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TRIASSIC AND PERMO-TRIASSIC PALAEOMAGNETIC DATA FOR S. AMERICA

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Palaeomagnetic studies have been made on 13 different rock formations. Results from 7 of these to which thermal or A.F. cleaning has been applied show that the south palaeomagnetic pole relative to S. America was situated at 82°S, 154°W with alpha 95 = 8°.
This pole falls in the same position as the Triassic to Cretaceous south palaeomagnetic pole for Africa when the two continents are placed in juxtaposition in the generally accepted configuration.

1. Introduction

Palaeomagnetic data obtained from studies on rock formations from S.America have been summarized by Creer [1–3] but Triassic palaeomagnetic pole positions were not included in the data presented. Preliminary surveys of formations of this age from Argentina and southern Brazil had revealed natural remanent magnetization (NRM) aligned approximately along the present field direction: the intensities were weak and the directions of RM after cleaning were often more scattered than those of the NRM giving no indication that a primary component was being isolated. It was suspected that the primary Triassic component might be aligned parallel to a secondary component built up in the Recent geomagnetic field, but this could not be established for certain.

Palaeomagnetic studies just completed on 13 Permo-Triassic formations of rock of which 3 are igneous and 10 sedimentary indicate that the Triassic geomagnetic field in S. America was indeed almost parallel to the present one. The position of the mean Triassic pole deduced for S. America is coincident at the 95% probability level with the Triassic pole for Africa, when the two continents are placed in juxtaposition in the generally accepted configuration. Full details of these and other investigations of the palaeomagnetism of S. American rocks will be published shortly.

2. Summary of palaeomagnetic results

The formations studied are listed in table 1. The localities of sampling are given, together with the names of the formations and the ages assigned to them in the literature. The numbers of samples taken from each formation are given. Sample-mean directions of RM were assigned unit weight in computing each formation-mean direction of RM and its statistics. Virtual geomagnetic poles were calculated for each sample-mean RM direction and these were assigned unit weight in the computation of each listed formation-mean virtual south pole and its statistical parameters.

The rock formations studied are briefly described below.

Table 1
Summary of formation-mean directions of RM and virtual pole positions

Ref. no.	Area sampled: State or province	Lat.	Long.	Formation	Age	Direction of RM: N_s	D	I	α_{95}	Polarity	Virtual south pole: Lat.	Long.	α_{95}
(I) *Thermally or AF cleaned data*													
1	Buenos Aires, Sierra de la Ventana (A)	38°S	62°W	sediments	P(u)	9	200°	+57°	14°	R	78°S	141°W	17°
2	La Rioja, Villa Union (A)	29°S	68°W	Paganzo	P-Tr	22	13°	−40°	6°	N	77°S	175°E	6°
3	Piaui and Maranhão (Br)	7°S	43°W	Motuca	Tr(1)	7	1°	+ 4°	11°	M	85°S	147°E	10°
4	Mendoza, S.Nihuil (A)	33°S	68°W	lavas	Tr(1)	41	2°	−62°	4°	M	81°S	78°W	6°
5	Colombia	8°N	73°W	Giron	Tr	28	13°	+10°	10°	N	70°S	142°E	16°
6	Mendoza, Cuesta los Teneros (A)	33°S	68°W	lavas	Tr	91	11°	−68°	8°	M	80°S	132°W	10°
7	Mendoza, Uspallata (A)	33°S	68°W	lavas	Tr(u)	30	10°	−65°	13°	M	74°S	94°W	14°
(II) *Uncleaned data*													
8	Parana (Br)	25°S	50°W	Corumbatai	P(u)	12	3°	−31°	10°	N	81°S	148°E	10°
9	R.G.do Sul (Br)	30°S	53°W	Santa Maria	T(m)	4	352°	−29°	14°	N	75°S	96°E	15°
10	Venezuela	9°N	71°W	La Quinta	Tr	38	347°	+16°	24°	N	65°S	76°E	24°
11	La Rioja (A)	29°S	67°W	Miranda	Tr	10	11°	−42°	22°	N	78°S	129°W	22°
12	Salta (A)	24°S	64°W	Red Beds	Tr	7	203°	+38°	26°	M	70°S	146°W	21°
13	São Paulo (Br)	235°S	49°W	Botucatu	Tr.J	9	353°	−31°	43°	N	78°S	81°W	58°

Ref. no. This refers to the sampling localities illustrated in fig. 1.
(A): in Argentina.
(Br): in Brazil.
N_s: number of samples.
N, R or M: normal, reversed or mixed polarity respectively.

2.1. *Formations from southern Brazil*

The upper Permian is represented by the Passa Dois Series and the Triassic by the São Bento Series. These two series are separated by an unconformity (see ref. [4] for an account of the geology).

The Corumbataí formation belongs to the Estrada Nova Group which is part of the Passa Dois Series. Samples of purplish-red silty shale were collected from 4 sites in Paraná State (locality 8, fig. 1). Twelve of these samples contained normal and six reversed remanence [5]. The former, to which the entry in table 1 corresponds, come from the upper part of the formation. The latter are correlated with the Kiaman Interval of reversed polarity.

The Santa Maria formation is considered to be middle Triassic as a result of the fossil tetrapods found in it [6]. It was sampled near the towns of Santa Maria and Rio Pardo in Rio Grande do Sul State (locality 9, fig. 1). The samples were of red fine-grained sandstone and all contained normal remanence [5].

The Botucatú Sandstone [7] comprises the largest known aolean deposit in the world. It contains fluviatile facies locally. It overlies the Santa Maria formation in Rio Grande do Sul State and underlies the Serra Geral formation which has been radiometrically dated at about 120 my. Samples of pale red fine-grained, well cemented sandstone were collected from three sites in São Paulo State (locality 13, fig. 1). All were normally magnetized [5].

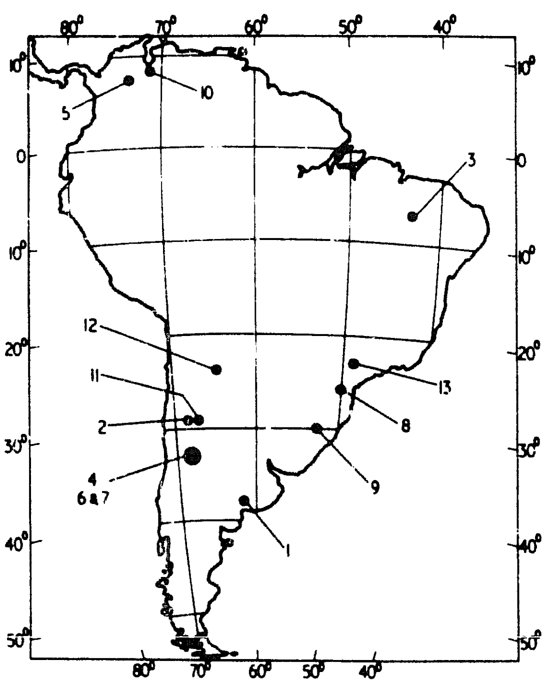

Fig. 1. Distribution of sampling localities. See table 1 and the text for explanation of locality reference numbers.

2.2. *Formations from northeast Brazil*

The lower Triassic Motucá formation was sampl at four sites in the Maranhão Basin (locality 3, fig. . The samples consisted of pale reddish brown sandstones and siltstones. Both normal and reverse pol ties were found. Thermal cleaning was carried out t no significant change of the mean direction was ob served [8].

2.3. *Formations from Venezuela and Colombia*

The La Quinta formation transgressively ov es Permo Carboniferous rocks in Venezuela and con predominantly of red or green clastic deposits. Th mean direction was obtained by thermally cleanir 42 specimens from 5 sites (locality 10, fig. 1). Th structural deformation of the Venezuelan Andes partly account for the high scatter observed [9].

The Girón formation is considered to be lower Mesozoic, probably Triassic. The result quoted is derived from 28 samples collected from 6 sites between Bogotá and Bucamaranga (locality 5, fig. 1). Thermal cleaning was applied up to 600°C and produced no significant change in the mean direction of RM.

2.4. *Formations from the Province of Buenos Aires, Argentina*

Fourteen samples were collected from the Tunas and Bonete formations of the Pillahuinco Group in the Southern Hills of Buenos Aires (locality 1, fig. 1). The results in table 1 are based on observations from eight samples of dark red mudstones and two samples of light grey siltstones. The two formations are conformable and a total thickness of about 400 m is represented by the samples. They are late Permian in age [10,11]. Application of the partial thermal demagnetization technique and Graham's fold test show that the primary magnetism pre-dates the Triassic tectonic episode (Embleton, unpublished work).

Twenty-six specimens were used in the analysis and the mean direction of remanence is that obtained by thermal treatment at 650°C. All RM directions were reversed.

2.5. *Formations from La Rioja Province, Argentina*

Twenty-six samples of red sandstones were collected from about 900 m of the Paganzo formation which outcrops east of Villa Union (locality 2, fig. 1). The beds are medium-fine grained sandstones, medium red in colour and dip uniformly over the area sampled. The age of the Paganzo formation ranges through Carboniferous and Permian into the Triassic [12,13]. Pilot specimens were heated stepwise to 650°C and cooled in zero field but the mean direction of RM did not change significantly. The data in table 1 are based on observations from sixty-five specimens after heating to 300°C; all RM directions were normal.

Triassic red beds outcrop in a road cutting from Villa Union to Sanogasta, in the vicinity of Miranda (locality 11, fig. 1). Ten samples were collected, all of which contain normal NRM. Neither AF nor thermal cleaning were applied.

2.6. *Formations from Mendoza Province, Argentina*

Sixty-nine samples of basalts, andesites and rhyolites belonging to the same magmatic episode were collected in the Nihuil area, south of San Rafael city (locality 4, fig. 1). The age of this magmatism is thought by some authors to the Triassic [14,15], and by others to the Permian [16,17]. At least two specimens from each sample were cleaned using the AF demagnetization technique; the results are quoted in table 1. Normal and reversed magnetizations were

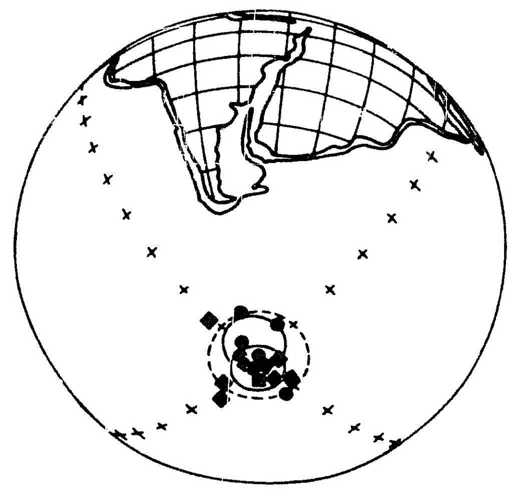

Fig. 2. Formation-mean virtual geomagnetic south poles for S. America (circles) and Africa (squares) plotted with respect to these continents in their pre-drift positions.

present, though normal directions were predominant. We deduce that the magmatic cycle occurred in the Early Triassic or Late Permian, after the Kiaman Interval because the virtual pole agrees with those obtained from formations of the former age and not of the latter [21].

An additional 112 samples of basalts, andesites and rhyolites of Triassic age [15] were collected around Cuesta de los Terneros directly south of San Rafael city (locality 6, fig. 1). The samples were AF cleaned; again normal and reversed TRM were obtained [18] (see table 1).

Thirty-six samples of basalts of Upper Triassic age were collected a few kilometers northeast of Upsallata (locality 7, fig. 1). AF demagnetization revealed

Table 2
Palaeomagnetic south pole position relative to South America for the late Permian and Triassic.

Population	Number of formations	South palaeomagnetic pole			
		Lat.	Long.	α_{95}	CSD
All formations (groups I and II)	13	86°S	165°W	8°	15°
Thermally or AF cleaned formations (group I only)	7	82°S	154°W	8°	11°

α_{95}: radius of circle of confidence about the mean pole at the probability level $P = 0.05$.
CSD: circular standard deviation of the population of formation-mean virtual geomagnetic south poles.

normal and reversed directions of thermoremanence [19].

3. Comments on the South American data

Samples of eight of the thirteen formations studied were cleaned by either AF or thermal techniques. The palaeomagnetic data from seven of these formations are listed in group I of table 1. The data from the other formations which, except for the La Quinta, have not been cleaned, are listed in group II of table 1. The result from the La Quinta formation has been included in group II rather than with the more reliable group I data because of possible inaccuracies involved in correcting for the structural deformation of the area of collection in the Venezuelan Andes.

The group II data are derived from samples, the remanent magnetization of which, though not cleaned, had good stability characteristics as determined its internal homogeneity within samples and the consistency of repeat measurements. An indication of the reliability of these data is that the palaeomagnetic pole computed from all 13 formation-mean virtual poles does not differ significantly from that computed from the 7 formation-mean virtual poles of group I (see table 2).

The 7 formation-mean virtual geomagnetic poles of group I are shown as circles in fig. 2 which is a tracing of a photograph of a globe on which S. America and Africa are drawn in juxtaposition in their generally accepted pre-drift configuration.

4. Comparison with African data

The south pole remained fixed with respect to Africa during the Triassic, Jurassic and Cretaceous periods [20]. We have plotted the formation-mean virtual poles (numbers 2.18, 2.24 2.32, 2.35, 2.48, 2.49, 2.50, 2.52 and 2.53 in ref. [20]) for these geological periods in fig. 2 where they are shown as squares. These African poles form a homogeneous group with the S. American poles. The mean pole position for each continent is just contained within the 95% circle of confidence surrounding the other.

We may regard each of these mean poles as a true "palaeomagnetic" pole for the respective continent for the intervals of geological time spanned by the respective formations. Whereas the palaeomagnetic pole for Africa remained fixed throughout the Mesozoic [20], we note that the South American Cretaceous palaeomagnetic pole (Serra Geral, 120 my) lies in a significantly different position from the South American Triassic poles [21]. Although the Serra Geral is the only S. American Cretaceous formation studied, its age spans more than 20 my [22] and it has been sampled in considerable detail [23] so that the mean pole obtained may reasonably be considered to be a "palaeomagnetic" pole for the Cretaceous rather than a virtual geomagnetic pole, secular variation having been averaged out.

No reliable Jurassic data yet exist for South America, so we cannot say exactly when the initial drift movements began, only that they must have been after the end of the Triassic and more than about 120 my ago.

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