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GR Letter

The Apparent Polar Wander Path for South America during the Permian–Triassic

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ABSTRACT

Many of the controversies that arise in global reconstructions for Permian–Triassic time could be resolved by taking into account the large latitudinal and counter-clockwise movement of Gondwana during that interval of time. The proper trace of the apparent polar wander curve should differentiate one position for the Early Permian, another position for the Late Permian and yet another for the Triassic. By doing so and comparing the Apparent Polar Wander Paths (APWP) of South America and Africa it is easy to see that both curves have the same shape, therefore it is possible to arrive at a good fit between them, which previous analyses were unable to achieve. This new proposed Permian–Triassic track of the APWP reveals a hook not hitherto recognized that should be accounted for in global reconstructions.

1. Introduction

During the geological history of the Earth, the continents have moved apart or come together many times, forming supercontinents. One of the purposes of paleomagnetic investigations is to provide information about the movement of the continent. The path of the successive position of the paleomagnetic poles from time to time on the present latitude–longitude grid is called the Apparent Polar Wander Path (APWP) for that region. If two continents were part of the same plate during the same epoch, these blocks have to share the same APWP. Matching of two paths should be undertaken with geological comparisons between the blocks or the matching of the continental margins.

Between 320 Ma (Late Carboniferous) and 180 Ma (Middle Jurassic), approximately, the collision of the continents produced the last supercontinent known as Pangea. Different proposals of Pangea's configuration have been made through the decades. Many proposals were based on matching Jurassic paleomagnetic poles; some variations are seen in Pangea A of Wegener (1924; Fig. 1) and Pangea A1 (Bullard et al., 1965; Fig. 1). For the time of the rupture these models are well-accepted, but not for the preceding times. The discrepancies were tackled by proposing different Pangea configurations such as Pangea A2 (Van der Voo and French, 1974), Pangea B (Irving, 1977; Morel and Irving, 1981; Muttoni et al., 1996; Torcq et al., 1997), Pangea C or A3 (Smith and Livermore, 1991), and others. However the Permian–Triassic configuration of Pangea is still unresolved.

The hypothesis presented here is that a possible explanation for the resolution of "Pangea's problem" lies in the erroneous superposition of different age sections of the APWPs. Using this perspective, a new track for the APWP for South America during the Permian–Triassic is proposed.

2. Paleomagnetic database

South America occupies an important position in paleogeographic reconstructions and crustal evolution history of the Gondwana supercontinent (e.g., Vaughan and Pankhurst, 2008; Teixeira et al., 2007). Since the 1970s, different authors proposed for the Late Permian–Early Triassic period a track for the Apparent Polar Wander Path (APWP) of South America, with movement first to the South and then to the West, to remain then in a quasi static period until the end of the Triassic (Embleton, 1970; Creer et al., 1970; Valencio et al., 1975; Vilas and Valencio, 1982). The observed differences with the APWP of Africa relative to South America have been explained as a consequence of the movement of Africa to the east during the same period of time (Embleton, 1970). For this reason, the superposition of the APWP of South America with that of Africa during the Late Permian–Triassic a good fit is not possible between them. Possibly one of the principal explanations is that it is not clear yet how to construct the South America track. In most cases, the reconstructions were based on comparing Upper Permian Paleomagnetic Poles (PPs) from South America with Triassic PPs from Africa, thereby producing an erroneous combination.

Improvements in methods, new theories, equipment, and so on invalidate most of the old paleomagnetic data because they

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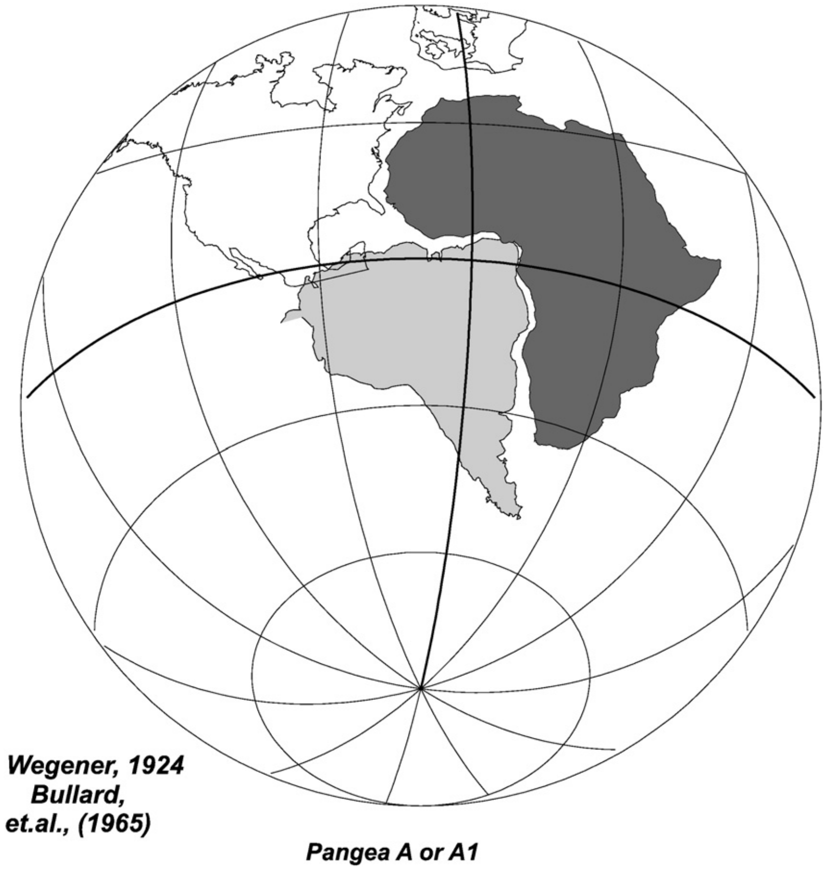

Fig. 1. First model of Pangea A (Wegener, 1924; Bullard et al., 1965).

Fig. 2. Acceptable APWP for South America, for the latest Paleozoic. All the paleomagnetic poles (see Table 1) were selected from the cratonic areas with a minimum of three of the reliability criteria of Van der Voo (1990). The mean positions for the Lower and Upper Permian are indicated as Lower Gondwanides (□) and Upper Gondwanides (○).

Table 1
Late Paleozoic and early Mesozoic South American poles selected from the cratonic areas of South America

Paleomagnetic pole	A95°	Lat. °	Long. °	PLat. °	PLong. °	Age (PP)	References
Up. Gondwanides	–	±36	±295	−72	039	270-uP	This paper
San Roberto○	11	−38.2	294.2	−70	49	270-up	Tomezzoli et al. (2006)
Tunas II Ar○	5.2	−38.2	298.6	−74.1	25.9	275-ulP	Tomezzoli (2001)
Low. Gondwanides	7	±36	±295	−64	14.2	285-ulP	This paper
Sierra Chica □	8	−37.5	295	−66.5	034	290?	Tomezzoli et al. (2008)
Cochico □	17.5	−34.5	291	−60.3	007	285–280lP	Tomezzoli et al. (2005)
Rio Curaco Ar □	5	−38.1	294.1	−64	005	280 lP	Tomezzoli et al. (2006)
Itarare I2 Br.	4	−21.5	312.8	−60.3	29.5	290-lP	Pascholati (1983)
Tunas I Ar. □	5.1	−38	298.2	−63	13.9	290-lP	Tomezzoli & Vilas (1999)
Lw. Colorados Ar	5	−29.5	293	−60	358	293-lP	Embleton (1970)
La Colina Ar.	8	−30	293	−49	343	294-lP	Sinito et al. (1979)
Itarare I Br.	4	−21.5	312.8	−56.7	350.6	295-lP	Pascholati (1983)
Tepuel Ar.	8.5	−43.5	289.6	−31.7	316	318-lC	Rapalini et al. (1994)

PP were taken from Van der Voo (1993) and McElhinny and Lock (1996) and the data were checked with the original contributions. A95(deg) = semi-angle of the 95% confidence cone. The PP were selected based on a minimum of three of the reliability criteria (1990); see Fig. 2. Symbols ○,□ identify data used for the PP average.

do not pass modern reliability criteria (Van der Voo, 1990). New paleomagnetic data from the cratonic areas along the Southwest Gondwana margin seems to confirm a large latitudinal and counterclockwise movement of South America between the Lower Permian and the Triassic (Tomezzoli, 1997, 2001, 2005; Tomezzoli et al., 2006, 2008; Fig. 2; Table 1). That implied a latitudinal difference of about 28°, which means a displacement of 3200 km, in approximately 40 Ma with a velocity of ~9 cm/year (Torsvik and Smethurst, 1997). This movement has been interpreted as the consequence of a late adjustment between the continental blocks after the collision of the Patagonia terrain during the Devonian and before the final assembly of Pangea (Tomezzoli, 2001; Tomezzoli et al., 2008). This evolutionary process is reflected in the geology of the area as well as in the paleomagnetic data. During the Permian occurred a widespread silicic volcanism which produced the Choiyoi Group, whose extension in Argentina exceeds 500,000 km^2 (Llambías et al., 2003). In the Lower Permian the magnetizations are all syntectonic (Tunas I PP; Cochico PP; Río Curacó PP; and Sierra Chica PP, among others; Fig. 2). This deformation episode is related to the San Rafaelic orogenic phase and has been dated at approximately 290 Ma. In the Lower–Upper Permian there is no evidence of deformation in the magnetization pattern (Tunas II PP; San Roberto PP) for ages of approximately 275 Ma. These new and reliable data permit a better track for

Table 2
Triassic selected poles from Argentina

Paleomagnetic pole	Q≥3*	PLat	PLong	α95°	Polarity	Reference
1 Cochico (Cta. De los Terneros)		−77	163	5	N/R	Vilas and Valencio (1982)
2 Colorados (Paganzo)	*	−78	249	3	N/R	Valencio et al. (1977)
3 Choique Mahuida		−75	344	15	R	Conti and Rapalini (1990)
4 Cuesta de los Terneros		−80	228	10	N/R	Creer et al. (1970)
5 SG3		−77.3	310.7	7.5	R	Rapalini (1998)
6 Copacabana	*	−68	321	5.2	R	Rakotosolofo et al. (2006)
7 Tambillos	*	−79	320	6.5	R	Rapalini and Vilas (1991)
8 Independencia	*	−80.7	7	6.6	N/R	Rapalini et al. (2006)
9 Lopez Lecube	*	−71	320	6	R	Tomezzoli (1997)
10 Gonzalez Chaves		−84	216	17	N/R	Tomezzoli and Vilas (1997)
11 Amana	*	83	317	8	N/R	Valencio et al. (1977)
12 Alto Paraguay		−78	319	6	R/N	Ernesto (2005)
13 El Nihuil (lavas)	*	−81	282	6	N/R	Valencio (1970)
14 Rincón Blanco	*	−77	294	4.9	R	Geuna and Ecosteguy (2003)
15 Chancañi	*	−85	359	8.8	N/R	Geuna and Ecosteguy (2003)
16 Cerro Colorado	*	−79	291	8	N/R	Geuna and Ecosteguy (2003)
17 Puesto Viejo		−76	236	18	N/R	Valencio et al. (1975)
18 Ischigualasto		−79	239	15	N/R	Valencio et al. (1975)
19 Rio Blanco	*	−82	298	8	N/R	Vizán et al. (2004)
20 Cerro Carrizalito		−65.5	218	11	N/R	Terrizzano (2005)
21 Quebrada del Pimiento		−65.5	189	12	N/R	Terrizzano et al. (2005)
22 El Horcajo		−72	265	12	N/R	Rapalini and Vilas (1991)
23 La Flecha	*	−64	245	15	N/R	Rapalini and Astini (2005)
24 Pavón	*	−83.7	271	6.8	N/R	Rapalini and Cingolani (2004)
25 Choiyoi Group		−67	290	10	N/R	Vilas and Valencio (1982)
26 Río Uruguay		−76	346	7	R	Buggisch et al. (1994)
27 Molles (sedimentary)	*	−78.7	330.8	7	R	Spagnuolo et al. (2008)
27 De La Cuesta	*	−76.9	345.2	6	R	Spagnuolo et al. (2008)
28 Lipeón	*	−74.9	214.8	9.9	N/R	Conti et al. (1995)
Triassic pole average		−81	279.5	4		This Work

The selection was done based on the PP position, and supposing a Triassic age, independently of the quality of the PP. For that reason are also included PP from mobile areas, some PP interpreted as rotated, and some that must be considered as virtual geomagnetic poles (VGPs). All the data were checked with the original contributions. α95° = angle of the 95% confidence cone. See Fig. 3.

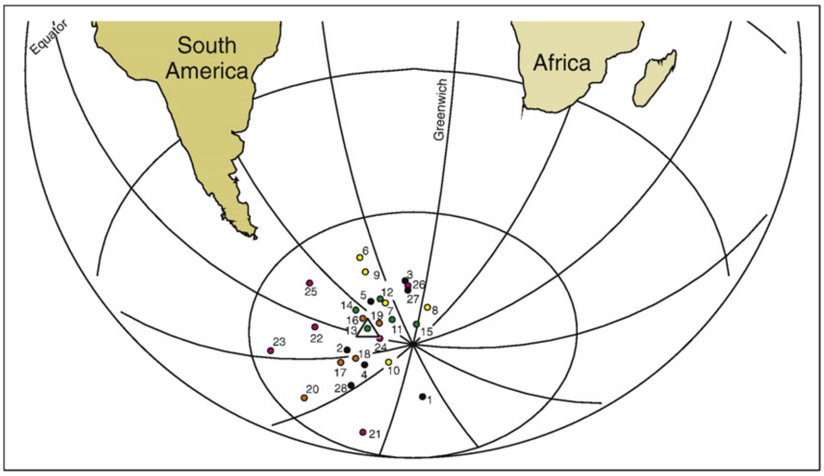

Fig. 3. Paleomagnetic Triassic poles from Argentina and South America, selected on the basis of the position instead of the quality (see Tables 2 and 4). The mean is indicated as a triangle.

the APWP from the Late Carboniferous to Early–Late Permian time. For some authors, this arrangement of the PPs yielded a Pangea type B (Rakotosolofo et al., 2006; Rapalini et al., 2006). However, even in these new paleoreconstructions, the absence of reliable paleomagnetic poles for the Early Triassic makes this part of the curve uncertain and creates controversy regarding the movement of the continents and the "correct Pangea" configuration.

According to the Geological Time Scale (Gradstein et al., 2004) the Kiaman Reverse Superchron ended near 263 Ma, following which the reversals of the magnetic field began again. A review of the original contributions of almost all published data for the Upper Paleozoic and Triassic of South America, most of them from Argentina (Table 2), reveals some interesting observations. Most of the PPs, instead of having the typical Kiaman reverse direction, have two polarities of the magnetic field (Table 2). Other examples are the equivalent paleomagnetic pole position of López Lecube (reverse; Lat.: 71°S, Long.: 320°E, $\alpha95°$: 6.2; Tomezzoli, 1997; Tomezzoli and Vilas, 1997; Table 2; Fig. 3) and Choique Mahuida (reverse; Lat.: 75°S, Long.: 344°E, $\alpha95°$: 15; Conti

Fig. 4. Mean positions in the APWP of South America showing the proposed loop between the Upper Permian–Triassic (dotted line).

Fig. 5. Selected paleomagnetic poles for the APWP for Africa, between the Late Paleozoic and Early Mesozoic times (see Table 3 and Fig. 5), with a minimum of three of the reliability criteria (Van der Voo, 1990). The mean for each position is indicated using the same symbols as in Tables 4 and 5:▲●■.

and Rapalini, 1990; Table 2; Fig. 3). Both localities are related to the same magmatic event with a similar age of approximately 240–250 Ma (Cingolani and Varela, 1973; Rapela et al., 1996). When reversals began again, following the Kiaman, the paleomagnetic poles began to occupy southern and western positions with respect to the Permian paleomagnetic poles (Fig. 4; Table 2). In other cases, the age of the rocks were assigned based on regional correlations or old radiometric age dating. As a consequence the positions of these PPs was explained as due to tectonic rotations because they have "anomalous" positions in the track. Vertical axis rotations up to

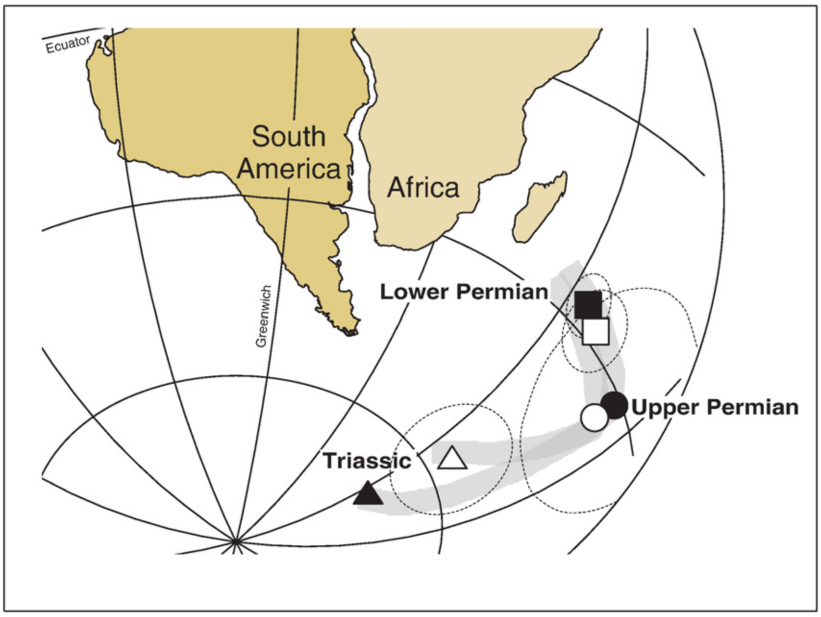

Fig. 6. Comparison between the mean positions in the APWP for South America (△○□) and Africa (▲●■). South American poles and continent were rotated to African coordinates, following Lottes and Rowley (1990) parameters.

Table 3
Selected Permian–Triassic paleomagnetic poles from Africa “in situ” (adapted from Tomezzoli, 1997 and Rakotosolofo et al., 2006)

Paleomagnetic poles	A95°	PLat.°	Rot.	PLong.°	Rot.	Age (PP)	References
#Ait-Aadet ▲	7.5	−72	−64.64	74.5	81.66	238-Tri	Hailwood (1975)
*Jwaneng ▲	5.1	−72		39.2		242-Tri	Hargraves (1989)
*Tanzania●	5.3	−27		85		240-Tri	Nyblade et al. (1993)
*Songwe ●	12	−27		089		260-uP	Opdyke (1964)
##Jebel Nehoud ●	6	−40.8	−39.59	71	72.07	280-lP	Bachtadse et al. (2002)
#Chougrane ■	5	−32	−25.31	064	67.38	273-uP	Daly and Pozzi (1976)
#Abadla ■	6	−29	−22.6	60	63.36	272-uP	Morel et al. (1981)
Dwyka Fm.■	12	−25		067		282-lP	Opdyke et al. (2001)
#Abdala Fm.■	3	−29	−22.77	057.8	61.28	285-lP	Merabet et al. (1998)
#Upper El Adeb ■	2.8	−38.5	−32.25	057.5	61.99	295-lP	Henry et al. (1992)
#Tiguentourine ■	4.1	−33.8	−27.28	61.4	65.12	290-lP	Derder et al. (1994)

Some of the PP were rotated to South Africa coordinates following Lottes and Rowley (1990) parameters: 9.34°N, 5.70°E, Ω=7.82 for NW (#) Africa and −16.3°N, 41.71°E, Ω=2.53 for NE (##) Africa. Symbols ▲●■, identify the PPs averaged. See Fig. 5.

40° have been reported (Rapalini and Vilas, 1991; Conti et al., 1995; Geuna and Escosteguy, 2003; Terrizzano et al., 2005; Spagnuolo et al., 2008; see Table 2), without considering alternative possibilities of incorrect age assignments for the rocks or younger remagnetizations during the Late Permian–Early Triassic. The consequence is an incorrect estimate of the Permo-Triassic position in the APWP. The present analysis has not attempted to reevaluate the age versus the rotation interpretations for these unusual cases, which ideally would involve more laboratory and field studies.

With a careful comparison between the APWPs for South America and Africa in the Early Permian–Triassic interval, it is easy to see that both curves have the same shape (Figs. 5 and 6; Table 3). Naturally this could be a coincidence. However, this Permian–Triassic hairpin curve (Fig. 4) connects smoothly with the Jurassic part of the path (Vizán, 1998; Iglesia Llanos et al., 2007). It is possible to arrive at a good adjustment between them, taking into account the three different positions: Early Permian, Late Permian and Triassic (Tables 4 and 5; Figs. 5 and 6). Otherwise, the latitudinal and counter-clockwise movement of the continents is not adequately accounted for.

3. Conclusions

There are still many controversies about the Pangea configuration during Permian–Triassic time, because of the absence of reliable paleomagnetic poles and modern radiometric age-dating of the rocks. As a consequence, it is common to see in paleoreconstructions that the Permian track for South America is superimposed on the younger Triassic track from Africa, instead of the logical superposition of tracks with similar ages. It is important to make a proper trace of the wander path because it could help in the resolution of tectonic problems of different scales, such as super-continental models or local rotations. After a reevaluation of the position of the available paleomagnetic poles from Permian–Triassic rocks (including some that could not be proven reliable), it is easy to see changes in the paleomagnetic directions and pole positions for this interval of time. The Permian rocks initially have the Kiaman reverse magnetization; however, for younger rocks, the magnetic field reversals start to appear, and the PPs positions moved principally towards the West and also to the South along the APWP. This gives grounds for suspicion that there is a different continental position for the Permian and the Triassic, which implies a latitudinal difference of about 28°, corresponding to a displacement of 3200 km, in approximately 40 Ma with a velocity of ~9 cm/year (Torsvik and Smethurst, 1997). Thus three different segments of the APWP of South America can be defined, for the Early Permian, Late Permian and the Triassic. Otherwise the large latitudinal and counter-clockwise movement of the continents (Tomezzoli, 1997, 2001) is not accounted for. This new proposed Permian–Triassic track of the APWP reveals a hook not hitherto recognized that should be considered in global constructions.

Table 4
Average paleomagnetic pole position for South America

Age	PLat.°	P.Long°	α95°	PLat.° #	P.Long°#
Triassic Δ	−81	279.5	4	−56.14	66.36
Late Permian ○	−72	039	–	−34.60	80.86
Early Permian □	−64	014	7	−28.12	68.79

Rotated to South Africa coordinates following Lottes and Rowley (1990) parameters: 46.82°N, −30.54°E, Ω=55.88. See Figs. 2–4. Symbols Δ○□ identify the PPs averaged. See Fig. 4.

Table 5
Average paleomagnetic pole position for Africa, based on the same position, assuming that the ages need some modifications

Period	*N*	PLat.° *	PLong.°*	A95°
Triássic ▲	2	−69.63	64.03	–
Late Permian ●	3	−31.38	082.5	15.9
Early Permian ■	5	−26.54	64.57	4.1

Symbols ▲●■ identify the mean PPs. See Fig. 6.

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