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Geologic and Metallogenic Significance of Pan-African Lineaments in the Central Eastern Desert of Egypt

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ABSTRACT. Landsat-1 images, computer - enhanced displays and field criteria have shown that the postkinematic granites and related hydrothermal mineralization in the Pan-African basement of the Central Eastern Desert of Egypt were controlled by well-defined lineaments trending NNE-to-NE, NW, WNW, N and ENE-to-E. These lineaments proved to be surface expressions of major fractures. The NNE - to - NE and NW lineaments are particularly significant; they have guided the emplacement of large volumes of granitic magma and are metallotects for hydrothermal mineralization containing as Au, U, Cu, and W. Field evidences prove that the tectonism responsible for these lineaments was recurrent, and alternated with the magmatic activity and hydrothermal mineralization. Preliminary investigations along the lineaments detected show indications of mineralization particularly in the vicinities of intersections.

Assuming a genetic relationship between structures, magmatic activity and mineralization, the Central Eastern Desert of Egypt (Fig. 1) was selected to study the twofold role played by Pan-African lineaments in the control of emplacement of postkinematic granites and related mineralization. The establishment of such a role may aid in better understanding of the metallogeny of the Egyptian basement Landsat imagery coupled with computer enhanced displays and field work were the main techniques employed in the study. The area was selected primarily for two reasons: First, the general geology and tectonic framework of the area are known to the author. Second, previous studies (*e.g.*, Kisvarsanyi and Habib 1982, and Habib and Sharara 1983) showed that the area in question was traversed by significant lineament metallotects that controlled the locations of many Pan-African hydrothermal occurrences, including those of Au, Sn, W, Mo, Cu and U.

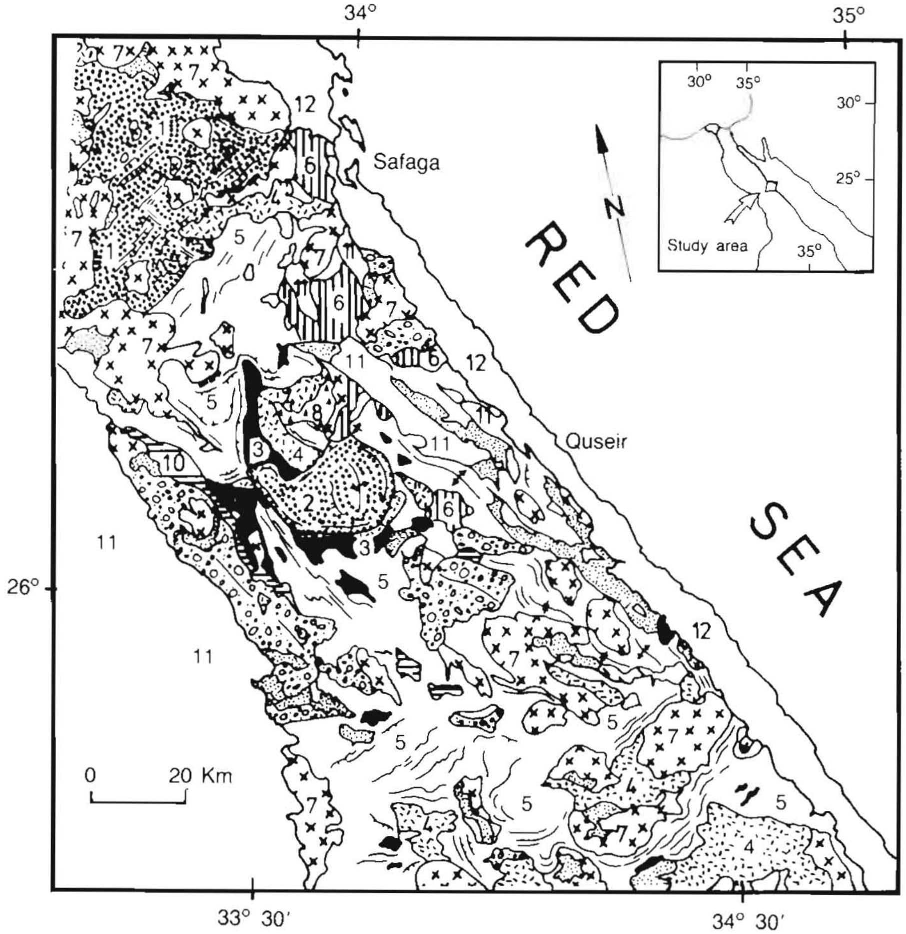

Fig. 1. Geological map of the Central Eastern Desert, Egypt 1 = Barud infrastructure, 2 = Meatiq infrastructure, 3 = serpentinite, 4 = metagabbro, 5 = metavolcanics and metasediments, 6 = arc volcanics, 7 = syn-to-postkinematic granites, 8 = gabbro, 9 = troctolite, 10 = felsite, 11 = Upper Cretaceous-Lower Tertiary rocks, 12 = Miocene-Quaternary deposits, 13 = Pleistocene-Recent deposits.

General Geology

The Central Eastern Desert of Egypt (ca. 22,000 km^2, from lat. 25° 10′ to 27° 00′ N.) is occupied by excellent exposures of Pan-African basement (ca. 15,000 km^2), which forms a mountainous belt (averaging 75 km wide) oriented N 25° W, parallel to the axis of the Red Sea. This belt is overlain unconformably on the west by the Cretaceous-Eocene sedimentary platform, and is fringed on the east by the Miocene - Quaternary deposits of the Red Sea coastal plain.

The Pan-African basement is differentiated into two major structural - metamorphic provinces, namely infracrustal and supracrustal provinces (Fig. 1). The infracrustal province is believed to have resulted from an old orogeny, referred to Meatiqian orogeny (Habib *et al.* 1985a), during the Early Pan-African of Gass (1981). It is further subdivided into Barud and Meatiq infrastructures. The former occupies the northern part of the study area and consists mainly of granite-gneisses and subordinate migmatites. The latter is exposed in a major domal structure, west of Quseir, and consists now of variably cataclastic granite-gneisses, mylonites, phyllonites and cataclastic amphibolites (Habib *et al.* 1985b). The supracrustal province belongs to a new orogeny designated as Abu Ziran orogeny (Habib *et al.* 1985a), which took place during the Middle-Late Pan-African. This orogeny might be equivalent to the Hejaz orogeny in Saudi Arabia (Brown and Coleman 1972). The supracrustal rocks make up the major part of the study area and are formed of weakly regionally metamorphosed flyschoid metasediments and dismembered ophiolitic segments (serpentinites and talc-carbonates, metagabbroid rocks, metadiabases and massive, locally pillowed, metabasalts), both of which constitute the Eastern Desert Ophiolitic Melange (Ries *et al.* 1983). They are overlain by magmatic arc volcanics (widely known as Dokhan Volcanics) and molasse-type sediments. Both the infracrustal and supracrustal provinces were intruded by synkinematic granitoids (tonalites and granodiorites) and postkinematic granitoids (adamellites and granites to peralkaline granites) in the Middle and Late Pan-African respectively. Minor outcrops of slightly metamorphosed silicic to intermediate, and less commonly basic, volcanics probably belonging to the supracrustal province occur on top of the infracrustal province.

Metallogeny

In agreement with Kazmin (1972), Piper (1972), Garson and Shalaby (1976), Church (1983), and Habib *et al.* (1985a) believe in the concept of disruption of cratonic crust during the formation of the Red Sea geosyncline in the Proterozoic time. Garson and Shalaby (*op.cit.*) noted that a marginal basin or basins were created prior to 1300 Ma above a long-evolving Benioff zone to the northeast, outside the Red Sea Region. According to these two authors, metallogenesis had taken place during cycles of marginal basin development, sedimentation and orogeny (three or four) perhaps concurrent with renewed marginal basin opening, moving progressively outwards from the African nucleus (Fig. 2a). To follow is a summary of these cycles and associated metallogeny:

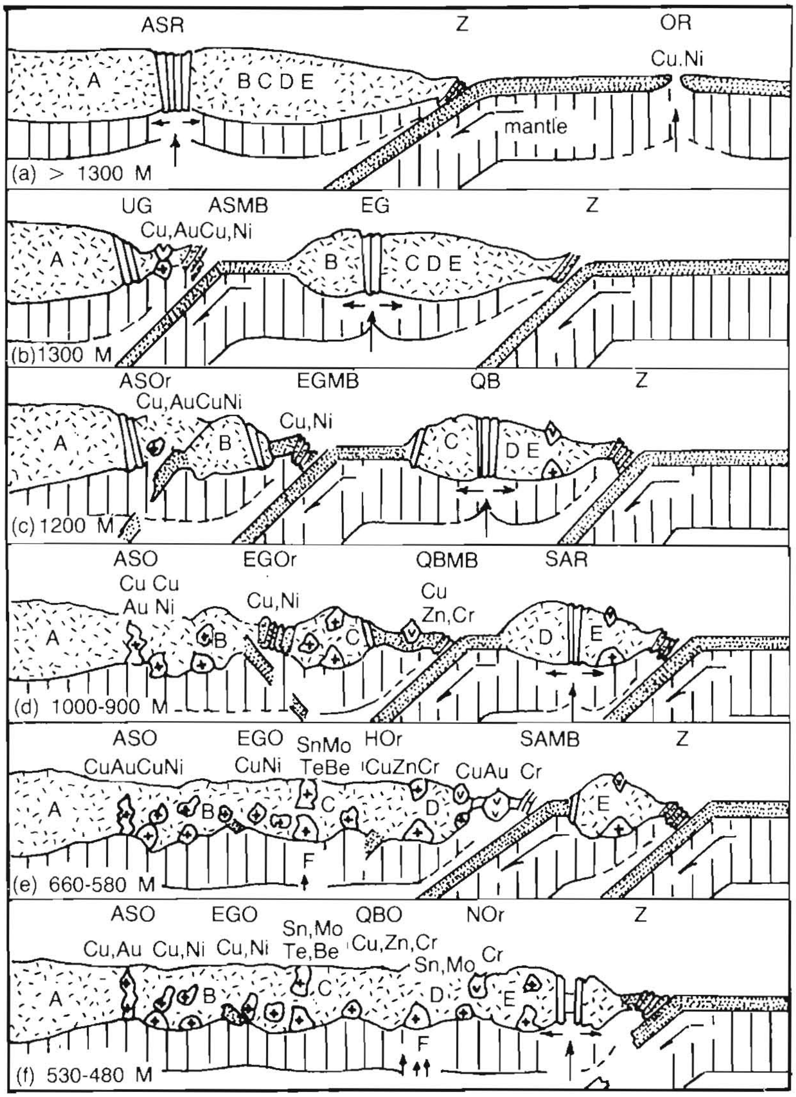

Fig. 2. Plate tectonic model for Red Sea region (after Garson and Shalaby 1976).

ABCDE	= Continental crust, Z = Zagros, OR = oceanic ridge,
ASR	= Abu Swayel Rift, ASMB = Abu Swayel marginal basin,
UG	= Um Garayat, EG = El Geneina, ASOr = Abu Swayel orogeny,
EGMB	= Um Garayat marginal basin, QB = Quseir - Berenice,
ASO	= Abu Suayel ophiolites, EGOr = El Geneina orogeny,
QBMB	= Quseir - Berenice marginal basin, SAR = Suez-Aqaba rift,
EGO	= El Geneina ophiolites, HOr = Hejaz orogeny, SAMB = Suez-Aqaba marginal basin, QBO = Quseir-Berenice ophiolites,
NOr	= Najd orogeny.

The first cycle involved the development of Abu Swayel marginal basin in which a subduction and trench with geosynclinal sedimentation occurred at around 1300 Ma. As a result of subduction, porphyry intrusions with possible Cu-Mo mineralization were emplaced in an island-arc at Um Garayat (Fig. 2b). Subsequently, a new basin termed El Geneina marginal basin was formed NE of the Abu Swayel basin. During the development of this new basin there was a resultant orogenic episode in the Abu Swayel area where oceanic crust with Cu-Ni-Co mineralization was obducted on the edge of the Archean craton (Fig. 2c).

The next cycle involved the development of the Quseir-Berenice marginal basin (to which the present area belongs) and subsequent orogeny in the El Geneina area where ophiolites with Cu-Ni mineralization and chromite pods were tectonically emplaced (Fig. 2d). According to Garson and Shalaby (1976), this was the main formation period of the syntectonic granitoids of 1000-900 Ma age in Egypt, Sudan and Saudi Arabia. The volcanics at Samiuki, Darhib and Asmara (825-856 Ma) and the layered ultrabasic complex at Gabbro Akarem were probably formed on transverse tectonic structures offsetting the axial ridge of this basin.

In the third cycle, the Suez-Aqaba marginal basin was formed and the Dokhan Volcanics (660 Ma) and some of the younger granites (660-580 Ma) of Egypt, Sudan and Saudi Arabia were emplaced (Fig. 2e). The extrusion of the Dokhan Volcanics with possible porphyry mineralization (Cu and Au) apparently took place on the continental margin (Andean type) above the steeply dipping end phase of the Quseir-Berenice subduction zone. The younger granites with apogranitic mineralization (Nb, Ta, Sn, Be, Li) were related to a stream of fluorine-rich volatiles above a migrating or steepening Benioff zone (Mitchell and Garson 1972, and Mitchell 1973) within the Suez-Aqaba marginal basin. The orogenic episode of this cycle was most marked in Saudi Arabia where it has been termed Hejaz orogeny (Brown and Coleman 1972). It is believed that extensive overthrusting occurred in the Eastern Desert of Egypt at this time, and subsequently molasse deposits (Hammamat Formation) filled the fault-basins.

The fourth cycle took place in the Cambrian (530-480 Ma) when the final Suez-Aqaba suture was closed during the Najd Orogeny (Fig. 2 f); this culminated with the intrusion of postkinematic granites. The younger fold-belt which was formed at this time was believed by Brown and Coleman (1972) to have been associated with major strike-slip faulting cutting across the Hejaz fold belt. Hydrothermal mineralization in this episode falls in two main categories, namely true hydrothermal fissure veins, and deposits formed by hydrothermal processes along shears and fractures (El Shazly 1957).

Fracture Pattern

Few studies have been made concerning the fracture pattern developed in the basement terrain of the Eastern Desert of Egypt. Garson and Krs (1976) noted that the main fractures of the Precambrian in Egypt were aligned at about N 45°E to N 65°E. This is roughly at right angles to the ancient geosynclinal tract, indicating a possibility that the fractures represent original transverse fracture directions with some intrusion of oceanic crust (Garson and Shalaby 1976). According to Kazmin and Garland (1973), similar Precambrian block faulting in the Afar region of Ethiopia is believed to have influenced sedimentation and tectonics for more than 1,000 Ma.

Abdel Rahman and El Etr (1980) detected and analyzed the linear features (*i.e.*, faults, fractures, bedding traces, foliations, and dykes) observed on aerial photographs of most of the Eastern Desert of Egypt. The analysis indicates that the NW and ENE trends are statistically significant, equally predominant, and regionally persistent over the entire area. In addition, the WNW and N trends are also found to be statistically significant; however, their areal persistence is only limited.

Based on the study of photo-detected linear structural elements of the Central Eastern Desert, Egypt, El Etr and Mohammed (1978) recognized two major trends, namely NW and ENE trends; less significant are WNW, NNE, N and NNW trends. The basic trends recognized are believed to be very old and one or more of them have been rejuvenated in later times. According to these two authors, the detected pattern represents the basic structural grain of the Arabian shield and is modified, only to a limited extent, by the Red Sea rifting. Later, El Etr *et al.* (1979) used Landsat images and conventional aerial photographs to detect linear structural features in the Central Eastern Desert and concluded that prevailing preferred orientations are: WNW, NNE and ENE.

Abdel Rahman *et al.* (1978) studied the relations between basement fractures, aeromagnetic lineaments and tectonic patterns in the South Eastern Desert of Egypt between lat. 25° 00′ and 23° 30′ N. They identified three main categories including NNW, WNW, and ENE trends, these are believed to date back to Precambrian time. Basement fractures show significant peaks of the three categories, whereas the significant peaks of aeromagnetic lineaments are known to mark a system of deep-seated tectonic zones (mainly occupied by unexposed basic dykes) which extend for more than 120 km paralleling the Red Sea. The WNW trend corresponds to shear zones along which intensive metamorphism, acid rock intrusion, and metasomatism had taken place. The ENE fracture zones form one of the most important structural trends in the whole Red Sea region.

Methodology

A Landsat-1 image (scene E-1180-02442) comprising a black-and-white positive transparency (Band 5) at scale 1:1,000,000, and a color composite paper print at scale 1:250,000 were used for visually detecting the lineaments in the study area. Computer-enhanced displays developed by contrast and color enhancement techniques using the Comtal Varian Image Processing System (CVIPS) program were also used to clarify lineaments of subtle linear tonal contrast. The lineaments detected comprised continuous and discontinuous types (O'Leary *et al.* 1976). Many lineaments, particularly the longer ones, are composite, *i.e.* defined by more than one type of feature such as lithostructural contacts, linear tonal contrast, straight segments of valleys, ridges and topographic escarpments. Pan-African lineaments were then differentiated from the bulk of lineaments. They comprised: (i) lineaments along which igneous bodies are located, (ii) lineaments running tangential to or delineating well-defined straight edges of igneous plutons, (iii) lineaments occupied by dykes, and (iv) lineament metallotects for known Pan-African hydrothermal mineralizations (*i.e.*, Au, Cu, Sn, W, Mo and U). The location and distribution of mineralization was reproduced from the maps published by Hume (1937), Sabet (1961) and Schurmann (1966).

Correlation between the observed lineaments and mapped faults followed. The map compiled by El Ramly (1972) was very useful in this respect. Many lineaments were found to accord with and extend the lengths of individual faults. On the other hand, other lineaments do not coincide with mapped faults. This feature may be due to lack of detailed field mapping rather than to absence of faults or structural zones. Ground-truth investigations are, therefore, significant in verifying the presence of such structural zones. The resultant lineaments which are thought to have guided the emplacement of the postkinematic granites were found to follow NNE to NE, N, NW, WNW, ENE and E trends (Fig. 3). These constitute lineament metallotects for hydrothermal mineralization (Fig. 4).

Many of the NW lineaments proved to be normal faults that divide the basement area into elongate segments or slices (horsts and grabens). These are parallel or subparallel to the Red Sea axis and are believed to represent old structural lines that were reactivated in the Miocene during Red Sea rifting. Some of these faults were accompanied by drag within zones up to 1.5 km wide (Fig. 5). The N, NNE-to-NE and E lineaments are represented by left-lateral strike-slip faults, some of which are associated with brecciated zones, up to a few meters wide, subsequently filled with mineralized or non-mineralized quartz veins (Fig. 6). Such faults developed tension fractures along which quartz veins were injected (Fig. 7). The ENE and WNW lineaments are normal faults which were reactivated in pre- and post-Nubian times.

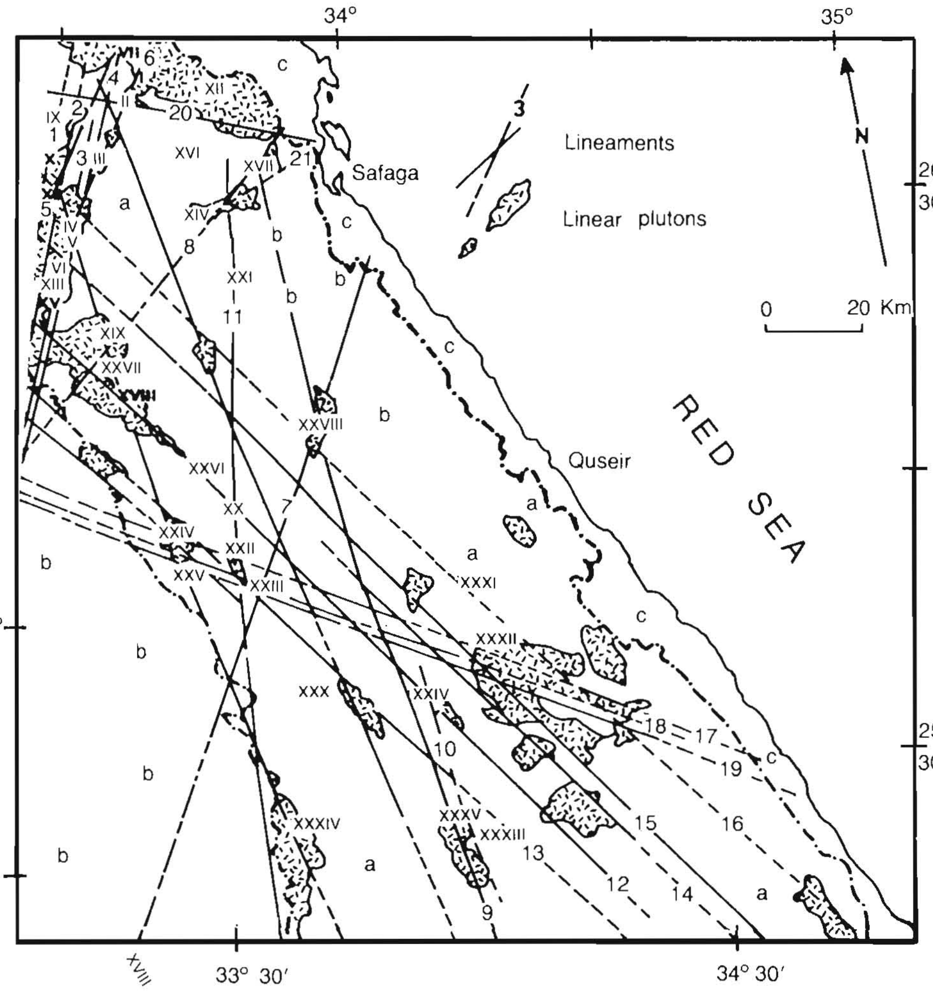

Fig. 3. Lineaments and linear granite plutons, Central Eastern Desert, Egypt.
a = Pan-African basement, b = Upper Cretaceous-Lower Tertiary sediments, 3 = Miocene-Quaternary deposits.
I = Um Gidri, II = Um Anab, III = Tarbush El Museiri, IV = El Urf, V = Abu Shihat, VI = Kafari, VII = El Shayeb, VIII = Abu Dalf, IX = Abu Hamr, X = Abu Kharif, XI = El Dob, XII = Abu Murrat, XIII = Faruqiya, XIV = Abu Furad, XV = El Markh, XVI = Wadi Barud, XVII = Um Taghir El Tahtani, XVIII = Eredia, XIX = Rie El Garra, XX = Um Esh, XXI = Waeira, XXII = Fawakhir, XXIII = El Sid, XXIV = Um Had, XXV = Hamama, XXVI = Atalla, XXVII = Maghrabiya, XXVIII = Abu Hayaya, XXIX = Zeidun, XXX = Bir Zeidun, XXXI = Kareim, XXXII = Sibayi, XXXIII = Sigdit, XXXIV = Shalul, XXXV = Um Bissilla.

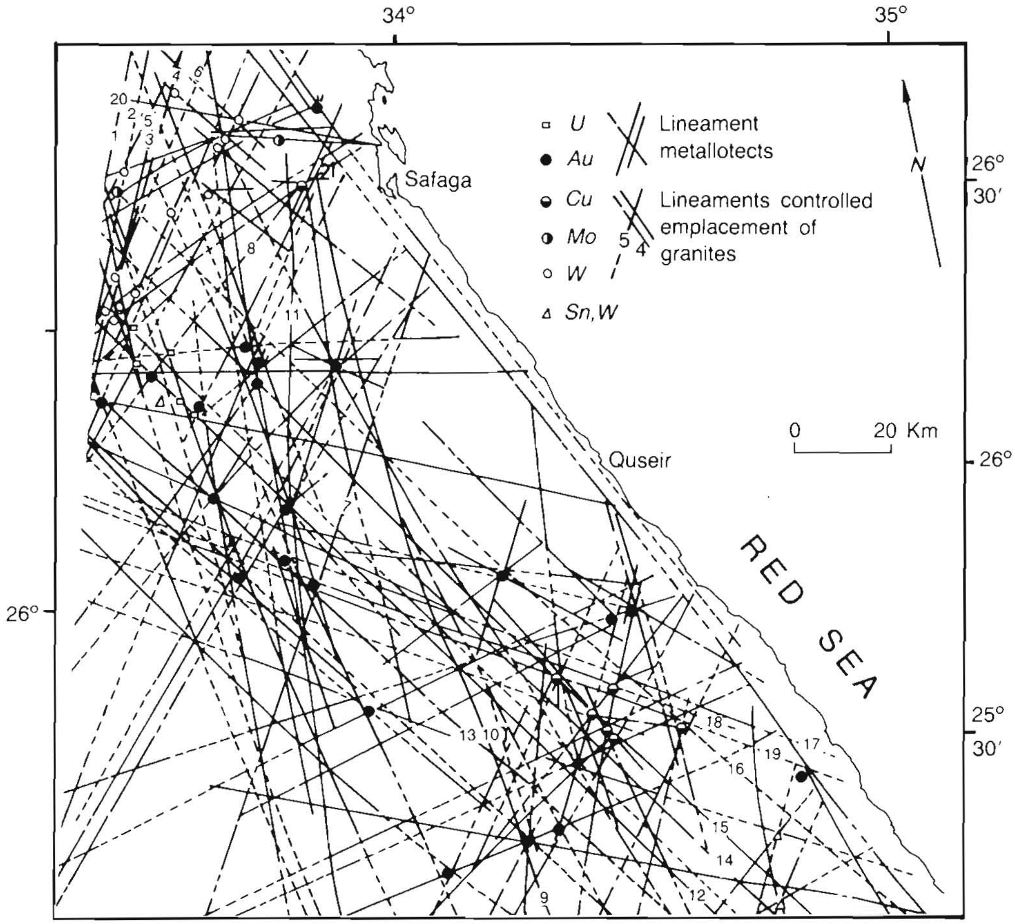

Fig. 4. Lineament metallotects and locations of hydrothermal mineralization.

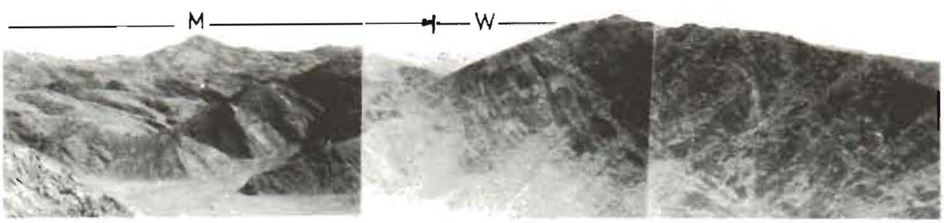

Fig. 5. Steeply inclined foliation due to drag along the western side (W) of the Meatiq dome (M); photo looking E.

Fig. 6. Quartz vein filling a shear zone developed at the intersection of two lineaments, west of Quseir.

Fig. 7. Quartz veins filling tension fractures in metagabbro, west of Quseir.

Postkinematic Granites and Mineralization

Close inpsection of the Landsat images revealed that many of the postkinematic granites (ca. 580-430 Ma; Hashad 1980) of the Central Eastern Desert are typically linear plutons, *i.e.* arranged along well-defined lineaments. Field evidence shows that many of these plutons represent composite intrusive masses emplaced in two main successive phases. The earlier phase is commonly coarse-grained to pegmatitic in texture, relatively rich in mafics, light buff to light grey in color, granodioritic to adamellitic in composition, forms low-lying country, and may contain xenoliths of country rocks. The later phase is generally medium- to coarse-grained (occasionally porphyritic), very poor in mafics, pink to red in color, granitic to alkali granitic in composition, forms bold mountainous masses, is devoid of xenoliths, possesses chilled border facies, and displays vertical or steeply inclined, sharp and fairly regular boundaries. These later phases are commonly invaded along the middle zones of the earlier ones and may extend out of them to become juxtaposed with the country rocks. Xenoliths of the earlier phases may be found within the later ones. Field criteria strongly suggest that both phases are structurally controlled, *i.e.* their emplacement took place along fracture-fault planes. Moreover, the later phases were succeeded by at least two major tectonic episodes. The first episode resulted in the development of a fracture system(s) along which quartz veins and dyke swarms were injected into the granitic masses and their wall rocks. Some of these quartz veins are mineralized and carry Au, Sn, W and Mo mineralization. The second episode led to shearing and cataclasis of the quartz veins and dykes as well as the invaded rocks. This second episode was followed by the development of hydrothermal mineralization (such as U, Cu and Fe) and metasomatic alteration (*e.g.*, greisenization, kaolinization, albitization).

Results

NNE -to- NE Lineaments

The postkinematic granite masses of Um Gidri, Um Anab, Tarbush El Museiri, El Urf, Abu Shihat, Kafari, El Shayeb, Abu Dalf, Abu Hamr, Abu Kharif and El Dob are linearly arranged in NNE to NE directions and constitute mountain ranges in the northwestern part of the study area (Fig. 3). They appear to have been emplaced along two sets of lineaments trending NNE and NE. The NNE set comprises four lineaments (# 1-4: 34, 62, 63 and 88 km long; Fig. 3) that are 3,3 and 1.5 km apart respectively. These lineaments are metallotects for the tungsten mineralization at Faruqiya, El Markh, and Abu Kharif districts (Fig. 4). The NE set includes two lineaments (# 5 and 6, 42 and 64 km long) 6 km apart, and can be regarded as metallotects for the tungsten mineralization in the Kafari and Um Anab districts, and the molybdenum deposit at El Dob. In fact, these lineaments are parts of megalineaments extending more than 200 km beyond the limits of the study area. The elongate Abu Hayaya postkinematic granite lies along a NNE lineament (# 7, 142 km long) which represents a metallotect for the El Sid gold deposit. Both the Abu Furad and Um Taghir El Tahtani granites are thought to have been partly controlled by a NE lineament (# 8, 88 km long) that can be considered as a metallotect for the Wadi Barud copper mineralization and the Rie El Garra uranium deposit (Fig. 4).

N Lineaments

The Um Bissilla postkinematic granite is believed to have been intruded along two parallel N lineaments (# 9 and 10; 160 and 53 km long). The former appears to be a metallotect for the Au, Sn and W mineralization of the Um Bissilla area. Also the postkinematic granites at Waeira and Shalul districts, and the synkinematic granodiorite in the Fawakhir area are aligned along a N lineament (# 11, 160 km long) that represents a metallotect for both the Fawakhir and Um Esh gold deposits.

NW Lineaments

Three postkinematic granites at Maghrabiya-Eredia, Atalla and Zeidun are located along a NW lineament (# 12, 178 km long), which is also a metallotect for both the Maghrabiya mineralization (Au, Sn, W and U) and the Um Esh gold deposit. About 10 km to the west of this lineament, another NW lineament (# 13, 163 km long) controlled emplacement of Bir Zeidun and Um Had postkinematic granites (Fig. 3). This latter lineament appears to have played a significant role in localizing the gold deposits at Hamama, Fawakhir and Sigdit. The Um Had granite itself was found to contain disseminations of molybdenite.

The Sibayi postkinematic granite is thought to have been partly controlled by three parallel NW lineaments (# 14-16: 118, 208 and 225 km long) 4.5 and 10 km apart. The longest lineament (# 16) represents a metallotect for the Dob mineralization (Au, Sn, W and Mo), the Kareim gold deposit and the Sibayi copper mineralization. The 208 km long lineament is also a metallotect for four copper centers in the Sibayi area.

WNW Lineaments

The emplacement of the Sibayi postkinematic granite also seems to have been guided by a set of three closely spaced parallel WNW lineaments (# 17-19: 165, 148 and 172 km long). These are significant metallotects for the gold deposits of both the Fawakhir and El Sid areas, and the copper centers of the Sibayi district. The southern boundaries of the Abu Murrat and Um Anab postkinematic granites are located along a WNW lineament (# 20, 57 km long) which is also a metallotect for wolframite mineralization.

ENE -to- E Lineaments

Again an ENE lineament (# 21, 26 km long) seems to have partly controlled emplacement of both the Abu Furad and Um Taghir El Tahtani granites. The E lineaments seem to have no effect on the emplacement of the postkinematic granites. The U mineralization detected in the Rie El Garra and El Eredia granite plutons is genetically connected with the E lineaments cutting these granites (Habib 1985).

Conclusions

Landsat-1 images, computer- enhanced displays and ground-truth investigations were used to establish the twofold role of lineaments in controlling the emplacement of postkinematic granites and related mineralization in the Pan-African basement of the Central Eastern Desert of Egypt. Five lineament trends were recognized and proved to be surface expressions of major fractures. These include NNE -to- NE, NW, WNW, N and ENE -to- E trends. At present, genetic relations between these trends are unclear. The NNE -to- NE and NW trends are particularly significant; they have guided the emplacement of large volumes of granitic magma and are metallotects for hydrothermal mineralization containing as Au, U, Cu and W. Field evidence shows that the tectonism responsible for the development of the lineaments detected acted at different times, which alternated with magmatic activity and hydrothermal mineralization. A sequence of events may be defined: (i) a first tectonic phase, (ii) emplacement of postkinematic granites (earlier phase), (iii) a second tectonic phase, (iv) emplacement of postkinematic granites (later phase), (v) a third tectonic phase, (vi) emplacement of dyke swarms and quartz veins (some of which are mineralized and carry Au, Sn, W and Mo), (vii) a fourth tectonic phase, and (viii) development of hydrothermal mineralization (U and Cu) and metasomatic alteration (*i.e.*, greisenation).

Preliminary investigations along the lineaments detected show indications of mineralizations particularly in the vicinities of intersections. A geochemical prospecting program is, therefore, recommended along the lineaments, with particular emphasis on areas occupied by the linear postkinematic granite plutons.

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المغزى الجيولوجي والتمعدني للخطيات البان أفريقية بوسط الصحراء الشرقية لمصر

محمد السيد حبيب

قسم الجيولوجيا - كلية العلوم - جامعة أسيوط - أسيوط - مصر

دلت دراسات صور اللاندسات والصور المحسنة الكترونياً (من خلال برنامج CVIPS) بالإضافة للمظاهر الحقلية على أن جرانتيات ما بعد الحركة وكذلك التمعدنات المائية الحرارية قد ارتبط تواجدها بخطيات محددة متجهة شمال شمال شرق - إلى - شمال شرق، شمال غرب غرب شمال غرب، شمال، شرق شمال شرق - إلى شرق. وقد ثبت ان هذه الخطيات ما هي إلا تعبير سطحي عن كسور كبيرة. وتعتبر الخطيات المتجهة شمال شمال شرق - إلى شمال شرق وشمال غرب ذات أهمية خاصة إذ تحكم هذان الاتجاهان في تداخل كميات كبيرة من الصهير الجرانيتي بالإضافة إلى تحكمها أيضاً في التمعدنات المائية الحرارية مثل الذهب واليورانيوم والنحاس والتنجستين. وتبرهن الأدلة الحقلية على أن الحركات التكتونية المسببة للخطيات عموماً قد حدثت على فترات زمنية تخللتها فترات تداخل الصهير الجرانيتي والتمعدنات المائية الحرارية، كما تدل الشواهد المبدأية على تواجد تمعدنات على طول هذه الخطيات وخاصة عبر نطاقات تقاطعها.