# PALEOMAGNETISM OF A PERMO-TRIASSIC BIMODAL DIKE SWARM OF NORTHERN PATAGONIA

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## ABSTRACT

Paleomagnetic data was obtained from 16 sites collected from mafic and acid dikes (< 250 Ma) of the La Esperanza Plutono-Volcanic Complex, outcropping in the northern Patagonia, Argentina. AF and thermal demagnetization procedures revealed mostly north-northwestern directions with moderate upward inclinations on specimens from 13 out of 16 analyzed sites. Site mean direction for the dikes clusters around Dm = 346°; Im = -60°, which allowed calculating a paleomagnetic pole for the La Esperanza dikes (LE pole), located at -82.5° (lat), 11.9° (long) ($\alpha95$=10.9º; N=13, k=17). The magnetization is primary and mainly carried by PSD magnetite and minor hematite as evidenced by textures observed by ore microscope and IRM and thermomagnetic curves. The LE pole is the first pole bracketed in age for the Permo-Triassic interval for central northern Patagonia calculated with a primary magnetization on igneous rocks. The comparison of the position of the LE pole with other poles of Patagonia and neighbouring areas of Gondwana suggests that these blocks were already juxtaposed earlier than 250 Ma, as suggested in previous geologic models.

**Keywords**: Permian, Paleomagnetism, APWP, North Patagonian Massif, La Esperanza dike swarm.

## RESUMO

Dados paleomagnéticos foram obtidos a partir de 16 localidades em diques ácidos e básicos (< 250 Ma) de Complexo plutônico- vulcânico La Esperanza, norte da Patagônia, Argentina. Os procedimentos de campos alternados (AF) e desmagnetização termal revelaram direções, em sua maioria, norte-noroeste com inclinações ascendentes moderadas em 13 dos 16 sítios analisados. As direções medias concentram-se em Dm = 346°; Im = -60° (N=13, K = 17), o que permitiu o cálculo de um pólo paleomagnético para o os diques (pólo LE), localizado em -82.5° (lat), 11.9° (long) ($\alpha95$ = 10,9°). A magnetização é primária e composta principalmente por magnetita MD e em menor medida, hematita, evidenciada pelas texturas observadas em microscópio de luz refletida e pelas curvas de IRM e curvas termomagnéticas. O pólo LE é o primeiro pólo do centro de Patagônia norte com idade máxima bem definida e que é baseada em rochas ígneas com magnetização primária. A comparação entre a posição do pólo LE com outros pólos da Patagônia e áreas vizinhas de Gondwana sugere que esses blocos já foram justapostos a mais de 250 Ma atrás, como sugerido em modelos geológicos anteriores.

**Palavras Chave**: Permiano, Paleomagnetismo, APWP, Maciço Nord Patagônico, Enxame de diques La Esperanza.

## Introduction.

The position of Northern Patagonia and relation with the Gondwana blocks during the Late Paleozoic has been a matter of debate for the last 30 years (see Rapalini *et al.* 2010, Pankhurst *et al.*, 2006 and 2014 among others). Paleogeographic models involving an allochthonous origin for the Patagonian block and collision during late Paleozoic are mainly challenged by the absence of high grade metamorphic rocks, ophiolitic sequences, and scarce juvenile additions to the crust or major crustal discontinuities. However, the existence of a massive batholiths (*i.e.* La Esperanza and Navarrete plutonic (volcanic) complexes) bracketed in age between 283 and 245 Ma in middle to upper crustal levels was interpreted as formed under the influence of a southward subduction and following a postcollisional process of magmatism and deformation. With this background, we conducted a paleomagnetic study on 16 sites of andesitic and rhyolitic dikes that intrude the main plutonic and volcanic phases of the La Esperanza Plutono-Volcanic Complex which activity was bracketed between 273 and 250 Ma (U-Pb SHRIMP dating on zircon, Martínez Dopico *et al.*, 2015) (Fig.1a, 1b)

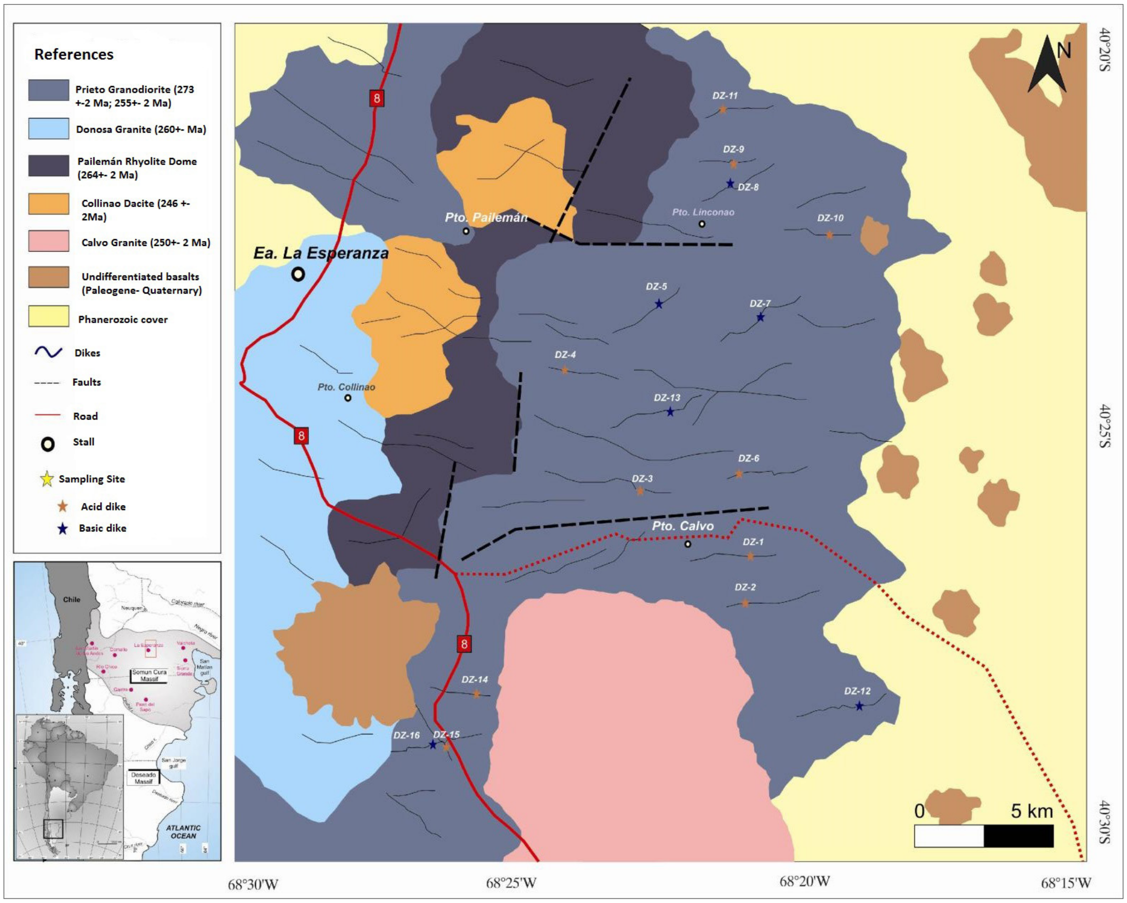


**Figure 1.** Geological map of La Esperanza area. Sampling sites are indicated with orange (violet) stars for acid (basic) dikes.

The dike swarm sharply intrudes mostly the plutonic and basal volcanic units of La Experanza Complex. It is composed of mostly <2 meters thick- NE-SW trending subvertical andesitic lithotypes (facies B) and decametric long, >1 m thick- E-W acid rhyolite dikes (facies A). Basic dikes are composed mostly of widely altered plagioclase, amphibole and some minor pyroxene whereas acid dikes are made up of K-feldspar, quartz and plagioclase, traces of biotite and common accessory minerals. Both types of dikes exhibit a constant composition but large textural variations reflecting somewhat different cooling dynamics. The age of the andesite dikes is conservatively bracketed between the age of the Donosa Granite, 260 ±2 Ma and the 250±2 Ma Calvo Pluton, which is not crosscut by the dike swarm (U-Pb SHRIMP in zircon, Martínez Dopico *et al.*, 2015; and Pankhurst *et al.*, 2006, respectively). Whereas, the acid dikes could be somewhat younger, bracketed between 255 ±2 Ma (U-Pb SHRIMP in zircon age of Prieto Granodiorite) and 245 ±2

Ma Collinao dacite Dome (Pankhurst *et al.*, 2006).

**Methodology**

Paleomagnetic sampling was performed using a portable water-cooled gasoline drill in 16 sites of dikes and, whenever possible, the host rock. Sampling sites were homogeneously distributed in the batholith in an area larger than 10 $m^2$ within each site to reduce the effect inhomogeneities and were oriented by sun and magnetic compasses. In the laboratory, cores were cut in two or three 2.2cm height specimens. Paleomagnetic samples were submitted to standard stepwise demagnetization techniques. Alternating field (AF) demagnetization involved steps of 3, 6, 9, 12, 15, 20, 25, 30, 35, 40, 50, 60 mT in most cases, with demagnetization steps of up to 100 mT used for some samples. AF demagnetization proves to be the more efficient in most sites. AF demagnetization was performed in a JR-6 spinner magnetometer (AGICO) where the remanence directions were measured. Additional thermal demagnetization was accomplished in a dual-camera TD-48 ASC oven, with internal magnetic fields below 10 nT. Bulk susceptibility was monitored after each demagnetization step with a Bartington MS-2 susceptibilimeter. Magnetic components were obtained by means of principal component analysis using the software REMASOFT 3.0 (Chadima and Hrouda, 2006). Maximum angular deviations up to 15° were accepted. After AF demagnetization, IRM (isothermal remnant magnetization) curves were constructed by submitting the samples to several increasing short-lived magnetic pulses (30, 45, 60, 90, 120, 150, 225, 300, 450, 600, 900, 1300, 1650, and 2000 mT) in an impulse magnetizer ASC Scientific Model IM-10-30 and measuring its remnant magnetization in a JR-6 spinner magnetometer (AGICO). All laboratory procedures were accomplished at the Laboratorio de Paleomagnetismo Daniel A. Valencio (IGEBA, Universidad de Buenos Aires).

**Table 1:** Site mean directions for all the analyzed sampling localities. Declination, inclination, α95 (95% confidence radio), k (clustering parameter), N (analyzed samples, n (samples used for building the VGP), and VGPLat and VGPLong (virtual geomagnetic pole latitude and longitude). Asterisk stands for the sites in which the directions were calculated using the maximum circles, α95 corresponds to the maximum angular deviation maxima -MAD.

| Site | Facies | Dec. (º) | Inc. (º) | $\alpha_{95}$ | k | N | n | VGP Lat. (°) | VGP Long. (°) |
|---|---|---|---|---|---|---|---|---|---|
| **DZ13** | B | 308.6 | -71.7 | 6.2 | 81.46 | 12 | 10 | -53.4 | 337.9 |
| **DZ15** | B | 352.4 | -65.6 | 3.4 | 200.71 | 11 | 10 | -80.8 | 325.5 |
| **DZ12** | B | 316.4 | -64.8 | 18.2 | 10.23 | 10 | 8 | -58.2 | 355.4 |
| **DZ2** | A | 7.7 | -55.2 | 9.4 | 172.91 | 9 | 3 | -82.4 | 166.4 |
| **DZ11** | A | 346.1 | -53.6 | 9.9 | 38.08 | 9 | 7 | -77.3 | 46.7 |
| **DZ3** | A | 4.8 | -51.1 | 13.6 | 32.7 | 11 | 5 | -80.6 | 137.3 |
| **DZ6** | A | 25.5 | -51 | 7.3 | 68.64 | 13 | 7 | -67.7 | 186.7 |
| **DZ16** | A | 334.6 | -43.6 | 14.2 | 5.78 | 6 | 6 | -64.1 | 49.1 |
| **DZ5** | B | 180.4 | 39 | 7.6 | | 13 | 6 | -71.6 | 112.8 |
| **DZ10** | B | 174.1 | 51.9 | 4.3 | | 11 | 3 | -80.8 | 78.7 |
| **DZ1** | A | 155.3 | 60 | 5.8 | 62.54 | 12 | 11 | -72.6 | 10.5 |
| **DZ9** | A | 168.1 | 63.3 | 9.7 | 62.64 | 11 | 5 | -79.6 | 338.7 |
| **DZ14** | B | 198.3 | 76.2 | 10.8 | | 10 | 4 | -64.2 | 273.1 |

**Paleomagnetic results and discussion**

Thirteen out of sixteen sites for both types of dikes provided reliable and consistent paleomagnetic results after detailed demagnetization. The remaining sites showed unstable magnetic behavior during demagnetization or random directions for the remanence. In most cases a well-defined magnetic component is erased by fields between 6 and 15 mT and blocking temperatures below 580° C with a linear trend towards the origin of coordinates in the Zijderveld plots. Magnetic mineralogy studies indicate that mid-coercivity and high-unblocking temperature minerals such as PSD titanomagnetite mainly carried ChRM directions, for the basic dikes. A contribution of an antiferromagnetic phase in case of the acid dikes (hematite?) was also detected (Fig. 2a). AF and thermal treatment revealed northern and complementary southernward (5 out of 13 sites) directions with moderate downward and upward inclinations, respectively on samples from 13 of the analyzed sites (Fig. 2b). The reversal test was successfully passed – C classification of McFadden and McElhinny (1990). Site mean directions cluster around the mean Dm = 346°; Im = -60°, which yielded calculating a paleomagnetic pole for the La Esperanza dikes (LE pole), located at -82.5° (lat), 11.9° (long) (A95=10.9º; N=13, k=17). Dm = 298.6°; Im = 27.4° (a95 = 10.1; K = 12.1) (Fig. 2c). The comparison of the position of the LE pole with other poles of Patagonia (*i.e.* SG pole, Rapalini 1998) and neighbouring areas outside the block (*i.e.* Sch b and ChY, Domeier *et al*. 2011 a, b) suggests that these blocks were already juxtaposed earlier than 250 Ma, as suggested in previous geologic models (Table 2).

**Table 2:** Paleomagnetic poles for the Permian to Triassic times for the South American continent. LE pole is really close in its position to the 254 Ma- AR pole of Yokoyama *et al.* (2013).

| | | Block | α95 | Paleomagnetic Pole | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Lat (º) | Long (º) | Age | | Reference |
| **Tep** | GrupoTepuel, sedimentary rocks | Ar- Tecka, Chubut | 8.0 | -32.0 | 316.0 | *318* | Stratigraphic age | Rapalini *et al*. (1994) |
| **LM** | Fm La Colina, Mina Las Mellizas, sedimentaryrocks | Ar- Cuenca Paganzo, La Rioja | 5.6 | -67.1 | 343.7 | *300-315* | Stratigraphic age | Geuna *et al*. (2010) |
| **SF** | Grupo Santa Fé, Red beds | Br- Mina Gerais | 4.0 | -66.0 | 331.0 | 300 | | Brandt *et al*. (2009) |
| **Col** | Los Colorados, Red beds | Ar- Cuenca Paganzo, La Rioja | 5.0 | -60.0 | 358.0 | 295 | | Embleton (1970) |
| **IT2** | Itararé II, sedimentary rocks | Br- Cuenca de Paraná | 4.0 | -60.0 | 29.0 | 290 | | Pascholati (1983) |
| **IT1** | Itararé I, sedimentary rocks | Br- Cuenca de Paraná | 4.0 | -57.0 | 351.0 | 295 | | Pascholati (1983) |
| **LC** | Fm. La Colina, Red beds | Ar- Cuenca Paganzo | 8.0 | -49.0 | 343.0 | 295 | | Sinito et al. (1979) |
| **RC** | Rio Curacó, Igneous rocks | Ar- La Pampa | 5.0 | -64.0 | 5.0 | 290 | | Tomezzoli *et al*. (2006) |
| **SCh a** | Sierra Chica; Ignimbrites, rhyolites | Ar- La Pampa | 8.0 | -66.0 | 34.0 | 290 | | Tomezzoli *et al*. (2009) |
| **Tu I** | Fm. Tunas, sedimentary rocks | Ar- Sierras Australes, Buenos Aires | 5.0 | -63.0 | 14.0 | 295 | | Tomezzoli y Vilas (1999) |
| **Cp** | Grupo Copacabana, sedimentary rocks | Pe- Subandino | 5.2 | -68.2 | 321.3 | *280* | | Rakotosolofo *et al*. (2006) |
| **CC** | Cerro Colorado-Caminiaga, sedimentary rocks | Ar- Cuenca Paganzo | 11.0 | -79.3 | 290.3 | 275 | Stratigraphic age | Geuna y Escosteguy (2004) |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **RB** | Rincon blanco, Volcanic and volcaniclastic rocks | Ar- Cuenca Paganzo, La Rioja | 6.7 | -75.0 | 291.5 | *275* | Stratigraphic age | Geuna y Escosteguy (2004) |
| **Tu II** | Fm Tunas II, sedimentary rocks | Ar- Sierras Australes, Buenos Aires | 5.0 | -74.0 | 26.0 | 275 | | Tomezzoli (2001) |
| **CF** | De la Cuesta, Famatina; sedimentaryrocks | Ar- Sierra de Famatina | 12.2 | -77.2 | 343.6 | *275* | | Spagnuolo *et al.* (2008) |
| **SG** | Sierra Grande; sedimentary rocks | Ar- Sierra Grande, Río Negro | 7.0 | -77.0 | 311.0 | 270 | | Rapalini (1998) |
| **SR** | San Roberto; Sedimentary rocks | Ar- Cuenca de Carapacha, La Pampa | 11.0 | -70.0 | 49.0 | *270- PS* | | Tomezzoli *et al.* (2006) |
| **ChY** | Choiyoi Superior; Ignimbrites, rhyolites | Ar- Bloque de San Rafael, Mendoza | 4.0 | -74.0 | 316.0 | 264.00 | U-Pb SHRIMP zrc | Domeier *et al.* (2011a, b) |
| **SCh b** | Sierra Chica; Ignimbrites, rhyolites | Ar- La Pampa | 3.0 | -81.0 | 349.0 | 263±3 Ma | U-Pb SHRIMP zrc | Domeier *et al.* (2011a, b) |
| **IN** | Grupo Independencia; Sandstones | Py | 7.0 | -81.0 | 7.0 | *260* | | Rapalini *et al.* (2006) |
| **PP** | Pluton Prieto, Igneous rocks | Ar- Los Menucos, Rio Negro | 10.9 | -67.4 | 13.9 | 260 | U-Pb SHRIMP zrc | MartínezDopico (unpubl.) |
| **PS** | Punta Sierra; Granites | Ar- Sierra Grande, Río Negro | 12.0 | -65.0 | 11.0 | ~260 | K-Ar | Tomezzoli *et al.* (2012) |
| **AR** | Araguinha Crater | Br- | 3.5 | -83.7 | 340.1 | 254 | U-Pb SHIRIMP zrc | Yokoyama *et al.* (2014) |
| **LE** | **La Esperanza; mafic and aciddikes** | **Ar- La Esperanza, Río Negro** | **10.9** | **-82.5** | **11.9** | **250** | **Stratigra - phic age** | Domeier *et a*l. (2011a, b) |
| **P** | Grupo Puesto Viejo; Volcaniclastic and volcanic rocks | Ar- Bloque de San Rafael, Mendoza | 7.0 | -76.0 | 312.0 | 250 | Ar-Arbtkfshb | Domeier *et al.* (2011a, b) |
| **AM** | Amaná; Red beds Paganzo Group | Ar- Cuenca Paganzo, La Rioja | 8.0 | -83.0 | 317.0 | *249* | | Valencio *et al.* (1977) |
| **APY** | Alto Paraguay; Volcanic rocks | Py | 6.0 | -78.0 | 319.0 | 242±1 Ma | Ar-Ar | Ernesto (2005) |
| **GC** | Gonzalez Chavez, Igneous Rocks | Ar- Buenos Aires | 17.0 | -84.0 | 216.0 | Low- Tr | | Tomezzoli y Vilas (1997) |

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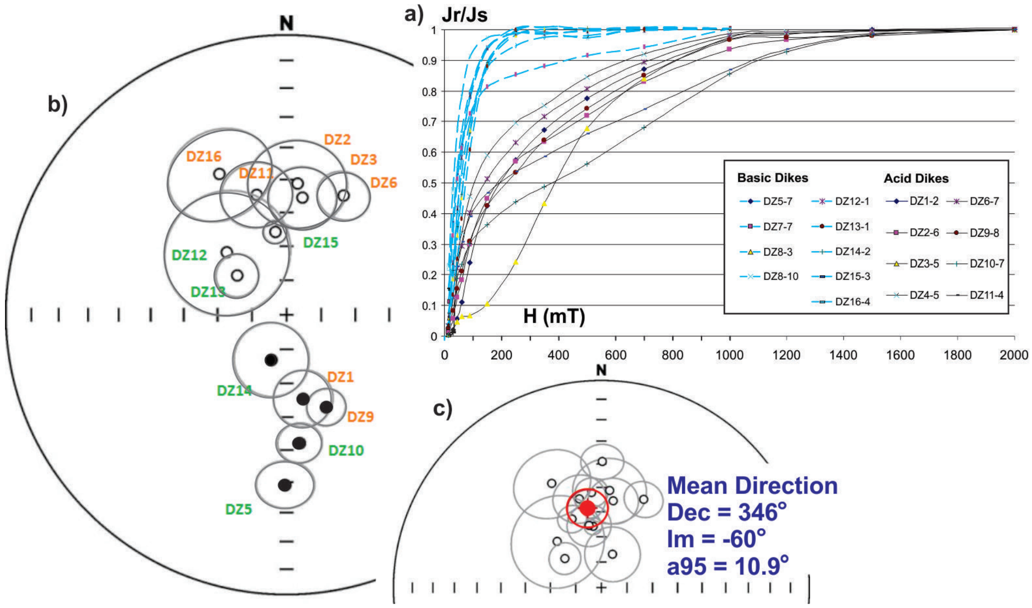


**Figure 2.** a) Isothermal magnetization for the basic dikes (dashed lines) and acid dikes (full line). Saturation is reached at 300 mT (magnetite) and 1500 mT (magnetite and hematite), respectively; b) Mean directions per site with their confidence circles, before and c) after the inversion. Highlighted in red is the total mean direction.

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