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GRANITIC RING COMPLEXES AND POST PRECAMBRIAN HOT SPOT ACTIVITY IN THE SOUTHEASTERN DESERT, EGYPT

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الحلقيات المعقدة الجرانيتية و نشاطات البقع الساخنة فيما بعد عصر ما قبل الكمبري
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الخلاصة: تعتبر الحلقيات المعقدة الجرانيتية فيما بعد عصر ما قبل الكمبرى فى مصر مثالَ ممتازَ لنوعية الحلقيات القلويةِ والمصاحبة لنشاطات البقع الساخنة والانصهار الانسيالى والتصدع غير المكتمل. لقد تم دمج الارتفاعات الرقمية عالية الدقة مع الجاذبية الارضية المقاسة من الفضاء والتى نشرت مؤخرا لتحسين نموذج الجاذبية الجيودية الإقليمية. حيث تم تكامل هذه البياناتِ مع التسلسل الزمنى الجيولوجى والتى تقترح ثلاثة من المسارات فيما بعد عصر ما قبل الكمبرى النارية فى مصر. ولقد أمكن الربط بدقة بين نمط انحراف الجيودات عن هيكل المجسم المرجعى فى مصر؛ والتى تؤدى إلى عدم التجانس فى الوشاح السفلى و القشرة الأرضية. ويشير تأثير هذه البقع الوشاحية السفلية والتى خلالها انجرفت مصر لمدة ٢٠± ٢٣٠ مليون سنة عبر اللوح الأفريقى والتى تقترح بأنها هى المسئولة عن وضعية هذه الصخور القلوية لعمل التعديلات التكتونية وزيادة التدرج الحرارى والتى تؤدى إلى تكوين بيئة مناسبة لتركيز الخامات فى صخور القاعدة مع ايضاح الدليل الداعم لهذه الفكرة، ولقد تم تفسيرتكوين الحلقيات المعقدة من خلال نموذج يشمل أربع مراحل متعاقبة من الأحداث البلوتونية والبركانية والهيكلية والتى تشمل حاجز اقحامى حلقى ثم تآكل فى المرتفعات البركانية مع التداخل البلوتونى الرئيسى يليه كشف القمة له.

ABSTRACT: *The Post Precambrian ring complexes in Egypt represent an excellent example of the type of alkaline ring complexes associated with intraplate hot spot activity, ensialic melting, and incomplete rifting. The high resolution SRTM Digital Elevation Model with the recently published GRACE gravity has been optimally combined to improve the regional gravimetric geoidal model. This data integrates with the geochronology of the anorogenic alkalic rocks dates that suggest three phases of Post Precambrian igneous activities in Egypt. A striking correlation is shown between the patterns of geoid departure from reference ellipsoid in Egypt, attributed to inhomogeneities in the mantle, and the crustal framwork. The effect of these mantle plumes, over which Egypt has been drifting for the past 230 ± 20 m. y. of African plate movement, suggests that the hot spot activity was responsible for emplacement of alkalic rocks, for tectonic adjustments and for increased geothermal gradient that created favorable ore-concentrating environments in the basement rocks. Evidence supporting this idea is provided. The development of the ring complexes is interpreted in terms of a model consisting of four successive stages of structural, volcanic, and plutonic events: cauldron subsidence, ring dike intrusion, erosion of the volcanic highlands, and intrusion of central pluton with unroofing of the central pluton.*

INTRODUCTION

The alkaline ring complexes province in the South Eastern Desert of Egypt is of limited distribution and is found mainly south of Latitude 25º N (Fig.1). They intrude a dominantly Proterozoic basement of gneisses, metasediments, island arc volcanics and older granitoids. They are circular to elliptical in plan, a few kilometres in diameter, and include a wide variety of granites, syenites, nepheline syenites and gabbros, as well as their volcanic equivalents, all arranged in a dominantly concentric fashion.

They represent the northward continuation of the belt of ring complexes associated with the East African rift system (El Ramly et al. 1971). Barthoux (1922) was the first to identify Abu Khruq as a mass of nepheline syenite, and many years later, Akkad and El Ramly (1960) recognized it as the first ring complex in Egypt, comparable in its main features to those found elsewhere in Africa.

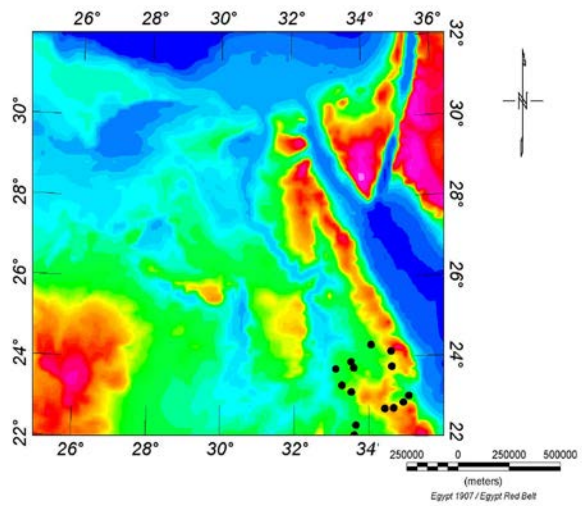


Fig. (1): Map of Egypt showing the location of some ring complexes.

El Ramly et al. (1971) stated that the distribution of the ring complexes in Egypt follows certain trends. For example, the Abu Khruq, El Kahfa, Zargat Naam, Nigrub El Tahtani and Nigrub E1 Fogani complexes lie along a NW-trending line, and those of Mansouri, E1 Naga, Mishbeh and Nigrub El Fogani lie on a NE trend. The largest ring complexes are those found where the two trends intersect. It was also stressed that ring complexes are restricted to crests of anticlines due to the high degree of fracturing along these crests" (El Ramly et al.1970, 1971). Garson and Krs (1976) subsequently suggested that the distribution of the ring complexes in Egypt is controlled by N60°E crustal block faults and shear zones, and N30°W deep-seated tectonic zones related to the opening of the Red Sea (Fig. 2). The best example for these features is the N60°E trend along which lie the ring complexes mentioned above.

El Ramly and Hussein (1985), depending on the basis of their magmatic differentiation, reflected in the variety of rocks they include, and on the degree of development of the ring nature and complexity of the structure. These ring complexes are classified into the five groups (I.Abu Khruq type - II. Gezira type - II1 - Mishbeh type - IV. Mansouri type - V. Tarbtie type).

Hashad and El Reedy (1979) using Rb/Sr isochron and conventional ages, together with previously published K/Ar dates suggest three phases of igneous activity, which assigned the following ages:

The 230 ± 20 m.y. phase: during which the more saturated massif of Zargat Naam (247 m.y.), Bir Um Hebal (223 m.y.) and Silai (221 m.y.) were emplaced. The ages correspond to a late Permian age and may in part be contemporaneous with the late Paleozoic ring complexes of Nigeria, Niger, and Cameron.

The 140 ± 15 m.y. phase: during which the more alkalic ring complex of Mishbeh (148 m.y.), El Naqa (146 m.y.), Nigrub El Tahtani (140 m.y.) and El Mansouri (132 m.y.) were formed. The ages correspond to an early Cretaceous age and correlate well with the published ages on some alkalic ring complexes in Sudan.

The 90 ± 20 m.y. phase: during which the alkalic volcanics of Wadi Natach (104 m.y.) were erupted, followed by the intrusion of Abu Khruq (84 m.y.) and El Kafa (81 m.y.) ring complexes. The ages correspond to the late Cretaceous time. Some K/Ar ages extend to volcanic activity in Wadi Natach to 70 m.y. before present.

Hashad and El Reedy (1979) tried to locate the ring masses on the map constructed by Garson and Krs (1976) showing the distribution of tectonic zones, probable transform faults and related igneous intrusions (Fig. 2). It will be noted that the granosyenite masses of Gebel Silaie and Gebel Zarget Naam fall along a major tranform fault (Fault D, Fig. 2) that runs approximately N60°E while bir Um Hebal complex is located along a parallel transform fault (Fault B in Fig. 2) somewhat to the north. The intersection of these transform faults with the northwestern faults seems to have controlled the exact location of the complexes. It seems that the transform faults, lineaments and zones of weakness trending approximately N50-60°E have had much more influence on the age of the different complexes compared to the northwestern faults.

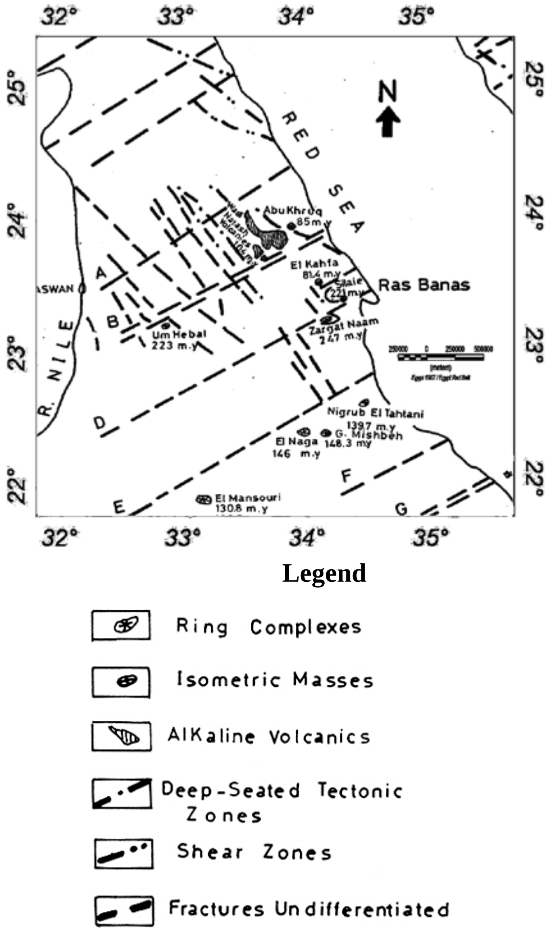


Fig. (2): Distribution and isotopic ages of the studied ring complexes and alkaline volcanics in the south Eastern Desert with their relation to the probable transform faults. (Structures simplified after Garson and Krs, 1976).

On a global scale, most of the continental provinces of alkaline rocks are located in cratons, i.e. tectonically stable regions of the crust (Sorensen 1974). Moreover, the association of most of these alkaline provinces with zones of rift is well-established, e.g. East Africa, Asia, the Rhine and the Monteregian Provinces. These zones of rift are the fractured crests of crustal arches. Hence, the Egyptian ring complexes can be related to swells or arches in the crust essentially distributed at random, but with some alignment along lines of weakness which probably existed since Precambrian times and which suffered frequent rejuvenation. In this connection, it is interesting to note that El Sharkawi and El Rabaa (1976) related the alkaline rocks of the Nuba Mountains in the Sudan to a NE-trending fault, along which earthquakes took place as recently as 1966. The cause of the swells and updomings of the crust is thought to be an intraplate mantle hot spot (Wright 1973) where parts of the plate overlying positive thermal anomalies are heated by the rising convection columns in the mantle (Briden and Gass 1974).

Data Used:

The South Eastern Desert is one of the most complicated area in Egypt from the view of rough topography, large lateral density and geoid height variations. The computation of a regional gravimetric geoidal model with high accuracy in mountainous regions is a difficult task that needs a special attention to obtain reliable results, which can meet the needs of the today's geodetic community. In this research different heterogeneous data has been used: which includes high resolution 30 m (1 arc-second) NASA Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model (DEM), recently published the Gravity Recovery And Climate Experiments (GRACE) Global Geo-potential Model. The above data has been optimally combined to improve the regional gravimetric geoidal model released later (Fig. 3). This data integrates with the geochronology of the anorogenic alkalic rocks such as Rb/Sr isochron and conventional ages, together with K/Ar dates that suggest three phases of Post Precambrian igneous activities in Egypt. The data reveals that the ring complexes of Nigrub El-Tahtani, Nigrub El-Fogani, Mishbeh, El-Naga, Gezeira and El Mansouri, extending southwestwards into Darfur volcanic province (western Sudan). So, the study area is extended to support this work.

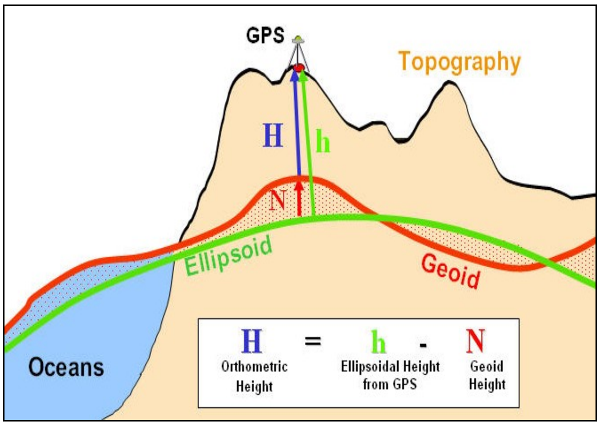


Fig. (3): Geoidal height (the reference ellipsoid used is WGS 84).

Hot spot Activity:

Wilson (1963) suggested that the time-progressive volcanism along the Hawaiian chain could be explained by the lithosphere moving across a "jetstream of lava" situated in the mantle under the island of Hawaii. 'Hotspots' are also called midplate volcanism, and mantle plumes. Most hotspots are not 'midplate'. Hotspots occur in extensional regions of the lithosphere, either plate boundaries or intraplate (lithospheric) boundaries. Morgan (1971) estimated that some 20 hotspots were underlain by deep mantle plumes, each equivalent in strength to the hypothetical Hawaiian plume. The common feature of the plume explanation for hotspots is that a deep thermal boundary layer–well below the upper mantle–creates an instability that gives rise to narrow buoyant upwelling. The concepts of 'plumes' and 'hotspots' have been coupled since these early papers, even though volcanoes, volcanic chains, time progressive volcanism and swells can exist without plumes. The plumes are not uniform in many aspects. Differences in their isotope signature imply that they have come from various depths and in a range of sizes (Vink et al. 1985) and also suggested that the discharge rate of a plume may vary over time and that their rocks may rise in blobs rather than in a continuous heat flow. The number of hotspots increased from the original 19–20 defined by Wilson and Morgan to 117–127 (Burke and Wilson, 1976). Courtillot et al (2003) tabulated the characteristics of 49 'hotspots' and compared them with a list of plume criteria. Courtillot lists included About 7 in Africa (Table 1 & Fig. 4). Data from Ring complexes terrane suggest that its evolution is related to subcontinental hot spot activity, ensialic melting, and incomplete rifting (Kisvarsanyi, 1976; Lowell, 1976). Several petrologic, geochemical, metallogenic and tectonic features are assumed to characterize hot spot activity within continental plates (Burke and Dewey, 1973; Sillitoe, 1974; Guild, 1974; Sawkins, 1976).

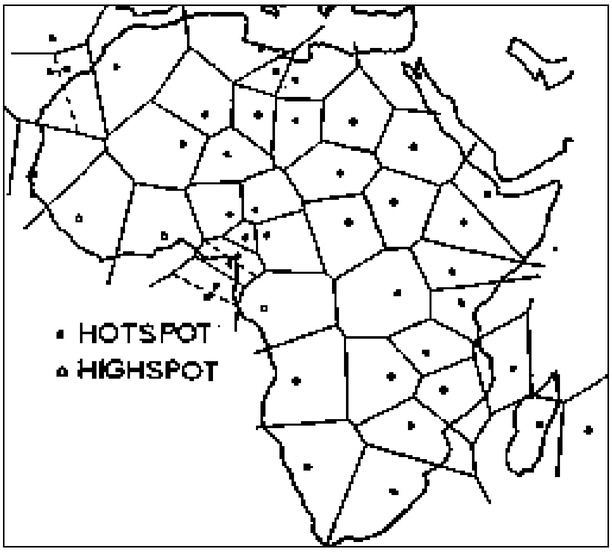


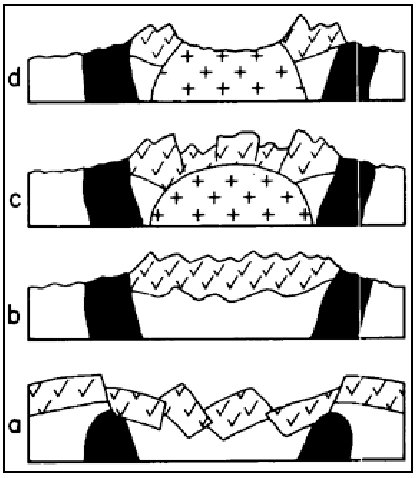
Fig. (4): Location of some hot (or high) spots in Africa.

Table (1) List of hot spots in Africa (After Courtillot et al, 2003).

No.	Name	Location	Type	Tectonics	Country
		Lat. Lon.			
1	Afar	12° 00´ 42° 00´	Triple Junction	T3	Ethiopia
2	Cape Verde	15°00´ -24°00´		Edge	Off NW Africa
3	Hoggar Mountains	23° 00´ 06° 00´			Algeria
4	Jebel Marra, Darfur	12° 57´ 24° 16´	Movable Plate	FZ	Sudan
5	Lake Victoria	-03° 00´ 36° 00´			East Africa
6	Mount Cameron	04° 12´ 09° 10´	Movable Plate	FZ	Atlantic Africa
7	Tibesti	21° 00´ 17° 00´			Chad

ɔle Junction

FZ = Fracture Zone



Legend

Volcanic rocks = v pattern
Subvolcanic granite = blank
Ring intrusion = solid black
Central pluton = + pattern.

Fig. (5) Schematic development of a ring complex (Smith and Bailly, 1968). The development of the ring complexes is interpreted in terms of a model consisting of four successive stages of structural, volcanic, and plutonic events. (a) cauldron subsidence and ring dike intrusion, (b) erosion of the volcanic highlands, (c) intrusion of central pluton, and (d) unroofing of the central pluton.

Four aspects of hot spot activity are especially pertinent to the crustal evolution of similar complexes in the midcontinent:

1. Mantle pluming may be extended through a long period of geologic time, and its manifestations and intensity may change.
2. The effect of hot spot activity may be limited only to epeirogenic uplift, incomplete rifting, and the emplacement of alkaline magmas derived from partial melting of lower crustal rocks (Bowden, 1974).
3. Probing mantle plumes seek out zones of previous crustal disturbance and thus renew igneous activity and/or movement along these zones (Burke and Dewey, 1973).
4. Certain types of mineralization are typically associated with intracontinental hot spot activity (Guild, 1974; Sillitoe, 1974; Sawkins, 1976). In the Egyptian terrane, these include possible U-Th and rare-earth-element mineralization in the granites. Recurrent hot spot activity may have had a role in the metallogenesis of the region.

The granitic rocks are assigned to three main stages during which magmas of distinctly different composition were emplaced: as subvolcanic massifs below the volcanic rocks (stage I), as ring intrusions in cauldron-subsidence structures (stage II), and as central plutons in resurgent cauldrons (stage III). The ring complexes are defined essentially by the ring intrusions and the central plutons (Fig. 5).

Evidence indicates that the Post Precambrian hot spot activity did not reach an advanced rifting stage, because the anorogenic complexes contain subordinate of basaltic rocks. Satellite measurements of the earth's gravity field have shown that hot spots are areas of anomalously high gravity. Kaula (1969) observed a relationship between the geoid highs and lows and the active geologic (tectonic) zones and concluded that the geoid is an expression of the deep-seated mantle movements (convection) that are responsible for geological activity. Fouad (1987) observed a striking correlation is shown between the pattern of satellite geoid departures from reference ellipsoid in Libya, attributed to inhomogeneities in the mantle, and the country’s tectonic (crustal) framework.

SRTM and GRACE Gravity Signatures:

The topographic features of the region east of the Nile are very different from those of the Western Desert (Fig. 6). The relatively mountainous Eastern Desert rises abruptly relative to the Nile valley and extends over an area of approximately 220,000 km2. The region's most prominent feature is the easterly chain of rugged mountains, the Red Sea Hills, which extend from the Nile Valley eastward to the Gulf of Suez and the Red Sea. This elevated region has a natural drainage pattern that rarely functions because of insufficient rainfall. It also has a complex of irregular, sharply cut wadis that extend westward toward the Nile. The importance of the Eastern Desert lies in its natural resources, especially oil and rare earth elements. The alkaline rocks are of limited distribution in the Southeastern Desert of Egypt and are represented mainly by some ring complexes, ring dykes, plugs and volcanic flows of variable ages.

The GRACE gravity measurements across the ring complexes from Egypt (Fig. 7) indicate different gravity signature, igneous complexes of dominant acid composition are characterized by low gravity values and those of dominant basic lithology are indicated by positive gravity signature. They were probably derived from hot spot activity and emplaced under effect of tensional tectonics. Acid to basic rock proportion probably controlled by the style and magnitude of the prevailing tensional forces during the formation of the igneous bodies i. e. the manifestation of hot spot activity, where ring complexes situated closer to the active continental margin contain more basic material than those located within the plate. Satellite measurements of the earth's gravity field have shown that hot spots are areas of anomalously high gravity.

According to Vink et al. (1985), this high gravity is due to excess mass which is attributed to broad bulges in the surface produced by the upwelling plumes. Fouad (1987), however, does not fully agree with this explanation as the plume produces uplifting not by bending the lithosphere but by thinning it, replacing the cold dense lithosphere with hot, buoyant rock from the asthenosphere.

The Darfur volcanic province, western Sudan, is an area of about 400 x 100 km with Tertiary to Holocene volcanic and subvolcanic activity. It is comparable in size and magma types with other volcanic centers in North Africa. Its origin ascribed to a mantle plume. New investigation on ages, uplifting with volcanic and subvolcanic activity, combined with a GRACE gravity map allow the construction of a model for development of an intraplate volcanic field. Hot spot action in Sudan was limited to the first stage, manifested by uplifting and has not led to rifiting.

Geoid Departure:

A variation of more than 20 m in the geoid relief is the first striking feature on such a relatively small area of the world. The most prominent parts of the geoid (14-15 m) are those at the northeastern region of the area. Away from this high, the geoid relief flattens out relatively steeply southeastwards. The striking correlation observed between the geoid relief pattern and the hot spot tracks affecting the area (Fig. 8) shows how the mantle plume tracks are neatly aligned with the geoid relief contours, whose correlation with the tectonic framework can also be readily recognized; the following are examples:

The Late Paleozoic uplifting encompasses most of the ring complexes of Zargat Naam, Hadayib, Um Risha, Bir Um Hebal, Tarbite South and Tarbite North correspond with a characteristic nosing of high relief geoid departure in the NE of the area.

Table (2): The hot spot tracks with the geochronology of the anorogenic alkalic rocks.

No.	**Name**	**Location**		**Type**	**Age**		**Country**	**Track**	**Ref.**
		Lat.	Lon.			m. y.			
1	Zarget Naam	23° 45´	34° 40´	Alkaline Volcanics & Ring Complexes	Late Paleozoic Magmatism 230 ± 20	247 ± 13	Egypt.	I	1
2	Hadayib	23° 08´	33° 33´						
3	Um Risha	23° 18´	33° 18´						
4	Bir Um Hebal	23° 43´	33° 14´			223 ± 9			1
5	Tarbite South	23° 44´	33° 38´						
6	Tarbite North	23° 53´	33° 34´						
7	Nigrub El Tatani	23° 01´	35° 01´		Late Jurassic-Early Cretaceous Magmatism 140 ± 15	139 ± 9		II	1
8	Nigrub El Fogani	22° 51´	34° 57´			139			2
9	Mishbeh	22° 43´	34° 41´			148 ± 12			1
10	El Naqa	22° 42´	34° 28´			146 ± 6			1
11	El Gezira	22° 18´	33° 40´			132.7			2
12	El Mansouri	22° 03´	33° 37´			131 .6			2
13	W. Natach	24° 30´´	34° 07´		Late Cretaceous Magmatism 90 ± 20	104 ± 7		III	1
14	El Kahfa	24° 08´	34° 39´			81.4 ± 7			1
15	Jabal Ameruk	19° 59´	33 01´	Uplifted Hills and Basaltic lava flows	Cenozoic buried Plugs	36	Sudan.	II	3
16	Jabal Agha	15° 48´	27° 56´			26			3
17	Meidob	15° 19´	26° 28´			23			3
18	Togabo	14° 40´	25° 50´		Miocene to Recent	16			3
19	G. Kussa	13° 40´	24° 40´			10			3
20	G. Murra	12° 57´	24° 16´			4.3			3

Refrences:

(1) Hashad And El Reedy (1979).

(2) Hashad (1980).

(3) Wooly, A. R. (2001).

Methods

Potassium –Argon (K-Ar)

Rubidium - Strontium (Rb-Sr)

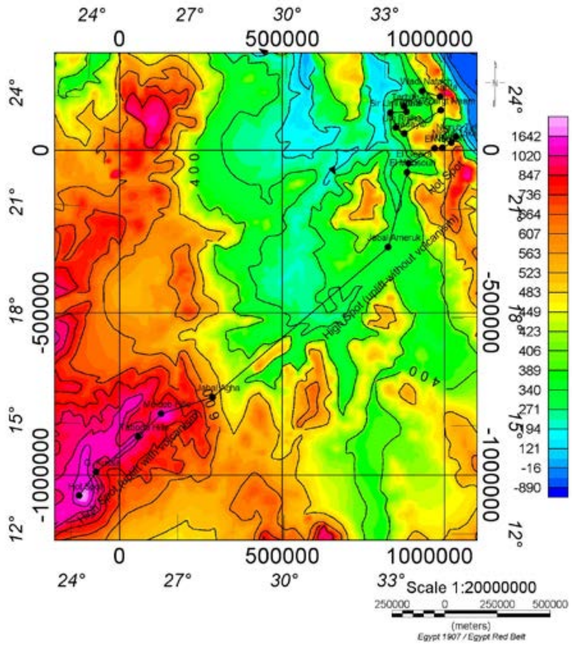


Fig.(6): SRTM Digital Elevation Model map of the study area.

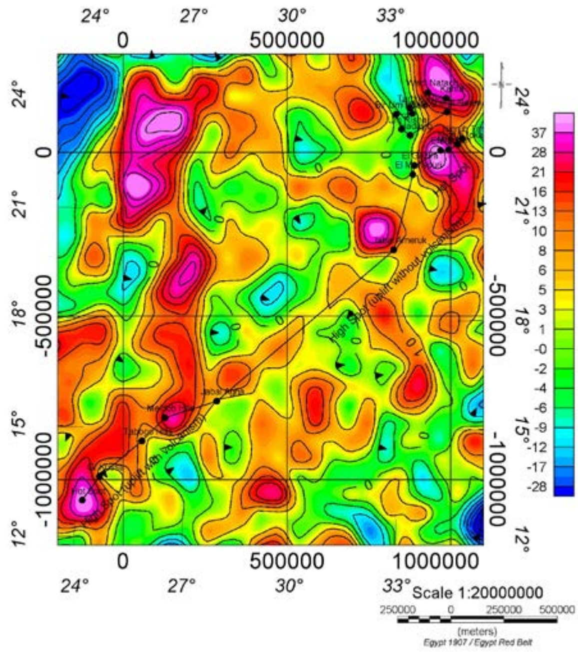


Fig.(7): GRACE gravity map of the study area.

The Late Jurassic-Early Cretaceous uplifting encompasses most of the ring complexes of Nigrub El Tahtani, Nigrub El Fogani, El Naqa, El Gezira and El Mansouri correspond with the near circular high relief geoid closure in the NE of the area.

The NE-SW orientation of Jabal Americ and Jabal Murra uplifting correspond with a characteristic nosing of geoid relief contours in the center and SW of the study area. The Jabal Agha, Meidob Hills, Tobago Hills, in between, show a pattern of geoid relief contours closely corresponds with the structure trends in the area.

The SW corner of Jabal Murra is manifested on the geoid relief map by correspondingly oriented contours, which likewise plunge relatively steeply southeastward into the south of Sudan.

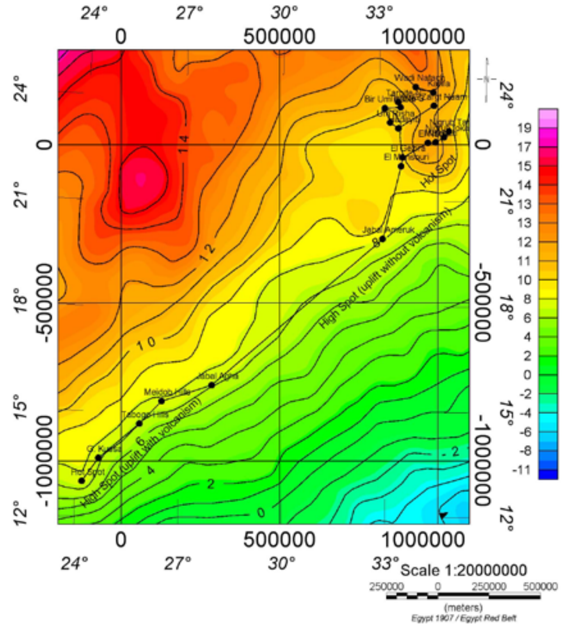


Fig. (8): Departure of the geoid from reference ellipsoid map of the study area.

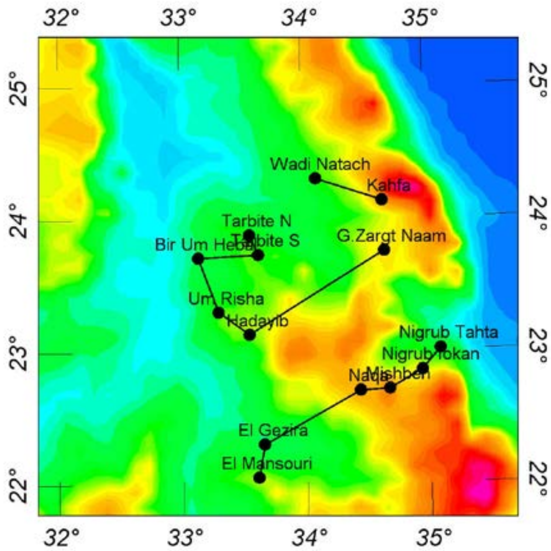


Fig. (9): Tracks of the three hot spots and its ring complexes in the south Eastern Desert of Egypt.

DISCUSSION

The analysis of the hot spot tracks reveals some important aspects, which are of significance to the present work. It is important to note that a plate motion is a rotation, and so the tracks approximate concentric circles rather than parallel straight lines. During about 230 ± 20 m.y. of African plate motion over these (practically fixed) hot spots, Egypt has been affected by three of them (Table. 2 & Fig. 9).

Track I hot spot (The Late Paleozoic magmatism, 230 ± 20 m.y. phase) indicates that the African plate, first rotated clockwise for about 50 m.y. in a WSW direction. Then the African plate rotation changed to counter-clockwise. Track I movement is believed to have taken about 175 m.y., as evidence produced by Bruke and Wilson (1972) which is sufficiently reasonable to suggest that the African plate stopped moving relative to the mantle 25 m.y. ago and has been at rest ever since. Hashad and El Reedy (1979) stated that the ages correspond to a late Permian age and may in part be contemporaneous with the late Paleozoic ring complexes of Nigeria, Niger, and Cameron. The present author, however, does not fully agree with this explanation but rather suggests that for the older part of this track is related to Mount Cameroon hot spot (04° 12´, 09° 10´) Atlantic Africa. Magmatism started 230 ± 20 m.y. ago through several ring complexes (Zargat Naam, Hadayib, Um Risha Bir Um Hebal, Tarbite South and Tarbite North). The high relief geoid departure along a mantle plume track coincides with pronounced geologic and/or tectonic activity where magmatism recurrent towards the SW at Jabel El Uweinat (the most recent complex, 38 m.y.). No essential difference in the alkaline magma types. This track (I) indicates that this hot spot was a relatively vigorous one.

Track II hot spot (The Late Jurassic- Early Cretaceous, 140 ± 15 m.y. Phase) is a result of the counter-clockwise drift of the African continent over a hot spot to the SSE of the one, which, produced, track I. The integration of the previous data with the geochronology of the anorogenic alkalic rocks dates suggests that for the older part of this track there is one choice a slightly more northern route (37°) to volcanics near Lake Nasser in Egypt passes to the active center of the Jebel Marra hot spot in Darfur dome (Sudan) that appears to be at Deriba Crater (13° 00´, 24° 12´, 2000 m) which had a major eruption 4000 years ago. Magmatism started 140 ± 15 m.y. ago through several ring complexes (Nigrub Tahtani, Nigrug Fogani, Mishbeh, El Naqa, El Gezira and El Mansouri). The study indicates that the discharge rate of a plume may vary over time even in the same track. Where a high geoid relief along a mantle plume track coincides with pronounced geologic and/or tectonic activity (Granitic ring complexes exposure or volcanic eruptions in Egypt). The geologic record of the region in Sudan suggests that recurrent, but localized and less intense hot-spot activities took place (Uplifting with and without volcanism). Where magmatism started again at 36 m.y. ago with buried Plugs and small volcanic fields to the extensive flows at Jabel Ameruk at a small subvolcanics complex to the center of Jabel Agha and Meidob Hills that was active in the same area between 26 to 23 m.y. Two major volcanic fields (Tagabo Hills and jabel Kussa) developed between 16 and 10 m.y. with a third volcanic at 4.3 m.y. in the Marra Mountains and the reaction of the center of activity then continued until the Later Quaternary.

Volcanism moved in 36 m.y. 300 km towards the SSW. No essential difference in the alkaline magma types. This is the best track on the African continent. This track (II) indicates that this hot spot was a relatively vigorous one relative to the others.

Track III hot spot (Late Cretaceous magmatism 90 ± 20 m.y. phase) Magmatism started 90 ± 20 m.y. ago through alkalic volcanics of Wadi Natach (104 m.y.) were erupted, followed by the intrusion of Abu Khruk (84 m.y.) and El Kahfa (81 m.y.). Its track shows the same African track trend characteristic of this period of time. The geologic record of the region in Egypt suggests that localized and less intense hot-spot activities (Uplifting with volcanism).

CONCLUSIONS

The motion of the African plate since the opening of the Atlantic Ocean has been traced from tracks. Evidence has been put forward regarding the mantle and crustal effects of hot spot both on geoid departures from reference ellipsoid and the recently published GRACE gravity. This data integrates well with the geochronology of the anorogenic alkalic rocks dates that suggest three phases of Post Precambrian igneous activities in Egypt. The geoid relief is a combination of the usual effects of the anomalous heterogeneity of the lower mantle and the superimposed upper mantle ones. Thus the geoid relief contours along the three hot spot tracks of Egypt were shown to indicate the relative intensities of these hot spots and their possible effect on the geologic evolution of the basement and volcanic areas. Satellite measurements of the earth's gravity field have shown that hot spots are areas of anomalously high gravity. The hot spot activity was responsible for emplacement of alkalic rocks, for tectonic adjustments and for increased geothermal gradient that created favorable ore-concentrating environments in the basement rocks.

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