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Radioactive characterization of Ar-Rassafeh Badyieh area (Area-2), Syria by using Statistical factor analysis technique

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Abstract: A scored lithological map including nine litho-factor units is established through applying the statistical factor analysis technique (SFAT) to aerial spectrometric data of Area-2 (Al-Rassafeh Area), which includes T.C, eU, eTh, K, eU/eTh, eU/K, and eTh/K. A model of four rotated factors F1, F2, F3, and F4 is adapted for representing 61712 data measured points in Area-2, where 90.3% of total data variance is interpreted. The isolated lithological units related to F1, F2, and F3 are characterized by an eU average of 2.15, 0.99, and 1.57 ppm respectively. Two geological scored pseudo-sections derived from the lithological scored map are established and analyzed in order to show the mutual environmental geological relationships between different lithological isolated units. This scored map will be the base for further geological investigations in Area-2. SFAT has proven its efficacy in the research study Area-2, and allowed the different isolated sectors to be characterized and interpreted geologically and radioactively.

Key words: Statistical factor analysis technique (SFAT), aerial spectrometry survey, stratigraphic, Al-Rassafeh area, Syria, environmental features

1. Introduction

Airborne gamma-ray spectrometric survey is one of the most important geo-exploration techniques oriented for uranium prospecting (*Hambleton-Jones et al., 1984*). This gamma spectrometric survey has been essentially oriented towards defining radioactive anomalies related to uranium mineralization. It can be also employed for investigating of other useful minerals and sometimes subsurface hydrocarbon accumulations (*Selley, 1998*). The gathered data of such a spectrometric radioactive gamma survey can be efficiently used for characterizing geological, structural and geochemical environment factors (*Aissa and Jubeli, 1997*), where it is possible to categorize the rock units in the study area, based on their radioactive responses.

The present paper concentrates on the application of the advanced statistical factor analysis technique (SFAT) on the aerial gamma spectrometric data of study area for clarifying more in details the radioactive geology and environmental features observed in the study area (Fig. 1).

A scored lithological map is established herein with its geological units, on which the radioactive anomalies observed in study area are identified.

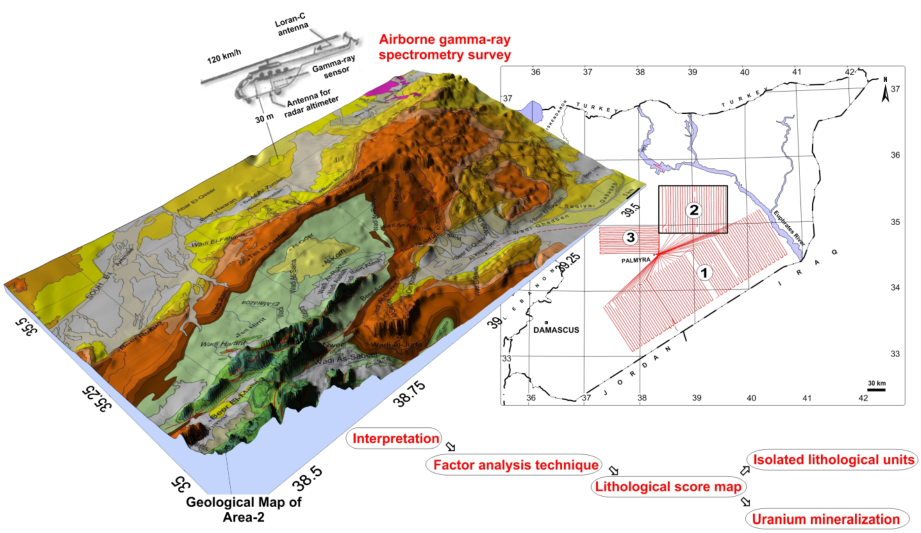

Fig. 1: Description of the study area and the investigation procedure scheme.

2. Object of study

The main objectives of this paper are therefore the following:

1. Asses the level of radioactivity TC, eU, eTh, and K, and determine the radioactive relationships with the geological and geochemical environments in the study region. The study region is particularly a very rugged terrain, where we ignore and have only a little information about its geology. A detailed field geological investigations are therefore extremely required. Such needed geological works are not actually an easy task to be carried

out in the near future, due to the present Syrian difficult conditions. The spectrometric gamma survey and its available data is therefore a powerful tool, and can be used for geologically characterizing the study region. Its application in the study replaces temporarily the field geological works, and remedies consequently the scarcity of geological information of the mentioned region.
2. Transfer the available geological map of the study into different isolated scored lithological units.
3. Analyze the mutual relationships between the different lithological isolated scored units at the light of available geology.
4. Interpreting the distinguished lithological scored units at the light of the available geology.

The first two objectives are achieved in the present research through the following:

1. Reinterpreting the aerial spectrometric gamma by applying SFAT.
2. Establishing the lithological scored map, with its different lithological units.

3. Area of study

The airborne gamma spectrometric technique was undertaken in Syria during a project conducted in 1987 in cooperation with the International Atomic Energy Commission and Riso National Laboratory SYR/86/005 (*Riso, 1987; Jubeli, 1990*).
This airborne survey was carried out in the following areas (Fig. 2A):

1. The Syrian Desert (Area-1) (7189 line km at 4 km line spacing).
2. Ar-Rassafeh Badyieh (Area-2) (2240 line km at 4 km line spacing).
3. The Northern Palmyrides (Area-3) (1600 line km at 3 km line spacing).

Fig. 2B shows the Syrian areas surveyed by airborne gamma-ray spectrometry, and the total radiometric map (T.C).

The present paper is concentrated on characterizing the radioactive behavior of Ar-Rassafeh Badyieh (Area-2) by using SFAT.

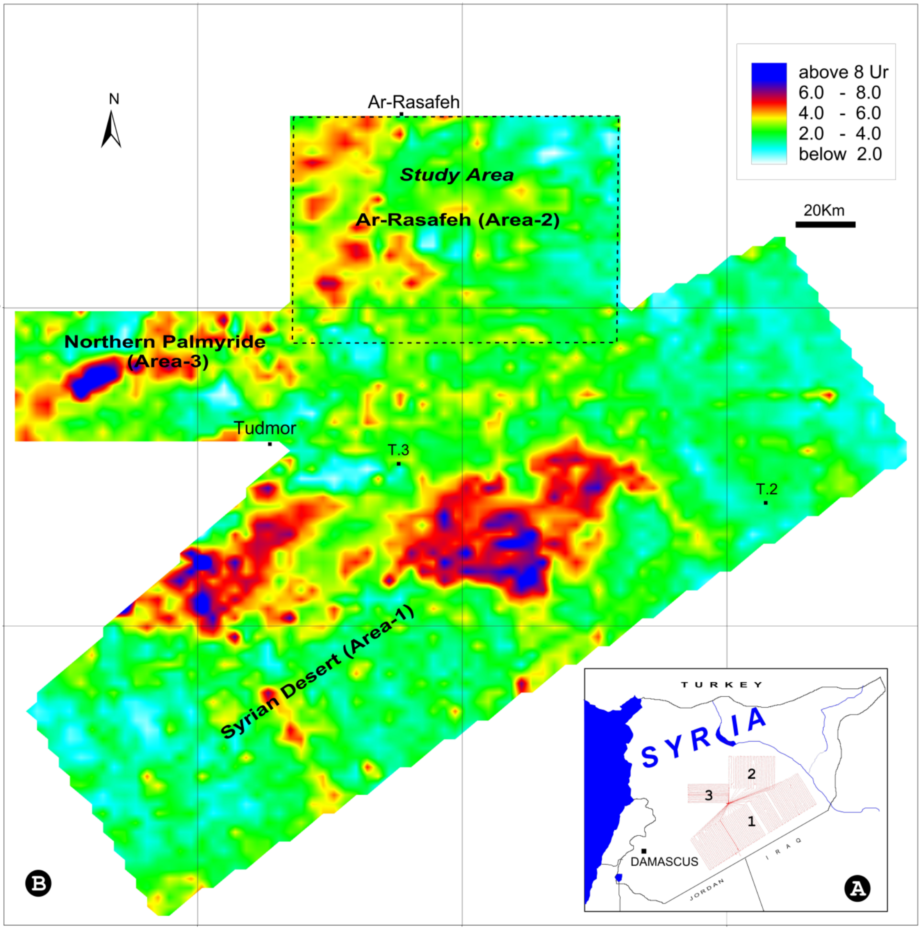

Fig. 2. (A) Total areas covered by airborne gamma-ray spectrometry in Syria. (B) Radiometric map resulting from spectrometric survey.

3.1. General Setting of the study area (Area-2)

Topography

The study area is considered as a transition zone between the low-mountain and the flat country. This mountain series form the northern limit of Palmyride range (Jabal AL-Bishri), the relief grades east, northeast and southeastwards flood- plains, until it declines to Al-Furat river course in the north-east direction (out of the study area). The undulate sloping flood-plains are cut by many erosional valleys, where some of them are tectonogenetic (*Technoexport, 1966; JICA, 1996*).

Stratigraphy

Cretaceous, Paleogene litho-facies crop-out, while the Neogene and Quaternary sediments cover vast area of wadis and low-lands and flood- plain terraces of the studied territory, Fig. 3.

Cretaceous system: The Cretaceous litho- facies are mainly represented by carbonate, marly- clayey limestone, dolomitic limestone, ferruginous sandy limestone organic limestone, phosphate with remnants of fish bones, and flint concretions and bands, sometimes bituminous limestone intercalations, Fig. 3.

Paleogene system: the boundary between Cretaceous and Paleogene litho-facies is not prominent. Paleogene outcrops are zonally distributed in the studied territory. It is dominated by the carbonate litho-facies such as clayey limestone, sandy limestone with bitumen occurrences, dolomite, organic limestone, chalky-like limestone, marl, glauconitic- phosphate beds and flint, which are occurred in most of the cross-sections of the studied territory. Those facies denote the palio- shoreline and deltas within littoral zone, Fig. 3.

Neogene system: Cover vast tracts of the marginal plains adjacent of Al-Bishri anticline. The lithofacies of Neogene (*Technoexport, 1966; JICA, 1996*) denote a continental conditions start with sandy-clayey silt, conglomerates and sandstone with carbonate cement, breccia-like limestone, organic limestone, and dolomite with bitumen and gypsum alternations, Fig. 3.

Quaternary and recent system: Eluviation, eolian sands, pebbles of various genetic types and evaporates (*JICA, 1996*), Fig. 3.

Tectonic

The study area is located in the mobile part of Arabian platform slope in the northern marginal zone Palmyride folding system (*Dill, 2009; Technoexport, 1966*) (Fig. 3).

The study area is characterized as block folds, brachy-coffer anticlines, depressions, and regional deep faults. The Palmyride folding system is complicated by deep regional faults, which take north-eastern trend (*JICA, 1996;*

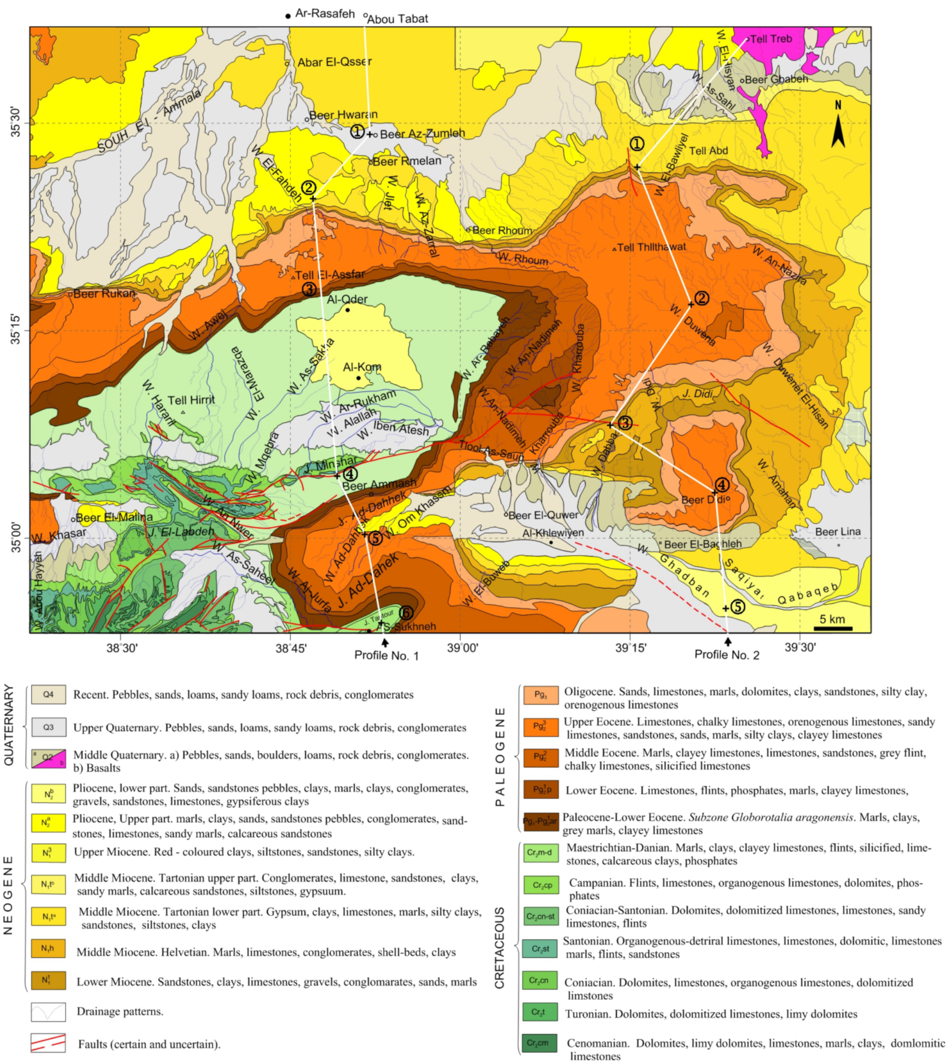

Fig. 3. Geological map of Ar-Rassafeh Badyieh (Area-2).

Litak et al., 1998). Faulted-flexures are also accompanied with coffer fold-axis. Most of those mentioned structural features are not marked at the surface, but inferred from geophysical data.

4. Methods of study

4.1. Aerial Gamma Spectrometric Technique

An airborne gamma-ray survey was carried out during 1987, over the Ar-Rassafeh Badyieh Area (Area-2) situated north of Syrian desert in the region between the northern Palmyrides in the south-west and the Euphrates in the northern and east. Area-2 were covered by 28 north-south oriented aerial survey lines. Those lines are of 80 km long, and spaced by 4 km, Fig. 2A. The typical survey speed was of 120 km/hr in a nominal survey, and the height was of 30 meters. A system of compact, lightweight, four-channel gamma-ray spectrometer, (GAD-6, Scintrex, Canada), with a detector of 12.5 litres NaI(Tl) volume has been used for conducting this aerial survey. The energy windows used in the four-channel gamma-ray spectrometer are shown in Table 1. The system calibration took place at the calibration pads at the Dala airport in Sweden (*Riso, 1987*). An IGI Loran-C navigation system was used to provide efficient flight path control. Potassium, uranium, thorium, and total gamma-ray counts were recorded over one-second intervals and stored on data tape together with the actual distance to the ground measured with a radar altimeter.

The raw data were corrected for background effects and the applicable interchange, Compton corrections. In addition, the exponential attenuation factors for height corrections were established (*Riso, 1987*).

Table 1. Range of energy with spectral windows used in airborne survey.

Window	Airborne Radiometric Survey (Mev)	Mainly Radioisotope
Potassium	1.38–1.56	K^{40}
Uranium	1.66–1.90	Bi^{214}
Thorium	2.44–2.77	Tl^{208}
Total-Count	0.40–2.77	–

4.2. Statistical Factor Analysis Technique (SFAT)

The aerial spectrometric data of the Ar-Rassafeh Badyieh (Area-2) have been subjected to a quantitative statistical factor analysis technique to establish lithological scored map for the study area with its various isolated lithological units. Using SFAT, a system of new factors is obtained through transforming the origin data of seven radiometric variables measured in the study area (T.C, eU, eTh, K, eU/eTh, eU/K, and eTh/K). Those new factors are constrained to reproduce as much as possible the total variance of the origin data. Each original data point gains factor score, representing the affiliation of the samples to the newly defined factors. The plotting of these new factor produces a set of new maps. The new maps are qualitatively compared with the available geological map to extract the most important geological characteristics of the study area. This step serves as a tool in reinterpreting the data to provide direct differentiation of all the lithological units depending on the established lithological scored map and its reflection on the environmental aspects.

5. Results and discussion

Single and bivariate statistical analysis techniques are applied to the aerial gamma-ray spectrometric data related to Area-2, to characterize the seven radiometric variables as shown in Table 2. It was found that gamma-ray anomalies are mainly associated with phosphate deposits and encountered at adjoining parts of hydrocarbon fields in Syrian desert (*Jubeli et al., 1997*). The eU varies in Area-2 between a minimum of 0.16 ppm and a maximum of 13.61 ppm, with an average of 1.59 ppm and a standard deviation σ of 0.95 ppm. Higher values of uranium more than 3.50 ppm in the study area are considered as anomalous eU values, by adapting the threshold concept of $\overline{X} + 2\sigma$ (*Asfahani et al., 2009; Gavshin et al., 1974*).

Uranium also exhibits a relatively high value of coefficient of variability CV (59.75%), in comparing with those of eTh (33.9%) and K (34%). The high CV value for uranium is due to the higher mobility of the uranium as compared to eTh and K, which are characterized by higher stability under the same conditions, (*Asfahani, 2002; Asfahani et al., 2005; 2007; 2010*). The eTh varies in Area-2 between a minimum of 0.16 ppm and a maximum of 9.28 ppm, with an average of 3.39 ppm and a standard deviation σ of 1.15 ppm. The K varies in Area-2 between a minimum of 0.02 and a maximum of 0.85, with an average of 0.26 and a standard deviation σ of 0.09.

Table 3. shows the bivariate correlation analysis results and the correlation coefficients between the seven radiometric variables obtained while interpreting the data of Area-2.

Table 2. Statistical characteristics of the 7 radioactive variables in Area-2.

Variable	T.C	K (%)	eU (ppm)	eTh (ppm)	eU/eTh	eU/K	eTh/K
Case number	61712	61712	61712	61712	61712	61712	61712
Min	0.23	0.02	0.16	0.16	0.024	0.33	1.17
Max	17	0.85	13.61	9.28	25.79	446	185
$\overline{X}$	4.55	0.26	1.59	3.39	0.57	7.15	14.1
σ	1.36	0.09	0.95	1.15	0.57	7.11	6.28
CV	29.9	34	59.75	33.9	100	99	44.5
$\overline{X}+2\sigma$	7.27	0.44	3.50	5.69	1.71	21.4	26.7

$\overline{X}$ – Mean, σ – Standard deviation,
CV – Coefficient of variability ($= \frac{\sigma}{\overline{X}} \cdot 100$).

Table 3. Correlation matrix of seven radiometric variables in Area-2.

Variables	**T.C**	**K**	**eU**	**eTh**	**eU/eTh**	**eU/K**	**eTh/K**
T.C	1						
K	0.61	1					
eU	0.68	0.04	1				
eTh	0.45	0.56	–0.16	1			
eU/eTh	0.27	–0.22	0.74	–0.52	1		
eU/K	0.21	–0.41	0.67	–0.34	0.68	1	
eTh/K	–0.2	–0.49	–0.16	0.29	–0.24	0.26	1

This correlation matrix shows a cluster of positive correlation between T.C and K (0.61), eU (0.68) and eTh (0.45). Positive correlation has also been found between K and eTh (0.56).

The above matrix is used to obtain seven un-rotated loading factors, which are difficult to be interpreted in geological terms. It is therefore necessary to rotate these seven factors to another form equivalent to the original un-rotated matrix. This rotation is achieved by using the varimax method to maximize the discriminability of the factors (*Comery, 1973*). The system of seven un-rotated factors are consequently reduced to only four principals factors F1, F2, F3 and F4 without losing significant information. In other words, varimax method allows a reduction from the original data system of seven dimensional factors into four interpretable principal factors (F1, F2, F3 and F4).

The results of this rotation are shown in Table 4. The four rotated factors are quite interpretable and represent 90.26% of the total system information, which is sufficient to interpret the variable data of Area-2 as shown in

Table 4. Eigen value of four rotated factors in Area-2.

	Eigen value	Total variance, %	Cumulative eigen value	Cumulative, %
F1	2.43	34.74	2.43	34.74
F2	1.93	27.57	4.36	62.31
F3	1.83	26.12	6.19	88.44
F4	0.128	1.83	6.32	90.26

Table 5.

The factor score coefficients shown in Table 6 are used to construct the three standard factor scored maps for F1, F2 and F3, for Area-2 as shown in Figs. 4, 5 and 6. F4 was not constructed because of its small eigen value of 0.128 from one side, and no clear geological significance is evident to be related with this factor from other side.

F1 explains 34.74% of the total variance, and has high loading values of 0.93, 0.82, and 0.85 for the variables of eU, eU/eTh, and eU/K respectively. This factor is therefore composed of those three variables and directly related to the uranium presence in the phosphorite of Cretaceous and Paleogene ages, outcropped in Area-2, Fig. 3 and Fig. 4, (*Slansky, 1986; Dill,*

Table 5. The four rotated factors in Area-2.

Variables	F1	F2	F3	F4
T.C	0.5	–0.13	0.798	0.15
K	–0.16	–0.48	0.799	–0.07
eU	0.93	–0.087	0.2	0.2
eTh	–0.33	0.31	0.82	0.029
eU/eTh	0.82	–0.2	–0.22	0.0005
eU/K	0.85	0.31	–0.17	–0.27
eTh/K	–0.064	0.98	–0.04	–0.03

Table 6. Factor score coefficients for Area-2.

Variables	F1	F2	F3	F4
T.C	0.155	0.036	0.46	0.213
K	–0.058	–0.128	0.387	–0.62
eU	0.46	0.04	–0.015	1.028
eTh	–0.099	0.124	0.34	–0.09
eU/eTh	0.103	–0.034	–0.06	–0.02
eU/K	0.39	0.059	0.02	–1.34
eTh/K	–0.036	0.87	0.12	0.25

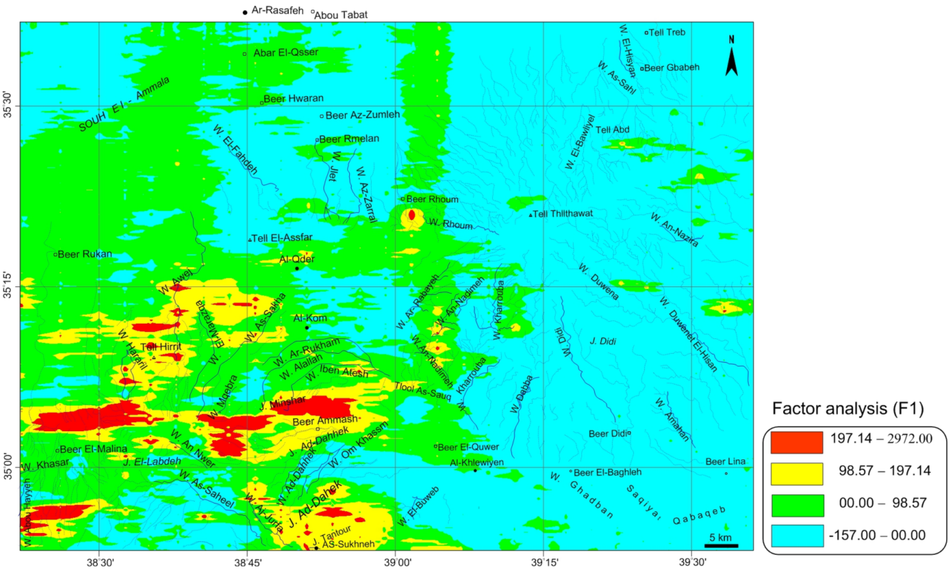

Fig. 4. Score map of F1 in Ar-Rassafeh Badyieh (Area-2).

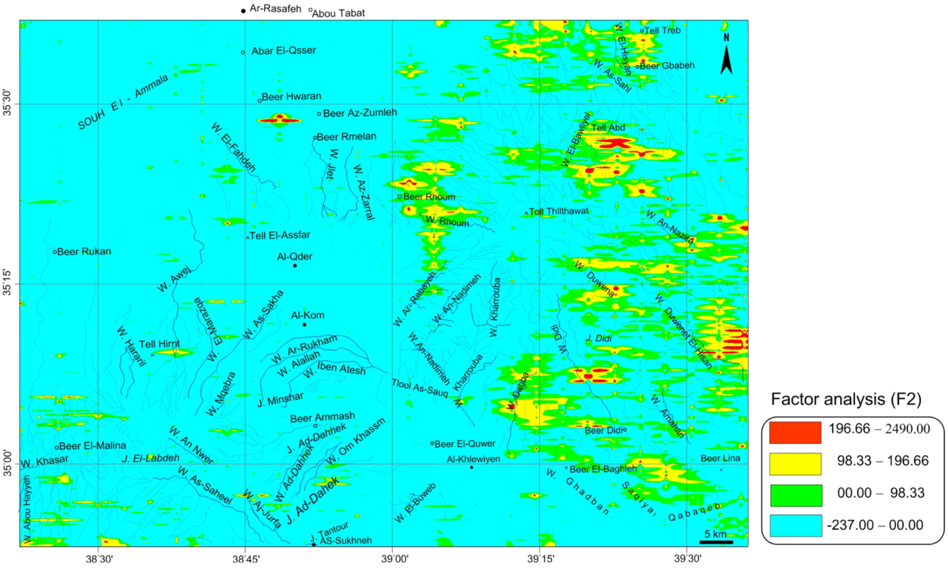

Fig. 5. Score map of F2 in Ar-Rassafeh Badyieh (Area-2).

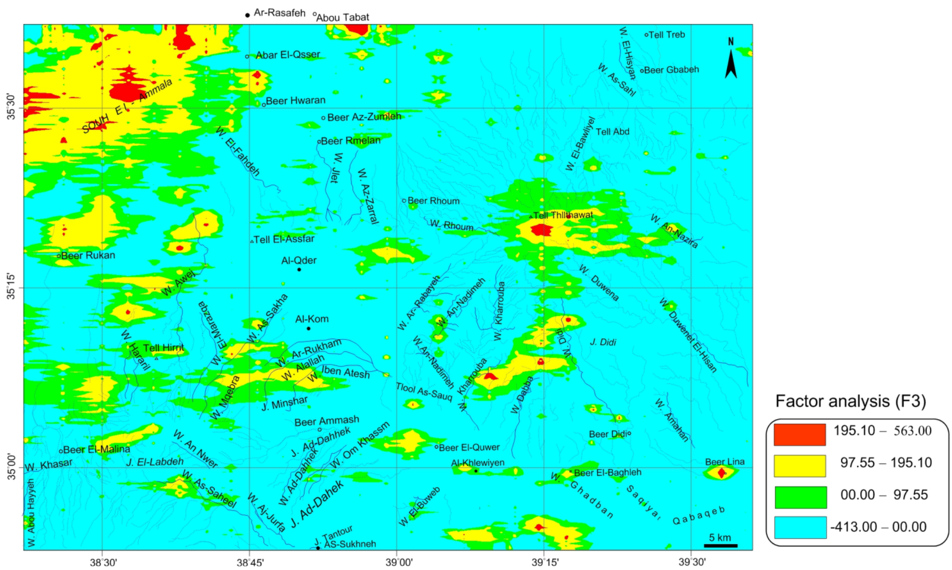

Fig. 6. Score map of F3 in Ar-Rassafeh Badyieh (Area-2).

2009). It is therefore called as *phosphate-uranium factor*.

The secondary uranium mineralizations are mostly concentrated along the marginal-faulted zones of the brachi-form anticline at the adjoined outcropped limits between late Cretaceous and lower Paleogene phosphatic and silicious rocks. The F1 factor shows a significant relationship between phosphate lithofacies and secondary uranium mineralizations, where the upward leaching and erosional loads drop along the marginal parts of active tectonic zones (*Wescott and Ethridge, 1980; Iilende, 2012*).

F2 explains 27.57% of the variability of geophysical data. It is negatively loaded for the K variable (–0.48), and positively for eTh/K (0.98). It is related to the facies, which are mostly composed of surficial washing and abrading products, characterized by prevailing of clayey facies, as marly clay, organic limestone, sandy limestone, sandy clay, sandy varieties intercalated with clayey limestone, silty clay, phosphorite and glauconite sands belonging to the Lower and Middle Paleogene, Fig. 3 and Fig. 5, (*Technoexport, 1966*). It is called as *littoral paleo-delta and alluvium fans factor*.

F3 explains 26.12% of the data variability, and is highly loaded with K (0.799) and eTh (0.82). This factor is related to the flood-closed basins, evaporation pans, bitumen appearances, and paleo-channels of tectonic origin, Fig. 3 and Fig. 6, (*Heath et al., 1984; Dickson, 1984; Al-Kawaz and Aljubouri, 2006*). F3 is called as *closed seasonal basin factor.*

F4 explains only 1.83% of the data variability, and is difficult at this stage for F4 to be geologically interpreted.

Table 7 shows that F1 is the highest in eU in comparing with F2 and F3. The eU in the area dominated by F1 varies between 0.16 and 13.6 ppm with an average of 2.15 ppm. The area dominated by F2 and F3 are characterized by comparable values of eTh and K, which are higher than those related to area dominated by F1. The eTh in the area dominated by F2 varies between 0.24 and 8.57 ppm with an average of 3.35 ppm. The K in the area dominated by F2 varies between 0.02 and 0.75 with an average of 0.24. The eTh in the area dominated by F3 varies between 0.16 and 9.28 ppm with an average of 3.70 ppm. The K in the area dominated by F3 varies between 0.04 and 0.85 with an average of 0.30.

Table 7. Statistical characteristics of the 4 radioactive variables for F1, F2 and F3 in Area-2.

	F1				F2				F3			
Variables	Min.	Max.	Mean	σ	Min.	Max.	Mean	σ	Min.	Max.	Mean	σ
T.C	0.23	17.11	4.93	1.43	0.56	7.38	3.67	0.88	0.54	12.02	4.86	1.31
K	0.02	0.63	0.24	0.08	0.02	0.75	0.24	0.07	0.04	0.85	0.30	0.10
eU	0.16	13.61	2.15	1.17	0.16	4.04	0.99	0.51	0.16	4.58	1.57	0.68
eTh	0.17	6.94	2.80	1.01	0.24	8.57	3.35	0.97	0.16	9.28	3.70	1.18

A scored lithological map is constructed through the comparison and matching between the established scored maps of F1, F2 and F3 (Figs. 4, 5 and 6) and the available geological map of the study area (Area-2) (Fig. 3) as shown in Fig. 7.

The established lithological scored map includes nine litho-factor units, described as presented in Table 8. Table 8 shows the ranges of the standard factor scores (F1, F2 and F3), that characterize the geological units of Area-2, and the litho-factor description of those units.

Geological field observations gathered during surfacial radiometric surveys project and lithological comparative columnar sections of (*Technoexport, 1966*) are used as a support to study two selected profiles (Profile No. 1 and Profile No. 2) located and shown in Figs. 3 and 7.

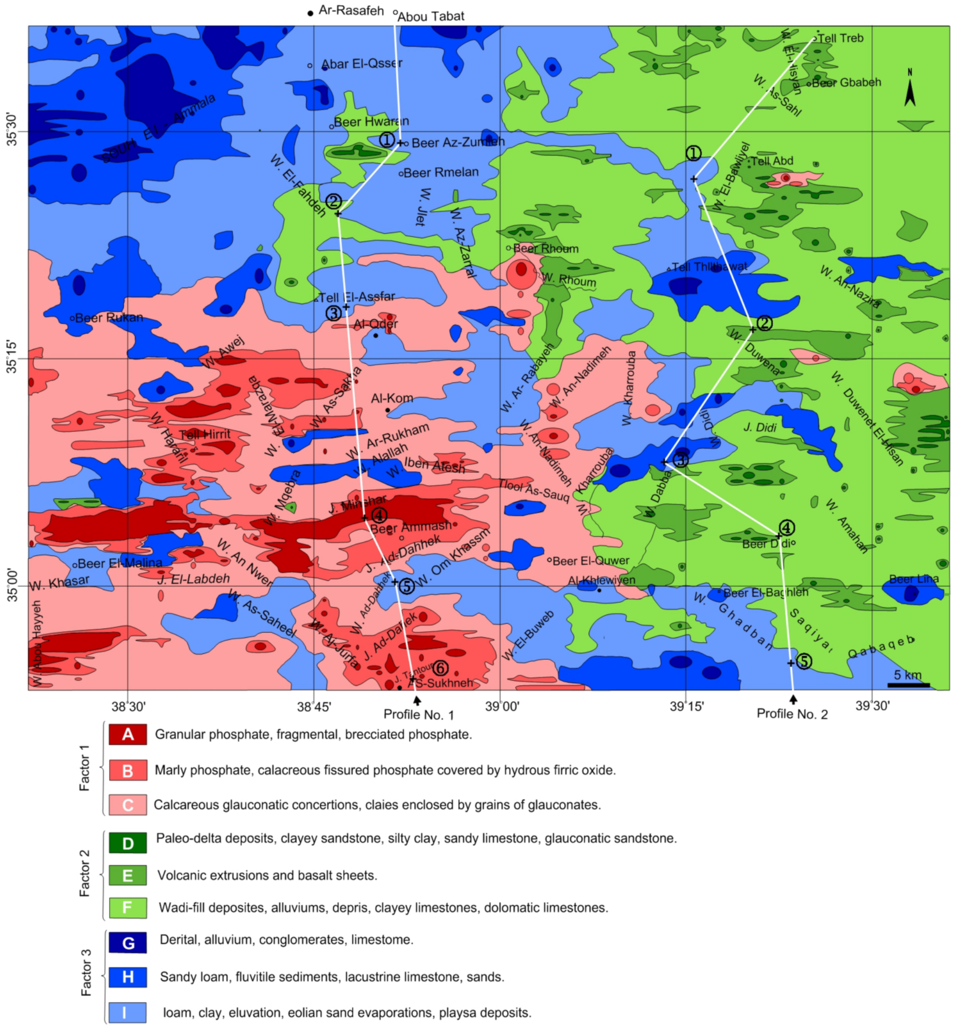

Fig. 7. Radiometric lithological scored map of Ar-Rassafeh Badyieh (Area-2).

The study of those two profiles is to delineate the phosphate sequences and to define favorable litho-facies for secondary uranium accumulation, and to delineate the subsurface structures. Those structures could be as significant structural and litho-stratigraphic traps, that must be localized for more geological details, Figs. 8 and 9.

Mutual geological relationships between the above distinguished nine lithological units (Table 8) along those two Profile No. 1 and Profile No. 2 have been analyzed, interpreted and discussed.

Profile No. 1: traverses through the core of brachi-form anticline of Cretaceous rocks, and passes through the faulted zone of the northern and southern flank of the anticline, Fig. 3. The pseudo-section drown along Profile No. 1 represents mostly the litho-factor units of F1, which reflect the secondary uranium mineralizations in phosphate beds of Upper Cretaceous rocks, Fig. 8. The other two factors F2 and F3 occupy the rest of the northern flank of the brachi-anticline and the adjacent plains related to Paleogene, Neogene and Quaternary, Fig. 8. The F2 and F3 litho-facies are characterized by prevalence of shallow marine environment and grade into lagoonal facies to paleo-delta and shore-line.

Profile No. 2: traverses through the eastern plunged flank of uplift (Al-Bishri), Fig. 3. The litho-facies along Profile No. 2 pass gradually from the

Table 8. Standard factor scores of the nine litho-factor units in Area-2.

Factor	Rock units	litho-factor range		Litho-facies description	Notices
F1	A	> 197.14		Granular phosphate, fragmental, brecciated-phosphate.	F1 is called as phosphate-uranium factor.
	B	98.57	197.14	Marly phosphate, calcareous- fissured phosphate covered by hydrous ferric oxide.	
	C	< 98.57		Calcareous glauconatic concretions, calcite- grains enclosed by glauconite.	
F2	D	> 196.66		Paleo-delta deposits, clayey sandstone, silty clay, sandy limestone, glauconatic sandstone.	F2 is called as littoral, paleo-delta and alluvium fans factor.
	E	98.33	196.66	Volcanic extrusions and basalt sheets.	
	F	< 98.33		Valley- fill deposits, alluviums, debris, clayey limestone, dolomatic limestone.	
F3	G	> 195.10		Detrital, alluvium, conglomerates, limestone.	F3 is called as closed seasonal basin factor.
	H	97.55	195.10	Sandy loam, fluvial sediments, lacustrine limestone, sands.	
	I	< 97.55		loam, clay, eluviation, eolian sand evaporates, and playa deposits.	

littoral zone to continental environments to turn finally into semi-closed seasonal basins, Fig. 9. The established scored pseudo-section of Profile No. 2 mainly shows the litho-facies related to F2 and F3, with the clayey-silty lacustrain carbonate and evaporates domination.

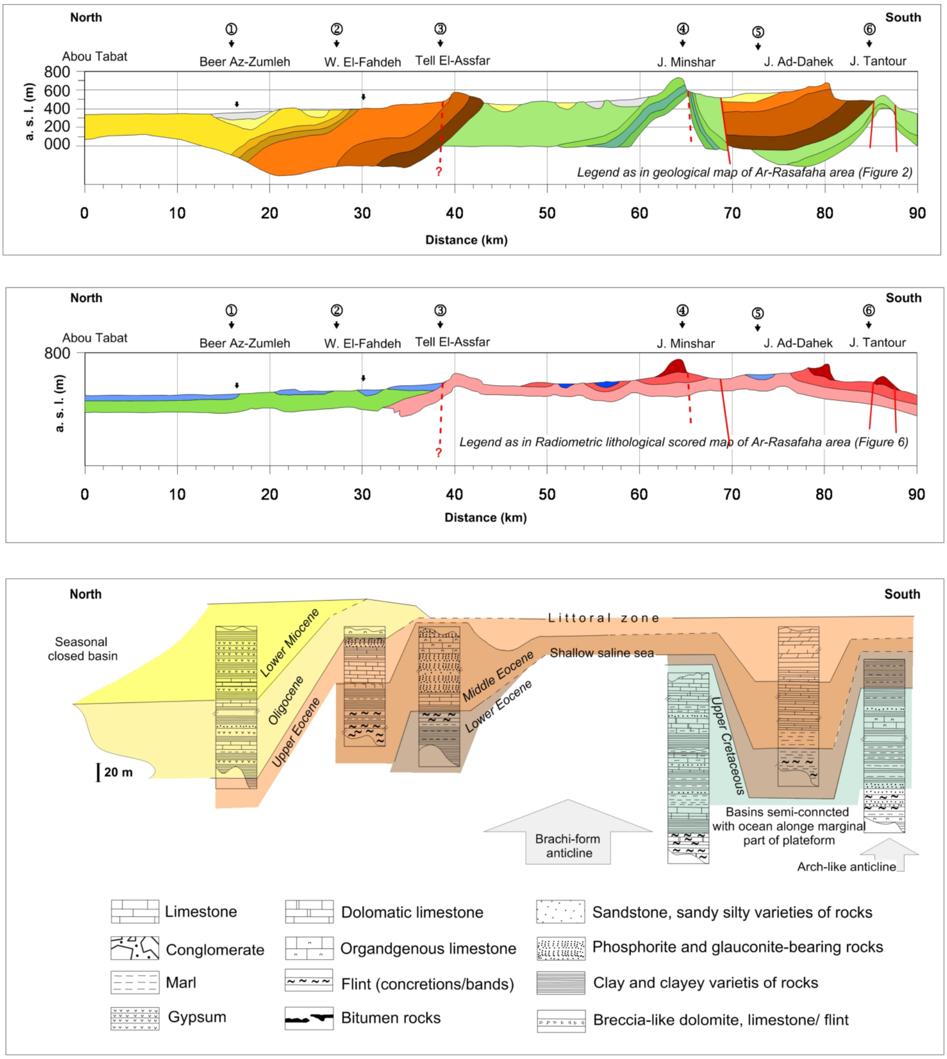

Fig. 8. Pseudo-section profile. No. 1 passing by different distinguished litho-factor units.

The faults indicated in Figs. 8 and 9 play in addition to litho-facial structure an important role in increasing radioactivity. Their evident role is shown in SW direction of profile No. 1, where high radioactivity is noticed. In fact, such an observed radioactivity is due to the uranium mobilization caused by ascending of solutions flows through those faults. In the other side, the role of the faults indicated in the other parts of the study area particularly in NE direction (Fig. 9) is limited because of two reasons; firstly

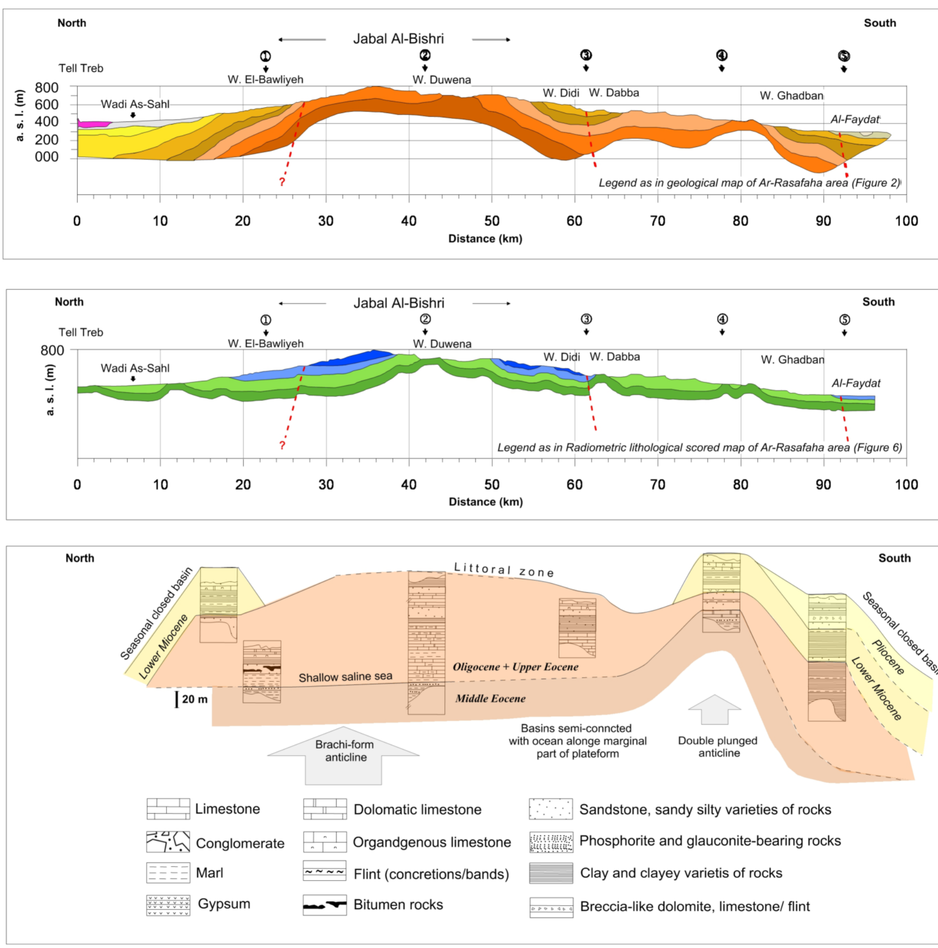

Fig. 9. Pseudo-section profile. No. 2 passing by different distinguished litho-factor units.

those faults may be buried under sediments cover of Neogene deposits, and secondly the superficial leaching is more prevailed than the deep- ascendant solution leaching.

The study and analysis of those two profiles give important geological insights on the geology of the study area. Those insights will be efficacy exploited when detailed field geological and geochemical mining investigations will be carried out.

6. Conclusions

Statistical factor analysis technique (SFAT) is applied in this research for interpreting aerial spectrometric data of Area-2 in Syria. The different obtained results in this paper are mainly oriented toward understanding the mutual relationships between different lithological units localized in a complicated geological area. The areas dominated by the resulting rotated three factors F1, F2, and F3 have been radioactively characterized for the parameters of T.C, eU, eTh, and K. Lithological scored map containing nine litho-factor units has been established through applying SFAT. The characteristics of those litho-factor units have been described through interpreting the established radioactive factors maps of F1, F2, and F3. Those defined litho-factor units will be the base for further geological and environmental investigation in Area-2. Two geological scored pseudo-section profiles (Profile No. 1 and Profile No. 2) have been selected and analyzed to show the mutual geological- environmental relationships between the different isolated lithofacies. SFAT has demonstrated its capability in dividing the study area to different isolated environments, where each one is characterized by its specific geology and radioactivity. The SFAT enables geophysicists to quickly establish radiometric maps with a least amount of subjectivity. This advanced statistical technique is therefore recommended to be applicable in dealing with other huge aerial spectrometric data related to other regions. SFAT tool has a strong potential in both geological and environmental mapping and locating areas of radioactive anomalies. The acquired knowledge of this paper will be potentially employed later, when detailed geological and geochemical mining investigations are lanced for radiometric and other useful elements prospecting.

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