. The fact that most data obtained so far is still scarce and questionable precludes a reliable answer to whether the southern Patagonian – Fuegian Andes are a true orocline

*KEYWORDS* **Paleomagnetism. Patagonia. Southern Andes. Orocline. Tectonic rotations.**

## INTRODUCTION

The Andean orogen presents a dramatic change (ca 90°) in its strike around 53°S, where from a roughly north-south direction in continental Patagonia turns into an east-west orogen in the island of Tierra del Fuego (Fig. 1). This bend is known as the Patagonian Orocline, after Carey (1955). Dalziel and Elliot (1973) proposed that an originally rectilinear orogen comprising the southern Patagonian-Fuegian Andes and the Antarctic Peninsula, was subsequently curved during the opening of the Drake Passage in the Tertiary. As already pointed out by Cunningham et al. (1991), a yet unresolved problem in the evolution of the Southern Andes is whether the Patagonian Orocline formed as a curved orogen, it is a non-rotational arc with domains offset by strike-slip faults or it has been produced by orogenic rotation (“oroclinal bending”). Paleomagnetism is a very powerful tool to discriminate between such end-models and to unravel the kinematic evolution of an arcuate orogen both in space and time (see Morris and Anderson, 1998). The available paleomagnetic information regarding this topic and its implications on the tectonic evolution of the southernmost Andes are presented and discussed in this contribution.

## DISCUSSION OF AVAILABLE PALEOMAGNETIC DATA

Paleomagnetic studies in the southernmost Andes are yet scarce and the quality of the data is far from ideal.

Figure 1 displays the distribution of paleomagnetic declinations obtained so far in this region. As previously pointed out from a much reduced database (Dalziel et al., 1973; Burns et al., 1980; Cunningham et al., 1991), these data seem to reflect a systematic pattern of counterclockwise (ccw) rotations that approximately follow the change of strike of the Andean chain. According to these authors, this should be interpreted as evidence in favor of an oroclinal bending of the Andean chain at these latitudes. The actual cause and mechanisms behind this bending, however, remain elusive. Cunningham (1993) proposed a tectonic model that involves inception of successive transversal strike-slip systems that migrate northwards along the south Patagonian Andes since the Cretaceous, producing ccw rotations and sinistral displacements that yield a regional curvilinear orogen. Kraemer (2003) has recently proposed a model for the origin of the Patagonian orocline related to the closure of the Rocas Verdes marginal basin in the mid- to Late Cretaceous. Other authors, however, have preferred a different mechanism, assigning at least part of the anomalous paleomagnetic declinations to counterclockwise block rotations associated to wrenching during Late Cretaceous tectonic inversion of the Rocas Verdes basin (e.g. Diraison et al., 2000), with a minor

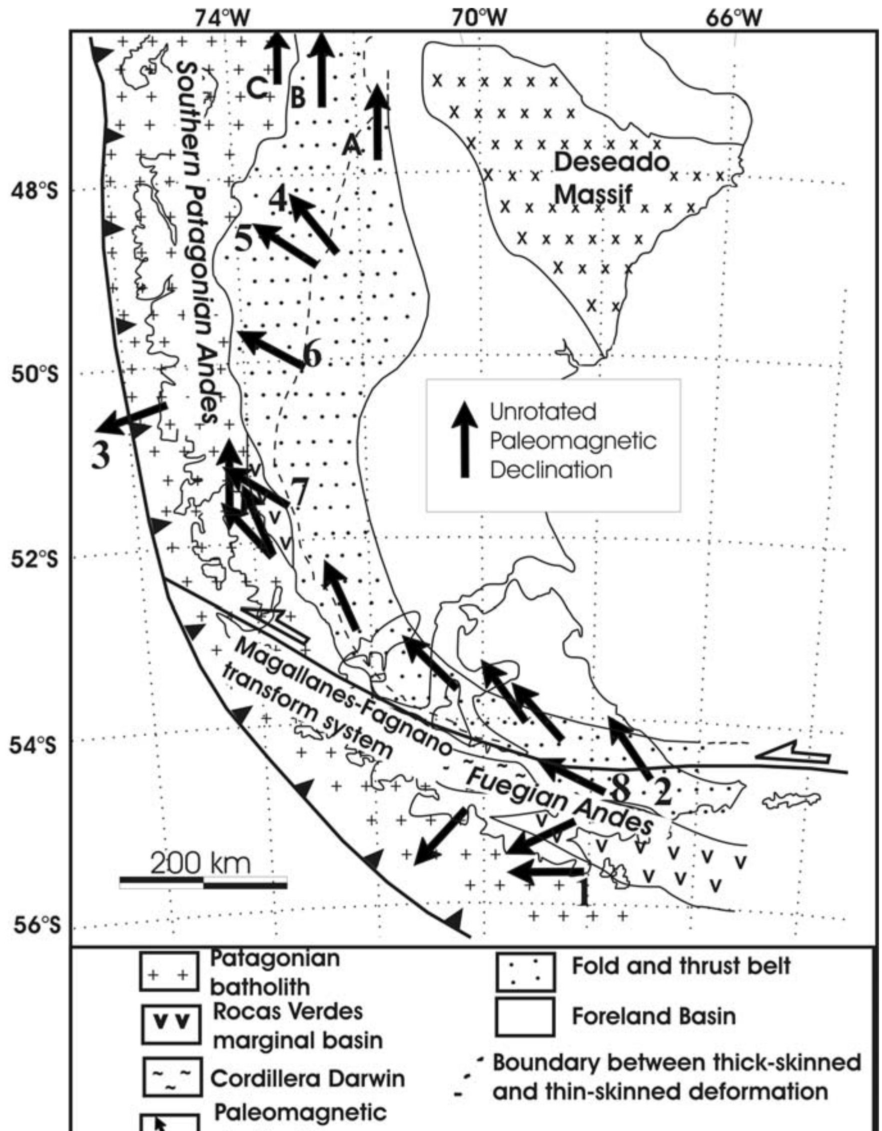


FIGURE 1 **Distribution of paleomagnetic declinations of published data from the Patagonian Orocline. Data from Dalziel et al. (1973), Burns et al. (1980), Cunningham et al. (1991), Rapalini et al. (2001, 2004, 2005), Baraldo et al. (2002), Iglesia Llanos et al. (2003). Numbered localities correspond to results selected in Table 1. A, B and C, results north of 48°S that do not show significant declination anomalies (from Iglesia Llanos et al., 2003, Roperch et al., 1997 and Beck et al., 2000, respectively). Map modified from Diraison et al. (2000).**

component of oroclinal bending. Other hypotheses suggest that the curvature of the southern Andes is a primordial feature and that tectonic rotations occurred only as discrete blocks associated to strike-slip displacement (Ghiglione, 2003; Ghiglione and Ramos, 2005). Under this latter model the evolution of the Fuegian Andes can be explained in terms of a non-rotational arc.

With the exception of the latter, the above-mentioned different hypotheses have not substantially questioned the reliability of the published paleomagnetic data. The seemingly systematic and coherent distribution of ccw rotated paleomagnetic declinations has probably given extra credit to the paleomagnetic data. However, an inspection of the published data indicates that some of these studies cannot pass present-day minimum reliability criteria (e.g. Van der Voo, 1990; Schmidt et al., 1990).

## Paleomagnetic database

The first published paleomagnetic results from the Patagonian Orocline belong to Dalziel et al. (1973). They reported results from 27 sites (191 samples) distributed in three localities (the Beagle Channel on the Navarino Island, the western Beagle Channel, NW of Londonderry Island and the southern Chile fiords region north of 52°S). Positive results were obtained in 50 samples from 7 sites. In general, the studied rocks were dikes and other intrusives, with ages ranging from Late Jurassic to Early Tertiary. Very large ccw rotations found on rocks south of the Patagonian bend and much reduced rotations to the north suggested to Daziel et al. (1973) a paleomagnetic support for the secondary (oroclinal) bend of the southern Patagonian Andes.

This study was followed a few years later by Burns et al. (1980), who presented paleomagnetic results from different localities around the bend, which included the Navarino island (Cretaceous Dientes de Navarino sill), the Sierra de Valdivieso (Isla Grande de Tierra del Fuego, Jurassic Serie Tobífera), the Isla Carlos in the strait of Magallanes (basaltic flows) and the lago San Martín area in the province of Santa Cruz (Argentina, diorite and andesite sills). These authors found smaller ccw rotations than those reported by the previous ones. Since they collected their samples in the inner arc, they concluded that the bending of the inner arc could not have been larger than around 50°, and that the Southernmost Andes were originally a partially curved orogen. Larger values in the outer arc, as obtained by Dalziel et al. (1973), might be due to an “oroclinal” rotation associated to the closure of the Rocas Verdes marginal basin in the Cretaceous, which might be the cause of the bending of the inner arc as well.

These two studies were the only published that have been undertaken in a regional scale, with their sparse sampling localities distributed along the whole bend. Therefore, these studies are the most significant for the oroclinal bending hypothesis (Fig.1). However, present-day reliability criteria for paleomagnetic data include the application of stepwise demagnetization techniques to all samples to discriminate different magnetic components, and vectorial analysis of demagnetization results in order to determine the direction of the magnetic components (e.g., Butler, 1992). In contrast, the previously mentioned studies are based on old-fashioned blanket demagnetization techniques with no application of vectorial analysis. Burns et al. (1980) study even lacks any single detail on magnetic behavior of the samples. On such experimental grounds, positive fold tests, as claimed for some localities, are at least dubious. According to present-day criteria these results cannot be accepted anymore for any significant tectonic interpretation. If results for these two studies are omitted, we are reduced to a much smaller paleomagnetic database to be used in tectonic interpretations (Fig. 2, Table 1). A much less impressive and significant distribution of declination anomalies remains in this case.

The filtered dataset is then composed of three paleomagnetic studies in southern Tierra del Fuego (Cunningham et al., 1991; Baraldo et al., 2002; Rapalini et al., 2005) and three in the southern Patagonian Andes (Rapalini et al., 2001, 2004; Iglesia Llanos et al., 2003; Table 1). Despite several problems with the age of the rocks, paleohorizontal control, amount of sites and samples, all the remaining studies can pass present-day laboratory reliability criteria which require complete stepwise demagnetization of all samples by either or both thermal and alternating magnetic fields and determination of magnetic components by vectorial analysis.

Three of these selected studies were carried out in Tierra del Fuego. One of them corresponds to the Upper Jurassic –Lower Cretaceous Hardy Formation (Fm) exposed in Peninsula Hardy (Hoste Island, Chile). There, Cunningham et al. (1991) reported a post-tilting, presumably mid- to Late Cretaceous, magnetization that indicates 90°±12° ccw rotation around a vertical axis, with no significant inclination anomaly. Another study was carried out on the monzogranitic intrusive body exposed at Cerro Hewhoepen in the Argentine sector of Tierra del Fuego. This intrusive has been dated as Late Cretaceous (93±4 Ma; Acevedo et al., 2000). The study reported by Baraldo et al. (2002) indicated an anomalous paleomagnetic direction which was interpreted as indicative of a 33°±7°ccw rotation and a northward tilting of the body of 40°±6°. The third result comprises only two sites reported by Rapalini et al. (2005), one on a Late Jurassic basaltic sill of the Lemaire Fm., with a likely Late Cretaceous post-tectonic remagnetization and the other on the Late Cretaceous Ushuaia dacite. A ccw declination anomaly of around 60° is observed for these two sites. A significant difference in amount of rotation is shown between the external and the internal areas of the Fuegian Andes, with an apparent decrease in the amount of rotation towards the north. If a broadly similar age for magnetization of all studied units is assumed, a geographic pattern of smaller rotations towards the north is possible. On the other hand, a northward decrease in magnetization age cannot be ruled out with the available results. In this case different rotation values may reflect progression of regional rotation. In any case, interpretation of these results in terms of oroclinal bending is not straightforward for several reasons, not the least that local crustal block rotations cannot be ruled out, considering the localized distribution of sampling sites. Further complications and uncertainties in the interpretation of the data are discussed below.

The studies in the southern Patagonian Andes correspond to the Upper Carboniferous to Lower Permian Tarlton and Denaro formations exposed in the Madre de Dios Archipelago (Rapalini et al., 2001), the Upper Jurassic El Quemado Complex (Iglesia Llanos et al., 2003) and the Late Jurassic – Early Cretaceous Sarmiento Ophiolitic Complex (Rapalini et al., 2004). The first mentioned study revealed a post-folding magnetization of possible

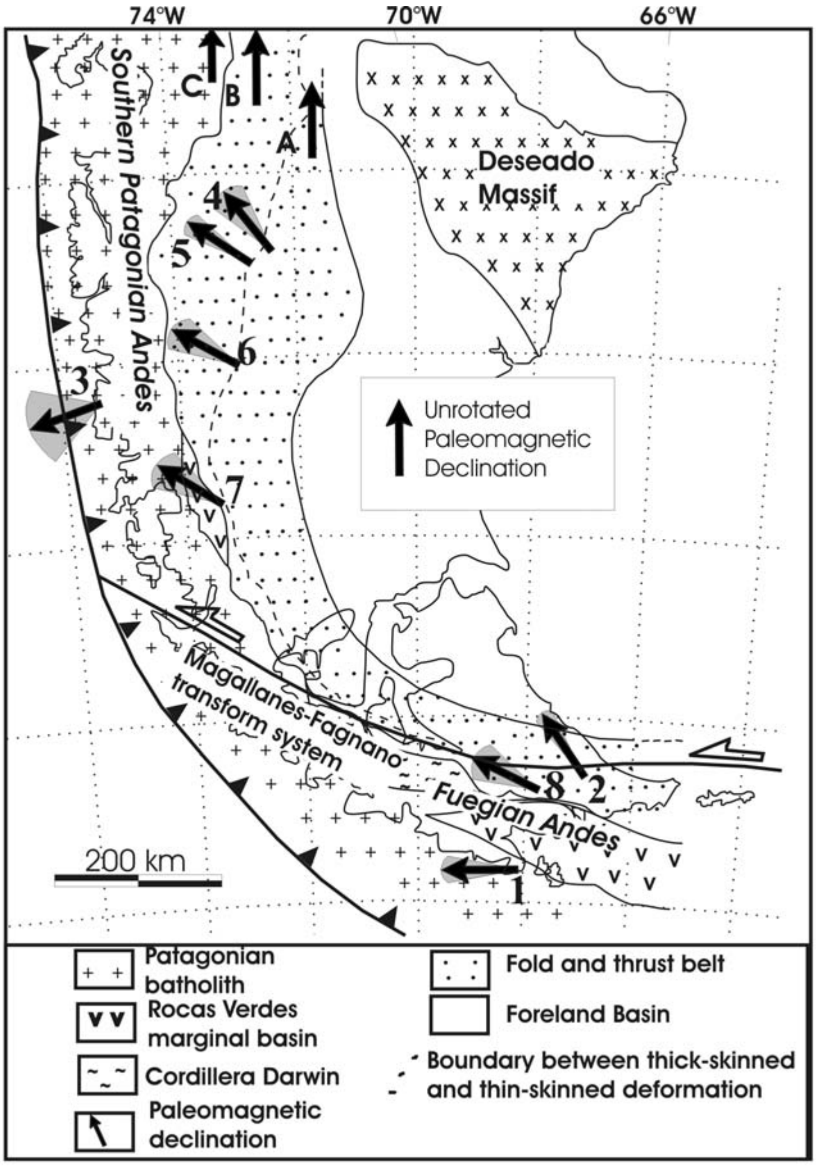


FIGURE 2 **Published paleomagnetic data from the Patagonian Orocline that pass present reliability criteria for laboratory procedures. Ninety per cent confidence limits for declination anomalies are shown as grey zones. Details of these studies are presented in Table 1. Map modified from Diraison et al. (2000).**

TABLE 1 | **Paleomagnetic data from the Patagonian Orocline that pass present-day reliability criteria of laboratory procedures. Numbered localities correspond to those shown in Figure 2.**

| Loc. | Geologic unit | Geog. Coord. | Rock type and age | Magnetization age | Paleohorizontal control | Rotation | Reference |
|---|---|---|---|---|---|---|---|
| 1 | Hardy Fm. | 55.5°S, 68.2°W | Late Jurassic-Early Cretaceous sedim. and volcanics | Mid Late Cretaceous? | NO | 90°±12° | Cunningham et al. (1991) |
| 2 | Hewhoepen Intrusive | 54.7°S, 67.3°W | Late Cretaceous (93±4Ma) monzodiorite | Late Cretaceous | NO | 33°±7° | Baraldo et al. (2002) |
| 3 | Denaro and Tarlton Fms. | 50.4°S,75.4°W | Late Carboniferus-Early Permian basalts and limestones | post-Early Cretaceous | NO | 118°±30° | Rapalini et al. (2001) |
| 4 | El Quemado complex (SMN) | 49.0°S, 72.2°W | Late jurassic arkoses, ignimbrites, rhyolites | Late Jurassic | YES | 30°±14° | Iglesia Llanos et al. (2003) |
| 5 | Idem (SMN) | 49.1°S, 72.5°W | Late Jurassic dacites, ignimbrites, rhyodacites | Late Jurassic | YES | 57°±9° | Idem |
| 6 | Idem (LA) | 50.2°S, 72.8°W | Late jurassic dacites, tuffs, ignimbrites | Late Jurassic | YES | 62°±15° | Idem |
| 7 | Samiento Complex | 51.7°S, 73.6° | Late Jurassic ophiolites (lavas, dykes, sills) | Late Cretaceous? | NO | 59°±17° | Rapalini et al. (2004) |
| 8 | Lemaire Fm and Ushuaia dacite | 54.6°S, 68.0°W | Late Jurassic basaltic sill and late Cretaceous dacite | Late Cretaceous? | NO | 66°±10° | Rapalini et al. (2005) |

Early Cretaceous age and apparently related to the intrusion of the south Patagonian batholith. The mean remanence direction shows a counterclockwise rotation of 118°± 30° with negligible inclination anomaly. The results presented in second term come from three different localities south of 49°S (Lago San Martin north (SMN) and south (SMS) and Lago Argentino (LA)) in the southern Patagonian Andes of Argentina. At two of these localities (SMS and LA, see Table 1) a positive tilt-test suggests a primary magnetic remanence. All three localities show ccw rotations around vertical axes of 39°±14°, 57°±9° and 62°±15°, respectively. Very similar rotation values are therefore found in rocks exposed over 100 km apart, suggesting a regional rotation or a systematic tectonic pattern. Finally, preliminary paleomagnetic data from widely distributed sites in the Late Jurassic – Early Cretaceous Sarmiento ophiolitic complex in southern Chile (Rapalini et al., 2004) yielded a post-folding (Late Cretaceous?) magnetic component which also shows a ccw declination anomaly of 59°±17° with very minor inclination anomaly. This result is almost identical to those from the El Quemado Fm. in the southern Andes of Argentina, suggesting a region of over 250 km long with very similar declination anomalies, both in sense and magnitude (Fig. 2). As in the case of the Fuegian Andes, a much larger rotation is found in the westernmost zone of the Andean orogen, oceanward from the Rocas Verdes back-arc basin.

Another interesting feature of the southern Patagonian data is that the amount of in situ rotation (near 50°) is significantly larger than the expected as the result of wholesale rotation of near 25° of a former N-S orogen at those latitudes. This implies that a simple oroclinal bending model cannot easily account for the rotation pattern already found. The much larger rotations observed outboard of the Rocas Verdes back arc basin, both in southern Patagonia and Tierra del Fuego suggest that its closure, which started in mid-Cretaceous, may have played a significant role in the extreme large rotations determined in these areas, as already proposed by Burns et al. (1980) and Kraemer (2003).

## Age of Magnetization and Paleohorizontal Control

Further problems in the analysis of the paleomagnetic data arise from the generally loose constraints in the age of magnetization for most of the results (see Table 1). A very common feature found so far is an Early to Late Cretaceous (?) remagnetization observed in several of the studies reported (1, 3, 7, 8, Table 1). This brings problems for a better constraint in the age of rotation as well as uncertainty on the paleohorizontal at the time of remanence acquisition. Lack of paleohorizontal control seems to be the rule more than the exception with the data obtained so far in the region. This is due to either post-tilting (or folding) remagnetizations or data coming from intrusive bodies. This lack of control turns the interpretation of declination anomaly as a record of crustal rotation around vertical axes non unique in many cases. Although in some cases an alternative explanation that involves rotation around a horizontal or inclined axis is unlikely considering the geological and structural evidence of the sampling locality, in other cases the interpretation of declination anomaly as tectonic rotation around a vertical axis is at least ambiguous. Figure 3 illustrates the latter case. Mean site directions obtained from the Late Jurassic Sarmiento ophiolite (7, Table 1) correspond to a post-folding (Late Cretaceus?) remagnetization. They show a systematic and important anomaly in declination. This can be due either to a large ccw crustal block rotation around a vertical axis or to a rigid-body tilting (rotation around a horizontal axis) of the Sarmiento ophiolite block (Cordillera Sarmiento).

The large ccw rotations found by Rapalini et al. (2001) and Iglesia Llanos et al. (2003) apparently die away very rapidly to the north (Fig. 1). The latter authors have found no significant rotations in Late Jurassic rocks of the Marifil Fm exposed at 47.9°S in the Lago Posadas and Sierra Colorada, Argentina. On the Chilean side, Roperch et al. (1997) reported no significant rotations in Jurassic to Cretaceous rocks exposed between 46° and 47.5° S near the Lago Cochrane and Lago Carrera in the Aysen region. Similar conclusions were published by Beck et al. (2000) for rocks from the same latitudes, but

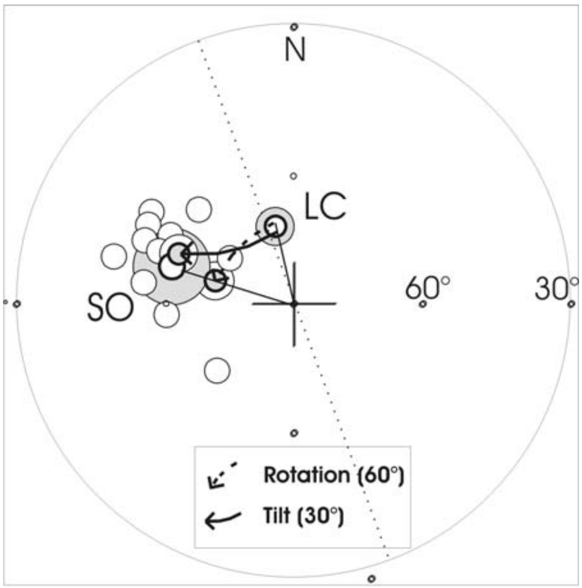


FIGURE 3 | **Example of the ambiguous interpretation of declination anomaly without paleohorizontal control. Mean site directions of the characteristic remanence of the Sarmiento ophiolite (Rapalini et al., 2004) correspond to a post-folding remagnetization (open small circles). Site mean direction for the Sarmiento ophiolite (SO) and the South American reference direction for the Late Cretaceous (LC, Somoza, 2002) with their a95: white small circles and large grey circles. The reference direction after 60° rotation around a vertical axis and after 30° rotation around a horizontal axis trending N 20° W (dotted line) are shown as small grey circles with large white circles (a95).**

located 30 to 50 km to the west in the Chonos Peninsula. According to this data, a significant change in the kinematic evolution of the tectonic deformation of the Southern Andes may have ocurred at some place between 48°S and 49°S.

Despite the paucity and uncertainties of the paleomagnetic data available, some speculations on the paleomagnetic results expected in different tectonic scenarios may be useful, mainly as guidance for future work in the region. There is general consensus that both thrust and strike-slip tectonics were active during the Late Mesozoic to Cenozoic evolution of the southernmost Andes (e.g. Cunningham, 1993; Diraison et al., 2000; Kraemer, 2002; Lodolo et al., 2003; Ghiglione and Ramos, 2005). The relative importance and timing of each is however matter of debate.

Tectonic rotations around vertical axes, as determined by paleomagnetism, could be explained in our case by i) regional flexural bending of the southernmost Andes (true orocline) or ii) local tectonic rotations associated to strike-slip faults or oblicue displacements of thrust sheets. In the first case a correlation is expected between sense and amount of rotation and the change of strike of the orogen. However, the superposition of local rotations may obscure the regional pattern up to some extent. On the other hand, a non-oroclinal tectonic evolution will produce only local rotations, which are expected to be much more variable in magnitude, although the sense may be constant. The presence of non-rotated areas is also likely in this case.

Considering the limited paleomagnetic data already discussed for the southernmost Andes, the presence of signifcant rotations not related to oroclinal bending are evident in the South Patagonian Andes (Rapalini et al., 2001; Iglesia Llanos et al., 2003; Fig. 2). Those obtained in the Fuegian Andes, on the other hand, can be reconciled with an oroclinal model, although the apparent reduction of amount of rotation northwards should be explained either by a complex tectonic process (e.g. Burns et al., 1980) or an age progression, with younger magnetizations northwards. Difficulties in determining the precise magnetization age in the rocks studied so far do not permit to test the latter possibility. On the other hand, non-oroclinal models require that rotations be associated to local tectonics. This cannot be ruled out with the present-day database, although non-rotated areas are still to be found and correlation between declination anomalies and deflection of structural trends have not been reported yet. Furthermore, structural trends and AMS (anisotropy of magnetic susceptibility) axes in rotated sites in the Fuegian Andes (Rapalini et al., 2005) do not show any significant deflection respect to the regional structures.

Systematic paleomagnetic data across the Andean chain at different locations may resolve this controversy.

## CONCLUSIONS AND FINAL REMARKS

Whether the 90° curvature of the Patagonian-Fuegian Andes is a primary or secondary feature can be tested with paleomagnetism. The available data show systematic ccw deflections of the paleomagnetic declinations, which could be consistent in a broad sense with a secondary curvature of the orogen. Other apparent features that can be observed are larger rotation values in the external arc (outboard from the Rocas Verdes marginal basin) and a possible progressive reduction of the declination anomaly towards the foreland. However, even taken at face value the data are not fully consistent with a simple oroclinal model as the magnitude of rotations in the northern branch of the orogen exceeds that predicted by the simple deflection of a former N-S structural trend. This may suggest a more complex tectonic scenario than a simple oroclinal curvature.

In spite of this, a meaningful paleomagnetic test is hampered by several problems. Among them, 1) insufficient laboratory procedures in the oldest paleomagnetic studies; 2) scarce and unevenly distributed paleomagnetic sampling coverage; 3) lack of paleohorizontal control in most studies, that may turn ambiguous the interpretation of declination anomaly; and 4) poor constrains in the age of rocks and magnetizations.

Future systematic paleomagnetic studies on well dated rocks along the whole Patagonian arc may shed light on the controversies regarding the tectonic evolution of the region.

## ACKNOWLEDGEMENTS

My involvement in the paleomagnetic study of the Patagonian Orocline is mainly due to the generous invitations of Pancho Hervé (Universidad Nacional de Chile) and Alejandro Tassone (CONICET) to join their already ongoing research projects in southern Chile and Tierra del Fuego, respectively, few years ago. Several new paleomagnetic results have been produced (and are being produced) due to this. Discussions both in the field and the lab with numerous colleagues like F.Hervé, A. Tassone, M. Calderón, S. Singer, H. Lippai, M.E.Cerredo, U. Cordani, V. Ramos, R. Somoza, I.Dalziel and many others are very much appreciated. Financial support by the Universidad de Buenos Aires (UBACyT X262) and CONICET are gratefully acknowledged. Critical comments by two reviewers and the editor significantly improved the final version.

## REFERENCES

Acevedo, R.G., Roig, C.E., Linares, E., Ostera, H.A., Valín-Alberdi, M., Queiroga-Mafra, Z.M., 2000. La intrusión plutónica del cerro Jeu-Jepén. Isla Grande de Tierra del Fuego, República Argentina. Cuadernos do Laboratorio Xeológico de Laxe, 25, 357-359.

Baraldo, A., Rapalini, A., Tassone, A., Lippai, H., Menichetti, M., Lodolo E., 2002. Estudio paleomagnético del intrusivo del cerro Hewhoepen, Tierra del Fuego, y sus implicancias tectónicas. 15° Congreso Geológico Argentino, El Calafate, Actas, 1, 285-290.

Beck, M. Jr., Burmester, R., Cembrano, J., Drake, R., García, A., Hervé, F., Munizaga, F., 2000. Paleomagnetism of the North Patagonian Batholith, southern Chile. An exercise in shape analysis. Tectonophysics, 326(1-2),185-202.

Burns, K.L., Rickard, M.J., Belbin, L., Chamalaun, F., 1980. Further paleomagnetic confirmation of the Magellanes orocline. Tectonophysics, 63, 75-90.

Butler, R.F., 1992. Paleomagnetism: magnetic domains to geologic terranes. Boston, Blackwell Scientific Publications, 319 pp.

Carey, S.W., 1955. The orocline concept in geotectonics. Proceedings of the Royal Society of Tasmania, 89, 255-288.

Cunningham, W.D., 1993. Strike-slip faults in the southernmost Andes and the development of the Patagonian Orocline. Tectonics, 12, 169-186.

Cunningham, W.D., Klepeis, K.A., Gose, W.A., Dalziel, I.W., 1991. The Patagonian Orocline: New paleomagnetic data from the Andean magmatic arc in Tierra del Fuego, Chile. Journal of Geophysical Research, 96, 16061-16069.

Dalziel, I.W.D., Elliot, D.H., 1973. The Scotia Arc and Antarctic margin. In: Nairn, A.E.M., Stehli, F.G. (eds.). The Ocean Basins and Margins, vol. 1: The South Atlantic. New York, Plenum Press, 171-245.

Dalziel, I.W.D., Kligfield, R., Lowrie, W., Opdyke, N.D., 1973. Paleomagnetic data from the southernmost Andes and the Antarctandes. In: Tarling, D.H., Runcorn, S.K. (eds.). Implications of Continental Drift to Earth Sciences. San Diego, California, Academic Press, 1, 87-101

Diraison, M., Cobbold, P.R., Gapais, D., Rossello, E., 2000. Cenozoic crustal thickening, wrenching and rifting in the foothills of the southernmost Andes. Tectonophysics, 316, 91-119.

Ghiglione, M., 2003. Estructura y evolución tectónica del cretácico-terciario de la Costa Atlántica de Tierra del Fuego. Doctoral Thesis. Universidad de Buenos Aires, 183 pp. (Unpublished).

Gighlione, M., Ramos, V.A., 2005. Progression of deformation and sedimentation in the southernmost Andes. Tectonophysics, 405, 25-46.

Iglesia Llanos, M.P., Lanza, R., Riccardi, A.C., Geuna, S., Laurenzi, M.A., Ruffini, R., 2003. Palaeomagnetic study of the El Quemado complex and Marifil formation, Patagonian Jurassic igneous province, Argentina. Geophysical Journal International, 154, 599-617.

Kraemer, P.E., 2003. Orogenic shortening and the origin of the Patagonian orocline (56°S. Lat). Journal of South American Earth Sciences, 15, 731-748.

Kraemer, P.E., Ploszkiewicz, J.V., Ramos, V.A., 2002. Estructura de la Cordillera Patagónica Austral entre los 46° y 52°S. In: Haller, M.A. (ed.). Geología y Recursos Naturales de la provincia de Santa Cruz. Relatorio del 15 Congreso Geológico Argentino, El Calafate, Santa Cruz, Asociación Geológica Argentina, 353-364.

Lodolo, E., Menichetti, M., Bartole, R., Ben Avraham, Z., Tassone, A., Lippai, H., 2003. Magallanes – Fagnano continental transform fault (Tierra del Fuego, southernmost South America). Tectonics, 22(6) p. 1076. DOI 10.10292003TC001500.

Morris, A., Anderson, M.W. (eds.), 1998. Paleomagnetism and tectonic rotations. Tectonophysics, 299(1-3), 1-253.

Rapalini, A.E., Hervé, F., Ramos, V.A., Singer, S., 2001. Paleomagnetic evidence of a very large counterclockwise rotation of the Madre de Dios archipelago, southern Chile. Earth and Planetary Science Letters, 184(2), 471-487.

Rapalini, A.E., Calderón, M., Hervé, F., Cordani, U., Singer, S., 2004. First Paleomagnetic Results on the Sarmiento Ophiolite, Southern Chile: Implications for the Patagonian Orocline. Geosur 2004, Internat. Symp. on the Geology and Geophysics of the Southernmost Andes, the Scotia Arc and the Antarctic Peninsula, Buenos Aires, Bolletino de Geofisica Teórica ed Applicata, 45, 246-249.

Rapalini, A.E., Lippai, H., Tassone, A., Cerredo, M.E., 2005. An AMS and paleomagnetic study across the Andes in Tierra del Fuego. 6th International Symposium on Andean Geodynamics (ISAG 2005, Barcelona), Extended Abstracts, 596-599.

Roperch, P., Chauvin, A, Calza, F., Palacios, C., Parraguez, G., Pinto, L., Goguitchaivilli, A., 1997. Paleomagnetismo de las rocas volcánicas del Jurásico tardío al Terciario temprano de la región de Aysén (Coyhaique-Cochrane). 8° Congreso Geológico Chileno, Antofagasta, Universidad Católica del Norte, Actas, 1, 236-240.

Schmidt, P.W., Powell, C.McA., Li, Z.X., Thrupp, G.A., 1990. Reliability of Palaeozoic palaeomagnetic poles and APWP of Gondwanaland. Tectonophysics, 184, 87-100.

Somoza, R., 2002. El campo magnético cretácico desde una perspectiva americana. XV Congreso Geológico Argentino, El Calafate, Actas, 1, 88-93.

Van der Voo, R., 1990. The reliability of paleomagnetic data. Tectonophysics, 184, 1-9.

**Manuscript received November 2005;**
**revision accepted December 2006.**