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URANIUM DEPOSITS AND OCCURRENCES IN IRAQ

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Key words: Uranium; Thorium; Radiometric survey; Iraq

ABSTRACT

This is a review paper on the results of the extensive exploration for radioactive minerals in Iraq, based on previous reports and published papers. The radiometric, geological and geochemical surveys carried out by the Nuclear Geology Department in the Iraqi Atomic Energy Commission since 1966 and later continued by Iraq Geological Survey showed significant radioactivity related to uranium and partly to thorium in the Zagros Suture Zone, mostly related to acidic intrusions of igneous rocks (anorthosite) and associated metamorphic rocks (olivine marble). The Qalat Diza region is the most prominent in this part of Iraq. The Lower Miocene Euphrates Formation is found with remarkable radioactivity along the Hit – Abu Jir (Euphrates) Fault Zone and related to uranium hosted in carbonate rocks in the uppermost part of the formation. The most prominent in this region is Abu Skhair uraniferrous deposit. Numerous areas with anomalous radioactivity are found in the Western and Southern deserts related to Paleogene and Upper Cretaceous phosphorite exposures. Several theories have been postulated to explain the source of syngenetic uranium enrichment in the Euphrates Formation along the Euphrates River, but it is agreed that successive oxidizing and reducing conditions were effective in the epigenetic uranium concentration in these carbonate rocks. Detailed exploration in the Abu Skhair deposit led to the opening of an underground mine and to the development of an efficient uranium extraction process despite the poor grade of the deposit classified as a lean ore. The results obtained so far point to the absence of commercial uranium deposits in Iraq, but the potential of phosphorites, as uranium-bearing rocks, is very significant. Industrial experience at Al-Qaim fertilizers plant proved that uranium can be effectively and commercially extracted as a by-product during the production of phosphate fertilizers.

رواسب وشواهد اليورانيوم في العراق

محمد عبد الامير مهدي

المستخلص

هذه ورقة مراجعة علمية عن الاعمال المكثفة التي تمت في العراق للاستكشاف والتحري عن الخامات المعدنية المشعة تم اعدادها على ضوء المعلومات التي افرزتها الدراسات السابقة التي نفذت من قبل قسم الجيولوجيا النووية في منظمة الطاقة الذرية العراقية منذ عام 1966 واستكملت لاحقا من قبل هيأة المسح الجيولوجي العراقية. أشارت نتائج المسوحات السابقة الى وجود مناطق محدده في نطاق زاغروس الالتحامي مرتبطة في معظمها باندفاعات لصخور نارية حامضية مثل الانورثوسايت والصخور المتحولة المرافقة لها مثل المرمر الحامل للاولفين وتعتبر منطقة قلعة دزه من أهم هذه المناطق. تم رصد واستكشاف العديد من المناطق ذات الاشعاعية العالية المرتبطة باليورانيوم الموجود في صخور كاربونيتية في الجزء الأعلى من تكوين الفرات (المايوسين الأسفل) على طول نطاق فالق هيت – أبو الجير المحاذي لنهر الفرات ويعتبر راسب اليورانيوم في منطقة ابو صخير من أهمها. أثبتت التحريات والمسوحات الأرضية ارتباط معظم

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المناطق ذات الاشعاعية العالية في مناطق الصحراء الغربية والجنوبية برواسب الفوسفات المكشوفة على سطح الارض. تم تقديم عدة فرضيات لأصل وكيفية إغناء اليورانيوم المرافق للترسيب في تكوين الفرات غير ان هناك اتفاق ان هناك عمليات أكسده تعرضت لها الطبقة الحاملة لليورانيوم رافقها انسلاخ لليورانيوم الأولي ثم اعادة ترسيب في ظروف اختزالية سادت المكان وأدت الى إغناء ثانوي لليورانيوم عند سطح التماس العلوي للتكوين. أدت التحريات التفصيلية في راسب ابو صخير الى فتح منجم تحت سطحي وتطوير مسار تكنولوجي لاستخلاص اليورانيوم رغم تدني محتواه في الصخور. تشير النتائج المستحصلة لغاية الان الى احتمالية ضعيفة لوجود رواسب اقتصادية من اليورانيوم غير ان الصخور الفوسفاتية في الصحراء الغربية تمثل مصدرا مهما لليورانيوم في العراق حيث أثبتت العمليات الصناعية في مجمع القائم للأسمدة الفوسفاتية امكانية استخلاص اليورانيوم بطريقة فعالة واقتصادية كناتج عرضي أثناء عمليات تصنيع الأسمدة.

INTRODUCTION

Exploration for radioactive minerals has rapidly developed in a relatively short time since the beginning of the last century because of the global interest in uranium as a vital source of energy. The extensive exploration activities for important uranium ores, covered many parts of the world in the past decades and revealed important data about the nature of these ores and the conditions of their formation in the earth crust, besides the estimation of their resources.

As for Iraq, the interest in the exploratory activities for uranium ores dates back to the beginning of the fifties of the past century. The first geological studies were carried out in the Iraqi Zagros Suture Zone, where the geological structures are accompanied by certain phenomena and lithology suitable for radioactive ores formation. In addition, the black shale deposits found in different localities of northern Iraq were considered another expected source for uranium. The early exploration works in the Zagros Mountains terrain were carried out by foreign companies including Iraq Petroleum Company (IPC), followed by the work of the Site Investigation Co. (UK) in 1955 and the Russian experts in the late fifties and early sixties.

The actual start of performing mineral exploration activities for radiometric ores in Iraq was after establishing the Nuclear Geology Department in the Iraqi Atomic Energy Commission in 1966. An exploration work plan was set out by a committee of Iraqi geological experts. According to the recommendations of the scientific committee, several strategic exploration projects were proposed and accomplished in the following years.

EXPLORATION HISTORY

- **Airborne Radiometric Survey** (1973 – 1974)

The airborne radiometric survey was executed by a French company (C.G.G.) who carried out aeromagnetic and aeroradiometric surveys for most parts of Iraq except for the eastern and northeastern regions for the benefit of Iraq Geological Survey (Formerly known as The State Company of Geological Survey and Mining). The results of this airborne survey were (35) radiometric anomalies distributed in various parts of the area covered by the airborne radiometric survey (Table 1 and Fig.1).

- **Radiometric ground surveys**

Radiometric carborne and footborne surveys started before the airborne survey in 1974 and continued after that. Verification measures of the radiometric anomalies detected in the airborne survey or in some areas of important geological nature were reassured. Radiometric surveys were performed in Al-Qaim, Sinjar and Qalat-Dizeh before 1974. Verification measures to check the anomalies from the airborne radiometric survey were also carried out by a number of specialists using ground radiometric surveys during (1974 – 1986). Al-Samaraei *et al*. (1975) surveyed the R_8 anomaly located SW of Rutba town (Western Desert), Al-Shibil and Al-Samaraei (1976) verified R28, R31, R32, R33, R34 anomalies at Al-Salman – Jill areas (Southern Desert), and Abdul Kadir *et al*. (1976) verified R_7 and R_8

anomalies at Akashat area and southwestern of Rutbah town. Abdul Fattah (1977) verified R_{25} anomaly at Al Ma'aniya – Waksah and R2, R1, R15, R18 anomalies at Taqtaqanah and Milutiyat areas. Al-Najim and Abid Al-Wahid (1982) investigated R_7 anomaly at Akashat area and also the radiometric anomalies R17, R18, R19, R20, R21, R22 and R23 in the Western Desert, Nukhaib (and its southern parts) and Wadi Al-Ubaiyedh area. Al-Atiya and Mahdi (1977 – 1981) verified R9, R10, R11 and R14 radiometric anomalies at Shithatha, Al-Rahaliya and Hit. Mahdi and Al-Kazzaz (1984) verified the radiometric anomalies at Al-Shannafiya area. The results of these studies defined the origin of radiometric anomalies in correlation with different kinds of exposed rocks and soil in the surveyed areas of Iraq.

Table 1: Results of the radiometric surveys (C.G.G., 1974)

No.	Anomalies	Anomaly Source	Values of Concentrations	Anomalies Correlation with Rocks and Containing Sediments
1	R7, R8, R18, R19, R21, R22, R23, R24, R25, R6, R26, R27, R28, R29, R30, R31, R32, R33, R34	Uranium	10 – 200 ppm	Correlated with Primary Originated Uranium in phosphate rocks
2	R5, R9, R11, R12, R13, R14, R15, R16, R20, R1, R10	Uranium	20 – 200 ppm 30 – 300 ppm	Correlated with primary uranium showings in the upper part of the Euphrates Formation. Correlated with uranium and radium in or around water springs and bitumen seepages
3	R17, R4, R3, R2	Uranium + Potassium	10 – 30 ppm	Correlated with uranium or potassium present in clayey depression sediments
4	R35	Uranium + Thorium	30 – 400 ppm	Correlated with uranium or thorium present in heavy minerals present in the sandstones of the Amij Formation

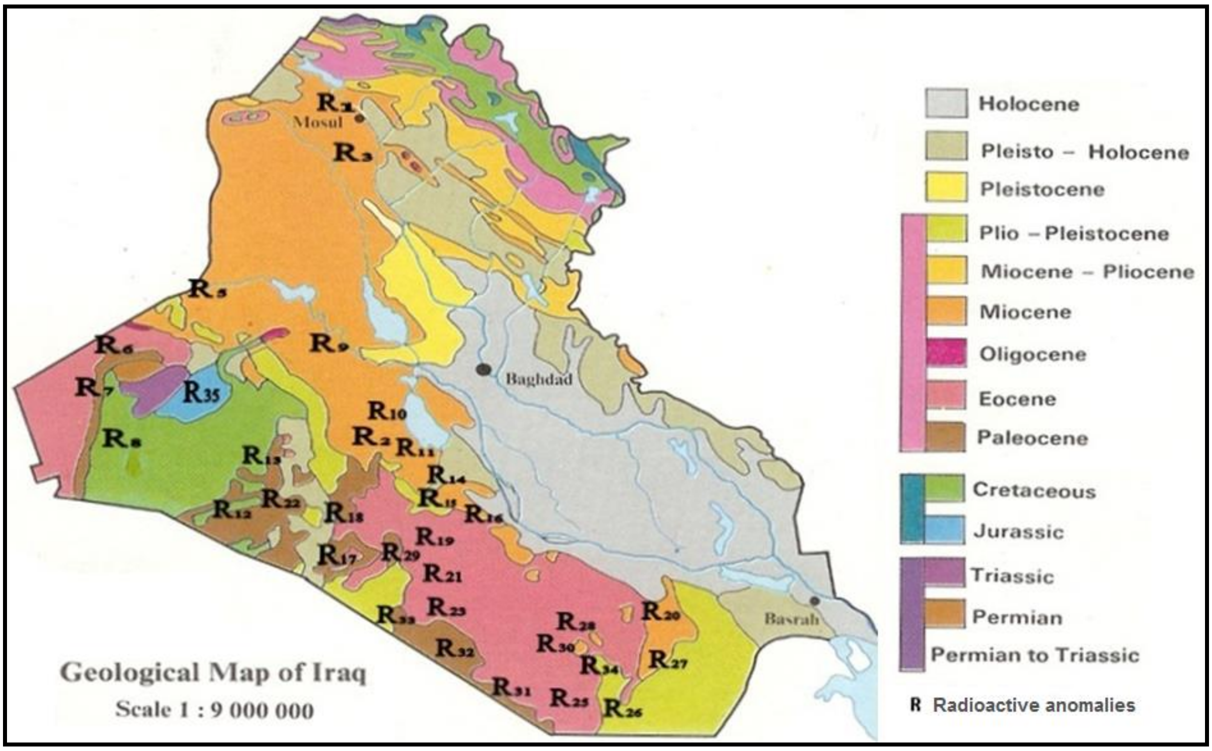


Fig.1: Location of the airborne radiometric anomalies (C.G.G., 1974) superimposed on regional geological map of Iraq (simplified after Jassim *et al*., 1986)

- **Geochemical surveys**

Different geochemical surveys covering very large areas have been performed at Qalat Diza area (about 115 Km^2) by taking water samples from streams and springs and from valley-fill deposits. The hydrochemical survey covered all drilled and hand dug wells in the Western Desert, the Southern Desert and Al-Jazera area. More than (70) water samples have been collected and analyzed for uranium and other elements (e.g., Fe, Cr, Ni, Cu and Zn). Geochemical surveys showed to be effective in defining radiometric anomalies in those areas, and they also verified the precision of the previous radiometric survey results (Al-Atiya *et al.*, 1976).

- **Detailed uranium exploration and pilot mining operations**

Based on various exploratory works, the area of Abu Skhair, south of Najaf City, has been selected for detailed subsurface exploration. The drilling results delineated a lean uranium deposit associated with the carbonates of the Euphrates Formation (Lower Miocene). The Abu Skhair uranium deposit was discovered accidentally in (1977) when the gamma-log of a well, drilled in the Abu Skhair region for groundwater survey, showed anomalous radiation at 70 m depth within the carbonate rocks of the Euphrates Formation (Lower Miocene) (Al-Atiya and Mahdi, 2005). The anomaly was followed by subsurface exploration that lasted for about ten years where about 400 exploratory wells were drilled, documented and logged. The reserves were estimated and the physical properties were determined. The final stages witnessed mine design and development of uranium extraction process. The mine was opened in 1988 and closed after ten years without actually producing any uranium ore, except what was excavated while tunneling. Samples for pilot plant ore dressing were collected and uranium, as a yellow cake, was recovered with significant purity. However, the deposit is far from being considered as an economic target, being a “lean ore” of no commercial value (Al-Atiya and Mahdi, 2005).

URANIUM OCCURRENCES AND DEPOSITS

- **The Zagros Suture Zone and the Imbricate Zone**

These parts of northern Iraq were not covered by airborne radiometric survey. Most of the exploration work for radioactive minerals was carried out by footborne radiometric surveys, geochemical surveys and direct geological prospecting (Fig.2). Most of the exploration work was carried out in the Zagros Suture Zone, NE of Iraq and especially in the Qalat Diza area.

– **Qalat Diza region:** Several localities within the Qalat Diza region showed interesting radiometric anomalies and anomalous uranium and thorium concentrations (Table 2). Mineralologic and petrographic studies have shown that there is a correlation between the radiometric anomalies in most of these locations with olivine marble and granite-pegmatite intrusions Thorium concentrations are much higher than uranium concentrations in these intrusions (Table 2) (Mahdi and Al-Delaimi, 2010).

The northeastern slopes of Shakha Rash Mountain contain high radiometric anomalies reaching up to 3500 c/s in pegmatite granite intrusions in gneiss penetrated by diorite and monazite. A new radioactive mineral has been discovered in this area, named Iraqite $\{KCa_2(La, Ce, Th)Si_8O_{20}\}$, found at the contact zones between coarsely crystallized granitic rocks and impure dolomitic marble which contains olivine and diopside (Al-Hermizy *et al.*, 1976). Some of the rocks at Geli Kiwi Mountain consist of serpentine marble with dunite. The radioactivity of these rocks reached to 700 c/s and uranium concentration reached up to 24 ppm and thorium concentration up to 860 ppm. At Deebza Mountain, which lies about 5.5 Km to the north of Hero village, the radiation intensity in some olivine marble reached up to 2700 c/s in comparison with the general background radiation of 50 c/s. Uranium concentration reached up to 830 ppm. At Kani Muwish locality, which is 1 Km NE of Belco village, the thickness of the radioactive ore-bearing rocks is in the range of 50 – 100 cm, extending to more than 70 meters and consists of anorthosite and probably pegmatite syenite. The radiation intensity of these rocks reached up to 3000 c/s in comparison with the radioactivity of the general background of 40 c/s. The uranium concentration reached up to 513 ppm and thorium concentration to 500 ppm. The radiometric anomaly at Wadi Nesi location, 3.5 Km NE of Hero village, is correlated with fault surfaces in olivine-bearing marble. The maximum radiation intensity is about 1200 c/s and uranium concentration reached up to 2640 ppm. Thorium is much higher than uranium and reach to 10170. The confirmed width of the anomaly is about 1 Km.

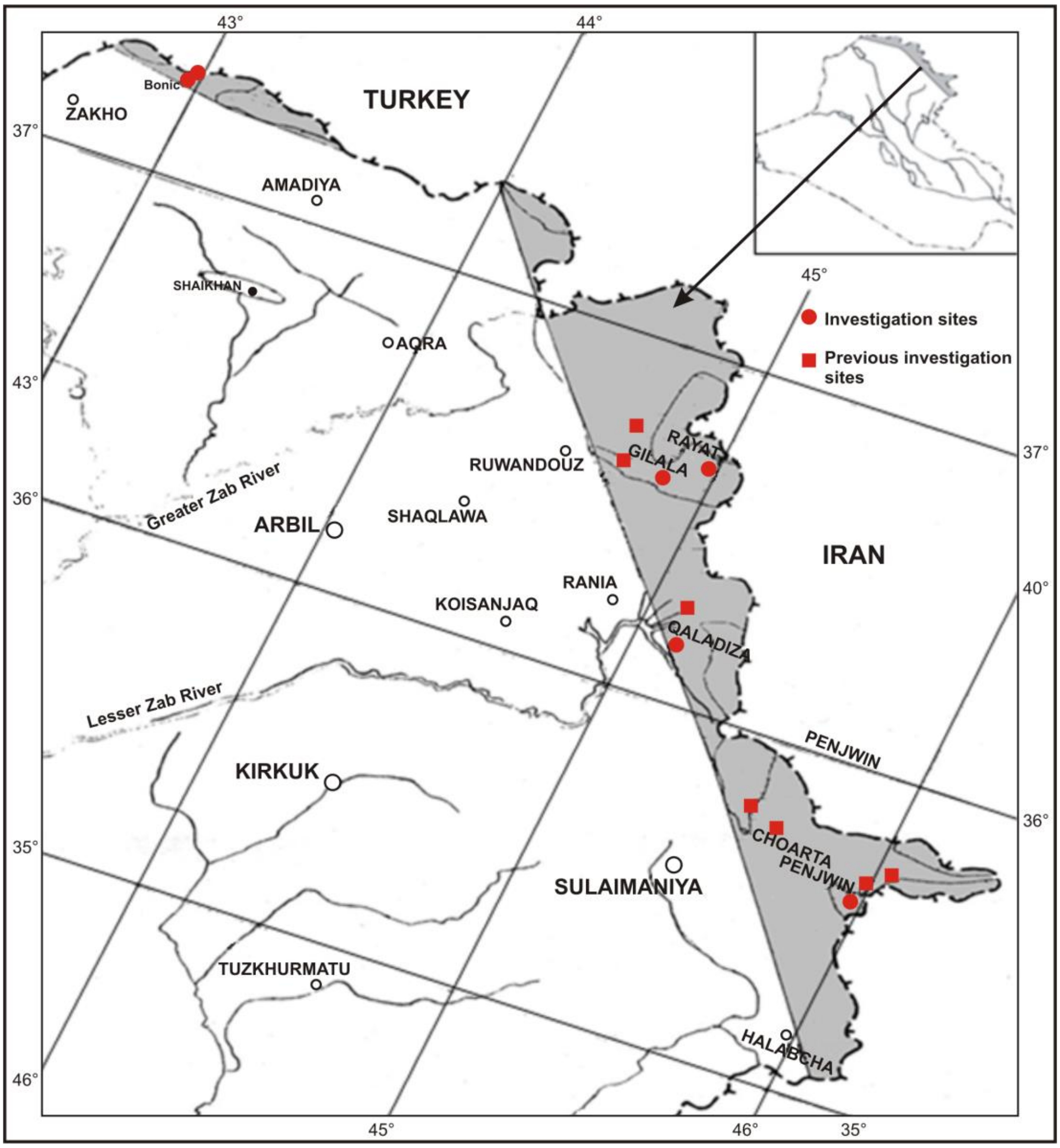


Fig.2: Location of mineral prospecting and exploration for radioactive minerals in the Kurdistan Region, Iraq (GEOSURV-Iraq)

Table 2: Uranium and thorium concentrations in radioactive rocks of Qalat Diza localities (Abdul Kadir *et al*., 1975 and Al-Hermezi *et al*., 1976)

Location	Sample No.	Uranium ppm	Thorium ppm	Type of Radioactive Rocks	Accompanied Igneous Rocks	Notes
Nesi (Qalat Dizah)	II	650	3140	olivine marble-granite-dunite	Dunite	Olivine marble radioactive mineral uranothorite
	I	1010	10170	olivine marble-granite-dunite	Dunite	
	5a	2640	8830	olivine marble-granite-dunite	Dunite	
	5b	1250	7530	olivine marble-granite-dunite	Dunite	
	Ro	1590	8550	olivine marble-granite-dunite	Dunite	
Deebza Mountain (Qalat Dizah)	A1	307	Nil	olivine marble-granite	Dunite	Olivine marble accompanied by different kinds of veins
	AB	650	Nil	olivine marble	Dunite	
	A5	830	Nil	olivine marble	Dunite	
	A10	210	Nil	olivine marble	Dunite	
	A13	230	Nil	olivine marble	Dunite	
	At	432	Nil	olivine marble	Dunite	
Shakha Rash – (Qalat Dizah)	D1	845	50	Green rock	Ultrabasic rocks	Thin veins of very high radiation
	D2	6	226	zoisite gneiss		
	A1	750	30500	veins of pegmatite granite rocks in marble		
	A2	850	27300	veins of pegmatite granite rocks in marble		
	A3	38	470	veins of pegmatite granite rocks in marble		
Keli Kiwi (Qalat Dizah)	3a	148	160	olivine marble	Pyroxenite	Serpentinite marble accompanying dunite, similar to the rocks of Deebza Mountain
	A1	4.2	180	olivine marble	Olivine marble	
	AB	5.5	24	olivine marble	Olivine marble	
	A12	24	860	olivine marble	Olivine marble	
	At	4.7	260	olivine marble	Olivine marble	
	A5	113	825	olivine marble	Olivine marble	
Kani Mewish (Qalat Dizah)	C15	67	250	anorthosite – pegmatite	Diorite, olivine, gabbro and dunite	Anorthosite
	C16	103	630	pegmatite syenite		
	C23	118	250	pegmatite syenite		
	C25	613	500	pegmatite syenite		
	C18	222	50	pegmatite syenite		

The radiation intensity at Shakha Rash Mountain reaches up to 3500 c/s in comparison to the general background radiation of the rocks in the area which reaches up to 50 c/s. At the northeastern slope of the mountain, some of the of alkaline pegmatite intrusions in marble and ultrabasic rocks contain laminated graphite with a radiation intensity of 3500 c/s. Tests upon a number of granules in these rocks show that they contain 97000 ppm thorium and 5300 ppm uranium. Iraqite was discovered in this locality and reported to contain 0.68% uranium and 24.6% thorium (Al-Hermezi *et al*., 1976). Previous studies suggested that this mineralization had taken place because of replacement process of some elements in some minerals like zircon and xenotime (Mohammad and Ibrahim, 1976).

The radiation intensity in the dug trenches at Kani Mewish reached up to 3000 c/s. The radioactive rocks are veins of (50 – 100) cm thickness of various compositions including anorthosite and may be biotite-rich syenite pegmatite. These veins are found in diorite, gabbro and dunite and the radiation increases with depth. Previous studies have shown that the radioactivity is caused by the existence of zircon in the veins, and the results showed that the radioactive equilibrium is for uranium, and this gives the possibility of the existence of other source of uranium (Al-Kazzaz and Husain, 1976). The radioactive intensity at Deebza Mountain is about 2700 c/s in the olivine marble rocks where uranium concentration reached to 30 ppm, while thorium concentrations are very low.

– **Penjween area:** The Dmamna locality in the Penjween area shows radioactivity in the range of (200 – 800) c/s and with concentrations of 40 ppm uranium in granite rocks. Mineral studies have shown that high concentrations of uranium are correlated with the increase in iron oxide content (Al-Shibil and Kettanah, 1972).

– **Rawanduz area:** The dolomitic limestone and black shale rocks containing carbonaceous components near Barserin and Naokelekan villages showed distinguished radiometric anomalies. The radiation intensity ranged between (200 – 400) c/s and uranium concentrations ranged between (20 – 100) ppm with an average of 60 ppm in thin veins of coal (Al-Kazzaz etai., 1972). The radiation intensity in Galala – Rayat localities was within the general radiation background (Abdul Kadir *et al*., 1971).

– **Zakho area:** Radiometric anomalies, up to 700 c/s, were found near Banik Village in black shales which contain with high content of asphalt (Khulaif and Taha, 2006).

- **Uranium deposits and occurrences along the Euphrates River**

The results of the radiometric airborne survey of Iraq by (C.G.G.) showed a group of radiometric anomalies of different intensities extending from Al-Qaim town in the NE to Samawah City in the SE. These radiometric anomalies are mostly associated with outcrops of Middle and Lower Miocene age (Table 3). The Upper Member of the Euphrates Formation and sometime the Ghar Formation are characterized by different uranium concentrations. The area forms a longitudinal strip of numerous radioactive anomalies extending along the west bank of the Euphrates River. The strip is (50 – 60) Km wide and about (600) Km long (Fig.3). This area is characterized by numerous radiometric anomalies and uranium occurrences which have been investigated over decades during the past century. The radioactivity is connected with certain lithological and stratigraphic units, located within the carbonate rocks of the Euphrates Formation (Lower Miocene) and the Nfayil Formation (Middle Miocene) as well as around spring-water deposits. They are mostly found in Hit – Abu Jeer, Shithatha and Al-Shannafiya localities (Tables 3 and 4).

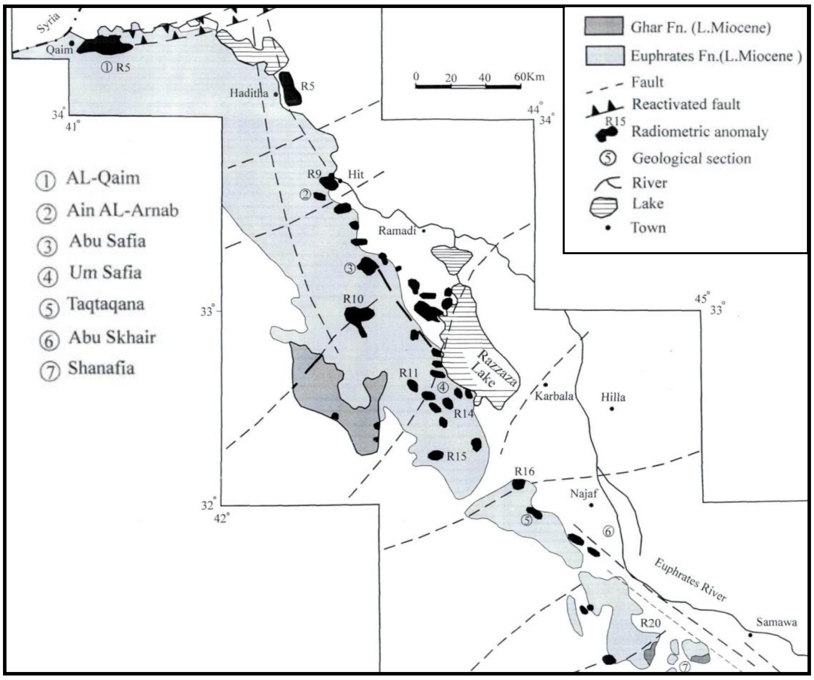


Fig.3: Geological, structural and radiometric map west of the Euphrates River (Compiled by Al-Bassam *et al*., 2006 from: C.G.G., 1974; Buday and Jassim, 1984; Jassim *et al*., 1986 and Fouad *et al*., 1986)

Table 3: Specifications of radiometric anomalies in the Euphrates Miocene Belt (C.G.G., 1974)

Area	Anomaly No.	Anomaly Causes	Radioactive Intensity	Notes	Anomaly Extension
Al-Qa'im	R5	U	more than 1200	Euphrates Formation	Wide areas
Hit - Abu Jeer	R9	U	500 – 3000	Sulfur Springs	Scattered locations
Shithatha	R11	U+K	400 – 1200	Euphrates Formation – Sulfur Springs	Wide and isolated areas
Taqtaqanah	R16	U	250	Euphrates Formation	Specific area
Abu Skhair	?	K	?	Recent Deposits	Specific area
Shannafiya	R20	U	250 – 400	Recent Deposits – Sulfur Springs	Wide area

Table 4: Uranium concentration and its equivalent in springs water and deposits in some areas west of the Euphrates River (Al-Atiya *et al*., 1976)

No.	Location	Spring	Spring Water		Spring Deposits	Spring Water Quality
			U_3O_8 ppb	pH	U_3O_8 ppm	
1	Hit - Abu Jeer	Al Khalidiyah	13.7	-	-	
2		Al- Marj	0.29	6.3	-	
3		Kubaisa	0.42	-	8	
4		Zazoo'o	0.4	7.2	7	Sulfuric
5		Mamooriya	0.1	7	-	
6		Hit	2.72	7.2	2	
7		Asforiyah	0.55	7.5	7	
8		Awazil	0.1	-	-	
9		Jabha	2.4	7.5	24	Na-Ca-Cl
10		Jabha	0.1		11	
11		Abu Jeer	0.1		3	
12		Abu Jeer	0.1		10	
13	Shithatha	As Sarga (Rahaliya)	2.8	(7 – 8)	17	SO_4,Ca,Mg,Na,Cl
14		Rahaliya (borehole)	4.97			
15		Imam Ahmed Ibn Hashim	4.7			
16		Sdaha	5.6			
17		Mnaiseeb	6.1			
18		Al Barakah	4.4			
19		Haji Sharif	4.38			
20		Al Maleh	5.3			
21	Al-Shannafiya	Al Aasi	5.7	7.1		SO4,Ca,Na,Cl
22		Abu Labak	2.7	6.8		
23		Al Qa'im	3.2	7.6	12	
24		Dhubab	1	7.9	< 10	
25		Al Mahari	6.4	7	14	
26		Dawood	9	7.4	< 10	
27		Um Dhrook	7.8	7.1	< 10	
28		Jsoom	8.5	7.4		
29		Dheej	7.6	7.2		
30		Al Hasooni	15.3	7.5	< 10	
31		Shweerj	9.5	7.4	< 10	

The radioactive anomalies detected by the C.G.G. (1974) are distributed along the Hit – Abu Jir (Euphrates) Fault Zone (Fig.3), which consists of a system of faults with strike slip general character, evidenced by pressure ridges and sag ponds on surface and the presence of positive and negative flower structures in subsurface (Fouad, 2004). In the Anah – Al-Qaim area these faults are related to the evolution of the Anah Graben and were reactivated during the inversion of the Anah Graben in the Miocene (Fouad *et al*., 1986. The age of the Euphrates Fault Zone is believed to be Campanian associated with an extension phase that affected the interior of the Arabian Plate, at that time and was reactivated in the

Early Miocene (Fouad, 2004). Evidence of the Early Miocene rejuvenation of the Euphrates Fault Zone can be seen as episodes of synsedimentary tectonic disturbance reflected by brecciated and/ or undulated horizons and slump structures in the upper parts of Unit C of the Euphrates Formation (Fouad *et al*., 1986 and Hassan *et al*., 2002).

– **Uranium deposits in the Al-Qaim area:** A series of different radiometric investigations and geological activities were intermittently carried out in Al-Qaim area from 1968 till 1990. These activities covered about (300) Km^2 which lies between Wadi Al-Jarwa from the east and Wadi Al-Qaim from the west. A dolostone layer, within the upper part of the Euphrates Formation (Lower Miocene), shows distinguished radioactivity and a good geographical extension between Wadi Al-Jarwah and Al-Qaim town. The thickness of this layer ranges between (1.15 m – 4.25 m). It contains high concentrations of uranium ranging between (10 – 264) ppm, with an average of (70) ppm. Mineral investigations during 1983 – 1984 resulted in defining a uranium-bearing layer within dark grey dolostone containing organic materials and important concentrations of uranium. The average of uranium concentrations in this layer is (247) ppm with average thickness of about (2.78) m (Abdul-Kadir and Mohammad, 1985; Al-Kazzaz and Mahdi, 1991).

Brecciated rocks, at the Upper part of the Euphrates Formation, adjacent to the Euphrates River, contain a considerable concentration of uranium and some other radioactive elements. Uranium concentrations range between (20 – 716) ppm. Distinguished radiometric activity in the soil surrounding sulfuric springs was detected and believed to have resulted from surface concentrations of uranium equivalent (radium). These concentrations decrease at depth and away from the sulfuric spring (Table 4). The spring waters mostly contain radium, but not uranium, specifically those of (Na – Cl) water type, which contain bituminous materials.

– **Uranium occurrences in the Shithatha area:** Anomaly (R11) (airborne survey C.G.G., 1974) was correlated to some outcrops and sulfuric springs at Shithatha – Rahaliya area. Geochemical, radiometric and geological prospecting activities were performed by drilling about (20) exploratory borehole in Shithatha areas (Al-Atiya *et al*., 1977; Al-Atiya and Mahdi, 1977 – 1981). The results show that the radiometric intensity at Shithatha area and its arable lands ranges between (20 – 400) c/s. and the concentration of (U_3O_8) in soil components near the springs ranges between (10 – 55) ppm, whereas the equivalent concentrations range between (10 – 54) ppm. The radioactive anomaly in the limestone of the Euphrates Formation is distributed in three uranium-bearing zones. Uranium concentration in the first zone ranges between (10 – 200) ppm, whereas in the other two zones, which are subsurface zones consisting of marl and limestone, the average uranium concentration is 71 ppm and 28 ppm, respectively. The exposed rocks of the Euphrates Formation at Abu Sfayah quarry, located about three kilometers to the south of Shithatha town, contain an average concentration of uranium exceeding (70) ppm and consist of tough recrystallized fossiliferous dolostone.

The groundwater in the Shithatha area dissolves uranium of the Euphrates Formation and transports it by spring water flowing to the surface. In the course of time, and as a result of quick evaporation, high radiometric anomalies were formed around the springs where they reached in some locations to more than (800) c/s as in a location near Bardaweel spring. Sulfatic springs of the Shithatha area have the composition (Ca, Mg, Na, Cl and SO_4) and contain high concentrations of uranium equivalent (radium). Some of the springs contain anomalous uranium concentrations which reached up to (50) ppb as in Ein Al-Barakah which is located at a distance of (4) Km to the west of the Shithatha town. The radioactive equilibrium in the area is for uranium equivalent which represents an average of (84%) and that for uranium by an average of about (10%).

All of the previous studies did not recommend further investigations in the Shithatha and Rahaaliya areas because the results showed that the source of the radioactive anomalies in these areas is the primary (syngenetic) uranium concentrations present in the Euphrates Formation. These uranium concentrations are considered economically insignificant in view of the difficulties encountered in uranium extraction from these rocks, as proved in Al-Qaim deposits where the uranium recovery did not exceed 7%.

– **Radioactive anomaly at Taqtaqanah area:** Anomaly (R16) at Taqtaqanah area has the same characteristics as that of Shithatha area. Footborne radiometric survey was carried out by Abdul-Fattah (1978). Al-Kazzaz and Mahdi (1982) performed surface and subsurface exploratory investigations by drilling of (20) exploratory boreholes in order to define the uranium-bearing layer and study the causes of the radiometric anomaly. The results showed the existence of two uranium anomalous layers within the upper part of Euphrates Formation. The first layer contains uranium concentrations in the range of (20 – 292) ppm and the thickness ranges from 20 cm to 40 cm. It consists of solid dolomitic limestone which contains iron oxides, while the second layer consists of porous granular limestone which contains iron oxides and lower uranium concentrations than the first layer. The uranium concentration in the second layer ranges between (20 – 118) ppm and its thickness is about (30) cm.

– **Radiometric anomaly at Al-Shannafiya area:** The radiometric airborne survey of Iraq defined anomaly (R_{20}) in several locations west of Al-Shannafiya town (C.G.G., 1974). The results of the radiometric survey showed the primary correlation of the radiometric anomaly with the locations of springs in the area and with some of the outcrops (Al-Najim and Abid Al-Wahid, 1984). These activities were followed by (Mahdi and Al-Kazzaz, 1984) by more exploration activities focusing upon the sources of the anomaly and assessing their significance. The results indicated that the radiometric anomaly is correlated with the locations of springs and surrounding soil and the intensity becomes lower away from the springs and with depth. The spring deposits contain high concentrations of radium of up to (86) ppm whereas some spring water in the area contain uranium concentrations up to about (15) ppm and the kind of water is (Cl, Na, Ca and SO_4). The source of this water is thought to be deep and it might be a mixture from two sources which is similar to the water of Shithatha area. On the other hand, dolomitic limestone in some layers of the Euphrates and Ghar formations contain uranium concentrations up to (59) ppm in the surface outcrops, but uranium was not detected in the subsurface layers. The study results of Al-Shannafiya showed that radiometric evidences in the area are economically insignificant because the host rocks do not contain valuable uranium concentrations.

– **Uranium deposits in the Abu Skhair Area:** Abu Skhair area is located 18 Km SW of Al-Najaf City (Fig.4). The area is characterized a plane surface containing recent deposits which are a mixture of clays, fine sand and vegetative organic materials resulted from root residues of grass, plants and trees. These deposits are black in some locations especially in Al-Jibsah Marsh. The area is surrounded from the east and northeast by the extension of Tar Al-Najaf highland which is comprised of pebbly sand and sandstone deposits of the Dibdibba Formation (Pliocene – Pleistocene). The Abu Skhair uranium deposit was discovered accidentally in (1977) when the gamma-log of a well, drilled in the Abu Skhair region for groundwater survey, showed anomalous radiation at 70 m depth within the carbonate rocks of the Euphrates Formation (Lower Miocene) (Al-Atiya *et al*., 1983; Al-Atiya and Mahdi, 2005).

The anomaly was followed by subsurface exploration that lasted for about ten years where about 400 exploratory wells were drilled. The final stages witnessed mine design and development of uranium extraction process. A pioneer underground mine was opened and (5) tons of uranium-rich deposits was produced for uranium extraction tests using a pilot plant unit. The mine was opened in 1988 and closed after ten years, according to the decision of the International Security Council, without actually producing any uranium ore, except what was excavated while tunneling.

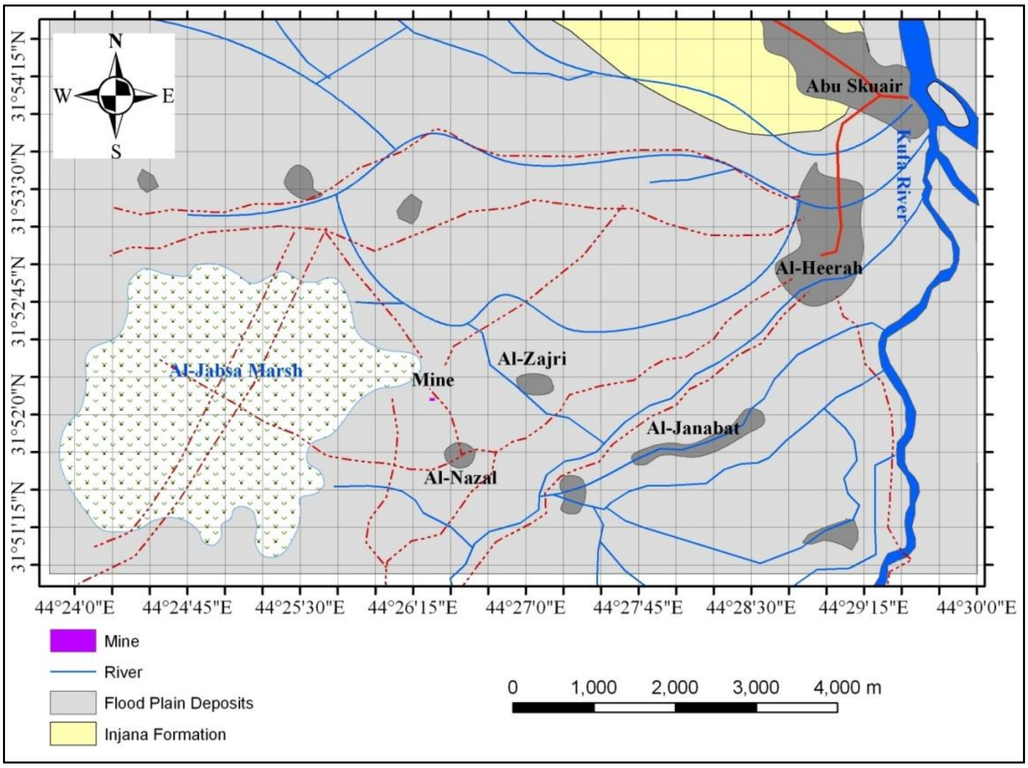


Fig.4: Geological map of the Abu Skhair area showing location of the uranium mine (extracted from Al-Bassam *et al*., 2013)

The results of the exploratory boreholes in the area showed two groundwater-bearing layers (limestone and dolomitic limestone) located at the upper part of the Euphrates Formation and forming two aquifers (upper and lower), separated by a (3) m thick marl layer, Uranium concentration in the groundwater of this area is about (250) ppb. Four carbonate layers containing abnormal concentrations of uranium have been identified (Fig.5). The first (upper) one is the main layer containing uranium deposits and it was the target of detailed assessment and reserve estimation because of its high uranium concentrations in comparison with the other layers.

The main uranium-bearing layer at Abu Skhair area is (0.2 – 4.7) m thick and consists of dolomitic limestone of dark grey color, rich in organic materials and bioclasts of oysters, Uranium concentration in this layer varies and reaches up to 0.4% (U_3O_8). The stratigraphic status of the main uranium layer in the area is determined by the contact zone between the Euphrates and the Ghar formations of Lower Miocene age (Ctyroky and Karim, 1971 and Buday, 1980). This layer is stratigraphically located between the upper part of the Euphrates Formation and the lower part of the Ghar Formation. The lithology of the Euphrates Formation in its upper part consists of dolomitic limestone rich in shelly fossils of pelycepods and gastropods. The rocks of the Ghar Formation, overlying the main uranium-bearing layer, consist of gray clayey sandstone. The other uranium-bearing layers within the Euphrates Formation, located below the main layer, are noticeably poor in uranium concentrations as compared to the upper main layer. Thus, the exploration results concerning these layers were not taken into consideration in the technical estimation of the uranium deposit at Abu Skhair area.

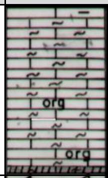
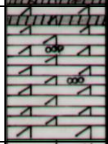
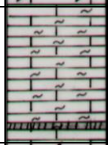
Characteristics of the Uranium Bearing Layers	Facies	No. of Radioactive Zone
Dolomitic limestone, clayey, gray to black in color, contains organic materials, shells and crushed fossils.		1
Dolomitic limestone, yellow in color, cavernous, contains fossils of oyster shells and forms an aquifer.		2
Dolomitic limestone, grey in color and contains organic materials		3
Dolomitic limestone, brown in color, very hard and contain fossils and forms an aquifer.		4

Fig.5: Columnar section showing the lithological characteristics of the uranium-bearing layers in the Abu-Skhair deposit (not to scale)

The nature of uranium mineralization in the main layer of the Abu Skhair deposit was studied by (Mohammad, 1983) and The Centre for Technical Studies of Special Materials (CETEM). Uranium distribution in this layer is agglomerated in the cavities and microscopic cracks of the crushed oyster shell, besides its random distribution in the textural components of the rocks, which is governed by the distribution of organic and clay materials. Two main phases of uranium mineralization were identified: The first one is in the form of uraninite (UO_2) which is not common (CETEM, 1986) and the second is in the form of adsorbed uranium on the organic and clay materials (Mohammad, 1983). The radioactive equilibrium of uranium in this layer is missing and it tends mainly towards uraninite (U_3O_8) at the expense of radium radioactive sequence (eU_3O_8). It was noted that the lack of radioactive equilibrium tended to increase with increasing uranium concentrations. The factor of radioactive equilibrium could be in the range of < 2 to 4.6.

- **Uranium showings in the Western and Southern Deserts**

Extensive exploration activities have been carried out using ground radiometric surveys and drilling of numerous boreholes to investigate the origin of 35 radiometric anomalies identified in the Western and Southern deserts of Iraq by airborne geophysical survey (C.G.G., 1974) (Fig.1). The follow-up results showed that (19) of the radiometric anomalies are correlated with uranium of primary origin present in the widely exposed phosphate rocks especially in the Western Desert. The uranium concentration in these phosphorites ranges between (20 – 100) ppm with an average of (60) ppm (Abdul-Kadir *et al.*, 1976; Al-Najim and Abid Al-Wahid, 1982; Al-Bassam, 2007). Yellow uranium oxides (metatyuyamunite) are noticed in the surface of cracks and rock joints formed due to uranium mobilization from its phosphatic primary sources.

– **Wadi Amij area (anomaly R35):** This radiometric anomaly is correlated with heavy minerals of zirconium and titanium in the sandstone of the Amij Formation (Middle Jurassic) where the radiometric intensity of the sandstone reached up to (500) c/s. It is proved that the radiometric anomalies are correlated with the presence of radioactive monazite and zircon granules (Ismael, 1996).

– **South and southwest of Rutba areas:** A radiometric footborne survey is performed in the area located southwest of Rutba town. The survey covered H_3, Msad Rag'gas, Shuaib Al-Tarfat and other locations south of Rutba town. The radiometric anomalies coincide with the exposures of phosphatic rocks of the Digma (Upper Cretaceous) and Akashat (Paleocene) formations. The radiometric intensity of these locations ranged between (50 – 200) c/s corresponding to an average uranium concentration in the rocks of (80) ppm (Al-Samaraei *et al*., 1975). To follow-up the radiometric anomalies in this area, (28) exploratory boreholes were drilled and (550) rock slides, prepared from samples of boreholes cores, were studied in order to delineate the distribution of phosphatic zones and their uranium content (Abdul-Kadir *et al*., 1976). The first phosphatic zone contains up to (180) ppm uranium; the highest uranium concentrations were found in phosphoclasts and ooids, but there is irregular correlation between uranium and P_2O_5.

– **Al-Salman and Al-Jill areas:** The exploration activities in these areas aimed at the verification of four radiometric anomalies (R33, R32, R31 and R28) by carborne and footborne radiometric surveys. The radiometric activity detected in the rocks of the Umm Er Radhuma and Dammam formations ranged between (160 – 180) c/s, and the highest radiation intensity reached to (680) c/s which is about (3 – 4) times the radiation intensity of the surrounding environment. The average uranium concentration is (60) ppm and P_2O_5 ranged between (5 – 7) wt.%. Al-Kazzaz and Al-Khafaji, (1987) used the (Track etch) method to define the radiation intensity depending on radon gas sensing to count alpha particle radiation emitted from radon gas decomposition in the anomaly areas R24, R23, R28. The study identified significant traces of radon gas leakage. The radiation intensity reached up to (160) c/s with a uranium average concentration of (65) ppm in dolomitic phosphatic rocks.

– **Nekhaib – Al-Lusuf area:** A number of exploration boreholes were drilled to investigate the airborne radiometric anomalies in the area (Khdair and Mohammad, 1984). Three boreholes were drilled with depths ranging from (160 – 180) m. Radiometric well logging of these boreholes were performed to select the sampling intervals. The boreholes penetrated the Zahra Formation (Pliocene – Pleistocene), Dammam Formation (Eocene), Umm Er Radhuma Formation (Paleocene) and Tayarat Formation (Upper Cretaceous). The well-logging process showed two radioactive zones. The radioactive intensity in the first zone is four times the surrounding background (25) c/s. This zone consists of clayey limestone with a thickness of (1 – 2) m and at a depth of (29) m. The radioactive intensity of the second zone is five times the general intensity of the surrounding background.

– **Akashat area (anomaly R7):** Carborne radiometric exploration survey was carried out to verify the source of anomaly R7 in the Akashat area. The results indicate that the anomaly coincides with the Paleocene phosphorite exposures in the area (Al-Najim and Abid Al-Wahid, 1982).

− **South of Nekhaib – Al-Birreet area:** A detailed subsurface investigation to follow up the radiometric anomalies has also been performed (Al-Kazzaz and Al-Khafaji, 1987) by drilling eight boreholes at Al-Birreet area near Keyhole (KH 417). Most of the rocks penetrated during the drilling belong to Tayarat and Hartha formations (Upper Cretaceous), which consist of organic-rich dolomitic limestone. Some anomalous zones of different uranium concentrations were identified. The thickness of these zones ranges between (15 – 70) cm and they contain high percentage of organic materials with uranium concentrations in the range of (14 – 284) ppm.

ORIGIN OF URANIUM MINERALIZATIOIN IN THE LOWER MIOCENE ROCKS

- **Syngenetic uranium mineralization**

Several theories have been presented to explain the uranium source and syngenetic uranium enrichment in certain horizons of the Euphrates Formation (Lower Miocene) along the western parts of the Euphrates River basin. The average concentration of uranium in this kind of rocks is generally low (e.g., about 80 ppm in the Abu Skhair deposit). Thus, it did not attract the attention of exploration surveys, but it is considered an important source of uranium for the epigenetic deposits if suitable conditions are found. The syngenetic uranium enrichment is considered a phenomenon that characterizes the Euphrates Formation along the Euphrates River basin, where uranium anomalies have been identified (Al-Kazzaz and Mahdi, 1991).

− **Phosphate rocks as source of uranium:** This theory is presented by Mahdi and Al-Delaimi (2005) who suggested the exposed marine phosphorites, as a source of syngenetic uranium mineralization in the Lower Miocene rocks. They suggest that upon exposure of these Upper Cretaceous and Paleogene deposits in the Early Miocene, uranium was leached and mobilized by surface waters during wet periods via great rivers flowing from the west, where the phosphorites are exposed, towards the shores of the Early Miocene sea in the east. Mahdi and Al-Delaimi (2005) also included the igneous rocks of the Arabian Shield to be a possible source of uranium transported by fluvial systems towards the Early Miocene sea.

− **Subsurface magmatic igneous rocks as a source of uranium:** This theory is presented by Al-Atiya *et al*. (1977) where a primary uranium source of magmatic origin close to the basement rocks was suggested. In this theory uranium was leached by hydrothermal solutions and travelled long distances upward, through fractures and faults. The dispersed uranium may have been trapped in certain horizons where favorable conditions for uranium accumulation existed. A uranium trap was speculated below bitumen accumulation in some areas such as Hit. The depth of the primary source of uranium was suggested by Al-Atiya *et al*. (1977) to be about 3500 m, based on temperature of spring water and on thermal gradient. They considered spring water as of hydrothermal origin and they suggest that uranium was transported by these waters and concentrated in shallower horizons, rich in hydrocarbon accumulation.

− **Subsurface Paleozoic clastic rocks as source of uranium:** A model is proposed by Al-Bassam *et al*. (2006) that consider the thick uraniferrous Paleozoic clastic rocks as source rocks, lying several kilometers underneath. The late Early Miocene tectonic unrest triggered fracturing and faulting that allowed for uranium-rich groundwater, trapped in the Paleozoic aquifers, to ascend to surface in the shallow parts of the late Early Miocene sea, together with bitumen and H_2S seepages. Uranium was precipitated in the interstitial pore environment, below sediment-water interface, where carbonate ion concentration was low, (following the precipitation of lime mud), uranium concentration was high and strong reductants were available (bitumen and H_2S). Short-lived tectonically-induced regressive phases led to episodes of emergence in the peritidal environment, which caused significant increase in the uranium concentration in the pore water environment leading to thin horizons of anomalous uranium concentration superimposed on a generally higher than background uraniferrous carbonates. Early diagenetic dolomitization trapped the uranium, as urano-organic phases or cryptocrystalline pitchblende, inside the minute dolomite crystals, which generally kept them from oxidation and remobilization.

- **Epigenetic uranium mineralization**

The second type of uranium deposits is epigenetic. Two theories are proposed in this respect for Al-Qaim deposit. The earlier one is postulated by Al-Fadhli and Abdul Kadir, (1969a). They argued about an epigenetic origin for Al-Qaim deposits and according to their hypothesis uranium ion-bearing solutions (pH about 7 – 8) was derived from the source area (uranium-bearing phosphate rocks of the Rutba area) by mean of groundwater. Later Al-Fadhli and Abdul Kadir (1969b) suggested that uranium was precipitated at and below the fluctuated paleo-water table within the pervious and semi-pervious rocks of the Euphrates Formation.

In the Abu Skhair deposit, detailed field and laboratory studies show that the Euphrates Formation suffered oxidation processes in its upper layer containing syngenetic uranium deposits. This resulted in secondary (epigenetic) enrichment of uranium, where the radiometric equilibrium of uranium is sharply inclined towards the radium series. The aforementioned case of oxidation and uranium enrichment was accompanied by a partial erosion of the upper syngenetic uranium-bearing layer, shown in the corrosive, uneven and cavernous contact surface of the oxidized layer with the syngenetic uranium layer below. This is considered as evidence of a short-term discontinuity in the deposition process (hiatus) in the area at the top of the Euphrates Formation. Following the oxidation process and the depositional discontinuity, a state of reducing conditions dominated the system, indicated by dark gray color, dominant presence of pyrite and organic materials including chops of wood and plant residues, suggesting growth of vegetation cover in the area (Al-Atiya and Mahdi, 2005).

URANIUM RESOURCES OF IRAQ

Two uranium deposits have been investigated in detail in Iraq; both of which are strata-bound to the carbonate rocks of the Euphrates Formation (Lower Miocene). The first one is the Al-Qaim deposit, located at the southern side of the Euphrates River near Al-Qaim town in Al-Anbar Governorate, and the second is the Abu Skhair deposit, located near Abu Skhair town in Najaf Governorate. Both deposits contain “lean uranium ore” but the Abu Skhair deposit was followed up by more detailed investigations which led to the opening of an underground mine and uranium extraction tests on a pilot plant scale.

- **Al-Qaim deposit**

Detailed investigations and prospecting for uranium have been carried out in the area between Wadi Al-Qaim and Wadi Al-Jarwa, which resulted in reserve estimation on category C2 by 6000 tons U_3O_8 in an area of 20 Km^2, average thickness of 1 m and average grade of 80 ppm U. Further work identified a 3.4 m thick dolomitic layer covering an area of 105 Km^2, containing 117 ppm U and reserves of 1683 tons U_3O_8 estimated on category C2. A third location in the neighborhood, 0.5 Km^2 in area, was investigated and assessed on category C1, where the average thickness of the U-bearing bed is 1.75 and the uranium concentration is 247 ppm (Al-Kazzaz and Mahdi, 1991).

- **Abu Skhair deposit**

Detailed mineral exploration and assessment have been carried out in the Abu Skhair deposit in the period (1978 – 1987). The results of these investigations pointed out to a uraniferrous clayey fossiliferous dolomitic limestone bed, 0.5 – 4.7 m thick (average = 1.5 m) with up to 3969 ppm uranium concentration. In 1984 the uranium reserves were estimated considering four uranium grades and a thickness range between 1.15 – 1.50 m (Al-Atiya *et al*., 1984) (Table 5). Further work at Hor Al-Jibsa (Fig.4) estimated 230 tons of U_3O_8 reserves on category C1 considering 1 m thick layer with 200 ppm U concentration and covering an area of 0.5 Km^2 (Mahdi and Al-Hamad, 1987).

Table 5: Reserve estimation of the Abu Skhair uranium deposit
(Al-Atiya *et al*., 1984)

Category of reserve estimation*	Reserves (ton)	Area (Km^2)	Number of boreholes	Thickness (m)	Uranium concentration (ppm)
C_2	9170	11.65	114	1.5	125
	3120	5.9	63	1.15	200
	1918	2.7	34	1.15	261
	1060	0.95	11	1.27	367

* Russian norms

CONCLUSIONS

- Uranium occurrences and deposits in Iraq are of three main geological associations; in the Zagros Suture Zone they are related to acidic igneous intrusions (mainly anorthosite) and associated metamorphic rocks (mainly olivine-marble). Along the Euphrates River basin they are related to Lower Miocene carbonate rocks of the Euphrates Formation, and in most of the Western and Southern deserts they are related to marine sedimentary phosphorites of Upper Cretaceous – Paleogene age (mainly Akashat Formation of Paleocene age).
- The uranium occurrences of igneous and metamorphic origin in the Zagros Suture Zone are interesting, but they are not investigated in detail and their subsurface extensions are not known. Hence it is difficult to assess their potential as economic raw material for uranium and other radioactive elements. The showings at Qalat Diza region are encouraging and deserve further work.
- All the uranium deposits and occurrences associated with the carbonate rocks of the Euphrates Formation, especially those investigated in detail at Abu Skhair and Al-Qaim, are lean uranium deposits. They cannot be considered as commercially economic deposits, especially with the problems of uranium extraction from carbonate rocks.
- The main resource of uranium in Iraq is the enormous Paleocene phosphorite deposits of the Western Desert (Akashat Formation). The proved reserves are estimated by about 10000 m.t. with an average uranium concentration of ~50 ppm (Al-Bassam, 2017). Uranium in phosphorites can be easily extracted from phosphoric acid, as by-product during the production of phosphate fertilizers. More than 150 tons of uranium was recovered as yellow cake (Jalhoom *et al*., 2017), but the plant was destroyed during the

1991 war. New industrial projects of phosphate fertilizers industry should consider the essential need to include a uranium-extraction unit from phosphoric acid.

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Mr. Mohammad A. Mahdi graduated from University of Baghdad in 1967 with B.Sc. degree in Geology. He joined the Nuclear Geology Department in the Iraqi Atomic Energy Commission in 1971, and then he moved to GEOSURV in 1979. After along field experience in performing many radiometric surveys and mineral explorations in different parts of Iraq, he was assigned as an expert in mineral investigation. During the last seven years, he was the head of Quality Management Division at GEOSURV. He has more than 80 documented reports and published papers.

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