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ABSOLUTE PALAEORECONSTRUCTIONS OF CONTINENTS BASED ON PALAEOMAGNETIC POLES AND VIRTUAL GEOMAGNETIC POLES?

Haroldo Vizan and Carlos Alberto Vasquez
Lab. de Paleomagnetismo Daniel Valencio. CONICET. Universidad de Buenos Aires.
Depto de Ciencias Geológicas. Fac. de Cs. Ex. y Nat. Pabellón II. Ciudad Universitaria.
1428 Nuñez. Buenos Aires.

ABSTRACT

Transitional Jurassic and Early Cretaceous Virtual Geomagnetic Poles (VGPs) repositioned according to absolute palaeoreconstructions, define two paths similar to those for reversals of the last 12 Myr. These paths roughly coincide with the regions of the present core mantle boundary (CMB) that lie below regions of the lower-mantle with fast seismic wave velocities. A statistical test applied to the population of Jurassic-Early Cretaceous transitional VGPs identifies two antipodal bands (105/137° E-285/317° E). Mantle convection and geoid models suggest that the present topographic temperature pattern over the CMB has persisted since the Late Paleozoic. Hotspot tracks are alternative tools to make absolute reconstructions, but they are not applicable to Late Paleozoic times due to lack of hotspot framework for those times. Absolute reconstructions of South America for the Late Permian based on a mean palaeomagnetic pole and on the position of the bands defined by transitional and oblique VGPs are presented. These reconstructions are compared with an alternative obtained by a different method.

RESUMEN

Polos geomagnéticos (PGVs) transicionales del Jurásico y Cretácico Inferior reconstituidos de acuerdo a paleoreconstrucciones absolutas, definen dos caminos similares a los de reversiones de los últimos 12 m.a. Estos caminos aproximadamente coinciden con zonas del límite manto núcleo (LMN) actual que se encuentran debajo de regiones de la base del manto con rápidas velocidades de ondas sísmicas. A través de modelos de geoide y convección se ha sugerido que el actual patrón de geoide y convección se ha sugerido que el actual patrón de topografía térmica en el LMN ha perdurado desde el Paleozoico Tardío. Para el Jurásico y Cretácico inferior un análisis estadístico aplicado a una población de PGVs transicionales de ese lapso definió dos bandas antípodas (105/137° E - 285/317° E). Las trazas de puntos calientes han sido empleadas como herramientas alternativas para efectuar reconstrucciones absolutas, pero ellas no son aplicables para el Paleozoico Tardío dada la carencia de grillas confiables de puntos calientes con esa edad. En este trabajo se presentan reconstrucciones absolutas de América del Sur para el Pérmico Tardío basadas en un polo paleomagnético promedio y en la posición de las bandas definidas por PGVs transicionales y oblicuos. Estas reconstrucciones son comparadas con una reconstrucción alternativa obtenida por un método diferente.

1. INTRODUCTION

Within the field of Paleomagnetismo there are three branches that, up too now, have practically evolved independently, (i) applications to geodynamics and tectonics; (ii) magnetostratigraphy and (iii) studies of the geomagnetic field (GMF) behaviour. Anyway there are some few papers that integrate evidence from the three branches (i.e., Livermore *et al.*, 1984; Courtillot and Besse, 1987; Besse and Courtillot, 1991).

The support given by Paleomagnetismo to geodynamics and stratigraphy has been singular. Both latitudinal reconstructions of continental plates and accurate stratigraphical correlations have been possible from palaeomagnetic and magnetostratigraphic studies. Paleomagnetismo is also the only tool that geomagnetists have for studying one intriguing process of the GMF: the polarity transitions. At the present time, it is controversial whether transitional virtual geomagnetic poles (VGPs) occurred along preferred longitudinal paths. For example, Gurary (1988), Clement (1991) and Tric *et al.* (1991), have observed that transitional VGP paths of different reversals for the last 12 Myr, are mainly distributed within two preferred and practically antipodal bands: one of them along the Americas and the other over Australia and Asia. Laj *et al.* (1991) suggested that these transitional paths would reflect a geomagnetic phenomenum related with regions of fast seismic wave propagation (and then, low temperature) in the lower mantle. However, this suggestion was happened by several possible flaws: 1) statistical errors (Valet *et al.*, 1992), 2) dependence of the VGP paths with the geographic locations of the sampling sites (Egbert, 1992; McFadden *et al.*, 1993), 3) transitional paths could be an artifact due to processes involved in the acquisition of the magnetic remanences by sediments (Langerais *et al.*, 1992; Quidelleur and Valet, 1994). These three arguments have been rejected by recent contributions: Laj *et al.* (1992) observed that there is no statistical errors in the determination of the preferred transitional paths. Zhu *et al.* (1994) demonstrated that the longitudes of the VGP reversal paths are independent of the longitudes of the sampling sites.

Hoffman (1992) and Brown *et al.* (1994) have observed transitional VGPs derived from Cenozoic volcanic sequences and show that they are distributed in patches located within the longitudinal bands considered by Laj *et al.* (1991). Vizán *et al.* (1993; 1994) have observed that preferred paths occur for Late Paleozoic-Mesozoic polarity transitions and that those are quite similar to the Late Cenozoic paths. On the basis of a model of reversals that considers the features of the GMF in historical and present times (Gubbins and Coe, 1993 and Gubbins, 1994), Vizán and Van Zele (1994) analysed the magnetic directions of the reversal recorded in the Stormberg Lavas (van Zijl *et al.*, 1962) of Jurassic age. They found that this reversal could have been driven by similar conditions to those that drive the Late Cenozoic polarity transitions. According to this model the structure of the GMF should be strongly non-dipolar during a reversal so that the transitional paths of VGPs of a same reversal recorded in different localities, would be confined in similar longitudinal bands but each path would have a different longitude.

The palaeomagnetic methodology used in the analysis of the reversals is different to that applied in geodynamics and tectonics. When palaeomagnetism is used to make palaeoreconstructions of continents, remanence directional data must be averaged for a geologic time spaning over 10.000 years according to the axial, geocentric and dipolar field hypothesis (i.e., Valencio, 1980). Apparent polar wander paths (APWP) not only provide information about the past movements of continental plates but also about true polar wander (TPW): the movement of the whole Earth with respect to the rotational axis (see Andrews, 1985; Cox and Hart, 1986; Courtillot and Besse, 1987; Besse and Courtillot, 1991). Another way of making palaeoreconstructions is by referring the continent positions to a hotspot framework, which is interpreted to belong to D" layer in the lower mantle (e.g. Stacey and Loper, 1983). Therefore, frameworks or tracks of hot spots and palaeomagnetic poles (PPs) can be used in conjunction to make absolute reconstructions of the palaeolatitudinal and palaeolongitudinal positions of the continents.

Hotspot framework can be identified from Jurassic to present times (Morgan, 1983; among others). For times before 200 Ma, there are fewer hot spots so that, only few tracks can be recognized (Zonenshain *et al.*, 1985). Thus, reconstructions based on hot spots older than the Lower Jurassic, have greater uncertainty.

In this paper, we describe a method of making absolute reconstructions of the continents for the Late Permian based only on palaeomagnetic data. This method is a two step process consisting in, first a latitudinal reconstruction of the continent using PPs and then a longitudinal reconstruction based on the preferred transitional VGP paths.

2. HYPOTHESIS AND METHOD

Vizán *et al.* (1994) defined two preferred longitudinal transitional VGP bands for the Lower Jurassic-Early Cretaceous based on the application of the Raleigh test to a population with a von Mises distribution (see Davis, 1986) defined by mean longitudes (θ) of 121-301° E, with an interval of uncertainty ($\Delta\theta$) of 16° for a 5% significance level. This defines two antipodal bands between: 105-137° E and 285-317° E longitude (Fig.1). The VGPs defining these bands were previously rotated according to the hotspot framework of Morgan (1983) and subsequently by TPW.

These VGP bands coincide with the lows of the residual geoid, i.e. the regions of the CMB of fast seismic waves (Vizán *et al.*, 1993; 1994). Different authors (Anderson, 1982; Chase and Sprowl, 1983; Hager *et al.*, 1985; Gurnis, 1988; 1993; among others) have suggested that the pattern of the residual geoid and the topography of the present CMB were determined by the mantle insulation and the thermal blanketing caused by the super continent Pangaea which existed in the Middle Carboniferous (Lefort and Van der

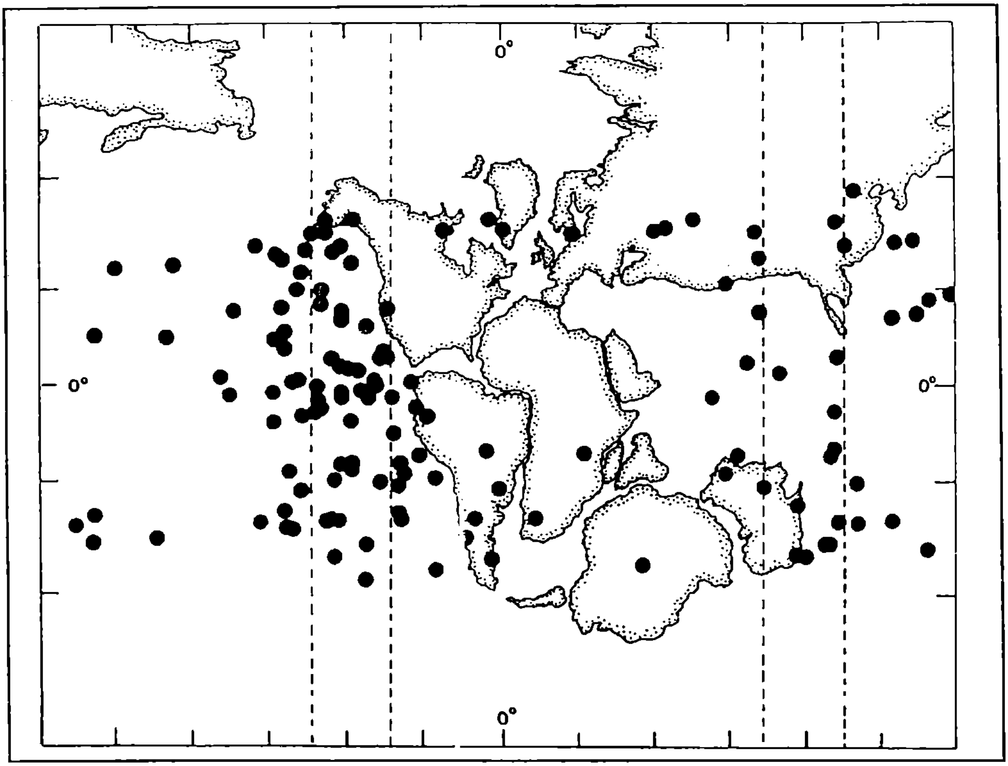

Fig. 1. Absolute reconstruction of Wegener's type Pangaea. Transitional Jurassic-Early Cretaceous VGPs (little black circles) and preferred longitudinal bands (dashed lines).

Voo, 1981; Veevers, 1991; among others). Therefore, it is possible to suggest that the pattern of the present CMB has existed since the Late Permian. It follows that, the preferred Jurassic-Early Cretaceous transitional VGP bands can be used to define a reference frame to make longitudinal reconstructions of continents for Pre-Jurassic times (i.e. Late Permian-Triassic). Jurassic and Early Cretaceous VGPs of stable polarity palaeomagnetic data of South America and Antarctica were found preferentially distributed along the same preferred longitudes of transitional VGPs (see Lanza and Zanella, 1993; Vizán *et al.*, 1993). If GMF conditions during the Late Permian were similar to those during the Jurassic - Early Cretaceous, it is possible that also elongated VGPs populations of Late Permian and Triassic sequences can be used to make longitudinal palaeoreconstructions of continents for these times. In our proposal (Fig. 2), a latitudinal reconstruction is made as a first step, by rotating the PP of the geologic

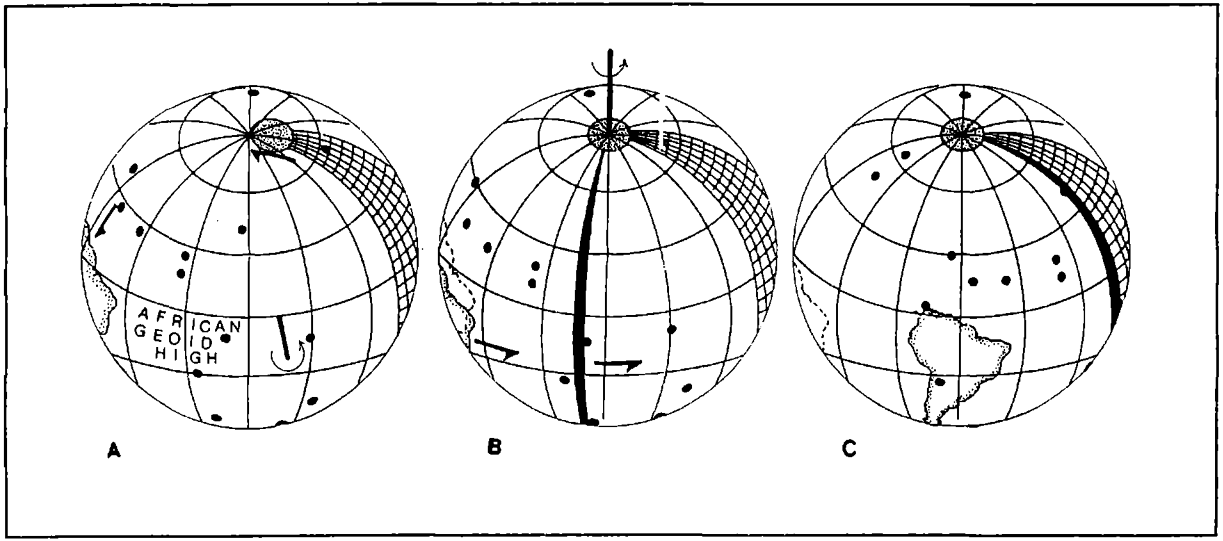

Fig. 2. Absolute reconstruction on the basis of palaeomagnetic data. Dotted circle: Late Permian mean palaeomagnetic pole (MPP) for South America. Squared longitudinal band: preferred longitudes of Jurassic-Early Cretaceous VGPs. Little black circles: VGPs of the Illawarra Zone, recorded in the upper section of Late Permian Paganzo Group. Black longitudinal band: statistically defined mean longitude. A) Latitudinal reconstruction using the MPP: the pivot is perpendicular to the great circle that contains MPP and the Earth rotation axis. The arrows indicate the sense of movement. B) Longitudinal reconstruction using the VGPs: the pivot coincides with the axis of rotation. C) Absolute reconstruction of South America after the rotations showed in A and B. The geographic position of the continent in the previous step is shown in dashed lines.

sequence being analysed through the great circle that contains the axis of rotation of the Earth and the PP or a coeval mean palaeomagnetic pole (MPP) for the continent (Fig. 2a). In other words, a pivot located on the equator is used to rotate the PP or the MPP, as well as all the VGPs and the continent itself, from their original positions to the Earth rotation axis. Thus, both the palaeomagnetic data and the continent are referred to the axis of rotation of the Earth. The rotated VGPs are statistically analysed in the same way as the preferred Jurassic-Early Cretaceous bands. It is important to point out here that if the longitudinal rotation of the continent is made using only the transitional VGPs (between 50° N and 50° S respect to the axis of rotation), the statistical values of a population will change according to the latitudinal rotation: i.e., a different number of VGPs with different geographic coordinates will be located between the mentioned parallels.

The applied statistics defines the mean longitude of the population of VGPs (Fig. 2b) and its intervals of uncertainty. The longitudinal rotation is made through a pivot at the Earth rotation axis until the mean longitude coincides with one of the Jurassic-Early Cretaceous bands (Fig. 2c). In Permian and Triassic sequences this rotation must be applied toward the African geoid high, or in the contrary sense of the drift of the plate. The same rotation is applied to the continent to obtained its longitudinal reconstruction (Fig. 2c). This analysis is illustrated with real palaeomagnetic data in Fig. 2. The position of the MPP on the northern hemisphere over the Jurassic-Early Cretaceous band (Fig. 2a), **does not** mean that it is related with this band, therefore this band **must not** be latitudinally rotated. The plotted VGPs belong to the Illawarra Zone recorded in the upper section of the Paganzo Group (Valencio *et al.*, 1977). The black meridional band is that defined by these VGPs. Its rotation up to 105°E meridian permits the best matching of South American reconstruction with an absolute reconstruction of this continent for 250 Ma obtained on the basis of hot spots (see below).

3. DISCUSSION AND POSSIBLE APPLICATIONS

In order to test the reliability of the absolute palaeomagnetic reconstructions, we compare it with a reconstruction of South America for 25O Ma ago based on the hotspot framework defined by Morgan (1983), from 200 Ma to present, and a hotspot track recorded in Siberia from 280 Ma to 130 Ma (Zonenshain *et al.*, 1985). To make the absolute reconstruction of reference (Ref) we considered two movements: 1) the movement of South America respect to the hot spots and 2) the TPW of this continent from 250 Ma to present. We obtained the pivot Phs (Table 1) to determine the position of South America with respect to the hot spots for the Late Permian by rotating South America to European coordinates according to Bullard *et al.* (1965), and then, adjusting both continents to the hotspot framework for 200 Ma (Morgan, 1983). The continents were then rotated again about the Siberian pivot (with its coordinates referred to 200 Ma)

TABLE 1: Pivots or Euler Poles to make the reconstructions.

Name	Geog.Coordinates Lat.(°)	Long.(°)	Angle of rotation	Movement of South America that is involved
Phs	51.5	8.5	83	referred to hot spots (250 Ma).
Pref	81.3	67.9	66.4	absolute (250 Ma).
Plat	0	215	-9.5	latitudinal (MPP Table 2).
Plon C	-90	0	-73	longitudinal (Corumbatai VGPs).
Plon P	-90	0	-87.7	longitudinal (Paganzo VGPs).
Plon CP	-90	0	-85	longitudinal (VGPs Cor.& Pag.).
Plon ob	-90	0	-79	longitudinal (oblique VGPs).
Pab C	82	71.5	73	absolute (VGPs Cor.).
Pab P	83	79	88	absolute (VGPs Pag.).
Pab CP	83	77.5	85.4	absolute (VGPs Cor.& Pag.).
Pab ob	82.5	74.5	79.5	absolute (oblique VGPs).

Latitude N (S) is positive (negative), longitude E (O) is positive (negative), clockwise (counterclockwise) rotation is negative (positive). The oblique VGPs for calculate the pivot Pab ob belong to Corumbatai Formation and Paganzo Group.

until the positions that they would have respect to the hot spots for 250 Ma. Previously, we calculated the possible amount of movement involved from 200 Ma to 250 Ma according to Zonenshain *et al.* (1985).

To correct the South American movement due to the TPW, we obtained a MPP for the Late Permian by averaging four reliable PP of that age from this continent (Table 2). The reliability criteria considered in the selection of the PPs are the following: 1) Reported test of the stability of the remanence applying AF or thermal cleaning in the original papers; 2) Interval of uncertainty (A_{95})<= 16; 3) Stratigraphic ages defined with an uncertainty lesser than a geologic period. The MPP was obtained using the statistics of Fisher (1953). The geographic coordinates (with South America in its present position) and statistical parameters for the calculated MPP are: Lat.= 80.5° S, Long.= 305° E, N= 4, R= 3.972, A_{95}= 9°, K= 106.35. This MPP was considered as the best estimator of the Earth rotational axis position respect to South America in the Late Permian.

We referred this MPP to the hot spots for 250 Ma through a rotation about Phs. The coordinates of the MPP after the rotation are: Lat.= 45.4° S, Long.= 121.4° E. According

TABLE 2: Late Permian plaeomagnetic poles of South America

Geologic sequence or locality	Age Geol.	Age Rad.	Pole position Long.(°E)	Pole position Lat.(°S)	A_{95} (°)	Ref.
Q.del Pimiento	Ps	263±5 Ma	282	81	12	Creer et al.,1971
Choique Mahuida	Ps	254±10 Ma	344	75	15	Conti and Rapalini,1991.
Paganzo G.	Ps	266±7 Ma*	249	78	3	Valencio et al., 1977.
Corumbatai F.	Ps-Tr		294	86	14	Valencio et al., 1975.

Mean Palaeomagnetic Pole (MPP): N= 4, Long.= 305° E, Lat.= 80.5° S, K= 106.

*The radimetric age of Paganzo G. belong to a volcanic level near the base of the section. The upper part of this section spans the boundary between Kiaman Magnetic Interval and Illawara Zone dated at 250 Ma (Harland et al., 1990).

to that, a possible TPW of about 45° must have occurred since the Late Permian. To make MPP, already referred to the hot spots, to coincide with the Earth rotation axis, we had to define a new pivot which, by definition, is perpendicular to the great circle that contain the MPP and the Earth rotation axis (Lat.= 0°, Long.= 31.4° E, clockwise rotational angle= 44.6°). So, this pivot was combined with Phs (Pref in Table 1) to make the Ref. The Ref is shown in figures 4 and 5 with dashed lines.

To perform the absolute palaeomagnetic reconstruction of South America, the latitudinal position of the continent was obtained rotating the MPP to the Earth rotation axis about the pivot Plat (Table 1). The VGPs used in the longitudinal movements, were also rotated about this pivot.

The longitudinal movement of South America was obtained using only the VGPs of Corumbatai Formation (Valencio *et al.*, 1975) and Paganzo Group (Valencio *et al.*, 1977) . The 4 VGPs of Quebrada del Pimiento (Creer *et al.*, 1971) and the 8 VGPs of Choique Mahuida (Conti and Rapalini, 1991) were not used, because they are not enough to accurately define a VGP band. Anyway, it is worth note that the VGP population of Choique Mahuida have a preferred distribution similar to those of Corumbatai Formation and Paganzo Group (see Table 3 and Fig. 3).

The VGPs populations of the latter sequences are formed by a significative numbers of VGPs (Table 3 and Fig. 3b and 3c). Therefore, they were employed to determine the longitudinal rotation of South America. The VGPs of Corumbatai Formation and Paganzo Group were analysed according to the Raleigh test. Combined VGPs of both sequences

TABLE 3: Mean longitudes and intervals of uncertainties for Choique Mahuida Formation, Corumbatai Formation and Paganzo Group (von Mises' distributions).

VGP Populations	N° of VGPs	Mean longitude ($\bar{\theta}$) (°E)	Interval of uncertainty	Rm
1. C. Mahuida F.	8	16	89° (10%)	0.258
2. Corumbatai F.	17	32	44° (5%)	0.415
3. Paganzo G.	168	17	20° (5%)	0.19
4. Cor.F.& Pag. G.	185	20	28° (5%)	0.209
5. Oblique	35	26	41° (10%)	0.257

The population 5 belongs to oblique VGPs of Corumbatai F. and Paganzo G. together. The values of Rm and θ of populations 2,3 and 4 belong to the 5% confidence level. The values of these parameters for the populations 1 and 5 belong to the 10% confidence level. All values of Rm pass the Rayleigh test. The values of Rm for the populations 1 and 5 that belong to the 5% confidence level do not pass the Rayleigh test.

were also analysed with the same test, considering the whole VGP population or only the oblique or transitional VGPs. The mean longitudes of the VGP populations of the different PPs are very similar (Table 3 and Fig. 3). These mean longitudes are also similar to those observed in 8 populations of Jurassic VGPs from South America (Vizán *et al.*, 1993).

The populations of the Corumbatai Formation, the Paganzo Group and both combined pass the Raleigh test with a 5% level of significance. The other analysed populations, pass this test with a 10% level of significance. To make longitudinal reconstructions of South America, the mean longitudes obtained for the Late Permian VGPs were rotated about a pivot at the Earth rotation axis until it coincided with the Jurassic-Early Cretaceous longitudinal band defined by the meridians 105-137° E. In the same way, South America was longitudinally rotated. The best fits with the Ref were obtained when the longitudinal movements were done up to the 105° E meridian (Figs. 4 and 5).

The main deficit of the palaeomagnetic absolute reconstructions here showed, are the intervals of uncertainties due to the scarce number of transitional and oblique VGPs (Table 3). Anyway, two palaeomagnetic reconstructions and the Ref are similar. The best fit with the Ref is undoubtedly obtained with the data of the Corumbatai Formation (Fig. 4a). When the VGPs of both the Corumbatai and Paganzo Formations are considered together, the best fit is obtained with the oblique or transitional VGPs (Fig. 5b).

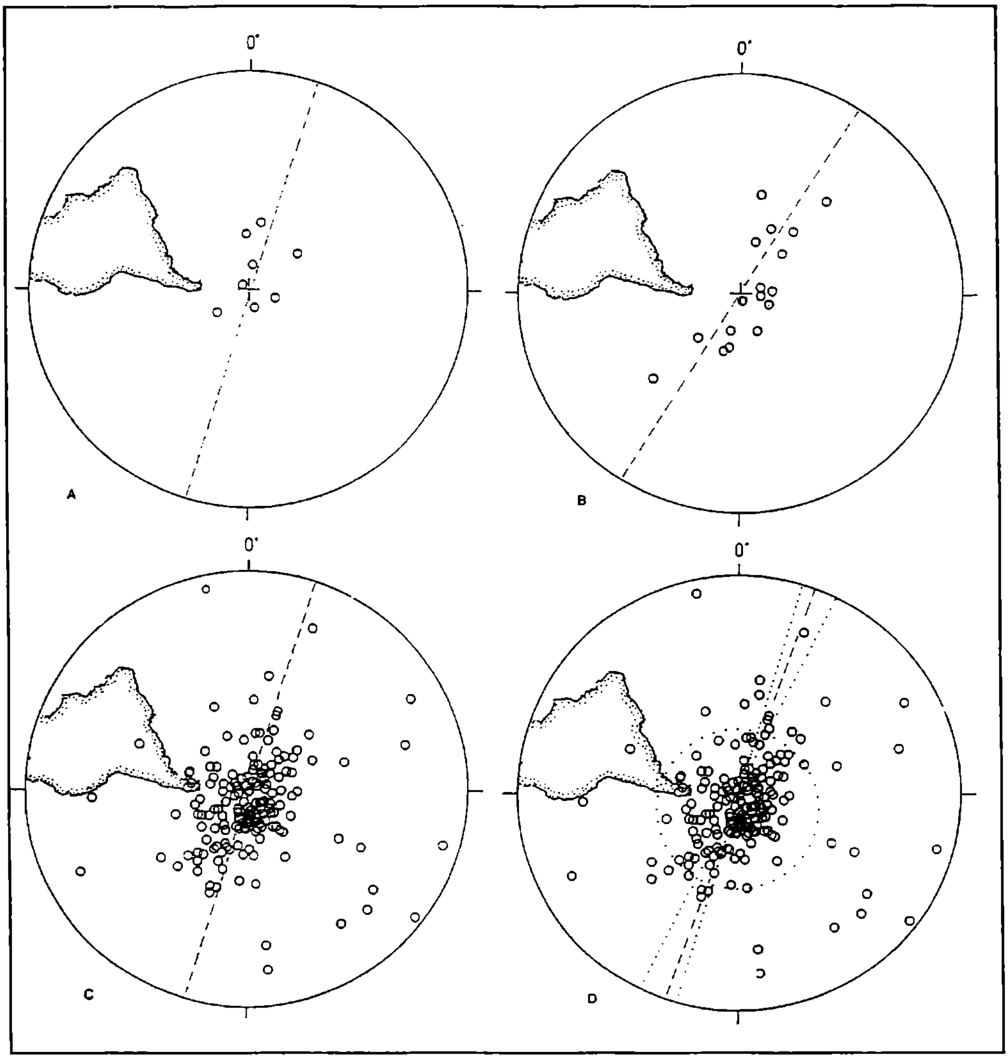

Fig. 3. Late Permian VGPs of different South America formations and South America's position after a latitudinal palaeoreconstruction, plotted in stereographic projections. The south geographic pole is at the center of the projections. The VGPs are only plotted in the southern hemisphere. In dashed lines: mean longitudes of VGPs. A) Choique Mahuida Formation. B) Corumbatai Formation. C) Paganzo Group. D) Corumbatai Formation plus Paganzo Group. Large dotted circle: window of 40° about the MPP. The mean longitudes corresponding to the VGPs of only stable polarities from each geologic formation are depicted in dotted lines.

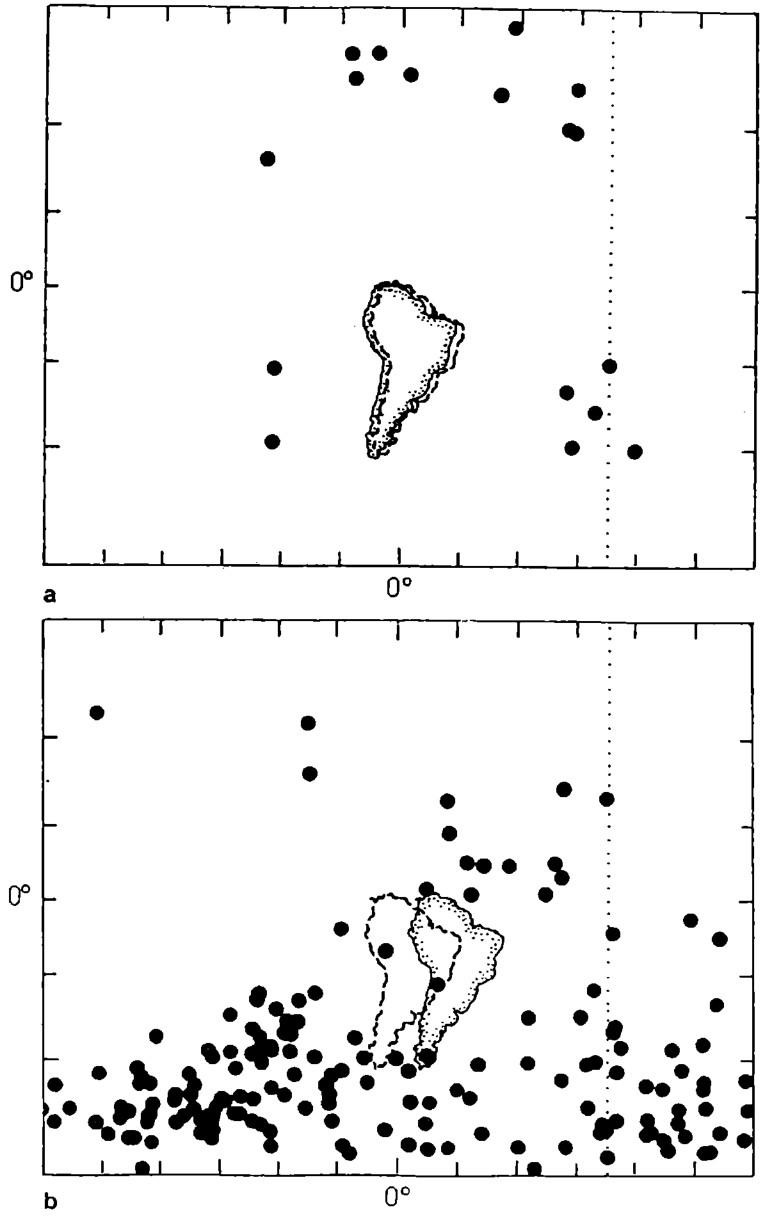

Fig. 4. Absolute palaeoreconstructions of South America. In dashed lines: reference absolute reconstruction. In dotted lines: 105°E meridian. A) Reconstruction using the VGPs of the Corumbatai Formation (pivot Pab C of table 2). B) Reconstruction using the VGPs of the Paganzo Group (pivot Pab P of Table 1).

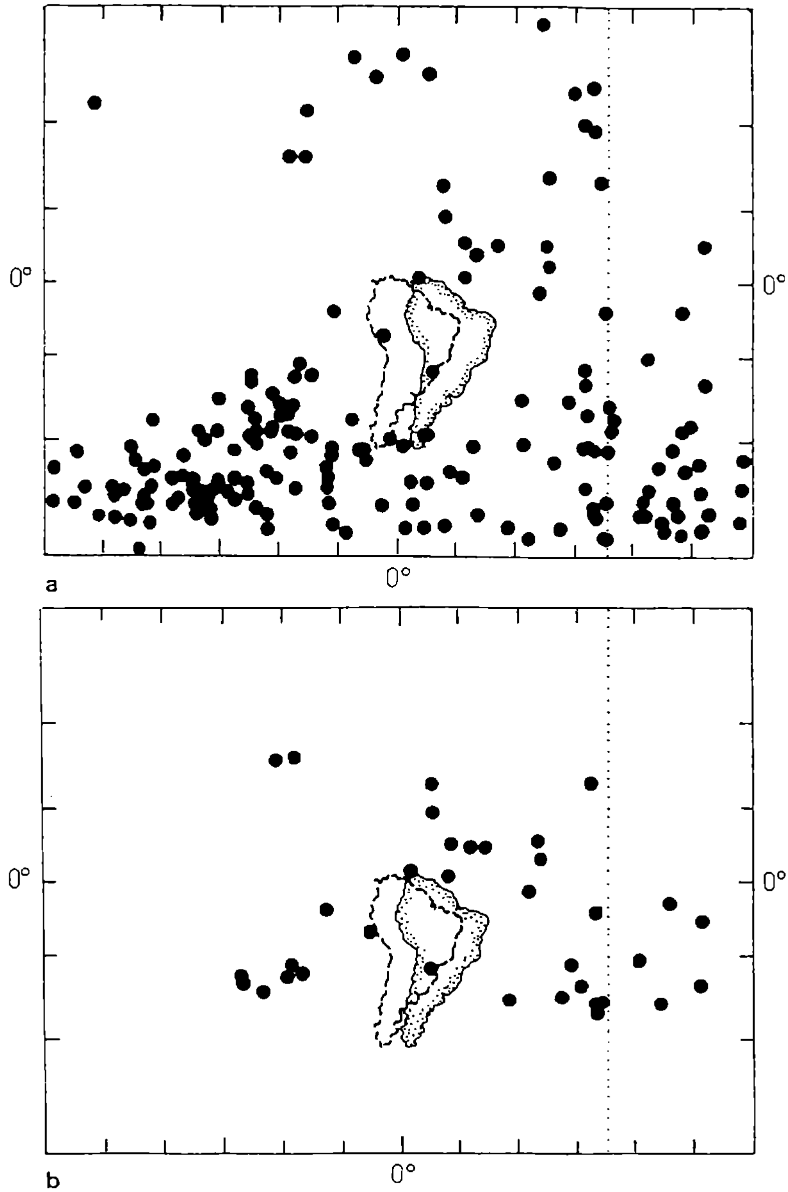

Fig.5. Absolute paleoreconstructions of South America. A) reconstructions using all the VGPs of both: the Corumbatai formation and the Paganzo Group (pivot Pab CP of Table 2). B) reconstruction using only the transitional or oblique VGPs of both sequences (Pivot Pab ob). See Fig. 4 for more information.

4. CONCLUSION

A methodology that allows possible absolute palaeomagnetic reconstructions is designed and appraised. This methodology was used in palaeoreconstructions of South America for the Late Permian, considering VGPs of two geologic formations of this age to determine the longitudinal position of this continent. The similitude between these absolute palaeomagnetic reconstructions and another obtained by a different way is quite encouraging.

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