J Geophys (1981) 50:16–22

Journal of Geophysics

Palaeomagnetism of Upper Cretaceous Volcanics and Nubian Sandstones of Wadi Natash, SE Egypt and Implications for the Polar Wander Path for Africa in the Mesozoic

A. Schult[1], A.G. Hussain[2], and H.C. Soffel[1]

[1] Institut für Allgemeine und Angewandte Geophysik, Universität München, Theresienstr. 41, 8000 München 2, Federal Republic of Germany

[2] Helwan Institute of Astronomy and Geophysics, Helwan, Cairo, Egypt

Abstract. Eighteen sites (342 samples) from Upper Cretaceous Wadi Natash volcanics (24.5° N, 34.5° E) yield a mean direction of magnetization $D=345.4°$, $I=16.7°$ with $\alpha_{95}=8.5°$, $k=21.4$, $N=15$ after AF cleaning resulting in a pole at 69.3° N, 258° E with $A_{95}=5.8°$ All sites have normal polarity consistent with their age and the magnetic stratigraphy in the Cretaceous. From 5 sites (85 samples) from Upper Cretaceous Nubian sandstone at Wadi Natash a mean direction $D=358.1°$, $I=32.0°$ with $\alpha_{95}=8.7°$, $k=143$ (mixed polarity) was obtained after thermal demagnetization. Combined with previous investigations on Nubian sandstone at other locations in Southern Egypt (Schult et al. 1978) this yields a pole at 81.8° N, 223° E with $A_{95}=3.3°$, $N=23$. 9 sites from Eocene Baharia iron ores (27.5° N, 29.0° E) yield a mean direction $D=188.0°$, $I=-43.6°$ and $\alpha_{95}=6.4°$, $k=65$ with a pole at 83.5° N, 139° E and $A_{95}=7°$

In addition the palaeomagnetism of some Tertiary basaltic rocks in Northern Egypt was studied. The polar wander path for Africa in Mesozoic time is presented showing more mobility than in earlier papers. For appropriate reconstructions of South America with respect to Africa the polar wander paths of both continents are substantially in agreement.

Key words: Palaeomagnetism – Africa – Mesozoic polar wander path

Introduction

The Cretaceous polar wander path for Africa is of particular interest because this time coincides with the opening of the Atlantic. An improvement in the time density of known African Cretaceous poles is desirable in order to define the polar wander path in a more detailed fashion for this period of time of about 75 m.y. duration. In this paper the palaeomagnetism of Upper Cretaceous volcanics and Nubian sandstones from Wadi Natash, Egypt is presented. Previous investigations of these formations were carried out by El Shazly and Krs (1973) and by Schult et al. (1978). Palaeomagnetic investigations of Tertiary iron ores and basalts from Baharia Oasis and Qatrani (SW of Cairo) were completed and the results are also presented here. A modification of the apparent polar wander path for Africa in the Mesozoic will be proposed.

Geological Setting

Wadi Natash Volcanics

Figure 1 shows a geological sketch map of the Wadi Natash area and the sampling sites. The volcanics include lava flows of basaltic, andesitic, phonolitic and rarely trachytic composition (El Ramly 1972). They are interbedded in the Nubian sandstone at some localities particularly in the south-western parts of the Wadi. The volcanics are dated as Upper Cretaceous for stratigraphic reasons (Said 1971) consistent with radiometric age determinations yielding ages between 100 and 86 m.y. (El Shazly and Krs 1973; El Shazly 1977). Samples were collected from 17 sites (Fig. 1). Two of them are located at the ring complex of Gabal El Ghorfa which is believed to be cogenetic with the other volcanics (Said 1971).

Wadi Natash Nubian Sandstone

The Nubian sandstone extends over large parts of Southern Egypt and has previously been studied palaeomagnetically at other localities (Schult et al. 1978). The age of the Nubian sandstone is Upper Cretaceous (Said 1971). Samples were collected from 12 sites (Fig. 1), some of them are associated with volcanics (e.g. sites 14, 15 and 26).

Tertiary Rocks from Qatrani and Baharia Oasis

The basalt from Qatrani (20 km SW of Cairo) was extensively sampled at widely spaced localities. This large flow represents one site only, with a mean radiometric age of 26 m.y. (El Shazly 1977). From basaltic rocks in the Baharia oasis, 5 sites were sampled. The basalts, which overlie the Eocene Baharia formation (El Akkad and Issawi 1963) have a radiometric age of 20 m.y. (El Shazly 1977). The sampling of the Baharia iron ores (Schult et al. 1978) was completed at two sites. An Upper Eocene age is attributed to these ores (Said 1971).

Sampling and Measurements

About six oriented blocks were collected from each site except for the Qatrani basalt and Baharia iron-ores where 15 blocks were taken. Cores of 2.5 cm in diameter were drilled from the blocks and cut into specimens of 2.4 cm length. The natural remanent magnetization (NRM) was measured using a spinner fluxgate or a stationary fluxgate magnetometer. Three or four pilot samples from each site of the volcanics were then subjected to alternating field demagnetization in steps up to 1,000 Oe peak value. In Fig. 2a–d vector diagrams show typical examples for the removal of viscous magnetization by AF treatment. All other samples were subjected to AF demagnetization with appropriate peak values according to the vector diagrams for the pilot samples and the characteristic remanent magnetization (CARM) was measured.

0340-062X/81/0050/0016/$01.40

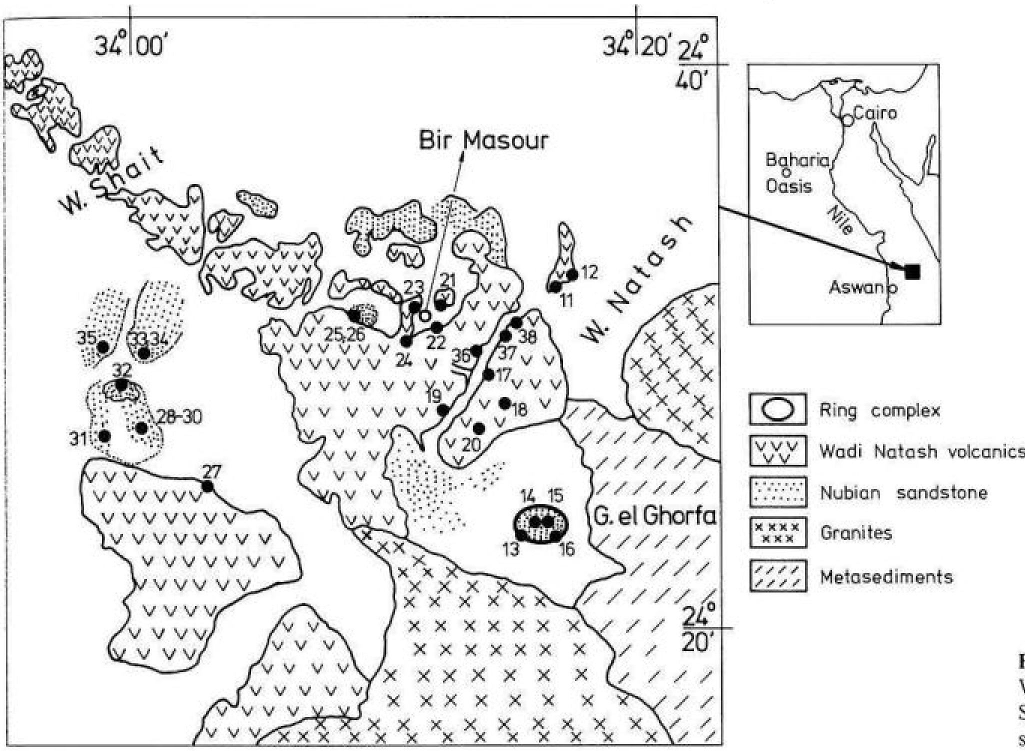

Fig. 1. Geological sketch map of Wadi Natash area (El Ramly 1972; Sabet et al. 1973) showing sampling sites

The samples from Nubian sandstone were subjected to thermal demagnetization because AF treatment had no effect on direction or intensity of the remanent magnetization. Typical vector diagrams of thermal demagnetization of pilot samples are shown in Fig. 3a–c from which the appropriate demagnetization temperature for all samples was chosen.

Results

Wadi Natash Volcanics

The results are summarized in Table 1 and the circles of confidence of the site-mean directions of NRM and CARM are shown in Fig. 4. The within-site scatter as well as the between-site scatter was reduced by the AF treatment. All sites have normal direction of magnetization. The NRM of site 27 (Fig. 2c, Fig. 4) was obviously overprinted by a nearly reversed direction, which was removed by the AF treatment. For three sites no consistent results could be obtained. Giving unit weight to each site the mean direction of CARM of 15 sites is $D=345.4°$, $I=+16.7°$ $\alpha_{95}=8.5°$. The mean palaeopole (69.3° N, 258.1° E, $A_{95}=5.8°$) is rather different from the result of El Shazly and Krs (1973) for the same formation. However their data show a relatively large scatter with $k=4.85$. This would yield a large circle of confidence about the mean giving unit weight to each site, rather than to each sample as was done by El Shazly and Krs (1973). The significance of the difference of the two collections might then be questionable. The angular standard variation of our collection ($s \approx 81 \times k^{-0.5}$, $k=21.4$) equals 17.5 and indicates the usual palaeosecular variation for that latitude (Brock 1971).

The observation of only normal direction of magnetization is consistent with the radiometric age (100–86 m.y.) and the geomagnetic polarity sequence for the Cretaceous. After Lowrie et al. (1980) the long normal polarity sequence lasted from 115–78 m.y. *B.P.* with some uncertain reversals between 109 and 96 m.y.

Wadi Natash Nubian Sandstone

The results are listed in Table 2 and shown in Fig. 5. For a relatively large number of sites no consistent result could be obtained, and site 26 was discarded because the respective VGP is far away from the mean. The average pole position of the remaining 5 sites (82.9° N, 231° E, $A_{95}=6.4°$) is different from the pole position of the Wadi Natash volcanics and agrees well with the pole position of Nubian Sandstone from other areas of Egypt previously published (80.4° N, 227° E with $A_{95}=4.1°$ and $N=18$) (Schult et al. 1978). The best estimate for the pole position is probably a combination of both collections (giving unit weight to each site). Together with a slight correction of the variance used in the previous paper (involved in the orientation of the samples) the new calculation yields a pole position at 81.8° N, 223° E with $A_{95}=3.3°$, $K=84$ and $N=23$ which is only slightly different from the present dipole position (see also Fig. 5).

The majority of the sites of the Upper Cretaceous Nubian sandstone have reversed polarity indicating an age younger than 78 m.y. *B.P.* (younger than the long normal polarity sequence in the Upper Cretaceous) (Schult and Guerreiro 1980).

Other Results

All other palaeomagnetic results are summarized in Table 3, together with the combined results from previous investigations. The pole for the Upper Eocene Baharia iron ores is in agreement with other Tertiary poles for Africa (Schult 1974). The Miocene basaltic flows of Baharia oasis and Oligocene basalts (Qatrani and other basaltic flows in the surroundings of Cairo (Hussain et al. 1976) have somewhat unusual palaeopoles for the Tertiary in relatively low latitudes. However, the number of sites is restricted at the present stage and it seems too early to draw further conclusions.

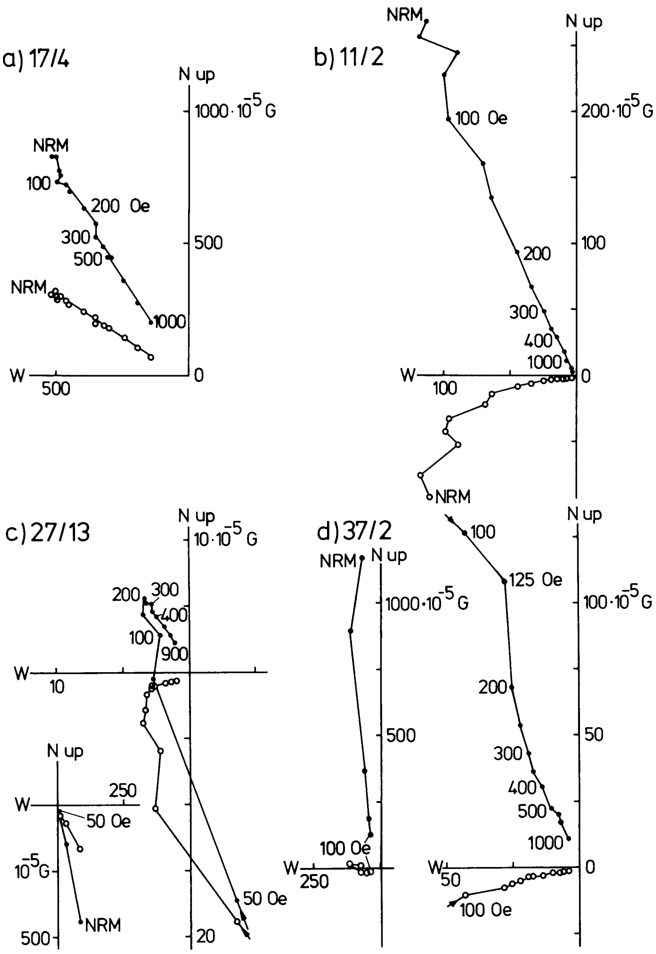

Fig. 2a–d. Vector diagrams showing the variation of the remanence vector during progressive AF demagnetization of samples from volcanic rocks. *Open* and *solid symbols* indicate components in the vertical EW and horizontal planes, respectively. The remanence is relatively stable in **a** and **b** and in some cases as in **c** and **d** it is relatively unstable. In **c** the horizontal component of CARM was overprinted by a reversed unstable component. 1 G $=10^3$ Am^{-1}, 1 Oe $\hat{=}\, 10^{-4}$ T

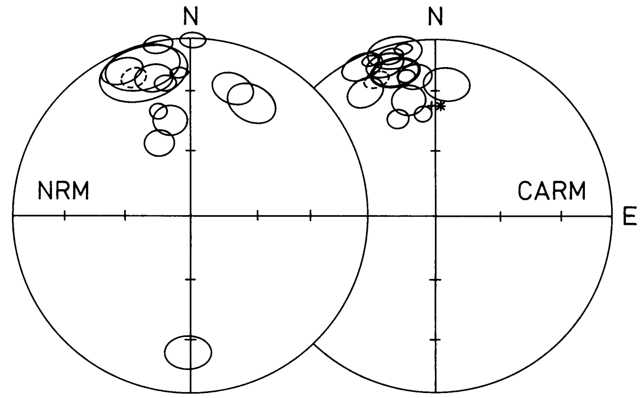

Fig. 4. Equal area projection of circles of confidence of site means for volcanic rocks from Wadi Natash; *broken-line curve* for negative inclination. *Thick curve* denotes circle of confidence of overall mean. *Cross* and *star* denote present central dipole field direction and earth's field direction, respectively

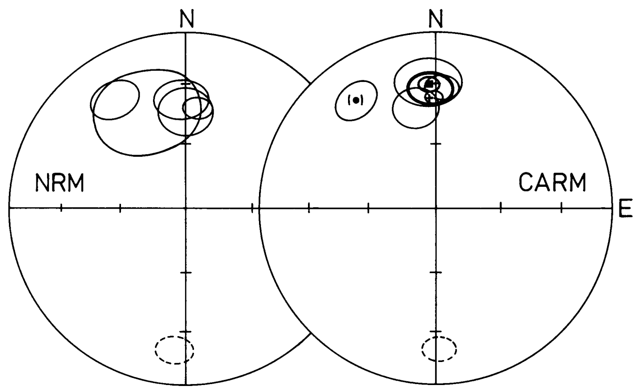

Fig. 5. Circles of confidence of site means for Nubian Sandstone from Wadi Natash. *Broken-line curve* denotes negative inclination, *thick curve* the overall mean omitting the mean in brackets. *Square* marks the overall mean with circle of confidence combining all data (see Table 2), calculated for a site location at Wadi Natash. *Cross* denotes present dipole field direction

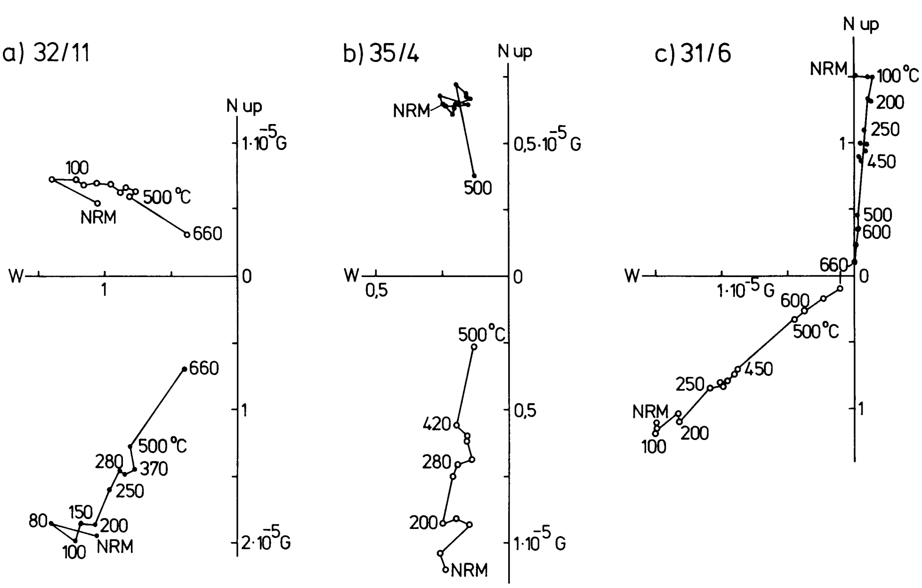

Fig. 3a–c. Vector diagrams showing the variation of the remanence vector during progressive thermal demagnetization of the Nubian sandstone. **a** and **b** *Open* and *solid dots* indicate components in the vertical EW and horizontal planes, respectively. **c** *Open dots* indicate components in the vertical NS plane with its Northern end pointing to the *left* (*W*); *solid dots* indicate components in the horizontal plane

Table 1. Site mean palaeomagnetic results for Wadi Natash volcanic rocks (mean site location 24.4° N, 34.25° E)

Site	NRM					MDF(Oe)	AF(Oe)	CARM					VGP	
	N	D	I	α_{95}	k			N	D	I	α_{95}	k	°N	°E
11	20	343	+16.1	16.1	5	150	250	19	346.6	+ 5.4	9.2	14.2	64.2	247
12	16	18	+25.3	8.0	18.6	80	200	21	345.0	+ 7.2	4.9	41.8	64.7	251
13	19	349	+44.3	7.4	21.0	100	150	21	347.7	+33.3	7.0	21.1	77.0	270
16	16	No consistent result												
17	18	339	−17.6	4.9	50	500	200	19	337.5	−18.1	4.5	56	49.8	250
18	15	28	+28.9	9.9	15.8	40	150	16	4.8	+26.2	8.5	19.7	78.5	190
19	3	343	+12.7	13	51	300	200	4	334.8	+ 7.4	9.1	103	58.1	268
20, 21	No consistent result													
22	20	344	+38.5	3.2	103	150	200	21	353.7	+41.7	4.1	61	84.2	302
23	20	336	+11.2	7.3	20.7	20	200	21	342.4	+11.4	6.3	26	64.8	259
24	22	356	+20.0	2.5	142	200	300	20	352.0	+17.1	2.0	269	72.6	242
25	31	338	+54.0	6.3	17.2	100	200	34	339.8	+41.2	4.3	33.7	71.6	307
27	15	181	+22.3	8.9	19.1	20	270	11	331.6	+21.9	7.4	39.1	60.1	284
36	5	350	+ 2.3	4.9	297	200	200	5	338.3	+ 6.0	2.7	763	60.1	262
37/1	8	1	+ 1.4	4.4	162	30	180	8	349.5	+ 4.5	3.4	275	65.6	241
37/6	4	346	+20.8	6.9	179	150	500	4	352.1	+21.5	6.6	195	74.8	245
38	24	350	+24.9	3.7	64	200	200	24	348.5	+20.4	3.6	68	72.3	255
Mean of site means								15	345.4	+16.7	8.5	21.4	69.3	258.1
													$A_{95}=5.8$	$K=44.9$

N = number of samples, D = declination, I = inclination, α_{95} or A_{95} = radius of 95% confidence circle, k or K = precision parameter, MDF = medium destructive peak field necessary to erase half of NRM intensity by alternating field demagnetitation, AF = peak value of alternating field used for demagnetization (10^4 Oe ≙ 1 T)

Table 2. Site mean palaeomagnetic results for Nubian Sandstone from Wadi Natash (ca. 24.45° N, 34.0° E)

Site	NRM					Cleaning	CARM					VGP	
	N	D	I	α_{95}	k° C	N	D	I	α_{95}	k	° N		° E
26	22	328	+28	9.3	12	450	23	(324.8	+24.5)	8.6	13.4	(54.8	291)
29	22	358	+38	10.2	10	450	21	3.4	+32.0	6.9	22.4	82.6	196
31	19	7	+42	5.6	38	400	19	0.2	+37.1	3.6	90	86.3	211
32	26	184	−20	6.9	18	350	29	178.6	−20.1	6.5	17.7	75.9	220
33	13	0	+44	11.1	15	300	13	350.1	+41.7	9.4	20.4	81.0	303
35	5	339	+40	22	13	500	8	357.2	+28.9	12.8	19.7	80.6	231
No consistent results for sites 14, 15, 28, 30, 34													
Mean of site means (4 normal, 1 reversed)							5	358.1	+32.0	8.7	78.4	82.9	231.4
												$A_{95}=6.4$	$K=143$
Mean of site means (this paper plus Schult et al. 1978; 10 normal, 13 reversed)							23					81.8	222.7
												$A_{95}=3.3$	$K=$ 84

Legend see Table 1

Polar Wander Path for Africa in the Mesozoic

Recent attempts to define the polar wander path for Africa for the Late Mesozoic (Hargraves and Onstott 1980; Hussain et al. 1980) implied relatively great mobility of the pole whereas in earlier papers it was often believed that in the Mesozoic the African palaeopoles were closely grouped. In Table 4 Mesozoic poles for Africa and South America are compiled. The same labels have been used for poles with approximately the same ages. The poles of these two continents may be compared with the aid of reconstructions of continental drift. The African poles and the proposed polar wander path are shown in Fig. 6a confirming the results of Hargraves and Onstott (1980) and Hussain et al. (1980), with some modifications. The "rotated" South American pole positions (together with the African polar wander path) are shown in Fig. 6b and listed with the rotation parameters in Table 4. It has been shown that for the Mesozoic a better coincidence of the South American and African poles can be achieved by not using the pre-drift reconstruction from Bullard et al. (1965) but by assuming a small separation of the continents from the so-called pre-drift position in the Southern Atlantic in Early and Middle Mesozoic time (Schult and Guerreiro 1979). This seems also to be valid for the Late Palaeozoic (Vilas and Valencio 1977). Therefore for the Triassic through Lower Cretaceous a reconstruction was chosen as proposed originally for 110 m.y. *B.P.*, about 15 m.y. after the assumed begin-

Table 3. Site mean palaeomagnetic results from Baharia Oasis (28.2° N, 28.9° E) and Qatrani basalt (29.8° N, 30.7° E)

Site	NRM					AF(Oe)	CARM					VGP	
	N	*D*	*I*	α_{95}	*k*		*N*	*D*	*I*	α_{95}	*k*	° N	° E
a) Baharia Oasis: basalts													
2	19	200.3	+61.1	12.6	7.9	200	18	174.0	− 3.1	9.1	15.1	62.9	222
3	25	213.5	+67.5	5.2	23.5	250	25	192.6	+ 5.2	6.4	21.4	56.6	185
4	No consistent result												
5	3	171.2	+63.2	20.7	36.6	250	4	176.1	− 7.9	5.9	244	65.3	216
6	11	212.6	+54.6	12.5	14.1	150	10	(210.0	+41.1)	15.7	10.3	(30.6	177)
Mean of site means							3	181.2	− 2.0	18.4	46	62.6	206.0
												$A_{95}=16.3$	$K=58$
b) Baharia Oasis: iron ores													
7	31	335.6	+48.2	8.5	10.0	250	27	349.6	+48.9	6.0	22.4	80.8	310
8	36	192.5	−51.0	3.6	43							78.3	95
Mean of site means (this paper plus Schult et al. 1978; 3 normal, 6 reversed)							9	188.0	−43.6	6.4	64.8	83.5	138.6
												$A_{95}=7.0$	$K=55$
c) Qatrani basalt													
1	38	201.4	−57.0	1.7	170	150	41	209.2	−60.2	1.0	472	63.8	87
Mean of site means (this paper plus Hussain et al. 1976; all reversed)							3	197.0	−59.1	8.7	202	72.7	81
												$A_{95}=12.7$	$K=95$

Legend see Table 1

Table 4. Mesozoic palaeomagnetic poles for Africa and South America

Pole	Africa Formation	Age m.y.	Pole Position			South America Formation	Age m.y.	Pole Position			Rotated[a]	
			° N	° E	A_{95}			° N	° E	A_{95}	° N	° E
1	Triassic mean		69	263	4.9	Triassic mean		78	56	6.3	70	247
2	Stormberg, Karroo	154–190	65	262	11.7	Chon-Aike	157–173	87	17	6	63	261
3	Hoachanas	161–173	62	252	7	Maranhão	158±12	85	83	6.9	62	250
4	Mateke Hills	~168	59	260	8.3							
5	Moroccan volcanics	Kl	44	251	10	R. de los Molinos	129–150	78	193	8	48	249
						Almafuerte	123±4	72	205	6	41	251
						C. Colorado	121±3	83	196	10	53	252
6	Kimberlite pipes	122–162	36	277	17							
7	Kaoko lavas	110–128	48	267	2	Serra Geral	115–130	78	234	5.7	47	261
						Serra Geral	119±5	85	295	3.7	57	266
						Maranhão	118±6	84	261	1.9	54	264
8	Mlanje Massif	116–128	60	262	12	Rumipalla	<121	88	326	9	60	261
9	Lupata volcanics	106–111	62	260	3.5	La Serena	~110	81	29	4.5	68	261
10	Wadi Natash volc.	77–100	69	258	5.8	Cabo de S. Agostinho	85–99	88	135	4.5	68	247[b]
11	Kimberlite pipes	82–88	61	224	7.4							
12	Volcanics Sicily	71–81	62	229	3.8							
13	Moroccan sediments	Kl–u	75	217	5.5							
14	Nubian sandstone	Ku	82	230	3.4	Poços de Caldas	63–80	81	53	10	85	211[c]
15	Red Siltstone	Ku	79	208	6							
16	Tororo	Ku(?)	76	195	9							

Rotation parameters for South America from present with respect to Africa (Sclater et al. 1977):

[a] 48.3° about a pole at 49.2° N, 31.8° W (originally estimated for a reconstruction for 110 m.y. *B.P.*, here tentatively taken as "pre-drift" position; see text)

[b] 40.1° about a pole at 56.6° N, 34.1° W, estimated for 95 m.y. *B.P.*

[c] 32.8° about a pole at 67.3° N, 39.5° W, estimated for 80 m.y. *B.P.*.

References for African poles: 2 Average of three Lower Jurassic poles after McElhinny (1973); 6, 11 Hargraves and Onstott (1980); 10, 14 this paper; other poles see Schult and Guerreiro (1979). South American poles: 9 Palmer et al. (1980); 10 Schult and Guerreiro (1980); other poles see Schult and Guerreiro (1979)

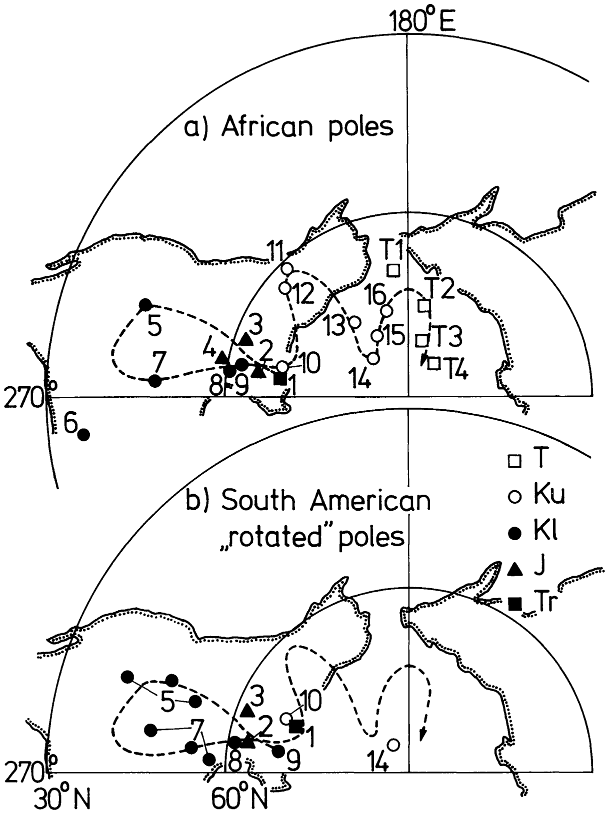

Fig. 6. **a** Triassic mean, Jurassic, Cretaceous and some Palaeocene poles for Africa and proposed apparent polar wander path. Actually the *dotted line* indicates the trend of pole positions and the "path" is of variable width depending on the α_{95} values of the poles. Labels 1–16 refer to Table 4. Tertiary poles: T1 Upper Eocene volcanics in Northern Egypt (Hussain et al. 1979); T2 and T3 Oligocene Ethiopian South-Eastern (Schult 1974) and Western (Brock et al. 1970) plateau basalts; T4 Eocene Baharia iron ores (Table 3). **b** "Rotated" South American poles using reconstructions of continental drift. Labels and "rotation" parameters see Table 4. Same labels in **a** and **b** refer to poles with approximately same ages. The indicated polar wander path is reproduced from **a**

ning of the rifting (Sclater et al. 1977). For the Upper Cretaceous the respective reconstructions for 95 and 80 m.y. *B.P.* after Sclater et al. (1977) were used.

Most of the African poles cluster around 65° N and 260° E but a few poles (5, 6, and 7 in Fig. 6a) indicate a loop of the polar wander path to lower latitudes in the Lower Cretaceous. Pole 7 (Kaoko lavas) seems to be reliable but unfortunately pole 6 (for Kimberlite pipes) was derived from only 4 sites with a relative large circle of confidence and pole 5 (Moroccan volcanics) is from rocks located in the tectonically active Atlas area. However, the loop to low latitudes is confirmed by several Lower Cretaceous "rotated" South American poles (Fig. 6b). There is also agreement of the pole positions of both continents at the beginning (Triassic/Jurassic) and at the end of the loop (early Late Cretaceous). Particularly the pole for the Wadi Natash volcanics (10) is near the "rotated" pole for Cabo de Santo Agostinho (10) of the same age (Schult and Guerreiro 1980), assuming a reconstruction for 95 m.y. *B.P.*

For late Upper Cretaceous times poles 11 and 12 imply another loop. Pole 12 is from South East Sicily which may be considered as part of the African plate (Schult 1973). For pole 11 (Kimberlite pipes) previous data (McFadden and Jones 1977) were recently improved by Hargraves and Onstott (1980). This loop is not recorded by the presently available scarce South American data for the Upper Cretaceous. The pole for the Nubian sandstone (14) is consistent with other high latitude Upper Cretaceous poles (13–16) for Africa and also consistent with the "rotated" pole 14 from South America (Schult and Guerreiro 1980) for a reconstruction for 80 m.y. *B.P.*

The location of selected Eocene and Oligocene African poles (Fig. 6a) may be interpreted as another loop of the polar wander path before it approaches the present geographic pole in Late Tertiary. Relative low latitude pole positions (e.g. Table 3) indicate further excursions in Tertiary time. However no definitive conclusions can be drawn from the data presently available.

The proposed African polar wander curve for the Mesozoic is different in detail from that transferred from North American data (Irving 1977) by applying the rotation poles for the opening of the North Atlantic according to Sclater et al. (1977). Similar differences exist when comparing with other indirectly obtained polar wander curves (Van der Voo and French 1974). There is agreement only in Late Triassic and Jurassic. The North American polar wander path is much better defined than the African one and therefore further confirmations of the African Mesozoic data are necessary. On the other hand large differences also exist for the Late Palaeozoic (e.g. Van den Berg 1979) and therefore reconstructions of drift of continents adjacent to the North Atlantic other than those usually used may be considered.

Acknowledgements. We thank Professor Dr. G. Angenheister and Professor Dr. M. Fahim for their advice and help. We also thank H. Winhard for carrying out part of the measurements. The research has been done within the bilateral agreement between the Deutsche Forschungsgemeinschaft (DFG), the Gesellschaft für Technische Zusammenarbeit (GTZ), and the Academy of Scientific Research and Technology (ASRT) of Egypt. The financial support of the DFG and GTZ is greatfully acknowledged.

References

Brock, A.: An experimental study of palaeosecular variation. Geophys. J. R. Astron. Soc. **24**, 303–317, 1971

Brock, A., Gibson, I.L., Gacii, P.: The palaeomagnetism of the Ethiopian flood basalt succession near Addis Ababa. Geophys. J. R. Astron. Soc. **19**, 485–497, 1970

Bullard, E.C., Everett, J.E., Smith, A.G.: The fit of the continents around the Atlantic. Philos. Trans. R. Soc. A, **258**, 41–75, 1965

El Akkad, S., Issawi, B.: Geology and iron ore deposits of the Bahariya Oasis. Geol. Surv., Cairo, Paper No. 18, 1963

El Ramly, M.F.: A new geological map for the basement rocks in the Eastern and south Western Deserts of Egypt, scale 1:1,000,000. Ann. Geol. Surv., Cairo, vol. **2**, 1–18, 1972

El Shazly, E.M.: The geology of the Egyptian region.: In: The Ocean Basins and Margins, Vol. **4A**, A.E.M. Nairn, W.H. Kanes, and F.G. Stehli, eds.. pp. 379–444. New York: Plenum Press 1977

El Shazly, E.M., Krs, M.. Paleography and paleomagnetism of the Nubian sandstone, Eastern Desert of Egypt. Geol. Rundsch. **62**, 212–225, 1973

Hargraves, R.B., Onstott, T.C.: Paleomagnetic results from some Southern African kimberlites, and their tectonic significance. J. Geophys. Res. **85**, 3587–3596, 1980

Hussain, A.G., Schult, A., Soffel, H., Fahim, M.: Magnetization and palaeomagnetism of Abu Zaabal and Abu Rawash basalts (Egypt). Helwan Obs. Bull. **134**, 1–15, 1976

Hussain, A.G., Schult, A., Soffel, H.: Palaeomagnetism of the basalts of Wadi Abu Tereifiya, Mandisha and dioritic dykes of Wadi Abu Shihat, Egypt. Geophys. J. R. Astron. Soc. **56**, 55–61, 1979

Hussain, A.G., Schult, A., Soffel, H.: Preliminary polar wander path of Egypt between Cretaceous and Quaternary. Berliner Geowissenschaftliche Abhandlungen A/**19**, 93–94, 1980

Irving, E.: Drift of the major continental blocks since the Devonian. Nature **270**, 304–309, 1977

Lowrie, W., Channell, J.E.T., Alvarez, W.: A review of magnetic stratigraphy investigations in Cretaceous pelagic carbonate rocks. J. Geophys. Res. **85**, 3597–3605, 1980

McElhinny, M.W.: Palaeomagnetism and plate tectonics. London: Cambridge University Press 1973

McFadden, P.L., Jones, D.L.: The palaeomagnetism of some upper Cretaceous kimberlite occurrences in South Africa. Earth Planet. Sci. Lett. **34**, 125–135, 1977

Palmer, H.C., Hayatsu, A., MacDonald, W.D.: Palaeomagnetic and K-Ar age studies of a 6 km-thick Cretaceous section from the Chilean Andes. Geophys. J. R. Astron. Soc. **62**, 133–153, 1980

Sabet, A.H., Tsogoev, V.B., Bessonenko, V.V., Babourin, L.M.: Geological map of the central Eastern Desert of Egypt. Cairo: The Geological Survey of Egypt and Mining Authority 1973

Said, R.: Explanatory notes to accompany the geological map of Egypt. The Geological Survey of Egypt, Paper No. 56, 1971

Schult, A.: Palaeomagnetism of Upper Cretaceous volcanic rocks in Sicily. Earth Planet. Sci. Lett. **19**, 97–100, 1973

Schult, A.: Palaeomagnetism of Tertiary volcanic rocks from the Ethiopian Southern Plateau and the Danakil block. J. Geophys. **40**, 203–212, 1974

Schult, A., Soffel, H.C., Hussain, A.G.: Palaeomagnetism of Cretaceous Nubian sandstone. J. Geophys. **44**, 333–340, 1978

Schult, A., Guerreiro, S.D.C.: Palaeomagnetism of Mesozoic igneous rocks from the Maranhao Basin, Brazil, and the time of opening of the South Atlantic. Earth Planet. Sci. Lett. **42**, 427–436, 1979

Schult, A., Guerreiro, S.D.C.: Palaeomagnetism of Upper Cretaceous volcanic rocks from Cabo de Sto. Agostinho, Brazil. Earth Planet. Sci. Lett. **50**, 311–315, 1980

Sclater, J.G., Hellinger, S., Tapscott, C.: The paleobathymetry of the Atlantic Ocean from the Jurassic to the present. J. Geol. **85**, 509–552, 1977

Van den Berg, J.: Paleomagnetism and the changing configuration of the western Mediterranean area in the Mesozoic and Early Cenozoic eras. Geol. Ultraiectina No. **20**, 1979

Van der Voo, R., French, R.B.: Apparent polar wandering for the Atlantic-bordering continents: Late Carboniferous to Eocene. Earth Sci. Rev. **10**, 99–119, 1974

Vilas, J.F., Valencio, D.A.: Palaeomagnetism of South American rocks and the Gondwana continent. IV. International Gondwana Symp., Calcutta, Papers Vol. **II**, 923–930, 1977

Received May 18, 1981, Revised Version July 17, 1981
Accepted July 20, 1981