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Palaeomagnetism of Cretaceous Nubian Sandstone, Egypt

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Abstract. From Upper Cretaceous Nubian Sandstone and iron ores in the Aswan area (25° N, 33° E) about 200 cores from 19 sites were collected. After thermal demagnetization the remanent magnetization of 18 sites showed stable components. Giving unit weight to each site direction (secular variation is probably not averaged out in the individual sites) the overall mean direction is $D=178°$, $I=-29.3°$ with $\alpha_{95}=5.8°$ (6 sites have normal and 12 sites reversed polarity). This yields a pole at 80° N, 227° E ($d_p=3.7°$, $d_m=6.3°$). This pole is nearer to the present geographic pole than most of the other Cretaceous poles for Africa but in view of only few known Cretaceous poles the agreement is fairly good.

The mean direction of magnetization of 7 sites of Baharia Oasis iron ores (28° N, 29° E) is $D=8.1°$, $I=+41.6°$ with $\alpha_{95}=7.0°$ (2 normal, 5 reversed polarities). The pole position (81.5° N, 145° E) is consistent with the probable Tertiary age of this formation.

Key words: Palaeomagnetism – Cretaceous sediments – Africa.

1. Introduction

Previous palaeomagnetic investigations have been carried out on Nubian Sandstone near Aswan and also on Upper Cretaceous volcanic rocks of Wadi Natash (about 150 km ENE of Aswan) by El Shazly and Krs (1973). In this paper palaeomagnetic results from the Nubian Sandstone in the Eastern desert of Egypt and in the Baharia Oasis are presented (Fig. 1).

Nubian Sandstone consisting of brownish, almost horizontal sandstone beds, often rich in iron ores and with interlayers of iron ore, is widely distributed in Egypt. The Nubian Sandstone was deposited in tropical and subtropical climates in shallow water (marine and non-marine) environments (El Shazly and Krs, 1973).

Generally an Upper Cretaceous age is attributed to the Nubian Sandstone

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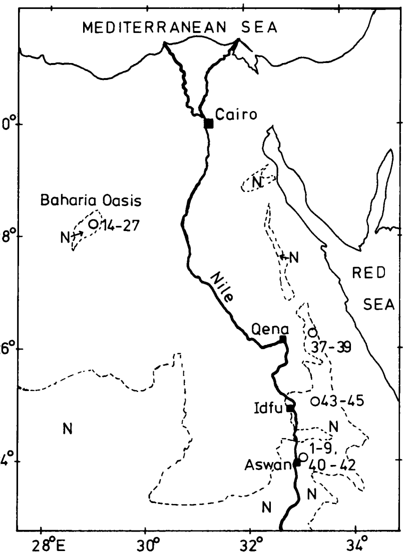

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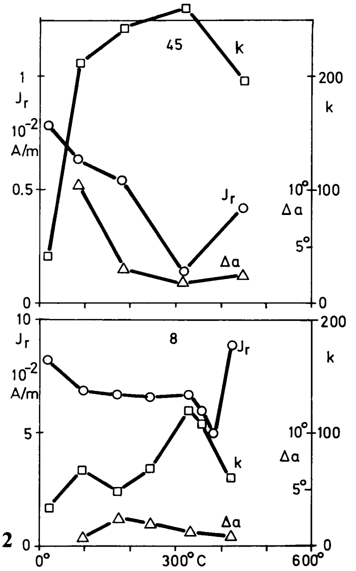

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Fig. 1. Map showing sampling sites and distribution of Nubian Sandstone (*N*)

Fig. 2. Intensity of magnetization J_r, precision parameter k, and change of direction of magnetization (change of azimuth Δa) as a function of increasing stepwise thermal demagnetization for typical cases (No. 8: iron ore, No. 45: sandstone)

according to fossils, at least in the South of Egypt (Said, 1962). The interlayers of iron ores occurring along the Nile valley have been formed together with the surrounding rocks and are therefore also of Upper Cretaceous age (El Shazly and Krs, 1973). The ore consists nearly completely of haematite (Gheith, 1955). The origin of the ore deposits in Baharia Oasis is not so clear. Probably the ore was formed by replacement during hydrothermal activities in Tertiary (post Eocene according to Attia (1955), or in Oligocene-Miocene according to Said (1962)). This Tertiary age is consistent with the palaeomagnetic results as shown later. The ore in the Baharia Oasis shows great variation with regard to its composition. It consists mainly of goethite, some haematite, and magnetite in minor amounts (Gheith, 1955).

2. Sampling and Measurements

In Figure 1 the location of the 34 sites sampled are shown. A total of about 330 cores (2.5 cm diameter) has been collected from the Nubian Sandstone and from the iron ore with a portable drilling machine (see Tables 1 and 2). Specimens (2.5 cm long) were cut from the cores. The natural remanent magnetization (NRM) was measured with a "Digico" spinner magnetometer or with a "Förster" flux gate magnetometer. Because alternating field demagnetization up to 2000 Oe peak field had no significant influence on the intensity or the direction of magnetization the specimens were subjected to thermal demagnetization.

Table 1. Site mean palaeomagnetic results from Aswan, Quena and Idfu

Site	Classification	Location		N	J_r (10^{-2} A/m)	NRM		α_{95} (°)	k	Cleaning (° C)	N	J_r (10^{-2} A/m)	CARM		α_{95} (°)	k	Pole position	
		° N	° E			D(°)	I(°)						D(°)	I(°)			° N	° E
1	iron ore	24.1	33.0	4	6.7	177.5	−42.9	9.5	94	400	4	5.9	176.0	−36.5	8.0	134	84.7	259
2	iron ore	24.1	33.0	8	5.6	179.7	−14.0	7.6	54	400	8	3.7	169.3	−12.9	10.0	32	69.7	245
3	iron ore	24.1	33.0	3	not measured						3	0.8	189.3	+ 6.9	27.9	21	61.0	193
4/1	iron ore	24.1	33.0	9	6.3	181.6	−28.1	3.9	182	400	9	5.2	179.4	−27.7	3.9	180	80.6	217
4/10	iron ore	24.1	33.0	9	8.1	180.0	−24.1	2.4	479	400	9	6.3	179.8	−22.9	2.6	406	77.9	214
5	iron ore	24.1	33.0	5	6.5	183.4	−28.4	12.6	38	400	5	5.1	182.9	−35.3	3.5	476	84.7	181
6	sandstone	24.1	33.0	12	1.4	177.8	−47.9	3.6	148	400	11	1.1	179.4	−34.2	2.7	285	84.7	219
7	iron ore	24.1	33.0	14	6.5	180.0	−22.1	4.0	99	400	12	6.0	176.2	−21.3	5.8	57	76.5	229
8	iron ore	24.1	33.0	12	7.0	175.0	−29.2	7.9	31	360	12	6.2	177.0	−29.7	4.2	107	81.4	233
9(−)	sandstone	24.1	33.0	5	1.1	183.8	−50.1	8.5	82	360	6	1.0	187.0	−48.9	11.0	38	81.4	78
9(+)	sandstone	24.1	33.0	6	0.8	359.6	+20.2	7.8	76	360	7	0.8	355.0	+29.7	7.5	66	80.6	244
40	sandstone	24.1	33.0	21	no consistent result													
41	sandstone	24.1	33.0	21	0.8	24.9	+18.0	9.1	9	350	13	0.6	353.4	+24.0	9.6	20	76.0	243
42	sandstone	24.1	33.0	15	0.7	19.1	+35.0	20.8	4	350	7	0.15	10.7	+31.8	19.0	11	77.8	155
37	sandstone	26.4	33.3		no consistent result													
38	sandstone	26.4	33.3	9	0.7	349.0	+37.4	8.8	35	300	10	0.35	346.2	+37.9	8.6	32	76.3	283
39	sandstone	26.4	33.3	3	0.7	346.0	+20.1	19.0	43	350	5	0.1	350.8	+25.7	15.4	26	74.5	249
43	sandstone	25.1	33.3	18	0.45	179.0	−32.8	14.2	7	300	11	0.25	172.4	−31.6	7.1	41	79.3	256
44	sandstone	25.0	33.6	10	0.34	193.4	−32.1	18.9	7	300	10	0.13	178.4	−41.9	4.7	107	88.3	273
45	sandstone	25.0	33.6	21	0.77	359.3	+44.3	6.8	23	300	13	0.10	357.9	+37.2	7.7	30	85.3	238
Mean of site means, 6 sites normal, 12 sites reversed											18	–	177.7	−29.3	5.8	37	80.4	227
											$d_p=3.7°$, $d_m=6.3°$, $A_{95}=4.1°$							
Mean of site means (this paper plus El Shazly and Krs, 1973) (7 sites normal, 15 reversed)											22	–	178.6	−27.3	5.6	32	79.3	220
											$d_p=3.6°$, $d_m=6.2°$, $A_{95}=4.0°$							

N=number of samples, J_r=remanent magnetization, D=declination, I=inclination, α_{95} or A_{95}=radius of the 95% circle of confidence, k=precision parameter, $CARM$=characteristic remanence (after thermal cleaning)

Table 2. Site mean palaeomagnetic results from Baharia Oasis (mean location 28.2° N, 28.9° E). For legend see Table 1

Site	Classification	N	J_r (10^{-2}A/m)	NRM		α_{95} (°)	k	Cleaning (° C)	N	J_r (10^{-2}A/m)	CARM		α_{95} (°)	k	Pole position	
				D(°)	I(°)						D(°)	I(°)			° N	° E
14	iron ore deposit	2	12.0	193.8	−33.5	13.0	373	thermal cleaning not possible							79.5	189
15	Nubian Sandstone	15	no consistent result													
16	Nubian Sandstone	12	no consistent result													
17	Limestone with iron oxides	12	1.6	359.9	+39.1	6.6	44	500	10	0.7	358.0	+38.5	8.3	35	83.2	225
19	iron ore		no consistent result					480	4	10.5	186.5	−36.2	7.4	154	80.0	171
20	iron ore	6	13.5	187.1	−40.6	6.4	112	480	5	8.6	184.1	−39.6	7.8	98	83.2	175
21	iron ore (goethite)	15	no consistent result													
22	iron ore	10	no consistent result													
23	iron ore	5	11.5	217.2	−37.5	18.7	18	350	5	3.8	207.5	−46.7	22.8	12	65.8	113
24	ferruginous sandstone	5	1.8	9.8	+45.8	27.8	9	500	5	1.5	3.4	+48.3	23.0	12	86.8	96
26	iron ore		no consistent result													
27	iron ore	15	15.5	196.9	−45.9	5.2	56	thermal cleaning not possible							75.0	118
Mean of site means (2 sites normal, 5 reversed)									7	–	8.1	+41.6	7.0	75	81.5	145.2
											$d_p=5.2°$, $d_m=8.6°$, $A_{95}=7.6°$					

In Figure 2 typical thermal demagnetization results for sandstone and iron ore are shown. There is only a slight reduction of the within site scatter (increase of precision parameter) of the directions in most cases accompanied by a slight drop of intensity of NRM. The total change of mean directions generally is also small. Above 300° to 400° an increase of intensity was observed in most cases together with an increase of scatter of the directions. Depending on the results of 3 or 4 pilot samples for each site the most appropriate thermal demagnetization temperature was chosen for all samples (see Tables 1 and 2). In some cases however thermal cleaning was not possible because the samples disintegrated during heating.

3. Discussion

3.1. Nubian Sandstone and Iron Ore of the Eastern Desert

Site mean directions with the respective circles of confidence before and after thermal cleaning are shown in Figure 3 for Nubian Sandstone and for iron ore. Sites from the Nubian Sandstone have mixed polarity, sites from iron have only reversed polarity. After inverting different polarities to one polarity in the usual way, there is no significant difference in the mean direction between normal and reversed sites or between sandstones and iron ores (see Fig. 4).

For the magnetic latitude of Egypt the angular standard deviation s for the direction due to palaeosecular variation should be about 17° with lower and upper limits of 10° and 25° respectively (e.g. Brock, 1971) yielding a precision parameter k of about 23 with the respective limits $k=66$ and $k=11$ $(s \approx 81(k)^{-0.5})$. Half of the sites have $k \geqq 66$ (see Table 1). It can therefore be assumed that the directions of magnetization of samples from one particular site contain only a relatively short interval of palaeosecular variation. The smaller k (larger angular standard deviation) for the other sites may at least partly be due to unstable magnetic properties of the samples and not due to palaeosecular variation. Therefore the best estimation of the overall mean is probably

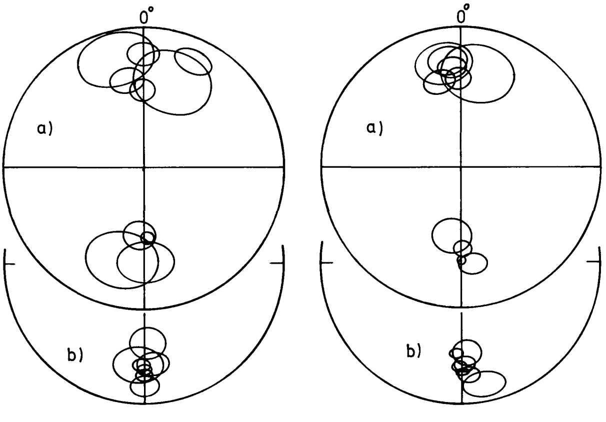

Fig. 3a and b. Equal area projection of site means (only the respective circles of confidence are shown) for sandstone (**a**) and iron ore (**b**) before (left side) and after (right side) thermal demagnetization

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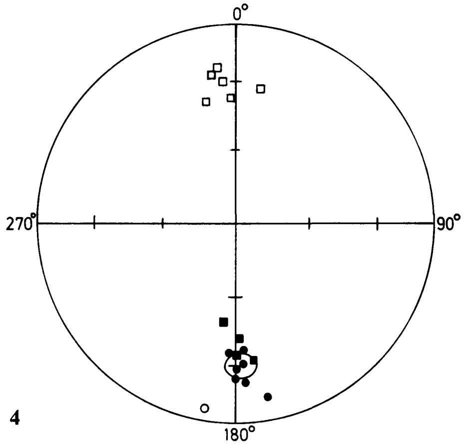

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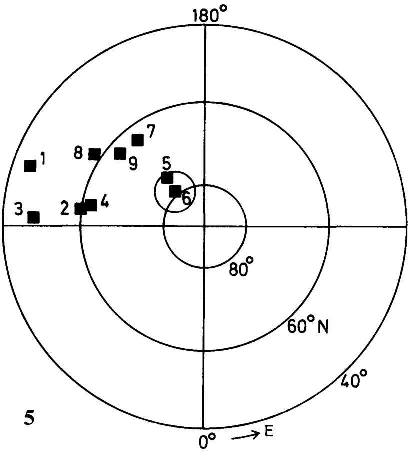

Fig. 4. Site means and overall mean circle of confidence for the Aswan area after thermal demagnetization. Squares denote the sandstone, circles the iron ore. *Open symbols:* oositive inclination. *Closed symbols:* negative inclination

Fig. 5. Cretaceous pole positions for Africa. For details see Table 3. Pole No. 6 with circle of confidence is from this paper

the average of the site mean direction giving unit weight to each site. The result $D=178°$, $I=-29.3°$, $\alpha_{95}=5.8°$ is in agreement with the previous one given by El Shazly and Krs (1973): $D=183°$, $I=-18.2°$, $\alpha_{95}=11°$. For further discussion the combination of the results of the two collections is used (see Table 1).

In Table 3 and Figure 5 Cretaceous pole positions for Africa are compiled including a pole position for South East Sicily which may be regarded as part of the African plate (e.g. Schult, 1973). Considering that the data represent a time span of about 70 My all Cretaceous pole positions for Africa are in fairly good agreement.

3.2. *Baharia Oasis*

The results are given in Table 2. From 12 investigated sites only 7 sites consisting of iron ores or iron ore rich sediments turned out to be suitable for palaeomagnetic measurements (5 normal, 2 reversed polarity). In the calculation of the mean two additional sites were included from which the samples could not be demagnetized thermally. This seems to be justified as the influence of thermal demagnetization on the directions was in most cases quite small.

The palaeopole for the Baharia Oasis sites is at 81.5° N, 145° E. This pole is significantly different from the pole for the Nubian Sandstone and iron

Table 3. Summary of African Cretaceous pole positions

No.	Age (My)	Formation	Site location	Pole position		$A_{95}(d_p, d_m)$	Reference
				° N	° E		
1	K_l	Moroccan volcanics	32° N, 354° E	44	251	10	Bardon et al. (1973)
2	116–128	Mljanje Massif	16° S, 36° E	60	262	12	Briden (1967)
3	110–128	Koaka lavas	20° S, 14° E	48	267	(2.5; 3.9)	Gidskehaug et al. (1975)
4	106–111	Lupata volcanics	17° S, 34° E	62	260	3.5	Gough et al. (1963)
5	K_l	Moroccan sediments	32° N, 353° E	75	217	5.5	Hailwood (1975)
6	K_u	Nubian sandstone, iron ores	25° N, 33° E	79	220	4.0	This paper
7	81–90	Wadi Natash volcanics	24° N, 34° E	64	218	(2.8; 5.6)[a]	El Shazly and Krs (1973)
8	83–89	Kimberlite pipes	29° S, 25° E	58	237	15.3	McFadden et al. (1977)
9	71–81	Volcanics, SE-Sicily	37° N, 15° E	63	229	3.8	Schult (1973)

[a] d_p, d_m was calculated from the sample means and not from the site means

ores of the Eastern desert and is in good agreement with Tertiary poles for Africa (e.g. Schult, 1974). This finding confirms the probably Tertiary age of the iron ores in the Baharia Oasis.

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