1971, *Phys. Earth Planet. Interiors* **4**, 370–380. North-Holland Publishing Company, Amsterdam

PALAEOMAGNETISM OF SURINAME DOLERITES

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Received 4 December 1970

Permo-Triassic and Precambrian dolerites have been collected for palaeomagnetic research in Suriname (South America) at 24 sites (280 oriented cores). After A.F. or thermal demagnetization, consistent directions were obtained for the following groups: Permo-Triassic (227×10^6 y), 10 sites, 90 samples, $D = 358°$, $I = -7°$, pole 82° S, 40° W; Precambrian (around 1.550–1.650×10^9 y), 2 sites, 17 samples, $D = 277°$, $I = +35°$, pole position 8° S, 53° E; Precambrian (about 1.750×10^9 y), 2 sites, 30 samples, $D = 314°$, $I = +3°$, pole 44° S, 30° E. Precambrian pole positions for South America, Africa, North America and Europe are discussed.

1. Introduction

In 1968, palaeomagnetic research on dated rocks in Suriname (South America) was started by the Palaeomagnetic Laboratory of the Rijksuniversiteit at Utrecht. A group from this Laboratory joined a group from the Z.W.O. Laboratory for Isotope Geology, which for some years had been studying the isotopic geochronology of Suriname. The fieldwork was carried out in close cooperation with the Geological and Mining Service of Suriname (G.M.D.).

Most promising for the initial palaeomagnetic work were dolerite sills and dykes, found at many places intruded in the Precambrian basement of Suriname. The granitoid–volcanic basement was formed about 1.8×10^9 y ago. Isotopic dating, through the use of K–Ar dating techniques, indicates that the dolerites were intruded during at least two widely different periods. Large sills and dykes of hypersthene–pigeonite dolerite yielded K–Ar dates ranging from 2.7–1.2×10^9 y and thus belong to the Precambrian history of the Guiana Shield. However, as they have intruded the Suriname basement rocks, they cannot be older than $(1.81 \pm 0.04) \times 10^9$ y (Priem *et al.*, 1970). The higher ages, which were all found in the western part of the country (an area affected by the Nickerie Metamorphic Episode (c.f. Priem *et al.*, 1968b, 1969, 1970) which occurred about $(1.2 \pm 0.1) \times 10^9$ y ago are ascribed by Hebeda and Priem (1970) to argon excess. Extensive NNW–SSE trending dykes of pigeonite–olivine dolerite were found to be 227×10^6 y old. This Permo-Triassic magmatic event might be related to the breaking up of the South American and African continents.

For details about isotopic ages of the Suriname rocks the reader is referred to Priem *et al.* (1966, 1967, 1968a, b, 1969, 1970) and Hebeda and Priem (1970).

2. Geological setting

Suriname is a part of the Precambrian Guiana Shield. Along the recent coast, the Precambrian basement is covered by the "coastal sediments" (Upper Cretaceous to Recent). The basement consists mainly of acid to intermediate plutonic rocks and metamorphosed geosynclinal volcanic and sedimentary sequences.

In the central part of Suriname, the basement is overlain by tabular sandstones of the Roraima Formation (Tafelberg–Emmaketen). This isolated occurrence of Roraima sediments is the most eastern remnant of the Formation, which once must have covered the central part of the Guiana Shield and still occupies large regions in Venezuela, Brazil and Guyana. At Tafelberg, a hypersthene–pigeonite dolerite dyke is found to cut the Roraima Formation. A sample from this dyke was dated by the whole-rock K–Ar method at $(1.66 \pm 0.06) \times 10^9$ y (Priem *et al.*, 1968a). On the other hand, Rb–Sr and K–Ar whole rock measurements on a tuff layer

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from the upper part of the Roraima Formation yielded a concordant age of $(1.61 \pm 0.05) \times 10^9$ y (Priem *et al.*, 1968b, 1969). Priem *et al.* (1970) tentatively assigned an age of about $1.6\text{–}1.65 \times 10^9$ y for the Roraima Formation. These field relations and ages of the flatlying Precambrian Roraima Formation and the hypersthene–pigeonite dolerite are of particular importance for this palaeomagnetic study: They indicate that since the deposition of the Roraima sequence, and therefore after intrusion of the post-Roraima group of older hypersthene–pigeonite dolerites, no appreciable tilting movements occurred in this area of the Guiana Shield.

3. Sampling

Outcrops of fresh dolerite are found practically only where the sills and dykes cross the rivers. Special care

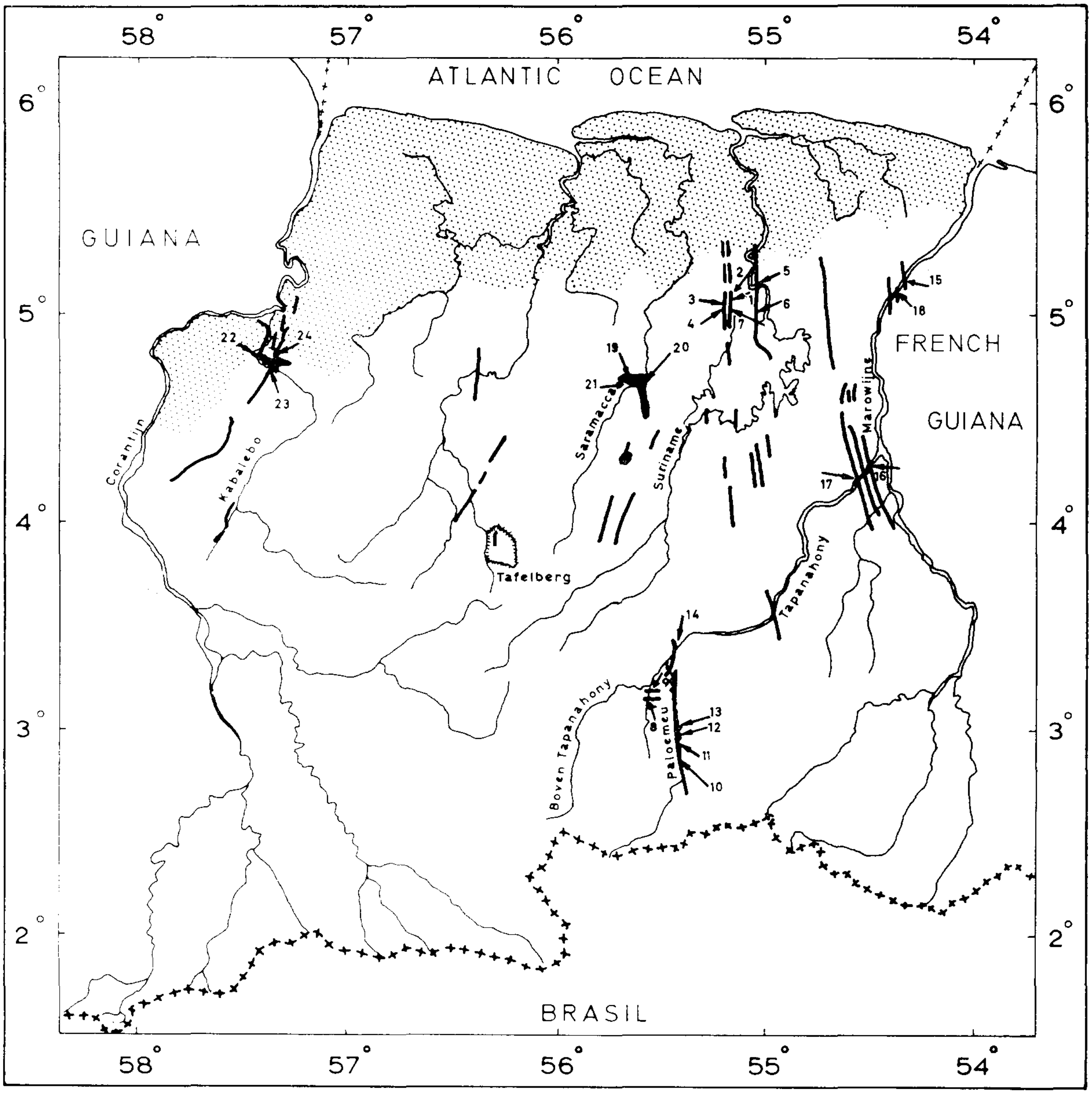

Fig. 1. Map of Suriname showing the sampling localities. Black: dolerite sills and dykes; dotted: coastal sediments; Tafelberg area: Roraima sandstones; white: undifferentiated Precambrian basement.

had to be taken that in those river outcrops samples were collected from fixed parts of the rocks, not moved by the stream of the river.

The collection was made in November and December 1968. Alltogether 280 oriented cores of dolerite were collected from 24 widely separated sites (fig. 1). All samples were obtained with a portable coring drill (DOELL and COX, 1967); most samples were oriented with a sun compas. At a few localities, a part of the samples could be oriented only with a magnetic compass owing to the local situation. Results from these samples were used when they proved to be consistent with those of the sun oriented samples.

Most samples were obtained from the Permo-Triassic dykes (sites 1–7 and 10–18). Some of them were taken in new road excavations around Brownsweg (sites 1–7), where the samples were collected from unweathered spheroidal boulders in the dolerites. At the other localities (sites 10–18), the samples were obtained from river beds, namely in eastern Suriname in the middle Marowijne river (sites 15 and 18) and in the lower Tapanahony river (sites 16 and 17), and in southern Suriname in the Paloemeu river (sites 10–14).

Samples of dolerite sills and dykes of Precambrian age were collected at three areas: in southern Suriname in the Blakawatra river (sites 8 and 9), a tributary of the upper Tapanahony river; in central Suriname at three localities near the Saramacca river (sites 19–21); and in western Suriname at three localities in the Kabalebo river (sites 22–24). The last sites belong to the Avanavero complex, many samples of which show abnormally high ages due to argon excesses. Since argon excess is thought to be related to the Nickerie Metamorphic Episode (HEBEDA and PRIEM, 1970), it is possible that the characteristic n.r.m. directions in the Avanavero area do not represent the geomagnetic field during the

TABLE I

Mean directions of remanent magnetization of the Permo-Triassic dolerites

Site number	Site name	N	n	Dec. (°)	Inc. (°)	k	α_{95} (°)	R
Brownsweg (55° W, 5° N)								
1[a])	Jungle 8.8 km N of Brownsweg	5/8	4/0		scattered			
2[a])	Jungle 9.5 km N of Brownsweg	10/17	8/0		scattered			
3	Road 3.5 km N of Brownsweg	12/27	10/8	355	+15	87	6	7.92
4	200 m E of Brownsweg	11/25	17/12	5	+10	242	3	11.95
5	1 km S of Berg en Dal	9/24	9/9	352	−17	130	4	8.94
6	12.5 km E of Brownsweg	6/15	10/10	348	−14	458	2	9.98
7	900 m E of Brownsweg	10/26	7/6	2	+ 6	149	5	5.97
Paloemeu (55½° W, 3° N)								
10[a])	Papadron falls	24/42	15/6	(359)	(−12)	(85)	(7)	(5.94)
11[a])	Kodabakoe falls	10/20	10/5	(354)	(−16)	(47)	(11)	(4.92)
12	Koesoekwatta falls	23/46	14/14	348	−14	183	3	13.93
13	Talimien falls	8/24	10/9	350	−15	150	4	8.95
14	Koemaroekondre falls	18/45	12/8	354	−13	109	5	7.94
Marowijne (54½° W, 4½° N)								
15	Apatoe	10/25	10/8	20	− 4	169	4	7.96
16[a])	Acote in Tapanahony	13/28	11/0		scattered			
17[a])	Gwetapoe falls	13/25	11/0		scattered			
18	Lamaké falls	13/26	6/6	6	−21	94	7	5.95
Mean direction of sites (10)				358	− 7	25	10	9.64
Mean direction of samples (90)				357	− 7	24	3	86.33

N – number of samples collected / number of specimens
n – number of specimens studied / number of specimens used in the computations
k – Fisher's precision parameter
α_{95} – semi-angle of cone of 95% confidence
R – vector sum of unit magnetizations of specimens used

[a]) results not used in the computations

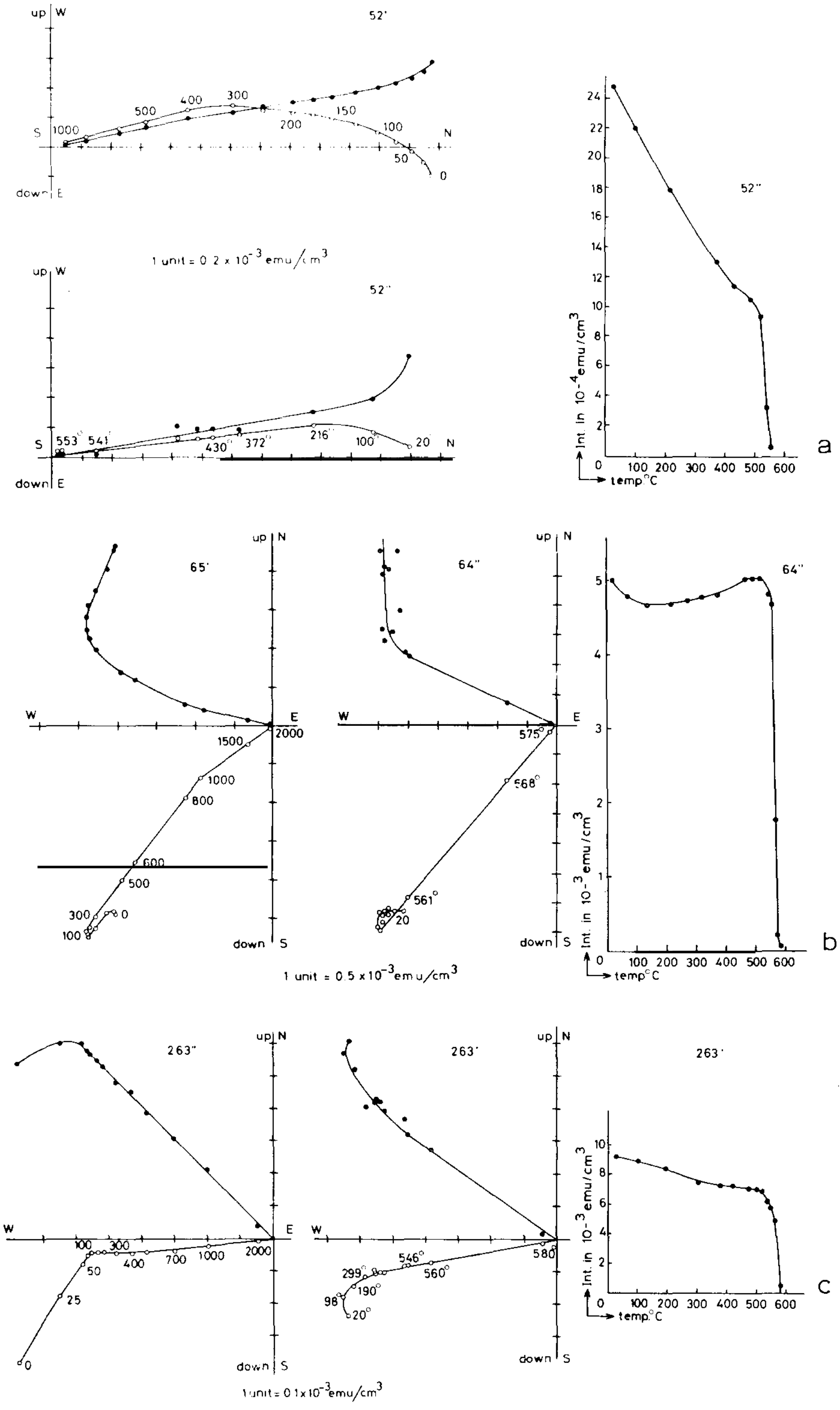

Fig. 2. Demagnetization curves (A.F. and thermal) for some typical samples of the Permo-Triassic and Precambrian groups (a, b and c, respectively). Plotted points represent successive positions (in orthogonal projection) of the end point of the vector of remanent magnetism. Full symbols represent projections on the horizontal plane; open symbols represent projections on a vertical plane. Numbers denote a.c. field intensities (Oe) or temperatures (°C). 1 e.m.u./cm^3 = 1 G.

TABLE 2

Mean directions of remanent magnetization of the Precambrian dolerites (Legend as table 1)

Site number	Site name	N	n	Dec. (°)	Inc. (°)	k	α_{95} (°)	R
Blakawatra (55½° W, 3° N)								
8	2 km from Upper Tapanahony	7/11	8/7	282	+42	148	5	6.96
9	300 m from Upper Tapanahony	9/19	12/10	272	+29	20	11	9.54
Mean direction of sites (2)				277	+35	—	—	—
Mean direction of samples (17)				276	+35	25	7	16.35
Saramacca (55½ °W, 4½ °N)								
19a)	4 km NE of Pakka Pakka	11/18	13/0		scattered			
20a)	6 km NE of Pakka Pakka	9/26	9/0		unstable remanence			
21a)	3 km NE of Pakka Pakka	10/24	13/6	(345)	(—13)	(204)	(5)	(5.98)
Kabalebo (57½ °W, 5° N)								
22	Devis Falls	12/35	12/12	311	0	147	4	11.92
23a)	Champion falls	8/24	16/0		scattered			
24	Avanavero falls	18/36	19/18	317	+ 7	124	3	17.86
Mean direction of sites (2)				314	+ 3	—	—	—
Mean direction of samples (30)				314	+ 4	95	3	29.69

a) results not used in the computations

intrusion of the dolerites (1.75×10^9 y), but may also be controlled by the Nickerie Metamorphic Episode (1.20×10^9 y).

K–Ar datings on samples of the Blakawatra dykes yielded an age of 1.54×10^9 y (HEBEDA and PRIEM, 1970). This result places the Blakawatra dykes definitely in the Precambrian, but they seem to be younger than the Precambrian hypersthene-pigeonite dolerites in western Suriname.

4. The natural remanent magnetizations

The n.r.m. intensities of the Precambrian dolerites were distributed between 2×10^{-4} and 2×10^{-3} G. The n.r.m intensity of the Permo-Triassic dolerites is consistently stronger. For these younger dykes the typical intensities lie in a small range between 2 and 4×10^{-3} G (all road-sites of Brownsweg, most of the Paloemeu sites). However, in samples from some of the Paloemeu sites and most of the Marowijne sites n.r.m. intensities up to 10^{-1} G were encountered. Blocking temperature measurements (fig. 2) indicate that magnetite is the most important remanence bearing mineral in the Suriname dolerites. Table 1 presents the site names, the numbers of samples, the mean palaeomagnetic directions after cleaning, and the statistical parameters for the Permo-Triassic sites; table 2 gives the same for the Precambrian dolerites.

4.1. *Brownsweg–Paloemeu–Marowijne (sites* 1–7 *and* 10–18*)*

The n.r.m. of the dolerites was analysed by means of alternating field (A.F. treatment) and thermal demagnetization series. Progressive demagnetization of several pilot samples of each site showed that the n.r.m. of the Permo-Triassic dolerites gradually changed in direction in alternating fields up to 150–200 Oe (sometimes up to 300–400 Oe), owing to the elimination of soft and viscous components. Upon further treatment with higher alternating fields, the direction of the decreasing n.r.m. remained steady, proving that only one component was left after elimination of the soft and viscous part of the remanence. The direction of this characteristic component was determined for each site by means of treating a number of specimens of the site with alternating field steps from 300 up to 1000 Oe (peak value). In nearly all samples of these Permo-Triassic dolerites, the n.r.m. was almost entirely eliminated by 1000 Oe. The characteristic directions (fig. 3) proved to be significantly different from the present local geomagnetic direction, and the corresponding

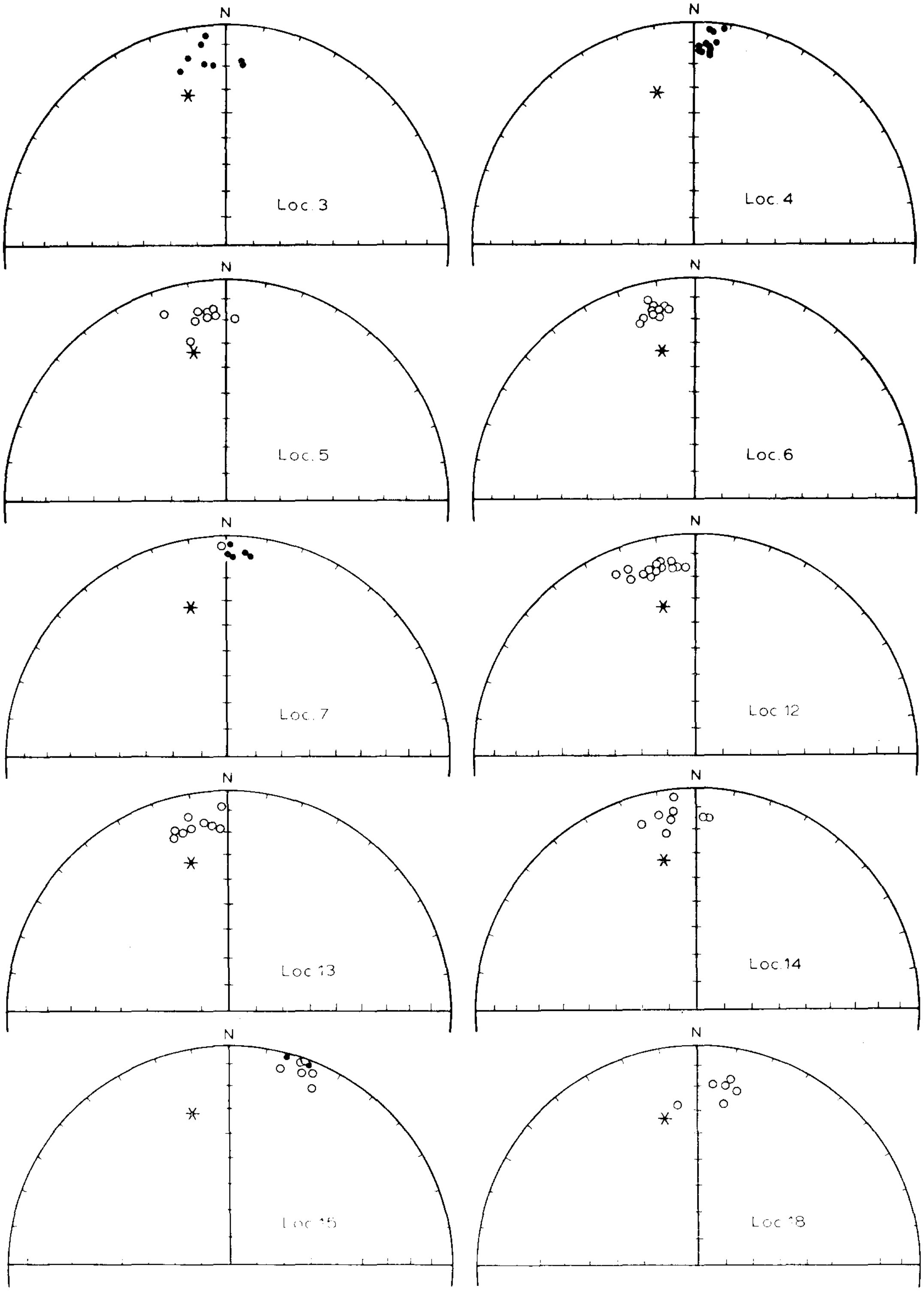

Fig. 3. Equal-area projections of the characteristic magnetic directions of Permo-Triassic samples. The asterisk is the present-day local field direction (pointing down). Full and open symbols mean positive and negative inclinations, respectively.

pole positions agree well with the positions obtained by other authors for Permo-Triassic rocks of South America.

Thermal demagnetization of some Permo-Triassic samples showed that the soft and viscous part of the n.r.m. was eliminated at about 200 °C and that the remaining characteristic remanence was eliminated at temperatures varying between 560 °C and 580 °C. There was no significant difference between the directions obtained by thermal demagnetization and those obtained for the same sample group, by treatment in alternating fields. An example of A.F. and thermal demagnetization of one sample of the Permo-Triassic dykes is shown in fig. 2a (upper part).

After elimination of the soft component, the remaining part of the characteristic component in the younger dolerites of the Brownsweg sites and most of the Paloemeu sites retained between 40% and 70% of the original total n.r.m. intensity, and its direction could be accurately determined. However, this was not found to be the case for the Marowijne sites 16 and 17 and the Paloemeu site 11. The dolerite samples from site 11 along the Paloemeu had outstandingly high n.r.m. intensities and high Q values (5 to 6×10^{-2} G and 20 to 40, respectively). The greater part of this n.r.m. proved to be very soft: After treatment at 200 Oe, only 3% of the original n.r.m. intensity remained. Although at this demagnetization stage the intensity of the remaining part of the characteristic n.r.m. resembled intensity values of other Paloemeu (and Brownsweg) sites, it was difficult to obtain reliable directions from site 11; therefore the result from this site is given in brackets. Interpretation of results of the Marowijne samples was hampered by similar difficulties. At these dolerite sites the total n.r.m., varying nonsystematically between 1×10^{-3} and 2×10^{-2} G, decreased to values below 6×10^{-4} G upon treatment at 200 Oe. The intensity of the characteristic remanence is thus distinctly lower than in the Brownsweg and Paloemeu dykes (and more like the intensity of the remanence of the Precambrian Kabalebo and Saramacca dolerites). The demagnetization results of several samples from sites 15 and 18 enabled us to establish the direction of the characteristic component with sufficient accuracy (fig. 3).

The data of two Brownsweg sites (1 and 2) yielded inconsistent results and are not reported. Both Brownsweg sites were on hill slopes in the jungle where creep was easily possible. For the greater part of the samples in the Paloemeu, site 10, sun compass measurements could not be made.

4.2. *Blakawatra (sites* 8 *and* 9*)*

The two east–west dykes in the Blakawatra river (sites 8 and 9) have been dated with whole-rock K–Ar methods at about 1.54×10^9 y and thus belong to a younger magmatic event than the Kabalebo dolerite sill. The total intensity of the n.r.m. of these dykes is mainly between 3 and 5×10^{-3} G and stronger than the n.r.m. of the Kabalebo dolerites. The intensity of the Blakawatra samples matches the average intensity of the Permo-Triassic dolerites.

Low alternating fields (up to 100 Oe) and thermal treatments (up to about 400 °C) revealed a soft component which had a consistent direction in all samples of the same site (NNE-up in site 8 and SW–flat in site 9). This soft magnetization component made up 30% to 75% of the total n.r.m. of the samples. Especially in some samples of site 9, the soft component represented a considerable part of the total remanence. Although the major part of this component was destroyed by alternating fields below 100 Oe, it appears that it could not be eliminated entirely below 800–1000 Oe. During further demagnetization beyond 1000 Oe, no further change in the n.r.m. direction occurred and the direction of the harder magnetization component could be determined. The n.r.m. was practically entirely eliminated at 2000 Oe. With thermal demagnetization the soft component was destroyed during heating up to 550 °C which saved the greater part of the harder component. The latter was eliminated mainly in the narrow range between 560 °C and 580 °C (fig. 2b, middle part).

The direction of the harder component was nearly the same for both sites. Therefore this direction was considered to be characteristic for the Blakawatra dykes (see fig. 4, upper part).

4.3. *Saramacca (sites* 19–21*)*

A number of samples was collected in a sill along the Saramacca river (sites 19–21). The results were inconsistent. The samples from site 19 had n.r.m. intensities between 10^{-3} and 10^{-2} G. For a part of the samples, demagnetization in A.F. fields and thermal cleaning resulted in a grouping of the characteristic directions

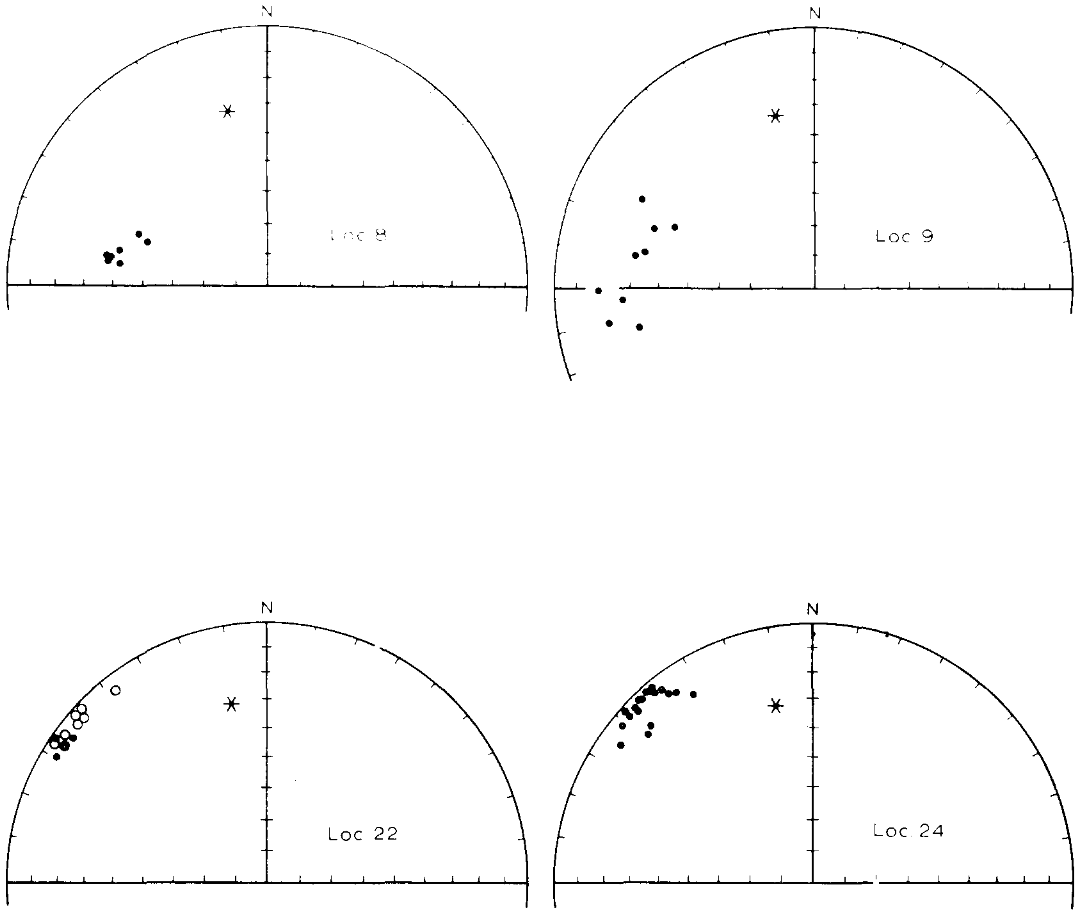

Fig. 4. Equal-area projections of the characteristic magnetic directions of "younger" Precambrian Blakawatra dolerite dykes (sites 8 and 9) and of "older" Precambrian Kabalebo dolerite sills (sites 22 and 24). Full and open symbols mean positive and negative inclinations, respectively.

which resembled those of the Blakawatra sites. However, the samples cored at site 21, which was 1 km from site 19, showed a quite different behaviour. The intensities of the n.r.m. of these samples varied between 10^{-4} and 10^{-3} G. After A.F. or thermal cleaning, the mean direction agreed with those of the Permo-Triassic dolerites, in spite of the supposed Precambrian age.

The characteristic directions at sites 19 and 21 were inconsistent and they have therefore not been used. The samples of site 20 appeared to contain unstable remanence.

4.4. *Kabalebo (sites* 22–24*)*

For the Precambrian dolerites (probably about 1.75×10^9 y old) collected along the Kabalebo river, only two sites (22 and 24) yielded consistent results (fig. 4). The total n.r.m. intensities were lower than those of the Permo-Triassic dykes.

In these Precambrian dolerites the A.F. demagnetization treatment (in fields up to 200 Oe) eliminated soft components with various directions (predominantly NNW with small up and down inclinations). After this treatment usually 30% to 80% of the n.r.m. remained. However, after treatment with higher alternating fields (varying from 500 to 1500 Oe) the remaining n.r.m. decreased without changing its direction. The n.r.m. was not eliminated by less than 3000 Oe alternating field. Thermal demagnetization showed that after elimination of the soft component at lower temperatures the characteristic remanence decayed between 500 °C and 580 °C (fig. 2c, lower part).

Although some dolerite cores taken at the Champion Falls (site 23) yielded characteristic directions similar to those of the two other sites in the Kabalebo region, not all data of this site were consistent and were therefore omitted.

5. Discussion of the results

The palaeomagnetic properties of dolerites in Suriname have so far shown that there are three different characteristic directions corresponding to different ages. The site mean directions are shown in fig. 5; table 3 gives the mean values of the directions and the pole positions. In fig. 6, South America and Africa are placed together according to the Bullard fit (BULLARD, 1965). It is shown (CREER, 1965) that for this reconstruction the Palaeozoic parts of the polar wandering curves of both continents coincide. In fig. 6 the Suriname poles of this study are drawn, together with poles for Triassic and older periods published so far for the two continents. Only those poles are given which are based on studies in which (a) magnetic cleaning had been applied, (b) the reported α_{95} was less than 20°, and (c) the number of samples was not too small. Pole positions for periods younger than Triassic were omitted.

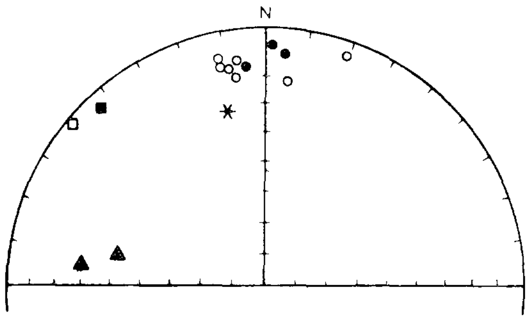

Fig. 5. Site means of characteristic magnetic directions (circles for Permo-Triassic, triangles for "younger" Precambrian, squares for "older" Precambrian). Full and open symbols mean positive and negative inclinations, respectively.

TABLE 3

Pole positions of the Precambrian and the Permo-Triassic dolerites from Suriname

Pole number	Number of sites	Age (10^9 y)	Dec. (°)	Inc. (°)	Pole position	
					Lat.	Long.
Pε1	2	1.75	314	+ 3	44° S	30° E
Pε2	2	1.60	277	+35	8° S	53° E
PTr1	10	0.227	358	− 7	82° S	40° W

The Permo-Triassic pole for Suriname (PTr 1) falls on the proposed (CREER, 1965) polar wandering curve for South America and Africa; its position is just between the Permian pole and the Triassic poles found by other authors (see fig. 6). The normal polarity of the characteristic remanence of the younger Suriname dykes is in accordance with the result of the radiometric dating, which places the time of intrusion close to the Permian–Triassic boundary.

For comparison of the Suriname Precambrian poles with those of other authors, all poles in fig. 6 have been drawn in the same hemisphere, irrespective of the polarity. Although it is questionable whether the Bullard fit holds for the Precambrian arrangement of the old continental nuclei, it is a remarkable fact that the greater part of the Precambrian poles for Africa and South America can be found in or near a band indicated by a light shade. The two Precambrian poles from Suriname are Pε 1 and Pε 2. However, it is doubtful whether this band can be considered as a polar wandering curve since some poles (Pε 1 and Pε 4 from Africa) are far from this band and since the radiometric ages do not allow such a conclusion. Plotting the Precambrian poles east of the South-American/African block is preferable to placing them in the other hemisphere as the gap between the lower Palaeozoic poles and the late Precambrian ones is relatively small in our presentation.

HARGRAVES (1968) has published a study on palaeomagnetism of dolerites in Guyana. He obtained samples from Proterozoic sills which intrude the Roraima sandstones, and from younger dolerite dykes. The remanence directions fall into three significantly different groups. Group 1 has pole coordinates 63° S, 51° E and group 2: 45° S, 13° W. The age of the Proterozoic dolerites is at least about 1.50×10^9 y, and there is no clear evidence of two separate periods of intrusion corresponding with groups 1 and 2. The samples of group 3 (pole position 73° S, 169° W) are from the younger Minor Dyke Suite which is a swarm of dykes of northeast strike. Most probably group 3 of Hargraves corresponds with our Permo-Triassic group. The mean pole position of Hargraves groups 1 and 2 corresponds with our older Precambrian pole. Our younger Precambrian directions of magnetization seem not to have been found in Guyana by Hargraves.

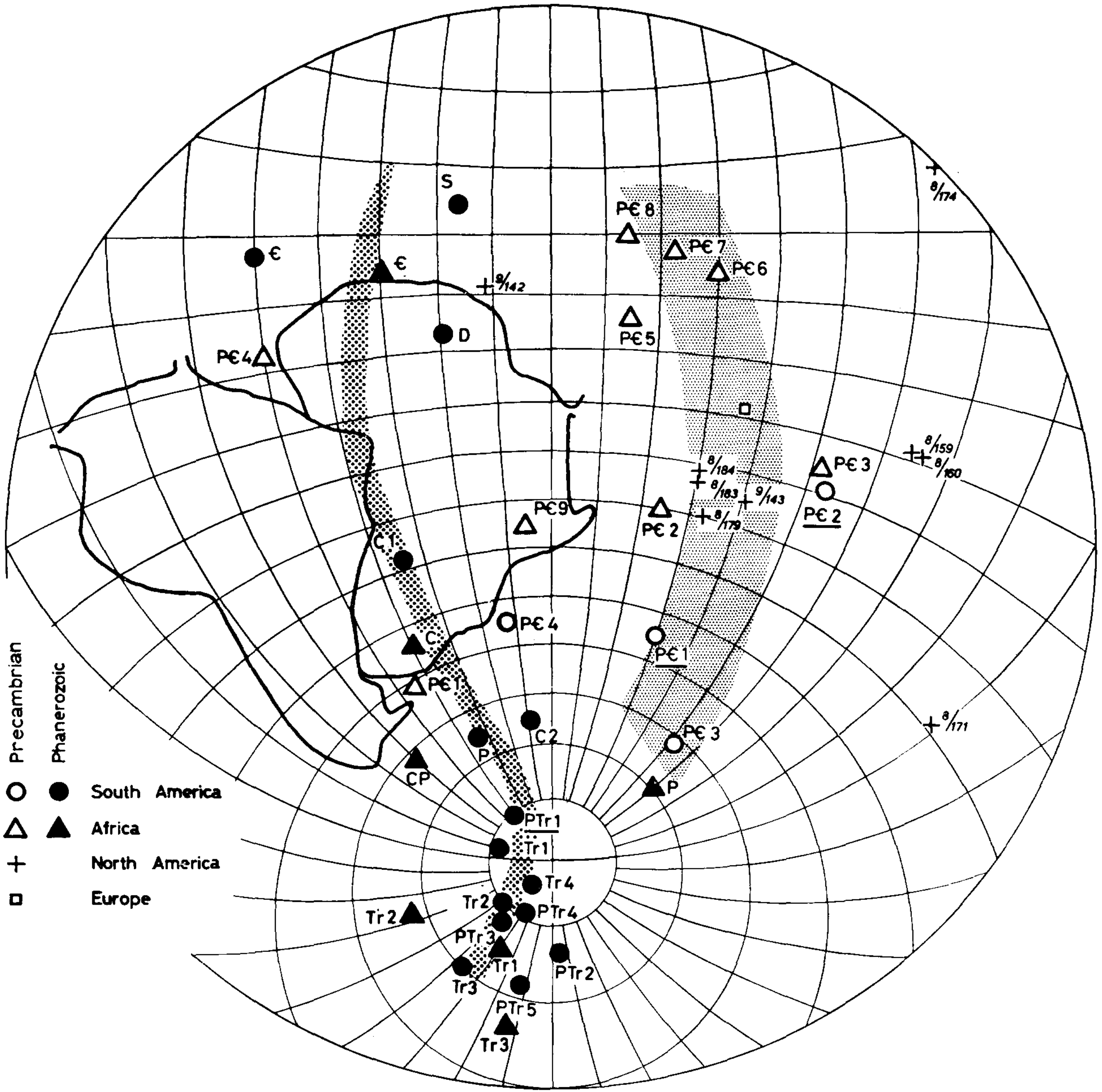

Fig. 6. Distribution of palaeomagnetic pole positions according to the Bullard fit. Pε – Precambrian, ε – Cambrian, S – Silurian, D – Devonian, C – Carboniferous, P – Permian, Tr – Triassic. South American poles: Pε1, Pε2, PTr1, this study; Pε3, Pε4, PTr5, HARGRAVES (1968); ε, CREER (1965); S, D*, C1, C2*, P*, CREER (1967); PTr2, PTr3, Tr3, Tr4, CREER *et al.* (1969); PTr4, CREER *et al.* (1970); Tr1, Tr2, VILAS and VALENCIO (1970). African poles abstracted from MCELHINNY *et al.* (1968). North American poles from lists VIII and IX of MCELHINNY (1968a, b). European Precambrian pole from MULDER (1970).

MCELHINNY *et al.* (1968) published a Precambrian polar wandering curve for Africa, connecting poles according to the age. They also compared their African polar wander curve with Canadian Precambrian poles and they found a similarity which places Africa in the opposite hemisphere compared with North America during part of the Precambrian.

Referring again to the Precambrian band in fig. 6, it should be remarked that there are considerable uncertainties in the ages of intrusion of dolerites due to processes that have affected the K–Ar system, and that

* Small errors have been reported by ZIJDERVELD (1968).

they can be greater than the uncertainties given for the laboratory determinations. For example, the dolerites of western Suriname may contain excess argon but they have also been affected by argon losses (HEBEDA and PRIEM, 1970). Moreover, the uncertainty of a pole position derived from intrusive rocks may be greater than the α_{95}, as it is for example not always certain that the time span covered by the collection of samples is large enough to eliminate deviations from the supposed axial dipole field. Therefore, such poles may have greater uncertainties in age and position than the margins derived from the direct measurements. Keeping this in mind, our preliminary conclusion is that the Precambrian poles for South America and Africa fall for the greater part within the indicated band.

We have also drawn the Precambrian poles for North America (crosses) and for Europe (square), maintaining the Bullard fit for these continents. The North American poles have been taken from MCELHINNY (1968a, b). The European pole has been derived from Precambrian rocks in Sweden by MULDER (1971). A number of these Precambrian poles appear to lie in the indicated band. However, other North American poles fall far outside.

More measurements are needed to answer the question whether or not the nuclei of the continents formed one cluster during the Precambrium.

Acknowledgments

The help and assistance of the Director (Mr. R. A. Cambridge) and staff of the Geological and Mining Service of Suriname is gratefully acknowledged. The following geologists took part in collecting the rock samples: W. Groeneweg, L. Krook, M. W. P. M. van Loon and J. Malm. The authors are much indebted to Prof. H. N. A. Priem and Mr. R. H. Verschure (Z.W.O. Laboratory for Isotope Geology) who took part in a joint palaeomagnetic–geochronological expedition. This study was supported by the Netherlands Organization for the Advancement of Pure Research (Z.W.O.).

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