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GEOLOGICAL PROSPECTS FOR URANIUM ORE DEPOSITS IN LEBANON

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Uranium exists in nature only as tetravalent (U^{4+}) or hexavalent (U^{6+}) compounds. From a geological point of view, the primary uranium mineral appears as tetravalent and is often found in acidic igneous rocks. It is converted in the surface oxidation zone to a secondary mineral where it becomes hexavalent. The latter is soluble and can be easily carried by surface or subsurface water until reenters a reducing environment where it deposits again in tetravalent form. Even though no acidic igneous rocks occur in the exposed rock formations of Lebanon, the occurrence of sandstone as a derivative of these rocks makes it favorable for uranium occurrence. In addition, the interbedding of shales, clays and lignite (as reducing agents) contribute to the favorability of uranium ore deposition. The location of Lebanon within the Mediterranean phosphatic belt, where uranium deposits often exist, adds another possibility for the natural occurrence of uranium ores. A ground radiometric survey, using a portable scintillometer has been carried out on selective sites in Lebanon, with a special emphasis on Neocomian-Barremian (sandstone and clay), Albian (shale) and Senonian (Marl) rock formations. Preliminary results show anomalous gamma radiation, which exceeded in many instances three times the background radiometric values. This is well pronounced in sandstone and clayey rocks. A detailed investigation should be carried out using gamma-ray spectrometers to build up a comprehensive survey on radioactivity type and concentration in the rocks of Lebanon.

INTRODUCTION

There are more than 200 radioactive isotopes in nature, but only 20 to 25 of them are used in energy generation. Uranium has become the most valuable one, notably for energy production purposes. In a worldwide view, the estimated amount of uranium is about two billion tons of ore deposits, which are believed to exist mainly in underdeveloped counties.

Currently, there are about 440 operating reactors in the world, which are concentrated mainly in the east USA and west Europe.Today uranium markets remain uncertain. Some is starting to come to world markets from the military inventories of the United States and Russia as a result of international agreements to dismantle a part of the huge stocks of nuclear weapons. Unlike other commodities, the demand for uranium is almost entirely for the generation of electricity.

Naturally occurring uranium contains mostly two isotopes, ${}_{92}U^{238}$ (99.3%), ${}_{92}U^{235}$ (0.7%), and traces of ${}_{92}U^{234}$. Each has its own chemical and radioactive properties as shown in Table 1.

Table 1. Major chemical and radioactive characteristics of uranium isotopes.

Isotope	# of electrons	# of neutrons	Atomic weight	Half life (year)	Decay constant (sec^{-1})	Radiation
${}_{92}U^{235}$	92	143	235	7.1 x 10^{8}	3.1 x 10^{-17}	α , γ, spontaneous fission
${}_{92}U^{238}$	92	146	238	4.5 x 10^{8}	4.0 x 10^{-18}	

The isotope ${}_{92}U^{235}$ is fissile, and if it irradiates with thermal (slow) neutrons, the nucleus will break up into two nuclei and liberate at least more energy than the chemical reaction. The fission of a kilogram of uranium releases as much as energy that obtained by burning 2500 tons of coal, or that generated in ten days by a 100,000 KW power station. This is the essential reason that makes uranium an important alternative source of energy. Below is an example showing the released energy.

$${}_{92}U^{235} + {}^{\circ}n^{1} \rightarrow {}_{56}B^{140} + {}_{30}K^{92} + 3({}^{\circ}n^{1}) + 10^{10}\ (KJmole^{-1}\ \text{“Energy”})$$

In nature, uranium occurs as primary and secondary minerals. Most primary ones are those formed by the heated solutions coming up from deep within the Earth. These are mainly in veins and acidic igneous rocks, and more likely in granite and other related intrusive rocks such as pegmatite and rhyolite. The chief primary compound of uranium is uranium dioxide, $UO_{2,}$ which makes up the mineral uraninite, also known as pitchblende.

The secondary minerals are those formed by the influence of several physical elements and processes, mainly weathering and groundwater. In the zone of weathering, uranium dioxides are converted to one or more of the bright, yellow colored oxidized uranium minerals including tyuyamunite $Ca(Uo_2)_2(VO_4)_2.6H_2O$, carnotite $KUO_2.VO_4$ and autunite $Ca(Uo_2)_2(PO_4)_2.8H_2O$.

Uranium has many valence states (+2, 3+, +4, +5, and +6), but U^{4+} and U^{6+} are the most abundant ions. Usually primary minerals of uranium U^{4+} are present in tetravalent (Uranous) form, in which they are black, bluish or greenish black. As the erosion of surfaces of the area are lowered, oxygen and water from the air and various ions from the host rocks react with primary minerals to produce more highly oxidized compounds. Uranium is oxidized to the hexavalent state U^{6+} (Uranyl) as carbonates, phosphates, sulfates, arsenates, and vanadates.

In the absence of suitable reductants or absorbents, uranium compounds of the high oxidized state are relatively soluble in groundwater and are ready to move vertically or laterally until reaching a reducing environment where they precipitate. A reducing environment is often characterized by H_2S, hydrocarbons, petrified wood, or any other organic matter. Uranyl ions may enter the reducing environment, where U^{6+} is reduced to U^{4+}, which is insoluble in the reducing environment and results in uranium deposition (Figure 1). Prospecting for uranium ore deposits requires determining two major factors: the source of the mineral and the environment of deposition, which are mainly governed by different geochemical processes.

MATERIALS AND METHOD

Occurrence of uranium ores in Lebanon

Proposing the occurrence of uranium deposits in Lebanon is based on a suitable environment of deposition for uranium ores among the rock sequences in Lebanon. Also, it is considered that the sequences are similar to neighboring regions, which have the same geologic characteristics. Therefore, there is a likelihood that uranium minerals occur in Lebanon based on its geologic characteristics.

Primary source rocks are not exposed on the stratigraphic sequence of Lebanon, but their derivatives occur, as well as a suitable environment of deposition. The generalized required conditions for uranium ore deposition were compared with the conditions in Lebanon in Table 2. They were approached according to the source rocks (primary and secondary) as well as the environment of deposition, which includes several reducing environments.

In addition, the structural and stratigraphic controls were considered. Therefore, it is obvious that some of the exposed rocks in Lebanon are suitable for the occurrence of uranium minerals. These are primarily sandstone and phosphate deposits. In addition, extrusive igneous veins and dykes within basaltic rocks are promising sources.

The primary source rock occurs in Lebanon as veins and dykes in different localities within the basaltic rocks. These rocks occupy a large geographic distribution and are found at different levels of the rock sequence, certainly within the rocks of the Pliocene (P), Neocomian-Barremian (C_1)/

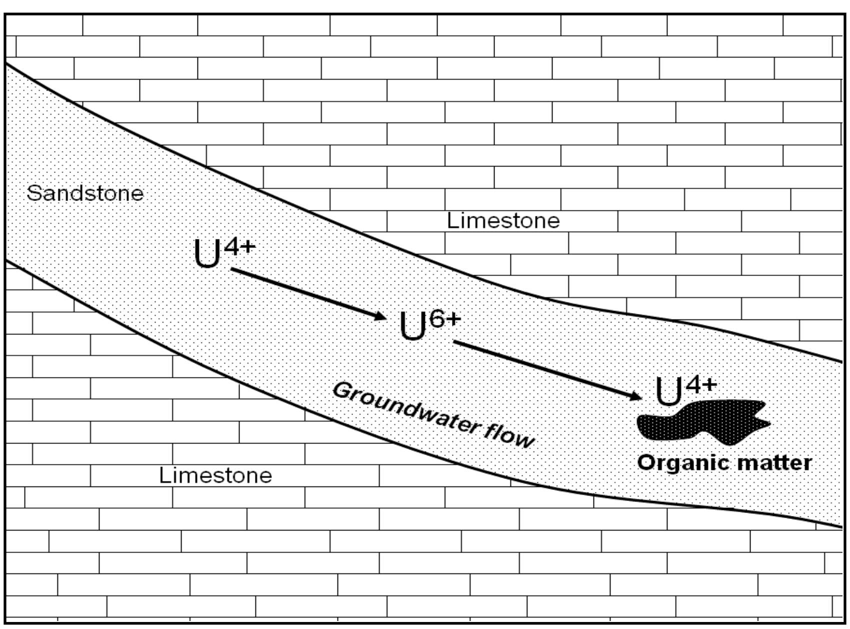

Figure 1. Schematic figure showing uranium mobility.

Lower Aptian (C_{2a}) and Oxfordian (J_5).

Accordingly, the proposed secondary source rock is divided into two rock types. These are:

- Sandstone rocks, which are well known to be derived from acidic igneous extrusives, as a parent rock, with a special emphasis on granites and pegmatites (Adler, 1974). In Lebanon, sandstone rocks exist, and they are included within a thick rock succession (~200m) of the Neocomian-Barremian age C_1 (Figure 2),
- Phosphate deposits, which are believed to occur in Lebanon, according to the concept of the extended Mediterranean phosphatic belt. It includes all southern Mediterranean regions from Turkey transecting Palestine, Egypt, and reaching Morocco. In these regions, shallow marine phosphate deposits are well known, and economically exploited. Several studies have indicated the presence of uranium minerals of commercial value within these deposits in Turkey (Erdem et al., 1995), in Jordan (Abed, 1981), in Libya (Hangari, 1983), and in Morocco (Berry, 1985).

In Lebanon, studies of phosphate deposits are rare and inadequate to form a complete picture, but all preliminary investigations have pointed to the possible existence of phosphate deposits (Dubertret, 1953, 1955; Beydoun, 1976, 1988; Ellezian, 1980; and Shaban, 1991). All these studies focused on phosphate deposition in the marly rocks of the Eocene and much more favorably in the Senonian marls (C_6).

Another essential condition for uranium is the reducing environment, which has many aspects in Lebanon, notably in silicate rocks (e.g. clay and shale). These rocks often contain organic

Table 2. Available conditions for uranium ore deposition in Lebanon.

Required conditions		Availability in Lebanon	
		Description	Geology/location
Source rock	Primary mineral	No primary rocks available (such as granite and other acidic igneous rocks) except some local dykes and veins.	a) No exposed acidic rocks in Lebanon, b) Dykes and vein exist, notably where basalt occurs.
	Secondary mineral	A) Sandstone, as a detritus of granite rocks, B) Phosphate deposits of shallow marine environment (expected due to the location in the Mediterranean phosphatic belt).	C) Sandstone of the Neocomian-Berrmian age (C_1), D) Phosphates of the Senonian marls (C_6), E) Marly limestone of the Eocene and Miocene are favorable for phosphate deposits.
Environment of deposition	Reducing environment	F) Clay, shale and lignite are available, G) Rocks with high content of organic matter, H) Hydrocarbon frictions.	I) Clays and lignite exist in C_1 and C_3, J) Organic matter found in different and local formations, K) Hydrocarbons exist as asphalt in South of Bekaa.
	Structural controls	Faults, fissures and joints	They structures and lithologic elements are widely occurred in different places and rock formations
	Stratigraphic controls	L) Contacts of different lithologic types, M) Unconformities.	

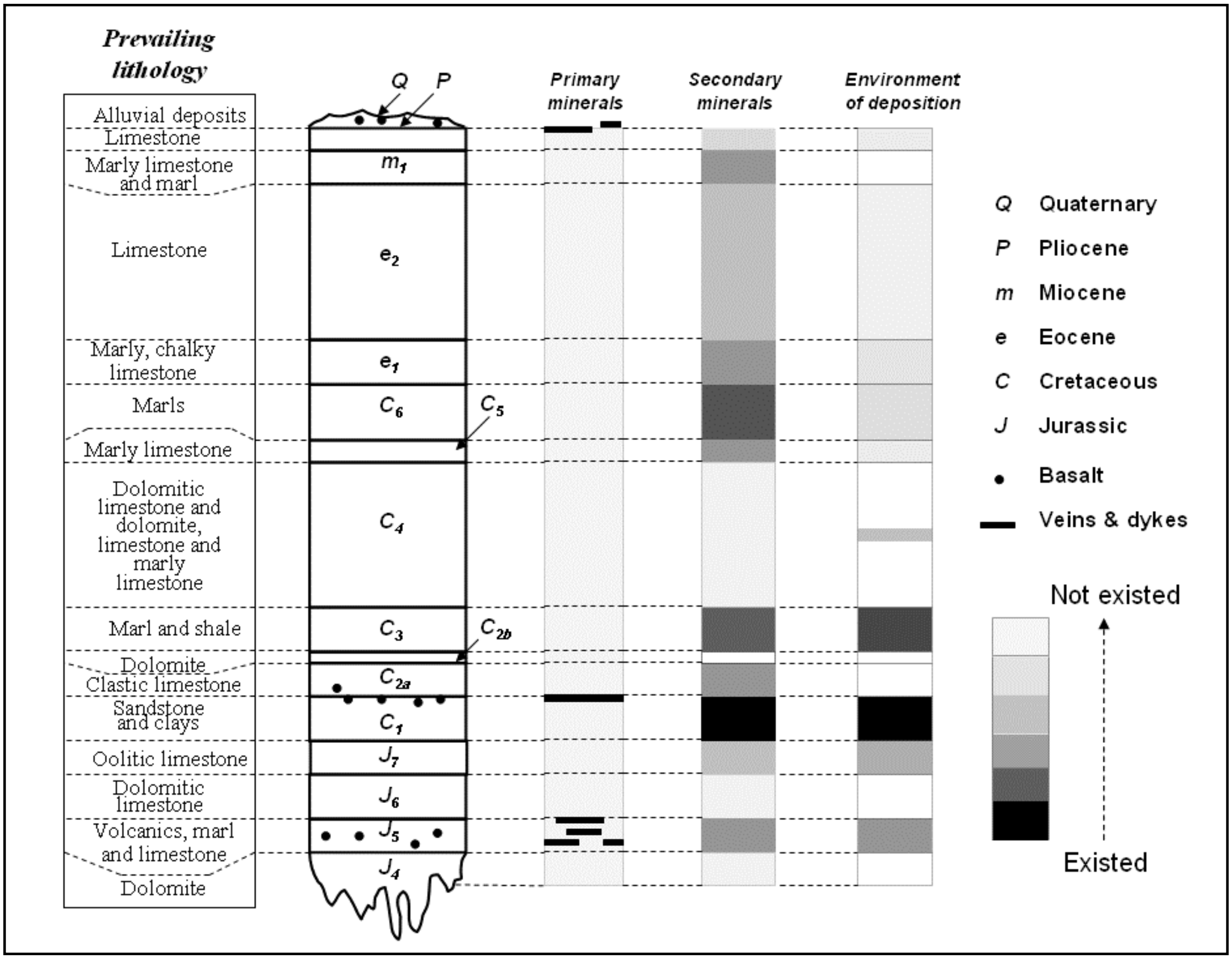

Figure 2. Stratigraphic sequence of Lebanon showing the existing conditions for uranium ore deposits.

materials and lignite, such as those included in the Neocomian-Barremian C_1 and Upper Aptian C_3 (Figure 2). This also accompanied by hydrocarbon frictions, which represent an important reducing agent and are known to occur as asphalt patches near Sohmor and the southern Bekaa region.

In addition, occurrence is more favorable if the environment of deposition is structurally and lithologically controlled. These conditions occur frequently in the Lebanese geological setting. Structures such as fissure, faults, joints and folded structures are common.

Considering the conditions for uranium occurrence in the rocks in Lebanon facilitates the planning of a radiometric survey, and makes exploration much less time consuming.

Radiometric survey

Prospecting for radioactive elements can be achieved by using the Geiger counter, or a more modified instrument called the scintillometer. These instruments cannot distinguish between different types of radioactive elements. For this purpose, a gamma-Ray spectrometer is often used to identify the radioactive element type.

In Lebanon, no radiometric survey had been conducted prior to this one, which was done in 1990. It is still a limited ground survey and needs more detailed application to include all favorable rock exposures in Lebanon over a large geographic extent. Moreover, the type of radioactivity should be confirmed using a spectrometer or X-ray diffraction. This survey used a scintillometer, which was provided by the American University of Beirut.

1. Scintillometer survey

The scintillometer survey followed several steps.

1. Rock types and geologic conditions for uranium ore deposition were primarily taken into account to select the route of the survey.

2. A background count was obtained first for the area under investigation. In this survey, the background counts were achieved by taking several readings of 2-3 minutes and at different times (preferably each hour) during the day (preferably over several days). In addition, these readings were done at locations that were well removed from the vicinity of the suspected deposits. The background count is a result of a residual effect (due to elements in the counter) and a cosmic effect due to cosmic radioactivity.

3. The survey followed linear traverses, and a grid method was applied depending on the area topography and size.

4. The counter was held parallel to the ground surface to give high precision.

5. The counter was close to the measured body (5-10cm).

6. Readings must range between at least 2 minutes and at most 5 minutes.

7. In case of a maximum and minimum reading for the same body, the average reading was used.

8. The residual and cosmic backgrounds were subtracted from the major reading.

9. The walking speed of the counter did not exceed 3 km per hour regardless of the sample spacing.

10. In the case of an anomalous reading, it was preferable to move a distance from the site, then return to obtain a new reading.

11. Soil has radioactive elements, thus soil covered areas were avoided as much as possible.

2. Anomalous readings

Usually, any reading which is at least three times greater than the background can be considered anomalous. Nevertheless, a known method to measure the anomalous reading was often applied as follows:

- Calculate the background (or the mean), X.
- Calculate the standard deviation, δ.

The anomalous reading equals $2\delta + X$.

In the 1990 survey, this general approach of identifying anomalous readings was applied, based on exceeding the background reading by three times.

3. Site selection

At the time of the survey, several man-made conditions existed, thus limiting the survey approach and its geographical coverage. Only selected sites were investigated taking into account the natural conditions for uranium deposits in the rock exposures.

Three major areas were surveyed. These are: Chekka (North Lebanon), Mansourieh-Baábdat road (Middle Lebanon) and Saida-Zaharani and Nabatieh area (South Lebanon).

RESULTS AND CONCLUSION

At these three areas there were 126 readings (sites). These were distributed as 34, 38 and 54 readings from north to middle to south Lebanon. The sites were selected at different sedimentary rock formations. The investigation on igneous rocks was not possible due to accessibility problems. The focus was on the sand/clay interface, marly facies with dominant glauconite, and rocks with high content of organic matter, and on lithologic boundaries.

The results of the survey were tabulated and accompanied by figures (see Tables 3, 4 and 5 and Figures 3, 4 and 5). They show the results of the radiometric survey in Lebanon at the three selected and accessible areas.

Table 3. Results of the radiometric survey in Chekka area (North Lebanon).

Site No.	Coordinates		Gamma readings (Count/sec)		Geologic formation	Proposed element for uranium deposition
	Latitude	Longitude	Background	Site		
1	34° 15' 23"	35° 39' 31"	65	125	C_6/C_5	
2	34° 15' 11"	35° 39' 10"		110	C_6/m_2	
3	34° 15' 35"	35° 40' 02"		205	C_6	This formation (Senonian, C_6) is believed contain phosphate deposits of the shallow marine environment. The existing rocks show a Maastrichtian facies, which are well known in containing phosphate deposits in the neighboring regions.
4	34° 15' 17"	35° 40' 43"		220	C_6	
5	34° 16' 23"	35° 40' 04"	55	170	C_6	
6	34° 16' 17"	35° 40' 08"		265	C_6	
7	34° 16' 09"	35° 40' 11"		185	C_6	
8	34° 16' 48"	35° 40' 28"		90	C_6	
9	34° 16' 19"	35° 41' 35"		75	C_6/C_5	
10	34° 16' 36"	35° 41' 08"		80	C_6	
11	34° 17' 21"	35° 41' 11"	60	225	C_6	Existence of lignite and organic matter and anticipated phosphates.
12	34° 17' 10"	35° 41' 18"		95	C_6	
13	34° 16' 52"	35° 42' 01"	65	135	C_6	
14	34° 17' 32"	35° 41' 32"	55	145	C_6	
15	34° 17' 36"	35° 41' 18"		210	C_6	Existence of lignite and organic matter and anticipated phosphates.
16	34° 17' 21"	35° 42' 01"		165	C_6	
17	34° 17' 13"	35° 41' 50"		105	C_6	
18	34° 18' 02"	35° 42' 09"	80	95	C_6	
19	34° 17' 34"	35° 42' 15"		120	C_6	
20	34° 16' 56"	35° 42' 41"	65	135	C_6	
21	34° 18' 12"	35° 42' 39"	85	185	C_6	
22	34° 16' 32"	35° 44' 37"	60	140	C_6/C_5	
23	34° 16' 36"	35° 44' 28"		125	C_6	
24	34° 16' 20"	35° 44' 11"		105	C_6	
25	34° 16' 13"	35° 43' 51"		95	C_6	
26	34° 15' 42"	35° 44' 39"	115	210	C_6	
27	34° 15' 01"	35° 43' 14"		185	C_6/C_5	
28	34° 16' 16"	35° 44' 11"	95	175	C_6	
29	34° 16' 12"	35° 43' 17"	70	185	C_6	
30	34° 16' 18"	35° 43' 22"		180	C_6/C_5	
31	34° 16' 20"	35° 42' 44"	75	155	C_6	
32	34° 16' 31"	35° 43' 24"		150	C_6	
33	34° 16' 38"	35° 43' 16"		175	C_6	
34	34° 16' 27"	35° 43' 28"		140	C_6	

Table 4. Results of the radiometric survey in Mansourieh-Baábdat road.

Site No.	Coordinates		Gamma readings (Count/sec)		Geologic formation	Proposed element for uranium deposition
	Latitude	Longitude	Background	Site		
1	33° 51' 39"	35° 35' 28"	85	265	C_1	Sandstone as a source rock mixed with clay as reducing environment
2	33° 51' 37"	35° 35' 37"		325	C_1	
3	33° 51' 02"	35° 35' 38"		195	C_1	
4	33° 51' 09"	35° 35' 31"		305	C_1	Sandstone/clay contact
5	33° 51' 38"	35° 36' 03"	75	205	C_1	
6	33° 51' 12"	35° 35' 05"	70	200	C_1	
7	33° 51' 34"	35° 35' 27"		235	C_1/C_{2a}	Sandstone as a source rock at a contact with clay and organic matter as reducing environment
8	33° 51' 35"	35° 36' 08"		285	C_1	
9	33° 51' 33"	35° 36' 11"		305	C_1	
10	33° 52' 17"	35° 36' 18"	70	220	C_1/C_{2a}	Sandstone/clay contact
11	33° 52' 19"	35° 36' 20"		185	C_{2a}	
12	33° 52' 16"	35° 36' 41"		170	C_1	
13	33° 52' 49"	35° 36' 22"	105	285	C_1	
14	33° 51' 34"	35° 36' 19"		255	C_1	
15	33° 52' 16"	35° 36' 44"		300	C_1/C_{2a}	
16	33° 52' 17"	35° 37' 16"	90	285	C_1	
17	33° 52' 15"	35° 37' 19"		310	C_1	Clastic rocks and clay
18	33° 52' 21"	35° 37' 21"		255	C_1/C_{2a}	
19	33° 52' 13"	35° 37' 46"		260	C_1	
20	33° 52' 15"	35° 37' 43"		375	C_1	Sandstone as a source rock mixed with clay as reducing environment
21	33° 52' 14"	35° 37' 40"		380	C_1	
22	33° 52' 19"	35° 37' 23"		295	C_1	
23	33° 53' 28"	35° 37' 21"	75	210	C_1	
24	33° 53' 25"	35° 37' 40"		285	C_1	Lignite in contact with sandstone
25	33° 53' 22"	35° 37' 41"		220	C_1	
26	33° 52' 17"	35° 38' 31"	65	200	C_1	Organic matter and lignite with sandstone as a source rock
27	33° 52' 12"	35° 37' 40"		240	C_1	
28	33° 52' 14"	35° 39' 01"		165	C_1	
29	33° 53' 18"	35° 38' 27"	85	285	C_1	Sandstone/clay contact
30	33° 53' 11"	35° 38' 29"		240	C_1	
31	33° 53' 15"	35° 39' 05"		235	C_1	
32	33° 53' 10"	35° 39' 07"		220	C_1	
33	33° 53' 09"	35° 39' 33"	100	290	C_1	
34	33° 53' 16"	35° 40' 12"	95	310	C_1	Sandstone/clay contact and organic matter
35	33° 53' 13"	35° 40' 09"		265	C_1	
36	33° 53' 12"	35° 40' 11"		255	C_1	
37	33° 53' 18"	35° 40' 51"		234	C_1	
38	33° 53' 14"	35° 40' 53"		275	C_1	

For the promising sites (i.e., high radioactivity values), a preliminary interpretation of data was carried out on the existing rocks defining the lithologic and structural controls.

Though the radiometric survey is a preliminary ground investigation, it exhibited anomalous readings within different rocks types. Out of 126 sites, there are 34 (27%) that are anomalous sites.

The concentration of radioactivity is found to be within the sandstone formation of the Neocomian-Barremian (C_1) where 16 anomalies exist among the 38 sites. In addition, the values of the measures of radioactivity were higher than in the carbonate rocks of the Eocene (e) and Senonian rocks (C_6).

Table 5. Results of the radiometric survey in Saida- Zahran and Nabatieh area (South Lebanon).

Site No.	Coordinates		Gamma readings(Count/sec)		Geologic formation	Proposed element for uranium deposition
	Latitude	Longitude	Background	Site		
1	33° 36' 40"	33° 24' 38"	60	155	C_6	
2	33° 36' 05"	33° 24' 36"		140	C_6	
3	33° 36' 09"	33° 24' 35"	60	170	C_6	
4	33° 36' 13"	33° 25' 11"		135	C_6	
5	33° 35' 27"	33° 24' 32"	55	135	C_6	
6	33° 35' 31"	33° 25' 49"		140	C_6	
7	33° 34' 51"	33° 25' 42"		130	C_6	
8	33° 34' 49"	33° 25' 10"		195	C_6	
9	33° 34' 21"	33° 25' 18"		165	C_6	
10	33° 34' 20"	33° 25' 47"	70	235	C_6	Anticipated phosphate deposits
11	33° 33' 36"	33° 26' 32"		180	C_6	
12	33° 34' 08"	33° 26' 30"		160	C_6	
13	33° 33' 32"	33° 24' 12"		95	e	
14	33° 33' 35"	33° 24' 30"		105	e	
15	33° 33' 34"	33° 25' 10"		115	e	
16	33° 33' 01"	33° 25' 50"	40	100	e	
17	33° 33' 04"	33° 26' 24"		85	e	
18	33° 32' 25"	33° 27' 02"		70	e	
19	33° 32' 26"	33° 27' 01"		115	e	
20	33° 33' 31"	33° 26' 29"	55	185	C_6	Anticipated phosphate deposits near folded zone
21	33° 33' 06"	33° 24' 30"		195	C_6	
22	33° 32' 26"	33° 24' 31"		145	C_6	
23	33° 31' 50"	33° 25' 12"	60	110	C_6	
24	33° 31' 46"	33° 26' 25"		100	C_6	
25	33° 31' 10"	33° 23' 22"		95	C_6	
26	33° 33' 11"	33° 26' 23"	60	105	C_6	
27	33° 33' 13"	33° 25' 13"		70	C_6	
28	33° 30' 07"	33° 24' 35"		85	C_6	
29	33° 30' 08"	33° 25' 10"	65	135	C_6	
30	33° 30' 33"	33° 25' 12"		150	C_6	
31	33° 30' 32"	33° 25' 09"		135	C_6	
32	33° 28' 46"	33° 23' 23"		185	C_6	
33	33° 28' 43"	33° 22' 53"	80	275	C_6	Existence of glauconite and clay in and anticipated phosphates
34	33° 28' 41"	33° 22' 11"		155	C_6	
35	33° 28' 40"	33° 22' 13"		160	C_6	
36	33° 28' 53"	33° 23' 22"	80	285	C_6	Channel deposits as a trap in phosphate deposits
37	33° 28' 51"	33° 23' 23"		200	C_6	
38	33° 28' 08"	33° 24' 04"		205	C_6	
39	33° 28' 55"	33° 21' 35"	45	120	e	
40	33° 28' 11"	33° 22' 10"		110	e	
41	33° 28' 12"	33° 23' 21"		105	e	
42	33° 26' 26"	33° 21' 37"		125	C_6	
43	33° 26' 27"	33° 21' 34"	55	170	C_6	Anticipated phosphate deposits with fissure system
44	33° 26' 25"	33° 21' 32"		185	C_6	
45	33° 26' 24"	33° 22' 10"		130	C_6	
46	33° 25' 11"	33° 21' 00"		185	C_6	Anticipated phosphate deposits
47	33° 25' 08"	33° 22' 03"	60	150	C_6	
48	33° 24' 39"	33° 21' 34"		165	C_6	
49	33° 25' 49"	33° 27' 33"	55	155	C_6	
50	33° 25' 51"	33° 28' 42"		140	C_6	
51	33° 21' 35"	33° 25' 50"		185	C_6	
52	33° 21' 39"	33° 26' 25"	70	245	C_6	Existence of glauconite and anticipated phosphates
53	33° 21' 34"	33° 27' 01"		230	C_6	
54	33° 21' 33"	33° 27' 39"		170	C_6	

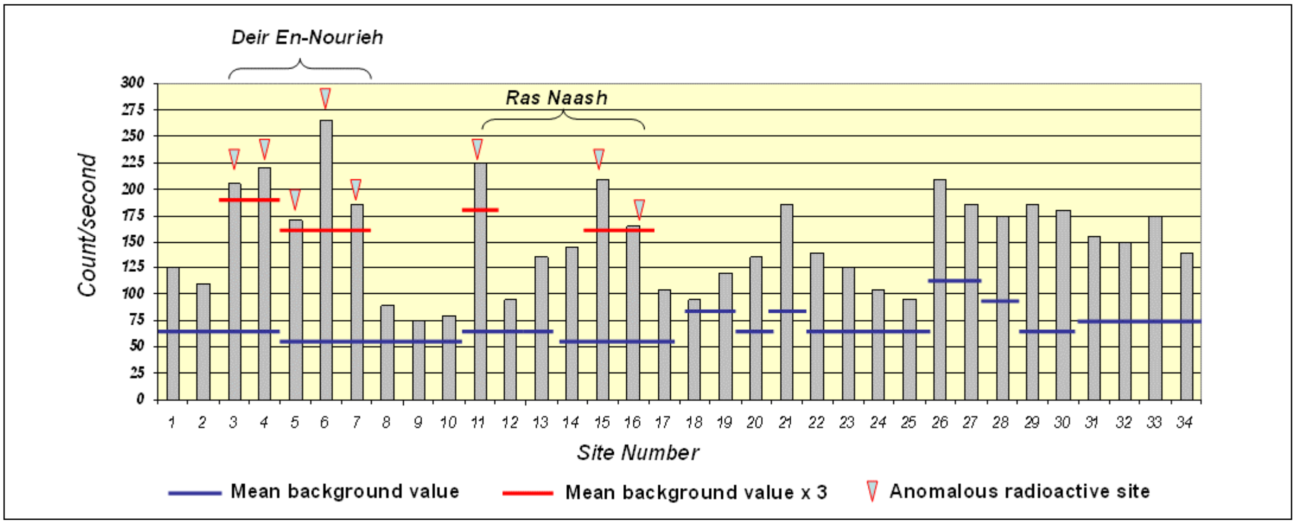

Figure 3. Graphic presentation of the radiometric survey in Chekka area showing the anomalous radioactive sites.

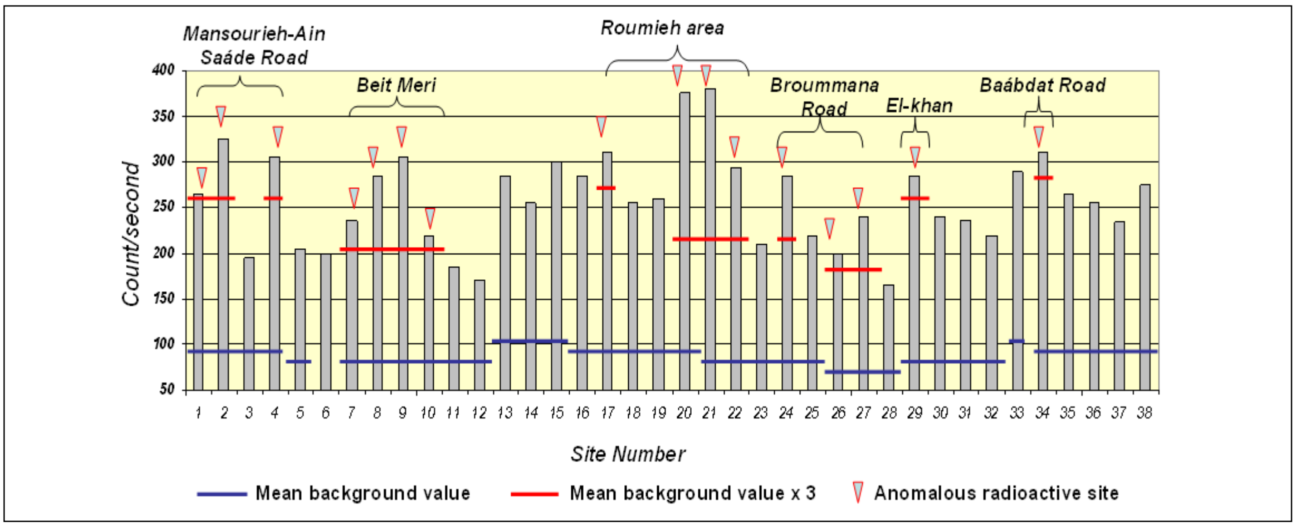

Figure 4. Graphic presentation of the radiometric survey in Mansourieh-Baábdat road, showing the anomalous radioactive sites.

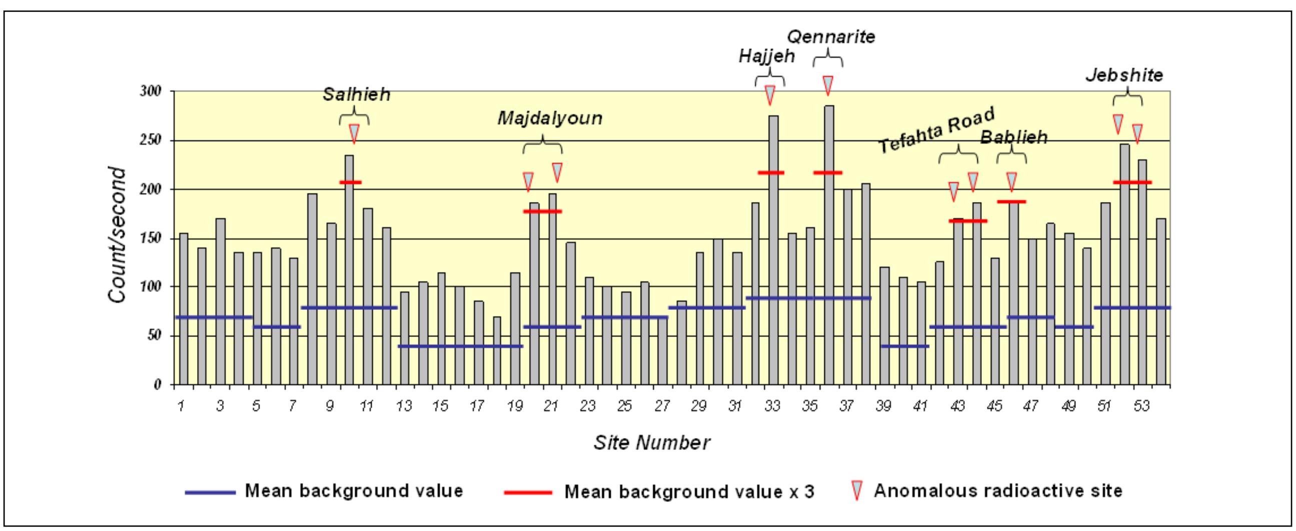

Figure 5. Graphic presentation of the radiometric survey in Saida-Zahrani and Nabatieh, showing the anomalous radioactive sites.

There is a continues concentration of radioactivity within the sandstone rocks over the measured traverse. High values of radioactivity were recorded in the carbonate rocks. The concentration of radioactivity is dominant in sandstone and restricted to specific sites of the marly rocks.

From the interpretation of the data, it was clear that the role of the reducing environment is effective in concentrating radioactivity. Higher values often occur where clay, shale, organic matter, and lignite.

To conclude, there is a significant radioactivity in all prospect areas. This clearly coincides with the type of rock formation and favorable conditions for uranium ore deposition, thus suggesting the existence of uranium minerals in these rocks. A detailed study is highly recommended to include a large geographic area of Lebanon.

Our study recommendations are as follows:

1. A grid radiometric survey is preferable, since a traverse survey may miss optimized sites.

2. Application of radiometric survey among the basaltic rocks is highly recommended, notably where dykes and veins exist.

3. Optical and petrographic analysis for phosphate deposits should be carried out to confirm the geologic relation of Lebanon to the Mediterranean phosphate belt.

4. gamma-ray spectrometer analysis or X-ray diffraction must be undertaken to identify and confirm the type of the radioactive anomalies.

5. Deep (excavated) sites for radioactive surveys must be included, since overburden rocks can hide radioactivity.

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