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Palaeomagnetic Investigations of the Volcanic Intrusion at Bir Al-Hammah Area, North Central Sinai, Egypt

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Abstract: Palaeomagnetic investigations have been carried out on the Bir Al-Hammah volcanic intrusion ,north central Sinai, Egypt. A total of 41 oriented core samples were taken at nine sites from the studied area. Alternating field demagnetization successfully enabled the isolation of stable characteristic remanent magnetization (ChRM) for most of the samples. Ore mineralogical investigations suggest that the remanence is carried by homogeneous magnetite. Isothermal remanent magnetization (IRM)and Curie temperature experiments support this conclusion. This magnetization is probably of primary origin and reflects the age of the volcanic intrusion in the studies area. The resultant direction of this magnetization (D = 169.0°, I = -65.6°, with K = 211 and α95 = 4.2°) corresponds to a palaeomagnetic pole lying at Lat. 71.0° S and Long. 190.5° E, with A95 = 6.1°. The age of magnetization is verified by comparing the obtained pole position with mean Egyptian and African corresponding palaeomagnetic poles. The obtained pole position is found consistent with the Tertiary basalts at Wadi Nukhul pole lat. 76° S and 193° E,(Wassif, 1991) , and tends to fall closer to the uppermost Oligocene or the earliest Miocene pole.

Key words: Palaeomagnetic - basaltic rocks - Sinai - curie temperature- ore mineralogy - palaeomagnetic pole- Bir Al-Hammah.

INTRODUCTION

From the view of palaeomagnetism, the Egyptian rocks have not been extensively studied compared to other parts of Africa, although paleomagnetic studies in Egypt have been made since 1970, El Shazly and Krs (1971) worked on the basalts of Abu Zaabal and Qatrani areas and found that these basalts carry a hard reversed magnetization. Hussain et al, (1980) have constructed an APWP for Egypt back to 120 m.y based on data from Egypt and other regions in Africa. Ressetar *el* at., (1981) used both palaeomagnetic and radiometeric methods to confirm the existence of two phases of igneous activity in the late Mesozoic and Cenozoic, whereas the second phase of activity is of Oligo-Miocene age and represented by a small tholeiitic basalt flows on the Red Sea coast and along the Nile Valley. Schult *et al.,* (1981) examined the paleomagnetism of some Tertiary basalt in northern Egypt. Wassif (1986) investigated the magnetic characteristics and opaque mineralogy of some basalts from El- Bahnasa and Tahna and found a genetic relationship between the magnetic properties and the type, grain size and oxidation state of magnetic minerals envolved. Kafafi (1987) studied the magnetic properties and mode of emplacement of Abu Zaabal basalt. Wassif (1988,1989,1991) have described the iron-titanium oxide minerals, rock magnetism and palaeomagnetism of some basalts from west central Sinai, Egypt, including Wadi Matulla, Wadi Tayiba and Wadi Nukhul. The present paper deals with similar studies carried out on Bir Al-Hammah basalt north center Sinai (Fig. 1) and includes a comparison of the some palaeopole positions obtained with the apparent polar wander path (APWP) for Africa (Irving and Irving, 1982).

2. Geological Setting:

The basement rocks of Sinai, dominated largely by calc-alkaline granitic batholithic intrusions enclosing remnants of metavolcanics, metasediments, metagabbro-diorite, intermediate to acid volcanics and molasses classic facies evolved and cratonized between 900-550 Ma, i.e. within the Pan-African realm. The phanerozoic volcanics of Egypt as general are related to Cretaceous or Mid-Tertiary times (Said, 1962; El Shazly and Krs, 1971 and Meneisy and Kreuzer, 1974a). The Mid-Tertiary basic volcanics, being more widespread in Egypt, are represented by a large number of basalt-dolerite dykes, sills and flows that intrude or cap rocks of different ages. In Sinai, the Mid-Tertiary basalts have various forms and caps or intrude rocks having different ages up to Late Eocene. In North Central Sinai, the main basaltic occurrences are in the form of doleritic dykes, tens of kilometers long *(e.g.* Rageibet el Naama and Iktefa) and trending E-W parallel to a large fault belonging to he Central Sinai shear zone. Based on stratigraphical evidences (Said, 1962 and El Shazly and Krs. 1973) and isotopic age determinations (Steinitz *et al.,* 1978; Eyal, et *al.,* 1981; Moussa, 1987; Saleeb *et al.,* 1989 and Scott, *et a!.,* 1991), these basaltic rocks are mainly assigned to a volcanic phase occurred in the period between the end of Oligocene to Early Miocene. The middle part of G. Maghara represents the highest part of the structure, which has the form of an asymmetric, east-northeast oriented doubly plunging anticline. South of Gebel Maghara, the basaltic rocks have the form volcanic intrusion of, are located at Bir Al Hammah (30 º 40 $^{/}$,33 º

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35 /). These basaltic rocks were found within the alluvial Hamada deposits and sand dunes (Said, 1962). the samples were collected from two igneous bodies (Fig. 2). The basaltic rocks of G. Maghara were dated by the K/Ar method and yields about 20 m.y. of age (El-Hemaly, 2004).

3. Sampling and Experimental Methods:

The study Bir AL-Hammah volcanic intrusion were sampled at nine sites (Fig. 2), where oriented block hand samples were obtained using magnetic compass in the field. A total of 41 core samples (1″ diameter and ~ 2″ long) were cored in the laboratory and sliced into specimens of ~2.1 cm length to conform to the optimum length of the palaeomagnetic measurements (Tarling, 1983).

Ten Polished section were prepared and examined under the ore microscope (maximum magnification,X 800). Some thin sections were also prepared to obtain more detailed results.

Different palaeomagnetic measurements were carried out in the Geophysical Laboratory at the Nuclear Materials Authority of Egypt. The natural remanent magnetization (NRM) measurements were made on a Jelinek JR-5A spinner magnetometer, with sensitivity reaching 2.4 μA/m. In order to remove secondary overprints and resolve the primary or characteristic remanent magnetization (ChRM), progressive alternating field (A.F.) demagnetization was carried out using a Molspin MSA2 shielded AF 2-axis tumble demagnetizer, with a peak Field of 100 mT. The Fe-oxides which carry the NRM were investigated through isothermal remanent magnetization (IRM) acquisition experiments (Dounlop, 1972), using a Molspin MMPM9 pulse magnetizer to produce fields up to 3.0 Tesla, followed by subsequent stepwise thermal demagnetization of acquired IRM, using a shielded MMTD-80 type furnace, capable of heating to 800°C.

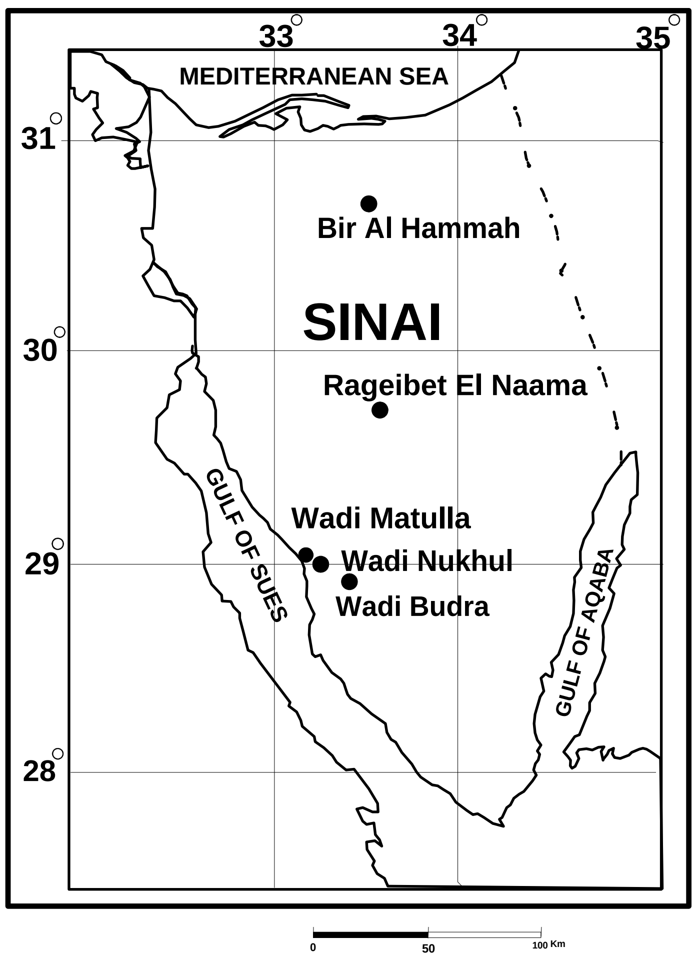

Fig. 1: Location map of some basaltic rocks in Sinai.

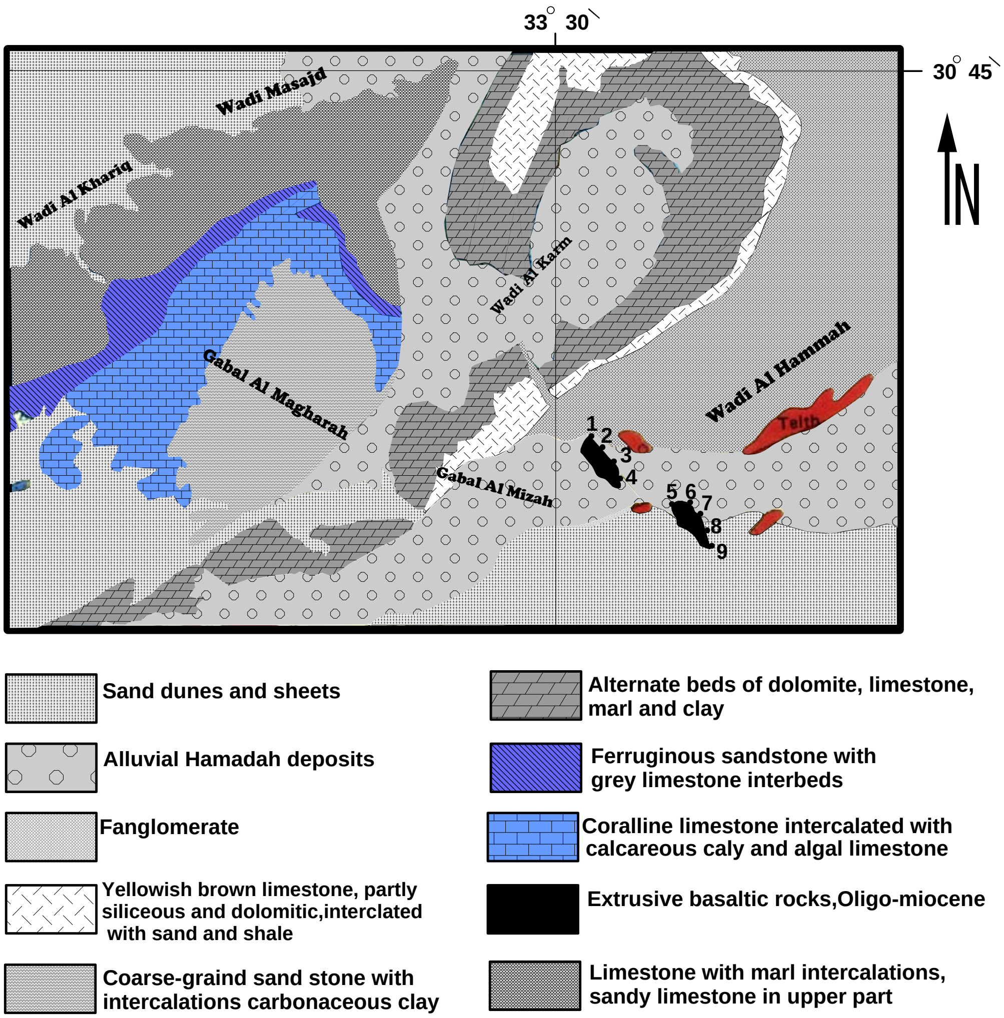

Fig. 2: Geological map of Gabal Al Magharah area North Central Sinai.

3. Microscopic Examination:

Petrographic studies show that basaltic rocks at Bir Al Hamama are mainly olivine dolerites with subophitic and intergranular textures. In all the basaltic polished surfaces examined the opaque minerals identified are mainly magnetite and ilmenite. Very minor amount of martite and sulphides are also present.

The opaque minerals constitute about 8% of the total rock; few samples are exceptionally rich in ore minerals(up to 12%). The magnetite is generally more abundant than ilmenite where it forms about (70 – 80 %) while the ilmenite is only form (20 -30%) of the total opaque minerals.

The shape of the magnetite grains are generally irregular although grains with partially developed boundaries (subhedral) and even completely idiomorphic grains are not common. The diameters of the grains are highly variable and range between 100 µ m and 500 µ m.

The magnetite present is mostly normal magnetite (Ti – poor) or (Ti –free), isotropic and is completely homogeneous under the highest magnification. It differs from the titanomagnetite in lacking the characteristic brownish pink tint and also it does not show any type of exsolutions or replacement intergrowth.

The magnetite crystals are generally interstitial between the plagioclase, pyroxene and olivine crystals and are of later crystallization. Besides these primary magnetite cyrastals,secondary magnetite is present in the form of fine grains or dust-like aggregates along cracks and grain borders of the olivine and pyroxene crastals. Also it is observed as elongated grains oriented along the cleavage planes of the plagioclase. Some times, this secondary magnetite is altered to martite.

Few minute grains of sulphides have been encountered. These are possibly of pyrrhotite and chalcopyrite and are present randomly distributed in the groundmass of the basalts.

The ilmenite appears grey white to brownish in color, its brownish or purple tint is rather distinguishable from magnetite and also its anisotropism. Internal reflections are not observed. Ilmenite is usually completely homogeneous and no exsolutions or replacement intergrowths are observed. It generally occurs as thin tabular elongated discrete crystals or plates, which are often terminated by the rhombohedral faces. Occasionally, the ilmenite forms subhedral to anhedral grains ranging from 100 µm to 300 µm in diameter. Skeletal crystals are sometimes observed and are possibly formed by the intensive corrosion of the ilmente by the silicate melt.

Few prismatic and bipyramidal idiomorphic crystals of apatite are frequently observed as inclusions in the ilmenite and magnetite grains indicating that they are earlier in their sequence of cyrastalization.

4. Results And Analyses:

4.1. Isothermal Remanent Magnetization (IRM):

Stepwise isothermal remanent magnetization (IRM) was carried out, using direct magnetic fields up to 1.0T, on two representative samples. The IRM intensity values were normalized to the saturating value as illustrated in Figure 3. The IRM acquisition results indicate the same behavior for the two samples. The IRM acquisition curves showed an initial rapid acquisition of ≥ 90% of the maximum IRM at fields ~ 0.3 T and typically acquisition saturation IRM at fields of 0.4 - 0.5 T (Fig. 3a). This behavior indicates that magnetite is probably the main ferromagnetic mineral present (Dunlop, 1971 & 1972; Collison,1983 and O'Reilly, 1984). Subsequent stepwise thermal demagnetization of the acquired IRM for the sample displays a maximum unblocking temperature at ~580°C (Fig. 3b). This behavior indicates that the dominant magnetic mineral is magnetite (low coercivity, maximum unblocking of 580°C).Ore microscopy support this conclusion.

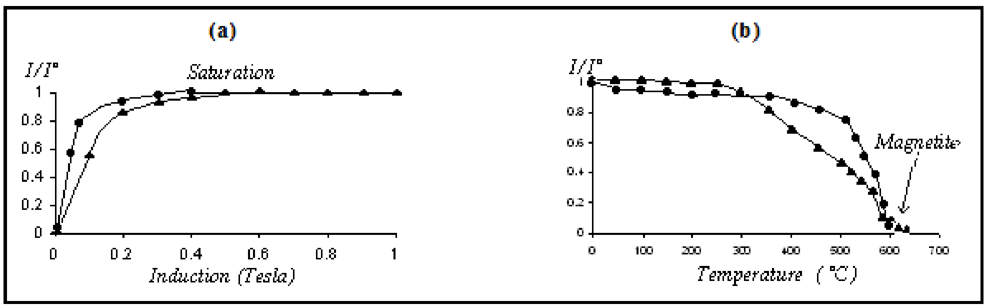

Fig. 3: Normalized curves of IRM acquisition and) stepwise thermal demagnetization of IRM for representative samples from Bir Al Hammah volcanic intrusion, Sinai, Egypt.

4.2. Initial Natural Remanent Magnetization (NRM):

Over the sampling area, the initial NRM measurements showed relatively homogeneous intensities, with moderate values. The site-mean intensities range from 0.05 to 1.2 A/m, with an average of 0.51 A/m (Table 1). The within-site NRM directions showed marked dispersion, with α_{95} between 17° and 44° (Table 1). The site-mean directions, on the other hand, are scattered in the northwest and southwest directions, at shallow to intermediate positive and negative inclination (Fig. 4). These directions are clearly distinguished from the present earth's magnetic field.

Table 1: Site-mean initial NRM data for Bir Al-Hammah volcanic intrusion,northt central Sinai, Egypt.

Site	*N*	*Dec. (°)*	*Inc. (°)*	*Int. (A/m)*	*K*	*α_{95} (°)*
B1	4	325	13.5	1.20	35	15.8
B2	4	335	14.0	0.83	24	19.3
B3	4	242	6.8	0.08	9	44.0
B4	5	245	-29.3	0.11	15	20.7
B5	6	236	10.9	0.05	14	18.5
B6	4	345	-21.8	0.55	17	23.3
B7	4	349	-38.9	0.36	19	21,6
B8	5	295	-23.4	0.28	21	17.0
B9	5	310	17.3	1.09	19	17.9

N: number of samples in each site
Dec. and Inc.: magnetic declination and inclination in degree
Int. : Intensity of magnetization, in A/m
K & α_{95} : precision parameter and semi-angle of confidence (Fisher, 1953)

4.3. Demagnetization:

The stability of NRM was tested against alternating field (A.F.) demagnetization by subjecting one representative pilot sample, which is carefully selected from each site, to a full-range of treatment. A.F. demagnetization was applied in increment steps of 2.5 mT up to 30 mT, then in increments of 10 mT up to the maximum available 100 mT field. Demagnetization results were then plotted on orthogonal demagnetization diagrams (Zijderveld, 1967) to allow detailed analysis.

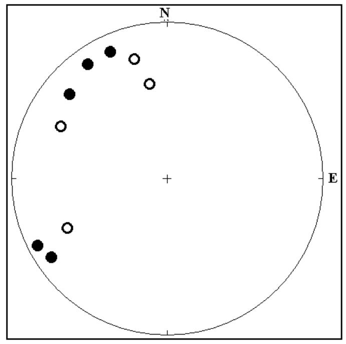

Fig. 4: Equal-area stereographic projection of the site-mean initial NRM directions of the volcanic intrusion, Bir AL-Hammah area, north central Sinai, Egypt.

The majority of the pilot samples behaved, rather, similarly. These samples displayed a relatively simple demagnetization behavior characterized by an almost univectorial decay of NRM directions towards the origin of orthogonal diagrams (Fig. 5). The stable remanent magnetization for most of the pilot samples was observed between ~30 and 80 mT. The median destructive field value (MDF), which is the measure of remanent magnetization stability, ranges from 17.5 to 25 mT for most of the samples.

In the light of visual and statistical analyses of the demagnetization data for the pilot samples, the optimum sequential steps that define the best linear component of magnetization, what is considered the characteristic remanent magnetization (ChRM), were determined where at least three steps within the best stability range were used for each site.

The ChRM were calculated using the Principal Component Analysis, PCA, (Kirschvink, 1980). The maximum angular deviation (MAD) values fall between 5.0° and 12.7° in the majority of samples. The components estimate with MAD greater than 15° were rejected as poorly defined. Site-mean directions of the obtained magnetic components were calculated using Fisher's (1953) statistics, then, the corresponding virtual geomagnetic poles (VGP) were computed for each site.

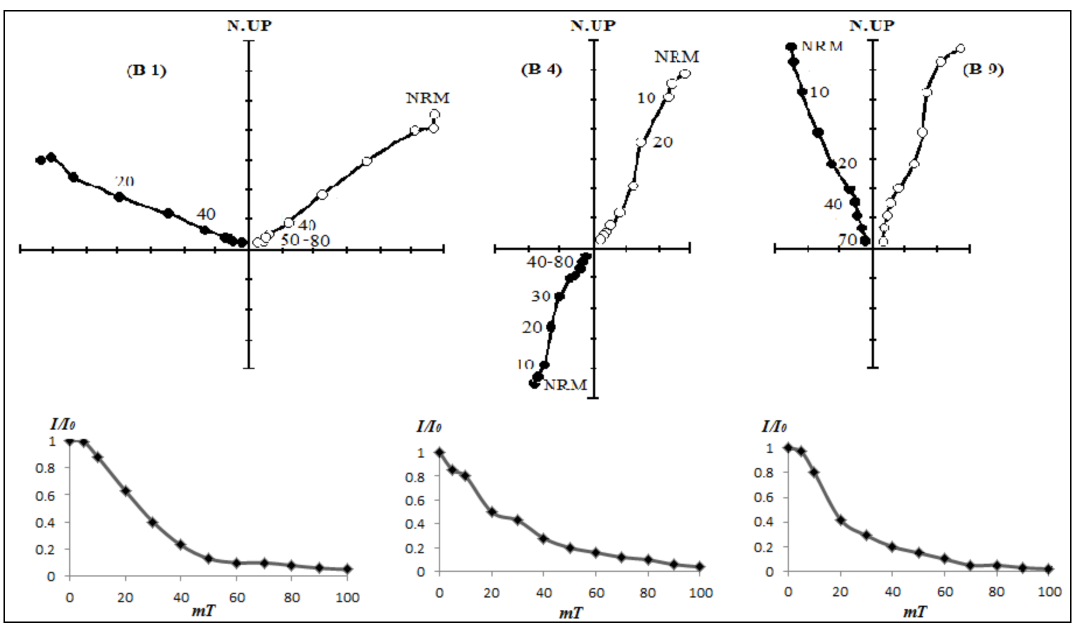

Fig. 5: Examples of orthogonal plots (Zijderveld, 1967) of progressive A.F. demagnetization and normalized intensity decay curves for representative samples from Bir Al Hammah volcanic intrusion, north central Sinai, Egypt.

4.4. Characteristic Remanent Magnetization (ChRM):

Bulk demagnetization of the sample collection of the study area resulted in a stable component of magnetization, after removal of the lower coercivity components. This magnetization is a high coercivity, isolated between ~40 and 80 mT, and referred to as characteristic remanent magnetization (ChRM). The site-mean ChRM directions and their corresponding virtual geomagnetic poles (VGP) were calculated and illustrated in Tables 2. Despite the consistent within-site directions for all sites ($\alpha95$ ranges from 5.9° to 12.2°), the between-site grouping are good for seven sites while the remaining two sites (B3 & B5) are scattered between-sites (Table 2).

At the site-mean level and after excluding two sites of inconsistent directions, the ChRM direction for the volcanic intrusions of Bir AL-Hammah volcanic intrusion could be identified by SSE declination with steep negative inclination. The computed overall mean direction is D = 169.0°, I = -65.6°, with K = 211 and $\alpha95$ = 4.2°. This direction (Fig. 6 a) corresponds to a palaeomagnetic pole lying at Lat. 71.0° S and Long. 190.5° E (Fig. 6 b), with $A95$ = 6.1°.

Table 2: Site-mean ChRM directions and corresponding VGPs for Bir AL-Hammah volcanic intrusion, noth central Sinai, Egypt.

Site	*N*	*Dec. (°)*	*Inc. (°)*	*K*	α_{95} *(°)*	*VGP* *Lat. (°)*	*VGP* *Long. (°)*
B1	4	160.5	-66.6	243	5.9	-66.4	180.5
B2	4	169.8	-64.7	218	6.2	-72.2	190.1
B3*	4	119.4	46.5	117	8.5	-7.8	84.5
B4	5	180.0	-67.0	102	7.6	-71.0	213.6
B5*	6	138.5	47.4	63	8.5	-18.8	71.5
B6	4	165.4	-58.3	87	9.9	-75.5	162.3
B7	4	155.0	-65.0	58	12.2	-64.8	171.0
B8	5	180.6	-64.3	76	8.8	-74.6	215.2
B9	5	173.6	-71.3	97	7.8	-64.7	205.3

Lat. & Long.: latitude and longitude of VGP
Site: site excluded from the overall mean calculations*
(The other abbreviations are as in Table 1)

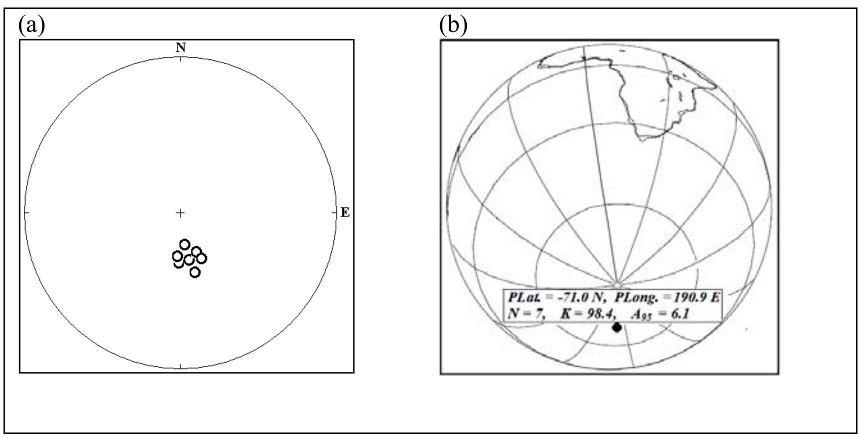

Fig. 6: a) Equal-area stereographic projection of the site-mean ChRM directions and b) Lambert equal-area projection of the paleomagnetic pole position of the volcanic intrusion, Bir AL-Hammah area, north central Sinai, Egypt.

Table 3: The Egyptian Early Tertiary paleopole position.

Pole	*Rock unit*	*Age*	*Paleopole position* *Lat.*	*Paleopole position* *Long.*	*Reference*
1	Wadi Tayaba	22.8 Mya	65 S	238 E	Wassif,1991
2	Wadi Matulla	23.7 Mya	76 S	269 E	Wassif,1991
3	Wadi Nukhul	24.8 Mya	79 S	193 E	Wassif,1991
4	Bir AL-Hammah	20 MYA	71 S	190.5E	This work
5	Tertiary Basalt, N. Sinai	20 Mya	73 S	207 E	El-Hemaly, 2004
6	Reference pole.	Oligo-Miocene	85 S	184 E	Besse & Courtillot, 2002.

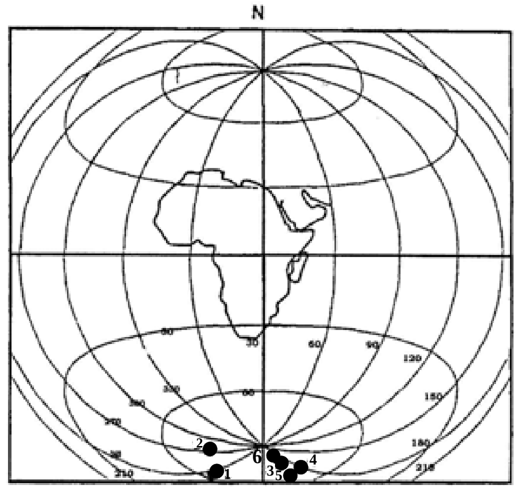

Fig. 7: Lambert equal area projection of the pole position.

Conclusions:

A directionally stable component of NRM was isolated by AF demagnetization in individual samples from the basalts studied. Median destructive field values were relatively high for the Bir Al Hamma basalts (17.5-25 mT) for most of the samples. The high intensities of the Bir Al Hamma basalts probably result from the presence of magnetite as the main magnetic mineral. The presence of magnetite is also suggested by the observed Curie Point values (≈580 °C) for this locality. Under the microscope, polished sections show that magnetite is generally more abundant than ilmenite where it forms about (70 – 80 %) while the ilmenite is only form (20 -30%) of the total opaque minerals.

Numerous lava flows, dikes and sills are known in Sinai near Abu Zenima and Hammam Faraun . This mainly basaltic, Early Tertiary igneous phase was generally interpreted as being related to initial faulting in the Suez rift. Basaltic bodies from northern Sinai have yielded K—Ar ages of 20.2—21.6 Myr (Siedner 1973) i.e. earliest Miocene. Similar ages were obtained for the associated rocks in Egypt (Meneisy & Kreuzer 1974). An age of 24.8Myr was recorded by Steinitz, Bartov & Hunziker (1978) for the rocks at Rageibet El Naama in central Sinai. Also, the basaltic rocks in west Sinai at Little Gebel Araba, Wadi Nukhul and Wadi Tayiba yielded ages of 24 ± 1.1, 22.3 ± 1.3 and 21.4 ± 1.1 Myr respectively using the K—Ar method for the whole rock (Steen 1982). All information in the area shows that the Suez rift was not active before late Eocene times, about 40 Myr ago, in agreement with Robson (1971), Lowell & Genik (1972), Berggren & Van Couvering (1974) and Hosney (1985). On the other hand, the rift was already well defined and sufficiently depressed to be inundated by the sea in the earliest Miocene (about 20 Myr ago). Thus the early rift-forming events must have occurred between the Late Eocene and the beginning of the Miocene (Garfunkel & Bartov 1977).

Nearly most of the palaeomagnetic studies on Tertiary basaltic rocks in Egypt given by (Refai et al.1972, Basta et al. 1981, Wassif 1988, 1989, 1991 and other) are characterized by reversed magnetization. Thus the common reversed polarity of the present Bir Al Hammah basalts is in agreement with the expectation that they were Tertiary (Oligocenc). The palaeomagnetic directions, statistical parameters and pole position results for some basaltic rocks in sinai are summarized in Table 3 and Fig. 7. The results of pole position studied agree with other Tertiary pole position from Africa and tends to fall closer to the uppermost Oligocene or the earliest Miocene pole.

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