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Paleomagnetism of selected Quaternary, Cainozoic, Jurassic, and Proterozoic to Lower Paleozoic volcanic rocks from Nigeria

Paleomagnetizmus vybraných kvartérnych, kenozoických, jurských a proterozoických až spodnopaleozoických vulkanických hornín z Nigérie

Oto Orlický[1]

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Magnetic minerals
Oxidized titanomagnetites
A. C. demagnetization tests
Computed pole positions

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Abstract: Paleomagnetic results have been obtained from seventeen localities (30 sites) in volcanic (mostly basaltic) rocks of Quaternary, Younger Cainozoic, Jurassic, and Proterozoic to Lower Paleozoic age from the Jos plateau, Biu plateau, Samunaki locality, and Runka locality, northern and north-eastern Nigeria. A complex of physico-analytical methods and laboratory procedures was used to obtain information on the carriers of the magnetism, paleomagnetic stability, and the distribution of the direction of the RMP in the mentioned geological complexes.

Oxidized (cation-deficient) titanomagnetites are the most frequent magnetic minerals in the studied rocks, but ilmeno-hematite solid solutions, ferroilmenite, and magnetite-hematite solid solutions also were revealed in some petrographical types of rocks. The *RMP* of studied rocks is a secondary one, probably of chemical (C.R.M.) origin. Most of the diabases, olivine basalts, and nepheline basanites under study (samples of rocks from 19 sites) are unstable with respect to the A.C. demagnetization tests. Quaternary (or Younger Cainozoic) olivine basanites from the Jos plateau (JP-2) give a stable direction of *RMP*. The paleomagnetic data are as follows: $I = 21.4°$, $D = 17.3°$; $\varphi_p = 72.9$ °N; $\lambda_p = 92.2$ °E. Three acceptable sites from the Biu plateau represented by a Quaternary (or Younger Cainozoic) olivine basalts (BP-2, BP-3), and albitized olivine basalts (BP-4) give a mean direction of the *RMP*, $I = -3.9°$; $D = 186.5°$, and virtual poles $\varphi_p = 79.2$ °N; $l_p = 154.9$ °E. Computed pole positions of the Jurassic alkali granite porphyry from the Jos plateau (JP-9), ($\varphi_p = 70.7$ °N; $\lambda_p = 259.0$ °E) are very close to those published by McElhiny et al. (1968 *in* Piper–Richardson 1972) for Mesozoic rocks from Africa.

No detectable movement of the African plate was revealed by the results of Quaternary or Younger Cainozoic age. But the shift of the African plate has been detected on the base of the direction of the *RMP* and computed pole positions of Jurassic alkali granite porphyry from the Jos plateau.

[1] *Geofyzika, s. p., Brno, závod Bratislava, Geologická 18, 825 52 Bratislava*

Introduction

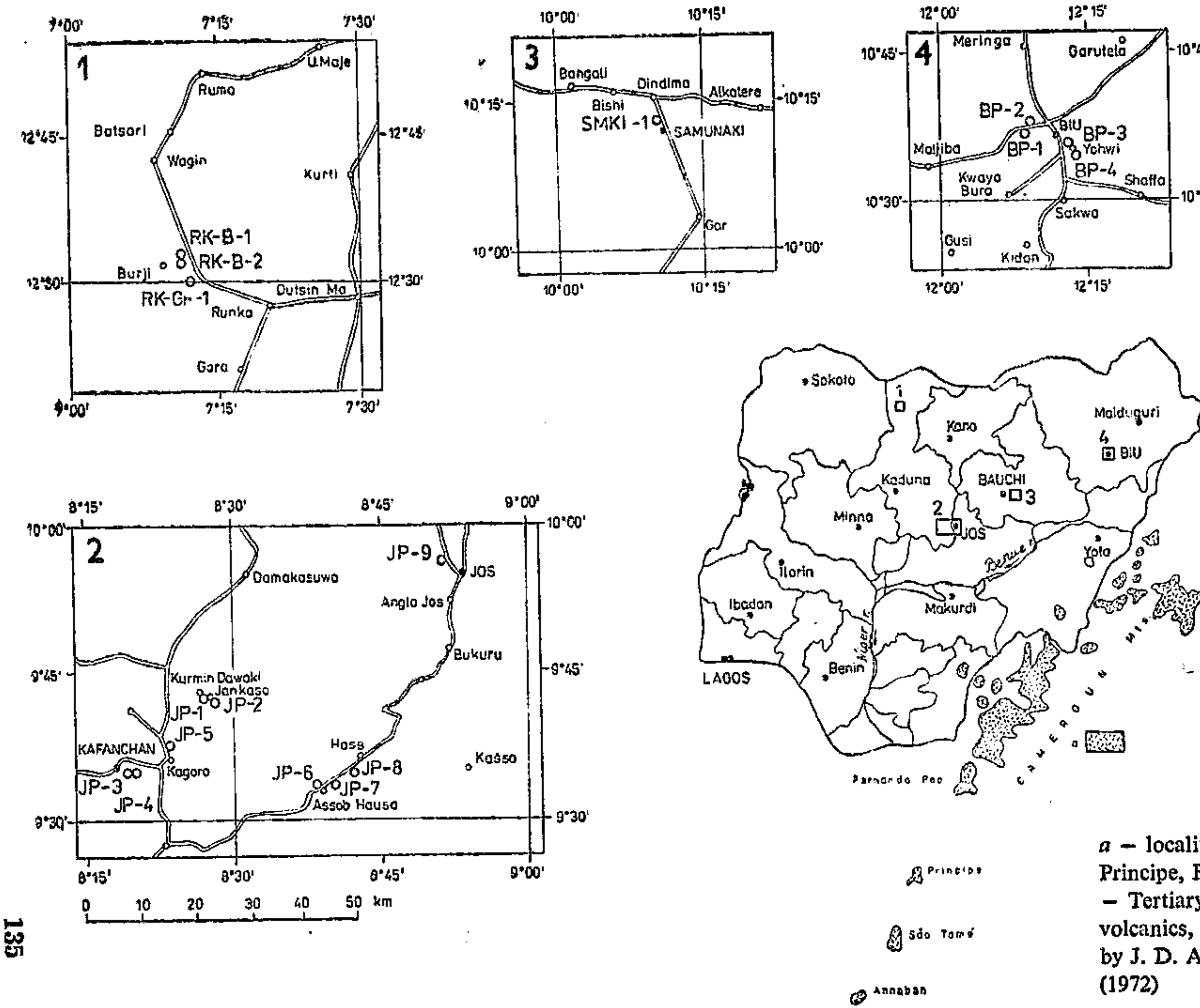
Piper and Richardson (1972) realized the paleomagnetic investigations of the Gulf of Guinea volcanic provinces (West Africa, fig. 1). They employed the computed pole positions of individual volcanic structures (age: 18.4 to 0.5 m.y.) of the Gulf of Guinea and from the western part along the volcanic line in Cameroun for the detection of the movement of the African plate. The above-mentioned authors presented in their work also poles computed for the Upper Tertiary and younger lavas of the East African Rift (Piper—Richardson 1972). The authors have demonstrated no detectable movement of the African plate relative to the geographic pole for about 25 m.y., according to the analysis of the Upper Tertiary paleomagnetic results.

This paper presents the results of paleomagnetic study of volcanic rocks from the following areas of northern and north-eastern Nigeria (fig. 1): basaltic rocks from the Jos plateau, Biu plateau (Quaternary and Cainozoic age), Runka locality (mid-Jurassic age), Samunaki locality (unknown age), alkali granite porphyry from Jos locality (JP-9, Jurassic age) and migmatized amphibolite from Runka locality (RK-Gr, Proterozoic to Lower Paleozoic age). The presented results are not the consequence of a systematic investigation, but they only point out partial problems concerning the convenience of the volcanic rocks under study for paleomagnetic investigations and for the detection of the movement of the volcanic complexes.

Geological outline

The Jos plateau is a restricted volcanic sequence paralleled by a similar larger volcanic area in Cameroun. The Jos plateau and the Cameroun highlands are part of a complex crustal dome, transected by the Benue trough and Cameroun rift, the whole constituting the Gulf of Guinea magmatic province (Le Bas 1971 *in* Kogbe 1976). The Biu basalt plateau lies on the axis of NE—SW direction which connects the volcanoes Annobon, Sao Tomé, Principe Fernando Poo in the Gulf of Guinea and Mt. Cameroun which were investigated by Piper and Richardson (1972) (fig. 1).

The Jos plateau is one of the Neogene uplifts tangential to the Chad basin believed to result from local partial melting of the asthenosphere. Its axis is marked



1. Schematic map of Nigeria, including selected areas 1, 2, 3, 4 – sampling localities
1 – Runka: outcrops RK-B-1 and RK-B-2 – mid-Jurassic nepheline basanites; RK-Gr-1 – Proterozoic to Lower Paleozoic migmatized amphibolite;
2 – Jos plateau: JP-1 – JP-8 – Cainozoic basaltic rocks, JP-9 – Jurassic alkali granite porphyry;
3 – Samunaki locality (olivine basalts); *4* – Biu basalt plateau: BP-1 – BP-4 – Cainozoic olivine basalts;
a – localities: Annobon, São Tomé, Principe, Fernando Poo, Cameroun – Tertiary and recent volcanics, which were investigated by J. D. A. Piper and A. Richardson (1972)

the influence on the magnetic needle of the compass by an anomalous local magnetic field was detected. (It was influenced by a very intensive *NRMP* of basaltic rocks — see tables 1 and 2. Jos plateau 5 places, Biu plateau 1 place, Samunaki locality 1 place, Runka southern facies 5 places).

All rock samples were shaped by a diamond saw to the cube of 20 mm edge.

Remanent magnetic polarization (*RMP*) of the rocks was measured with the spinner magnetometer JR-4, and with the astatic magnetometer LAM-24. All samples were subjected to progressive demagnetization in alternating fields up to 48 or 64 $kA . m^{-1}$ in steps 2, 4 and 8 $kA . m^{-1}$. The external magnetic field was compensated by the Helmholtz coils and controlled by a flux-gate magnetometer or by a ROCOMA system.

Magnetic susceptibility ($\varkappa$) measurements were performed using A. C. KLY-2 bridge. This instrument was employed also for the measurements of the change

Table 2

Magnetic characteristics of rock samples

Number of outcrop (region)	Number of samples	$\varkappa \times 10^6$ (SI)	*NRMP* (nT)	*Q*
Jos plateau				
JP-1	5	10 028	74 292	148.2
JP-2	21	25 113	5 740	4.6
JP-3	3	12 294	15 610	25.4
JP-4	6	17 948	80 702	89.9
JP-5/2	2	16 319	20 983	25.7
JP-5/1a, 3a, 4, 4a, 6b	19	22 486	126 908	112.9
JP-6-3/1	2	14 457	30 962	42.8
JP-6-4	8	92 902	4 721	1.02
JP-6-6	4	12 744	1 215	1.91
JP-7	4	11 544	110 703	191.8
JP-8	5	9 455	131 783	278.8
JP-9	14	1 769	64.5	0.73
SMKI-1	3	18 496	182 188	197.0
SMKI-2	4	21 000	2 042	1.9
Biu plateau				
BP-1	2	20 957	166 873	159.3
BP-2	17	28 355	4 390	3.1
BP-3	19	26 317	4 369	3.3
BP-4	6	21 756	7 627	13.0

For explanation see table 1

of the $\varkappa$ of powdered rocks during their Curie temperature (T_C) measurements. The complete apparatus for the T_C measurements consists of a special device (nonmagnetic furnace and cooling system) of our own construction. This device serves for the gradual heating of the powdered sample. The nonmagnetic furnace is gradually supplied by automatically controlled electrical power. Continual and regular increasing of the temperature within the furnace was 10 °C . min^{-1}.

Using several methods, petrographic description of rocks, identification of main chemical components, and determination of the magnetic minerals as the carriers of *RMP* of rocks were carried out. Petrographic analyses and ore microscopy were performed in the laboratories of the Dionýz Štúr Geological Survey, Bratislava. X-ray spectroscopy by Philips PW 1420 X-ray spectrometer and PW 1150 diffractometer were executed mostly in the laboratories of the Geological Institute of the Slovak Academy of Science in Bratislava. Mössbauer spectroscopy was performed in the laboratory of the Department of Nuclear Physics and Technology of the Slovak Technical University in Bratislava (Lipka et al. 1983, 1988). The additional electron microprobe analyses were performed by means of the JEOL electron microscope with the EDAX system in the laboratory of the Dionýz Štúr Geological Survey, Bratislava. Several samples of magnetic fraction of basaltic rocks were investigated by X-ray and Mössbauer spectroscopy, also in the Laboratory of Applied Physics II, Technical University, Lyngby, Denmark (Lipka et al. 1988). The magnetic fraction of rocks for both X-ray and Mössbauer spectroscopy was obtained by their crushing, grinding, cleaning by alcohol and subsequent separation.

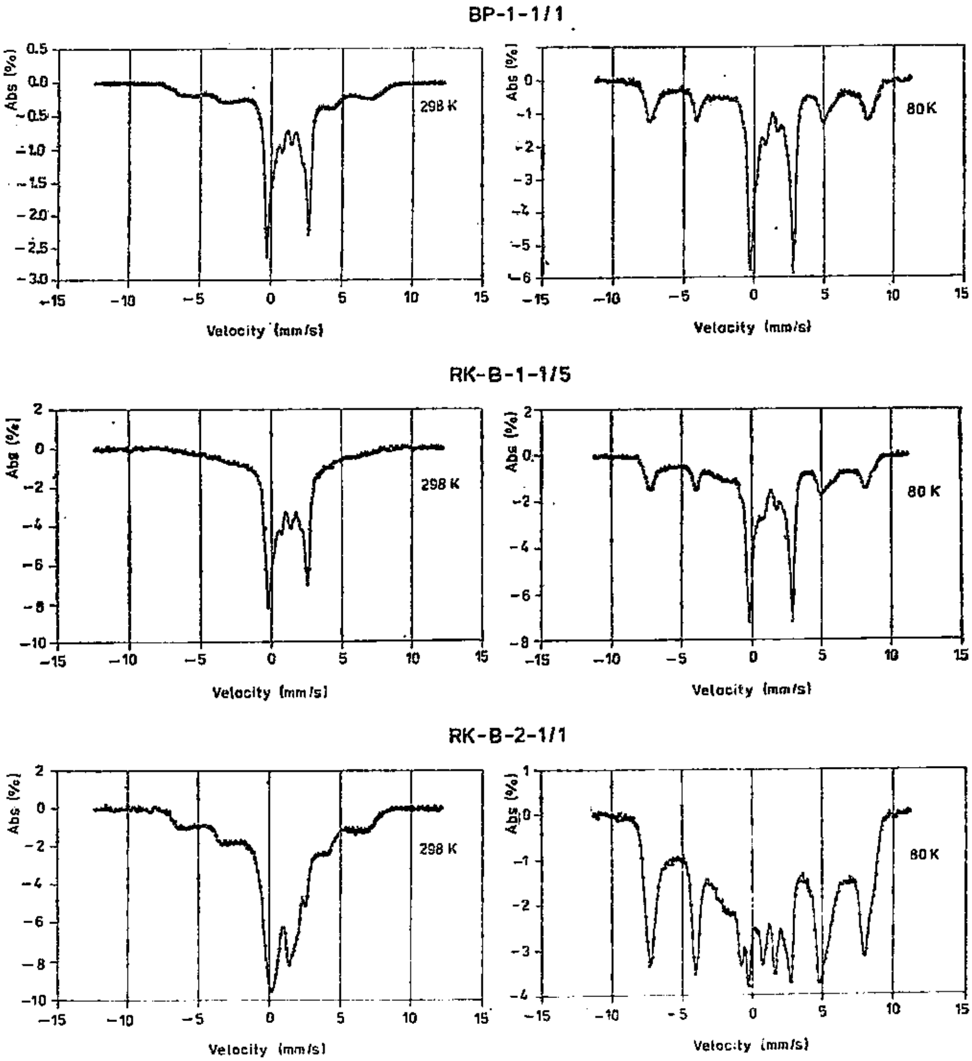
The results of individual laboratory methods

Brief petrographical description of rocks (according to microscopical analyses made by A. Mihalíková, written report):

- the rocks of the Jos plateau (JP): JP-1, JP-7 diabase with olivine; JP-2 olivine basanite; JP-3 to JP-6 and JP-8 olivine basalts; JP-9 alkali granite porphyry;
- the rocks of the Biu basalt plateau (BP): BP-1 olivine basalt; BP-2, BP-3 olivine basalts; BP-4 albitized olivine basalt (spilite ?);
- the rocks of the Samunaki locality (SMKI): SMKI-1, SMKI-2 olivine basalts;
- the rocks of the Runka localities (RK): RK-1, RK-2 nepheline basanites;
- the nonbasaltic rocks of the outcrop near Runka village (RK-Gr): migmatized amphibolite.

Brief outline of the presence of magnetic minerals in the rocks according to the results of individual methods:

Ore microscopy (J. Beňka and Š. Suchý, written report): Hematite was identified in all studied samples of rocks. Magnetite is present (except of the hematite) in the olivine basalts from the localities JP-4, JP-5, JP-8, BP-2, BP-3, also in the olivine



2. Mössbauer spectra of samples BP-1-1/1, RK-B-1/5, RK-B-2-1/1 obtained at room temperature (298 K) and at the temperature of liquid nitrogen (80 K)

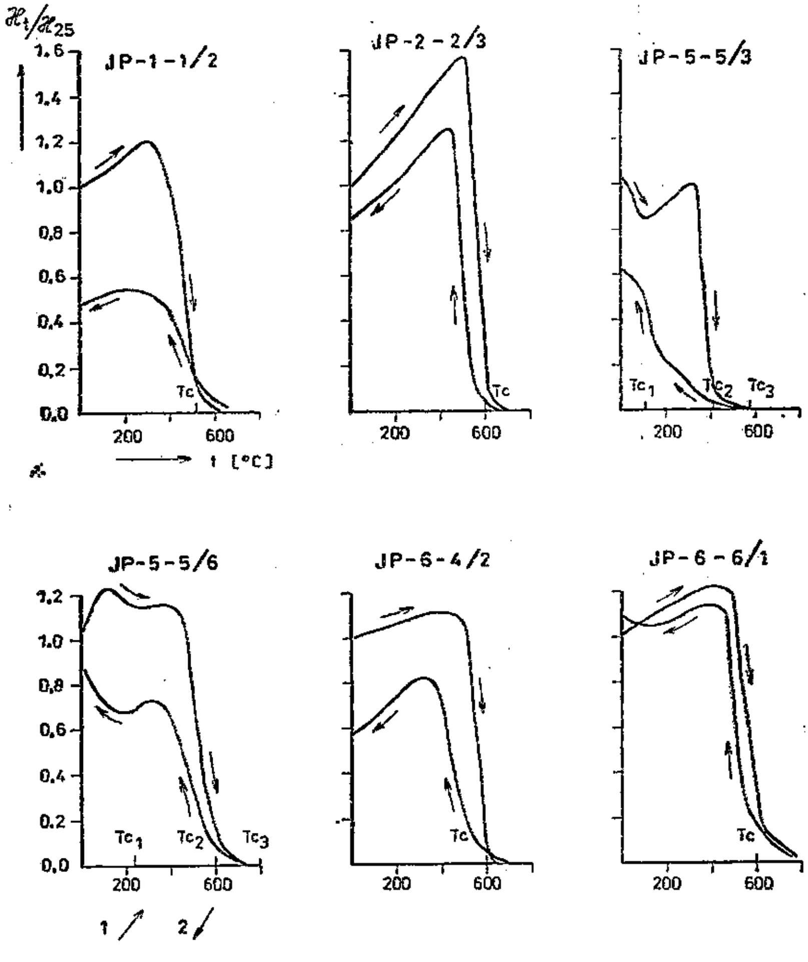
basanite from the locality JP-2, and in the nepheline basanites from the localities RK-1 and RK-2.

X-ray spectroscopy: Two groups of basaltic rocks were investigated by X-ray powder diffraction. The results of one group of basaltic rocks were published by Lipka et al. (1988). The results of second group were reported by B. Toman (written report). The results of analyses made by B. Toman are as follows:

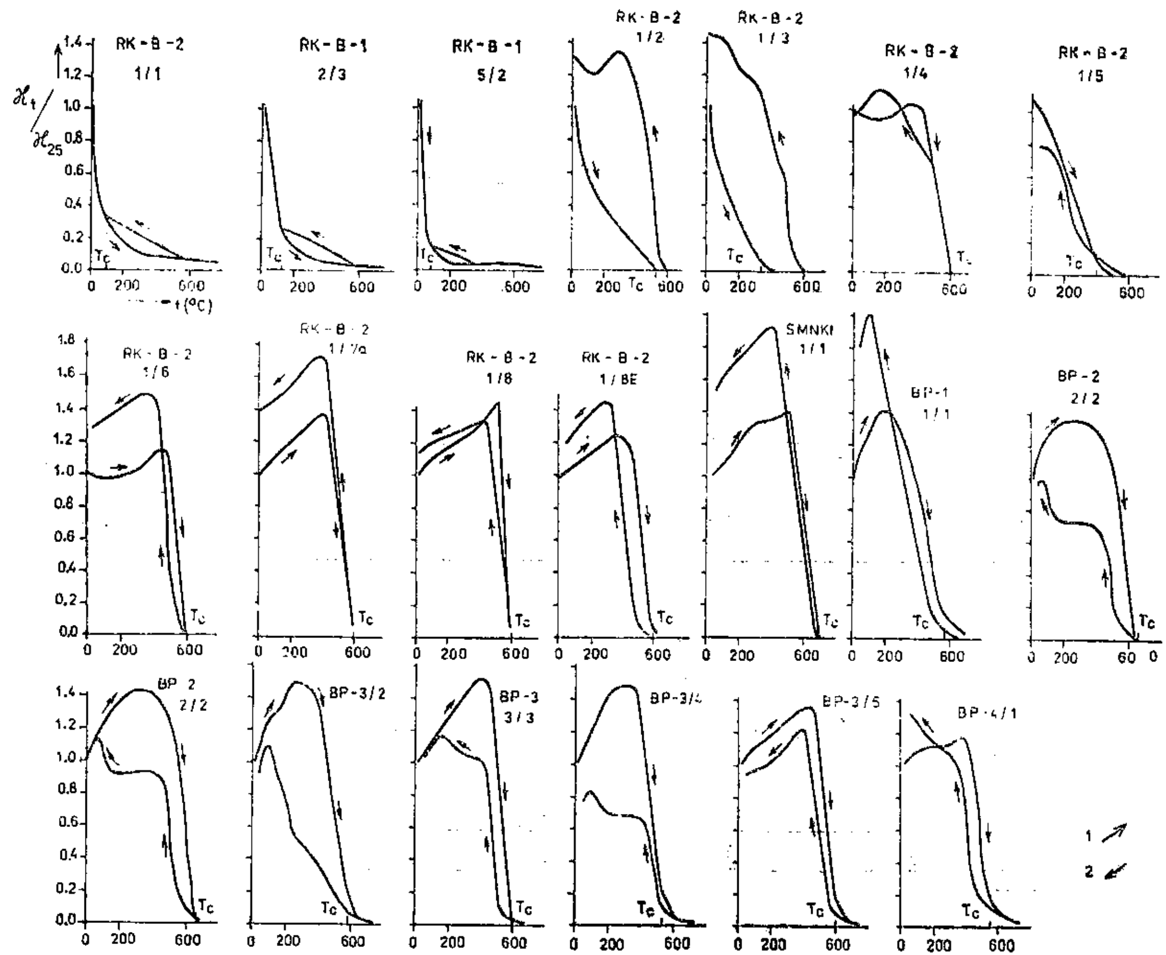
– titanomagnetites ($Fe_{3-x}Ti_xO_4$) with hematite (α-Fe_2O_3), and ilmenite ($FeTiO_3$) are present in the investigated olivine basalts from the locality BP-3,

– hematite (α-Fe_2O_3), and magnetite (Fe_3O_4) are present in the albitized olivine basalt from the locality BP-4,
– titanomagnetites ($Fe_{3-x}Ti_xO_4$), with hematite (α-Fe_2O_3), ilmenite ($FeTiO_3$), brookite (TiO_2), and pseudobrookite (Fe_2TiO_5) are present in the nepheline basanites from the localities RK-1, and RK-2.

Titanomagnetites ($Fe_{3-x}Ti_xO_4$) were identified in all studied samples according to Lipka et al. (1988). The unit cell parameters of the titanomagnetites are as follows: $a = 0.852\,4$ nm, and $a = 0.846\,3$ nm in the samples of the nepheline



3. The results of the Curie temperature measurements of powdered rock samples
$\varkappa_t, \varkappa_{52}$ – magnetic susceptibility of the sample – after heating to the temperature $t(\varkappa_t)$, without the heating effect ($\varkappa_{25}$); *1*, *2* – Curie temperature, curve registered during the heating (*1*) and the cooling (*2*) of the sample; T_c – Curie temperature of magnetic mineral of rock sample



4. The results of the Curie temperature measurements of powdered rock samples
$\varkappa_t$, $\varkappa_{25}$ – magnetic susceptibility of the sample – after heating to the temperature $t(\varkappa_t)$, without the heating effect ($\varkappa_{25}$);
1, *2* – Curie temperature curve registered during the heating (*1*) and the cooling (*2*) of the sample; T_C – Curie temperature of magnetic mineral of magnetic mineral of rock sample

basanite (RK), and in the sample of the olivine basalt (BP-1), respectively. A mineral intermediate between α-Fe_2O_3 and $FeTiO_3$, i.e. hematite-ilmenite solid solution was identified in the samples JP-2, BP-1, BP-2 and SMKI-1.

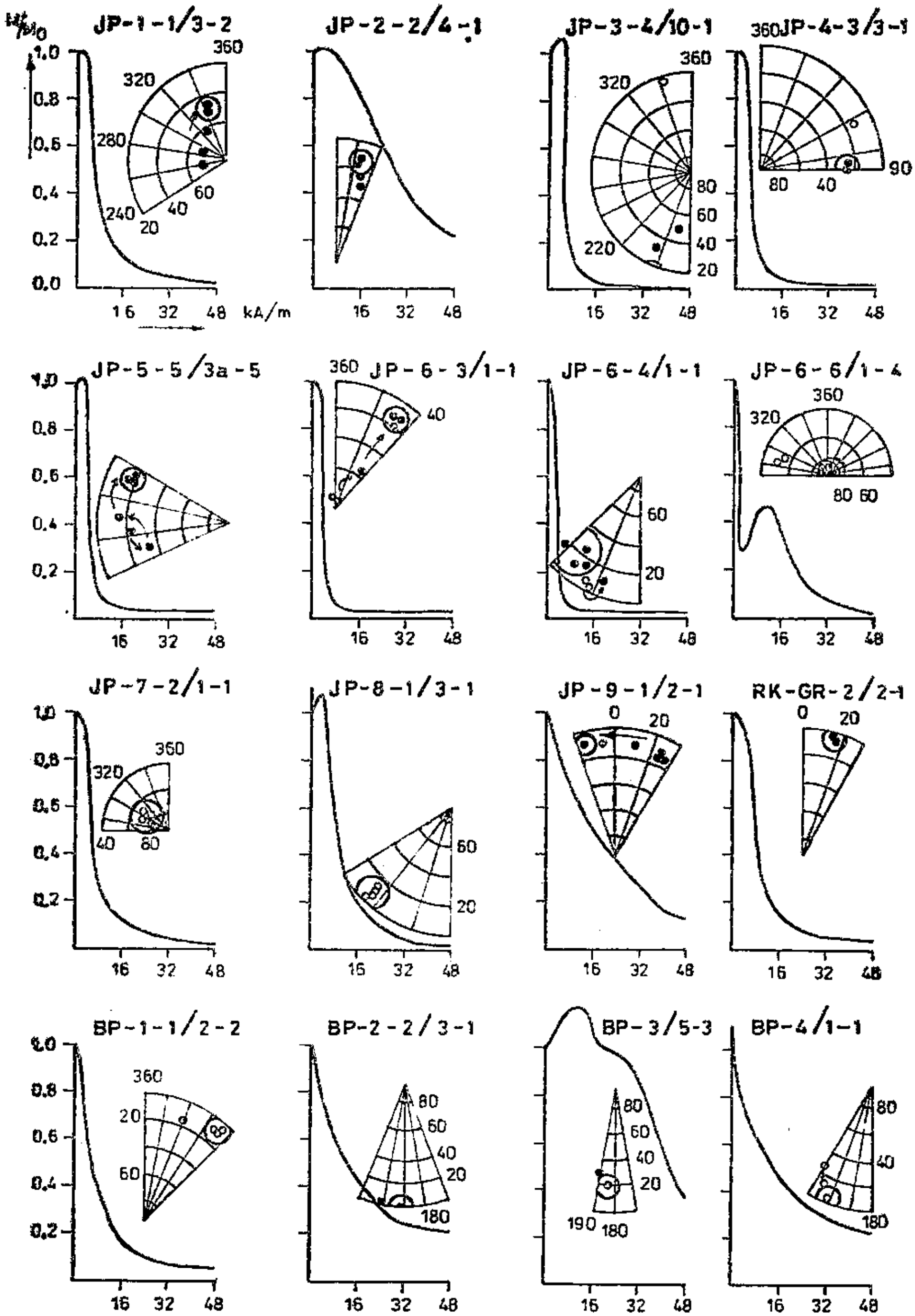
Mössbauer spectroscopy of magnetic fraction was mostly applied at room temperature, but in several cases also at the temperature of liquid nitrogen (see fig. 2). Mössbauer spectra of samples were measured also after heating of magnetic fraction. Sixteen samples of the studied rocks were analysed by this method. Volume portion of the Fe-Ti oxides was determined in the magnetic fraction on the base of the results of Mössbauer spectroscopy. The composition of the titanomagnetites in the samples was estimated from their unit cell parameters. It is as follows: BP-1 $Fe_{2.4}Ti_{0.6}O_4$; BP-2 $Fe_{2.5}Ti_{0.5}O_4$; SMKI-1 $Fe_{2.9}Ti_{0.1}O_4$; RK-1 $Fe_{2.3}Ti_{0.7}O_4$; RK-2 $Fe_{2.4}Ti_{0.6}O_4$.

Mössbauer spectroscopy and X-ray diffraction showed that heating of the samples RK-1, RK-2 and BP-1 causes a transformation of titanomagnetites into almost titanium-free magnetite, hematite, brookite and ilmenite (Lipka et al. 1988).

Electron microprobe analyses were realized on the samples of four petrographical types of studied rocks. The content of both Fe and Ti components (according to the analyses made by F. Caño, written report) is as follows:

	FeO(%)	TiO_2(%)
– olivine basalt (BP-2, BP-3)	74.48	23.30
– olivine basanite (JP-2)	72.54	26.01
– albitized olivine basalt (BP-4)	89.33	8.66
	45.39	54.46
– nepheline basanite (RK-1)	74.83	24.41
	48.06	51.60
– nepheline basanite (RK-2)	75.27	24.30
	48.45	51.23

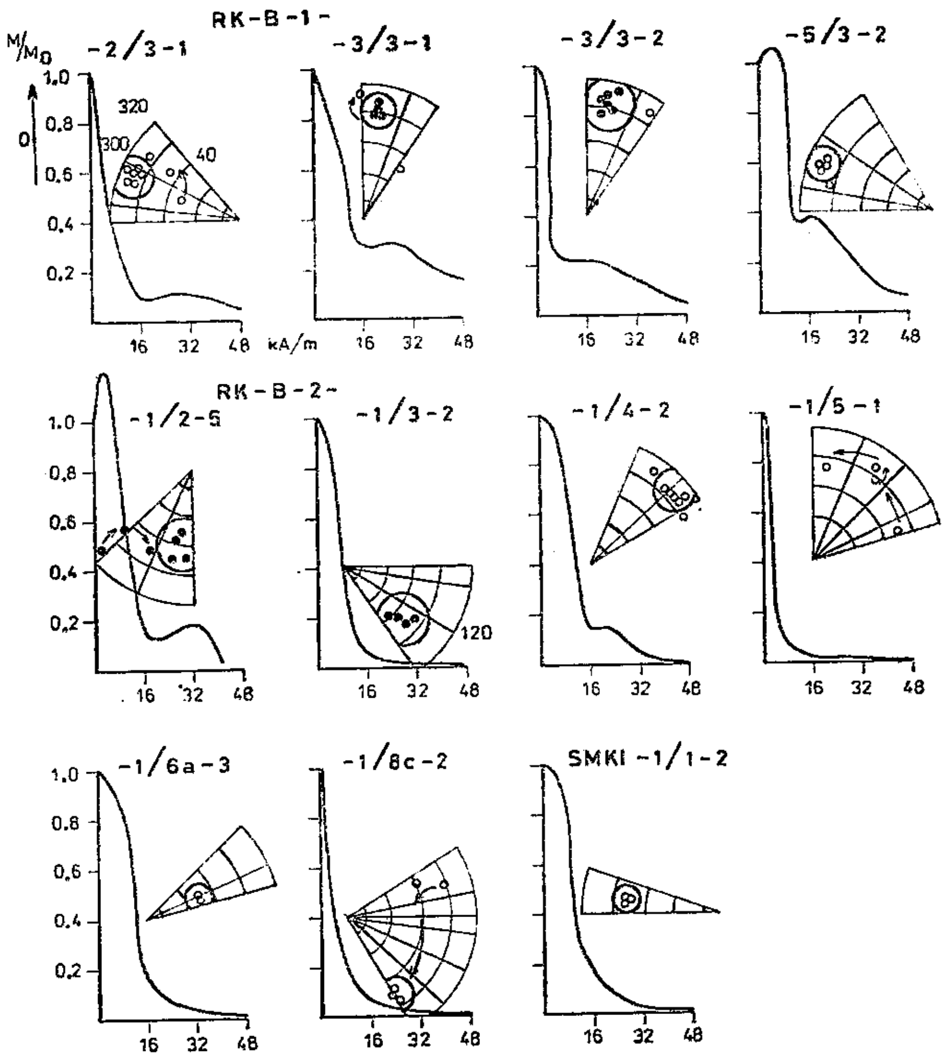
Curie temperature measurements: It is well known that a quite successfull identification of magnetic constituents of rocks can be obtained by determining their Curie temperature. We have applied the method of change of magnetic susceptibility of a powdered sample with the temperature. The applied method was worked out by the author of this article. Curie temperature curves of the samples are shown in figs. 3 and 4. We see that the main carriers of magnetism within the rocks of Jos plateau are minerals with T_C close to magnetite (fig. 3). Olivine basalts of Biu plateau localities (except loc. BP-1) show T_C – around 600 °C. The albitized olivine basalt of the loc. BP-4 shows T_C close to magnetite, but also the second magnetic phase (T_C about 350 °C) is present in this rock. There is a presence of the mineral with $T_C = 150-250$ °C after heating over 750 °C and cooling up to laboratory temperature in the rocks of the localities BP-2, and BP-3 (fig. 4). Nepheline basanites of the localities RK-1 and RK-2-1/1 show T_C around 200 °C.



5. A.C. demagnetization in nonmagnetic medium
M – magnetic remanent moment of the specimen demagnetized by field *H*; *full, open circle* – positive, negative *RMP* respectively

The samples of other RK-2 localities and locality SMKI-1 show T_C close to magnetite (except RK-B-2-1/2, 1/3) (fig.4).

Basic magnetic and paleomagnetic results are presented in tables 1, 2, 3, 4. The results of A.C. demagnetization are in figs. 5 and 6. Average directions of *RMP* and computed pole positions of rocks of selected localities are presented in figs. 7 and 8. The results which have been taken over from Piper and Richardson (1972) in fig. 8 are also presented.



6. A.C. demagnetization in nonmagnetic medium
M – magnetic remanent moment of the specimen demagnetized by field *H*; *full, open circle* – positive, negative *RMP* respectively

Table 3

Paleomagnetic characteristics of rocks

Region	φ_L	λ_L	D_s	I_s	α_{95}	k	n	$\varphi_{p(N)}$	$\lambda_{p(E)}$	δ_m	δ_p
Runka – loc. 1											
RK-1	12.505	7.186	326.9	13.5	26.5	3.6	12	56.9	270.9	27.1	13.8
RK-Gr	12.500	7.205	18.8	4.9	8.1	69.4	6	69.9	125.8	8.1	4.1
Runka – loc. 2											
1/2	12.503	7.186	161.2	28.9	22.5	9.8	6	56.4	221.4	24.8	13.6
1/3	12.503	7.186	132.3	41.3	9.6	165.8	3	30.9	239.4	11.7	7.1
1/4	12.503	7.186	34.9	−13.4	9.1	760.1	2	50.3	124.3	9.3	4.7
1/5	12.503	7.186	324.6	18.6	36.2	5.4	5	55.1	276.0	37.6	19.6
1/6	12.503	7.186	56.9	−63.4	24.4	7.1	7	22.8	220.0	38.5	30.4
1/7	12.503	7.186	260.0	−51.1	6.7	81.6	7	14.9	67.2	9.1	6.2
1/8	12.503	7.186	129.8	10.7	25.0	6.8	7	37.0	260.5	25.3	12.8
1/2+1/3 +1/8	12.503	7.186	137.0	27.1	19.6	4.5	16	45.1	249.5	21.4	11.6

φ_L, λ_L – geographical coordinates; D_s – mean declination of remanent magnetic polarization I_s – mean inclination of remanent magnetic polarization; α_{95} – semi-angle of the cone confidence for $p = 0.05$; k – precision parameter; n – number of samples; φ_p, λ_p – coordinates of the virtual pole calculated to the north (N), east (E); δ_m, δ_p – dimensions of the reliability oval for pole position

Conclusion and discussion

A complex of physico-analytical methods and laboratory procedures was used during the study of Quaternary, younger Cainozoic, Jurassic, and Proterozoic to Lower Paleozoic volcanic rocks from Nigeria, to obtain information on the carriers of the magnetism, paleomagnetic stability, and the distribution of the direction of the *RMP* in the mentioned geological complexes.

As mentioned previously the Fe-Ti oxides are the main carriers of the magnetism in the studied volcenic rocks. They are in various magnetic state and chemical stages, corresponding to different degrees of their alterations. Also the products of the alterations of the titanomagnetites are present in some rocks. Abundant ilmenite is e.g. present in the nepheline basanites of the northern facies (RK-1), also in the northern part of the southern facies (RK-2), according to the results of microscopical analyses, electron microprobe analyses, and Curie temperatures, except for the non-stoichiometric (cation-deficient) titanomagnetites. The Möss-

Table 4

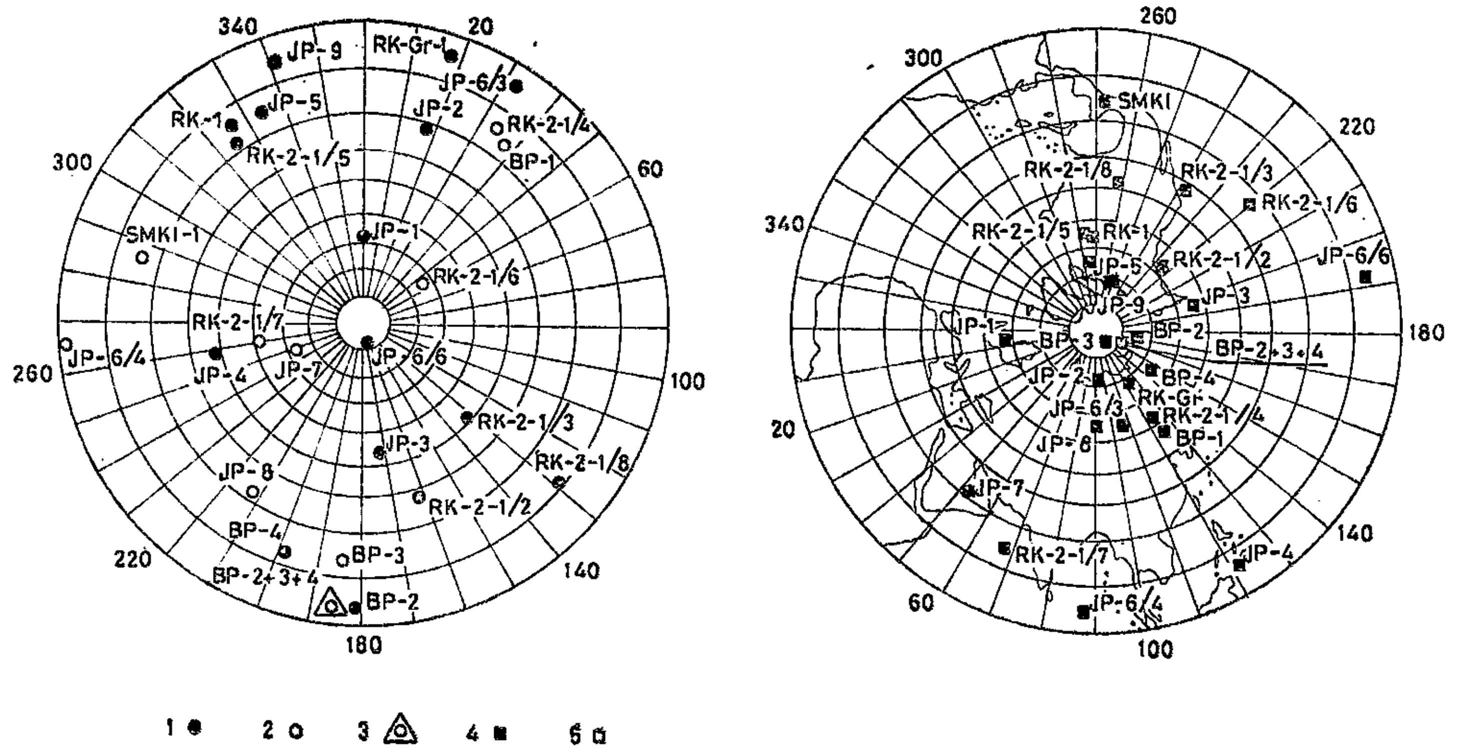
Paleomagnetic characteristics of rocks

Region	φ_L	λ_L	D_s	I_s	α_{95}	k	n	$\varphi_{p.m.}$	$\lambda_{p.m.}$	δ_m	δ_p
					Jos plateau						
JP-1	9.709	8.450	359.6	59.0	17.3	20.5	5	59,9	7.9	25.8	19.3
JP-2	9.700	8.467	17.3	21.4	2.5	161.7	21	72.9	92.2	2.6	1.4
JP-3	9.584	8.318	172.6	45.7	107.3	2.5	3	52.5	199.3	136.8	87.2
JP-4	9.584	8.336	258.6	38.9	131.9	1.2	8	6.8	122.0	157.1	93.5
JP-5	9.627	8.391	334.8	14.0	20.0	3.4	22	64.9	274.6	20.4	10.4
JP-6/3	9.559	8.641	32.8	4.4	10.0	627.3	2	56.5	109.0	10.0	5.0
JP-6/4	9.559	8.641	265.9	−1.4	55.0	2.0	8	4.1	89.3	55.1	27.5
JP-6/6	9.559	8.641	164.6	81.4	46.0	3.1	6	6.6	192.8	89.1	86.3
JP-7	9.559	8.679	249.6	−64.8	13.2	21.9	7	20.9	52.1	21.2	17.1
JP-8	9.580	8.705	212.8	−23.3	54.6	2.2	7	57.7	91.1	58.1	30.9
JP-9	9.936	8.859	341.8	6.4	6.4	40.1	14	70.7	259.6	6.4	3.2
					Biu plateau						
BP-1	10.614	12.141	38.4	−15.1	24.4	26.5	3	47.7	126.2	25.1	12.9
BP-2	10.636	12.152	182.9	4.3	13.6	11.2	12	76.9	179.3	13.6	6.8
BP-3	10.600	12.216	184.3	−13.8	11.0	7.3	27	84.4	142.4	11.3	5.8
BP-4	10.573	12.232	197.4	12.8	10.7	24.0	9	65.7	146.0	10.9	5.6
BP-2 + +BP-3 + +BP-4	10.603	12.200	186.5	−3.9	7.8	8.0	48	79.2	154.9	7.8	3.9
SMKI	10.223	10.168	288.3	−14.8	9.5	17.2	15	16.4	269.1	9.8	5.0

For explanation see table 3

bauer spectra of the magnetic fraction from the nepheline basanites (all samples of the locality RK-1, and the samples of northern outcrops of the locality RK-2) are very complicated. The basic spectra probably correspond to non-stoichiometric titanomagnetites. The presence of the ilmenite is also reflected in the samples. The ferroilmenite is probably the main carrier of the magnetism in these rocks, to judge from their magnetic characteristics and all the data mentioned above. Most of these rocks have extreme high magnetic susceptibility.

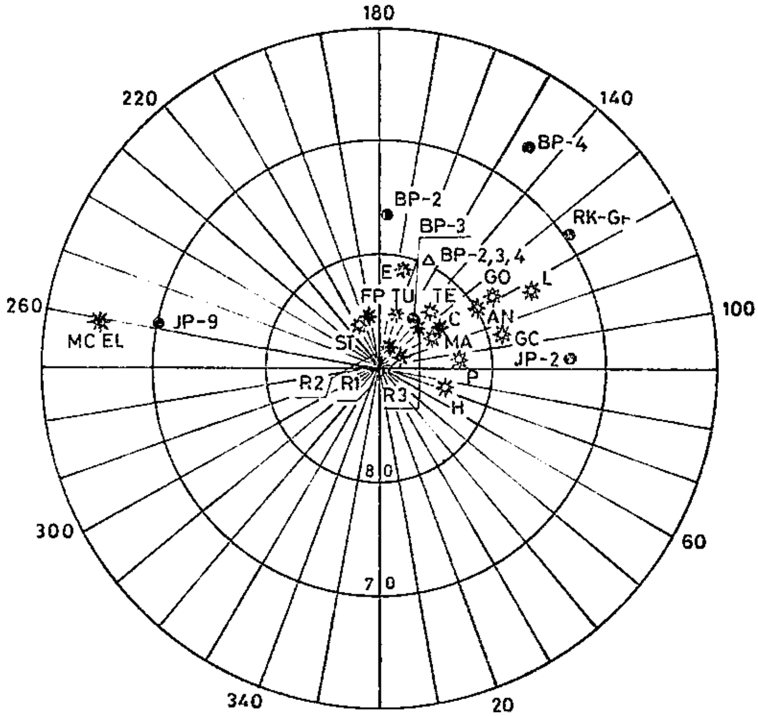
The cation-deficient titanomagnetites are probably the main carriers of the magnetism in the nepheline basanites of the southern part of the locality RK-2. Most of these rocks have extremely intensive *NRMP*. The cation-deficient titanomagnetites are probably the main carriers of the magnetism in the olivine basalts from the localities of the Jos plateau. The ilmeno-hematites are present in the



7. Stereographic projections of mean direction of the *RMP* and pole positions of the rocks of individual outcrops under study; *1*, *2* – positive, negative *RMP* respectively; *3* – mean direction of *RMP* of the localities BP-2, BP-3 and BP-4; *4* – mean virtual pole position of the outcrop under study; *5* – mean virtual pole position of the localities BP-2, BP-3, BP-4

olivine basalts of the localities BP-2, BP-3, and in the olivine basanite of the locality JP-2, except the cation-deficient titanomagnetites. The ilmeno-hematites are only present in the albitized olivine basalt of the locality BP-4.

The magnetite-hematite solid solution is probably the main carrier of the magnetism in the olivine basalt of the locality SMKI-1, and in the alkali-granite porphyry of the locality JP-9, also in the migmatized amphibolite of the locality RK-Gr. The ferroilmenite is probably present in the olivine basalt of the locality BP-1.



8. Pole positions of the selected localities under study and paleomagnetic pole positions according to J. D. A. Piper and A. Richardson (1972)
JP-2 – olivine basanite from the Jos plateau of Cainozoic age;
JP-9 – alkali granite porphyry of Jurassic age; BP-2, BP-3, BP-4 – olivine basalts from the Biu basalt plateau of Cainozoic age;
RK-Gr – migmatized amphibolite of Proterozoic to Lower Paleozoic age
Explanations according to J. D. A. Piper and A. Richardson (1972):
the continental (*closed stars*) and oceanic (*open stars*) parts of the African plate; FP – Fernando Poo, AN – Annobon, P – Principe, ST – São Tomé, C – Cameroun, E – Ethiopian traps, TU – Turkana lava, MA – Madeira, GC – Gran Canaria, GO – Gomera, H – Hierro, TE – Tenerife, L – La Palma; R1, R2, R3 – African rift valley: 0–2.5 m.y. (R1), 2.5–5.0 m.y. (R2), 5.0–7.5 m.y. (R3);
MCEL – the Mesozoic poles from Africa published by McElhiny et al. 1968 (*in* J. D. A. Piper, A. Richardson 1972)

All analysed properties and detected signs indicate that the above-discussed rocks have been altered from the time of their origin. I suppose that their remanence is not a primary one, but that it has been acquired during the alteration processes. It means that the *RMP* is a secondary one, probably of chemical origin (C.R.M.).

The alterations of the magnetic properties of the rocks with regard to an alteration of their Fe-Ti oxides have been described by many authors, e.g. by Ade–Hall et al. (1971); Tarling (1974); Stacey–Banerjee (1974); Pecherskij et al. (1981); Pecherskij (1985); Orlický (1987); Orlický–Lipka (1987). But it is complicated to reconstruct the whole alteration process in the individual rock with regard to detection of the stages of forming of the magnetic fraction from its origin. This means that the considerations concerning the carriers of the *RMP* and their origin in the rocks under study are despite many particular results of analyses not definite in all cases.

It remains to examine whether we can separate the influences of an alteration processes on the *RMP* of volcanic rocks, the reflections of nondipole behaviour of the field and real polar wandering or continental drift in the Jurassic, Middle Jurassic, Upper Tertiary and Quaternary times.

The virtual pole position obtained from Middle Jurassic (Runka localities), Younger Cainozoic (Biu plateau), Quaternary (Jos plateau) basaltic rocks, including nonbasaltic rocks (alkali granite porphry from JP-9 locality and migmatized amphibolite from RK-Gr locality) are in fig. 7.

The virtual pole of JP-2 locality is derived from the results of olivine basanites, the magnetic minerals of which are believed to be of secondary origin. This means that this virtual pole corresponds to the time of alteration of original magnetic minerals, or to the time after, but not to the time of the origin of the mentioned rocks. The olivine basanite of JP-2 locality belongs to Newer basalts of Jos plateau (age: 2.1 – 0.9 m.y.). As already indicated, there is not always a distinction between the Fluviovolcanic series (age of basalts up to 7.0 m.y.) and Older basalts, and the subdivision between Older and Newer basalts may also be artificial.

The Biu basalt plateau of a Younger Cainozoic age is represented by three virtual poles (BP-2, BP-3, BP-4). There is evident distinction among the carriers of the magnetism of the albitized olivine basalt (BP-4), and those from the olivine basalts of the localities BP-2, BP-3. There are different positions of the virtual poles of these localities in fig. 8. The individual localities differ in the inclinations of the *RMP* of rocks, but the declinations of all three localities are close to each other. I suppose that the differences in the inclinations are probably due to a local irregular slope of concrete volcanic bodies. Unfortunately it has not been corrected due to the lack of detailed geological data. The petrographic signs, magnetic characteristics and Curie temperature curves of the samples of the locality BP-4, and those of the localities BP-2, BP-3 suggest that the process of the origination or postvolcanic development of these rocks has not been uniform. A total sum of φ_p and λ_p of all three localities is believed to be the probable virtual pole for the Biu basalt plateau of a Younger Cainozoic age.

The alkali granite porphyry of JP-9 locality belongs to the porphyry ring dyke complex of the large Jurassic (160–170 m.y.) Younger Granite massif centered on the Jos plateau, according to Kogbe (1976). It has been reported that the emplacement of the Younger granites was associated with epeirogenic uplift. The ring complexes of the entire Nigeria – Niger provinces lie on a north-south belt which is 1,200 km long. This can be related to two major features of the African continent. First it corresponds to the central part of the north-south trending Pan-African orogenic belt and second, it forms a northerly continuation of the continental margin of southern Africa. These may be inter-related. The rifting and separation of South America from Southern Africa during Jurassic to Cretaceous times was guided by structural trends in the basement. It seems probable that the Younger Granites lie on an extension of this ancient rift structure on a zone of incipient faulting where crustal separation did not take place (Black 1965 *in* Kogbe 1976).

The computed pole position of alkali granite porphyry from JP-9 locality is $\varphi_P = 70.7°$ N; $\lambda_P = 259.6°$ E. The *RMP* is probably a secondary one of C.R.M. origin. It is probable that a stable *RMP* of these rocks was acquired in the times close after the forming of the Jurassic Younger Granite massif. Migmatized amphibolite of the RK-Gr locality belongs to the Older Granite suite of an Upper Proterozoic to Lower Paleozoic age. In north-eastern Nigeria, a group of fine-grained granites is described as being earlier than the migmatites. These granites represent a minor, discordant intrusion of small areal extent occurring as dykes and irregular bodies rarely extending for more than 200 m, according to Kogbe (1976). The magnetism of migmatized amphibolite of RK-Gr locality is believed to be a secondary one, of C.R.M. origin. The origin of the magnetism falls probably into a Brunhes epoch of positive polarity. This means that a stable *RMP* of rocks has been acquired during the recent time, and not in the Proterozoic to Lower Paleozoic.

The other 18 derived poles have been exluded from this discussion due to insufficient paleomagnetic stability, anomalous magnetization or shortage of rocks of individual outcrops.

Piper and Richardson (1972) investigated rocks of 205 sites from the Upper Tertiary to recent lavas and intrusions in the Gulf of Guinea volcanic area of equatorial West Africa. They have presented an idea "that there is no paleomagnetic reason for believing that the African plate has moved relative to the pole in Upper Tertiary times", on the base of their results, supported by the results of other authors (see fig. 8).

The nine Mesozoic poles from Africa group closely at near 65° N and 261° E have been published by McElhiny et al. (1968 *in* Piper–Richardson 1972). The youngest Mesozoic pole is of about 100 m.y. age and the shift of the African ného titanomagnetitu, ktorý je nositeľom novej pomerne stabilnej *CRMP*. Vedľa neho je v hornine ilmenit, ktorý je magneticky pasívny.

Výsledkami je potvrdené, že extrémne intenzívnú *NRMP* vykazujú nefelinické bazanity Runka lokality a olivinické bazalty Jos plató s jednou Curieovou teplotou (T_C) blízkou T_C magnetitu, pričom nefelinické bazanity s nízkymi hodnotami T_C, u ktorých je potvrdená zároveň prítomnosť $FeTiO_3$, vykazujú výrazne nižšie hodnoty *NRMP*.

V olivinických bazaltoch troch lokalít Biu plató (BP-2, BP-3 a BP-4) je okrem titanomagnetitov zistená aj prítomnosť tuhých roztokov ilmenito-hematitov. Tieto olivinické bazalty vykazujú relatívne nízke hodnoty *NRMP*, reverznú polaritu a stabilný smer *RMP* voči demagnetizácii striedavým poľom.

Olivinické bazanity JP-2 lokality, alkalické granitové porfýry lokality JP-9 a migmatitizované amfibolity lokality RK-Gr obsahujú z magnetických minerálov hlavne nestechiometrický magnetit. Magnetizácia týchto hornín je pravdepodobne sekundárna, avšak magneticky i smerovo pomerne stabilná.

Iba 6 vypočítaných pólov (JP-2, JP-9, RK-Gr, BP-2, BP-3, BP-4) z celkového počtu 25 na obr. 7 bolo využitých pre záverečnú analýzu výsledkov.

Virtuálny pól lokality JP-2 je odvodený z výsledkov olivinických bazanitov, magnetické minerály ktorých sú považované za sekundárne. To znamená, že odvodený virtuálny pól zodpovedá obdobiu alterácie pôvodných minerálov, nie však obdobiu vzniku pôvodných hornín. Vek tzv. „Newer bazaltov“, do ktorých sú začlenené i bazanity predmetnej lokality, je ca 2,1 – 0,9 mil. rokov (alebo 7,0 mil. rokov – Fluvio – volcanic serie). Výsledky poukazujú, že alterácie minerálov prebehli v olivinických bazanitoch lokality JP-2 v recentnom období.

Bazalty Biu plató – lokalít BP-2, BP-3, BP-4 – sa vypočítanými hodnotami smeru strednej *RMP* i virtuálnych pólov medzi sebou vzájomne líšia. Deklinácia *RMP* všetkých troch lokalít je veľmi blízka, inklinácia *RMP* je ovplyvnená pravdepodobne nepravidelným zaklesnutím individuálnych telies, z ktorých vzorky pochádzajú. Žiaľ, pre nedostatok ďalších geologických údajov tieto lokálne zmeny polohy telies a ich vplyv na inklináciu *RMP* horniny nie je možné vylúčiť.

Vieme, že všetky tri lokality patria do Biu bazalt plató, vrchnokenozoického veku. Podobné petrografické znaky, magnetické charakteristiky, rovnaké Curieove teploty i ďalšie výsledky analýz poukazujú, že pôvod alebo postvulkanický vývoj týchto hornín boli pravdepodobne rovnaké. Na základe uvedeného predpokladám, že stredné hodnoty φ_p a λ_p vypočítané z individuálnych výsledkov lokalít BP-2, BP-3 a BP-4 sú pravdepodobným virtuálnym pólom olivinických bazaltov vrchnokenozoického veku Biu plató.

Alkalický granitový porfýr lokality JP-9 patrí do porfýrového – „ring-dyke“ – komplexu rozsiahleho jurského (160 – 170 mil. rokov) mladšieho granitového masívu, vyskytujúceho se v rámci Jos plató (podľa Kogbeho 1976).

Vypočítaná poloha pólu pre granitový porfýr lokality JP-9 je $\varphi_p = 70,7°$ N, $\lambda_p = 259,6°$ E. *RMP* týchto hornín je pravdepodobne sekundárna (CRM). Je pravdepodobné, že stabilná *RMP* granitového porfýru vznikla v období veľmi blízkom po formovaní jurského mladšieho granitového masívu.

Migmatitizovaný amfibolit lokality RK-Gr patrí do „staršej granitovej formácie" proterozoického až spodnopaleozoického veku.

Magnetizmus migmatitizovaného amfibolitu lokality RK-Gr má pravdepodobne sekundárny pôvod. Stabilná zložka *RMP* týchto hornín vznikla v recentnom období, pravdepodobne počas Brunhesovej epochy.

Zo skúmaných hornín poukazujú na možný pohyb a rotáciu africkej litosférickej dosky iba výsledky meraní jurského granitového porfýru lokality JP-9. Ostatné výsledky buď nepoukazujú na pohyb africkej dosky, alebo z dôvodov nestability *RMP*, nedostatočného počtu experimentálneho materiálu sú výsledky pre takúto interpretáciu nevyužiteľné.

Ako je známe z úvodu práce, Piper a Richardson (1972) vyslovili názor, že na základe paleomagnetických výsledkov recentných až vrchnoterciérnych vulkanitov z oblasti Guinejského zálivu a rovníkovej západnej Afriky nie je detegovaný pohyb africkej dosky relatívne voči pólu v období vrchného terciéru.

Mc Elhiny et al. (1968 *in* Piper—Richardson 1972) publikovali deväť mezozoických pólov lokalít Afriky $\varphi_p = 65°$ N, $\lambda_p = 261°$ E. Podľa uvedených autorov došlo k premiestneniu africkej dosky v období od mezozoika do vrchného terciéru (v intervale 100 až 25 m. r.).

Ako vidieť z obr. 8 i z predchádzajúceho textu, pomerne dobrá zhoda je medzi strednou hodnotou pólu vypočítaného pre mezozoické horniny lokalít Afriky podľa Mc Elhinyho et al. (l.c.) a hodnotou pólu pre granitový porfýr jurského veku lokality JP-9. Naše výsledky taktiež poukazujú na okolnosť, že od obdobia vzniku jurského granitového porfýru lokality JP-9 došlo k premiestneniu africkej dosky z jej predošlej polohy.

Paleomagnetické výsledky mladších vulkanických hornín pohyb africkej dosky nedetegovali.

Vysvetlivky k tabuľkám

Tabuľka 1, 2. Magnetické charakteristiky hornín.

$\varkappa$ — objemová magnetická susceptibilita; *NRMP* — prirodzená remanentná magnetická polarizácia; *Q* — Koenigsbergerov koeficient.

Tabuľka 3, 4. Paleomagnetické charakteristiky.

φ_L, λ_L — geografické súradnice; D_s — stredná deklinácia remanentnej magnetickej polarizácie; I_s — stredná inklinácia remanentnej magnetickej polarizácie; α_{95} — polovičný uhol kužela spoľahlivosti pre $p = 0{,}05$; k — koeficient presnosti; n — počet vzoriek; φ_p, λ_p — súradnice virtuálneho pólu počítaného voči severu (N) a východu (E); δ_m, δ_p — parametre oválu spoľahlivosti pre vypočítaný pól.

Vysvetlivky k obrázkom

1. Schematická mapa Nigérie, včítane vybraných oblastí, z ktorých boli odobrané vzorky.
1 – oblasť Runka: odkryvy RK-B-1 a RK-B-2 – strednojurské nefelinické bazanity, RK-Gr-1 – proterozoický až spodnopaleozoický migmatitizovaný amfibolit; *2* – Jos plató: JP-1 až JP-8 – kenozoické bazaltické horniny, JP-9 – alkalický granitový porfýr jurského veku; *3* – lokalita Samunaki (olivinické bazalty); *4* – Biu plató (bazaltové): BP-1 až BP-4 – kenozoické olivinické bazalty; *a* – lokality Annobon, São Tomé, Principe, Fernando Poo, Kamerun – terciérne a recentné vulkanity skúmané J. D. A. Piperom a A. Richardsonom (1972).
2. Mössbauerove spektrá vzoriek BP-1-1/1, RK-B-1-1/5 a RK-B-2-1/1 získané pri izbovej teplote (298 K) a pri teplote kvapalného dusíka (80 K).
3. a 4. Výsledky merania Curieových teplôt práškových vzoriek hornín.
$\varkappa_t$, $\varkappa_{25}$ – magnetická susceptibilita vzorky – po vyhriatí na teplotu $t(\varkappa_t)$, bez tepelného účinku ($\varkappa_{25}$); *1*, *2* – krivka merania Curieovej teploty počas vyhrievania (*1*) a počas chladnutia (*2*) vzorky; T_C – Curieova teplota magnetického minerálu vzorky horniny.
5. a 6. Výsledky demagnetizácie vzoriek hornín striedavým poľom, s kompenzovaním geomagnetického poľa.
M – magnetický moment po demagnetizovaní vzorky poľom *H*; *plný*, *otvorený krúžok* – kladná, záporná *RMP*.
7. Stereografické projekcie stredných smerov *RMP* a polôh pólov hornín jednotlivých študovaných odkryvov.
1, *2* – kladná a záporná *RMP*, *3* – stredný smer *RMP* lokalít BP-2, BP-3 a BP-4; *4* - stredná virtuálna poloha študovaného odkryvu; *5* - stredná virtuálna poloha pólu lokalít BP-2, BP-3 a BP-4.
8. Polohy pólov vybraných študovaných lokalít a paleomagnetické polohy pólov (podľa J. D. A. Pipera a A. Richardsona 1972).
JP-2 – olivinický bazanit z Jos plató kenozoického veku; JP-9 – alkalický granitový porfýr jurského veku; BP-2, BP-3, BP-4 – olivinické bazalty z Biu-bazaltového plató kenozoického veku; RK-Gr – migmatitizovaný amfibolit proterozoického až spodnopaleozoického veku. Vysvetlivky podľa J. D. A. Pipera a A. Richardsona (1972): kontinentálne (*plné hviezdičky*) a oceánické (*prázdne hviezdičky*) časti africkej dosky; FP – Fernando Poo, AN – Annobon, P – Principe, ST – São Tomé, C – Kamerun, E – etiópske trapy, TU – turkanská láva, MA – Madeira, GC – Gran Canaria, GO – Gomera, H – Hierro, TE – Tenerife, L – La Palma; R1, R2, R3 – africké riftové údolia: 0–2,5 mil. rokov (R1), 2,5–5,0 mil. rokov (R2), 5,0–7,5 mil. rokov (R3); MCEL – mezozoické póly z Afriky, publikované Mc Elhinym et al. 1968 (*in* J. D. A. Piper–A. Richardson 1972).

Палеомагнетизм избранных четвертичных, кайнозойских, юрских и протерозойских до нижнепалеозойских вулканических пород Нигерии

Большинство изученных диабазов, оливиновых базальтов и нефелиновых базанитов является с палеомагнитной точки зрения нестабильным.

Четвертичные (или верхнекайнозойские) оливиновые базаниты из Джос плато (JP-2) имеют стабильное направление остаточной намагниченности (ОН). Основными магнитными минералами являются нестехиометрические магнетиты с небольшим присутствием гематита. ОН горных пород является вторичной, имея вероятно химическое происхождение ($I = 21{,}4°$; $D = 17{,}3°$; $\varphi_p = 72{,}9°$ N; $\lambda_p = 92{,}2°$ E).

Среднее направление ОН четвертичных (или верхнекайнозойских) оливиновых базальтов с трех мест Бию плато (BP-2; BP-3; BP-4) характеризовано следующими величинами: $I = -3,9°$; $D = 186,5°$; $\varphi_p = 79,2°$ N; $\lambda_p = 154,9°$ E. Магнитными минералами в этих породах являются титаномагнетиты и твердые растворы ильменито-гематитов.

Юрские щелочные гранит-порфиры из Джос плато (JP-9) имеют малоинтенсивную естественную ОН, вероятно химического происхождения. Исчисленный палеомагнитный полюс ($\varphi_p = 70,7°$ N; $\lambda_p = 259,9°$ E) очень близок полюсу, исчисленному для мезозойских горных пород Африки авторами Mc Elhiny et al. (1968 *in* J. D. A. Piper—A. Richardson 1972).

Результаты показали, что в течение четвертичного и верхнекайнозойского времени Африканская литосферная плита не перемещалась, но с времени возникновения стабильного компонента ОН юрских щелочных гранит-порфиров она переместилась из ее прежнего положения.

Přeložil autor