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A Geostatistical Study of Gamma Radioactivity at Some Anomalous Localities in Qatar Peninsula, The Arabian Gulf

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Abstract. Reconnaissance airborne radiometric survey of Qatar Peninsula revealed a number of radiactive features. Ground geologic and radiometric investigations led to the localization of some twenty anomalies having radioactive intensities ranging from 21 cps up to 615 cps, while the background radioactivity varies between 8 and 18 cps.

This paper deals with a statistical analysis of 1994 readings of field measurements of gamma radioactivity of the various lithologies at the twenty anomalous localities. It has been found that these radioactive anomalies are associated mainly with four different lithologies namely: sabkha deposits, depression silts, wadi (alluvial) deposits and Lower Dam marly limestones.

Geostatistically, the recorded radioactive anomalies in Qatar Peninsula can be grouped into two main types. The first and more significant type is characterized by a sharp peak, and it comprises most of the anomalies in sabkha deposits. The second type displays a broad anomalous zone, and it includes all other anomalies which represent lithologic anomalies due to the relatively higher natural radioactivity of their host materials with respect to the surroundings.

Introduction

During March 1978, a regional airborne radiometric investigation was conducted for the first time in Qatar Peninsula by Geoterrex Ltd., Canada, as a subcontractor to Seltrust Engineering Ltd., (SEL), England, for the Government of Qatar. This work was one of several tasks of a large national project entitled "Investigation of the Development Potential of Mineral Occurrences in Qatar", commissioned by the Industrial Development Technical Centre (IDTC) of Qatar. The recorded aerial radiometric data has been corrected, reduced and compiled to indicate uranium, thorium and potassium in counts per second (cps) response, from which

U/Th and U/K ratios have been computed. Based on these data, three radiometric contour maps for the U, U/Th ratio and U/K ratio have been constructed for the whole territory of Qatar Peninsula [1]. Following this reconnaissance survey, Seltrust Engineering Limited [2] carried out the interpretation of radiometric data and the ground follow up, where fifteen localities with twenty radioactive anomalies have been identified in different parts of Qatar peninsula (Figs 1, 2).

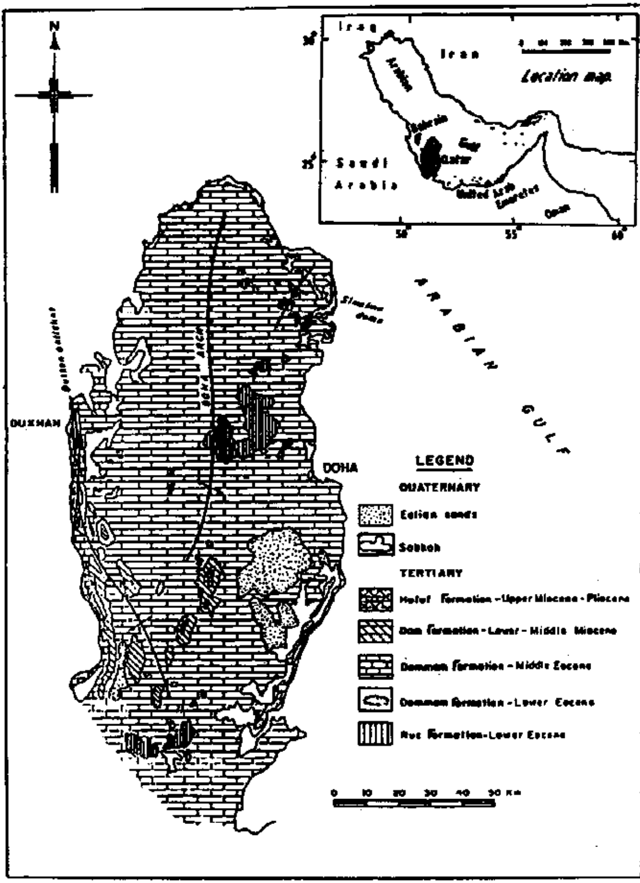

Fig. 1. Geological map of Qatar Peninsula

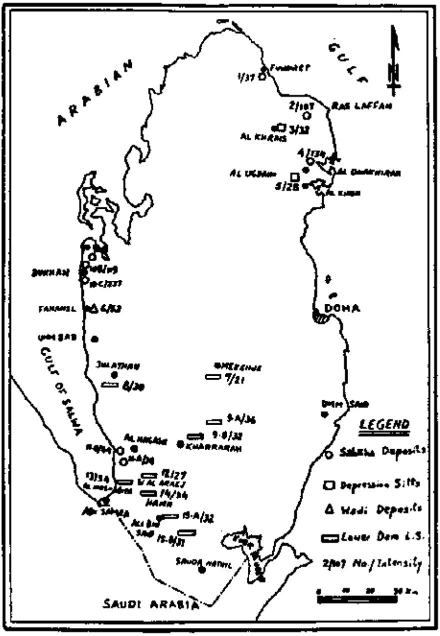

Fig. 2. Locations, types and intensities of radioactive anomalies in Qatar Peninsula

None of these anomalous localities has been associated with radioactive occurrences of economic significance.

The present paper deals with a geostatistical study of gamma radioactivity values measured in the field at the twenty anomalies, aiming at characterizing them in terms of lithology and radioactivity. The statistical parameters calculated from the radiometric measurements at each anomaly include: the arithmetic mean, standard deviation, coefficient of variation and standard error of estimate.

Methods of Radiometric Investigation

Airborne radiometric survey

This method was applied to cover the entire territories of Qatar peninsula along E-W flight lines spaced two miles apart, with some additional short fill-in flight line, where a total of 2895 line miles were flown. The flight altitude was maintained during the survey at 120 meters above the average terrain elevation. The equipment used for this aerial radiometric survey consisted of a four-channel gamma ray spectrometer, model DGRS-1000, manufactured by the Exploranium Canada. It has a detector of over 2000 cubic inches of thallium-activated sodium iodide, NaI(T1), crystals consisting of five 7″×4″ and eleven 6″×4″ Harshaw cylinders. This spectrometer and other airborne geophysical systems were fixed in a Super Canso aircraft, model CF-MIR, equipped with all controlling and navigation systems necessary for such a geophysical survey. The measured data were digitally recorded on 7-track magnetic tapes of 200 BPI density, using a Geometrics G-704 and Cypher tape recorder. The used spectrometer is of the window type which records broad energy bands in the vicinity of gamma-ray energy peaks at 2.62 MeV, 1.76 MeV and 1.46 MeV, representing thallium-208 in the thorium decay series, bismuth-214 in the uranium decay series, and potassium-40 respectively. A total count window is also used. Covering an energy range from 0.40 to 2.82 MeV. The gamma ray spectrometer was calibrated using sources of pure uranium and thorium, where the four windows were set at the corresponding energy levels (Table 1).

Table 1. Energy levels of the measured gamma radioactivity

No.	Channel	Range of energy level, MeV	Energy peak, MeV	Radioisotype
1	Potassium	1.36 – 1.56	1.46	K–40
2	Uranium	1.56 – 2.42	1.76	Bi-214
3	Thorium	2.42 – 2.82	2.62	Ti-208
4	Total Count	0.40 – 2.82	–	–

Ground radiometric prospection

From the interpretation of airborne radiometric data, a number of areas which exhibited anomalous response were recommended to be followed up on the ground. Firstly, the anomalous areas were identified in the field using topographic maps, scale 1:50,000, and aerial photographs, scale 1:16,000. Then, each area was thoroughly covered by ground radiometric survey along an approximately 25 meters spaced grid of points. Field measurements of gamma radioactivity was carried out using a portable gamma ray spectrometer manufactured by Geometrics, model GR-310. Radiometric readings were recorded in counts per second (cps), for the total radioactivity, at every point of the grid pattern and at narrower intervals in-between wherever some changes were noticed. From these field measurements contour maps, scale 1:5000, for the uranium and total count rates were prepared for each investigated anomalous area.

Laboratory radiometric analysis

During the field work, a number of samples were collected from surface material at the spots of maximum uranium count rates. At the most pronounced anomalies, some shallow trenches and auger holes were drilled for sample collecltion at various depths to investigate vertical extent of radioactivity. These samples were comprehensively studied and analysed by different techniques at the Institute of Geological Sciences in London, the Atomic Energy Research Establishment at Harwell, and the Atomic Weapons Research Establishment at Aldermaston, U.K. [3]. The laboratory studies incorporated X-ray fluorescence analysis, delayed neutron analysis, radiometric assay and gamma ray spectrometry. Radiometric assay was carried out using Harwell 2000 end-window Geiger-Muller counting equipment. This work aimed mainly at identifying the cause of the anomalous high radioactivity shown in the field and revealing the radioactive mineral content in the collected samples.

Statistical Treatment of Radiometric Data

Field data of total gamma radioactivity systematically measured at the twenty anomalous localities in Qatar Peninsula have been statistically analysed and evaluated in the context of the geological and structural features. This technique is applied in order to determine significant levels of gamma radioactivity and to compute some statistical measures characterizing the various lithologies in the studied areas, as well as to evaluate the discovered anomalies. The main statistical parameters calculated for each radioactive locality include the arithmetic mean ($\bar{X}$), the standard deviation (S) the coefficient of variation (CV) and the standard error of estimate (SE). From the calculated values of $\bar{X}$ and S for each locality, the background (threshold) radioactivity was designated as all values falling within the limits of $\bar{X} \pm 3$ S. This limit is commonly chosen because of the fact that about 99.73% of all values in any normal frequency distribution should fall in this range. Any value beyond this limit is considered to be of a statistical significance. Generally, the values of gamma radioactivity exceeding the threshold, and which could not be discarded on geological grounds are regarded as anomalous and they should have geological significance.

Results and Discussion

The computed statistics of a total number of 1994 field measurements of the total count rates of gamma radioactivity in the studied twenty anomalous localities are summarized and compiled in Table 2. Also, they are graphically represented by frequency histograms shown in Fig. 3. These statistics display great variations in the distribution of gamma radioactivity at the investigated localities. The average level of radioactivity in areas outside the anomalies ranges from 8 to 18 cps, while the maximum recorded values are greatly varying from 21 to 615 cps. Meanwhile the arithmetic mean values of radioactivity in all anomalies range from 16 to 75 cps.

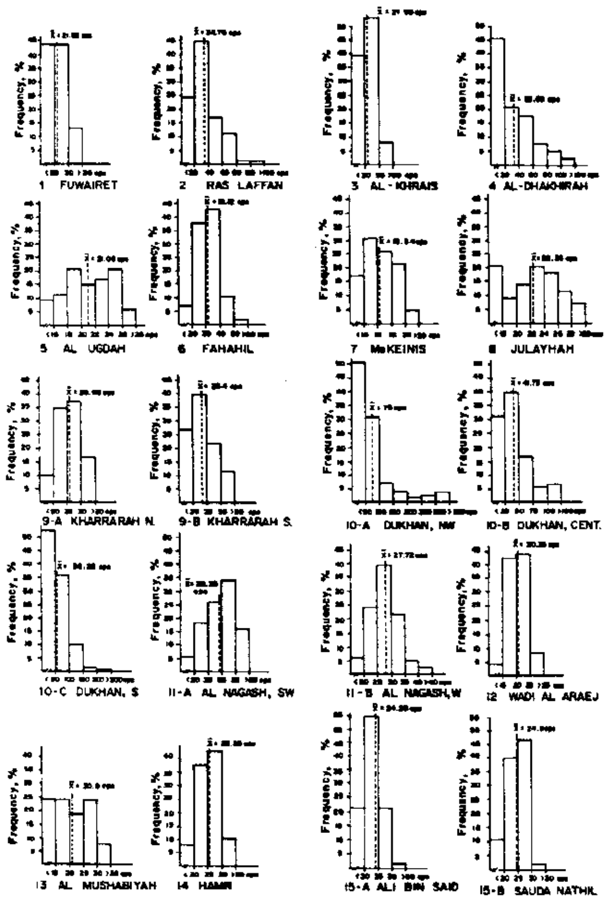

Fig. 3. Histograms of radioactivity in the anomalous localities

Table 2. Statistic of total radioactivity measured at the anomalous localities in Qatar Peninsula

No.	Anomaly No.	Locality	Background material	Anomalous material	Statistics N	B.G.	Max.	$\bar{X}$	S	CV	SE
1	1	Fuwairet	Simsima L.S.	Sabkha deposits	39	10	37	21.92	6.94	31.66	1.11
2	2	Ras Laffan	Simsima L.S.	Sabkha deposits	160	9	107	34.75	21.17	60.92	1.67
3	3	Al Khrais	Simsima L.S.	Depression silts	36	12	32	21.95	6.16	28.06	1.03
4	4	Al Dhakhirah	Beach sands	Sabkha deposits	77	8	134	32.86	26.98	82.11	3.07
5	5	Al Ugdah	Simsima L.S.	Depression silts	53	14	28	21.08	3.48	16.51	0.48
6	6	Fahahil	Rus Limestone	Wadi Deposits	58	18	52	31.21	8.27	26.50	1.09
7	7	Mekcinis	Hofuf sands	Lower Dam L.S.	42	12	21	16.34	2.26	13.83	0.35
8	8	Julayhah	Aeolian sands	Lower Dam L.S.	44	10	30	22.36	3.74	16.73	0.56
9	9-A	Kharrarah North	Hofuf sands	Lower Dam L.S.	88	15	36	25.56	4.44	17.37	0.47
10	9-B	Kharrarah South	Hofuf sands	Lower Dam L.S.	78	15	32	23.40	4.80	20.51	0.54
11	10-A	Dukhan, NW	Beach sands	Sabkha deposits	357	17	615	75.00	7.50	10.00	0.39
12	10-B	Dukhan, Central	Beach sands	Sabkha deposits	90	10	119	41.75	28.28	67.74	2.98
13	10-C	Dukhan, South	Beach sands	Sabkha deposits	227	15	237	56.28	39.05	69.38	2.59
14	11-A	Al Nagash, SW	Lower Dam L.S.	Sandy sabkha	126	16	38	29.35	5.60	19.08	0.50
15	11-B	Al Nagash, West	Lower Dam L.S.	Sandy sabkha	250	15	44	27.72	5.39	19.44	0.34
16	12	Wadi Al Araej	Aeolian sands	Lower Dam L.S.	68	13	27	20.35	3.57	17.54	0.43
17	13	Al Mushabiyah	Aeolian sands	Lower Dam L.S.	37	10	34	20.90	6.48	31.00	1.07
18	14	Hamr	Aeolian sands	Lower Dam L.S.	63	8	34	25.35	3.94	15.54	0.50
19	15-A	Ali Bin Said	Aeolian sands	Lower Dam L.S.	56	15	32	24.29	3.53	14.53	0.47
20	15-B	Sauda Nathil	Aeolian sands	Lower Dam L.S.	45	15	31	24.50	3.55	14.49	0.53

N = The total number of measurements
B.G. = The background value of radioactivity, cps
Max = The maximum value of radioactivity, cps
$\bar{X}$ = The arithmetic mean, cps
S = The standard deviation, cps
CV = The coefficient of variation, cps
SE = The standard error of estimate

From the frequency distribution histograms, the recorded radioactive anomalies can be grouped into two basic types. The first and more significant type is characterized by a sharp peak, and it comprises most of anomalies in the sabkha deposits. The second type displays broad anomalous zones, and it includes all other anomalies which represent lithologic anomalies due to the relatively higher natural radioactivity of their host materials with respect to the surroundings.

Furthermore, the recorded anomalies are classified according to the intensity of gamma radioactivity and their host materials (Table 3). Based on this classification, the studied anomalies are found to be associated with four different lithologies namely sabkha deposits, depression silts, wadi (alluvial) deposits and Lower Dam marly limestones.

Table 3. Classification of radioactive anomalies according to their intensities and host materials in Qatar Peninsula

Sr. No.	Host materials	Anomalies		Radioactivity classes, cps							
				50		50–100		100–200		200	
		No.	%	No.	%	No.	%	No.	%	No.	%
1.	Sabkha Deposits	8	40	3	37.5	–	–	3	37.5	2	25
2.	Depression Silts	2	10	2	100	–	–	–	–	–	–
3.	Wadi Deposits	1	5	–	–	1	100	–	–	–	–
4.	Lower Dam L.S.	9	45	9	100	–	–	–	–	–	–
	Total	20	100	14	70	1	5	3	15	2	10

Anomalies in sabkha deposits

The sabkhas are highly saline flats that are normally found adjacent to or near the coasts. Qatar Peninsula is bordered by extensive sabkha deposits such as those of Umm Said, Al-Khor, Al Dhakhira and Abu Samra. It also encounters some large inland sabkhas to the east of Dukhan near the western coast and at Sauda Nathil along the southern frontier with Saudi Arabia (Fig. 1). Most of these sabkha deposits are composed of calcareous clay, silt or sand, with saline encrustations. They are usually characterized by a shallow phreatic water table of very high salinity. Due to high evaporation by the effect of hot climate in Qatar Peninsula, various types of evaporite minerals, mainly gypsum, anhydrite, celestite and halite are crystallized as thin surface crust.

Eight radioactive anomalies have been recorded in sabkha deposits on the surface of Qatar Peninsula, with radioactive intensities ranging from 37 to 615 cps. The most highly radioactive anomalies are recorded in the peripheral parts of Dukhan sabkha, followed by the anomalies located in the coastal sabkhas at Al-Dhakhira and Ras Laffan. The high radioactivity at these anomalies is suggested to be due mainly to the daughter elements of uranium, principally Ra^{226}, which is coprecipitated with strontium in the celestite crystals [2]. Small quantities of celestite are known to occur in most sabkha deposits in Qatar Peninsula, where the mineral has been precipitated along with other substances of evaporitic environment. Samples from some sabkhas were examined by Cavelier [4] who recorded strontium values up to 0.8%. The average values in the Earth's Crust are about 375 ppm according to Taylor [5]. Basham [3] analysed two samples from the highest radioactive anomaly in the silty material of Dukhan Sabkha, where the strontium content proved to be 1.95% and 2.95%, existing in the form of minute crystals of celestite.

Anomalies in depression silts

The surface of Qatar Peninsula is stippled by numerous depressions which lie below the surrounding land surface at a depth ranging from a few meters up to 20 meters. Most of these depressions are filled by shallow silts and muds which were deposited by the surface runoff carrying weathering products from the surrounding rock exposures. Two radioactive anomalies are located in such depression silts at Al-Khrais and Al-Ugdah depressions in northern Qatar (Fig. 1). Their radioactive intensities are only three times the background. This radioactivity is mostly related to their contents of some heavy mineral grains, of eolian origin, that have been transported by the action of wind and runoff.

Anomalies in wadi deposits

Only one radioactive anomaly is found associated with the surficial wadi deposits, located to the southeast of Fahahil Cracking Plant (Fig. 1). In this area, wadi deposits are mainly composed of detrital material derived from a nearby remnant exposures of the Hofuf Formation. The weathering products of the original sediments, that was derived from the disintegration of the basement rocks of the Arabian Shield in western Saudi Arabia, contain some heavy mineral concentrates which are the main source of the recorded high radioactivity.

Anomalies in lower dam limestones

The outcrops of Lower Dam Formation are mainly localized in the southwestern part of Qatar Peninsula, with considerable occurrences preserved in some depressions caused by folding or collapse structures in the south central part of the Peninsula. Lithologically, these outcrops are formed of intercalations of clayey beds and fossiliferous limestone, with some calcareous clay layers. The nine radioactive anomalies recorded in the Lower Dam outcrops have been found to be associated with phosphatic material embedded in the limestone beds. The essential phosphate mineral is the fluorapatite and its cryptocrystalline variety, collophane, seem to be formed by the solution of calcium carbonate by sea water and deposition of the dissolved phosphate ions. However, investigation for phosphate rocks in Qatar shows that they are found in a very small amount, where the content of several analysed samples is generally less than 1% P_2O_5 [2, 4, 6]. Meanwhile, there is no possibility for potential phosphatic deposits in the Lower Dam or any other exposed formation. The cause of radioactive anomalies recorded in the Lower Dam limestones is mostly the presence of some vertebrate remains (bones, teeth and coprolites) rich in phosphate. However, there is no obvious correlation between the anomalous radioactivity in the Lower Dam sediments and their content of phosphatic material. This could be explained by the high mobility of uranium in oxidizing near-surface water, where some of its decay products are usually removed from their original source and reprecipitated far away wherever the geochemical conditions permit deposition. This is evidenced by the disequilibrium state shown by some analysed samples [7].

Conclusions

Radiometric investigation carried out in Qatar Peninsula have not pointed to any radioactive occurrence of economic significance. However, twenty radioactive anomalies have been found in various lithologies having different intensities of gamma radioactivity. As a result of the geostatistical study discussed in this paper, the recorded anomalies can be grouped into two main types. The first and more significant type comprises most of anomalies located in sabkha deposits, and they are characterized by sharp peaks. The second type displays broad anomalous zones located in depression silts, wadi deposits and Lower Dam marly limestones. Furthermore, the following conclusions and recommendations can be drawn:

1) The high radioactivity of all anomalies recorded in Qatar Peninsula is due mainly to uranium and its decay products, in particular Ra^{226} which appears to have coprecipiated with the hosting material.

2) The effect of water (surface runoff, groundwater and seawater intrusion) is of paramount importance in the distribution of uranium due to its high mobility in oxidizing near-surface waters. Some of its decay products are more soluble in alkaline water and they may thus be removed and re-precipitated far from their original source.

3) The most significant radioactive anomalies are located in the Dukhan inland sabkha which occupies an isolated extensive depression of an important structural setting. This area is worthy of further radiometric investigation, particularly for evaporitic encrustations and impregnations in the subsurface.

4) The largest number of anomalies (45%) are associated with marly and phosphatic limestones of the Lower Dam Formation, but none of them has significant radioactivity. However, the environment of sedimentation of this formation and its stratigraphic position encourage further radiometric investigation, particularly along the surface of unconformity with the underlying Dammam Formation.

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دراسة جيو إحصائية لإشعاعات جاما في بعض المواقع الشاذة بشبه جزيرة قطر ـ الخليج العربي

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ملخص البحث. أوضح المسح الإشعاعي الجوي لشبه جزيرة قطر عن وجود عدد من المواقع الشاذة إشعاعيًا متناثرة في أنحاء شبه الجزيرة، كما أسفرت الدراسات الجيولوجية والإشعاعية الحقلية عن تحديد عشرين شاذة يتراوح نشاطها الإشعاعي الجامي بين ٢١ـ٦١٥ عدة لكل ثانية، بينما تتراوح الخلفية الإشعاعية في المواقع الشاذة بين ٨ـ١٨ عدة لكل ثانية.

وقد تم في هذا البحث إجراء تحليل إحصائي على ١٩٩٤ قراءة حقلية لقياسات أشعة جاما لمختلف الرواسب والصخور الموجودة في المواقع الشاذة التي وجد أنها ترتبط بأربعة أنواع ليثولوجية رئيسه وهي: رواسب السبخة، غرين المنخفضات، رواسب الوديان، الأحجار الجيرية التابعة لمتكون الدمام السفلي. وقد تم حساب عدد من المعاملات الإحصائية عن النشاط الإشعاعي لكل من هذه الأنواع الليثولوجية، منها المتوسط الحسابي، الانحراف المعياري، معامل التغير، الخطأ القياسي في التقدير.

كما أوضحت هذه الدراسة الجيو إحصائية أن المواقع الشاذة إشعاعيًا المسجلة في شبه جزيرة قطر يمكن تصنيفها إلى نوعين رئيسين: النوع الأول وهو الأكثر أهمية، يتميز بتوزيع إحصائي ذو قمة عالية، وهو يتضمن معظم المواقع الشاذة إشعاعيًا المرتبطة برواسب السبخة. أما النوع الثاني فهو يتميز بتوزيع إحصائي ذو قمة عريضة، وهو يتضمن جميع المواقع الأخرى الشاذة إشعاعيًا التي تمثل شاذات ليثولوجية نتيجة لارتفاع النشاط الإشعاعي الطبيعي للرواسب والصخور التي توجد فيها بالنسبة لما حولها من رواسب وصخور.