

Investigation for Uranium Dispersion Adjacent to Cretaceous Phosphatic Outcrops in Al-Nassrieh Basin, Southern Palmyrides, Syria

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ABSTRACT: A detailed radiometric survey including soil gas radon measurements and field gamma-ray survey, in accordance with geochemical and geological investigations were carried out in Al-Nassrieh basin (central Syria), for the purpose of uranium exploration. Thirty six samples were collected from various lithofacies of the survey area and analyzed by γ -ray spectrometric technique for determining the concentration values of major radioelements. The relationships between the concentrations of equivalent eU, eTh, and their ratios were examined in order to define their trend of variations and evaluate the degree of uranium remobilization and redistribution. Although the initial results indicated that uranium enrichment is mostly restricted to the upper Cretaceous phosphate rocks, a considerable portion of uranium appeared to be leached out of the primary phosphatic source and dispersed in the adjacent recent sediments. Further, notable increases of radon level associated with relatively high values of uranium concentration and gamma count rates were found to be spatially correlated with the transition zone between the marine Paleogene and continental Neogene formations throughout the study basin. This observation demonstrates the importance of the concerned zone as a suitable geological environment for hosting probable uranium mineralization along a chemically reducing interface where surface water of terrestrial and marine origin mingled at depth and away from surficial conditions.

KEY WORDS: radiometric survey, geochemistry, uranium exploration, Al-Nassrieh Basin, Syria.

0 INTRODUCTION

A comprehensive national program for uranium exploration was carried out in Syria during the period from 1987 to 1990. The project was supported by the United Nation Development Program (UNDP) in cooperation with the International Atomic Energy Agency (IAEA), No. SYR/86/005 (Jubeli, 1990). The exploration project consists of three main stages including geological ground investigations, an airborne radiometric survey and follow-up detailed ground studies. Although, the airborne survey did not reveal strong indications of economically feasible uranium mineralization in the country, the results provided good quality radiometric maps and assessment of uranium potential in selected areas through the Syrian desert and the Palmyrides region. The present work represents part of the ongoing follow-up investigations for uranium over some promising targets which were delineated by the results of the airborne radiometric survey. In view of that, several exploration techniques were applied in this study including soil gas radon measurements, gamma-ray survey and geochemistry in order to investigate for uranium and to outline

its dispersion pattern in recent sediments adjacent to some uranium-bearing phosphate outcrops in Al-Nassrieh basin of central Syria (Fig. 1).

Radon (Rn-222) is a daughter nuclide of radium (Ra-226), which in turn is produced from the decay of uranium (U-238). As a naturally occurring radioactive gas with half-life of 3.82 days, radon is widely used in a variety of earth science disciplines. Common radon applications include earthquakes prediction (Ghosh et al., 2009; Al-Hilal et al., 1998; Hauksson, 1981), characterizing hidden faults (Ioannides et al., 2003; Baubron et al., 2002; King et al., 1996) as well as uranium exploration (Khattak et al., 2011; Jubeli et al., 2000; Gingrich, 1984; Dyck, 1975). Since radon is a radioactive progeny of naturally occurring uranium, there is a coherent relationship between its outflow emission and the occurrence of subsurface ore deposits. Therefore, radon is commonly used as a pathfinder in most uranium exploration programs where it could provide a potential opportunity to locate buried uranium mineralization that might not be detectable in other radiometric techniques. Radon is also proven useful in identifying some deformed structures such as fault zones that may be responsible for hosting some important uranium ore deposits (Qureshi et al., 1991). Although radon measurement technique is commonly used in combination with gamma-ray survey in most exploration programs, it appears to have an advantage over gamma-ray detectors because of the larger depth of penetration. However, the gamma-ray spectrometric method is

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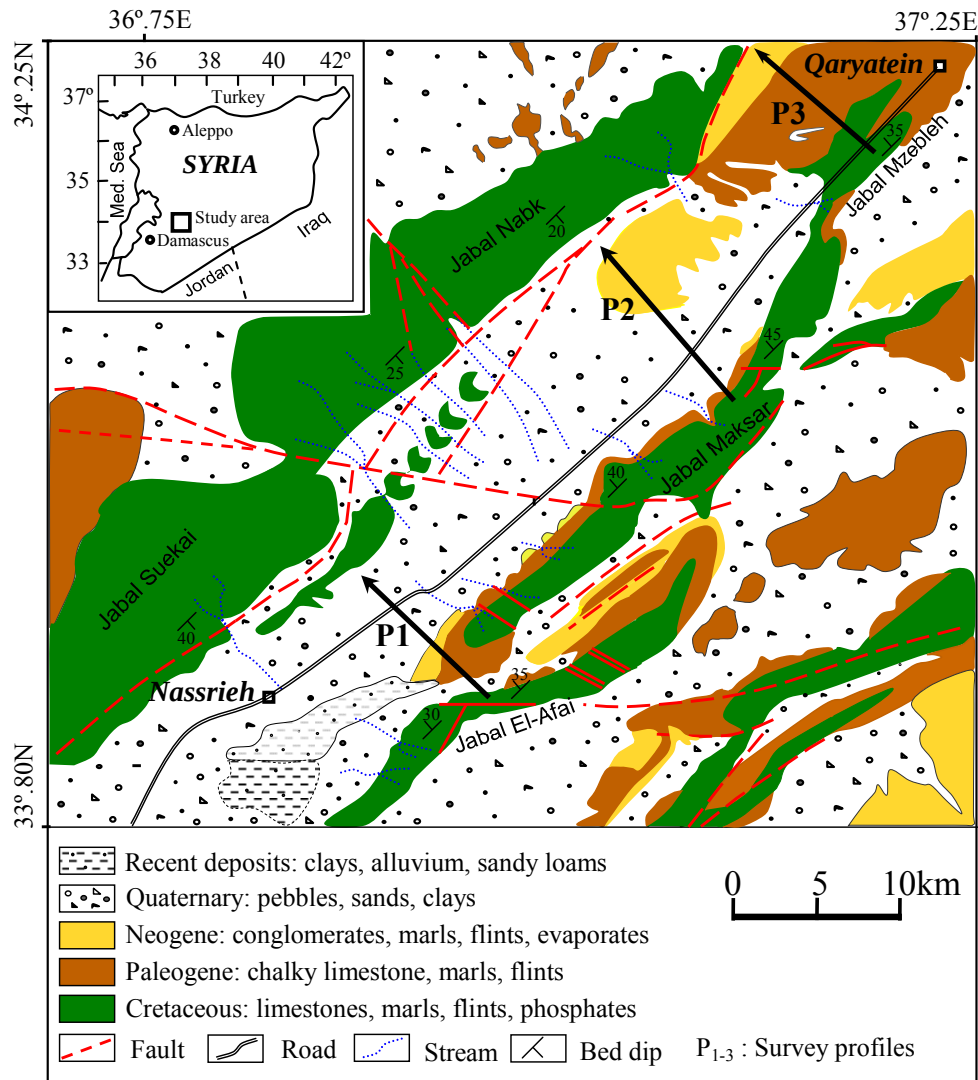


Figure 1. A geological map of Al- Nassrieh basin showing the locations of the radiometric survey profiles (P1, P2 and P3).

considered to be an essential technique in any uranium exploration project as it enables an immediate identification of the anomalous sources at the topmost part of the earth's crust in terms of the parent element (Adams and Fryey, 1964). The intensity of gamma rays emitted from the ground surface is principally related to the mineralogy and geochemistry of the bedrock and surficial weathered materials. Therefore, such radiometric data is regarded as a vital source of information for geological mapping and some other environmental studies as well as for mineral exploration (Al-Hilal and Aissa, 2015; Chiozzi et al., 2002; Jubeli et al., 1997).

1 GEOLOGICAL SETTING

The study area represents an elongated basin with general SW-NE direction, trending over a distance of about 50km. It extends between longitudes (36.75° E–37.25° E) and latitudes (33.80° N–34.25° N), as a gently rolling plain broken by a network of U-shaped valleys and dry erosional channels. The survey area is bounded from the southeast by El-Afai and Maksar mountains and from the northwest by Suekai and An-Nabk mountain chains (Fig. 1). Such topographic setting appears to be quite suitable for accumulation of weathering

products that are derived from the surrounding hills and carried down by seasonal valleys either as clastic or dissolved materials. The overburden geology of the study area consists mainly of alluvium, sandy loam, pebbles, marls and clays of recent and Quaternary ages. The underlying continental Neogene (Pliocene) formations are basically composed of sands, silts, conglomerates as well as some evaporative materials. These formations are underlain by the Paleogene (Eocene) rocks which represent shallow marine depositional environment that is characterized by chalky limestone, calcareous marls, flints and some phosphates. The upper Cretaceous unit (Santonian–Campanian) outcrops commonly on the flanks of the neighboring Palmyrides Mountains and along some gently rounded hills that are distributed along the center of the study basin. The Cretaceous rocks are composed mainly of calcareous rocks alternating with marls, cherts, and uranium-bearing phosphates (Jubeli, 1997; Ponikarov, 1963).

2 METHODOLOGY

2.1 Soil Gas Radon Measurements

The application of radon technique for detecting subsurface uranium deposits is based mainly on the ability of

radon, as a non-reactive gaseous element, to migrate away from the site of its origin by diffusion and advection along joints, faults and other permeable pathways (Al-Hilal and Al-Ali, 2010). The concentration and the mobility of radon gas in geological environment are dependent on several factors such as the types and nature of rocks, the content and distribution of radium in soil, fluid motion, moisture content, permeability as well as the effects of meteorological parameters. Radon measurements in soil gas were carried out in this study based on direct active method. A portable vacuum soil probe assembly model (Pylon-154) was used for quantitative radon determinations in soil gas. The system is attached to a vacuum hand pump and it is connected with a scintillation Lucas cell model (Pylon-110A). In practice, at each measuring point a borehole, (5cm diameter. and 60 cm depth), is made in the ground. The soil probe is gently inserted into the hole with the probe valve is closed tightly. The scintillation cell is evacuated with a hand pump to approximately 25 In Hg. The same vacuum should be used for all other sampling points. Then the probe valve is slowly opened and the soil gas is drawn gradually through a closed-circuit from the hole into the scintillation cell until the system comes to atmospheric pressure. For quantitative measurements, the radon sample must be allowed to decay inside the scintillation cell for three hours so that the radon daughters come into equilibrium with the radon gas. Then, the scintillation cell is placed in the counter (RM 1003-Radon Detector), and the alpha activity is measured in count per minute basis, and then converted to concentration as Bq/m³. The radon counter was frequently calibrated during the survey, using a standard test cell containing a source of ²²⁶Ra with known activity. The calibrations ensured an acceptable detection limit, and thereby the measurements may give reasonable determinations of radon concentration in soil gas throughout the survey area.

2.2 Field γ -Ray Survey

Field gamma-ray survey was performed using a compact portable field spectrometer, (type GRS-500 Differential Gamma-ray Spectrometer, Scintrex), with a 124 cm³ NaT detection crystal. The calibration constants of this instrument have been derived from standard test pads located in Ottawa, Ontario, Canada and Grand Junction, Colorado, U. S. A. Previous measurement over a water background was carried out over natural Shakra Lake, northeast of the study area (Jubeli, 1990). The instrument was calibrated using a ¹³³Ba radio-isotope source. One ten-minute count was performed with the instrument placed in an upright position on the terrain surface at each sampling site. In practice, the instrument is basically used to measure gamma rays emitted by natural radioactive elements contained in rocks such as U, Th and K which may eventually lead to the discovery of uranium deposits. It is characterized by high gamma detection efficiency, giving high count rates and relatively low statistical fluctuations. This permits the recognition of small changes in the concentration of radioactive elements. In fact, the radioelements (U, Th, and K) were detected by the GRS-spectrometer using four gamma-ray energy windows. Only values of total counts and equivalent uranium (eU) showed

significant differences, therefore, radioactivity of the area is mainly a reflection of the uranium content at each sample site. Although eU is usually used instead of total counts, for comparison with radon measurements, we only considered total counts of gamma-ray activity, which are presented in this study as counts per second (CPS).

2.3 Laboratory γ -Ray Spectrometric Analysis Technique

Gamma-ray spectrometry is an indirect analysis technique that gives the result of uranium content as equivalent uranium (eU), which is equal to the true uranium concentration only if there is radioactive equilibrium in the rock being analyzed. The gamma-ray spectrometer consists of a 12.5% relative efficiency Ge detector, with an energy resolution of 0.998 keV at 122 keV, and 1.88 keV at 1332 keV, coupled to an S-100 spectroscopy system with an 8192 ADC card. More information regarding calibration process, accuracy and detection limits of the spectrometer can be found in IAEA (1976). Thirty-six soil and rock samples were collected from the same points where the radon measurements had been carried out through the survey area. The samples represent various lithological formations outcropping in the study basin including the uraniferous phosphate rocks and the adjacent recent clastic sediments. The main purpose of this geochemical sampling survey is to investigate the dispersion pattern of uranium and some other associated radioactive elements along the survey profiles. All samples were air-dried, sieved and analyzed for determining the concentrations of U, Th and K by using γ -ray spectrometric analysis technique. The results of this chemical analysis along with the concentration of radon in soil gas were shown in Table 1.

In order to verify the procedure of the field γ -ray survey, the obtained values of equivalent uranium concentration were correlated and regressed against the analytical values achieved through laboratory γ -ray spectrometric technique (Fig. 2). Accordingly, a good correlation between the two sets of values has been found with correlation coefficient of $R^2 = 0.86$, which reveals the accuracy of the measurements as well as the sensitivity of the system and the reliability of the detection limits.

2.4 Geochemical Indicators for Uranium Remobilization

The two main radionuclides, uranium and thorium, are usually found in association for most geochemical environments due to the similarity in their ionic radii. However, uranium is characterized by high mobility under oxidizing conditions, especially in acid or carbonate-rich waters. Nevertheless, uranium becomes immobile in reducing geochemical environment, where it is strongly adsorbed to organic matter, clay particles and Fe-oxides. During weathering and other erosional processes, U⁴⁺ is easily oxidized into hexavalent state (U⁶⁺), which is quite soluble and mobile in groundwater. Whereas thorium is generally refractory and resisting the alteration processes, so it remains insoluble in the oxidization zone. As the mobility of thorium is extremely low, it can be used as a reference for studying the original concentration of uranium in various geochemical and geological environments.

The ratio of eU/eTh could be considered as a good indicator for uranium migration, because it is supposed to be almost constant in rocks of the same type if migration has not occurred. Furthermore, the correlation between the equivalent eU, eTh and their ratios can be used as a useful geochemical sign for uranium remobilization. A positive relationship between eU/eTh and eU accompanied with inverse relationship

between eU/eTh and eTh is a potential evidence of uranium redistribution and remobilization. While small or moderate increases of eU/eTh and eU indicate that uranium might not have been significantly remobilized, either because of a lack of solutions needed for uranium dissolution, or because the uranium is hosted in resistant lithological units (Abu-Deif et al., 2001; Fouad et al., 1998).

Table 1. Summary statistics showing the results of laboratory γ -ray spectrometric analysis data, besides the values of radon concentrations measured throughout various geological units in Al-Nassrieh basin.

Geological Unit	Variables	No. of sampling	Min.	Max.	Mean	σ	CV%	F-Parameter
Quaternary (clays, alluvium, sandy loam)	eU (ppm)	7	2.2	4.8	3.3	0.85	26	0.17
	eTh (ppm)	7	1.2	5.72	3.5	1.38	39	
	K (%)	7	0.03	0.4	0.18	0.12	67	
	eU/eTh	7	0.55	4.0	1.27	1.15	91	
	eU/K	7	8.50	73.3	29	21.24	73	
	eTh/K	7	6	133	34	41.1	121	
	Rn (Bq/m ³)	30	2 870	19 760	5 774	3 068	53	
Neogene (sands, conglomerates, marls)	eU (ppm)	8	3.46	17.1	8.2	4.67	57	0.33
	eTh (ppm)	8	3.1	7.4	5.4	1.40	26	
	K (%)	8	0.01	0.6	0.21	0.22	105	
	eU/eTh	8	0.82	2.55	1.5	0.57	38	
	eU/K	8	8	1270	264	429	163	
	eTh/K	8	10	740	167	250	150	
	Rn (Bq/m ³)	21	9 588	24 555	17 701	4 728	27	
aleogene (chalky limestone, calcareous marls)	eU (ppm)	7	3.19	15.9	6.58	4.06	62	0.46
	eTh (ppm)	7	2.8	5.5	4.07	0.87	21	
	K (%)	7	0.1	0.8	0.29	0.22	76	
	eU/eTh	7	0.82	2.89	1.59	0.73	46	
	eU/K	7	14	56	26.3	13.07	50	
	eTh/K	7	7	28	18	7.16	40	
	Rn (Bq/m ³)	21	3 536	29 120	7 493	6 774	90	
Cretaceous (limestone, flints, phosphates)	eU (ppm)	14	18	46	27	9.86	37	0.84
	eTh (ppm)	14	1.5	4.9	3.1	1.39	45	
	K (%)	14	0.02	0.2	0.10	0.09	90	
	eU/eTh	14	4.3	20.7	10.5	6.25	60	
	eU/K	14	145	1265	527	426	81	
	eTh/K	14	11	185	77	78	101	
	Rn (Bq/m ³)	18	17 056	121 264	48 565	30 085	62	

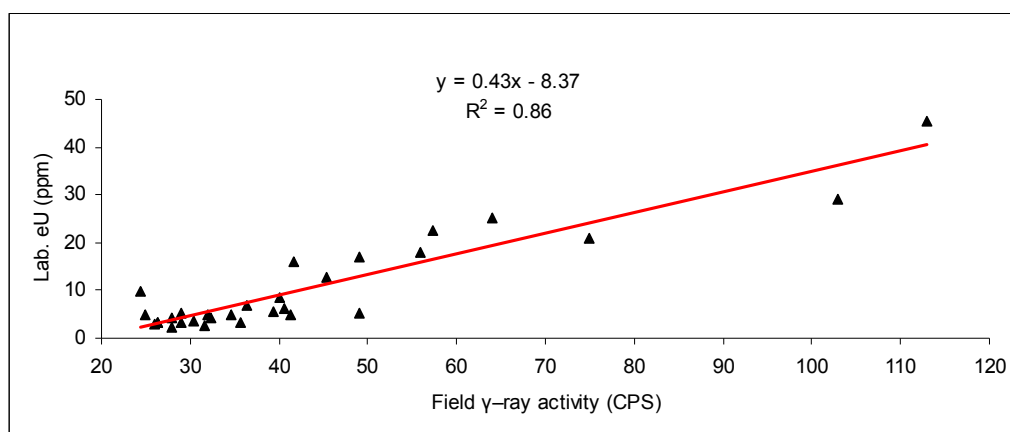


Figure 2. Plot of laboratory γ -ray analysis data (ppm eU) vs. field γ -ray activity measurements (count per second: CPS).

3 STATISTICAL ANALYSIS OF THE DATA

Table 1 includes the results of analysis for all measured radioactive variables and their ratios, besides the values of radon concentration in soil gas. The obtained data was subjected to quantitative and qualitative statistical analysis in order to characterize the natural radioactivity levels in each geological unit. The analysis includes minimum, maximum, mean value ($\bar{X}$), standard deviation (σ) and the coefficient of variability ($CV\%$), which indicates the degree of homogeneity; the higher the coefficient of variability, the lower the homogeneity of the radioactive variable in a certain geologic unit (Asfahani et al., 2010). The coefficient of variability ($CV\%$) can be estimated for each radioactive variable through the following formula:

$$CV\% = (\sigma / \bar{x}) \times 100 \quad (1)$$

where CV is the coefficient of variability, $\bar{x}$ is the mean value and σ is the standard deviation.

An additional statistical index, called the F -parameter, was also applied in order to realize the degree of rock alteration for different geological units in the study area. The F -parameter was estimated based on data derived from the laboratory γ -ray spectrometric analysis. Two specific characteristics about the rock environment and history can be clarified by using this index: the uranium abundance relative to $eTh/K\%$, and the potassium abundance relative to the eTh/eU (Abu-Deif et al., 2001; Fouad et al., 1998). The F -parameter is expressed through the following equation:

$$F = \frac{K\%}{\frac{eTh}{eU}} = \frac{eU}{\frac{eTh}{K\%}} = \frac{K\% \times eU}{eTh} \quad (2)$$

4 RESULTS AND DISCUSSION

Radiometric and geochemical surveys were carried out along three parallel measuring profiles, denoted as P1, P2, and P3, traversing the main basin of the study area as shown in Fig. 1. The lithology is almost identical in all survey profiles, which begin eastward over the uranium-bearing phosphate outcrops of Cretaceous age, and extend westward passing through the Paleogene and Neogene formations into the Quaternary overburden. The measurements of radioactivity levels through the recent formations of the Quaternary unit revealed low values with average concentration of 5.774 Bqm^{-3} for ^{222}Rn , 3.3 ppm for ^{238}U , 3.5 ppm for ^{232}Th and 0.18% for ^{40}K . These notable decreases of radioactivity over the Quaternary deposits might be attributed to the lack of a suitable reducing depositional environment, which is quite necessary for precipitation and preservation of the leached uranium solutions. In other words, through time, oxidizing rather than reducing conditions were most likely the dominant controls of the geochemical environment throughout the region. Nevertheless, the radiometric survey through the Cretaceous unit, where the phosphate rocks are outcropped, showed relatively the highest radon concentration values that ranging from 17.056 to 121.264 Bqm^{-3} , with mean value of 48.565 Bqm^{-3} and standard deviation of 30.085 Bqm^{-3} . Moreover, these radon results appear to be in a general agreement with uranium concentration

values that varying between 18 and 46 ppm , with mean value of 27 ppm , which obtained by γ -ray spectrometric analysis technique for some samples collected from the same sites where the radon measurements had been carried out in the Cretaceous rocks. On the other hand, the radiometric levels that measured throughout the Paleogene and Neogene formation units revealed generally normal values with average concentration of 7.493 Bqm^{-3} for ^{222}Rn and 6.58 ppm for ^{238}U in the Paleogene unit; 17.701 Bqm^{-3} for ^{222}Rn and 8.2 ppm for ^{238}U in the Neogene unit. Although the dispersion path of uranium halo does not seem to extend over a large distance from the phosphates, remarkable increases of radioactive intensities were observed along the Paleogene-Neogene transitional contact zone through all the survey profiles (Figs. 2, 3, 4 and 5). From these figures, it can be seen that the depositional formation of the Paleogene-Neogene contact zone exhibits relatively higher levels of both radon and uranium concentrations. Additionally, these abnormal radiometric data were found to be well corresponding with the level of the recorded field γ -ray activity (using a portable field spectrometer, type GRS-500), along the same transition zone. Accordingly, it can be deduced that although most of uranium enrichment is essentially restricted to the Cretaceous formation where the phosphate rocks are deposited, uranium showed also a significant occurrence over the contact surface between marine Paleogene sediments and continental Neogene formations, apart from the phosphates. This observation may indicate the importance of such transition zone as a favorable structure for preserving a probable uranium mineralization along a chemically reducing zone where surface water of terrestrial and marine origin is merged.

Further, such geochemical environment may form a potential geological setting for hosting secondary uranium mineralization at depth away from oxidizing conditions and other surficial weathering processes. In other words, the possibility of downward migration of a leached solution that could be enriched in uranium should not be totally excluded. Previous studies from the nearby Wadi Qasser Al-Hallabat and Ad-Daww basin showed many uranium anomalies with some other associated elements, (like Sr, As, Se, Ba and V), in the groundwater samples (Jubeli et al., 2000). Such hydrogeochemical anomalies seem to have originated from the passing water through the dominant phosphorites outcropping over the Palmyrides Mountains (Jubeli, 1990). Thus, it can be argued that uranium has probably entered the sediments epigenetically in solution and has been precipitated in a likely reducing zone where the mixing of continental fresh and salt marine waters would be relatively efficient during the gradual uplifting of the Syrian platform in the late Paleogene. Uranium deposits of this general type have been discussed by Dickinson et al. (1988) and Tilsley, (1988). They concluded that the low Eh of shallow marine environment in contrast with relatively higher oxidizing Eh of terrestrial water due to the mixing of surface runoff and salt marine waters mostly result in a chemically reducing zone which could provide suitable geochemical conditions for probable uranium precipitations.

From geochemical point of view, the ratio of eU/eTh is considered as a good index for uranium migration, because it is

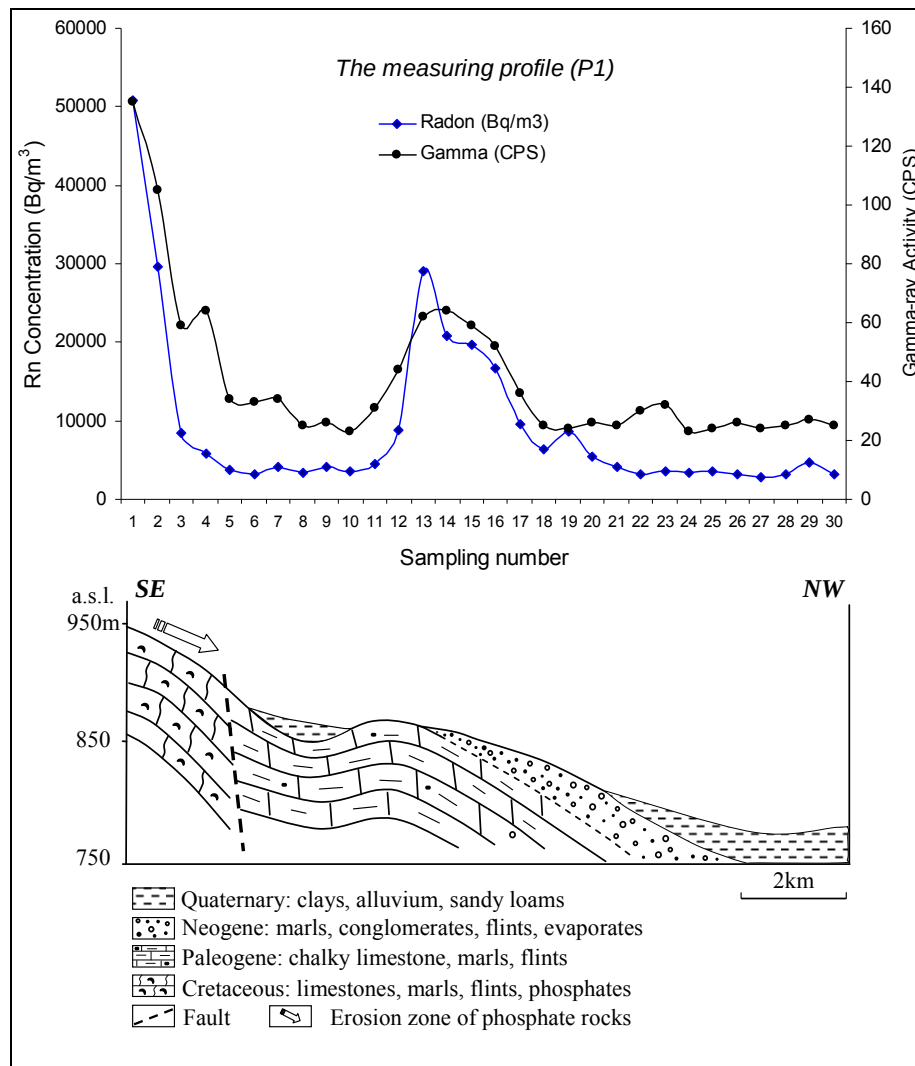


Figure 3. Radiometric and geologic survey along the measuring profile (P1).

supposed to be almost constant in rocks of the same type if migration has not occurred. Furthermore, the correlation between the equivalent eU, eTh and their ratios can be used as a useful geochemical indicator for uranium remobilization. A positive relationship between eU and eU/eTh, associated with a negative relationship between eTh and eU/eTh are evidence of uranium redistribution and remobilization. While small increases of eU/eTh and eU indicate that uranium might not have been totally remobilized, either because of a lack of solutions needed for uranium dissolution, or because the uranium is hosted in resistant lithological units (Fouad et al., 1998; Abu-Deif et al., 2001).

The diagrams in Fig. 7 describe the trend of variations for eU, eTh and their ratios in the upper Cretaceous rocks, which contain a considerable amount of uranium minerals. Positive relationship between the ratio eU/eTh and eU, ($R^2=0.68$), accompanied with a corresponding inverse relationship between the ratio eU/eTh and eTh, ($R^2=-0.67$), indicate that uranium has been subjected to redistribution processes. According to the tendency of these variations, it can be said that an important portion of uranium might be detached from

its phosphate source rocks, and it was mostly dispersed into the neighboring sediments and recent formations. Further, the correlation between the two main radioelements (U and Th) through the Cretaceous unit of Al-Nassrieh basin reveals a weak relationship ($R^2=0.18$). This is most likely referred to the differences in the geochemical behavior and mobility between U and Th. Even though uranium is highly soluble and mobile, thorium is characterized by strong stability, and it generally resists alteration and weathering.

The coefficient of variability (CV%) is a measure of the homogeneity for uranium distribution in the geologic unit; a higher coefficient of variability implies a lower degree of homogeneity. As shown in Table 1, the highest value of the uranium coefficient variability, (CV=62%), was recorded in the Paleogene rocks which relatively reflects low homogeneity of uranium due to the common occurrences of some discrete and minor spotty uranium mineralization through the calcareous marls and chalky limestone rocks of the Paleogene unit. While, in the Cretaceous unit, the value of coefficient variability for uranium was found to be quite low (CV=37%). This discrepancy may possibly referred to the fact that although

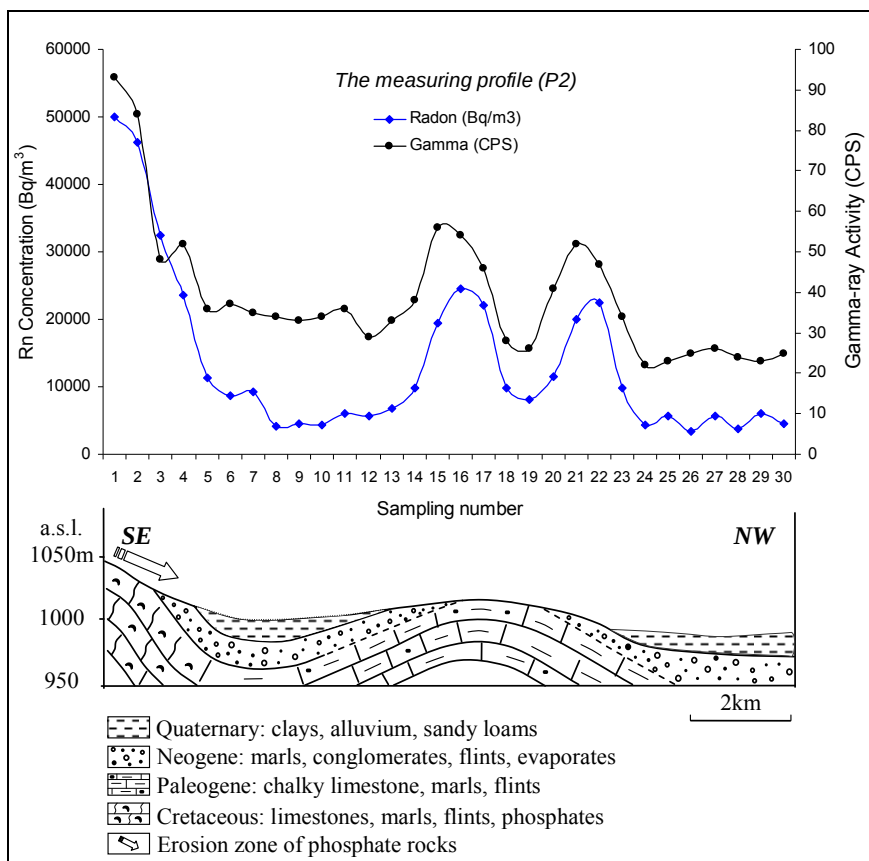


Figure 4. Radiometric and geologic survey along the measuring profile (P2).

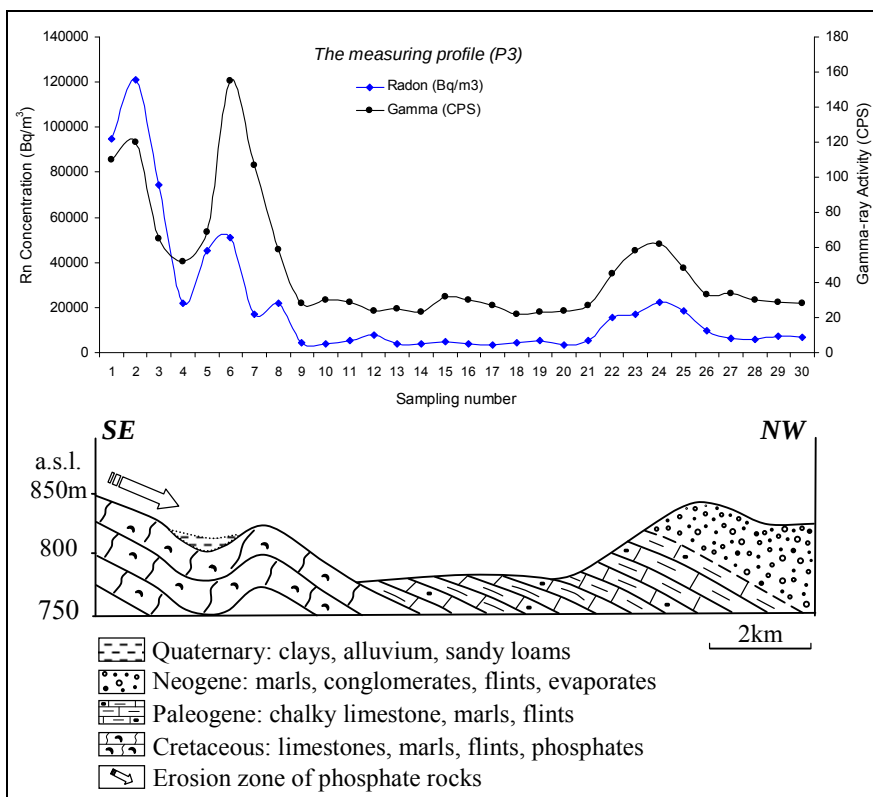


Figure 5. Radiometric and geologic survey along the measuring profile (P3).

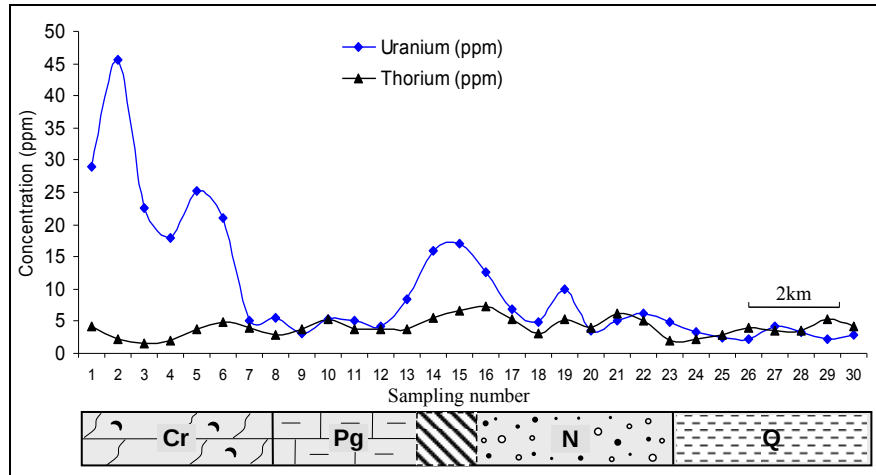


Figure 6. Concentrations of uranium and thorium in rock/soil samples collected from various geological units throughout Al- Nassrieh basin. Diagonal straight lines indicate the transitional zone between the marine Paleogene and continental Neogene formations.

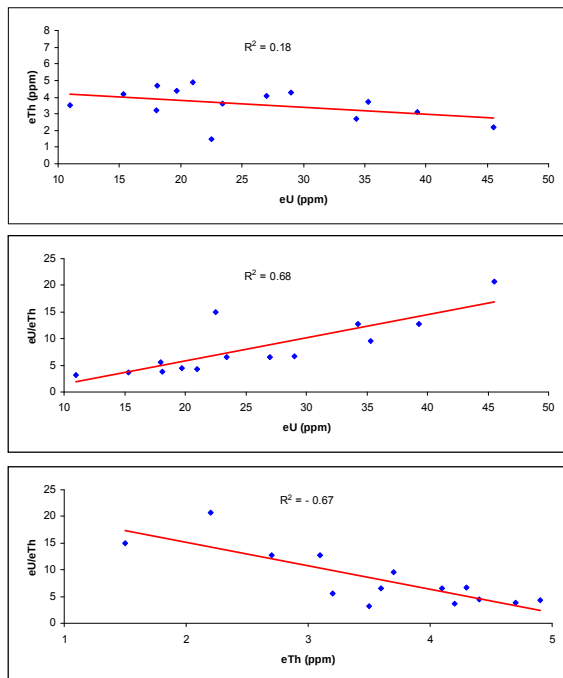


Figure 7. Variation diagrams showing the relationship between eU, eTh and their ratios in the upper Cretaceous formation of Al- Nassrieh basin.

the uranium-bearing phosphate rocks are believed to be partially diluted due to intensive processes of mechanical weathering and chemical leaching, an important amount of uranium is assumed to be still homogeneously hosted in some resistant lithological formations of the Cretaceous unit. On the other hand, the Neogene and the Quaternary formations, which consists mainly of clastic materials and other recent sediments derived from older rocks, reveal a moderate coefficient of variability for the Neogene unit ($CV=57\%$) and very low coefficient of variability for uranium in the Quaternary unit ($CV=26\%$). Although, the coefficient of variability seems to be rather variable throughout the four surveyed geologic units (Table 1), it is generally less than 100% for uranium, which likely means that the variability of uranium within the surficial environment of the study area as a whole exhibits normal to

moderate distributions.

The F -parameter is a statistical guide reflecting the extent of rock alteration due to various chemical and mechanical weathering processes. Figure 8 shows a plot of the F -alteration parameter against different geological units outcropped in the study area. From this figure it can be observed that the F -alteration parameter is seemed to be directly proportional with the geologic age of rocks; the older the rocks the more they are vulnerable to erosion and weathering processes. Additionally, this may also indicate that the Cretaceous phosphate rocks, which contain a significant portion of uranium and are marked by the highest value of the F -alteration parameter (0.84), had been continuously exposed to leaching and dissolution through long period. Additionally, the Paleogene formation, which consists mainly of shallow marine deposits of chalky limestone, calcareous marls and flints are characterized by moderate value of rock alteration parameter (0.46). Whereas the clastic and aggregated continental deposits of the Neogene and Quaternary units reveal lower values of alteration index, $F=0.33$ and 0.17 respectively (Fig. 8). Accordingly, the apparent changes of the F -alteration parameter values could be referred basically to the nature of rocks and their geological age as well as the differences in the depositional conditions and environments.

Consequently, the overall results of our survey reveal that although a large quantity of uranium is thought to be still strongly attached with the atomic structure of phosphates, an important portion of uranium was almost remobilized through time from its primary source in the phosphate rocks. The leached uranium was presumably moved under surficial oxidizing conditions where it widely dispersed and diluted in the adjacent recent sediments. Such oxidizing environment would prevent any substantial uranium accumulation except for some secondary uranium mineralization along fractures and joints, or as surficial crusts developed through evaporative processes resulting in gypcrete and calcrete types. However, another possible fate for the leached uranium is the downward migration of the uranium-bearing solutions to some depth below the erosion surface where it might have survived and precipitated under favorable geochemical and geological conditions. In view of that, the transition zone between the

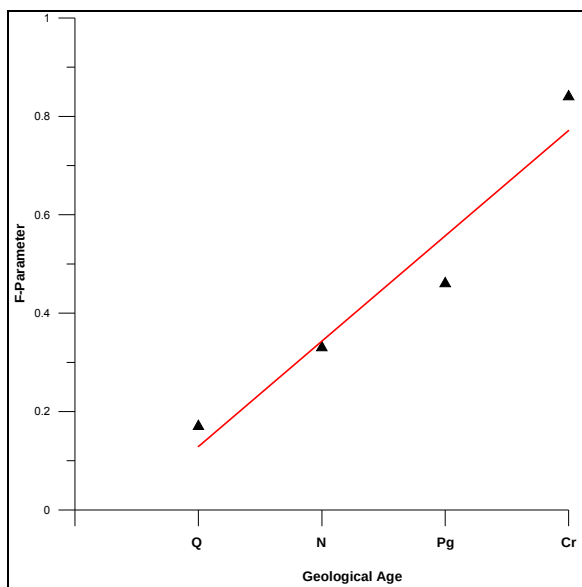


Figure 8. The distribution of F -parameter values vs. each geological unit.

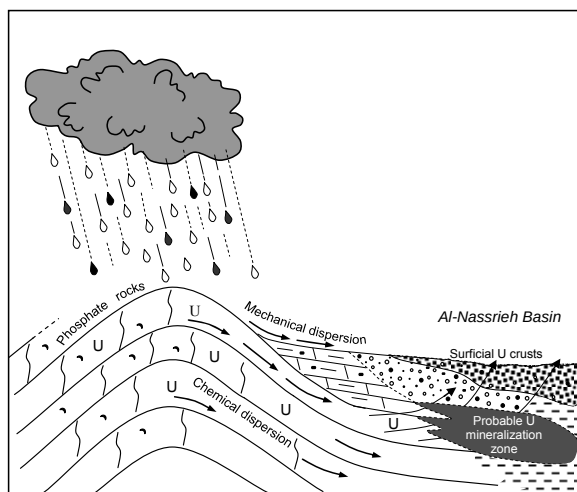


Figure 9. A schematic proposed model illustrating the probable fate of the dispersed uranium pattern in Al-Nassrieh basin.

Paleogene and Neogene formations would preferentially constitute an appropriate environment where solution could move toward a probable oxidation/reduction interface, which represents a suitable geochemical barrier for high uranium enrichment and preservation at depth (Fig. 9).

5 CONCLUSIONS

Radiometric survey integrated with geochemical and geological investigations have successfully defined the locations of the uranium-bearing phosphate rocks in Al-Nassrieh basin, and outlined the general pattern of uranium dispersion in the surrounding environment. The obtained radiometric data is regarded as a vital source of information for exploring and identifying the economically important phosphate deposits in the region. On the other hand, the correlation between eU , eTh and their ratios, besides the tendency of radon variations and γ -ray activity along the measuring profiles, indicated that a considerable portion of the

original uranium was presumably remobilized out of the Cretaceous phosphate rocks and consequently dispersed through the adjacent recent sediments. Remarkable increases of radioactivity levels were noticed across the transitional zone between the marine Paleogene and continental Neogene formations throughout the study basin. This could be an important evidence of probable downward migration of the leached uraniferous solutions to some depth below the erosion surface where uranium might have precipitated along a promising geological environment that is suitable for hosting uranium mineralization. Accordingly, a new model has been proposed to explain the likely fate of the dissolved uranium towards appropriate structures that would provide the necessary conditions for preserving potential uranium deposits along a chemically reducing zone where surface water of terrestrial and marine origin combined at depth and away from surficial weathering. Such depositional structures merit further detailed studies throughout the Palmyrides region in order to evaluate their radioactive characteristics and delineate their subsurface extensions.

Finally, a fairly good correlation has been found between the results of field and laboratory γ -ray spectrometric data, which may demonstrate the accuracy of measurements and certify the sensitivity of the detection limits for both methods.

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