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GEOLOGY OF WADI SIDRI RADIOACTIVE OCURRENCES, WESTERN SINAI, EGYPT

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جيولوجية التواجدات المشعة بوادي سدري ، غربي سيناء ، مصر

إبراهيم علي القصـــاص

تم إجراء دراسات جيـولوجية وإشعاعية بمنطقـة وادي سدري في غربي سيناء ، وقـد أسفرت عن وجود بعض الشاذات الإشعاعية المختلفة في شدتها وامتدادهـا وأصلها في عدة أنواع من الصخور . وقد أمكن تصنيف الشاذات المكتشفة إلى مجمـوعتين رئيسيتين مع احتمال وجود عـلاقة بينهما من نـاحية أصل النشأة ، لكنهما تختلفـان في ظروف التواجـد الحالية . فالنوع الأول من الشـاذات الإشعاعية مـرتبط بصخور الجرانيت وبعض عروق الصخور النـارية الحمضية التابعـة لما قبل الكمبري المتأخر ، وغالباً ما تكـون هذه الشاذات من مصدر أولي ، تحكمها عـوامل تركيبية وتصاحبهـا ظواهر لتأثير المحـاليل المائية الحارة . أما النـوع الثاني من الشاذات الإشعـاعية فإنها محكومـة بخصائص صخريـة معينة حيث وجـدت عدة شـاذات في طبقة من الحجـر الغريني الحديـدي التي تصاحبهـا رواسب المنجنيز والحديد والتي تنتمي إلى العصر الكربوني المتأخر .

ومن تكامل دراسة الخصائص الجيولوجية وتوزيع النشاط الإشعاعي بمنطقة وادي سدري في غربي سيناء ، فإنه يمكن الإشارة إلى احتمال وجود رواسب مشعة على امتداد أو بالقرب مـن الحد الفاصل بين صخور القاعدة القديمة (ماقبل الكمبري) والـرسوبيات التي تعلـوها (حقب الحياة القـديمة) خاصـة على مقربة من خط الشـاطىء القديم للعصر الكربوني .

Key Words : Basement complex, Carboniferous sediments, Fe-Mn deposits, Late orogenic plutonites, Radioactive anomalies, Uranium

ABSTRACT

Geologic and radiometric investigations have been carried out in the environs of Wadi Sidri in Western Sinai, applying a combination of various geological, geophysical and geochemical techniques. This work revealed the presence of some radioactive anomalies of various intensities, extensions and origin, associated with different rock types. The discovered anomalies are classified into two main groups of quite different types but they seem to be genetically related to each other. The first type is connected to Late Precambrian granites and related dyke-forming rocks. These anomalies are mostly of epigenetic origin showing some hydrothermal features and structural control. On the other hand, the second type of radioactive anomalies is lithologically controlled where several anomalies are localized in a ferruginous siltstone bed of presumably Early Carboniferous age, which is frequently associated with sedimentary manganese and iron deposits.

Both the geological criteria and the distribution of radioactivity in Western Sinai show that the principal areas for potential radioactive deposits are confined along or near the contact between Precambrian basement rocks and Paleozoic sedimentaries, particularly along the Carboniferous shoreline.

INTRODUCTION

A long time ago, the Ancient Egyptians investigated the Wadi Sidri area mainly for copper minerals and preceious stones, as witnessed by the ruins of old turquoise mines at Gebel Maghara and Temple of King Senusert-I with inscriptions from the First Dynasty. In recent times the area, as a part of Western Sinai, was subjected to several regional geological works, with emphasis on the Carboniferous formations including economic deposits of manganese and iron ores [1–10].

On the other hand, the first work on radiometric investigation in Western Sinai was carried out at the end of 1957 by the Geology and Nuchlear Raw Materials Department of the Egyptian Atomic Energy Establishment (presently the Nuclear Materials Authority), where some radioactive occurrences were recorded in some Mn-Fe ore deposits at Um Bogma area [11]. Sinc then, some other studies were conducted mainly on the radioactivity of the exploited manganese-iron ores at Um Bogma and its environs [12–14]. During 1966/1967 field season, the present author carried out regional geologic and radiometric investigations of a large area in Western Sinai, as a part of the national program of prospection and exploration of nuclear raw materials in the Peninsula of Sinai. This work has led to the discovery of several radioactive anomalies other than those associated with Mn-Fe ores of Um Bogma type [15].

In the present work, detailed geological and radiometric studies are carried out in Wadi Sidri area as a good representative of the west central Sinai region (Fig. 1). The area was selected because it encounters exposures of most of the main rock units from Precambrian basement rocks and the younger sedimentary formations cropping out in the west central Sinai. The investigated area is located between latitudes 28° 50' and 28° 59' N and Longitudes 33° 10' and 33° 30' E, covering about 400 km^2 in west central Sinai. Apart from the wide coastal plain of El-Markha, including Elwa Bada and Elwa Sidri, the area is moderately mountainous with very rugged topography. It contains some relatively high mountains such as G. Atairtir El-Dahami (1057m), G. Moneiga (950m), G. Abu Qafas (688m), and G. Maghara (470m). In addition to Wadi Sidri and its numerous tributaries, the study area is traversed by some other wadis such as Wadi Baba, Wadi Shellal, Wadi Abu Natash, Wadi Budra, Wadi Qenaia, and Wadi Igna. Most of these wadis are highly bifurcating where their branches are generally arranged in a dendritic pattern while the main wadis are almost of parallel to subparallel types. The drainage pattern, as well as other morphological features of the area are generally controlled by its lithology and structure. Irrespective their density, pattern, length and orientation, all drainage lines are finally draining, through Wadi Sidri and Wadi Baba, westwardly to the Gulf of Suez. The area shows a typical desert type of climate, where rainfall is very rare and occasionally happens for a short duration during winter season, while the summer is completely dry. Some water wells (Birs) and rock basins (Qattars) are found along the main courses of some wide wadis, e.g. Bir Um Hamd and Bir Abu Sibeikhat. The level and quality of groundwater in these wells greatly varies seasonally, dpending on the amount of rainfall water and the type of surrounding formations.

This paper provides the main geological criteria controlling the distribution of natural radioactivity among the different lithological units of rock exposures in Wadi Sidri area.This could be helpful to determine the most favourable host rock, structure and alteration features associated with potential radioactive occurrences.

GEOLOGY AND LITHOSTRATIGRAPHY

The investigated area of Wadi Sidri is covered by a wide variety of rock exposures (Fig. 2) belonging to two main divisions: (A) Basement complex of Precambrian igneous rocks intruded by basic volcanics of Jurassic age, and (B) Sedimentary formations ranging from Early Carboniferous to Recent.

A. Basement Complex

This complex includes the oldest rock exposures in the study area represented by Precambrian late orogenic plutonic rocks, as well as Phanerozoic basalts forming Farsh El-Azrak volcanics.

1 – Late orogenic plutonic rocks: The Precambrian rocks occurring in the studied area of Wadi Sidri are mainly composed of different varieties of pink granites and associated rocks related to the late orogenic plutonism. They are mainly exposed in the northern and east central part of the investigated area, representing the extreme northwestern limit of Precambrian outcrops which occupy most of southern Sinai. In the northern and northeastern parts, the Precambrian rocks are unconformably overlain by Carboniferous sediments, while they are bounded from the south and southwest by a belt of Nubian Sandstone.

The late orogenic plutonic rocks exposed in Wadi Sidri area are essentially formed of granodiorite and basic granite, equigranular pink granite and porphyritic red granite. They are commonly associated with related dyke-forming rocks, including aplites and felsites, which are considered to be derived from the same magmatic evolution at a later stage.

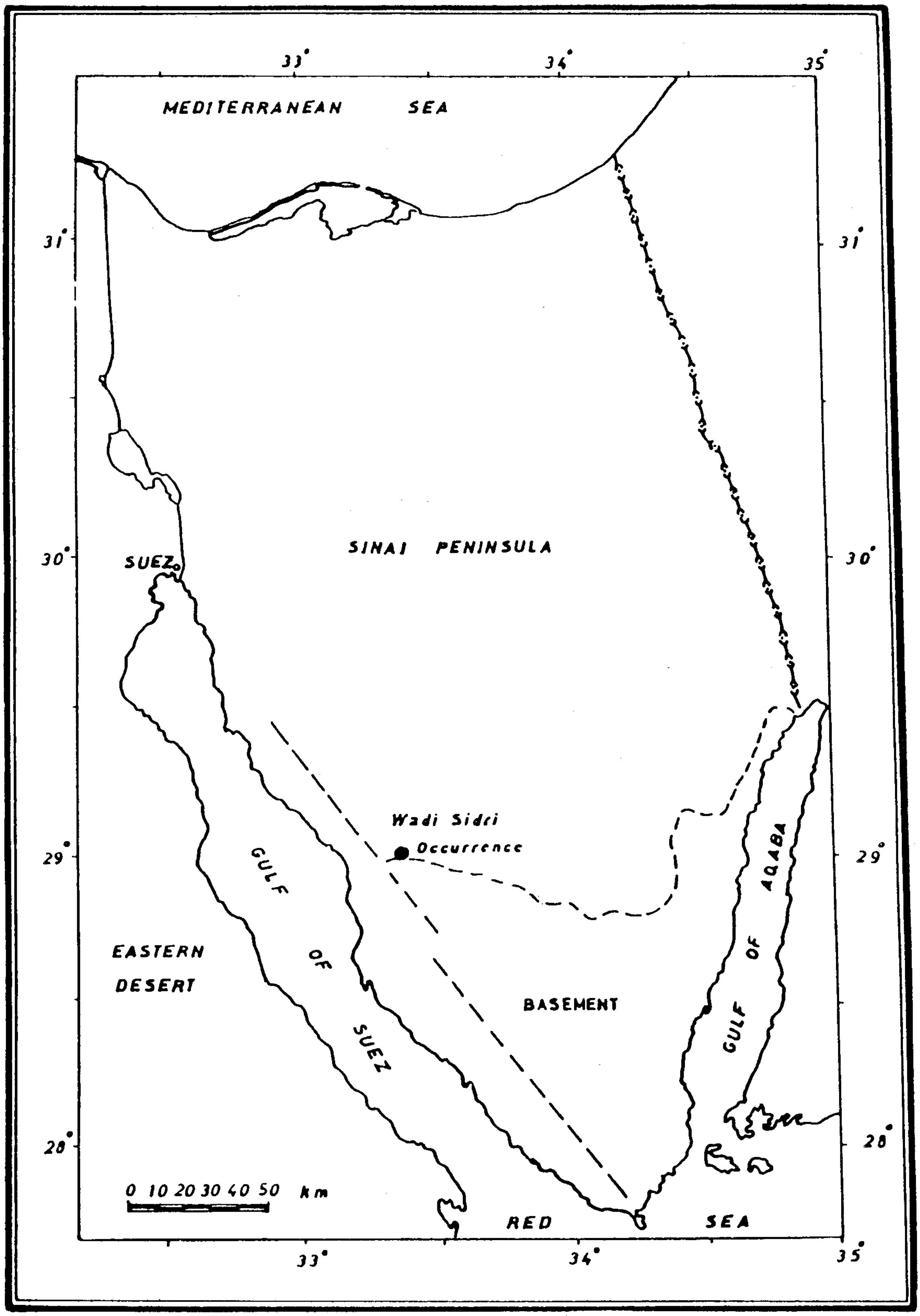


Fig. 1. Key Map Showing the Location of Wadi Sidri Radioactive Occurrence, Western Sinai.

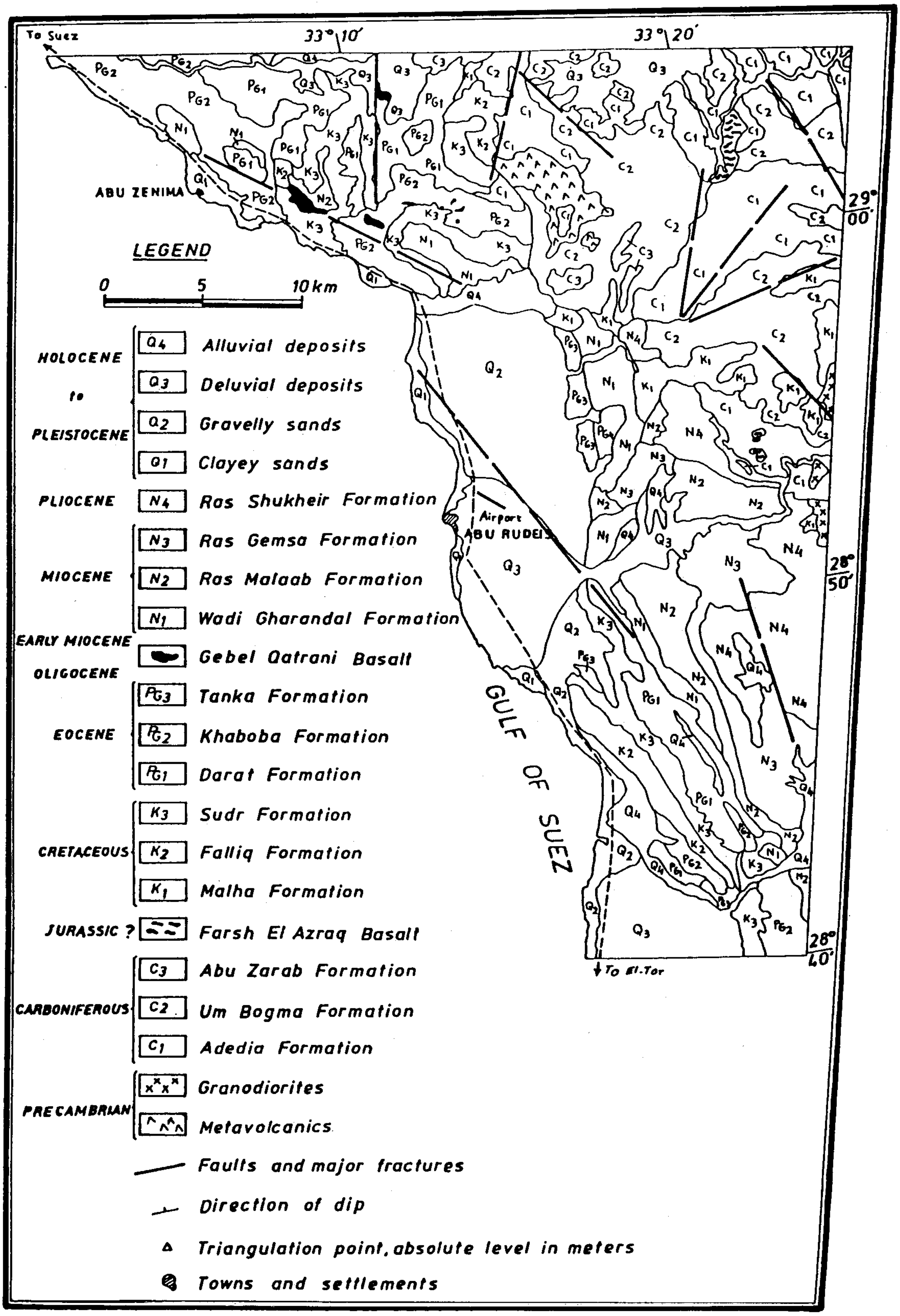


Fig. 2. Geological Map of Part of Western Sinai (After El Shazly etal, 1980) Showing Location of Wadi Sidri Radioactive Occurrence

Along some major faults, the granitic rocks are higly tectonized, showing gneissic and mylonitic cataclastic textures.

2 – Farsh El-Azrak volcanics : These are basic volcanics mainly represented by olivine basalts commonly found as sheets and flows, and occasionally form dykes and sills invading the Carboniferous sediments, as well as the older Precambrian granites. They are exposed at many places in the studied area, particularly at Wadi Abu Natash and Wadi El-Sahu, where they extend northeastwards beyond the mapped area to be well developed at the type locality, Farsh El-Azrak. Radiometric age determination by K/Ar isotopic method on a basalt sample from Um Bogma area gave an apparent age of 178 my [16].

B. Sedimentary Cover

The oldest sedimentary rocks cropping out in Wadi Sidri area are those of Carboniferous sediments which unconformably overlie the Precambrian basement rocks. The Carboniferous sediments intercalate the overlying Nubian Sandstone which is followed upwardly by marine Cretaceous sediments, then Eocene, Miocene, Pliocene, Pleistoncene and Holocene sediments. This succession is well developed in the west central Sinai, including the area under consideration of Wadi Sidri. Table (1) gives a summary of the lithostratigraphic sequence of the main sedimentary formations in the studied area. Many workers have dealt with the geology and stratigraphy of the above-mentioned sedimentary formations in west central Sinai [17–19]. Since all radioactive anomalies discovered so far in the sedimentary formations in Wadi Sidri area are associated with Carboniferous rocks, emphasis is given to their regional geology and stratigraphy as briefly discussed in the following.

The Carboniferous sediments in west central Sinai are divided into three main formations, starting from the bottom:

1. Adedia Formation, which unconformably overlies the peneplaned surface of Precambrian basement rocks, is mainly formed of unfossiliferous massive bedded

Table (1) Lithostratigraphic Sequence of Sedimentary Rocks in Wadi Sidri Area, West Central Sinai

Age	Formation	Lithology
Quaternary	Holocene to Pleistocene	Alluvium, sand, gravel and conglomerate
Pilocene	Ras Shukheir Formation	Gravel, sand and clay
Miocene	Ras Gemsa Formation	Clayey sandstone with gypsum
	Ras Malaab Formation	Gypsum with marly limestone
	Wadi Gharandal Formation	Shale, marl, sandstone and conglomerate
Eocene	Tanka Formation	Brown limestone with shale
	Khaboba Formation	Crystalline limestone and marl
	Darat Formation	Shale and marly limestone with flint
Cretaceous	Sudr Formation	Chalky and impure limestone
	Falliq Formation	Limestone, sandstone and shale
	Malha Formation	Thick bedded Nubian Sandstone
Carboniferous	Abu Zarab Formation	Sandstone with Lepidodendron flora
	Um Bogma Formation	Dolomitic limestone and clay
	Adedia Formation	Unfossiliferous sandstone and shale

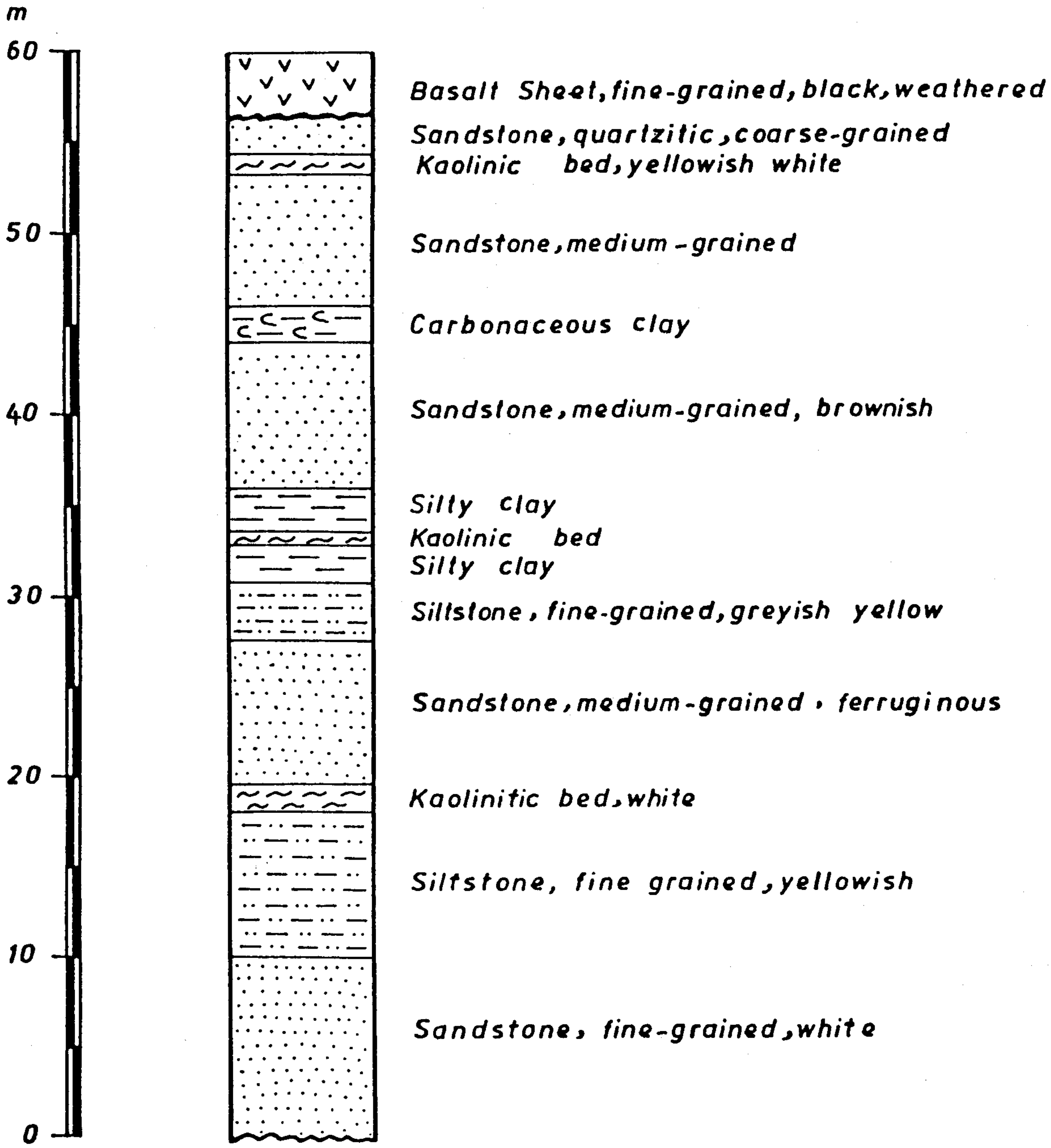


Fig. 3. Composite Columnar Section In Adedia Formation at Wadi Sidri, Western Sinai

sandstone, siltstone and subordinate shale (Fig. 3). It contains some economic kaolin deposits in its basal beds while the uppermost beds are mineralized, in part, with manganese and iron oxides.

2. Um Bogma Formation, made up essentially of dolomitic limestone and limestone with clay and shale intercalations, with deposits of Mn-Fe ores.

3. Abu Zarab Formation, which is mainly constituted of cross- laminated sandstone, with some carbonaceous shales having Lepidodendron flora. The uppermost beds of this formation is formed of white glass sand and covered, in part, by basalt sheets.

It is obvious that sandstone rocks predominate in the Carboniferous formations, with relatively minor siltstone and shale intercalations. Petrographic characteristics of these Carboniferous sandstones, and the presence of dolomite-limestone sequence in between the lower and upper sandstone formations reflect wide and great variation in the sedimentary environment during the Carboniferous. It seems that sedimentation began by a stable shallow marine environment, very near to the source rocks, with evidence of aeolian deposition in the basal part followed by an oscillating transitional environment with a progressively increasing aqueous contribution vertically. The continuous transgression of the Carboniferous sea led to the deposition of dolomite-limestone sequences in a marine environment. This was followed by a successive regression of the sea, where the sedimentary environment changed through transitional oscillating to continental with dune facies at the top closing the sequence of Carboniferous sedimentation in west central Sinai.

Moreover, some changes in the sedimentary environment took place also during the deposition of each formation, as represented by the variations in their lithology. The composition of Adedia Formation shows that its depositional environment changed from subaeolian continental through transitional deltaic to marine environments. The latter environment prevailed during the deposition of Um Bogma Formation, then it began to retreat through fluviatile, deltaic and swamp environments. This is indicated by the presence of carbonaceous matter in the lower beds of Abu Zarab Formation. Continuous regression of the sea led to a subaerial continental environment changed to a truely continental environment where sand dune facies prevailed and deposited friable white glass sands forming the uppermost part of Abu Zarab Formation. In many places of west central Sinai, the Carboniferous formations are topped by thick sheets of Farsh El-Azraq basalts. The contact line between these basalts and Carboniferous sediments is characterized by a thin alteration zone with kaolinized material and other features of thermal effect of basalt flow on the older sediments.

Facies maps of the lower Carboniferous in Sinai Peninsula and Gulf of Suez constructed by Kostandi[5] show the areal distribution, variation in thickness and in the sand-shale-carbonate ratio of these sediments. From these maps, there is a general northward increase in the clay and carbonate content on the expense of sand, indicating that Carboniferous marine transgression came from the NNW direction[10].

DISTRIBUTION OF RADIOACTIVITY AND RADIOACTIVE ANOMALIES

Field radiometric investigation of Wadi Sidri area and its environs was carried out using a portable scintillation counter, Type Scintillator Model 111-B De Luxe, manufactured by Precision Radiation Instruments Inc., U.S.A. Gamma radioactivity was continuously measured along regional traverses of about 400–500m interval, using normal aerial photographs of scale 1:40,000 as base maps. The traverses were oriented almost perpendicular to the main geological structures in the area. At localities of abnormally high radioactivity, detailed work with dense measurements was carried out to precisely locate the radioactive anomalies. In such localities, gamma radioactivity was systematically measured on a grid pattern of 10–20m spacing and becoming closer in the case of abnormal distribution of radioactivity.

As a result of this radiometric investigation, it has been found that each lithological unit, exposed in Wadi Sidri area, has its specific range of gamma radioactivity depending mainly on its mineralogic composition. However, secondary alteration or diagenetic features may cause some variation in the intensity of natural radioactivity. At the same time, this work has led to the discovery of ten radioactive anomalies scattered in the area under consideration (Fig. 4). These anomalies show a wide variation in their radioactive intensities ranging from 110 μR/h up to more than 1500 μR/h (Table 2). According to their host rocks, these anomalies are classified

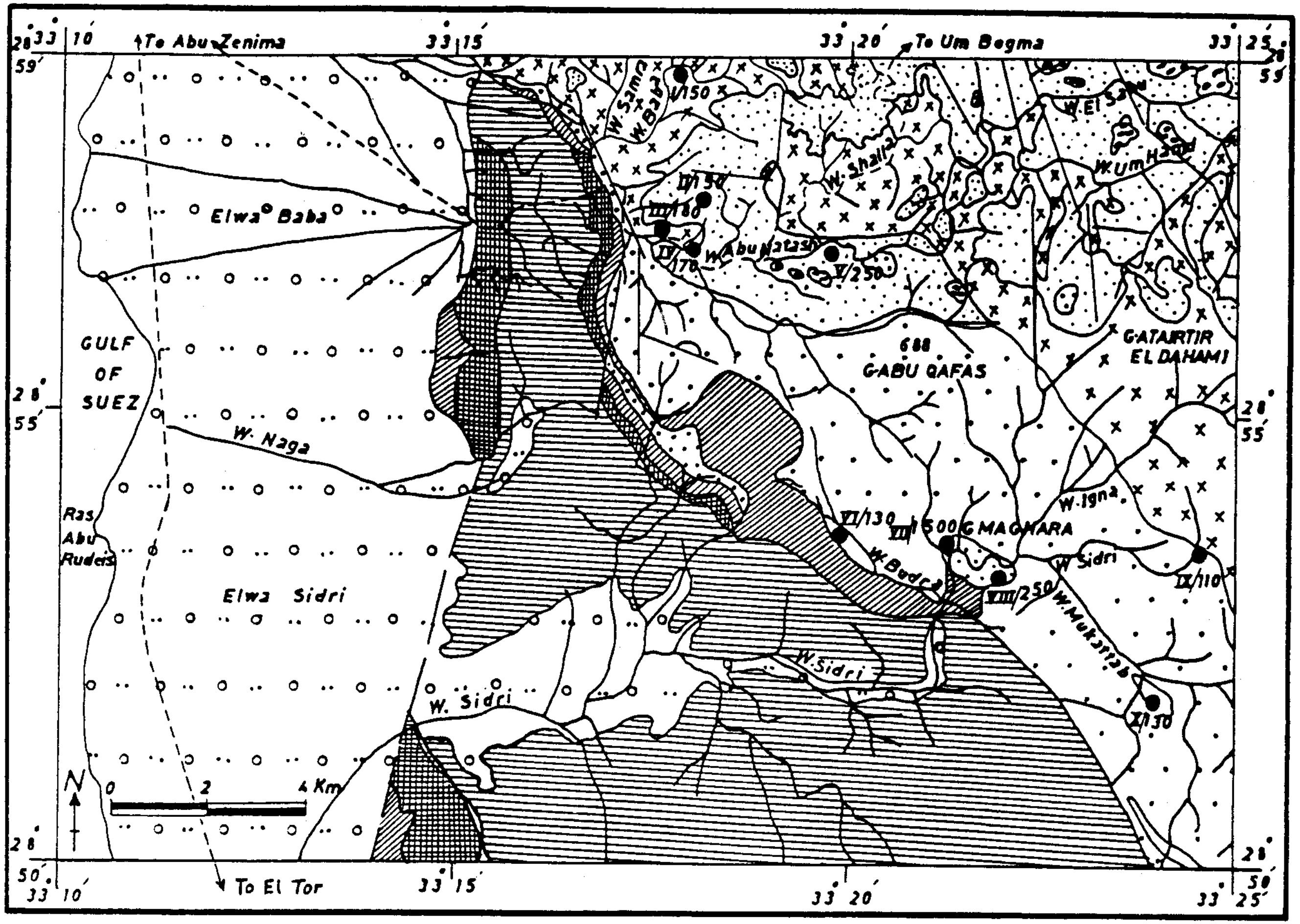


Fig. 4. Geological Map of Wadi Sidri Area, With Radioactive Anomalies

LEGEND

Quaternary	Nubian Sandstone
Miocene	Basalt Sheets and Flows
Eocene	Carboniferous
Cretaceous	Granites and Granodiorites
Major Fault Lines	II/250 Radioactive Anomaly No/Intensity

Table (2) Summary Description of the Radioactivie Anomalies in Wadi Sidri Area

Anomaly No.	Location	Country Rock	Host Rock	Radioactivity, µR/h			Remarks
				B.G.	Aver.	Anom.	
I	Wadi Baba	Gneissose granite	Aplite dyke	10	60	150	Silicified zone
II	Wadi Baba	Carboniferous S.S.	Ferruginuos siltstone	15	50	150	Mn & Fe mineralization
III	Wadi Baba	Biotite gneiss	Red granite dyke	10	70	180	Along the contact
IV	Naqb Budra	Carboniferous S.S.	Red granite boss	15	50	170	Highly fractured
V	Wadi Abu Natash	Carboniferous S.S.	Ferruginous siltstone	12	30	250	Mn & Fe mineralization
VI	Wadi Budra	Carboniferous S.S.	Ferruginous siltstone	15	50	130	
VII	Gebel Maghara	Carboniferous S.S.	Ferruginous siltstone	10	150	1500	Mn & Fe mineralization
VIII	Wadi Sidri	Carboniferous S.S.	Ferruginous siltstone	12	60	250	
IX	Wadi Seih Sidri	Nubian Sandstone	Pink granite	10	60	110	Along fracture
X	Wadi Mukattab	Nubian Sandstone	Ferruginous siltstone	8	70	130	Carbonaceous

into two groups, namely (1) Basement complex, and (2) Carboniferous sediments. The distribution of gamma radioactivity among the anomalies associated with each host rock type is briefly given in the following.

1. Basement Complex : The Precambrian igneous rocks exposed in Wadi Sidri area are represented by late orogenic granites and some related dyke-forming rocks of aplites and felsites. The normal gamma radioactivity of these rocks is generally ranging from 10 to 20 μR/h, with the high values mainly associated with the more acidic and highly differentiated varieties. The mean gamma radioactivity of granodiorites and basic granites ranges from 10 to 12 μR/h, while the mean of equigranular pink granites ranges from 12 to 15 μR/h. The higher values of radioactivity among the late orogenic granites are recorded on the exposure of porphyritic red granite which has an average ranging from 15 to 20 μR/h. The gamma radioactivity of aplite and felsite dykes are generally similar to those of equigranular pink granite with some relatively higher values reaching 20 μR/h.

The natural radioactivity of the late orogenic plutonic rocks can be attributed mainly to their contents of accessory minerals such as zircon, apatite and sphene which may carry uranium and/or thorium. The abundant presence of iron oxides in these rocks may also be responsible for some radioactivity due to their ability to adsorb uranium minerals. Also, a considerable part of the normal radioactivity of these granitic rocks may be due to their content of the radioactive potassium isotope (k^{40}) usually present in the abundant constituents of potash feldspars.

Among the discovered anomalies in Wadi Sidri area, four anomalies are found to be connected to the late orogenic plutonic and their related rocks of the basement complex. One anomaly is located at the southwestern periphery of a pink granite exposure in Wadi Sidri, having a maximum radioactivity of 110 μR/h. Two anomalies are found along a hydrothermally altered zone in prophyritic red granite mass between Wadi Baba and Naqb Budra, with highest values of radioactivity reaching 180 μR/h and 170 μR/H respectively. The fourth anomaly is connected to silicified aplite dyke occupying a N-S fault zone in gneissic granite at Wadi Baba, with maximum radioactivity of 150 μR/h. Radiometric analysis of a representative sample from this aplite dyke gave 40 ppm eU and 20 ppm eRa (Table 3). No visible radioactive mineralization have been found to be associated with these anomalies.

The localization of radioactive anomalies in the late differentiates of late orogenic plutonic rocks, associated with silicification and other alteration features may support an epigenetic origin of the high radioactivity. After partial consolidation of the granitic rocks, they have been subjected to tectonization, which created some favourable structural features. At a later stage of magmatic evolution hydrothermal solutions responsible for high radioactivity followed the weak structural lines, deposited the radioactive minerals and causing alteration of the host rock.

Jurassic basalts, forming Farsh El-Azrak volcanics, have low intensity of gamma radiocativity, ranging from 4 to 8 μR/h. Field radiometric investigation of basalt sheets of this type did not reveal the presence of anomaly in them. However, Gindy [13] considered that hydrothermal solutions following such basic volcanicity may be good mineralizers for uranium, by leaching and carrying upward indigenous uranium during their ascent from lower horizons.

2. Carboniferous Sediments : Normal gamma radioactivity of Carboniferous sediments in Wadi Sidri area shows great variations according to their lighological and mineralogical composition. The dolomitic limestone, clay, kaolin and glass sand have the lowest intensity of radioactivity with a mean value ranging from 7 to 10 μR/h. The sandstone and shale have a moderate intensity of radioactivity with an average of 10–12 μR/h, while the siltstones are of higher mean value of radioactivity ranging between 12 and 15μR/h, reaching 10–25 μR/h in ferruginous beds. In addition to this ligthological variation, there are two other factors controlling the distribution of radioactivity and radioactive anomalies in Carboniferous sediments exposed in Wadi Sidri area and its surroundings. These factors include the stratigraphic horizon and the geographic location with respect to the Carboniferous shoreline (Fig. 5). Field radiometric investigation revealed the presence of six radioactive anomalies in the outcrops of Carboniferous sediments in Wadi Sidri area. All of these anomalies are connected to a definite stratigraphic horizon of ferruginous siltstone forming the uppermost layers of Adedia Formation. They are mostly confined to two successive layers, the lower one is relatively rich in Mn-Fe oxides, while the

upper layer is contaminated with some carbonates from the overlying Um Bogma Formation. Table (3) gives the results of semiquantitative X-ray spectrochemical analysis of two average samples from highly radioactive anomaly No. VII at Gebel Maghara on the northern side of Wadi Sidri. The areal distribution of radioactive anomalies in the ferruginous siltstones show that they are localized along or very near to the Carboniferous shoreline.

The maximum value of gamma radioactivity at these anomalies ranges between 130 and 150 μR/h, except for anomaly No. VII where it reaches 1500 μR/h and even more (Table 2). The results of radiometric analysis of some grab samples representing different rock types at these radioactive anomalies are shown in Table (4).

RESULTS AND DISCUSSION

From field observations, radiometric investigation and analytical data the following results have been reached:

1) Radioactivity is mainly due to uranium with substantial contribution of thorium which is erratically distributed in the different anomalies.

2) The radioactive occurrences are in a disequilibrium state, which is partly in favour of uranium enrichment and partly due to its depletion.

3) There is no direct or obvious relation between radioactivity and any specific alteration feature or other

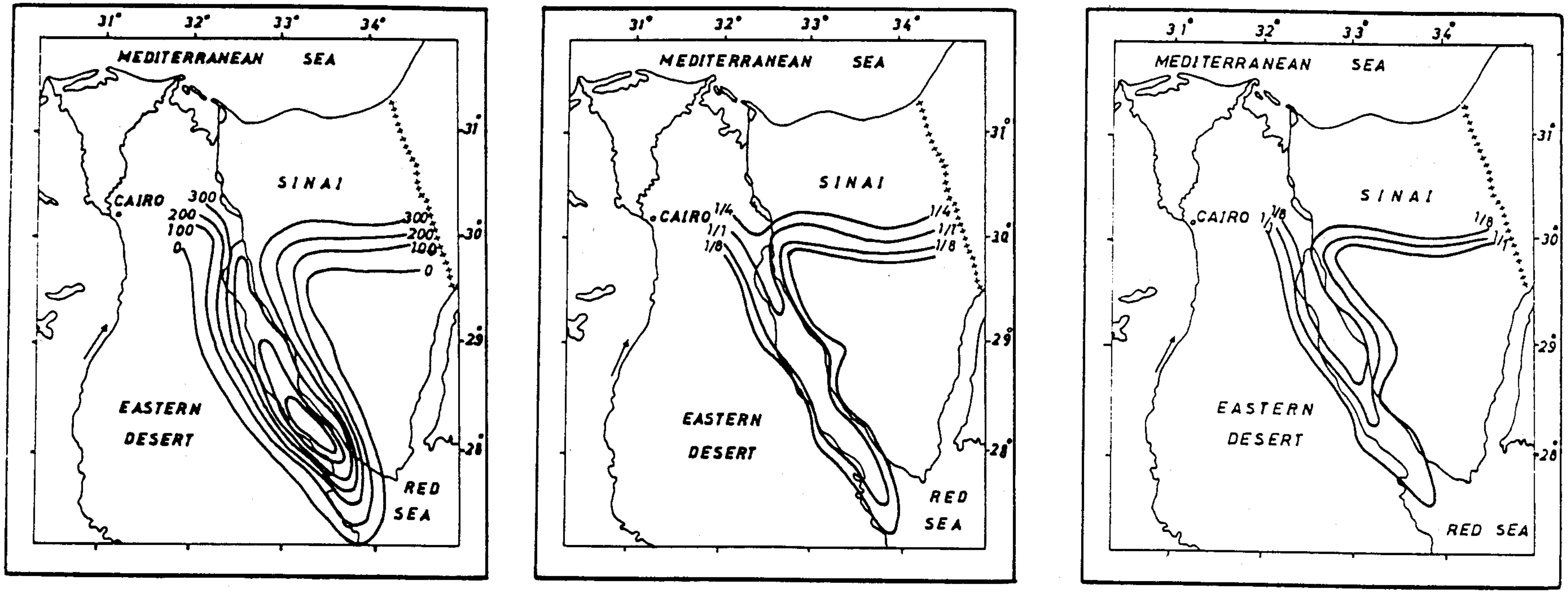
Table (3) Semiquantitative X-ray Spectrochemical Analysis of Two Average Samples from the Radioactive Occurrences At Wadi Sidri, West Central Sinai

Elements / Horizon	Major	Minor	Trace
Upper Horizon	Ca, Fe	Mn	Rb, St, Ti, Y, U
Lower Horizon	Fe, Mn	Ca, Zn, Cu, Ni	Pb, Ba, Zr, Sr, Ti, Y, U, Th.

Table (4) Results of Radiometric Analysis* of Representative Samples from Some Radioactive Anomalies at Wadi Sidri Area

Sample No.	Anomaly No.	Rock Type	eU, ppm	eRa, ppm	U_3O_8, ppm	ThO_2, ppmI	P= eU/eRa
S–34	I	Silicified aplite	40	20	40		2.0
S–24	V	Ferruginous siltstone	40	50			0.8
S–25	V	Mn-and Fe-rich siltstone	130	150	110	70	0.9
S–15	VI	Ferruginous siltstone	20	30			0.7
S–20	VII	Brown coarse sandstone	270	370	270	30	0.7
S–21	VII	Reddish shaly siltstone	1290	1060	1300		1.2
S–29	VII	Ferruginous siltstone	520	480	680		1.1
S–31	VIII	Medium grained sandstone	40	20			2.0
S–28	X	Clayey sandstone	20	40	30	10	0.5

* Samples were analyzed by combined techniques of total beta - gamma activity and gamma - ray spectrometry at the NMA, Cairo, Egypt.



(A) Isopach Contour

(B) Clastic Ratio

(C) Sand-Shale Ratio

Fig. 5. Facies Maps of Lower Carboniferous in sinai Peninsula and Gulf of Suez (After Kostandi, 1959)

type of mineralization such as the Mn-Fe ores commonly deposited in the surroundings.

4) Although radioactivity generally increases in sheared and ferruginated zones, there is no obvious control of large structural features on radioactivity.

5) The distribution of normal gamma radioactivity shows a general increase from the north and NNW southwards.

6) Most of the highly radioactive anomalies are located in the topographic lows along or very near to the Carboniferous shoreline.

All of these evidences are in favour of syngenetic origin of radioactive minerals in the Carboniferous siltstones, where they have been deposited together under the same sedimentary environment in the Early Carboniferous time. Mineralogic studies show that the principal mineral responsible for radioactivity is the uraniferous xenotime. The presence of this mineral together with its major associates; rutile, zircon and magnetite, indicates some sort of placer deposits. However, due to the presence of disequilibrium where uranium is either enriched or leached, the presence of uranium mineralization or minerals apart from xenotime should not be excluded at the present stage of knowledge.

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