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Tectonic implications of a paleomagnetic study of the Sarmiento Ophiolitic Complex, southern Chile

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Abstract

A paleomagnetic study was carried out on the Late Jurassic Sarmiento Ophiolitic Complex (SOC) exposed in the Magallanes fold and thrust belt in the southern Patagonian Andes (southern Chile). This complex, mainly consisting of a thick succession of pillow-lavas, sheeted dikes and gabbros, is a seafloor remnant of the Late Jurassic to Early Cretaceous Rocas Verdes basin that developed along the south-western margin of South America. Stepwise thermal and alternating field demagnetization permitted the isolation of a post-folding characteristic remanence, apparently carried by fine grain (SD?) magnetite, both in the pillow-lavas and dikes. The mean "in situ" direction for the SOC is Dec: 286.9°, Inc: −58.5°, α95: 6.9°, N: 11 (sites).

Rock magnetic properties, petrography and whole-rock K–Ar ages in the same rocks are interpreted as evidence of correlation between remanence acquisition and a greenschist facies metamorphic overprint that must have occurred during latest stages or after closure and tectonic inversion of the basin in the Late Cretaceous.

The mean remanence direction is anomalous relative to the expected Late Cretaceous direction from stable South America. Particularly, a declination anomaly over 50° is suggestively similar to paleomagnetically interpreted counter clockwise rotations found in thrust slices of the Jurassic El Quemado Fm. located over 100 km north of the study area in Argentina. Nevertheless, a significant ccw rotation of the whole SOC is difficult to reconcile with geologic evidence and paleogeographic models that suggest a narrow back-arc basin sub-parallel to the continental margin. A rigid-body 30° westward tilting of the SOC block around a horizontal axis trending NNW, is considered a much simpler explanation, being consistent with geologic evidence. This may have occurred as a consequence of inverse reactivation of old normal faults, which limit both the SOC exposures and the Cordillera Sarmiento to the East. The age of tilting is unknown but it must postdate remanence acquisition in the Late Cretaceous. Two major orogenic events of the southern Patagonian Andes, in the Eocene (ca. 42 Ma) and Middle Miocene (ca. 12 Ma), respectively, could have caused the proposed tilting.

Keywords: Paleomagnetism; Ophiolite; South America; Patagonia; Orocline; Remagnetization

1. Introduction

The Andean orogen changes its strike at around 53°S from a roughly north–south direction to the north into an east–west orogen in the south. This bend is known as the Patagonian Orocline, after Carey (1955). As already pointed out by Cunningham et al. (1991), a yet unresolved problem in the evolution of the Southern Andes is the origin of such curvature. Paleomagnetism is a very powerful tool to reconstruct the kinematic evolution of an orocline both in space and time (see for instance Morris and Anderson, eds., 1998). Therefore, reliable paleomagnetic data from outcrops distributed along the whole Andean orogen between 50°S and 56°S would be significant for unravelling the tectonic evolution of this region.

Despite the fact that several different tectonic models have been put forward to explain the late Mesozoic–Cenozoic tectonic evolution of this part of the Andes, considering a full, partial or no oroclinal bending (e.g. Wilson, 1991; Cunningham, 1993, 1995; Diraison et al., 2000; Kraemer, 2003; Fildani and

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Hessler, 2005; Ghiglione and Ramos, 2005, Ghiglione and Cristallini, 2007), very few paleomagnetic studies have been carried out yet in the region (Dalziel et al., 1973; Burns et al., 1980; Cunningham et al., 1991; Rapalini et al., 2001; Baraldo et al., 2002; Iglesia Llanos et al., 2003). As recently pointed out by Rapalini (2007) the available database is insufficient to test different models of tectonic evolution of the Patagonian Orocline.

A transitional volcanic-rifted to back-arc basin developed along the southern continental margin of South America during the Late Jurassic to Early Cretaceous. This is generally known as the Rocas Verdes basin (e.g. Dalziel et al., 1974; Stern and De Wit, 2003) and is inferred from discontinuous ophiolitic complexes exposed along the present Pacific margin of the southern Patagonian and Fuegian Andes and in the northern Scotia Arc (Mukasa and Dalziel, 1996). The opening and subsequent closure of this basin is considered a major tectonic development of the South American margin that may have had a substantial impact in its present configuration (e.g.Burns et al., 1980; Kraemer, 2003).

In order to obtain new paleomagnetic data to constrain models of the kinematic evolution of the Patagonian orocline, a reconnaissance paleomagnetic survey was carried out on the northern seafloor remnant of the Rocas Verdes basin, the Sarmiento Ophiolitic Complex (SOC), as part of a multidisciplinary project. Our results suggest a complex tectonic and magnetic history of these rocks which are carrier of a characteristic remanence acquired after the main deformational event that closed and inverted the Rocas Verdes basin. Although a significant declination anomaly was found in these rocks, the simplest interpretation of the paleomagnetic results does not need any tectonic rotation around vertical axes that might be related to a secondary curvature of the orogen.

2. Geology and sampling

Seafloor remnants of the Rocas Verdes basin are exposed discontinuously from about 51°S (SOC) to 55°S (Tortuga Ophiolite) in southern South America (Dalziel et al., 1974; Stern and De Wit, 2003). Mafic metaigneous complexes comprise sills and dikes of amphibolitized gabbro, rare plagiogranites and amphibolites and a thick extrusive unit composed of pillow basalts and pillow breccias with intercalation of radiolarian bearing cherts and siltstones. The SOC bears bimodal extrusive and intrusive terrains that have been associated with the initial stages of lithospheric rupturing along a volcanic-rifted margin in Late Jurassic times (Calderon, 2006). This evolved into a back-arc basin in the Early Cretaceous (Wilson 1991). The Rocas Verdes basin was tectonically closed and inverted in several pulses starting in the Mid-Cretaceous (Dalziel, 1981; Kraemer, 2003).

The studied area comprises four main N–S trending and east-verging thrust sheets(Fig. 1), in which three of them form elongated mountain belts of supracrustal rocks and shallow intrusives, flanked to the west by granitic rocks of the South Patagonian batholith (Fig. 1). The westernmost thrust slice comprises Paleozoic metamorphic rocks of the Staines Complex (Forsythe and Allen, 1980; Hervé et al., 2003) which to the north at Seno Yussef are unconformably overlain by volcano-sedimentary rocks of the Jurassic Tobífera Formation. Part of the Tobífera Formation was deposited under relatively deep marine conditions (Allen, 1982; Wilson, 1991) and has an estimated minimum thickness of 1000 m (Allen, 1982). It is generally interpreted as deposits associated with the rift processes that preceded and accompanied the opening of the basin floored with quasi-oceanic crust. This quasi-oceanic crust is represented by the SOC, that is conformably overlain by the clastic Zapata Formation consisting of ammonite, belemnite and radiolarian bearing successions of siltstones and mudstones which reach a minimum thickness of 1000 m. Biostratigraphic age of the Zapata Formation is restricted to the Tithonian–Neocomian (ca. 150–125 Ma) according to Fuenzalida and Covacevich (1988). In the study area the Zapata Formation is exposed on top of the extrusives of the SOC, being affected by large scale folding and thrusting (Fig. 1).

The SOC is constituted by two imbricated N–S to NNW–SSE trending thrust sheets in a sub-vertical to east-verging fold and thrust belt. It is mainly exposed along the Cordillera Sarmiento, a NNW trending mountain block with peaks reaching over 2000 m above sea level and covered by thick caps of ice. It is limited to the east by the Canal de las Montañas, a straight, narrow depression along which one or more NNW–SSE thrust faults are inferred (Fig. 1). The Canal de las Montañas separates the Cordillera Sarmiento from the Cordillera Riesco on the East, mainly composed of foliated volcanosedimentary successions assigned to the Tobífera Formation (Galaz et al., 2005), upon which the SOC has been overthrust (Calderón et al., 2005). Folded shales of the Zapata Formation and sheared silicic tuffs of the Tobífera Formation are in turn cross-cut by a few sub-vertical and east–west trending lamprophyric dikes.

In order to make a reconnaissance paleomagnetic study of the SOC, a regional sampling was carried out on 13 sites (98 samples) distributed along the whole exposure of the ophiolitic complex (almost 100 km long, see Fig. 1). Access to sampling localities was only possible by boat. Sampled lithologies comprised pillow and massive olivine–clinopyroxene basalts, sub-vertical dikes of amphibolitized fine gabbro and medium-grained gabbro sills. A lamprophyric dike was also studied. For the lavas, bedding attitude was estimated from overlying sediments of the Zapata Formation. Samples were collected with a gasoline-powered portable drill, and oriented both with sun and magnetic compasses whenever weather conditions permitted. At several sites, samples were also taken for radiometric dating through K–Ar whole-rock analysis (see Fig. 1).

3. Paleomagnetic results

Collected cores were sliced into standard 2.2 cm long specimens. At least one specimen per sample was submitted to full demagnetization following a stepwise procedure. All measurements were carried out at the Paleomagnetic Laboratory of the INGEODAV (University of Buenos Aires). Remanence was measured with a DC squids 2G cryogenic magnetometer. Demagnetization was performed either with a 3 axis automatic static degausser attached to the magnetometer or with a dual-