Paleogeography and Paleomagnetism of the Nubian Sandstone Eastern Desert of Egypt

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With 7 Figures and 4 Tables

Zusammenfassung

Die vorliegende Arbeit ist das Ergebnis paläomagnetischer Untersuchungen, die in kretazischer Nubischer Serie und zugehörigen vulkanischen Gesteinen sowie in hämatitisch-oolithischen Eisenerzen in der östlichen Wüste in Ägypten durchgeführt wurden. Es wird die Paläogeographie der Nubischen Serie, besonders der östlichen Wüste, diskutiert, einmal anhand verschiedener geologischer Beobachtungen und darüber hinaus anhand der paläomagnetischen Daten; beides weist auf ähnliche Deutungen hin. Die Lage des Paläoäquators und des Paläobreitenkreises 20° S zeigt an, daß die Nubische Serie in der Umgebung des damaligen Äquators abgelagert wurde. Die paläomagnetischen Ergebnisse bestätigen frühere afrikanische Daten, nach denen keine Kontinentaldrift für diesen Raum zwischen 210 und 110 Mill. Jahren stattfand, und erweitern diese Periode bis 85 Mill. Jahre. Es wird angenommen, daß die Nubische Serie in tropischem bis subtropischem Klima abgelagert wurde, und zwar unter den verschiedensten kontinentalen Ablagerungsbedingungen.

Abstract

The present work gives the results of the paleomagnetic investigations carried out on the Cretaceous Nubian Sandstone and associated volcanics and hematitic oolitic iron ores in the Eastern Desert of Egypt. The paleogeography of the Nubian Sandstone especially for the Eastern Desert is discussed in the light of the various geological data as well as the paleomagnetic results, both of which point to certain conceptions. The position of the paleoequator and paleolatitude 20° S were derived from the paleomagnetic data indicating that the Nubian Sandstone was originally deposited in the paleoequatorial to subequatorial zone. The paleomagnetic results corroborate previous African data that there has been no polar wandering and continental drift for Africa during 210 to 110 million years and extend this period to 85 million years.

It is concluded that the Nubian Sandstone is deposited under tropical to subtropical climate and that it is formed under various continental conditions excluding eolian merging intermittently into shallow marine.

Résumé

Le présent travail est le résultat des recherches paléomagnétiques effectuées sur le grès nubien crétacé, les volcanites associées et les minerais de fer hématitiques et oolithiques dans le désert oriental de l'Egypte. La paléogéographie du grès nubien, surtout celui du désert oriental, est discutée à la lumière des différentes observations géologiques variées et, en outre, des données paléomagnétiques; toutes deux concluent

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a la même signification. La position du paléoéquateur et de la paléolatitude 20° S montre que la série nubienne a été déposée dans le domaine proche de l'équateur relatif à cette époque.

Les résultats paléomagnétiques corroborent les données africaines antérieures d'après lesquelles il n'y aurait pas eu, pour ces régions, de dérive continentale entre 210 à 110 millions d'années; ils prorogent cette période jusqu'à 85 millions d'années.

On admet que le grès nbien fut déposé sous le climat tropical à sub-tropical et effectivement sous les différentes conditions de dépôt continentales.

Краткое содержание

В данном опубликовании приводят результаты палеомагнитных определений, проведенных на нубийских свитах возраста нижнего мела, а также на соответствующих вулканических породах и гематито-оолитовых железных рудах восточной пустыни Египта. Обсуждается палеогеография этой свиты, составленная как на основании различных геологических наблюдений, так и по данным палеомагнитных измерений. В обоих случаях приходят к тем же самым выводам. Положение палеоэкватора и палеотропика рака у 20° южной широты указывает на то, что нубийская свита отложилась в области тогдашнего экватора. Данные палеомагнитных измерений подтвердили прежние выводы о том, что не только в период 210—110 миллионов лет тому назад, но идо 85 миллионов лет тому назад никакого дрейфа Африканского континента не происходило. Считают, что нубийская свита отложилась в тропическом и субтропическом климате при самых разнообразных условиях континентального осадконакопления.

Introduction

Two areas of Nubian Sandstone exposures in the Eastern Desert of Egypt have been chosen for paleomagnetic studies in order to help to reveal together with the various geological investigations the paleogeography of this sediment. This problem is considered of certain importance due to the wide extension of the Nubian Sandstone in a large region in northern Africa and south western Asia and because of the controversies on its paleogeographic environment of deposition.

The first area chosen for study is that of Wadi Natash (Fig. 1) where the Nubian Sandstone is invaded by volcanics. While the second area is located to the east of Aswan with the Nubian Sandstone showing intercalations of hematitic oolitic iron ore beds.

The geological works, especially those related to the examined areas, and considered by the authors to be of particular interest from the environmental point of view are correlated with the results of the paleomagnetic studies in order to interpret the paleogeography of the Nubian Sandstone.

Geological evidences on the paleogeography of the Nubian Sandstone

Russegger (1837) was the first to use the term "Nubian Sandstone", as it outcrops in Nubia. He described the Nubian Sandstone as Early Cretaceous in his maps of Egypt and Arabia Petraea. Since Russegger the term has been used widely in northern Africa and south western Asia, either restricted to the Cretaceous sandstones, especially those of Lower Cretaceous age, or extended as a facies to various Mesozoic and Paleozoic sandstones. Pomeyrol (1968) after reviewing the various uses of the term "Nubian Sandstone" concluded that this term must be abandoned. Klitzsch (in press) introduced the term Messak Sandstone instead of Nubian Sandstone for certain Mesozoic sediments in south western Libya believed to be of continental derivation. It is not the purpose of this work to review the stratigraphy or the usage of the term in question, but to give some relevant data which may help to characterize the paleogeography of the Nubian Sandstone with particular emphasis on the studied areas in the Eastern Desert of Egypt. Here the Nubian Sandstone is applied to those detrital sediments which are of Cretaceous age and which are bounded on the top by the fossiliferous essentially calcareous sediments of Upper Cretaceous age. The Nubian Sandstone has been reported from a certain large geographic region in northern Africa and south western Asia including Egypt where it has been first reported, northern and central Sudan, Libya, Arabian Peninsula, the Levant, Jordan, etc. The presence of Nubian Sandstone in such a geographic region is in itself a strong evidence in favour of its unique depositional environment.

Fossils found in the Nubian Sandstone give a clue to its environment of deposition. NEWTON (1909) examined fossils collected by Ball, Hume, Murray and Crosthwaite from the Nubian Sandstone in the vicinity of Aswan and the southern parts of Egypt. He recorded from Jowikol 40 km south of Aswan, four new species of fresh water shells which are Unio humei, Unio crosthwaitei, Unio jowikolensis and a marine annelid Galeolaria filiformis. BARTHOUX and FRITEL (1925) described a variety of fossil plants from the Nubian Sandstone to the east of Aswan iacluding Weichselia sp., Frenelopsis hoheneggeri (Ettinghausen), Dadoxylon aegyptiacum Unger and fern fragment indet. ATTIA & MURRAY (1952) found Lower Cretaceous ammonites in marine intercalations in the Nubian Sandstone of Wadi Qena area in the Eastern Desert of Egypt. Cox (in ATTIA, 1955) described marine and non-marine lamellibranchs collected from ferruginous sandstone overlying the upper oolitic iron ore band in the Nubian Sandstone to the east of Aswan. The marine fossils are Isocardia aegyptiaca and Cyprina Humei, while the non-marine are Unio jowikolensis-Newton, Unio Attiai, Unio nubianus, Iridina (Pleiodon) aswanensis and Iridina (Pleiodon) sp. Inoceramus probably belonging to the species Iballi-Newton has also been found. Furthermore, carbonaceous beds have been recorded in Nubian Sandstone in various countries where it is encountered. The fossil evidences in the localities mentioned suggest the following: 1. The Nubian Sandstone is of Cretaceous age with both Upper Cretaceous and Lower Cretaceous fossils. 2. The fauna and flora recorded suggest non-marine and shallow marine environments of deposition where the waters have been warm, and 3. the presence of occasional wet humid conditions during the deposition of the Nubian Sandstone.

Geological, structural and mineralogical evidences point out ideas regarding the environment of deposition and origin of the Nubian Sandstone. SHUKRI (1945) from Egyptian evidences considered the Nubian Sandstone as beach and off-shore shallow marine deposit of a sinking peneplained land mass, and excluded the possibility of an eolian origin or its deposition under fluviatile, lacustrine, deltaic or estuarine environment. He based his conclusions on the following observations: 1. the upward transition from sands to clays to limestones, 2. the regular stratification and large lateral extension of the sandy beds, and, 3. the presence of water ripple marks, current bedding with horizontal and inclined laminae at 26° with the horizontal, and bands of transported quartz pebbles of spherical and discoidal shape.

The heavy minerals in the Nubian Sandstone in Aswan have been found to be mainly iron ores, zircon, tourmaline and rutile (Shukri & El Ayouty, 1953). The minerals gave evidence of their derivation from pre-existing sediments, and that the Nubian Sandstone is a typical platform deposit poor in heavy minerals. The authors assumed the presence of two sources for the lower and upper horizons. The lower horizons which contain angular and prismatic zircon are probably derived from the local underlying basement rocks. The upper horizons containing rounded zircons are derived from sources situated further to the south. Attia (1955) following considerable field work concluded that the Nubian Sandstone outcropping to the east of Aswan is of marine origin and that the deposition of strata began under shallow water conditions, the continent was not far away and the area must have been subjected to uplift and subsidence. His conclusions are based on upward transition from sands to sandy clays and clays, large extension and regular stratification of the beds, occurrence of fossil fresh-water shells and plant remains as well as marine shells in other beds, water ripple marks, type of current bedding present, and the base of the Nubian Sandstone being somewhat irregular. McKee (1962) carried out reconnaissance studies on statistical analysis of cross stratification of Nubian and similar sandstone in some countries in northern Africa and south western Asia including Egypt, Sudan, Libya and Jordan. Tabular-planar cross stratification of medium scale has been found predominating in the sandstone. Such structures are interpreted to be formed where currents drop their load due to a sudden decrease in velocity as a result of an abrupt increase in water depth. Moreover, penecontemporaneous folded structures are common in the sandstone. McKee concluded that the Nubian type sandstones are not eolian in general and that they developed largely in a marginal or continental environment, predominantly lagoonal, estuarine or lacustrine and fluviatile. Directions of sand transportation in the Cretaceous Nubian Sandstone possess a general northerly direction in Kharge Oasis, Aswan and Wadi Araba (Egypt), Fezzan (Libya) and Khartoum (Sudan). Furthermore, there are evidences indicating the presence of certain laterites and occasional carbonaceous beds in the Nubian Sandstone in several countries (for the Sudan see Whiteman, 1970; Kheiralla, 1966).

The deposition of the Nubian Sandstone in Egypt is greatly controlled by the numerous minor oscillations prevailing in the Cretaceous, until the environment has been greatly changed by major subsidence and sea transgression in the Upper Cretaceous leading to the formation of the fourth calcareous sediments (Ataqa-Mokattam sediments) of Upper Cretaceous to Middle Eocene age. The change of environment is synchronous with the intensification of the crustal disturbances and the development of the alkaline to acidic volcanics with type locality Wadi Natash (El Shazly, 1966).

The mentioned studies on the Nubian Sandstone in the examined areas point out to the following conclusions: 1. The Nubian Sandstone is not of eolian deposition, thus indicating that the present day arid to semi-arid conditions in the region where the Nubian Sandstone is recorded have not been prevalent during its deposition in the Cretaceous. On the other hand, there are indications of occasional wet humid conditions, 2. the environment of deposition is ranging from various continental environments (excluding eolian) to shallow marine, and, 3. the changes in the environment are generally numerous but of small magnitude until the major change to marine environment occurred in the Upper Cretaceous in most countries where the Nubian Sandstone has been observed. These changes are explained by crustal disturbances.

Paleomagnetism of rocks studied

Samples representing the Nubian Sandstone were collected from two areas in the Eastern Desert of Egypt, namely from Wadi Natash and East Aswan (Fig. 1).

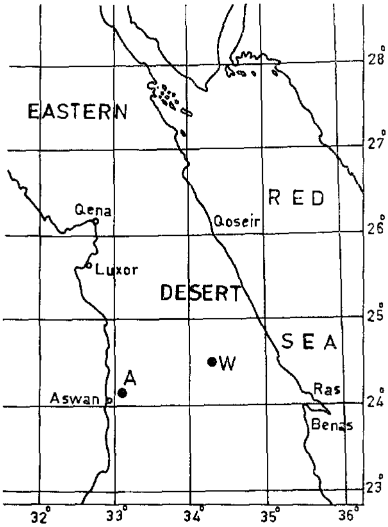

Fig. 1. Location map of Wadi Natash area (W) and East Aswan area (A) in the Eastern Desert of Egypt.

Representative samples from each exposure were subjected to laboratory stability tests using A.C. and thermal treatments. For A.C. treatment an A.C. demagnetization equipment was used, in which the rock sample was rotated during the demagnetization process around two perpendicular axes. For thermal treatment, samples were placed in a non-magnetic oven with compensated magnetic field down to a few tens of gamma. The remanent magnetization of weakly magnetic samples was measured by means of a high-sensitivity rock-generator, which enabled to determine the directions and amplitudes of remanent magnetization down to 2—3.10^{-8} emu/cc.

Wadi Natash area: Sedimentary and volcanic rocks of Upper Cretaceous age were sampled from nine different localities in Wadi Natash area with outcrops representing various strata of Nubian Sandstone and lavas of trachyte and trachyte tuffs, they were previously studied in detail for their paleomagnetic stability but not from the paleogeographic point of view (El Shazly & Krs, in press). The age of Wadi Natash volcanics has been determined as Upper Cretaceous by Barthoux (1922) based on field evidence, the age of a basalt flow from these volcanics has been determined by K/A method to be 85.6 ± 4.3 million years which corroborates the field evidence. The sandstones examined are medium grained with grains mainly subangular to subrounded, and constituted of quartz and felspars. Interstitial hematite is present either dispersed or in grains occasionally replacing the quartz and felspar. In the trachyte hematite is notably dispersed in the groundmass or between the felspar laths and it may even form aggregates.

Fig. 2 demonstrates results of A. C. demagnetization on representative samples. The intensity decay graphs clearly show that even in very high A. C. fields the majority of the samples did not loose substantially their remanent magnetic moment. However, some samples possess considerable portions of soft components of magnetization which could be removed in low A. C. fields. Table 1 reviews data obtained during A. C. treatment. Fisher's (1953) statistics were employed for the statistical evaluation of the mean directions of remanent magnetization. The symbols used: α_{95} is the semi-vertical angle of the cone of confidence at the 95% probability level, k is the precision parameter, N is the number of samples analyzed.

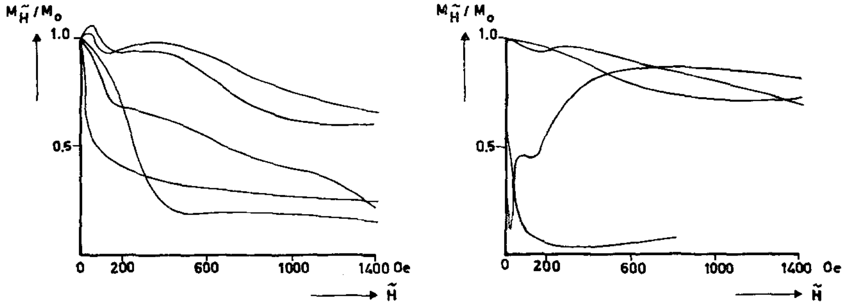

Fig. 2. A. C. demagnetization of representative samples from Wadi Natash area. $M_{\tilde{H}}$ — remanent magnetic moment of the samples demagnetized in the A. C. field $\tilde{H}$, in oersteds; M_0 — natural remanent magnetic moment.

Decay of natural remanent magnetic moments during thermal treatment is demonstrated in Fig. 3. It is evident that in many samples at least two-phase magnetic components are carriers of remanent magnetization, but hematite is almost always present. Table 2 summarizes data obtained during thermal treatment.

The intensity decay graphs on Figs. 2, 3, and the statistical data in Tables 1, 2 permit to formulate the following conclusions: Many of the samples show soft components of magnetization, which may be removed or reduced by treatment in the A. C. fields of 30 Õe. Consequently, all the samples, for which paleomagnetic directions had to be determined, were subjected to a cleaning process using A. C. fields of 30 Õe. However, A. C. treatment at 30 Õe cannot sufficiently clean all the samples since many of them contain magnetic phases with higher magnetic hardness. The next step of magnetic cleaning required thermal treatment. The semi-vertical angle of the cone of confidence α_{95} is minimum and the precision parameter k maximum for the temperature 550° C from the

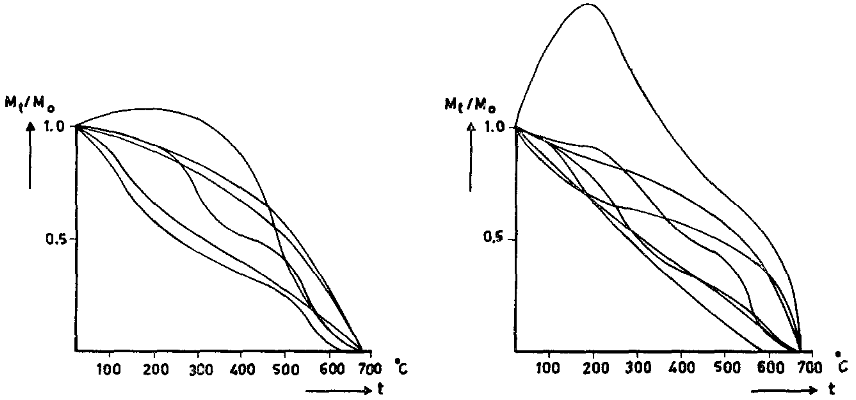

Fig. 3. Thermal demagnetization of representative samples from Wadi Natash area. M_t — remanent magnetic moment of the sample demagnetized in the thermal field at the temperature t, in centigrades; M_0 — natural remanent magnetic moment.

Table 1. A. C. demagnetization of samples from Wadi Natash area.

A. C. demagnetizing field	Direction of remanent magnetization		α_{95}	k	N
	Declination	Inclination			
0 Õe	6,5°	14,3°	26,73°	4,67	9
30 Õe	357,6°	13,9°	24,72°	5,29	9
60 Õe	356,0°	9,3°	32,17°	3,52	9
90 Õe	354,1°	4,7°	35,85°	3,02	9
120 Õe	0,2°	9,2°	38,28°	2,77	9
150 Õe	357,2°	16,6°	58,42°	1,74	9
200 Õe	355,0°	12,6°	37,65°	2,83	9
250 Õe	354,6°	16,8°	37,87°	2,81	9
300 Õe	352,2°	18,8°	36,99°	2,89	9
400 Õe	351,8°	16,3°	36,80°	2,91	9
500 Õe	349,5°	19,2°	33,92°	3,26	9
700 Õe	341,6°	12,6°	37,78°	2,82	9
900 Õe	343,2°	12,2°	35,12°	3,11	9
1200 Õe	342,3°	12,5°	44,93°	2,48	8
1400 Õe	2,0°	24,9°	46,90°	2,35	8

whole temperature range of < 50° C, 550° C >; consequently all the samples were subjected to thermal cleaning at this temperature. After thermal cleaning at 550° C few samples showed scattered results, but the main group of samples formed a good statistical set for evaluation of the mean paleomagnetic direction. Fig. 4 demonstrates a stereographic projection of the directions of remanent

Table 2. Thermal demagnetization of samples from Wadi Natash area.

Temperature in ° C	Direction of remanent magnetization		α_{95}	k	N
	Declination	Inclination			
20° C	357,9°	12,4°	23,07°	4,20	13
50° C	0,0°	11,5°	25,11°	3,69	13
100° C	358,9°	9,0°	25,57°	3,60	13
150° C	356,7°	7,6°	28,82°	3,04	13
200° C	356,2°	6,0°	29,24°	2,98	13
250° C	358,2°	6,8°	29,21°	2,98	13
300° C	354,1°	2,3°	29,90°	2,89	13
350° C	355,0°	3,8°	29,74°	2,91	13
400° C	353,3°	— 0,6°	28,78°	3,04	13
450° C	354,2°	1,2°	26,88°	3,35	13
500° C	350,8°	5,0°	28,11°	3,14	13
550° C	350,5°	— 3,0°	24,21°	3,90	13

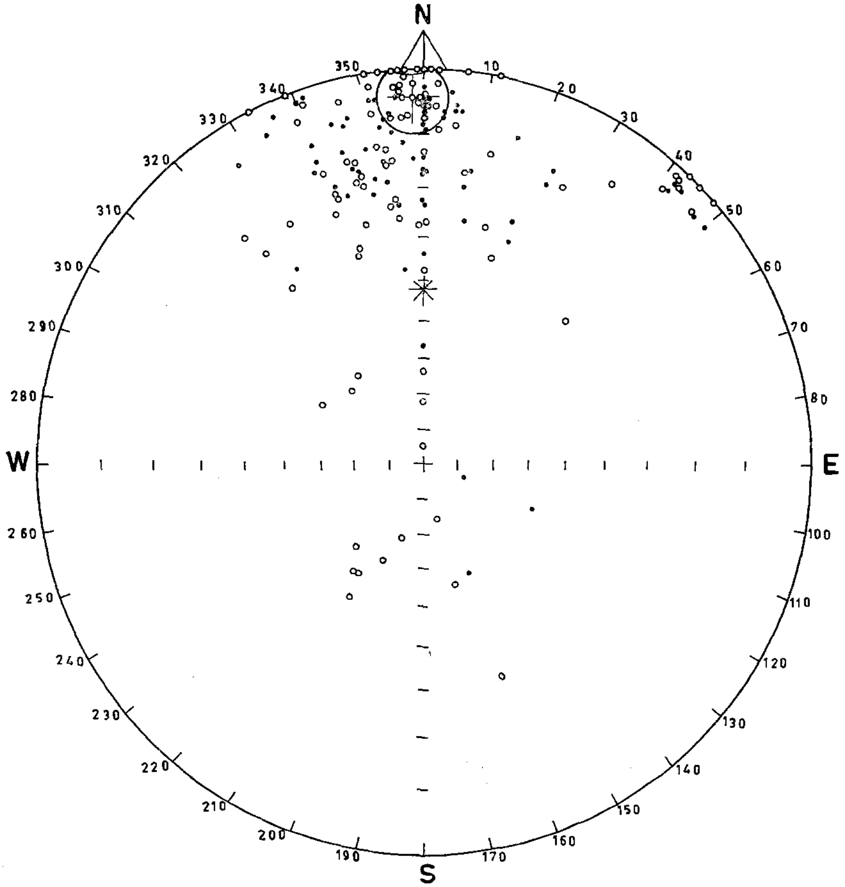

Fig. 4. Stereographic projection of directions of remanent magnetization for Upper Cretaceous rocks from Wadi Natash area, after thermal treatment at 550° C.

magnetization of samples treated at 550° C, the mean paleomagnetic direction is designated by a cross across an open circle, and the corresponding confidence circle was calculated according to Fisher (1953) at the 95% probability level. Projection into the upper (lower) hemisphere is designated by an open (solid) circle.

East Aswan area: Only twelve samples of sandstones rich in hematite and hematitic iron ores rich in quartz were collected from five exposures located in the iron ore mines to the east of Aswan. The samples were obtained from two oolitic hematitic iron ore beds, a lower bed (A) and an upper bed (B) according to the following scheme:

Sample No.	Locality	Bed
E 72—73	Um Baramil area	Lower part of A bed
E 74—76	Um Baramil area	B bed
E 77—78	Aqaba area	Top of A bed
E 79—80	Main quarry, s.c. area	B bed
E 81—83	Timsah area	B bed

The iron ore beds are enclosed in the Nubian Sandstone succession considered of Upper Cretaceous age in this locality, although it may be Lower Cretaceous towards the base and it overlies the igneous-metamorphic basement rocks essentially Precambrian passing into Paleozoic. Attia (1955) grouped the Nubian Sandstone succession in the area to the east of Aswan into the following: lower beds, 40 to 55 m thick, sandstones and clays with grits, clayey sandstones and sandy clay, and with characteristic conglomerates, pebble beds and kaolinic sandstones; middle beds, 10 to 22 m thick, sandstones, clayey sandstones, sandy clays, clays, ferruginous sandstones, with oolitic iron ore deposits; and upper beds 20 to 85 m thick, variegated clays, sandy clays, clayey sandstones, sandstones, grits and quartzites. Three samples (Nos. E 74, 77, 78) were found not suitable for paleomagnetic studies, since phase changes occurred in them in the initial stages of thermal treatment. The remaining nine samples after thermal treatment were subjected to statistical evaluation, and sample E 79 with normal polarization of magnetization was considered with reverse polarization during the statistical treatment. Table 3 reviews data obtained. The best results of

Table 3. Thermal demagnetization of samples from East Aswan area.

Temperature in ° C	Direction of remanent magnetization		α_{95}	k	N
	Declination	Inclination			
20° C	181,3°	—12,8°	13,77°	14,94	9
60° C	183,3°	—16,3°	12,14°	18,93	9
100° C	181,5°	—17,3°	11,72°	20,26	9
150° C	182,2°	—18,6°	11,26°	21,88	9
200° C	182,6°	—18,2°	11,02°	22,80	9
300° C	182,6°	—17,4°	12,02°	19,31	9
400° C	182,2°	—16,7°	12,55°	17,78	9
525° C	181,8°	—15,3°	14,64°	13,32	9

thermal cleaning were obtained for temperature 200° C, consequently the mean remanent magnetization of samples treated at this temperature was considered as paleomagnetic direction for samples from East Aswan area. However, this direction is close to the mean direction of remanent magnetization of samples in natural state. Fig. 5 demonstrates, in a stereographic projection, the directions of remanent magnetization of samples treated at 200° C.

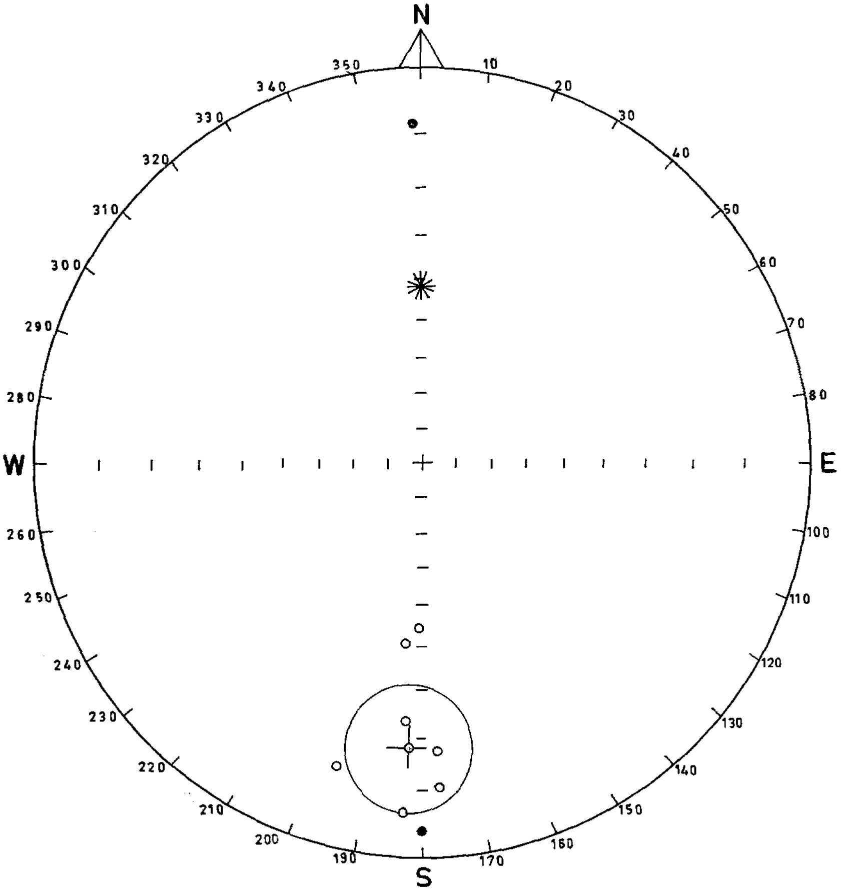

Fig. 5. Stereographic projection of directions of remanent magnetization of samples rich in hematite from East Aswan area, after thermal treatment at 200° C.

Table 4 summarizes the paleomagnetic data for both Wadi Natash and East Aswan areas. The calculated virtual pole positions for the rocks from Wadi Natash and East Aswan are close to each other, but not corresponding exactly within the confidence limits. This shows: a) either the age of formation of the Nubian Sandstone and enclosed iron ores examined from East Aswan area is not the same as the rocks from Wadi Natash area, b) or there is a disturbing effect of tectonic movement on a regional scale, or both. From the geological point

Table 4. Palaeomagnetic data from Cretaceous rocks in the Eastern Desert of Egypt.

Area	Mean geographic coordinates of area φ	λ	Mean palaeomagnetic directions D	I	α_{95}	k	N	Ancient pole positions φp	λp	Ovals of confidence δm	δp	Notes
Wadi Natash	24,50° N	34,17° E	358,35°	—3,84°	5,62°	4,85	163	63,53° N	142,13° W	5,63°	2,82°	Demagn. at 550° C
East Aswan	24,13° N	33,05° E	181,29°	—12,80°	13,77°	14,94	9	72,31° N	151,17° W	14,03°	7,15°	Natural state
			182,56°	—18,24°	11,02°	22,80	9	75,03° N	156,77° W	11,45°	5,95°	Demagn. 200° C

of view Wadi Natash flows and sandstones may be later than the sandstones and iron ores examined from East Aswan although both of them are considered to belong to the Upper Cretaceous. Furthermore, considerable tectonic movements have notable influence in the Upper Cretaceous, and they mark the transition from the Nubian Sandstone sedimentation to the proper marine sediments of the overlying fossiliferous Upper Cretaceous. The development of Wadi Natash volcanics is one of the expressions of these tectonic movements (El Shazly, 1966). More paleomagnetic studies are necessary to elucidate the influence of these factors on a regional scale.

Paleogeographic reconstruction of the paleomagnetic data

The data presented in Table 4 may be considered as a basis for paleogeographic reconstruction. The pole position 1 (Fig. 6) was derived from rocks of Wadi Natash. With the assumption of the theoretical magnetic dipole field in the past, the paleoquator and paleolatitude 20° S were derived, too. The geophysical interpretation shows the original position of the Nubian Sandstone in the paleoequatorial to subequatorial zone.

For the evaluation of the present data on an African scale, they are correlated with other comparable African investigations as given by Girdler (1969) who referred African paleomagnetic data to the paleolatitude of Nairobi (1,27° S, 36,80° E). When derived from Wadi Natash results the paleolatitude of Nairobi would be 28° S, and paleodeclination would be —2°, if measured anticlockwise from the present north. In Fig. 7 the results of Wadi Natash rocks — which have been formed about 85 million years ago — are plotted on a diagram giving the paleolatitude of Nairobi which has been presented by Girdler; the Wadi Natash data fit generally in the diagram. As the latter have been derived from both data fit generally in the diagram. As the latter have been derived from both sedimentary and volcanic rocks, and the samples were subjected to

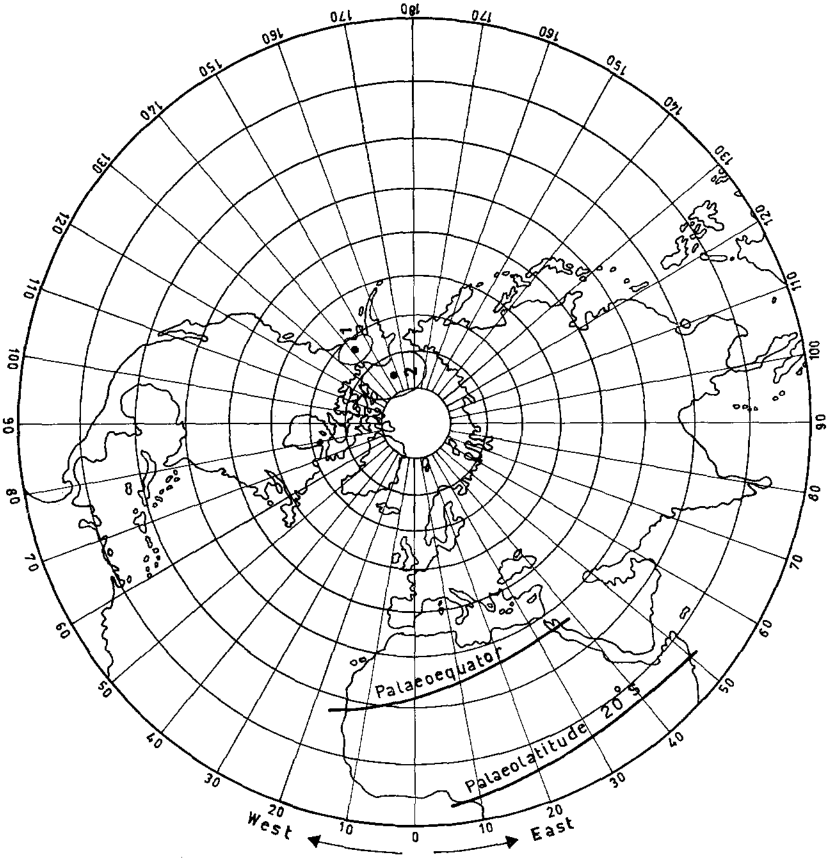

Fig. 6. Virtual pole positions derived from paleomagnetism of Upper Cretaceous rocks from Wadi Natash area (1) and from samples rich in hematite from East Aswan area (2). Paleoequator and paleolatitude 20° S correspond to pole position 1.

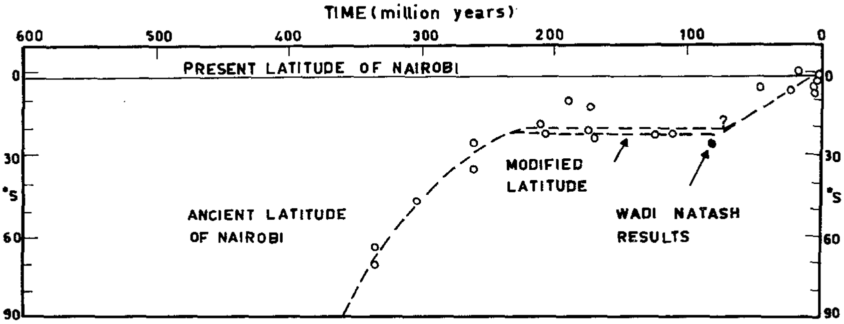

Fig. 7. Paleolatitudes of Nairobi as reference for Africa presented by Girdler (1969) and indicated by open circles. Wadi Natash data transferred to the paleolatitude of Nairobi are indicated by a solid circle. Change in the paleolatitude of Nairobi by adding Wadi Natash results is given by a thicker line.

extensive laboratory stability tests and magnetic cleaning procedures, so that they may be considered very reliable in respect to other data for Africa which have been obtained from either volcanic or sedimentary rocks. However, the present results support the picture visualized by Girdler for the continental movement of Africa in so far as there is no polar wandering including continental drift of Africa from 210 to 110 million years and possibly longer. In fact, Wadi Natash results extend this period to about 85 million years. For the greatest part of the following period the available data indicate — as can be seen from Fig. 7 — that Africa has been moving northwards. The latter period corresponds in time to important rifting of the Red Sea and to remarkable manifestation of the Alpine orogeny.

Paleogeographic conclusions

Based on the present paleomagnetic studies as well as various geological evidences, the authors of this work arrived at the following conclusions regarding the paleogeography of the Nubian Sandstone:

1. The climatic conditions prevailing during the deposition of the Nubian Sandstone are tropical to sub-tropical as evidenced by the position of the paleo-equator arrived at by the paleomagnetic studies and from the fossils present in the sandstone.

2. Crustal disturbances and oscillations have been prevailing during the deposition of the Nubian Sandstone which are indicated by the magnetic data, and evidenced by the presence of various geological phenomena including the volcanicity of Upper Cretaceous age in Wadi Natash, the occurrence of non-marine and marine fossils in closely alternating beds, the quick lithological changes from sandstone to sandy clay to clay and sometimes to calcareous beds, the presence of zircons from two sources in the same geological succession, the development of tabular-planar cross stratification and penecontemporaneous folded structures, etc.

The authors may sum up that they believe that the Nubian Sandstone is deposited under tropical to sub-tropical climate, and that it is formed under continental conditions which may be fluviatile, lacustrine or even paludial merging inter mittently into shallow marine because of the particular oscillations predominant at that time which have been generally frequent and small leading to the development of large areas with gentle slopes and topography giving characteristic weathering conditions until finally drastic crustal disturbances changed this environment in the Upper Cretaceous into proper marine with dominant calcareous deposition.

References

Attia, M. I.: Topography, geology and iron ore deposits of the district east of Aswan. — Geological Survey, Cairo, 262 p., 1955.

Attia, M. I., & Murray, G. W.: Lower Cretaceous ammonites in marine intercalations in the "Nubian Sandstone" of the Eastern Desert of Egypt. — Q.J.G.S., **107**, 442—443, London 1952.

Barthoux, J.: Chronologie et description des roches ignées du Désert Arabique. — Mém. Inst. Egypte, **5**, 262 p., 1922.

Barthoux, J., & Fritel, P. H.: Flore crétacée du grés de Nubie. — Inst. Egypte Mém., **7**, fasc. 2, 65—119, 1925.

El Shazly, E. M.: Structural development of Egypt, U.A.R. — Programme and Abstracts, Fourth Annual Meeting, The Geological Society of Egypt, 31—38, 1966.

El Shazly, E. M., & Krs, M.: A paleomagnetic study of Cretaceous rocks from Wadi Natash Area, Eastern Desert, Egypt. — Geophysical Journal of the Czechoslovak Academy of Sciences, Prague, No. 329, 323—334, 1972.

Fisher, R.: Dispersion on a sphere. — Proceedings of the Royal Society, London, **217**, A, 295—305, 1953.

Girdler, R. W.: The Red Sea — A Geophysical Background. — In: Hot Brines and Recent Heavy Metal Deposits in the Red Sea, 38—58, New York (Springer-Verlag) 1969.

Kheiralla, M. K.: A study of the Nubian Sandstone formation of the Nile Valley between 14° N and 17° 42′ N with reference to groundwater geology. — M. Sc. Thesis, Khartoum University, Sudan, 1966.

Klitzsch, E. H.: Continental Mesozoic strata of southwestern Libya (Messak Sandstone, Former Nubian Sandstone). — African Geological Congress, Ibadan, Nigeria 1970 (in press).

McKee, D. Edwin: Origin of the Nubian and similar sandstones. — Geol. Rdsch., **52**, 551—587, Stuttgart 1962.

Newton, R. B.: On some fossils from the Nubian Sandstone series of Egypt. — Geol. Mag., **6** (decade 5), 352—359, 1909.

Pomeyrol, R.: Nubian Sandstone. — A.A.P.G. Bull., **52**, 589—600, 1968.

Russegger, J.: Kreide und Sandstein, Einfluß von Granit auf letzteren. — Neues Jahrb. Mineral., 665—669, 1837.

Shukri, N. M.: Geology of the Nubian Sandstone. — Nature, **156**, No. 3952, 116, 1945.

Shukri, N. M., & El Ayouty, M. K.: The mineralogy of the Nubian Sandstone in Aswan. — Inst. Desert Egypte Bull., **3**, No. 2, 65—88, 1953.

Whiteman, A. J.: Nubian Group: Origin and Status. — A.A.P.G. Bull., **54**, 522—538, 1970.

Geochemistry of ground waters from some localities West of the Nile Delta

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With 11 figures and 2 tables

Zusammenfassung

Diese Arbeit beschäftigt sich mit der Geochemie der Grundwässer der Tahrir-Provinz und des Gebietes des Wadi El-Natrun, westlich vom Nildelta.

Die Verteilung der Kationen und Anionen in diesen Wässern zeigt, daß der Gehalt an Kalzium und Magnesium niedriger, dagegen der Gehalt an Natrium-, Karbonat- und Chloridionen höher im Gebiet des Wadi El-Natrun, als in der Tahrir-Provinz ist. Kalium- und Sulfat-Gehalte sind identisch.

Die regionalen Unterschiede im Chemismus der Grundwässer wurde mit Hilfe der Iso-Konzentrationskarte von Kationen und Anionen untersucht. Vom Nildelta bis Wadi El-Natrun wird eine zunehmende Tendenz der Salinität bzw. der meisten Kationen und Anionen festgestellt.

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