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# Palaeomagnetism of Permo-Carboniferous and Triassic Rocks from Venezuela and Colombia

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# VI. PALAEOMAGNETISM OF PERMO-CARBONIFEROUS AND TRIASSIC ROCKS FROM VENEZUELA AND COLOMBIA

## CONTENTS

The remanent magnetization of rock formations ranging in age from Permo-Carboniferous to Cretaceous from the Venezuelan and Colombian Cordillera is shown to have been acquired in part after folding. Nevertheless the direction of primary remanence can sometimes be inferred. The Permo-Carboniferous Pipiral formation from the Llanos region of Colombia was not so severely remagnetized and appears to be of the same magnetic age as the Pennsylvanian Taiguati formation from Bolivia.

## 1. GEOLOGY

The Venezuelan Andes run from San Cristobal in the southwest to Barquisimento (figure 1) and are about 100 km wide. They separate the Maracaibo depression in the northwest from the llanos in the southeast of the country, and extend in the southwest direction into Colombia.

They are a folded range of mountains, separated into different tectonic blocks by cross faulting but there are no overthrust sheets as in the Alps (Lopez *et al.* 1956).

Permo-Carboniferous beds are widely distributed and have been subdivided into lower and upper formations named the Sabanata and the Palmarito respectively. The latter is placed in the upper Carboniferous or Permian on fossil evidence.

The principal formation sampled was the La Quinta which transgressively overlies either the above Permo-Carboniferous beds or the Devonian. Locally it may consist of a basal conglomerate containing pebbles of older formations. There are few fossils since the beds are prevelantly red or green clastic continental deposits. The few fossils which have been found in the middle part indicate a Triassic—Jurassic age but the time span covered by the deposition of the whole La Quinta formation is not well established. The La Quinta is intruded by basic rocks such as diabase.

The basal Cretaceous formations are transgressive in most places in the Andes. The Cretaceous is particularly well developed in parts of the Maracaibo depression and the middle parts, the Cogollo and Luna formations are rich reservoirs of petroleum.

In Colombia samples were collected on the region illustrated in figure 8. The collection was concentrated in (i) the Surata Series and (ii) the Girón formation (Olsson 1956).

The Surata series comprises the lower member of a Permo-Carboniferous sequence of rocks which may be up to 2400 m thick, e.g. near Labateca (area 5, figure 8). It consists of brick red shale with sandy beds of fine quartzite, bluish limestone, blue-grey and sandy shales. It is overlain by the Bocas series of black and dark brown shales with a few thin beds of coal.

The Girón 'complex' consists of a group of red, green, purple and varicoloured sediments plus some igneous material which lie either above proved Palaeozoic or directly upon the crystalline basement. As originally described it included rocks now known to range in age from lower Cretaceous to Palaeozoic, but the term Girón is nowadays restricted to the lower Mesozoic.

The type section is at the town of Girón which is situated north of Bucamaranga (figure 8). At the base is found a hard, quartzitic, coarse conglomerate which usually rests on beds of the Bocas formation. Higher in the section, brick red shales are common. Red beds are missing in the middle section which consists of hard bluish quartzite and shale. The upper parts contain both white and bluish quartzite and brick red and sandy shale.

The Girón formation is typically unfossiliferous, but suspected dinosaur bones have been found at one locality.

## 2. Palaeomagnetic results

### 2.1. *La Quinta Formation*

A map of the area of collection is shown in figure 1 on which the sampling sites are marked. Further information about the localities is given in tables 1 and 2 together with brief descriptions of the lithology and colour of the samples and of the dip of the strata.

A fairly thorough collection was made at the type locality from two large outcrops and the results from these samples (table 2) will be discussed separately from the regional collection (table 1).

The regional collection is discussed first. Of the 26 samples collected, only 18 were measured, the remainder having either broken up during coring in the laboratory or being too weakly magnetized to measure. The dip of the beds varies between 30° and 65°, the strata being folded parallel to an approximate northeast—southwest strike direction. Samples from sites on both limbs were collected.

The mean of sample-mean n.r.m. directions does not differ significantly whether referred to the present horizontal or to the bedding. The circular standard deviation of the former population of directions is slightly less than that of the latter (see table 3, lines 1 and 2), but not appreciably so. Therefore it cannot be established on these grounds whether magnetization was acquired before or after folding. The two groups of directions are shown in figure 2, where it is seen that the mean direction referred to the present horizontal does not quite differ significantly from either the present field (p.f.) or axial dipole field (a.d.f.) directions. (The $P = 0.05$ level of significance is represented approximately by twice the standard error circle shown.) This suggests that magnetization after folding may be more probable than before.

The collection was subjected to stepwise thermal demagnetization. Geometric-mean intensities with their standard errors are illustrated in the thermal decay curves of figure 3 (curve R). A large increase in remanence was observed at 630 °C due to the influence of an accidental non-zero magnetic field during cooling, so the results after cleaning at 550 °C will be discussed. These are illustrated in figure 4 and listed in table 3, lines 3 and 4. The mean direction referred to the present horizontal moved towards both the present field and axial dipole field directions after cleaning (figure 4*a*). The difference between the circular standard deviations (c.s.d.) of the populations of sample-mean directions referred to the present and to the palaeohorizontal (i.e. the bedding) increased after cleaning (n.r.m. 57 to 62°; cleaned r.m. 63 to 71°).

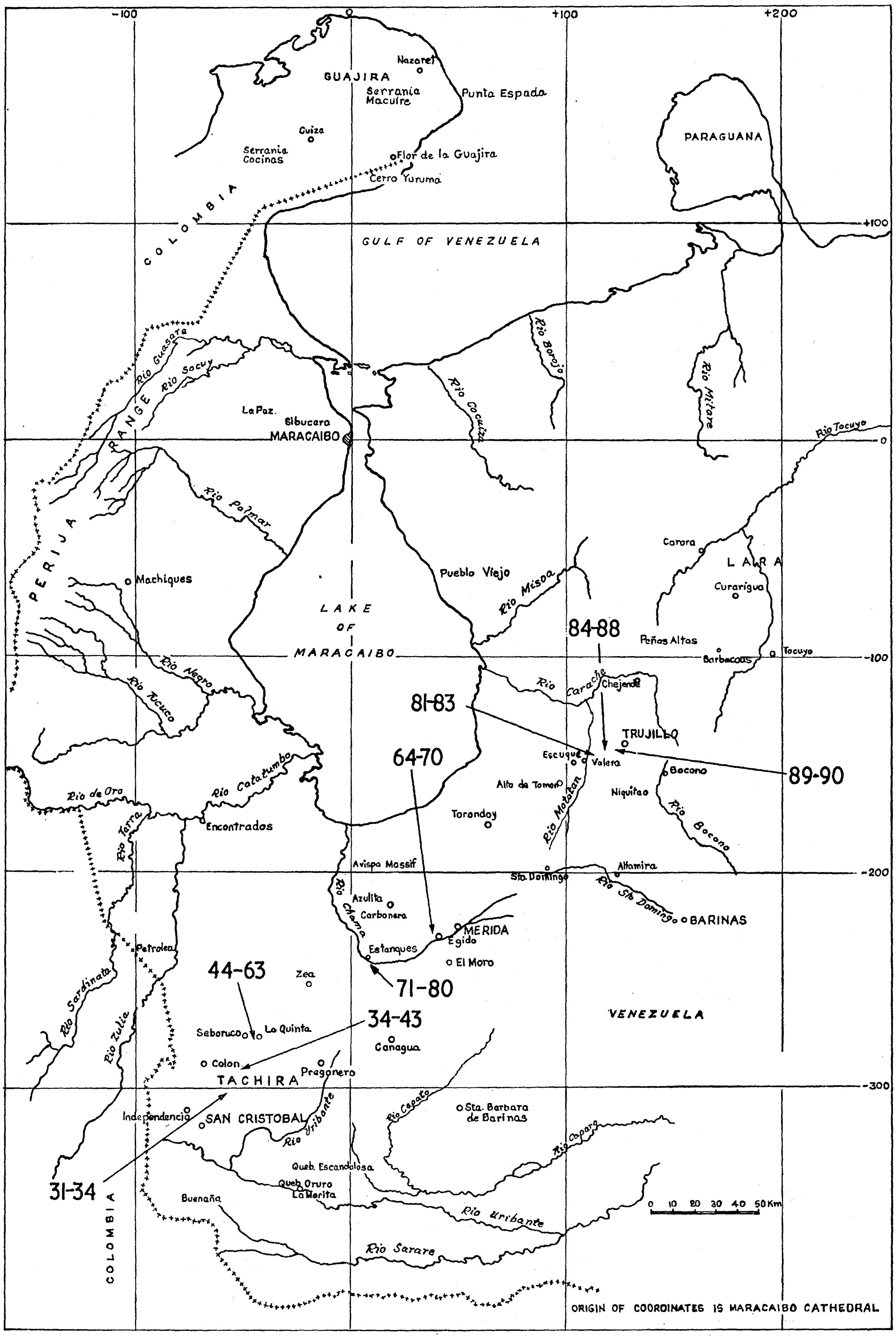

FIGURE 1. Map of part of Venezuela showing sampling sites.

This suggests that a large part of the hard component of remanence was acquired after folding, although the difference between the c.s.d. values is not large enough to lay much emphasis on this point. Although the c.s.d. values are high (60 to 70° at the different stages of cleaning of 400, 530 and 550 °C) the mean direction varies but little.

The inference that secondary magnetization was imposed on the La Quinta formation after folding is strengthened by the results of measurements on pebbles of the La Quinta formation contained in the basal conglomerate of the overlying formation. In figure 5, the directions of

TABLE 1. LA QUINTA (REGIONAL): DESCRIPTION OF SAMPLES

| sample no. | site | lithology | dip of beds | colour | colour code no. |
|---|---|---|---|---|---|
| 31 | at Ficala (km 26), the first exposure in the La Quinta after passing through Famon fm | m.-f.g. sandstone | 36° at 220° | greyish red | 10R–4/2 |
| 32 | | | | greyish red | 10R–4/2 |
| 33 | | | | greyish red | 10R–4/2 |
| 34 | | | | pale reddish brown | 10R–5/4 |
| 35 | 1½ km before Quebrada de Mesera | muddy sandstone, m.g. sandstone | 60° at 90° | moderate reddish brown | 10R–4/6 |
| 36 | | | | pale red | 5R–6/2 |
| 37 | | | | greyish red | 5R–4/2 |
| 38 | 1½ km before Quebrada de Mesera | m.-f.g. sandstone | 65° at 150° | moderate reddish brown | 10R–4/6 |
| 39 | | | | pale red | 5R–6/2 |
| 42 | 1½ km before Quebrada de Mesera | softish sandstone | 55° at 30° | blackish red | 5R–2/2 |
| 43 | | | | dark reddish brown | 10R–3/4 |
| 82 | near Trujillo, overlooking Valera | f.g. sandstone | 40° at 130° | pale yellowish brown | 10YR–6/2 |
| 83 | | | | greyish red | 10R–4/2 |
| 84 | km 19, Trujillo-Bocono road | m.-c.g. sandstone, conglomerate sandstone | 65° at 300° | greyish red | 10R–4/2 |
| 85 | | | | | |
| 87 | | | | | |
| 88 | | | | | |
| 89 | Trujillo–Bocono road, 5 km above bridge crossing river at Santiago, a suburb of Trujillo | f.g. muddy sandstone | 32° at 100° | brownish grey | 5YR–4/1 |
| 90 | | | | | |
| 64 | between Egidi and La Mesa de los Indios | m.g. sandstone with some 1–3 mm quartz grains | 50° at 145° | greyish red | 5R–4/2 |
| 65 | | | 45° at 130° | | |
| 66 | as 64, 65, from other limb of anticline | m.g. sandstone | 50° at 320° | greyish red | 5R–4/2 |
| 67 | | | 50° at 320° | | |
| 68 | | | 35° at 300° | | |
| 69 | | | 40° at 295° | | |
| 70 | | | 55° at 290° | | |

TABLE 2. DESCRIPTION OF SAMPLES AT LA QUINTA TYPE LOCALITY

| sample no. | locality | lithology | dip of beds | colour and code no. |
|---|---|---|---|---|
| 44–51 | large outcrop near by road outside La Quinta | m.g. sandstone | 60–65° at 285° | olive grey 5Y–4/1 speckled with blackish red 5R–2/2 |
| | | sandy mudstone | ,, | pale red 5R–6/2 |
| | | mud conglomerate | ,, | blackish red 5R–2/2 |
| | | m.-f.g. sandstone | ,, | brownish grey 5YR–4/1 |
| 52–62 | from outcrop of beds higher in succession than 41–51, further along the road | m.-f.g. red sandstone with lighter patches (5 mm across) | 50–70° at 300° | greyish red 5R–4/2 with olive grey patches 5Y–4/1 |
| | | m.-f.g. sandstone | ,, | greyish red 5R–4/2 |
| | | m.-f.g. sandstone | ,, | olive grey 5Y–4/1 |

n.r.m. of specimens from 10 such pebbles, all referred to the present horizontal are illustrated. If their n.r.m. were completely of primary origin these directions would be randomly distributed. However, they are not: the pebbles seem to have become partly (but not completely) remagnetized in the axial dipole field (a.d.f.) or the present field (p.f.) direction.

The measurements made on the 18 samples from the type locality at La Quinta are now discussed. The mean direction of n.r.m., referred to the present horizontal differs considerably from the present field and the axial dipole field directions. The c.s.d. values are appreciably the same (48 and 49°) whether the sample-mean directions are referred to the present horizontal or to the bedding. This is what we should expect because, since the dips and strikes of all the samples from these two exposures do not vary greatly, approximately the same 'bedding' correction is made to all of them. The two populations of directions are illustrated in figure 6 and the statistics listed in table 3, lines 4 and 5.

Table 3. R.m. data of La Quinta formation

| group of samples | plane of reference | number of samples | direction of r.m./degree | | | | treatment |
|---|---|---|---|---|---|---|---|
| | | | $D$ | $I$ | $\delta$ | $\delta_m$ | |
| regional | present horz. | 18 | 336 | +29 | 57 | 13 | n.r.m. |
| | bedding | 18 | 330 | +35 | 62 | 15 | n.r.m. |
| | present horz. | 18 | 357 | +22 | 63 | 15 | cleaned, 550 °C |
| | bedding | 18 | 343 | +27 | 71 | 17 | cleaned, 550 °C |
| type locality | present horz. | 18 | 270 | +15 | 48 | 11 | n.r.m. |
| | bedding | 18 | 265 | −40 | 49 | 12 | n.r.m. |
| | present horz. | 16 | 248 | −29 | 62 | 15 | cleaned, 590° C |
| | bedding | 16 | 189 | −56 | 63 | 16 | cleaned, 590 °C |

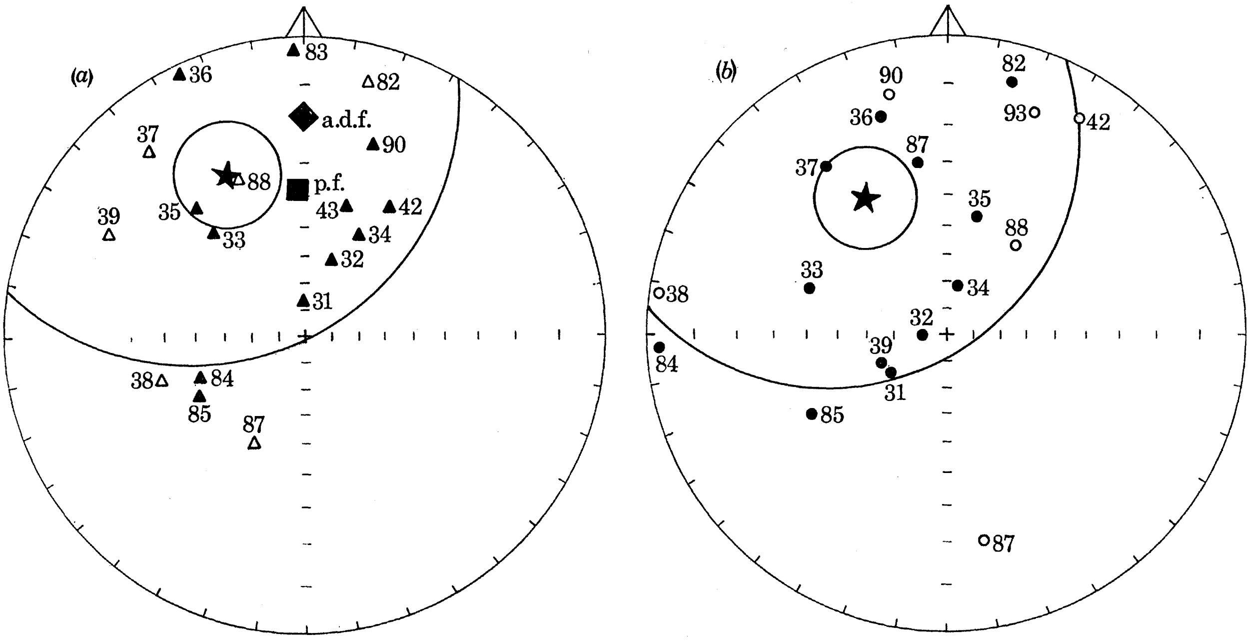

Figure 2. N.r.m. sample-mean directions for the regional collection from the La Quinta formation: (*a*) referred to the present horizontal, and (*b*) to the bedding (palaeo-horizontal). Solid symbols represent downward inclinations, open ones upward inclinations. The mean direction is represented by a star and the c.s.d. and c.s.e. circles are also shown. The point a.d.f. represents the normal direction of the axial dipole field and p.f. the present field.

Thermal demagnetization was carried out in steps. The thermal decay curve (figure 3, curve TL) shows an increase in intensity after cleaning at 600 and 640 °C (points marked with open rather than solid dots). This would be due to the accidental presence of a weak field acting on the samples when they were cooled, though this is not made evident by a change in the mean directions at 600 °C as compared with 590 °C. Nevertheless, the statistics for the former are listed in table 3 (lines 7 and 8) because of this suspicion about the results for the 600 and 640 °C steps. The sample-mean directions at 590 °C are plotted in figure 7. The c.s.d.

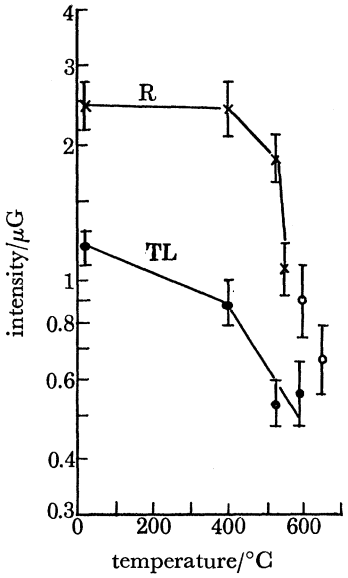

FIGURE 3. Thermal decay of r.m. of La Quinta formation. Curve R (crosses) is for the regional collection and curve TL (solid and open dots) for the type locality. Geometric mean values of intensity in microgauss are shown with standard error bars.

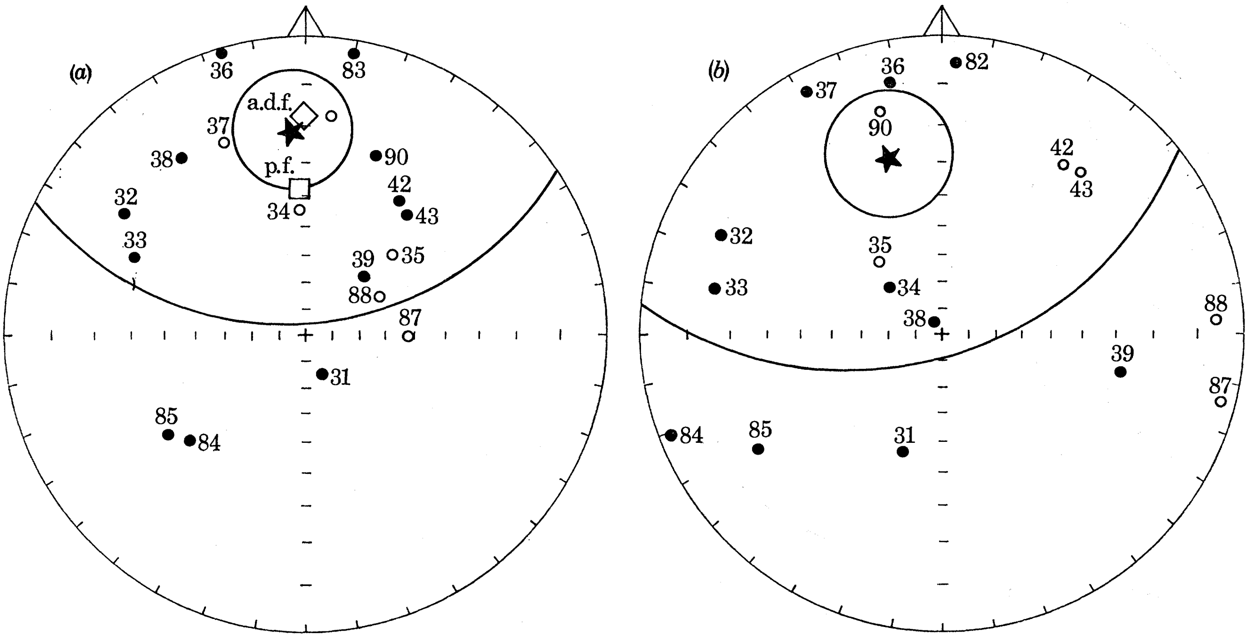

FIGURE 4. Sample-mean directions of r.m. for the regional collection (cleaned at 550 °C) of the La Quinta formation: (a) referred to the present horizontal, and (b) to the bedding. Key to symbols as for figure 2.

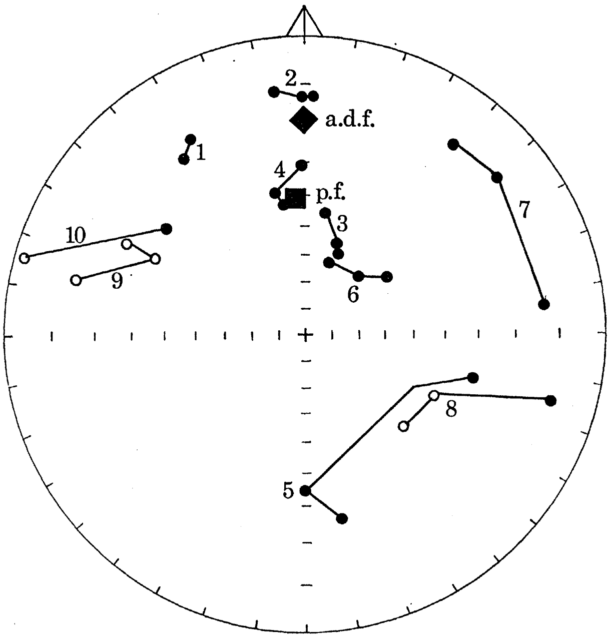

FIGURE 5

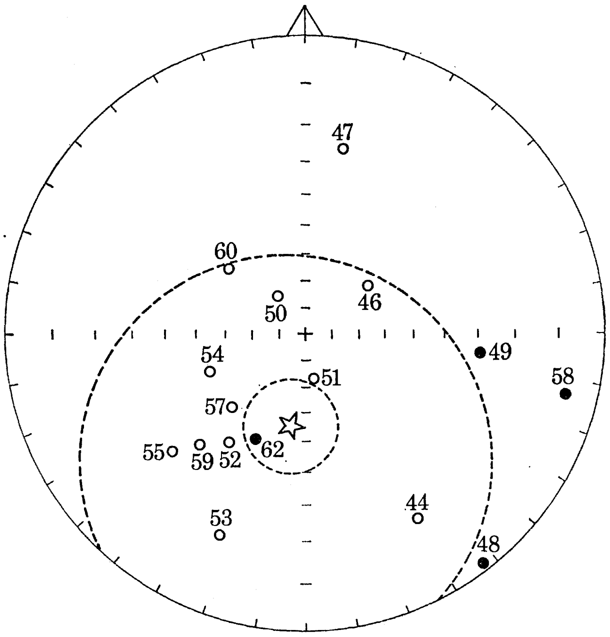

FIGURE 7

FIGURE 5. Directions of n.r.m. of disks cut from pebbles of La Quinta rock contained in a younger conglomerate. Disk directions from the same pebble (numbered 1 to 10) are connected by a line. The present horizontal is the plane of reference.

FIGURE 7. Sample-mean r.m. directions referred to the bedding planes for the La Quinta type locality after thermal cleaning at 550 °C.

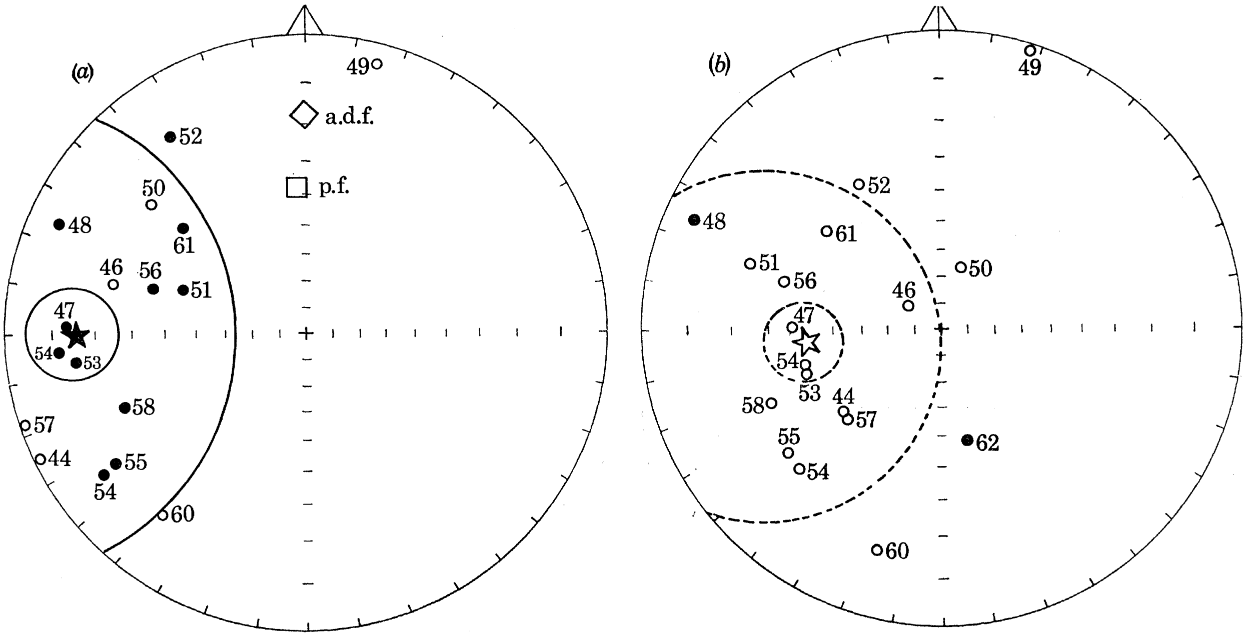

FIGURE 6. N.r.m. sample-mean directions for the La Quinta type locality: (*a*) referred to the present horizontal, (*b*) to the bedding. Key to symbols as figure 2.

of the thermally demagnetized directions is higher than those of n.r.m. Therefore the result is not considered reliable enough for interpretation in terms of continental drift and the south virtual geomagnetic pole given by this mean direction (line 8 of table 3), situated at latitude 46° S, longitude 151° E, with c.s.d. = 68° and c.s.e. = 11°, $N$ = 16, does not in fact correspond with any well-established palaeomagnetic pole corresponding to the age of La Quinta formation (or for any other geological period).

### 2.2. *The Girón formation*

A map of the sampling area is given in figure 8 and particulars about the samples collected, and of the dip and strike of the strata are given in table 4.

The n.r.m. sample-mean directions are illustrated in figure 9. The mean direction referred to the present horizontal differs significantly both from the present field and from the axial dipole field direction (figure 9*a*) while that referred to the bedding is close to the axial dipole field direction and barely significantly different from the present field direction (it is about twice the standard error radius away figure 9*b*). The c.s.d. of the population of directions in figure 9*a* is 44° as compared with 41° for figure 9*b*. Thus the magnetization was possibly acquired before the strata were folded at the end of the Mesozoic or in the Tertiary.

Thermal cleaning (figure 10) produced a systematic though not significant change in mean direction, see table 5. Because of the increase in scatter of directions during cleaning, the n.r.m. population may best represent the Triassic geomagnetic field. Its south pole, situated at latitude 70° S, longitude 142° E, with c.s.d. = 43°, c.s.e. = 8° is 16°, away from the mean S. American Triassic palaeomagnetic pole (Creer *et al.* 1970). However, it is noted that the cleaned r.m. (600 °C) yields a pole at 77° S, 106° W which is closer still to the mean Triassic pole.

### 2.3. *Permo-Carboniferous*

The sampling sites are shown in figure 8 and particulars of the samples collected are given in table 6.

N.r.m. site-mean directions, referred to the bedding, are given in table 7. Those for the first two sites, viz. Soapaga and Totomo bridge, are close to one another. Similarly, those for the Pamploma and Quebrada del Aji sites agree well with each other. However, the two pairs of directions differ significantly from one another. It is relevant to note that the dip of the strata at the first two sites is in the direction N 60° E, while that at the second two sites is at N 60–70° W, the structure being synclinal. Younger beds of the Girón formation are found in the core of this syncline (see figure 8). At the fifth site, Rio Negro, the strata dip very steeply and it is not known for sure whether the beds are inverted or not. Therefore, in deducing the formation-mean prefolding component (see below), site 5, Rio Negro, has not been included (entry 5, table 7); only the pairs of sites from each side of the syncline have been used.

The collection was subjected to stepwise thermal demagnetization at 400, 530, 590 and 600 °C. The resulting movement of the site-mean directions are given in figure 11 where they are plotted (*a*) with respect to the present horizontal, and (*b*) with respect to the bedding. The r.m. directions at the two pairs of sites remain significantly different after cleaning. The observation that both the n.r.m. and the cleaned r.m. directions are related to the geological structure indicates that the magnetization was acquired in part after folding, but not completely so, otherwise the directions of all sites would coalesce when plotted with respect to the present horizontal: in fact they do not (figure 11*a*).

The results of thermal cleaning did not allow the separation of the components of remanence acquired before and after folding by thermal cleaning, since both appear to have blockage temperatures higher than 600 °C (as is shown on the thermal decay curve in figure 12). However, we may attempt to do so by the following graphical method, illustrated in figure 13. Let us suppose that the secondary component was acquired after folding in the normal direction of the present axial dipole field, i.e. $D = 0°$, $I = +12°$. This is represented by the black diamond marked a.d.f. relative to the present horizontal in figure 13. The diamonds marked 1 to 4 show

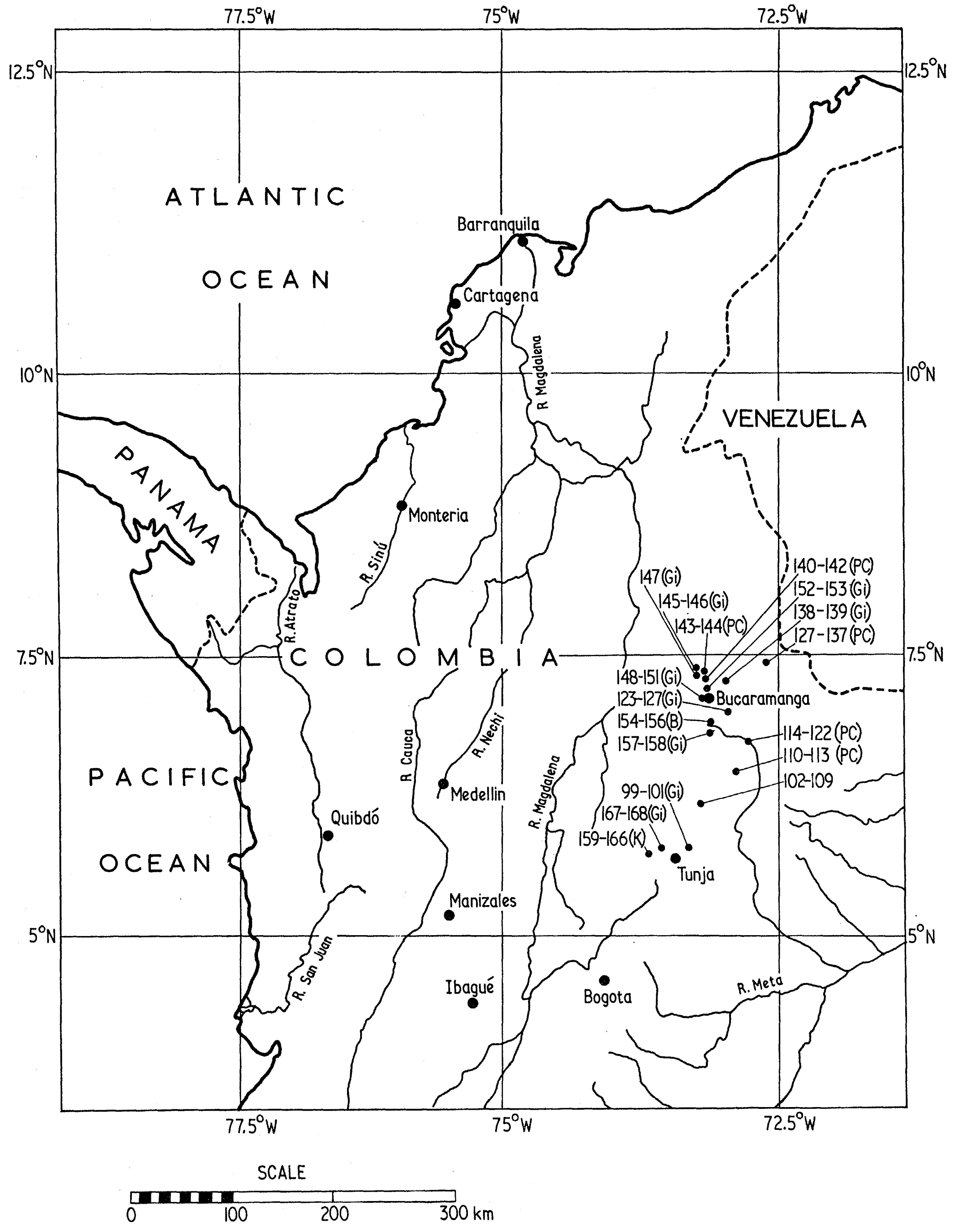

FIGURE 8. Map showing sampling sites in Colombia. PC, Permo-Carboniferous; Gi, Girón; Cr, Cretaceous.

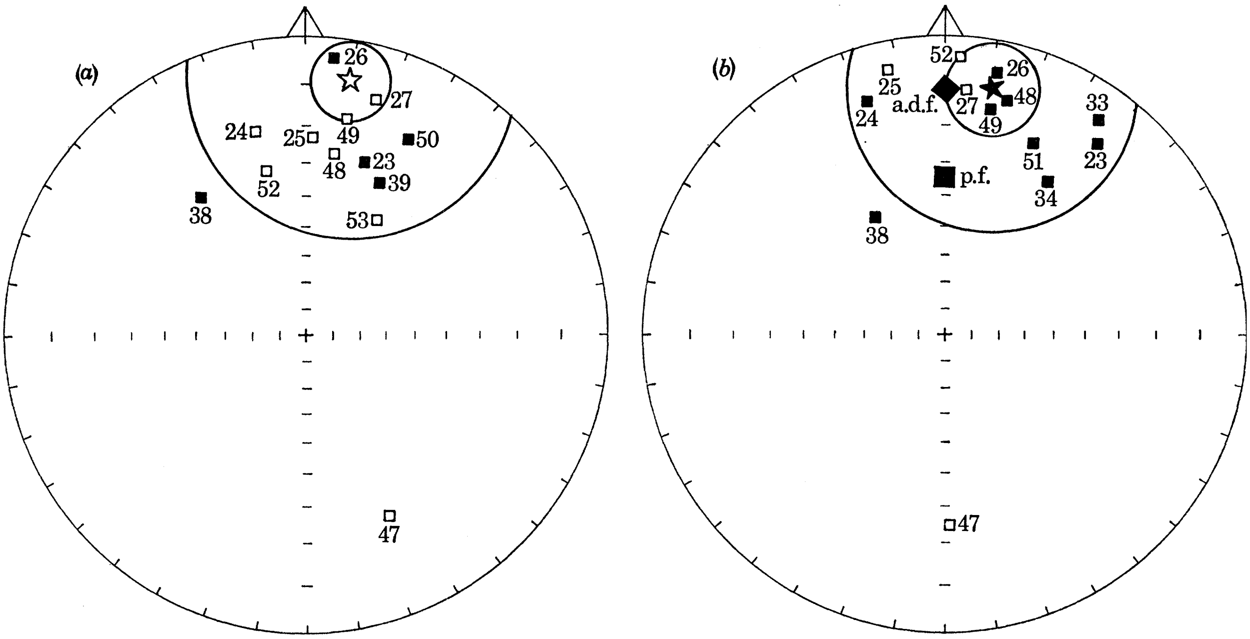

Figure 9. N.r.m. sample mean directions for the Girón formation: (*a*) referred to the present horizontal, and (*b*) to the bedding. Key to symbols as for figure 2.

### Table 4. Girón formation, Colombia: description of samples

| sample no. | site | lithology | dip of beds | colour | code no. |
|---|---|---|---|---|---|
| 91–94 | La Floresta | f.g. well bedded sandstone | 25° at 280° | greyish red | 10R–4/2 |
| 102–105 | Soapaga | metamorphosed arkose | 45° at 115° | light brownish grey<br>brownish grey | 5YR–6/1<br>5YR–4/1 |
| 106–109 | between Belen Cerinza and Susacon | f.g. sandstone | 20° at 205° | greyish red | 10R–4/2 |
| 123–126 | road cutting between Malaga and San Andres | f.g. sandstone | 54° at 105° | greyish red<br>greyish red<br>pale red<br>greyish red<br>moderate red | 5R–4/2<br>5R–4/2<br>10R–6/2<br>10R–4/2<br>5R–5/4 |
| 138–139 | on Pamploma–Bucamaranga road | badly sorted sandstone with mud specks | 15° at 100° | pale red<br>pale red | 5R–6/2<br>5R–6/2 |
| 148–151 | type locality at Floresta Blanca | soft micaceous sandstone | 15–50° at 240–270° | greyish red<br>greyish red<br>pale red | 5R–4/2<br>10R–4/2 |
| 152–153 | Bucamaranga–Floresta Blanca road | f.g. sandstone | 50° at 230° | greyish red | 10R–4/2 |
| 157–158 | Pescadero–Arateca road | c.g. sandstone | 40° at 260° | greyish red | 10R–4/2 |

### Table 5. Thermal demagnetization of Girón formation

| | | direction of r.m./degree | | | |
|---|---|---|---|---|---|
| treatment | number of samples | $D$ | $I$ | $\delta$ | $\delta_m$ |
| n.r.m. | 13 | 12 | +10 | 41 | 11 |
| cleaned at 400 °C | 13 | 12 | +13 | 47 | 13 |
| cleaned at 530 °C | 13 | 11 | −1 | 52 | 14 |
| cleaned at 600 °C | 11 | 9 | −7 | 64 | 19 |

Directions referred to the bedding.

this a.d.f. direction relative to the bedding planes, the poles of which are shown as open squares (again numbered 1 to 4). The measured, i.e. composite directions, (mean of n.r.m. and r.m. cleaned at 590 °C), are shown as circles (numbered 1 to 4). The primary component must lie

TABLE 6. PERMO-CARBONIFEROUS, COLOMBIA: DESCRIPTION OF SAMPLES

| sample no. | site | lithology | dip of beds | colour | code no. |
|---|---|---|---|---|---|
| 110–113 | Soapaga | hard f.g. muddy sandstone | 70° at 60° | greyish red<br>pale red | 5R–4/2<br>5R–6/2 |
| 114–122 | Totomo bridge near Capitanejo | f.g. sandstone | 25° at 60° | pale red<br>greyish pink<br>greyish red<br>pale reddish brown | 5R–6/2<br>5R–8/2<br>5R–4/2<br>10R–5/4 |
| 128–133 | Pamploma–La Bateca road | well bedded f.g. sandstone | 20° at 300° | moderate red<br>greyish red | 5R–5/4<br>10R–4/2 |
| 134–137 | Quebrada del Aji (near La Bateca) | f.g. sandstone | 30° at 290° | pale red<br>moderate red | 5R–6/2<br>5R–5/4 |
| 140–144 | Rio Negro, near Bucamaranga | f.g. sandstone | 80° at 180° | moderate red<br>pale red<br>pale reddish brown<br>moderate reddish brown | 5R–5/4<br>5R–6/2<br>10R–5/4<br>10R–6/6 |

TABLE 7. N.R.M. DIRECTIONS AND STATISTICS FOR PERMO-CARBONIFEROUS

| | | direction of r.m./degree | | | |
|---|---|---|---|---|---|
| site | number of samples | $D$ | $I$ | $\delta$ | $\delta_m$ |
| 1. Soapaga | 12 | 96 | $-13$ | 64 | 19 |
| 2. Totomo bridge | 24 | 120 | $+15$ | 42 | 9 |
| 3. Pamploma | 12 | 203 | $+41$ | 45 | 13 |
| 4. Quebrada del Aji | 8 | 215 | $+5$ | 42 | 15 |
| 5. Rio Negro | 10 | 246 | $+34$ | 26 | 8 |
| deduced pre-folding direction | — | — | — | — | — |
| assumed post-folding direction | — | 0 | $+12$ | — | — |

Directions are referred to the bedding.

TABLE 8. SAMPLE AND SITE DESCRIPTIONS FOR PIPIRAL FORMATION

| site | sample no. | locality | lithology | dip of beds | colour |
|---|---|---|---|---|---|
| 1 | 169–174 | Choapal, near electric generating station | well cemented f.g. and m.g. sandstone | 15–30° at 290–300° | greyish red purple 5RP–4/2 |
| 2 | 175–188 | 5–6 km outside Villa Vicencio on road to Quetame | f.g. muddy sandstone slightly sheared | 50–60° at 340° | greyish red purple 5RP–4/2 |

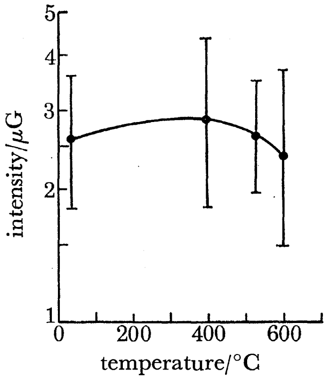

FIGURE 10. Thermal decay of r.m. of the Girón formation. Geometric mean intensities (μG) with standard error bars are shown.

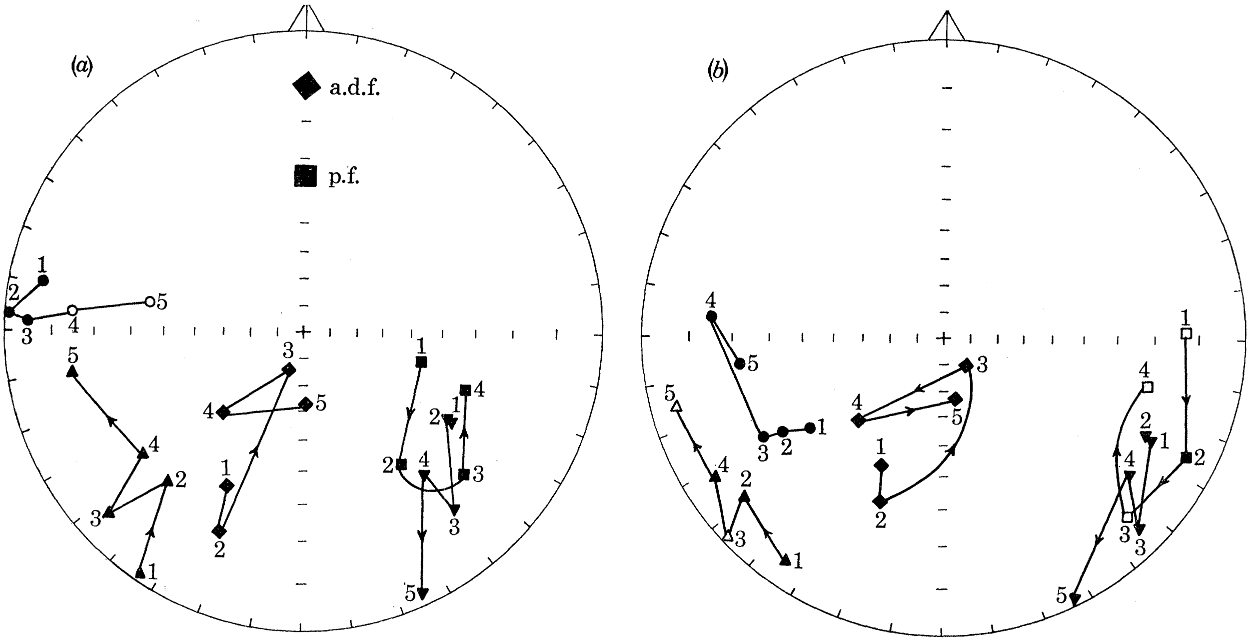

FIGURE 11. Site-mean directions of r.m. during thermal cleaning of the Colombian Permo-Carboniferous collection; (*a*) referred to the present horizontal, and (*b*) to the bedding. Squares, Soapaga site; inverted triangles, Totomo Bridge; diamonds, Pamploma; triangles, Aji; dots, Rio Negro. Numbers refer to the stage of thermal cleaning, see § 2.3.

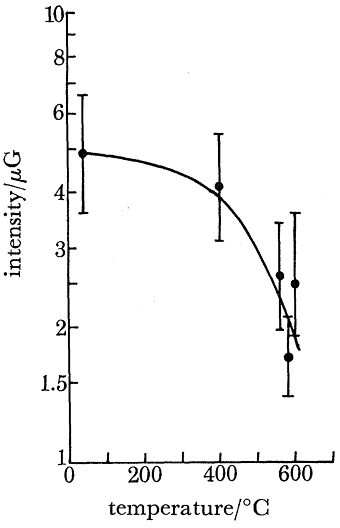

FIGURE 12

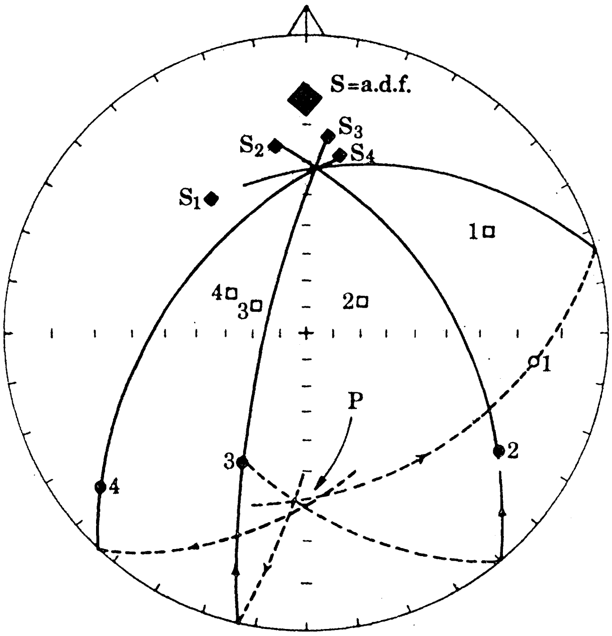

FIGURE 13

FIGURE 12. Thermal decay of r.m. of the Colombian Permo-Carboniferous. Geometric mean intensities ($\mu$G) with standard error bars are shown.

FIGURE 13. Deduction of direction of primary magnetization of Permo-Carboniferous Red Beds, Colombia. The large diamond, S = a.d.f. represents the present axial dipole field referred to the present horizontal. The smaller diamonds, S, represent this direction referred to the bedding planes; 1 for the Soapaga site; 2 for the Totomo Bridge site; 3 for the Pamploma site and 4 for the Quebrada del Aji site (see table 6). The squares, labelled 1 to 4 represent the poles of the bedding planes at these sites and the dots the mean of the n.r.m. and the r.m. cleaned at 590 °C. The direction of primary remanence is given by the points of intersection of the great circles. Open symbols and broken lines are plotted from the upper hemisphere and solid symbols and continuous lines are plotted from the lower hemisphere.

along the great circle connecting the a.d.f. and measured directions. These have been drawn in figure 13 and it is seen that they intersect within a well-defined region of the projection. This direction ($D$ = 177 to 187°, $I$ = −27 to −32°) is taken as that of the primary remanence and the virtual magnetic pole corresponding to it lies at 80° S, 118° E approximately.

This pole must correspond to a magnetization acquired before folding, i.e. to a pre-Tertiary field, but its position is more consistent with a post-Triassic possibly Cretaceous rather than a Permo-Carboniferous magnetic age.

### 2.4. *The Pipiral formation*

This is exposed in the Llanos region of Colombia near Villa Vicencio which is situated near the intersection of the 950 km north to south line and the 1050 km east to west line on the Girardot area sheet of the Geological Map of Colombia (1:250 000) produced by the Shell-Condor Petroleum Company. This sheet covers the area to the south of the larger South Colombia Sheet (Strauffer *et al.* 1947).

According to the legend produced by Shell-Condor for their geological map, the Pipiral formation is Permo-Carboniferous. However, no Carboniferous is mapped and the Devonian is shown in the legend below the Pipiral formation.

The collecting sites and rock samples are described in table 8. The strata at site 1 were thought to be of possible Lower Cretaceous age, but the palaeomagnetic results suggest rather that they belong to the Pipiral formation to which the samples collected from site 2 certainly belong.

Thermal cleaning was not carried out on these samples because their n.r.m. intensities were very low, of the order of 1 μG. Therefore an attempt was made to separate the more reliable data by dividing the samples into two groups, depending on whether the scatter of n.r.m. directions of specimen disks from a given hand sample was greater or less than 25°.

The n.r.m. directions of those samples with low internal scatter are plotted in figure 14: (*a*) with respect to the present horizontal, and (*b*) with respect to the bedding. Each point represents the n.r.m. direction of a disk, those from site 1 being plotted as dots and those from site 2 as squares. When referred to the bedding planes, two groups of directions appear, namely: (i) normally magnetized with northwest declinations and negative inclinations, and (ii) reversely magnetized with southeast declinations and positive inclinations (figure 14*b*). The former group lies close to the present field direction when referred to the present horizontal (figure 14*a*). The c.s.d. of 18° is slightly less than that of 20° for the same population referred to the bedding (see table 9) but this difference cannot be considered significant. Thus, while we must bear in mind the possibility that this group of samples may have been magnetized after folding, we note that the virtual geomagnetic pole, situated at latitude 64° S, longitude 16° E is only 13° away from the established mean Permo-Carboniferous pole for S. America which is situated at 62° S, 14° W computed from four formation-mean poles and which has c.s.d. = 5° (Creer *et al.* 1969).

The second group comprises samples from both sites. The c.s.d. of the population of directions is lower when referred to the bedding (14°) than when referred to the present horizontal (28°) and the mean direction in the latter case is strongly oblique to either the normal or reversed sense of the present axial dipole field and to the present field (see figure 14 and table 9). The position of the south virtual geomagnetic pole lies at latitude 39° S, longitude 12° W and this agrees well with one of the two virtual pole positions (at 31° S, 24° W) obtained from the

Taiguati formation of Bolivia which is Pennsylvanian in age (part IV). The other Taiguati pole position (54° S, 15° W) is considered to be Permo-Carboniferous. Thus the magnetization of the upper parts of the Pipiral and Taiguati formations may have been acquired during the Permo-Carboniferous but the lower parts yield poles which fall in group C of figure 1, p. 555.

The directions of n.r.m. of disks from those samples with greater inhomogeneity in their remanence (c.s.d. of disk directions greater than 25°) are illustrated in figure 15 where they are referred to the bedding. It would appear that n.r.m. of these samples is composite and it is highly desirable to prove this by applying thermal cleaning to a new and larger collection.

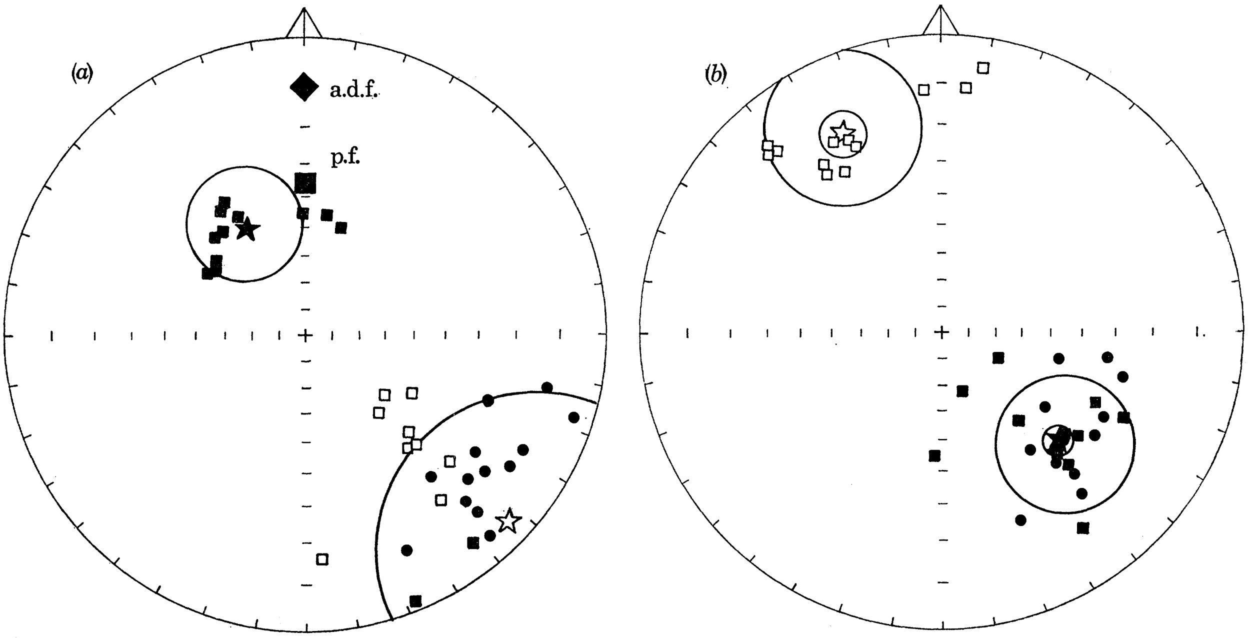

FIGURE 14. N.r.m. of specimens from the samples with c.s.d. less than 25° from the Pipiral formation. In (*a*) the primitive represents the present horizontal and in (*b*) it represents the bedding planes.

TABLE 9. N.R.M. OF PIPIRAL FORMATION

| | | | direction of n.r.m./degree | | | | south palaeopole | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| polarity | number of samples | plane of reference | *D* | *I* | $\delta$ | $\delta_m$ | lat. | long. | $\delta$ | $\delta_m$ |
| reversed | 7 | bedding | 133 | +33 | 14 | 5 | 39° S | 12° W | 15 | 6 |
| | | present horiz. | 133 | −4 | 28 | 11 | — | — | — | — |
| normal | 4 | bedding | 334 | −17 | 20 | 10 | 64° S | 16° E | 20 | 10 |
| | | present horiz. | 332 | +46 | 18 | 9 | — | — | — | — |
| present field | — | — | 0 | +35 | — | — | — | — | — | — |
| axial dipole field | — | — | 0 | +12 | — | — | — | — | — | — |

### 2.5. *Cretaceous formations*

The Aptraxa sandstone was sampled in Colombia at the site described in table 10 and the Yeguera and Cazuela formations from the vicinity of Caracas in Venezuela at the sites described in table 11.

Only the n.r.m. was measured: thermal cleaning was not applied. The results of the measurements are presented in table 12. The Aptraxa sandstone yielded a well defined group of reversed directions (figure 16). Similarly, the Yeguera formation contained some samples which yielded reversed remanence (figure 17). The south virtual geomagnetic poles of these two groups of samples are in good agreement with one another (table 12).

Some samples from the Yeguera formation were normally magnetized, but the mean direction is significantly different from the present field or axial dipole field directions as shown in figure 17*a* where the primitive of the projection represents the present horizontal. C.s.d. circles are shown. There is some indication of streaking towards the a.d.f. and p.f. directions within this normally magnetized group of disks, so that the virtual pole given in table 12 must be regarded with some suspicion.

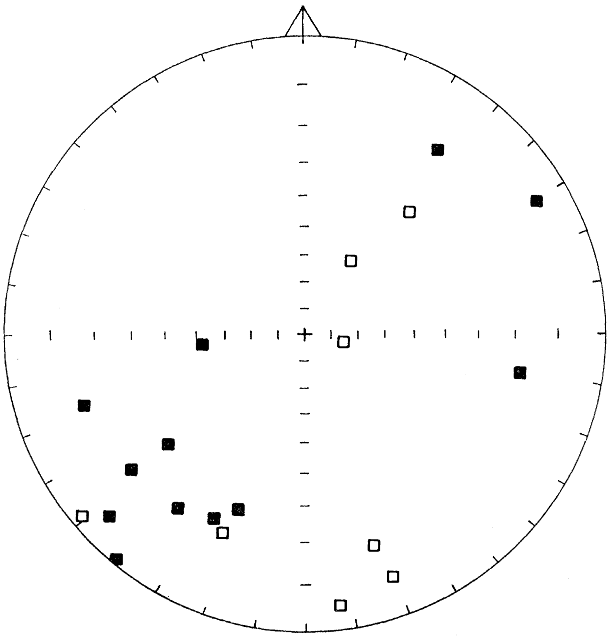

FIGURE 15

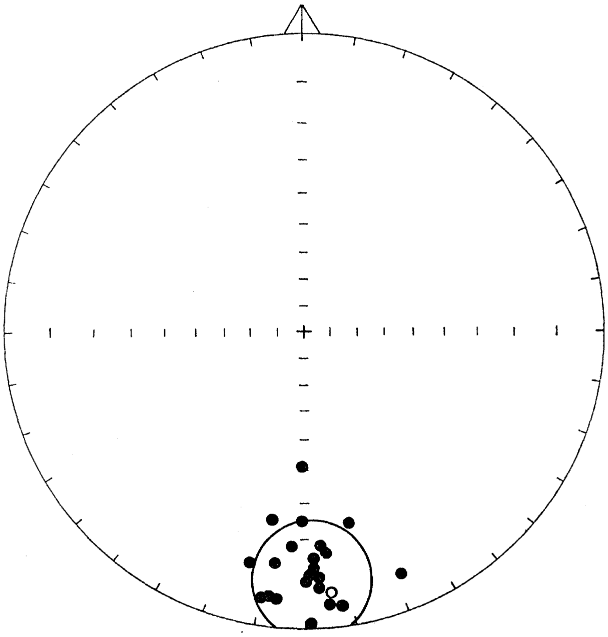

FIGURE 16

FIGURE 15. N.r.m. of specimens from samples with c.s.d. greater than 25° from the Pipiral formation. The primitive represent the bedding planes.

FIGURE 16. N.r.m. directions of specimens from the Aptraxa formation. The primitive represents the bedding planes.

TABLE 10. APTRAXA SANDSTONE

| age | sample no. | locality | lithology | dip of beds | colour |
|---|---|---|---|---|---|
| Upper Cretaceous | 159–160<br>161–162<br>163–164<br>165–166 | near Villa de Leiva (about 20 km E.N.E. of Tunja) | m.-f.g. well cemented sandstone<br>f.g. sandstone<br>f.g. muddy sandstone<br>m.f.g. well cemented sandstone | 30–35° at 285–305° | greyish red 5R–4/2 |

Samples 160 and 161 are separated by shales which were not sampled.

TABLE 11. CRETACEOUS SEDIMENTS FROM VENEZUELA

| formation | place | sample nos. | dip of beds |
|---|---|---|---|
| Yeguera | near Manrique at 9° 01′ N, 68° 08′ W | 10–13 | 10–20° at 150–160° |
| Cazuela | 9° 00′ N, 68° 08′ W | 14–17 | 60° at 350–355° |

The Cazuela formation has clearly been remagnetized in the a.d.f. and p.f. directions as shown in figure 18*a*, although the n.r.m. directions, when viewed from the bedding planes form a compact group (figure 18*b*). However, the fold test cannot be applied here because all the samples come from one site where the dip of the strata is uniform.

TABLE 12. N.R.M. OF CRETACEOUS FORMATIONS

| formation | number of disks | plane of reference | direction of n.r.m./degree | | | | south virtual pole | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | $D$ | $I$ | $\delta$ | $\delta_m$ | lat. | long. | $\delta$ | $\delta_m$ |
| Aptraxa | 23a | bedding | 179 | +12 | 13 | 3 | 80° S | 72° W | 10 | 2 |
| | | present horiz. | 177 | −2 | 13 | 3 | — | — | — | — |
| Yeguera (N) | 10 | bedding | 18 | −5 | 17 | 5 | 68° S | 127° W | 17 | 5 |
| | | present horiz. | 17 | +4 | 17 | 5 | — | — | — | — |
| Yeguera (R) | 12 | bedding | 187 | −7 | 17 | 5 | 81° S | 120° W | 11 | 3 |
| | | present horiz. | 187 | −1 | 14 | 4 | — | — | — | — |
| Cazuela | 12 | bedding | 259 | +68 | 19 | 6 | — | — | — | — |
| | | present horiz. | 5 | +27 | 19 | 6 | | | | |

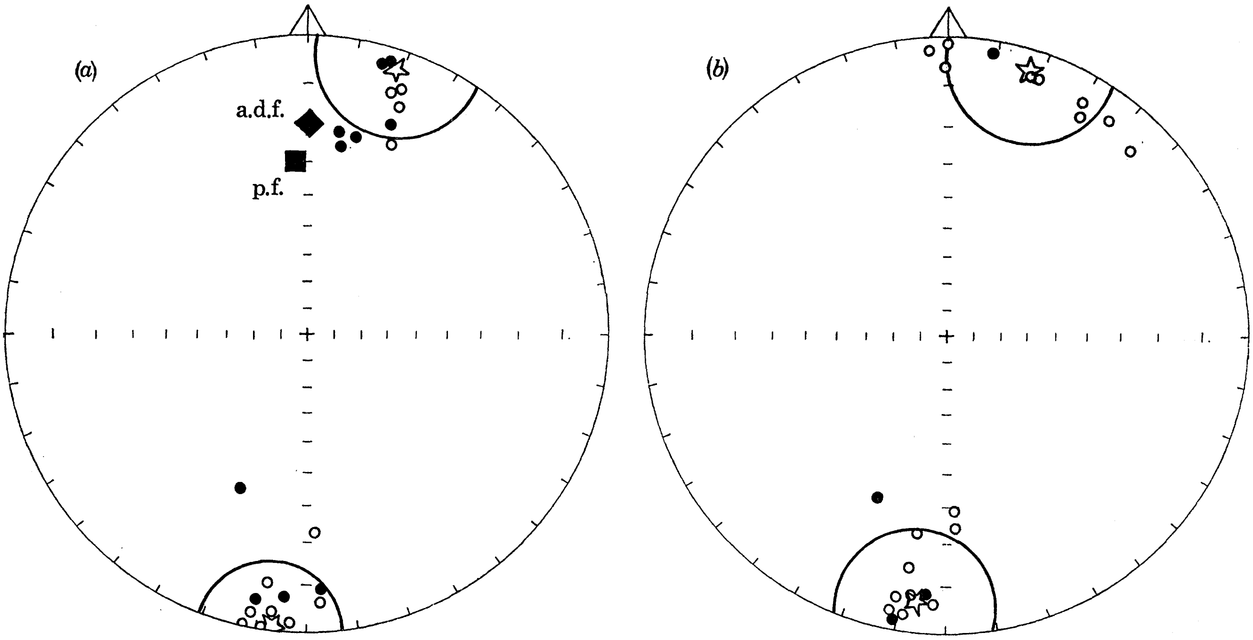

FIGURE 17. N.r.m. directions of specimens from the Yeguera formation plotted (*a*) with respect to the present horizontal, and (*b*) to the bedding planes. In (*a*) the a.d.f. and p.f. directions are shown.

## 3. CONCLUSIONS

The rock formations studied, from the Venezuelan and Colombian Andes have composite n.r.m., having been remagnetized after folding.

Thermal demagnetization failed to reveal the direction of the primary (i.e. pre-folding remanence of the La Quinta formation. Measurements of pebbles of this formation contained in an overlying conglomerate confirmed the presence of secondary magnetization.

The strata of the Girón formation from Colombia were not inclined so steeply as those of the La Quinta formation (compare the data in tables 1, 2 and 4), and this may explain why the r.m directions, both before and after thermal cleaning are consistent with magnetization in the Triassic. Permo-Carboniferous samples also from the cordillera region of Colombia have a composite n.r.m. from which a primary component cannot be isolated by thermal cleaning. Nevertheless, by relating the r.m. directions to the dip and strike of the strata, the direction of primary remanence has been inferred and is consistent with magnetization in the Triassic geomagnetic field before folding.

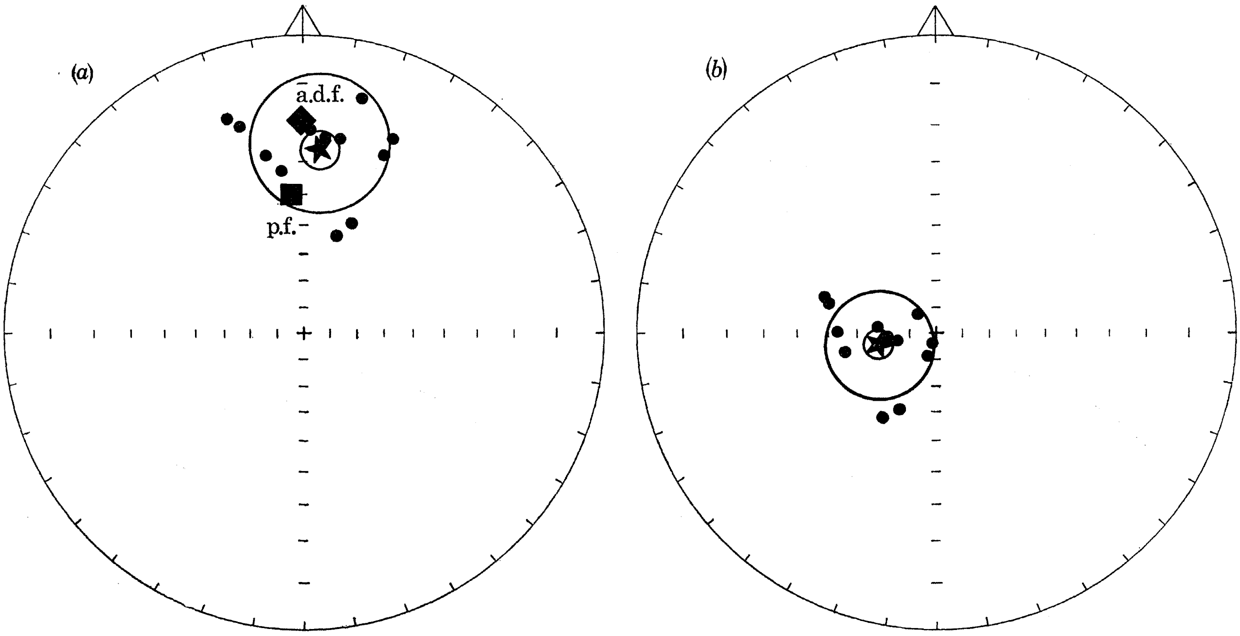

Figure 18. N.r.m. directions of specimens from the Cazuela formation plotted (*a*) with respect to the present horizontal and (*b*) to the bedding planes. In (*a*) the a.d.f. and p.f. directions are shown.

The Pipiral formation, from the Llanos region of Colombia appears to have acquired some of its remanence in the M. Carboniferous and some in the Permo-Carboniferous. Its magnetic ages are thus the same as those of the Taiguati formation of Bolivia.

Various younger formations of Cretaceous age, from the Colombian and Venezuelan cordillera appear to have been partly remagnetized after folding, but examples of reversed magnetization have been discovered which are thought to reflect a late Cretaceous geomagnetic field.

In general, the palaeomagnetism of the rock formations from these folded strata of the cordilleras of Columbia and Venezuela is highly complex and can only be interpreted with the help of data from other regions of S. America where the structure is simpler.

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