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Cenozoic to Cretaceous paleomagnetic dataset from Egypt: New data, review and global analysis

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ABSTRACT

Different phases of igneous activity took place in Egypt during the Mesozoic and the Cenozoic and oriented samples were collected from three Cenozoic localities (Baharya oasis in the Western Desert, Abu Had in the Eastern Desert and Quseir along the Red Sea coast), and four Cretaceous localities (Toshki & Abu Simbel south of Aswan, and Shalaten & Abu Shihat along the Red Sea coast). Rock magnetic properties of the samples indicate magnetite and titanomagnetite as the main carrier of the remanent magnetization. Following stepwise demagnetization, characteristic remanent directions were identified only for 62% of the samples, a fairly low rate for that type of samples, and 8 new paleomagnetic poles were calculated. All our Cenozoic poles fall clearly off Master Polar Wander Paths proposed for South Africa. Therefore, all paleomagnetic results, previously published for Egypt, were compiled from Cretaceous to Quaternary. The published poles largely overlap, blurring the Egyptian Apparent Polar Wander Path. A new analysis at the site level was then carried out. Only poles having a kappa larger than 50 were selected, and new pole positions were calculated by area and by epoch, when at least 3 sites were available. Even though the selection drastically reduced the number of considered poles, it allows definition of a reliable Cenozoic apparent polar wander trend for Egypt that differs from the South African Master Polar Wander Path by about 10–15°. If the Cretaceous igneous poles are in good agreement with the rest of the African data, the sedimentary poles plot close to the Cenozoic portion of the South African Master Polar Wander Path, a discrepancy that could be related either to inclination flattening and/or error on age and/or remagnetization in the Cenozoic.

1. Introduction

During the Phanerozoic, Egypt was affected by intermittent igneous activity, mainly in relation with the Late Precambrian fracture system. A compilation of more than 150 isotopic ages (Rb/Sr with a few K/Ar) was used to construct a sequence of Phanerozoic igneous activity in Egypt (Meineissy, 1990): i) Early Paleozoic vulcanicity associated with or closely related to the Pan-African tectono-thermal event; ii) Late Paleozoic magmatism related to the initial break-up of Pangea and the closure of the Tethys; iii) Mesozoic igneous activity related to the rifting of the South Atlantic, the corresponding Africa–South America compression and Afro-Arabian strike slip faulting; iv) Cenozoic volcanic pulses associated with the Red Sea opening; and v) Quaternary igneous activity, not very well documented, that could be of early Pleistocene age along the Red Sea and in the south Western Desert.

It is often difficult to decipher between the different episodes and, in the absence of radiometric dating, paleomagnetism is a very convenient tool to estimate the age of an intrusion or an extrusion. Paleomagnetic data can further constrain the local and global tectonic activity in the area. Although there have been many paleomagnetic studies undertaken in the past century, the definition of an apparent polar wander path is not straightforward for Egypt and new Cretaceous and Cenozoic samples were collected in order to improve the quantity and quality of paleomagnetic information from this region. All samples were drilled in the field using a gasoline-powered drill and oriented using both magnetic and sun compasses.

2. Cretaceous igneous activity and sampling

Mesozoic igneous activity resulted in the intrusion and/or extrusion of various types of rock, abundant and diversified in size, form and composition. The basaltic rocks and alkaline ring complexes can generally be related to two main phases of igneous activity: i) *a Late Jurassic–Early Cretaceous phase* (140 ± 15 Ma) and

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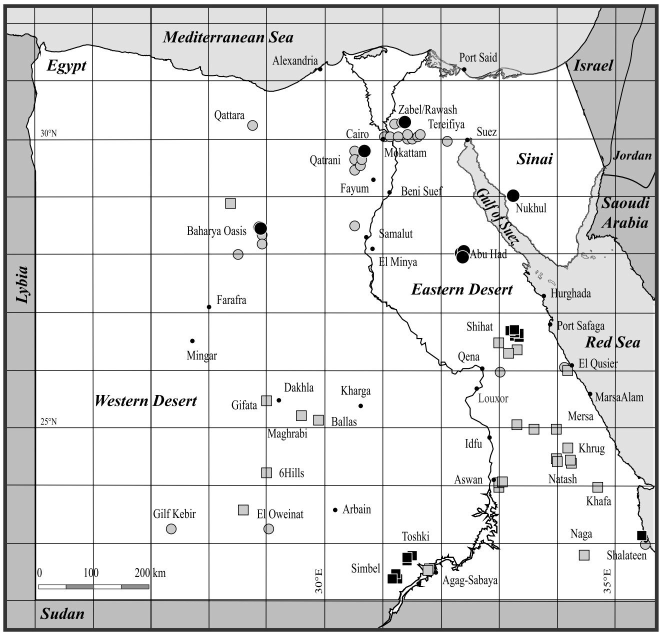

Fig. 1. Cenozoic (circle) and Cretaceous (square) paleomagnetic sites for Egypt. Light/dark: literature/our sites (this study & Perrin et al., 2009), dots: cities.

ii) a *Late Cretaceous–Early Tertiary phase* (90 ± 20 Ma). Most of the Mesozoic igneous activity is located in the southern Eastern and Western Deserts and in Sinai (Meineissy, 1990).

Most samples related to the ***Late Jurassic–Early Cretaceous*** phase are alkaline ring complexes from the south Eastern Desert. This 140 Ma episode of alkaline magmatism in Egypt coincided with a major episode of alkaline magmatism occurring in the areas surrounding the South Atlantic and related to the initial rifting of Africa from South America. Ring complexes of the same age have also been reported in northeastern Sudan. Examining the tectonic distribution map of the ring complexes in the south Eastern Desert, it can be noted that these complexes are confined to a slightly curved zone of weakness that extends 200 km and trends in a NE direction parallel to the Aswan trend, the regional fault system of Wadi Halfa, Aswan, and Marsa Alam. The generation of this magma may have been triggered by some "hot spot" mechanism.

The ***Late Cretaceous–Early Tertiary phase*** is perhaps one of the most documented events of alkalic igneous activity in Egypt, formed during large scale strike-slip faulting in Afro-Arabia. The best record of the event is undoubtedly the volcanic rocks of Wadi Natash, about 125 km ENE of Aswan, along the boundary between the Nubian sandstone and the Precambrian basement complex, for which a mantle-plume source has been suggested (Mohamed, 2001). In the south Western Desert, some alkaline volcanics that pierce Paleozoic sandstones can be correlated to the Wadi Natash volcanics (Oweinat and Gilf El Kebir areas). The same alkaline magmatism gave rise to Gebel El Kahfa, Gebel Abu Khrug, and partly Gebel El Naga and Gebel Mansouri ring complexes.

Different localities, supposed to be Cretaceous in age, were sampled south of Aswan and along the Red sea (Fig. 1): 3 sites (29 samples) in Toshki area [22.78°N, 31.48°E] and 3 sites (26 samples) north of Abu Simbel city [22.43°N, 31.21°E], in the south Western Desert; 21 dikes (122 samples) in the wadi Abu Shihat, along the Red Sea; and 4 flows (25 samples) close from Shalaten (23.12°N, 35.46°E). As isotopic ages are missing, the age of the basaltic rocks was based on field relations, within wide error limits, and therefore has to be taken with caution.

3. Cenozoic igneous rocks and sampling

Several volcanic events took place during the Cenozoic, the earliest of Paleocene age being the continuation of the extensive late Cretaceous igneous activity. Mid Tertiary volcanism is widespread, with several pulses in the Late Eocene (Red Sea doming and extension) followed by phases related to the opening of the Red Sea and Gulf of Suez and ranging in age from Late Oligocene to Middle Miocene (Meineissy, 1990). This volcanism is uniformly basaltic and widely distributed in the northern part of Egypt and in Sinai. Basaltic extrusives cover a large area beneath the Nile delta and adjacent parts of the Western Desert. Isolated outcrops also occur along the Fayum–Rawash, and Cairo–Suez stretches. In the south Western Desert, some Tertiary basaltic occurrences are sparsely distributed, associated sometimes with minor occurrences of acid to alkaline rocks. Along the Red Sea coast, south of Quseir, some dolerite flows occur. A few scattered basaltic dykes and plugs intruding Nubian sandstones in the south Eastern Desert are also considered of Tertiary age. Finally in Sinai, several Tertiary basaltic outcrops occur, especially in the western and central areas.

The Tertiary basaltic rocks are found mainly in the form of sheets, dikes, sills, widening sometimes into plugs, cinder cones or small ridges. The basalts of Abu Zabel, Abu Rawash, Djebel Qatrani, and the Cairo–Suez district are described as quartz tholeiitic basalt whereas the basalts from Baharya Oasis and the Nile district are alkali olivine basalts. Trace elements abundances and Sr–Nd–Pb–Hf isotopic signatures are consistent with contributions from two distinct source regions, one similar to the Afar plume and the other analogous to the rejuvenated Pan-African lithosphere that likely underlies most of the continent (Endress et al., 2011).

Using K/Ar on whole rock ages, Meineissy (1990) proposed different volcanic episodes: i) *Late Eocene–Early Oligocene* (40±10 Ma) possibly due to emergence related to a shallowing of the Tethys, and volcanics developing along the fracture systems associated to these tectonically-controlled movements, in the south Western Desert (Gebels Oweinat, Arkenu, Kamil, Darb El Arbain); ii) *Oligo-Miocene phase* (24 ± 2 Ma) related to the opening of the Red Sea – the Red Sea formed by continental rifting in the Late Oligocene or Early Miocene and widened through a combination of normal faulting and of dike injection – well documented in northern Egypt (in the north Western Desert at Wadi Samalut and Gebel Qatrani, in Cairo–Suez area, mainly at Abu Zabel, and along the Red Sea, south of Qusier) and in western Sinai (Gebels Matulla and Araba); and iii) *Lower-Middle Miocene phases* (20, 18 and 15 Ma) as in Baharya Oasis.

More recently, $^{40}Ar/^{39}Ar$ dating confirms the short duration of the Oligo-Miocene phase in the Cairo–Suez area, with ages indistinguishable from those of early syn-rift Red Sea-parallel dikes in western Arabia, Sinai and the Eastern Desert of Egypt. This suggests that the Red Sea propagated through Arabia/Sudan as a single, very rapid pulse and only stopped et the interface with stronger Neotethyan oceanic crust near the coast of the modern Mediterranean Sea. Although the volcanism of northern Egypt is volumetrically smaller than that of Afar, it has been proposed (Bosworth et al., 2015) that it played a similar role as a trigger for a large-scale rift event, with a Cairo mini-plume. The age of the igneous activity of the Baharya Oasis was found to be similar to the rest of the Oligo-Miocene phase ($^{40}Ar/^{39}Ar$ ages between 21–25 Ma, Bosworth et al., 2015), questioning the existence of the last volcanic phase of Meineissy (1990).

During previous field work, different localities have been already sampled in the Oligo-Miocene phase (Perrin et al., 2009): 2 flows (27 samples) at Abu Zabel (30.28°N, 31.36°E) north of Cairo; 3 flows (23 samples) around Quatrani (29.71°N, 30.65°E) in the Fayum district; and 3 sites (18 samples) in Wadi Nukhul (29.02°N, 33.16°E), western Sinai. All these basalts yielded $^{40}Ar/^{39}Ar$