Paleomagnetic evidence of an early Paleozoic rotated terrane in northwest Argentina: A clue for Gondwana-Laurentia interaction?

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ABSTRACT

Paleomagnetic results from three Lower Ordovician units in northwest Argentina are reported. When assessed with available geologic evidence, these data permit the definition of the Puna Oriental–Famatina rotated terrane. Paleogeographic reconstructions based on these paleomagnetic results place Puna Oriental–Famatina in the South Iapetus ocean, close to the Gondwana margin and near some of the Lower-Middle Ordovician Central Mobile belt terranes of the Northern Appalachians. The accretion of Puna Oriental–Famatina may have resulted from the closure of this ocean in Middle Ordovician time.

INTRODUCTION

The possible connection between western South America and eastern North America in the Late Proterozoic–early Paleozoic has been the focus of recent research (see Dalziel et al., 1994, and references therein). Several Paleozoic suspect terranes have been proposed on the southwestern South American margin, two of them, the Arequipa-Antofalla and Precordillera terranes, of possible Laurentian origin. However, their nature and evolution remain controversial (see Ramos, 1988; Dalla Salda et al., 1992; Omarini and Sureda, 1993; Astini et al., 1995, and references therein). All these models rely primarily on tectonic and biostratigraphic evidence. The paleomagnetic data obtained so far from these suspect terranes (Forsythe et al., 1993; Rapalini and Tarling, 1993; Conti, 1995) are scarce, and in some cases of doubtful reliability. An outstanding geologic feature of northwest Argentina is a north-trending Lower Ordovician magmatic belt (Fig. 1) that comprises the Famatina system and the "Faja Eruptiva de la Puna Oriental." A paleomagnetic study was carried out on several Early Ordovician geologic units in this belt in order to define its paleogeographic evolution.

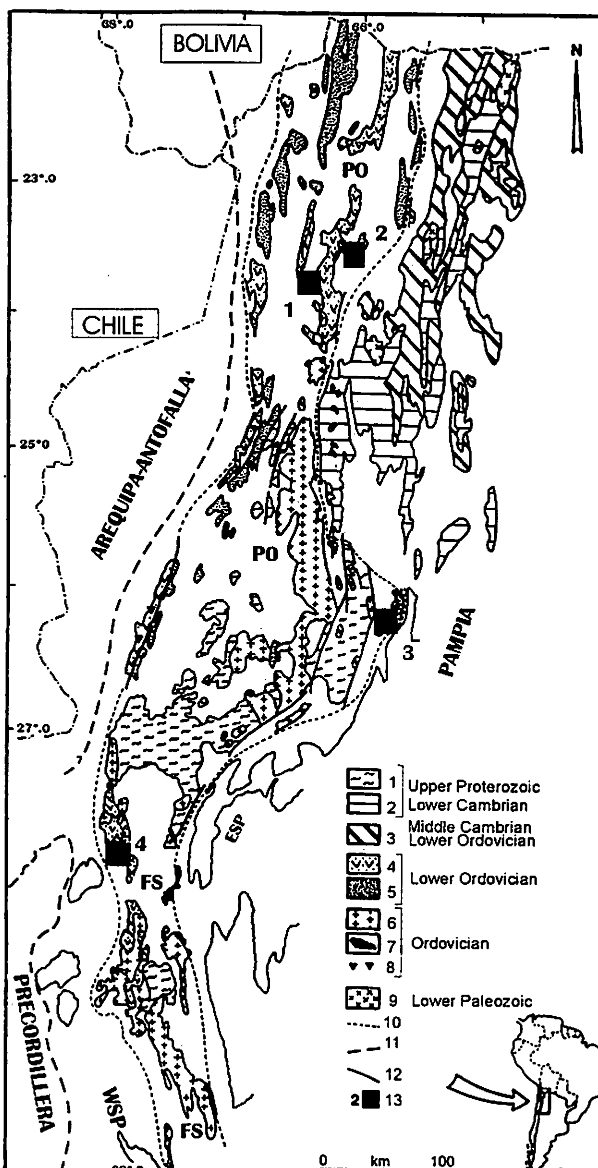

Figure 1. Upper Proterozoic–lower Paleozoic schematic geologic map of Puna Oriental–Famatina terrane, northwest Argentina. PO—"Faja Eruptiva de la Puna Oriental"; FS—Famatina System; ESP, WSP—Eastern and Western Sierras Pampeanas, respectively. 1—metamorphic rocks, 2—Puncoviscana Formation, 3—Mesón–Santa Victoria Groups, 4—volcano-sedimentary rocks, 5—sedimentary rocks, 6—Puna Oriental and Famatina granitoids, 7—mylonites, 8—mafic and ultramafic rocks, 9—Eastern Cordillera granitoids, 10—proposed Puna Oriental–Famatina boundaries, 11—western terranes boundaries, 12—fault, 13—sampling locality. Modified from Rapela et al. (1992).

PALEOMAGNETIC STUDY

The paleomagnetic data reported here come from four different localities (1 to 4, Fig. 1): Two localities in Puna Oriental (1 and 2), one in the Cafayate area (3), and one in Famatina (4). Nonuseful results, obtained from other localities in Puna Oriental, were excluded from this report.

Nine sites (36 samples, mostly block samples) were located at Huancar (locality 1), six in the Tremadoc-Arenig (?) sedimentary Susques Formation and three in the conformably overlying Arenig-Llanvirn volcanic Acoyte Formation. Seven sites (27 block samples) were located in the Arenig-Llanvirn sedimentary Chiquero Formation at Quebrada de las Burras (locality 2). For details on the geology and stratigraphy of the region see Nullo (1988) and references therein. The 472 ± 15 Ma (K/Ar, biotite;

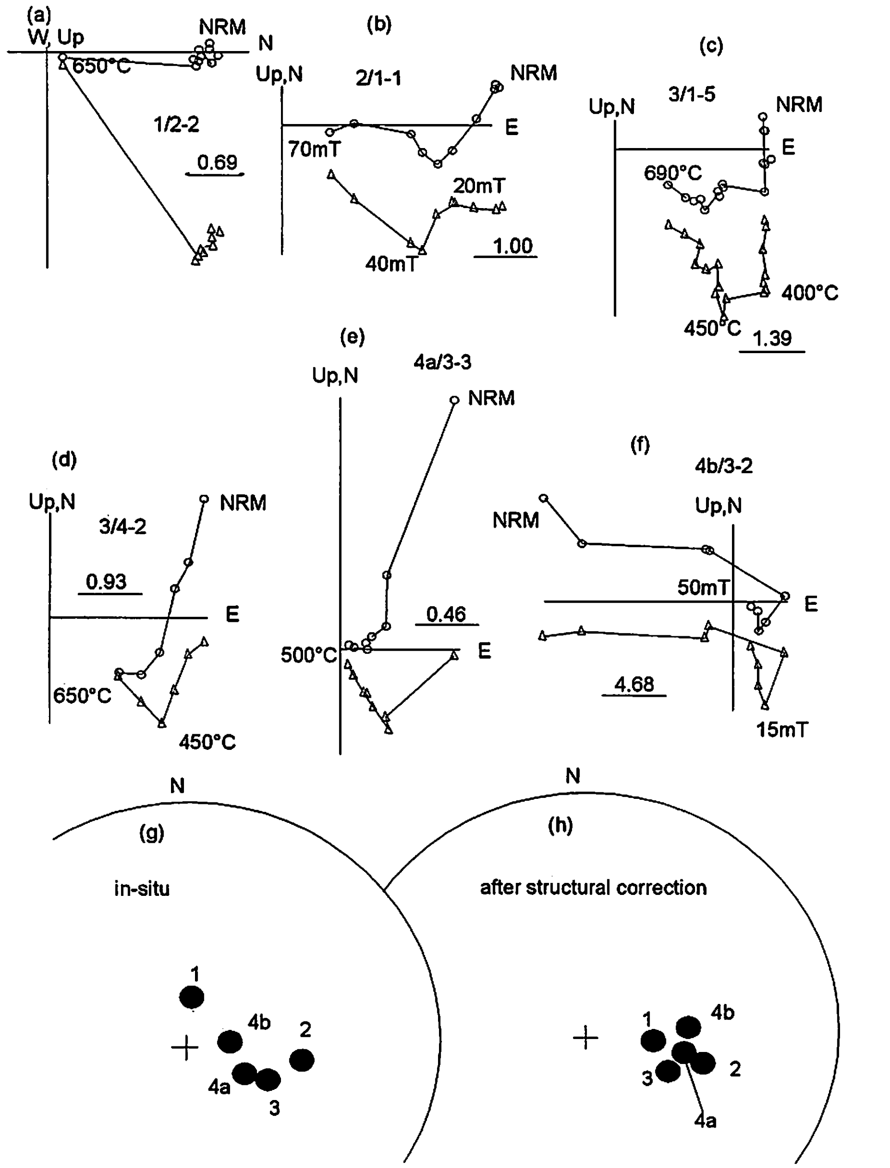

Figure 2. a to f: Orthogonal projection diagrams showing representative magnetic behavior of samples from all sampling localities (in situ coordinates); component C is defined as higher coercivity-temperature component in all samples. Apparent unblocking temperature over 690 °C of sample 3/1-5 (locality/site-sample) is probably artifact of problems with furnace calibration. Sample 3/4-2 is shown as example of component C not determined by principal component analysis but by remagnetization circles due to uncomplete demagnetization caused by chemical changes over 650 °C. Circles (triangles) mean vectorial projection on the horizontal (vertical) plane; scales are in mA/m. g and h: Positive regional tilt test of component C mean locality directions; closed circles mean positive inclinations.

Rapela, 1976) Cuchiyaco granitoid, exposed at locality 3 was sampled at nine sites (42 samples) with a portable drilling machine. Original paleomagnetic data from a previous study by Valencio et al. (1980) on the Arenig-Llanvirn volcanic and sedimentary rocks of the Las Planchadas and Suri Formations in Famatina (locality 4) were fully reanalyzed.

Stepwise thermal and/or alternating field demagnetization was applied to all samples from localities 1 to 3. Two magnetic components were isolated at localities 1 and 2 by principal component analyses (Fig. 2). Great circle analyses (McFadden and McElhinny, 1988) also had to be performed on some samples from most sites to define the characteristic remanence. A posttectonic low coercivity-unblocking temperature component (A) coincident in situ with the present geomagnetic field direction was found in most sites at both localities. A second steep downward-directed magnetic component (C) was also isolated in both localities (Table 1). Unblocking temperatures around 650–680 °C (Acoyte Formation, locality 1) and 530–560 °C (Chiquero Formation, locality 2) suggest, respectively, hematite and magnetite as the ferromagnetic carriers (Figs. 2a and 2b). These magnetic mineral identifications were confirmed by isothermal remanent magnetization (IRM) acquisition curves and thermal demagnetization of three-axes IRM.

Component A was also found in the granitoid rocks from locality 3. A second magnetic component (B), with unblocking temperatures of 650 °C and of possible Late Paleozoic age according to its direction, was isolated at three sites. Component C was also found in five sites of the Cuchiyaco granitoid (Figs. 2c and 2d; Table 1). Unblocking temperatures (650–690 °C) and IRM acquisition curves indicate that hematite is the ferromagnetic carrier.

Original data from the study of the Suri and Las Planchadas Formations were reanalyzed. After deletion of a soft, sometimes randomly oriented, magnetization, component C directions were also isolated in samples from both formations (Figs. 2e and 2f; Table 1). In this case, magnetite is interpreted to be the magnetic carrier (unblocking temperatures around 500 °C).

INTERPRETATION AND DISCUSSION

Comparison of in situ and tilt-corrected mean directions of component C for the five geologic units shows a substantially better clustering after tilt correction, both within and between localities (Figs. 2g and 2h; Table 1). A regional tilt test for component C mean site directions (McFadden, 1990; SCOS is the test statistic parameter of correlation for the fold test) indicates a pretectonic nature for this component (SCOS in situ = 12.803, SCOS 100% bedding corrected = 0.042, SCOS critical = 6.516). A main tectonic phase of Middle-Late Ordovician age (Coira et al., 1982) affecting these rocks and most of northwest Argentina suggests that the magnetization is probably a primary Early Ordovician remanence. The regional consistency of component C isolated from different lithologies spanning several hundred kilometres is further evidence of its primary origin. A paleomagnetic pole for each region (Puna Oriental, Cafayate, and Famatina) and a single mean pole were calculated on the basis of component C mean site directions (Table 1). The Famatina pole replaces the Suri Formation pole of Valencio et al. (1980). However, its new position is very similar to the previous one.

The Puna Oriental–Famatina paleomagnetic pole has a discordant position in respect to reliable coeval poles for Gondwana (Fig. 3). The discordance implies a clockwise rotation of 52.6° ± 11.1° but no significant paleolatitudinal transport (−1.0° ± 9.4°) when compared with the Gondwana Early–early Middle Ordovician mean pole. The overall consistency of pole positions as well as multiple geological correlations and

TABLE 1. COMPONENT C PALEOMAGNETIC DATA

Locality	Site	Att.	In situ N	Dec.	Inc.	α95	K	Tilt corrected Dec.	Inc.	α95	K
Puna Oriental (PO)											
1	1-1	(41/37)	(3)	10.5	70.8	55	6	98.8	58.4		
	1-2	(41/37)	(5)	2.6	61.5	8	103	79.9	62.0		
2	2-1	(99/5)	(5)	101.2	40.9	11	58	105.5	40.6		
	2-2	(119/6)	(3)	93.7	34.9	28	53	98.1	37.5		
	2-3	(74/9)	(5)	94.1	44.1	18	22	101.4	40.7		
Mean PO			5	76.9	57.1	30	7	98.1	47.9	12	40
mean PO			(21)	77.9	56.5	21	13	98.0	48.0	7	21
Cafayate (CY)											
3	3-1		(5)	114.6	49.4	15	41				
	3-2		(5)	93.9	58.2	5	292				
	3-3		(3)	114.7	52.0	35	18				
	3-4		(6)	121.7	40.9	18	17				
	3-5		(4)	105.2	52.5	10	113				
Mean CY			5	111.1	50.9	9	79				
mean CY			(23)	111.4	50.4	5	36				
Famatina System (FS)											
4a	4a-1	(332/18)	(4)	117.8	59.1	15	36	98.6	46.8		
	4a-2	(332/18)	(3)	116.1	59.2	19	39	98.5	46.3		
	4a-3	(332/18)	(3)	106.4	65.9	24	27	89.0	51.1		
4b	4b-1	(358/24)	(2)	84.9	73.8	12	279	86.7	49.8		
	4b-2	(358/24)	(4)	77.0	65.2	21	30	81.9	41.4		
	4b-3	(358/24)	(2)	85.0	70.7	33	59	86.6	46.7		
Mean FS			6	100.5	66.5	8	73	90.5	47.2	5	175
mean FS			(18)	100.0	65.5	6	34	90.4	46.7	5	43
mean PF			(61)	93.4	57.7	5	13	100.5	48.8	4	27
Mean PF			16	97.6	59.6	9	17	98.9	49.0	5	57
Mean PF*			10	101.8	56.6	12	17	101.7	49.2	6	57

Poles	Code	Long	Lat	N	A95	K	Long#	Lat#
Puna Oriental	PO	2.1 W	17.7 S	5	13	38	41.1E	11.5N
Cafayate	CY	0.5 E	30.0 S	5	10	58	48.5E	1.1N
Famatina	FS	3.7 W	13.0 S	6	6	145	38.1E	15.1N
PF Terrane	NOA	1.3 W	21.8 S	10	7.5	57	43.9E	8.0N

Note: N: number of sites (between brackets, number of samples); α95 and K are Fisher's statistic parameters; Att.: bedding attitude in degrees (strike/dip, in a direction 90° clockwise from strike); declination (Dec.), inclination (Inc.), longitude (Long), latitude (Lat) and A95 values are in degrees. Means (means) computed on site (sample) basis. Paleomagnetic poles in South American coordinates.

* Mean direction computed from sites with $\alpha95 < 20°$.

Poles after rotation to South African coordinates according to Lottes and Rowley (1990).

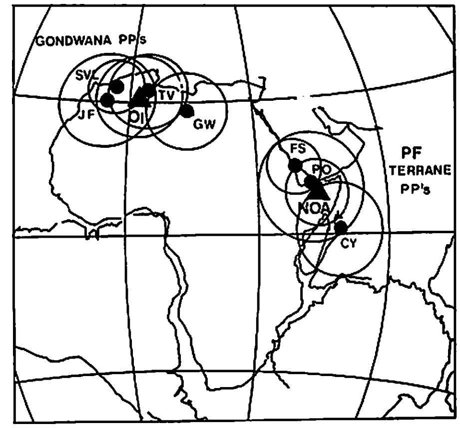

Figure 3. Gondwana reconstruction (Lottes and Rowley, 1990) with Early–early Middle Ordovician paleomagnetic poles from Puna Oriental–Famatina (PF) terrane (circles, see Table 1), and Gondwana (triangles) as compiled by Grunow (1995). SVL—Southern Victoria Land, TV—Taylor Valley, GW—Graafwater Formation, JF—Jinduckin Formation, OI—mean pole, FS—Famatina, PO—Puna Oriental, CY—Cafayate, NOA—Puna Oriental–Famatina mean pole, PP—paleomagnetic pole.

continuous structural trends along the belt suggests that Puna Oriental, Cafayate, and Famatina constitute a coherent tectonic block. Therefore, the paleomagnetic data are interpreted in terms of coherent movements of the Puna Oriental–Famatina terrane relative to Gondwana after the Early Ordovician.

Several authors interpreted the Puna Oriental–Famatina magmatic belt as an outer magmatic arc (Rapela et al., 1992). Evidence concerning type of sedimentation, volcanism, and fossil assemblages indicate that it was formed in an oceanic environment (Toselli et al., 1991; Bahlburg, 1990). Geologic data (Coira et al., 1982; Allmendinger et al., 1983; Astini et al., 1995) support the existence of an oceanic realm between the Arequipa Antofalla and Precordillera terranes on one side (Fig. 1) and Puna Oriental–Famatina on the other during Ordovician times. The southeastern boundary of this terrane is a thick mylonitic belt (Lopez and Toselli, 1993) that marks the limit with the Proterozoic Pampia terrane (Ramos et al., 1993), and it has been commonly interpreted as produced by the closure of a back-arc basin in Ordovician times (Mannheim, 1993). The northeastern boundary, instead, is not so clearly defined by a mylonitic zone, although it is entirely tectonic in nature (Allmendinger et al., 1983; Mon and Hongn, 1987). The northwest margin of the Pampia terrane (Fig. 1) is characterized by two cycles of passive margin sedimentation: the Upper Proterozoic–Lower Cambrian Puncoviscana Formation and the Upper Cambrian–Lower Ordovician Mesón–Santa Victoria Groups. These are not found in Puna Oriental–Famatina, suggesting crustal discontinuity with Pampia. Allmendinger et al. (1983) speculated about the possible existence of an Ordovician ocean between these two regions. Different petrological and geochemical signatures have also been indicated for the basements of both terranes (Viramonte et al., 1993). Puna Oriental–Famatina basement was correlated by the latter authors with the Grenville orogen in eastern Laurentia. Geologic evidence summarized above supports the interpretation of the paleomagnetic data (Figs. 3 and 4) that portrays Puna Oriental–Famatina as a mobile terrane.

An Early Ordovician paleogeographic reconstruction (Fig. 4A) shows Puna Oriental–Famatina located close to the southwestern Gondwana margin in the South Iapetus ocean (Dalziel et al., 1994). The paleolatitudinal position of the island arcs of the Lower-Middle Ordovician Central Mobile belt of the northern Appalachians, as obtained by paleomagnetic studies (Van der Voo et al., 1991), is also shown. These island arcs were interpreted by Van der Voo et al. (1991) as remnants of the Iapetus Ocean. Similar paleogeographic positions, age, and oceanic affinities between Puna Oriental–Famatina and the Central Mobile belt suggest a possible correlation between both. Dalziel et al. (1994) proposed that the South Iapetus ocean between Western Gondwana and Laurentia was closed during Ordovician times. Paleomagnetic poles from Gondwana and Laurentia (Fig. 4B) suggest that closure of this ocean most probably occurred in the Middle Ordovician (≈460 Ma). The accre-

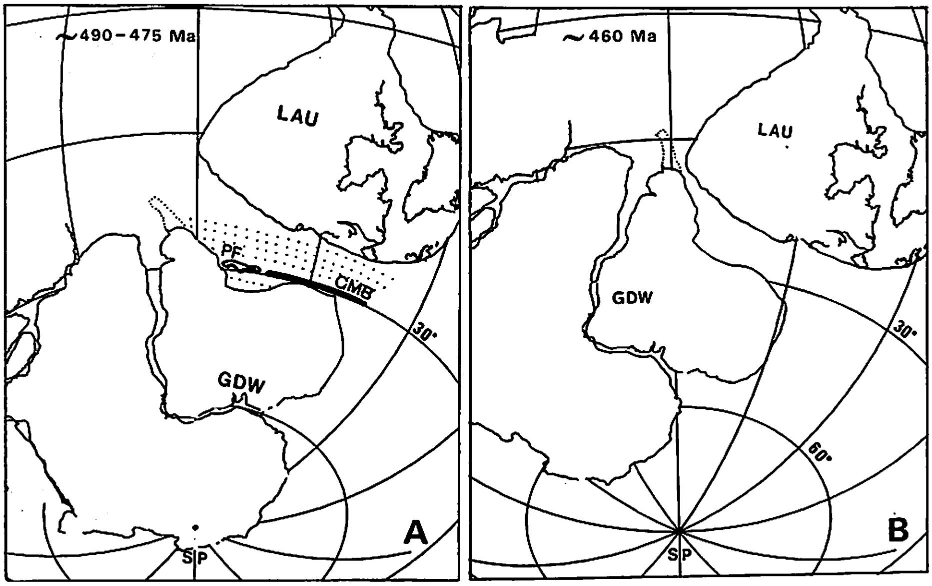

Figure 4. A: Paleogeographic reconstruction showing Early–early Middle Ordovician positions of Puna Oriental–Famatina terrane (NOA, Table 1), Gondwana (OI, Fig. 3), and Laurentia (mean paleomagnetic pole from Van der Voo, 1993); dotted area indicates paleomagnetically deduced locations of several vestiges of Iapetus ocean (Van der Voo et al., 1991), now in northeastern North America. Western margin of South America after removal of Paleozoic suspect terranes. B: Middle Ordovician paleogeographic reconstruction showing closure of South Iapetus ocean between southwestern Gondwana (reconstruction based on Salala Ring complex pole, Bachtadse and Briden, 1989) and eastern Laurentia (Van der Voo, 1993). LAU—Laurentia, GDW—Gondwana, PF—Puna Oriental–Famatina, CMB—Central Mobile belt, SP—south pole.

tion of these short-lived magmatic arcs to their respective margins probably occurred as a consequence of this event.

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