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Natural magnetization of deep core samples of basaltic rocks from Brazil

By A. Schult, München[1])

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Summary: Natural remanent magnetization, inclination and susceptibility of 159 basaltic cores (876 samples) from 65 drillings (max. depth 4 km) in Brazil have been measured. The drillings cover the extended area of extrusive and intrusive basaltic rocks of the Paraná and Maranhão Basin and the intrusive basaltic rocks of the Amazon Basin.—No significant variation of intensity of magnetization and of susceptibility with depth was found but in some cases a dependence of the inclination on depth could be established indicating different ages for the basaltic rocks. This is not confirmed in all cases by radiometric age datings.—The geomagnetic paleolatitude of Brasilia (present value 16° S) was estimated to have been 50° S in the Permian, 70° S in the Carboniferous and then decreasing toward lower Paleozoic times.

Zusammenfassung: Die natürliche remanente Magnetisierung, die Inklination und die Suszeptibilität von 159 Basaltbohrkernen (876 Proben) von 65 Tiefbohrungen (bis zu 4 km Tiefe) in Brasilien wurden gemessen. Die Bohrungen durchteufen die ausgedehnten mesozoischen basaltischen Deckenergüsse und Intrusionen des Paraná- und Maranhão-Beckens und die Intrusionen des Amazonas-Beckens. Es konnten keine signifikanten Variationen der Intensität der Magnetisierung und der Suszeptibilität mit der Teufe gefunden werden. Dagegen ergab sich für die Inklination eine gewisse Abhängigkeit von der Teufe, was durch unterschiedliches Alter der Basalte gedeutet werden kann. Dies wird durch absolute Altersbestimmungen nicht in allen Fällen bestätigt. Die geomagnetische Paläo-Breite wurde abgeschätzt. Während sie heute (für Brasilia) 16° S beträgt, betrug sie im Perm 50° S, im Karbon 70° S. Im unteren Paläozoikum war die geomagnetische Breite wieder kleiner.

Introduction

The magnetization of deep core samples of basaltic rocks from Brazil was measured. The samples originate from wells drilled by Petrobrás (Petroleo Brasiliero S.A.) in the Amazon, Maranhão, and Paraná Basin (Fig. 1). Data from 876 samples of 159 cores taken from 65 wells are presented.—Previous palaeomagnetic measurements on surface samples of basaltic rocks from Paraná Basin were done by Creer [1962].

Geology

The geology and petrology of the basaltic rocks of Paraná Basin were studied by Leinz [1949], Bischoff [1957], Sanford et al. [1960], Leinz et al. [1966], and Cordani et al. [1967]. A brief description of volcanism in the Maranhão Basin was published

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by MESNER et al. [1964]. The geology of the basaltic intrusions of the Amazon Basin was described by VOLLBRECHT [1964].

During the Mesozoic the three principal Palaeozoic basins of Brasil, the Amazon, the Maranhão, and the Paraná Basin (Fig. 1) were subjected to one of the largest and most widespread series of intrusions and extrusions of igneous basaltic rocks in geologic history.

In the Paraná Basin (Fig. 2) the main part of the basaltic material forms a large number of induvidual lava flows covering an area of more than 1.200.000 km^2 (The so called Serra Geral Formation). The total thickness of the flows locally exceeds 1000 meters, up to 1500 meters have been noted [SANFORD et al. 1960]. The total volume of the extruded basaltic rocks is in the order of 650.000 km^3 [LEINZ et al. 1966] which constitutes the greatest known mass of volcanic rocks on the continents.

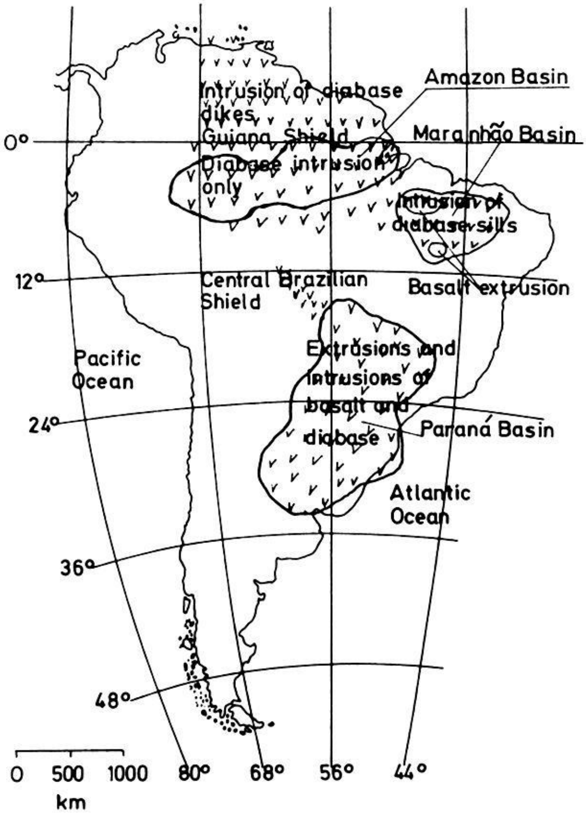

Fig. 1: Map showing Brazilian principal Palaeozoic basins and the possible extent of Mesozoic intrusions ("diabase") and extrusions ("basalts") of igneous basaltic rocks according to MESNER et al. [1964].

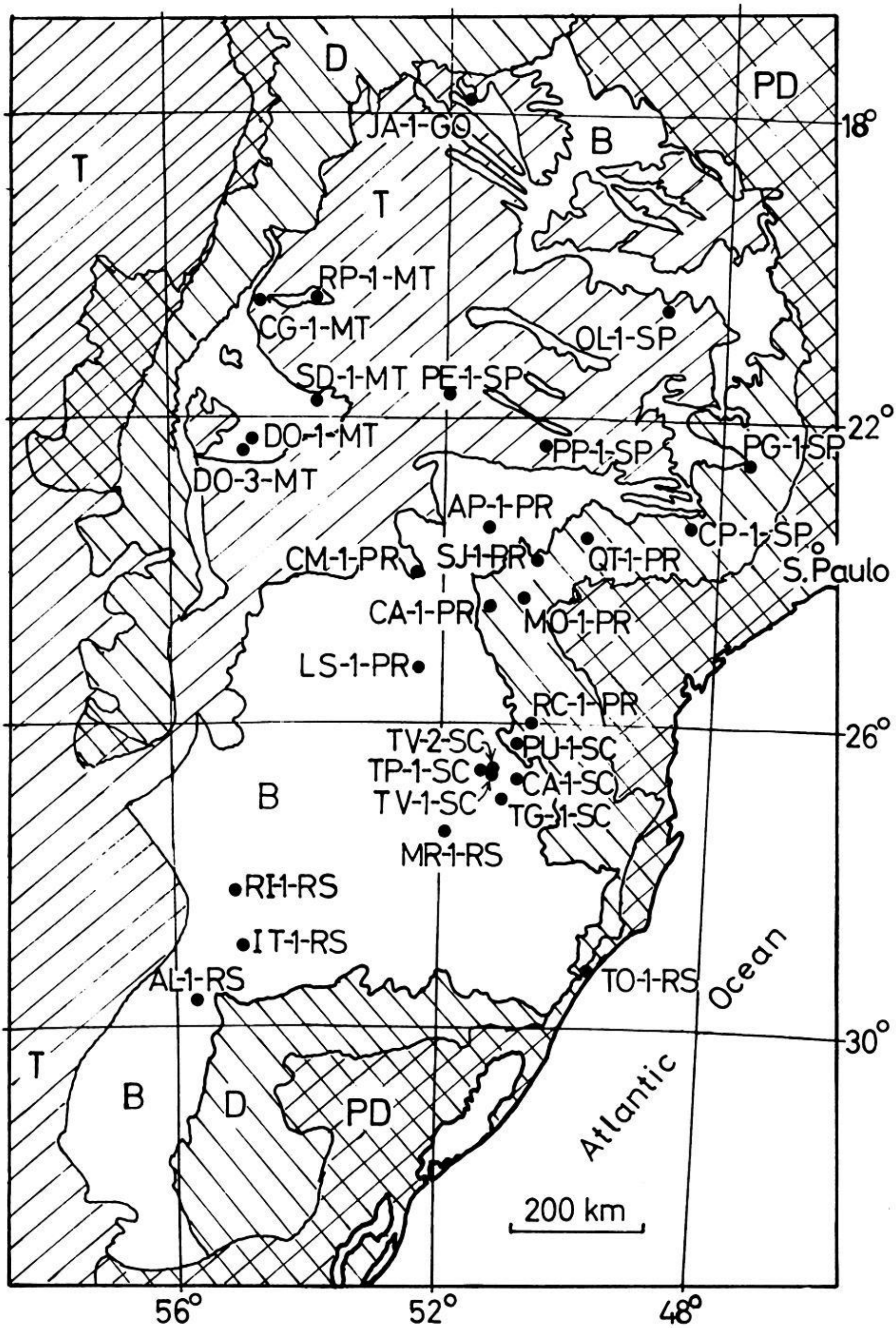

Fig. 2: Geological environment of the Paraná Basin and location of wells from which basaltic core samples were measured.

PD = Pre-Devonian basement rocks,
D = Pre-volcanic sedimentary rocks,
B = Basalt flows (Serra Geral Formation),
T = Post-volcanic sedimentary rocks.

The individual thicknesses of the flows vary from a few to more than 100 meters and more than 35 flows have been recognized in drill hole profiles [LEINZ et al. 1966].— Many Dikes are associated with the lava flows particularly in the area surrounding the lava flows. This thickness varies from a few centimeters up to 100 meters and their length sometimes exceeds 100 kilometers [CORDANI et al. 1967].— A large number of sills intruded the sediments adjacent to and below the lava flows. Their thickness varies between a few meters and more than 200 meters. The average total thickness of the intrusions (down to Precambrian basement rocks) is about 350 meters exceeding 600 meters in some places [BIGARELLA et al. 1967]. The dikes and sills outcrop at many places in the area surrounding the lava flows.

The basaltic rocks of Paraná Basin are tholeiitic according to CORDANI et al. [1967]. There is no difference in chemical composition and in mineralogy between intrusive and extrusive rocks. Due to the different conditions of cristallization the extrusive rocks are almost microcrystalline whereas the intrusive rocks have coarser grains up to 1 mm.—In Brazil extrusive basaltic rocks (flows) are usually named "basalt" and intrusive rocks (dikes and sills) are named "diabase". We intend to follow this practice in this paper—. The iron oxide minerals of the basaltic rocks from Paraná Basin are titanomagnetite, magnetite, ilmenite and hemo-ilmenite [CORDANI et al. 1967]. For the surface "diabase" and "basalt" samples CREER [1962] measured on single Curie-point near 580 °C which is that of magnetite.

The "basalts" (extrusive rocks) in the Maranhão Basin (Fig. 3) cover an area of about 100.000 km^2 with a maximum total thickness of about 150 m [MESNER et al. 1964]. Large parts of the "basalts" are covered with post-volcanic sediments. The total thickness of the "diabase" intrusions in the Palaeozoic sediments is about 400 m with an extension of about 300.000 km^2 [MESNER et al. 1964]. "Basalts" and "diabases" are of equal basic composition [MESNER et al. 1964].

The "diabase" intrusions of the Amazon Basin (Fig. 4, outcrops of "diabases" are not known) cover a large area (possible limits of intrusions are indicated in Fig. 1). The mean total thickness of intrusions in the pre-volcanic sediments is about 260 meters exceeding in some places 600 meters. The thicknesses of the individual intrusions vary from a few meters to several hundred meters. In the Amazon Basin probably no extrusive volcanic activity took place [VOLLBRECHT 1964].

Radiometric ages of a few dozen samples of "diabases" and "basalts" (surface and core samples) from the Paraná Basin have been determined by several authors [CREER et al. 1965; AMARAL et al. 1966; MCDOUGALL et al. 1966; VANDOROS et al. 1966; MELFI 1967]. Ages between 119 and 147 m. a. have been found. The great majority of determinations is between 120 and 130 m. a. (Lower Cretaceous). Some lateral variations in age do not seem to be very significant. No variation of age could be detected in samples from various depths [MELFI 1967].

Three surface samples ("diabase") from Maranhão Basin (collected near 10 °S 47 °W and 7 °S 43 °W) have been investigated giving an average age of 127 m. a. (Lowe Cretaceous) [CORDANI 1969].

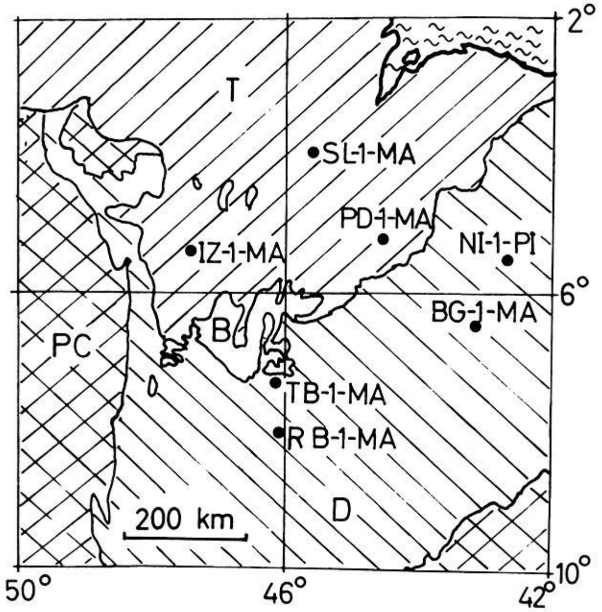

Fig. 3: Geological environment of Maranhão Basin and location of wells.

PC = Pre-Cambrian basement rocks,
D = Pre-volcanic sedimentary rocks,
B = Basalt flows,
T = Post-volcanic sedimentary rocks.

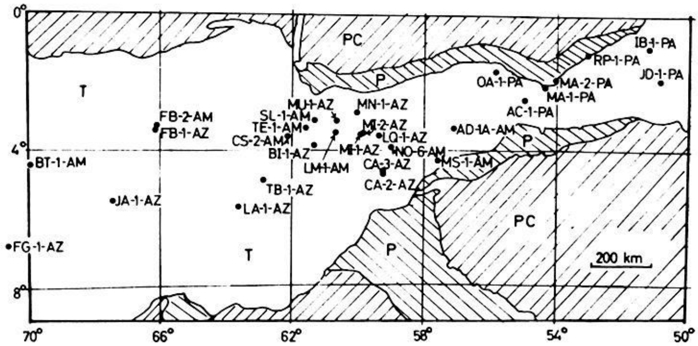

Fig. 4: Geology of Amazon Basin and locations of wells.

PC = Pre-Cambrian basement rocks,
P = Permian and Pre-Permian sedimentary rocks,
T = Tertiary and younger sedimentary rocks.

The age of 4 "diabase" core samples from the Amazon Basin has been measured by CORDANI [1967]. Locality (see table 3 or Fig. 4) depth and age are as follows:

LA—1—AZ	614 m depth	170 and 182 m. a.
IB—1—PA	584 m depth	171 m. a.
AM—7—AM (near 3 °S 60 °W)	580 m depth	202 m. a.
FG—1—AZ	1740 m depth	293 m. a.

The last sample indicates a Late Carboniferous or Early Permian age. The three samples from about 600 m depth have an average age of 181 m. a. (Upper Triassic or Lower Jurassic).

Measurements and classification

Measurements were done with a fluxgate magnetometer (Förstersonde) on the cylindrical core samples (diameter 4 to 9 cm, length from a few centimeters to about 25 cm). Natural remanent magnetization and susceptibility were determined (The susceptibility in a field of about 0,3 Oe). As the samples were only orientated with respect to their vertical axis only the inclination of magnetization could be determined. The results of the measurements are listed in table 1, 2 and 3 for core samples from the Paraná, Maranhão and Amazon Basin, respectively.

Table 1: Magnetization of core samples from Paraná Basin

1	2	3	4	5	6	7	8
Location	Core No.	Depth (*m*)	N	i°	J_r (γ)	$k \cdot 10^4$	Q
AL-1-RS 29°49′S 55°46′W 84 m	22D	1906,8	1	−58	150	22	2,9
AP-1-PR	1B	235,5	4	+11,8	200	35	2,4
23°29′S 51°13′W	2B	652,5	4	−42	270	22	5,3
823 m	3B	1132,5	7	+14,9	160	29	2,4
	7D	1633,7	4	−47,7	160	52	1,2
	10D	2285,2	10	−76,1	140	54	1,1
CA-1-PR	23D	1960	4	−65,7	230	46	2,1
24°32′S 51°23′W 482 m	32D	2782,5	1	−41	320	60	1,1

Column 1 = denotation of the well, its location and altitude; column 2 = number of the core (a letter "B" indicates that the core is composed of "basalt", a "D" of diabase); column 3 =depth of the top of the core; Column 4 = number of samples from the core measured; column 5 = averaged inclination i of remanent magnetization (a negative sign denotes normal magnetization, a plus sign reversed magnetization, no sign indicates an uncertain orientation of the core); column 6 = intensity of natural remanent magnetization J_r in γ ($1\gamma = 10^{-5}$ Gauss); column 7 = susceptibility k; column 8 = Q-ratio (remanent magnetization divided by induced magnetization for an inducing field of 0.25 Oe).

1	2	3	4	5	6	7	8
CA-1-SC	1B	104,8	4	−40,1	1550	8	>20
26°52′S 50°50′W			7	−43,5	180	8	30
1103 m	2B	213,5	12	−39,3	510	4,8	>20
	3B	256,6	8	−46,2	150	25	2,7
	6B	457	2	−74	70	8	1,5
CG-1-MT	1B	107,0	5	+26,2	100	20	2,3
20°27′S 54°37′W	2B	145,0	6	+30,5	200	26	3,3
510 m							
CM-1-PR	1B	211	3	−51,1	270	63	1,4
27°07′S 30°52′W	2B	571	13	−46,8	170	21	3,5
637 m							
CP-1-SP	47D	1290,8	2	−46,2	430	32	5,4
23°24′S 48°28′W	48/49D	1304,8	2	−51,3	950	56	6,4
685 m							
DO-1-MT	1B	132	3	−44,5	40	9	1,8
22°20′S 54°53′W	2B	222,2	10	−36,0	180	20	4,1
384 m	3B	297,1	13	+21,6	420	12	22
DO-3-MT	1B	337,5	3	+16	110	1,7	15
22°20′S 54°53′W	5D	938	4	+41,1	330	47	3
380 m	22D	2224,7	1	−45	310	39	3,2
IT-1-RS	surface B	0	3	+43,4	40	13	2,4
29°01′S 54°59′W	3B	134,6	7	−30,8	70	22	1,3
360 m	4B	148	1	?	50	35	0,5
	7B	345	7	+44	40	26	0,6
	8B	358	19	+40,5	80	8,4	4,6
JA-1-GO	1B	68	6	−54,4	630	66	5,2
17°49′S 51°47′W	32D	1799,2	2	−14,6	900	36	9,5
595 m							
LS-1-PR	1B	109,8	4	−53,9	380	39	3,8
25°24′S 52°25′W	2B	372	21	+34,2	290	30	4
842 m	3B	704	10	−54,4	230	27	3,5
	16D	2358,8	7	−76,2	50	11	2,1
MR-1-RS	1B	116	1	51	500	29	7
27°32′S 51°56′W	2B	211,5	6	6,5	20	4,2	2
372 m			12	+22,6	33	5,3	3,4
			2	68,5	26	10	0,9
	3B	341,5	15	−41,7	17	1,9	4,2
	13D	1444,2	3	−71,7	890	40	10
MO-1-PR	21D	1913,8	1	−42	400	26	6
24°22′S 50°52′W							
834 m							
OL-1-SP	1B	75	8	−41,2	130	12	5
20°41′S 48°56′W							
499 m							

1	2	3	4	5	6	7	8
PE-1-SP	1B	104	5	27,1	610	27	10
21°45′S 52°06′W	2B	925	14	−46,7	850	29	16
262 m	3B	945	11	−19,2	810	24	17
	4B	1135	4	−59,5	110	25	1,8
	5B	1237,2	4	+35,4	480	50	4,2
	6B	1318,9	3	+47,1	270	14	7,7
	7B	1409	3	+16,9	220	13	6,8
	8B	1475	3	+29,6	80	2,7	18
	9B	1595	3	+16,2	100	12	3,4
	21D	2443,5	2	−48	220	30	3,1
	23D	2554,2	2	−70	260	47	2,3
			2	−61	55	1,1	>20
	29D	3010,7	7	−65,5	40	0,8	>20
PG-1-SP	5D	490,3	3	−40	1750	36	22
22°33′S 47°39′W	6D	587,3	10	−51,3	940	51	7,9
637 m							
PP-1-SP	1B	133	4	+52,4	65	57	0,4
22°25′S 50°35′W	2B	295,9	4	−43,7	420	80	1,9
474 m	3B	510,3	3	−76,4	330	44	3,5
	4B	820	20	+27,5	500	20	10
PU-1-SC	25D	1991,3	2	−55	290	35	3,2
26°16′S 51°03′W							
754 m						33	
QT-1-PR	9D	1384,6	2	−51	700	31	8,9
23°37′S 49°57′W							
530 m							
RC-1-PR	18D	1737	4	15,2	180	24	3,2
26°01′S 50°42′W							
810 m							
RI-1-RS	1B	32	3	59,5	120	26	2
28°18′S 55°03′W	2B	168	3	−40	100	10	4
155 m	11D	1490	3	−42,6	80	9	4,4
RP-1-MT	1B	178	2	−24,3	240	11	8,9
20°25′S 53°57′W	21D	3035,8	5	−39,7	400	57	2,7
417 m	23D	3254	4	−48,5	170	45	1,6
SD-1-MT	1B	134,2	31	+25,8	350	26	5,5
21°53′S 53°52′W	2B	168,1	33	+20,5	170	7	13
281 m	6D	1451,6	4	−68,4	170	58	1,2
SJ-1-PR	1D	115,8	11	−42,4	270	38	4,1
23°17′S 50°39′W	9D	826,6	2	−43	20	24	0,4
1047 m							
TG-1-SC	1B	120	19	−57,4	600	25	11
27°05′S 51°15′W	2B	252,1	12	−42,3	230	23	4,2
644 m	19D	1459	1	−72	170	26	2,7

1	2	3	4	5	6	7	8
TO-1-RS 29°20'S 49°48'W 28 m	1B	141,3	2	−64	440	33	5,9
	10D	683,2	6	−62,8	54	5	5,8
TP-1-SC 26°42'S 51°26'W 1292 m	1B	99,5	9	−50,5	570	45	5,4
	2B	125,0	4	−47,8	220	64	1,4
		125,8	2	−31	800	58	5,6
	3B	150	1	−65	110	63	0,7
	4B	164	1	−32	100	29	1,3
	5B	175	3	−44,8	200	1	20
	6B	668	14	−33	340	12	20
	7B	707,1	2	+51	250	~0	>20
TV-1-SC 26°44'S 51°19'W 1075 m	1B	280	2	−42	400	36	4,6
TV-2-SC 26°44'S 51°19'W 1073 m	78D	2963,5	5	−43,9	120	15	3,1

Table 2: Magnetization of core samples from Maranhão Basin

1 Location	2 Core No.	3 Depth (*m*)	4 N	5 i°	6 $J_r\,(\gamma)$	7 $k \cdot 10^4$	8 Q
BG-1-MA 6°26' S 43°09' W 263 m	25D	1160	1	−42	50	9	2
IZ-1-MA 5°31' S 47°30' W 119 m	1B	87,2	3	−30,9	80	17	1,9
	5B	140,4	8	−31,8	150	16	3,1
TB-1-MA 7°23' S 46°07' W 303 m	20D	1002,5	7	+ 7	10	2	1,7
	21D	1041	2	+ 8	130	25	1,7
NI-1-PI 5°36' S 42°35' W 164 m	9D	2140,6	1	− 9	670	57	4
	13D	2223,2	2	+ 7	230	40	2
PD-1-MA 5°20' S 44°33' W 143 m	27D	2054,9	3	13	390	40	3,6
	31D	2302	2	0	340	47	2,4
RB-1-MA 8°03' S 46°05' W 578 m	56D	1816,3	2	7	130	67	0,7
SL-1-MA 4°00'S 45°39'W 51 m	52D	1754	2	+49,1	170	20	2,7

Legend see table 1; *Q*-ratio for an inducing field of 0.3 Oe.

Table 3: Magnetization of core samples from Amazon Basin

1 Location	2 Core No.	3 Depth (m)	4 N	5 $i°$	6 J_r (γ)	7 $k \cdot 10^4$	8 Q
AC-1-PA 2°30′ S 55° W 20 m	220D	1091,8	1	4,2	150	36	1,6
	223D	1116	1				
	224D	1117	1				
	225D	1118	1				
	226D	1142	1				
	339D	2256	4	−14,7	500	60	3
	340D	2257	2				
	396D	2949	5	51,8	290	72	1,3
AD-1A-AM 3°18′ S 57°05′ W 55 m	7D	798,6	8	+24,2	90	35	0,9
	8D	846,3	7	− 8	170	36	1,6
	16D	1255,7	1	+39	360	137	0,9
BI-1-AZ 3°54′ S 61°23′ W 40 m	1D	582,2	8	−54,4	130	44	1
BT-1-AM 4°24′ S 69°57′ W 80 m	6D	728,3	8	−32,6	50	22	0,7
	7D	794,0	5	−28,2	40	30	0,5
	10D	837,1	10	−28,8	40	23	0,6
CA-2-AZ 4°49′ S 59°15′ W 0 m	1D	252,3	3	+25,0	100	34	0,9
	2D	334	8				
CA-3-AZ 4°43′ S 59°13′ W 7 m	6D	663	6	+21,3	250	65	1,3
	8D	773	5	12,4	240	40	1,9
CS-2-AM 3°49′ S 62°07′ W 37 m	2D	450,3	5	−23,8	45	18	0,8
	3D	519,8	10	−35,3	70	19	1,4
FB-1-AZ 3°31′ S 66°05′ W 73 m	18D	1123,5	3	51,5	40	21	0,7
	30D	1775,6	1	28,7	260	45	1,9
	32D	1804,5	6	+76,9	380	56	2,5
	33D	1825,7	6	+73,8	410	39	3,7
FB-2-AM 3°17′ S 66°02′ W 57 m	14D	1287,7	3	14,3	54	89	0,2
FG-1-AZ 6°48′ S 70° 38′ W 148 m	9D	1740,1	7	+48,8	90	7	4,2
	10D	1768,1	9	+41,7	400	6	10
	11D	1840,1	5	+82,1	110	19	1,8
	13D	1980,6	5	+72,3	90	23	2,2
IB-1-PA 0°57′ S 51°13′ W 4 m	2D	538,9	4	40	90	22	1,3

Legend see table 1; Q-ratio for an inducing field of 0.3 Oe.

1	2	3	4	5	6	7	8
JA-1-AZ	1D	635,9	10	41,5	170	34	1,7
5°30′ S 67°28′ W	2D	763,5	10	+50	120	22	1,8
3 m	15D	1381,9	5	+71,3	100	20	1,6
JD-1-PA	24D	1290,6	4	68,4	230	4	> 20
1°57′ S 50°25′ W							
5 m							
LA-1-AZ	13D	613,5	2	+29	60	24	0,8
5°42′ S 63°42′ W							
58 m							
LM-1-AM	1D	457,6	4	8	120	110	0,3
3°31′ S 60°35′ W	23D	1247,5	1	58,3	140	23	2
26 m							
LQ-1-AZ	5D	1665,1	2	70	120	13	3,7
3°38′ S 59°22′ W							
21 m							
MA-1-PA	31D	2528,2	5	+46,5	130	40	1
2°07′ S 54°20′ W	38D	2840	3	− 8	200	42	1,6
20 m	40D	2883	5				
MA-2-PA	11D	1750,2	2	+39	110	23	1,5
1°53′ S 54°01′ W							
19 m							
MI-1-AZ	1D	350,7	2	65	150	24	2,2
3°38′ S 59°52′ W	2D	661,3	5	−63,1	800	140	2
27 m							
MN-1-AZ	1D	337	8	8	150	54	1
2°53′ S 60°01′ W	2D	340.5					
90 m							
MS-1-AM	1D	236,8	5	−19,3	23	10	0,8
4°19′ S 57°36′ W	2D	426,9	2	−33	64	33	0,7
23 m							
MU-1-AZ	1D	276,1	5	− 9,3	140	33	1,4
3°17′ S 60°35′ W							
30 m							
NO-6-AZ	7D	855,1	5	+10,8	210	31	2,2
3°54′ S 59°06 ′W							
39 m							
OA-1-PA	2D	382,6	6	+53,5	120	21	1,8
1°44′ S 55°54′ W							
31 m							
RP-1-PA	6D	1239,7	1	9	10	4	1
1°07′ S 53°03′ W							
9 m							

1	2	3	4	5	6	7	8
SL-1-AM	7D	444,5	6	+19,1	55	20	0,9
3°05′ S 61°26′ W	29D	1827,0	9	+32	160	31	1,9
29 m	30D	1870,8					
TB-1-AZ	2D	643	2	− 8	220	70	1
4°55′ S 62°50′ W							
50 m							
TE-1-AM	1D	493,5	9	−18,5	60	18	1
3°21′ S 61°41′ W	4D	857	8	−55,6	100	33	1
50 m	5D	996	1	70	100	50	0,7

The measurements listed in table 1 for the Paraná Basin are plotted in Fig. 5 for "basalt" cores and in Fig. 6 for "diabase" cores. The measurements listed in table 3 (Amazon Basin) are plotted in Fig. 7.

The results for the Paraná Basin (table 1) have been classified into 3 categories, viz. normal "basalts" reversed "basalts", and all "diabases" (only one "diabase" core was reversely magnetized, orientation of one core was uncertain). Averaged values are listed in table 4. For comparison the results form surface samples from Paraná Basin according to CREER [1962] are listed in table 5.

Averaged values for the Maranhão Basin (table 2) and for the Amazon Basin (table 3) are given in tables 6 and 7, respectively. In table 7 results have been classified in groups of core samples from depths above 1000 meters and below 1000 meters (In the latter group samples with $i < 20°$ have been omitted). This classification was used because the inclination is significantly higher for most core samples from below 1000 m depth than for those from above 1000 m depth (see Fig. 7). See also next chapter.

Because of the experimental conditions it was not possible to "clean" the samples by treatment in an alternating magnetic field. (All measurements were done by the author in Petrobrás laboratories where the cores have been stored. A demagnetization apparatus was not available.) Therefore it may be possible that some of the rocks have acquired a viscous magnetization which masks the direction of the original thermoremanent magnetization. It is known however that regarding the mean value of direction of magnetization of many samples the influence of the viscous magnetization on the direction of the original thermoremanent magnetization is averaged out [SCHULT 1963]. Similar results were obtained by CREER [1962] for surface samples from the Paraná Basin who obtained changes in inclination of less than 2,5° by "cleaning".

Discussion and conclusion

No significant variation of the intensity of magnetization J_r, Q-ratio or susceptibility k with depth could be detected (see Fig. 4—6). However some dependence of inclination of magnetization from depth may be there and also some descrepance

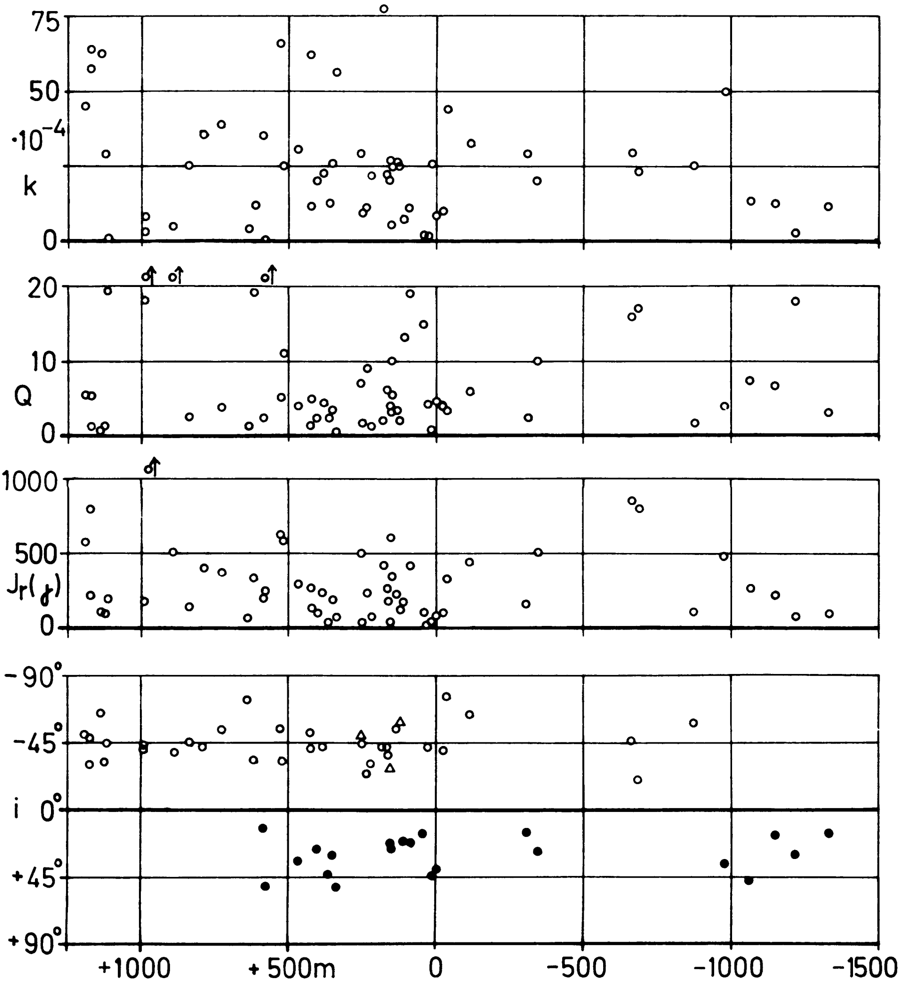

Fig. 5: Inclination *i* and intensity J_r of natural remanent magnetization, susceptibility *k* and *Q*-ratio for "basalt" core samples from Paraná Basin (as listed in table 1) versus altitude from sea level.

△ denotes uncertain orientation of core.

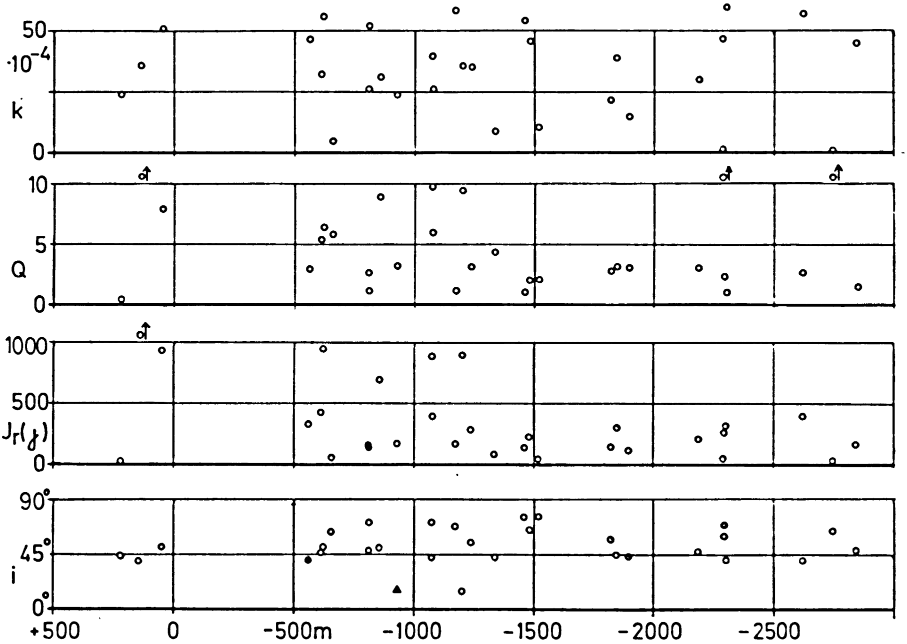

Fig. 6: As Fig. 5 for "diabase" core samples from Paraná Basin. The meaning of symbols for the inclinations is:

○ = normally magnetized cores,

● = reversely magnetized cores,

△ = orientation of the core is uncertain.

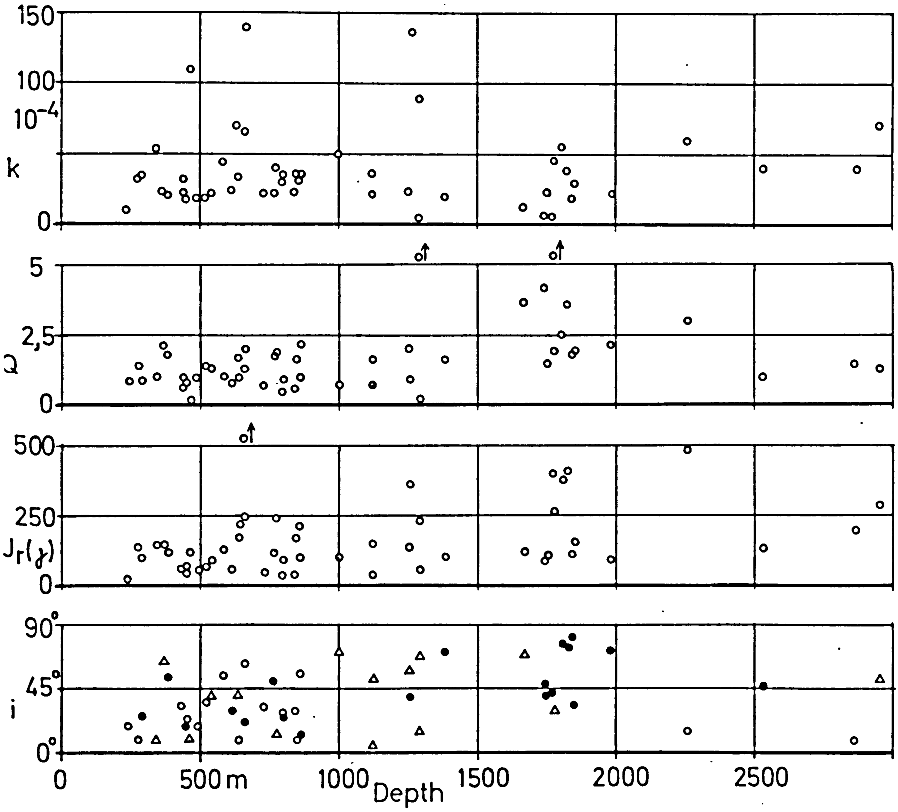

Fig. 7: Inclination *i* and intensity J_r of magnetization, susceptibility *k* and *Q*-ratio for "diabase" core samples from Amazon Basin (as listed in table 3) versus depth from the surface. The meaning of symbols for the inclinations is:

○ = normally magnetized cores,

● = reversely magnetized cores,

△ = orientation of the core is uncertain.

Table 4: Average values for core samples from Paraná Basin

	N	i	m_i	J_r	$k \cdot 10^4$	Q
Normal "basalts" (3 uncertain)	37	$-45{,}8°$	2,4°			
Reversed "basalts"	21	$+29{,}5°$	2,7°			
All "basalts"	58	39,9°	2,1°	290 γ	26	8,9
All "diabases"	31	51,5°	2,8°	370 γ	33	5,8
29 normal						
1 reversed						
1 uncertain						

m_i is the angle in degrees equivalent to the standard error of a Gaussian distribution.

Table 5: Average values for surface samples from Paraná Basin according to Creer (1962)

	N	i	m_i	D	J_r	$k \cdot 10^4$
Normal "basalts"	14	$-41{,}8°$	3,1°	342°		
Reversed "basalts"	20	$+36{,}6°$	4,2°	170°		
All "basalts"	34	38,8°	2,7°	351°	960 γ	20
Normal "diabases"	23	$-33{,}8°$	5,2°	342°		
Reversed "diabases"	17	$+37{,}1°$	6,0°	167°		
all "diabases"	40	36,9°	4,6°	343°	2100 γ	70
all "basalts" and "diabases"	74	37,9°	2,8°	347°		

D = Declination

Table 6: Average values for core samples from Maranhão Basin

	N	i	m_i	J_r	$k \cdot 10^4$	Q
All "basalts" and "diabases"	11	18,6°	5°	210 γ	30	1,8

Table 7: Average values for core samples from Amazon Basin

	N	i	m_i	J_r	$k \cdot 10^4$	Q
All "diabases" above 1000 m depth	28	29,4°	3,4°	140 γ	42	1.2
All "diabases" below 1000 m depth and $i > 20°$	18	56,8°	3,9°	180 γ	37	2,3

between surface samples and core samples from the Paraná Basin. The following points are noted:

1) All core "basalt" samples from the Paraná Basin taken from above + 600 m altitude (from sea level) are normally magnetized. Normally and reversely magnetized cores came from altitudes between + 600 and 0 m. Below sea level alternately normally and reversely magnetized cores were found (Fig. 5). This alternating polarity of magnetization is only found in plots versus altitude but not in plots versus depth.

2) Averaged inclination for "basalt" core samples and surface samples seems to be the same (table 4 and 5).

3) Most "diabase" core samples from the Paraná Basin are normally magnetized (29 normal, 1 reversed, 1 uncertain) whereas mor than one third of the surface samples are reversely magnetized (23 normal, 17 reversed) (see Fig. 6, table 4 and 5). The differences between the averaged inclination of "diabase" core samples and "diabase" samples taken from surface outcrops (51,5° and 36,9° respectively) are considered to be significant as well as the difference of the averaged inclination of "diabase" and "basalt" core samples (51,5° and 39,9°).—The differences in the directions of magnetization noted may be explained by differences in age but this does not agree with radiometric age datings [CORDANI et al. 1967].

4) Intensity of magnetization and susceptibility (only for "diabases") is much higher for surface samples than for deep core samples from Paraná Basin (table 4 and 5). This may be due to weathering.

5) Core samples from Amazon Basin, classified into groups from below and above 1000 m depth, have significant different inclinations of magnetization (see table 7 and Fig. 7). Samples from below 1000 m have, significant higher inclination (except a few samples with very low inclination) than samples from above 1000 m. This can be explained by large differences in age of these sample groups which was found by radiometric age measurements (see chapter Geology). Therefore a Late Carboniferous or Early Permian age is assumed for the majority of the samples from below 1000 m depth (except those samples with an inclination less than 20° or so) and Upper Triassic or Lower Jurassic age for the majority of the samples from above 1000 m depth. This means that the volcanic activity in the Amazon Basin took place in two periods of time. The "diabase" intruded first into a lower level of the sedimentary rocks and then after a period of inactivity mostly into a higher level.—Another indication for the Late Carboniferous or Early Permian age of the deeper samples is the lack of normally magnetized samples in this groups. The mean direction of remanent magnetization of rocks formed in the time range of uppermost Carboniferous to uppermost Permian are characterized by reversed polarity all over the world [IRVING 1964].—The samples from below 1000 m depth with low inclination of magnetization may have the same age as samples from above 1000 m depth.

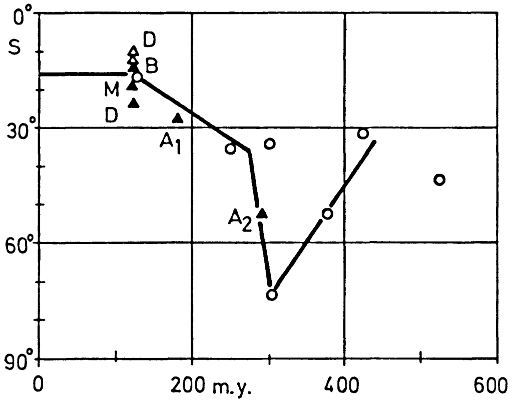

Fig. 8: Change of geomagnetic palaeolatitude of Brasilia (16° S 48° W).

△D, B = "diabase" or "basalt" surface samples from Paraná Basin according to CREER [1962].

○ = sedimentary rocks from South America [CREER 1965].

▲D, B = "diabase" or "basalt" core samples from Paraná Basin, present work.

▲M = basaltic core samples from Maranhão Basin, present work.

▲A_1 = "diabase" core samples from Amazon Basin from above 1000 m depth, present work.

▲A_2 = "diabase" core samples from Amazon Basin from below 1000 m depth, present work.

Assuming a dipol field for the earth's magnetic field the magnetic palaeolatitude can be calculated from the inclination of magnetization. The palaeolatitude was calculated for Brasilia (16° S 48° W) under the assumption that the declination of the direction of magnetization was not far from 0° (or 180°) in former times. This condition is sufficiently satisfied for South America up to Permian age [CREER 1965]. The change of magnetic palaeolatitude for Brasilia with geological time is illustrated in Fig. 8. Results of the present work are plotted together with those of CREER [1965]. Going back in time the magnetic palaeolatitude of Brasilia increased from its present value of about 16° S to about 50° S in the Permian, 70° S in the Carboniferous and then decreased again during Lower Palaeozoic.

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