

# Paleomagnetism and AMS of Early Cretaceous Rocks from Mishbeh Ring Complex, South Eastern Desert, Egypt

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# ABSTRACT

Rock magnetic, paleomagnetic and magnetic fabric characteristics of the Mishbeh ring complex of Cretaceous age (Ca: 142 ± 15 Ma) have been investigated for establishing a new paleomagnetic pole for this Era. Rock magnetic measurements performed on these rocks reveal that both magnetite and titano-magnetite, with traces of hematite, are the principal magnetic carriers. Demagnetization processes reveal a single magnetic component of interpreted primary origin that reflects the age of this complex. The (ChRM) component isolated from Mishbeh ring complex has a mean direction of  $D/I=332^{\circ}/22^{\circ}$ , k=71.4,  $\alpha_{95}=7.1$ , and N=94 specimens from six sites. This direction corresponds to a north paleomagnetic pole at *Lat.* 58°N and *Long.* 290°E, with K=70 and  $A_{95}=9.2$ . The consistency of resultant pole with the Cretaceous poles from Egypt and other parts of Africa implies the primary origin of this magnetization. Magnetic fabric measurements on these rocks indicate that most parts of the complex retain their primary fabric. These rocks are characterized by a weak foliated fabric with no signs of high degree of deformation.

**KEYWORDS:** Paleomagnetism; Magnetic fabric; Mishbeh ring complex; South Eastern Desert; Egypt

## INTRODUCTION

The ring complexes of the South Eastern Desert of Egypt are similar in composition to those found elsewhere in Africa reported that the ring complexes of Egypt range in age from Cambrian (Ca: 554 Ma) to Late Cretaceous (Ca: 89 Ma) with wide variety of rock types, ranging from mafic to silicic and from under-saturated to quartz bearing. They increase in age westwards along a postulated N60°E lineation [1-7]. Figure 1 shows seventeen ring structures identified in the Egyptian Eastern Desert.

The Mishbeh ring complex is one of the Egyptian ring complexes located in the South East Desert at a midway distance between the two ring complexes of Gabal Nigrub El Fogany to the east and Gabal El Naga to the west Figure 1. It is of Late Jurassic to Early Cretaceous (Ca: 142  $\pm$  15 Ma) age [8]. Its peak rises up to 1353 m above sea level and lies at the intersection of latitude 22° 42' 52" N, and longitude 34° 41' 27" E. It is a relatively large complex, about 8 km across that is characterized by the slight differentiation of its rocks, hardly recognizable ring nature and rather complicated internal structure in Figure 2. (a) greenish gray coarse-grained alkaline syenites, (b) thick ovalshaped alkaline syenite dyke enclosing a block of basement rocks formed of granites, granodiorites, gneisses and metavolcanics cut by numerous post-granite dykes, (c) stock-like nepheline-bearing body, and (d) cross cutting dykes and veins [9].

The present study summarizes results of rock-magnetic, paleomagnetic and magnetic fabric investigations of well dated alkaline rock from Mishbeh ring complex (Ca:  $142 \pm 15$  Ma), located in the South Eastern Desert of Egypt, to give clear information about the direction of the geomagnetic field in the Early Cretaceous as well as the position of paleomagnetic pole [8].

## SAMPLING AND METHODS

Ninety-four oriented hand samples were collected from six sites at the main mass of Gabal Mishbeh ring complex and oriented with magnetic compass in Figure 2. Areas of high alternation were avoided and samples from only fresh exposures were collected. In the laboratory, one-inch core samples have been drilled and then cut into standard specimens with dimension  $(2.5 \times 2.2 \text{ cm})$  yielding ninety-four specimens.

The measurements have been carried out in three different laboratories; National Research Institute of Astronomy and Geophysics (NRIAG), Helwan, Egypt, Institute of Geophysics,

According to El Ramly et al. Mishbeh ring complex consists of:

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Figure 2: Photogeological map of the Gabal Mishbeh ring complex (after El Ramly et al., 1971) with locations of the collected samples.



Figure 3: Thermomagnetic curves for specimens from Mishbeh ring complex.

ninety-four specimens have been measured using both Molspin Spinner Magnetometer and Cryogenic SQUID Magnetometer of sensitivity about  $1 \times 10^8$  mA/m; the high resolution of used magnetometers enables detecting weak magnetized specimens. Ranges of the NRM intensities for sites from Gabal Mishbeh ring complex are shown in Table 1.

Table 1: Ranges of the NRM intensity of sites from Gabal Mishbeh ring complex.

Site	No. specimens	NRM (emu/cc)		
Site 1	12	~ 3 × 10.9		
Site 2	20	~1 × 10 <sup>.10</sup>		
Site 3	15	~2 × 10 <sup>-8</sup>		
Site 4	10	~2 × 10 <sup>.10</sup>		
Site 5	12	~2 × 10 <sup>.9</sup>		

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Several rock magnetic experiments have been carried out to identify the magnetic minerals that may be responsible for magnetization; including measuring the Natural Remanent Magnetization (NRM), a construction of Isothermal Remanent Magnetization (IRM) acquisition curve, Back field determination, Hysteresis Loops and Curie temperature determination (Thermomagnetic analysis). All samples were subjected to stepwise thermal and Alternating Field (AF) demagnetization. Vector components were identified from visual inspection of demagnetization diagrams [10] and directions have been calculated using Principal Component Analysis (PCA) [11]. Site means were calculated using Fisher statistics [12].

### ROCK MAGNETIC RESULTS

The initial Natural Remanent magnetization intensities for the whole

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### Thermomagnetic analysis (Js-T curve)

This analysis has been performed on 9 specimens representing all rock types by applying a field of (0.7T) to saturate the specimens and heating them in air to  $^{7}700^{\circ}$ C and subsequently cooling them back to room temperature in zero magnetic field. Saturated magnetization was measured continuously during heating plus cooling (Js-T) using a Polish made balance. The heating-cooling cycle repeated for the same specimens for monitoring any changes due to the initial heating process.

Studied specimens show two different behaviors; the first one with Curie temperatures ranging from 620°C to 675°C (e.g., Ms63) revealing the presence of hematite. Second behavior with Curie temperatures range from 550°C to 575°C revealing the presence



Figure 4: IRM acquisition curves of specimens from Mishbeh ring complex.



Figure 5: Back-field curves of specimens from Mishbeh ring complex.

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of magnetite. Some specimens have shown drop of magnetization around 200°C, indicating the probable presence of titanomagnetite which changed by heating to magnetite in the 2<sup>nd</sup> curve (e.g., Ms 51) (Figure 3).

# Isothermal remanent magnetization (IRM) and Back field determination

The specimens have been subjected to progressive IRM acquisitions steps until 600 mT using Pulse Magnetizer (PM10). The remanent magnetization has been measured after each step (Figure 4). Slopes of magnetization curves have an initial slow acquisition rate with 55% of the maximum IRM by 0.1 T, followed by a slower acquisition rate with no saturation up to the maximum field of 500 mt (e.g., Ms63) revealing the presence of hematite. Some specimens have shown saturation (e.g., Ms56), indicating the presence of magnetite and/or titanomagnetite[13-16].

The obtained remanence has been destroyed by applying a stepwise increasing field in steps of 500 mT in the opposite direction (back-field). The coercivity of remanence (*Hcr*) was determined from the back-field curves in Figure 5. It is around 50 mT for some specimens (e.g., Ms56) confirming the presence of low coercivity magnetic phase (magnetite) and >100 mT for some other specimens (e.g., Ms51 and Ms63) indicating the presence of high coercivity magnetic phase (hematite).

## Hysteresis loop analysis

The hysteresis properties for representative specimens from all sites have been measured using a Vibrating Sample Magnetometer (VSM). A typical example is shown in Figure 6; where complete saturation was nearly achieved at 200 mT, with a narrow loop of low coercivity force (Hc) revealing the presence of magnetite (e.g., Ms56). In some other sites, the saturation wasn't achieved even



**Figure 6:** Hysteresis curves of representative specimens from Mishbeh ring complex.





Figure 7: Day plot for hysteresis data for specimens from Mishbeh ring complex.

after 500 mT (e.g., Ms63) (Figure 6) revealing the presence of hematite.

The grain size of magnetic minerals is important in terms of the evaluation of magnetic stability of remanence in igneous rocks. Magnetic granulometry based on hysteresis parameters has been applied to estimate the grain size of magnetic minerals. Figure 7 shows the ratio of saturation remanence to saturation magnetization (Mrs/Ms) ranging from 0.1 to 0.25, and that of coercivity of remanence to coercive force (Hcr/Hc) ranging from 2 to 4.5. When presented on day plot indicates that the average magnetic grain size falls mostly within the field of pseudo-single domain (PSD) [2]

### Demagnetization

Alternating field demagnetization (AF) has been performed using the instrument made by 2G-Enterprises, attached to the Cryogenic magnetometer with 2.5 mT incremental steps up to 20 mT, then 10 mT up to 100 mT. Then, steps increased to 20 mT intervals up to maximum available demagnetization field (160 mT). Thermal demagnetization has been performed using the thermal Demagnetizer (MMTD80). Progressive stepwise heating from room temperature up to 700°C has been done.

Magnetic remanence has been measured after each demagnetization step (AF and Thermal) using a SQUID Magnetometer. Possible mineral changes resulting from heating in the air during the thermal demagnetization of the measured specimens have been monitored by measuring the low field magnetic susceptibility after consecutive heating-cooling cycle using an Agico KLY4 - susceptibility unit[17-20].

During AF demagnetization process, some specimens have shown a steady decrease of intensity under the influence of AF demagnetization, while others have shown relatively high coercivities in Figure 8. The steady decrease of intensity can be observed in specimens from sites (1 to 4) (e.g., Ms54) which display vectoral decay of NRM directions towards the origin of orthogonal plot and about 90% of the initial

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NRM is removed at the demagnetization field of about 25 mT. Specimens belonging to this type of behavior respond well to the AF treatment and comprise a low coercive magnetic carrier responsible for the greatest part of NRM. The NRM of these specimens may therefore be carried by magnetite and/or titanomagnetite. The second behavior has been observed in specimens from sites (5 and 6) (e.g., Ms63) due to isolation of a low coercivity component below 50 mT, after which AF decay is ineffective up to 100 mT, revealing the presence of traces of hematite.

Two different behaviors have been observed during thermal demagnetization treatment in Figure 9. The first behavior has been observed in samples from sites (1 to 4) (e.g., Ms46) which lost  $^{\sim}98\%$ of NRM intensity at 580°C; indicating that most NRM is probably carried by magnetite and/or titanomagnetite. The second behavior has been observed in samples from sites (5 and 6) (e.g., Ms60) as 10% of the initial NRM was unblocked at about 300°C, after which, the rest of the remanence decreased rapidly, losing about 95% of the total NRM at 575°C, leading also a single stable component.

### Magnetic fabrics

Measurements of magnetic susceptibility and its anisotropy (AMS)

Table 2: Site and component-mean ChRM and secondary NRM data and corresponding virtual paleomagnetic poles for Mishbeh ring complex.

Site	N		Ch	VGP			
		D(°)	I(°)	α <sub>95</sub> (°)	k	Long.	Lat.
Site 1	12	328	23	11	80	290	58
Site 2	20	329	17	11.2	62.5	296	42
Site 3	15	336	26	3.0	27.3	286	66
Site 4	10	334	26	5.1	28.9	289	64
Site 6	25	330	21	3.8	27.4	287	59
							РР
Mean (5)	82	332	22	7.1	71.4	Long.	Lat.
$(\mathcal{I})$						290	58

Where, N: number of samples in each site, D & I: Magnetic declination and inclination angles, in degrees, K,  $\alpha_{95,\&}$  A<sub>95</sub>, precision parameter and semi-angle cone of 95% confidence about site- and component- mean direction (Fisher, 1953), Lat. & Long.: latitude and longitude of the Virtual (VGP) and paleomagnetic (PP) pole position.

Table 3: Site-mean magnetic susceptibility and AMS data for Mishbeh ring complex.

Site	N	K (*10 <sup>m</sup> SI unit)	P'	Т	L	F	Magnetic susceptibility axes		
							K <sub>max</sub>	K <sub>int</sub>	K min
Site 1	12	43	1.03	0.143	1.014	1.015	244/7	333/60	156/43
Site 2	10	136	1.053	0.5	1.015	1.043	125/65	8/53	325/52
Site 3	15	784	1.053	0.106	1.026	1.027	134/61	292/35	335/15
Site 4	10	372	1.085	-0.439	1.045	1.037	199/35	293/9	36/54
Site 5	12	1950	1.153	0.245	1.056	1.092	134/62	31/53	300/42
Site 6	15	133.6	1.029	0.013	1.014	1.014	260/19	113/75	30/78
Mean	74	570	1.061	0.094	1.028	1.038			

Where, N: number of specimens.

*Km*: mean susceptibility= $(K_{12}K_{22}K_{3})/3$ , in 10<sup>6</sup> SI.

*P*': anisotropy degree= $exp\sqrt{\{2[(\eta_1\cdot\eta_m)^2+(\eta_2\cdot\eta_m)^2+(\eta_3\cdot\eta_m$ 

Where:  $\eta_1 = \ln K_1, \eta_2 = \ln K_2, \eta_3 = \ln K_3$  and  $\eta_m = \sqrt[3]{\eta_1}, \eta_2, \eta_3$ *T*: ellipsoid shape=[2 ln ( $K_2, K_3$ )/ln ( $K_1, K_3$ )] -1

L: magnetic lineation= $K_1/K_2$ , F: magnetic foliation= $K_2/K_3$ .



Figure 8: AF demagnetization plots [Stereonet, Zijderveld diagram and intensity decay curve] for specimens from Mishbeh ring complex.

have been performed on a total of 74 standard cylindrical rock specimens collected from the six sites distributed throughout Mishbeh ring complex using the kappa-bridge KLY-4S made by the AGICO-Brno with the  $10^8$  SI sensitivity.

Table 3 lists the site-mean magnetic susceptibility, AMS parameters

magnitudes and axes orientations. The mean magnetic susceptibility has shown variable magnitudes among different sites that reflects a variation in the concentration and type of the ferromagnetic minerals.

The relation between the anisotropy degree P' and the mean



Figure 9: Thermal demagnetization plots [Stereonet, Zijderveld diagram and intensity decay curve] for specimens from Mishbeh ring complex.

magnetic susceptibility Km in Figure 10a is a general increase of magnetic susceptibility with increase of anisotropy. The magnetic lineation L and magnetic foliation F are rather weak with predominance of magnetic foliation over lineation in Figure 10b.

The overall site-mean T value is 0.094, i.e., in the range of  $0 \le 1$ , also confirming predominance of foliation over lineation. No significant relation exists between the shape of susceptibility ellipsoid T and the anisotropy degree P' shown in Figure 10c.



Demagnetization and rock magnetic experiments of Gabal Mishbeh ring complex suggests that titanomagnetite, magnetite of pseudosingle domain (PSD) and traces of hematite are the principal magnetic carriers that dominate the rocks collected at six sites.

Analysis of thermal demagnetization data show single magnetic component (A). The site-mean directions for this component are listed with its corresponding virtual geomagnetic poles (VGP) in Table 2 and plotted on an equal-area projection in Figure 11.

The site-mean ChRM are of shallow positive inclinations with normal polarities predominantly directed to the NNW, and mainly carried by magnetite. The overall mean ChRM direction is  $D/I=332^{\circ}/22^{\circ}$ , with k=71.4 and  $\alpha_{95}=7.1$ . This direction corresponds to a north paleomagnetic pole at *Lat.* 58°N and *Long.* 290°E, with K=70,  $\alpha_{95}=9.2$ , and N=82 specimens (Table 2).

The bulk AMS axial distribution together with the weakly developed magnetic fabrics indicate that the magnetic fabric is most probably of primary magnetic origin with respect to the original emplacement process through magma flow with subsequent cooling and further crystallization in a weak compression condition. Such results support the paleomagnetic interpretation and give much confidence in the presumed primary nature of two ChRM of these rocks.



**Figure 11:** Equal-area stereographic projections of site-mean component **(A)** direction from Mishbeh ring complex.



**Figure 10:** a) Relationship between magnetic susceptibility  $K_m$  and anisotropy degree *P*'. b) Foliation *F* versus lineation *L* plot to study the ellipsoid shape and c) Relationship between ellipsoid shape *T* and anisotropy degree *P*' of specimens from Mishbeh ring complex.

Reference	Site			Age (Ma)	Paleopole		α
	<b>Locality</b> El Naga Ring	<sup>®</sup> N 22.7	<sup>в</sup> Е 34.5	140	Long. Lat.		- 95
					268	68	5
Mostafa [13]	Nigrub El Fogany	22.5	34.5	139	296	54	13
Mostafa [13]	Nigrub El Tahtany	23.0	35.0	140	298	49	9
Schult et al. [18]	Natash	24.4	34.3	93	258	69	7
Mostafa et al. [15]	Sabaya	22.6	31.8	83	280	78	5
Mostafa et al. [15]	Aggag	22.6	31.8	83	283	83	5
El-Shayeb et al. [14]	6 Hills/Balas	25.0	29.5	145	294	78	8
Ressetar et al. [17]	Qusseir	26.0	34.2	80	252	63	2
Lofty [11]	Natash	24.5	34.3	104	250	55	5
This Study (A)	Mishbeh Ring	22.4	34.4	142	290	58	3.7

Table 4: List of the selected African Jurassic and Cretaceous north Paleomagnetic poles.



A: denotes the pole for Mishbeh Ring complex

Figure 12: Jurassic- Cretaceous paleomagnetic-pole positions of Africa.

Demagnetization processes reveal a single magnetic component. This component has an overall mean direction of D/I=332°/22°, with k=71.4 and  $\alpha_{95}$ =7.1, corresponding to a north paleomagnetic pole at Lat. 58°N and Long. 290°E, with K=70,  $\alpha_{95}$ =9.2, and N=94 specimens from six sites.

The correlation between present study paleomagnetic pole and some selected reliable African Cretaceous Paleomagnetic poles show very good agreement Table 4 and Figure 12; proving that Mishbeh Ring complex is of Cretaceous age.

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