IRAQI BULLETIN OF GEOLOGY AND MINING
Impact Factor (Arcif) 2020 Q1: 0.0556
IBGM

Iraqi Bulletin of Geology and Mining *Vol.17, No.1, 2021* *p 59 – 72*

CONTRIBUTION TO THE ORIGIN OF THE URANIUM ANOMALY IN THE PLIOCENE AND PLEISTOCENE SEDIMENTS OF THE BASRAH REGION, SOUTH IRAQ

Khaldoun S. Al-Bassam

Received: 19/ 09/ 2020, Accepted: 27/ 12/ 2020
Key words: Uranium; Anah – Abu Jir fault system; Groundwater; Radiation hazard; Basrah; Iraq

ABSTRACT

A spatially large uranium anomaly covering about 20000 Km^2 has been identified in the Basrah region as a result of the regional geochemical soil survey of the Western and Southern deserts of Iraq carried out in the period (1978 – 1983). The anomaly is geogenic; related to a specific bedrock lithology and detected before the Gulf Wars of 1991 and 2003. The mineralogy of the Pliocene – Pleistocene sediments covering most of the anomalous area suggest that part of the U source may be attributed to the U-bearing primary unaltered U-bearing minerals in the fine clastic sediments, derived from the Arabian Shield. On the other hand, the hydrochemistry of the groundwater system and the origin of the uranium occurrences west of the Euphrates River, from Hit to Samawa, permit another possibility to explain the source of U-enrichment in the soils and sediments in the Basrah region, which is the epigenetic enrichment of U associated with evaporate minerals on the land surface originating from uraniferrous groundwater seepages. Uranium enrichment in the shallow aquifers of the area can be supplied from deep uraniferrous sources similar in this respect to numerous cases reported along the Anah – Abu Jir Fault system.

مساهمة في دراسة أصل شاذة اليورانيوم قي ترسبات البلايوسين والبلايستوسين في منطقة البصرة، جنوب العراق

خلدون صبحي البصام

المستخلص

أظهرت المسوحات الجيوكيميائية الإقليمية للتربة في الصحراء الغربية والجنوبية التي أنجزت خلال الفترة 1978 – 1983 وجود منطقة واسعة ذات تراكيز عالية من اليورانيوم تغطي حوالي 20000 كم^2 ضمن محافظة البصرة. ان ارتباط هذه الشاذة بصخارية محددة يؤكد الأصل الجيولوجي الطبيعي لها بالاضافة الى كون المسوحات تمت قبل حربي الخليج في 1991 و 2003. على ضوء المعلومات المتاحة عن معدنية الفتاتيات التي تغطي المنطة يمكن إرجاع جزء من أصل هذا الإغناء الى المعادن الأولية غير المتغيرة الحاملة لليورانيوم في الجزء الناعم من الرواسب. تقدم هذه الدراسة وجهة نظر جديدة لتفسير التراكيز العالية لليورانيوم في المنطقة التي تغطيها ترسبات البلايوسين والبلايستوسين، حيث ترجح الدلائل المتوفرة عن شواذ اليورانيم الموجودة على طول منظومة فالق عنه – ابوجير الذي يمتد جنوبا الى السماوة ان مصدر اليورانيوم يمكن ان يكون المياه الجوفية من الخزانات الجوفية الضحلة الصاعدة الى سطح الأرض بفعل الضغط الهيدوليكي على شكل ينابيع وتسربات مكونة أحواض وترسبات متبخرات ذات محتوى إشعاعي عالي ويعود إغناء الخزانات الجوفية الضحلة باليورانيوم الى صعود مياه جوفية غنية باليورانيوم من خزانات عميقة.

Czech Geological Survey, Prague, Czech Republic, e-mail: albassam703@gmail.com

INTRODUCTION

The regional geochemical survey of the Iraqi Western and Southern deserts, carried out by Iraq Geological Survey in the late seventies and early eighties of the past century, was based on more than 17000 samples collected from top soil and analysed for 13 chemical elements. The analytical data was processed statistically to derive background and threshold values for each element and spatial distribution maps were constructed (Al-Bassam and Yousif, 2014). The regional soil geochemical survey showed outstanding uranium anomaly in the region of the Basrah Governorate covering about 20000 Km^2, in addition to several other anomalies elsewhere in the desert. The sampling and analysis was achieved before the Gulf wars in 1991 and 2003, when depleted uranium was used in military action and before the Chernobyl nuclear accident in 1986, which contaminated soils in some parts of Iraq. For this reason the anomaly is considered geogenic; related to a specific lithology of clastic sediments (Al-Bassam and Yousif, 2014). Some high U concentrations in the soil and groundwater in the Basrah area are proved geogenic after isotopic speciation of U, which excluded the depleted uranium as a source (Alkinani and Merkel, 2018).

The Desert Terrain was dealt with collectively as one physiographic province in the study of Al-Bassam and Yousif (2014), which includes several sub provinces (domains); divided according to dominating bed rock lithology, to show the influence of parent rocks on the elements concentration in the overlying soil (Table 1 and Fig.1). The "Dibdibba Sand Domain", which covers most of the Basrah Governorate, is the subject of the present work; it is part of the Desert Terrain and defined to include collectively the clastics of the Dibdibba Formation (Pliocene-Pleistocene) and the Al-Batin Alluvial Fan sediments (Pleistocene) (Fig.2). This part of Iraq was covered by air-borne radiometric survey carried out by Compagnie General de Geophysique (CGG, 1974), but the results were not presented in the final interpretation report and radiometric maps.

The relatively high background of uranium in the soils and groundwater of the Basrah region has received a lot of attention among the scientific community in Iraq and abroad. Depleted U and radioactivity were linked to the noticeable increase in cancer cases and birth defects among the Basrah citizens (e.g., Al-Azzawi and Al-Naemi, 2002, Al-Hadithi *et al*., 2012, Al-Azzawi, 2015, Al-Hamdany, 2020). The aim of the present contribution is to discuss the possible geogenic sources of the anomalously high uranium concentration in the soils and sediments of the Dibdibba Sand Domain (Basrah Governorate).The ideas presented may add a new perspective on understanding the origin of the anomaly in the area; considering the role of uraniferrous groundwater in the epigenetic enrichment of U in the soils and surface sediments, which can be compared to several uranium anomalies along the Euphrates Fault Zone.

Table 1: Areas covered by the soil geochemical survey in the Desert Terrain (Al-Bassam and Yousif, 2014)

Location	Area (Km^2)	No. of samples	Sampling density Km^2/sample
1. Total Desert	197100	17653	11.2
1.1. Carbonate domain	118600	10742	11.0
1.2. Phosphate domain	20400	2238	9.1
1.3. Laterites domain	13300	1399	9.5
1.4. Dibdibba sand domain	20500	1541	17.2
1.5. Habbariyah gravel domain	18300	1733	10.6

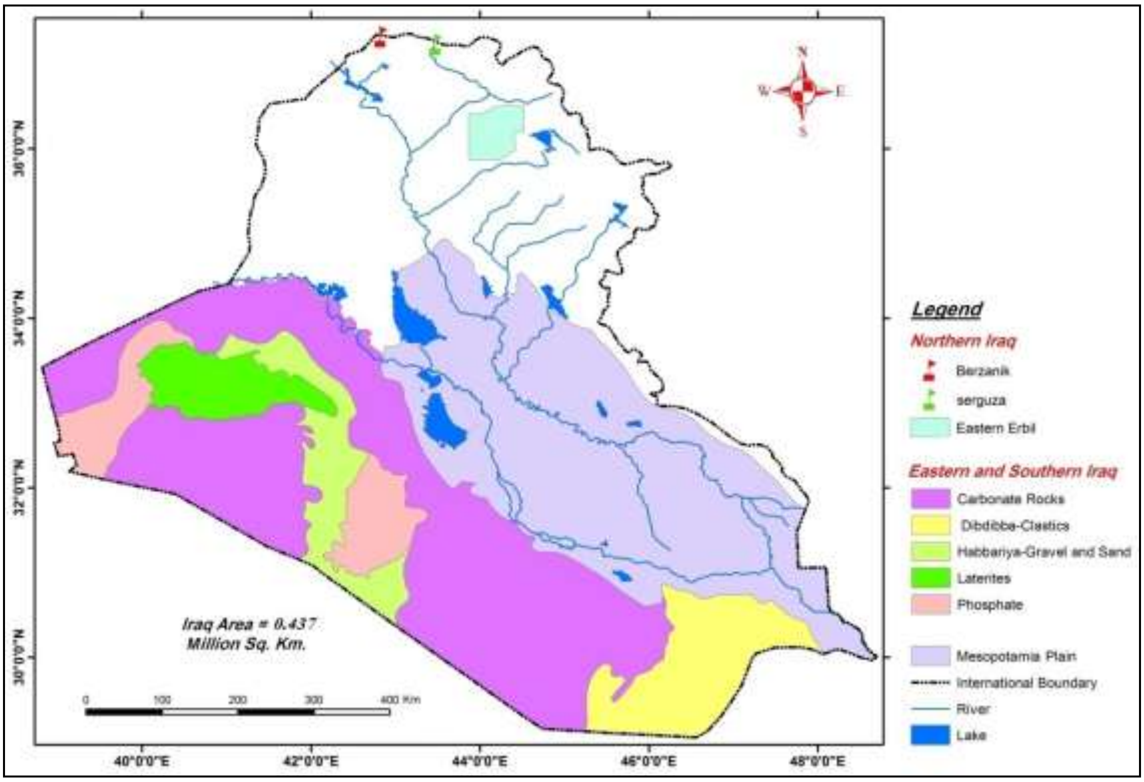

Fig.1: Areas covered by the regional geochemical soil survey
(Al-Bassam and Yousif, 2014)

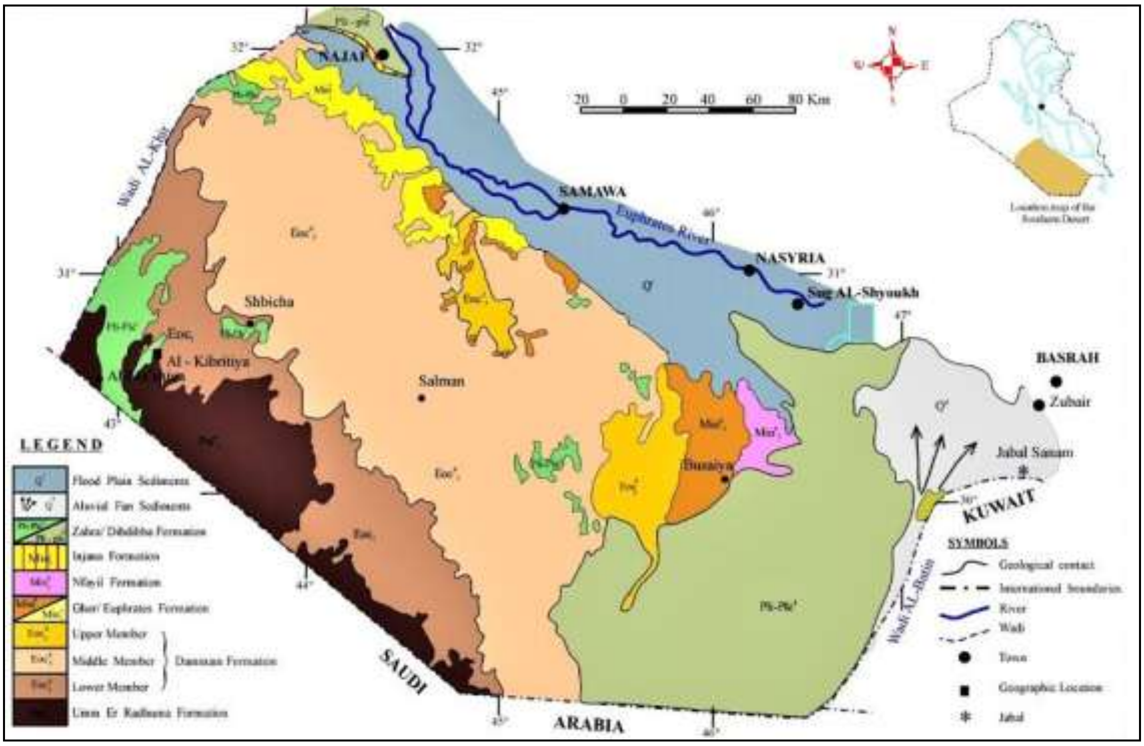

Fig.2: Geological map of the Southern Desert (Adopted from Ma'ala, 2009 after Sissakian, 2000)

PREVIOUS WORK

The Basrah region received the attention of several workers dealing with environmental problems present in this part of Iraq. Several studies have been accomplished, among which are Khwedim *et al*. (2009a) who studied the distribution of heavy metals in the Basrah soil, Khwedim *et al*. (2009b) studied the heavy metals concentration in mollusk shells in the rivers and streams of Basrah City, Al-Muslih (2012) studied the hydrochemistry in the groundwater in the area, but did not include uranium in the analysis, Khwedim *et al.* (2017) studied the Dibdibba aquifer system in the Safwan – Zubair area and found high uranium concentrations in the groundwater which they attributed to geogenic sources.

Alkinani and Merkel (2017 and 2018) and Alkinani *et al*. (2016 and 2019) accomplished interesting results on the distribution of U and other metals in the sediments and groundwater of the Al-Batin Alluvial Fan in the Basrah Governorate. Their work is probably the first systematic approach to present ideas about the uranium enrichment in the sediments and groundwater of the Pleistocene Al-Batin alluvial fan which represents a small part (~6200 Km^2), located in the eastern part of the Dibdibba Domain (Fig.2). The previous authors assume a geogenic source of U from the Arabian Shield in Saudi Arabia, derived by floods and trapped in the east and northeast under reduced conditions. Alkinani and Merkel (2018) explained the release of uranium into the groundwater of Al-Batin aquifer by three hypotheses: The first is desorption of U sorbed onto ferric minerals, the second is desorption of U from clay minerals in mudstone lenses within the aquifer and the third hypothesis is the release of U from the carbonate lattice structure; present as replacement of calcium.

SOURCES OF THE AIR-BORNE RADIOMETRIC ANOMALIES

In 1974 the CGG carried out air-borne radiometric survey for most of the Iraqi territory, excluding the Kurdistan Region. The Basrah Governorate was covered by this survey, but was excluded from the radiometric interpretation maps produced by CGG (1974) for unknown reason. More than 30 radiometric anomalies were identified in the Desert Terrain (Mahdi, 2019); most of them are related to uranium radioactivity and a few to potassium. Later ground follow-up surveys by Iraq Geological Survey provided lithological links and sources of these anomalies, with the exception of the Basrah region obviously (See references listed in Mahdi, 2019). Some of the most outstanding of these radiometric anomalies are reflected and spatially coincided with uranium anomalies in soil.

A remarkable group of semi continuous radiometric anomalies, aligned in N – S direction at the 40º longitude, from the Akashat phosphate mine to Saudi Arabia borders were identified by the CGG air borne survey (see Mahdi, 2019). These anomalies are verified on the ground by U anomalies in the soil overlying the Paleocene and Late Cretaceous phosphorite-bearing rock units (Akashat and Digma formations). Other series of phosphorite-related radiometric anomalies are connected to the Paleocene phosphorite-bearing unit of the Umm Er Radhuma Formation; exposed in the vicinity of the Nukhaib town and extend towards west to the Saudi Arabia boarder. The Iraqi phosphorites, like all marine sedimentary phosphorites, are rich in uranium (Al-Bassam, 2007). The Iraqi deposits contain 30 – 100 ppm uranium; most of it is linked to the apatite structure in substitution for Ca^{2+} as confirmed by several authors (e.g., Altschuler, 1958).

Another group of radiometric anomalies of different intensities extends from Al-Qaim town in the NW to Samawah City in the SE, along the Anah – Abu Jir Fault system (Fig.3). Some of these anomalies were correlated with primary and syngenetic uranium showings in the upper part of the Euphrates Formation, whereas others were attributed to elevated uranium and radium concentrations in and around groundwater springs and bitumen seepages (Mahdi, 2019 and references therein). The radiation intensity ranged in these areas between 500 and 3000 C/S. Uranium analysis of the groundwater flowing from the water springs showed up to 15 ppb U and up to 55 ppm U in the spring sediments (Mahdi, 2019 and references therein).

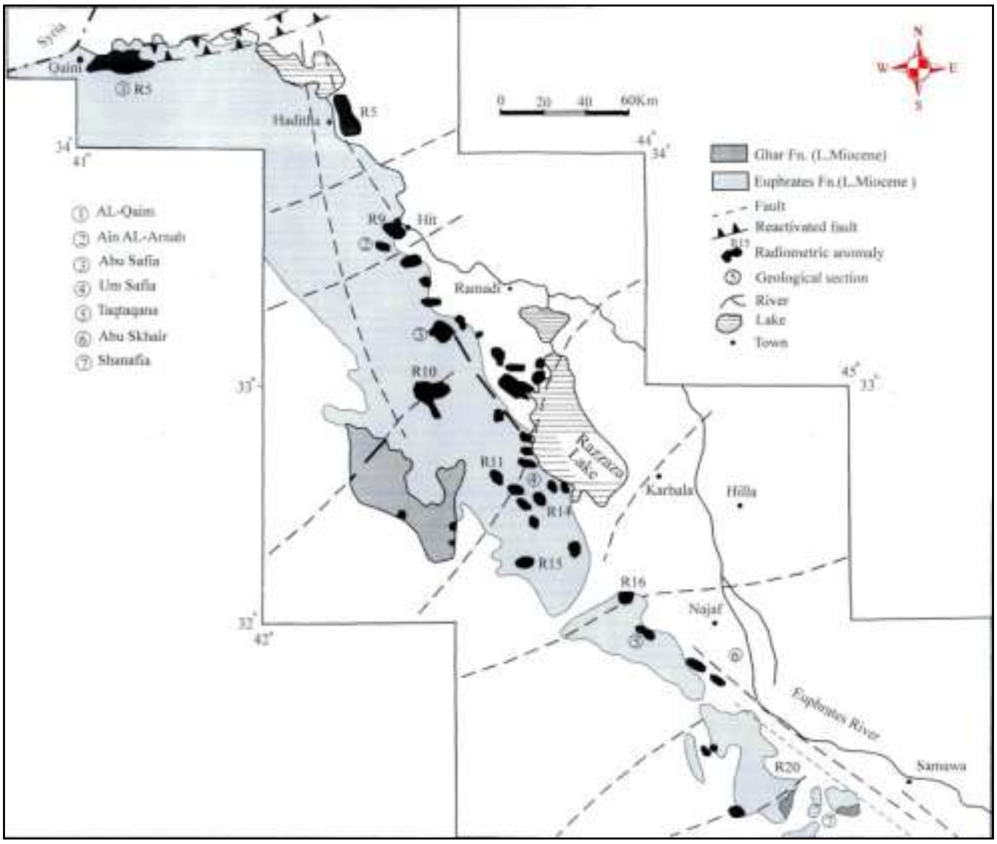

Fig.3: Geological, structural and radiometric map west of the Euphrates River (Compiled by Al-Bassam *et al*., 2006 from: C.G.G., 1974; Buday and Jassim, 1984; Jassim *et al*., 1984 and Fouad *et al*., 1986)

THE DIBDIBBA SAND DOMAIN

It covers most of the Basrah Governorate and dominated by the Dibdibba Formation (Pliocene – Pleistocene) and the Al-Batin Alluvial Fan sediments (Pleistocene) which cover the eastern corner of the Dibdibba Sand Domain (Fig.2). The surface gently declines towards SE, with maximum elevation of 190 m (a.s.l.) and minimum elevation of 1 m (a.s.l.). The area is influenced by several structural features. It is affected by the SE proximity of the NW – SE trending Anah – Abu Jir Fault system (Fouad, 2004, Fouad, 2012 and Sissakian *et al*., 2014) intersected by several NE – SW lineaments; suggested to be faults by Al-Hadithi and Al-Mehaidi (1982). The so-called "Safawi Arch"; trending NE, is a basement swell with down warping on both flanks which created basins, such as the Dibdibba Basin; known as the Basrah – Kuwait Basin (Henson, 1951 and Roychoudhury and Nahar, 1980; in Ma'ala, 2009).

The general aridity of the climate does not exclude intermittent wet periods during the Pliocene and the Pleistocene which are shown in various geomorphological features in the Desert Terrain, such as deeply incised wadis (e.g., Wadi Swab, Wadi Hauran and Wadi Amij) and huge alluvial fans. The gravelly sand sheets of the Dibdibba Formation, and the Al-Batin

Alluvial Fan sediments were transported, under intermittent heavy-rain periods, by flash floods, from the northern Arabian Peninsula via great wadis, such as Wadi Al-Batin, and laid down their loads of sediments as they approached the Mesopotamia Basin (Ma'ala, 2009 and references therein). The Pliocene – Pleistocene (5.3 – 1.8 Ma) was the time of strong influx of terrigenous clastics from the Arabian Shield, due to climatic changes. The sediments filled the structural down warped area of the Dibdibba Basin (Powers *et al*., 1962 in Ma'ala, 2009). During the pluvial periods of the Pliocene and Pleistocene this depression was filled with clastics brought by Wadi Al-Batin.

The lithology of the Dibdibba clastics consists of (80 – 85) % pebbly quartz-sand (monocrystalline quartz), (8 – 9) % igneous rock fragments (granite, granodiorite, rhyolite and andesite) and (7 – 8) % feldspar (fresh and mostly orthoclase) (Sadiq, 1977). Secondary gypsum and gypcrete cement the clastics at surface (Ma'ala, 2009, Jassim and Al-Jiburi, 2009). The Al-Batin Alluvial Fan deposits resemble to some extent those of the Dibdibba Formation and consist of igneous rock fragments, quartz, feldspar, calcite, Fe-oxyhydroxides, clay minerals and secondary gypsum and celestite (Alkinani and Merkel, 2018). The groundwater movement in the area is from WSW to ENE, with groundwater salinity of the Dibdibba aquifer increasing in the lower part to > 10000 mg/l and TDS range between 4790 mg/l and 35710 mg/l; mainly of sulfate and chloride types (Al-Jibburi and Al-Basrawi, 2009).

METHODS OF REGIONAL SOIL SAMPLING AND URANIUM ANALYSIS

Soil and Recent sediments samples were collected during the period (1978 – 1983) from the upper 25 cm section by digging a shallow pit using soil auger. All soil samples were collected from pollution-free areas; away from anthropogenic activities, and before the start of the Gulf war on Iraq, providing an excellent opportunity to drive natural (geogenic) geochemical background values for 13 chemical elements, including uranium, in top soil and sediments in various physiographic terrains of Iraq. The total number of samples collected from the Desert Terrain is 17653 samples and from the Dibdibba Sand Domain (Basrah region) 1541 samples covering areas of 197100 Km^2 and 20500 Km^2, respectively (Table 1). All samples were sieved using a nylon cloth and the (–80) mesh fraction was collected; air dried and kept in polyethylene bags for analysis. Uranium was analysed in the laboratories of Iraq Geological Survey by Fluorometry (Al-Janabi *et al*., 1992), after concentrated HNO_3 digestion and fusion with sodium fluoride.

RESULTS OF THE GEOCHEMICAL SOIL SURVEYS IN THE AREA

The soil samples of the Desert Terrain show U concentrations range of (0.01 – 19) ppm (median 0.1 ppm) (Table 2), which is generally within world average values of (0.3 – 11.7) ppm reported by the United Nation Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 1993). Removing anomalous values (above threshold) a background range of (0.01 – 1.3) ppm (median 0.1 ppm) is obtained for the Desert Terrain soil, where about 99% of the values are less than (2) ppm, and only 1% of the population exhibit higher values (Al-Bassam and Yousif, 2014).

Significant variation of U range and median values exists in soil overlying different lithologies in the Desert Terrain (Table 2); demonstrating parent rock influence. Soils overlying laterites, phosphorites and sandstones (Dibdibba Formation) exhibit higher median values than those overlying carbonates. This is shown in the spatial distribution map of uranium in the Desert Terrain (Fig.4). Uranium only positive correlation; considering the whole sample population of the Desert Terrain, is with P_2O_5 with a poorly expressed log-normal distribution (Al-Bassam and Yousif, 2014).

Table 2: Uranium concentration (ppm) in the soil and Quaternary sediments of the Desert Terrain (Al-Bassam and Yousif, 2014)

Area	No. of samples	Minimum	Maximum	Mean	Median	Standard Deviation
Total Desert terrain	17653	0.01	19	0.3	0.1	0.5
Carbonate domain	10703	0.01	15	0.3	0.1	0.5
Laterites domain	1399	0.07	9	0.6	0.7	0.4
Phosphorite domain	2238	0.1	8	0.6	0.4	0.7
Dibdibba sand domain	1541	0.01	14	0.5	0.3	0.8
Habbariyah gravel domain	1733	0.04	19	0.2	0.1	0.7

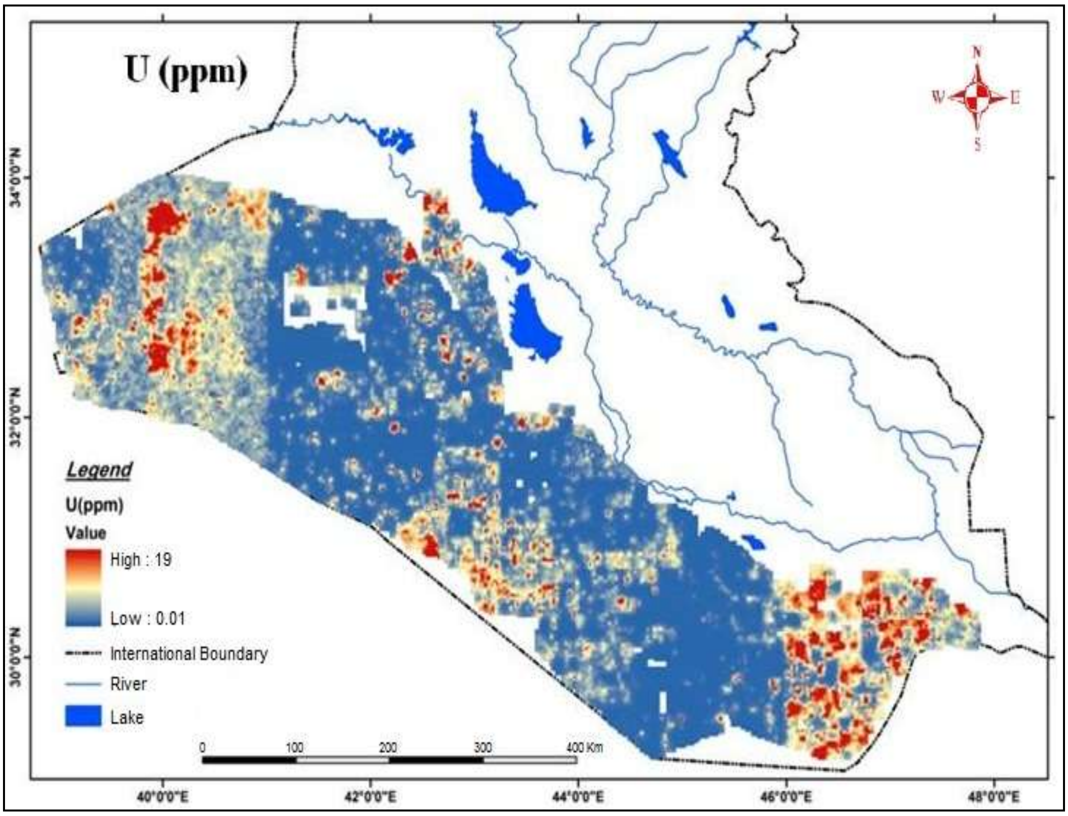

Fig.4: Spatial distribution of uranium concentration in soil of the Desert Terrain (Range = 0.01 – 19.0 ppm) (After Al-Bassam and Yousif, 2014)

The U anomalous zone detected in the regional geochemical survey and discussed in this work covers all the Dibdibba Domain and extends further N and NW to cover parts occupied by carbonates of the Dammam, Ghar and Nfayil formation (compare Figs.2 and 4). Uranium concentration in the soils and surface sediments of the Dibdibba Sand Domain, reported in the regional geochemical soil survey, ranges between (0.01 – 14) ppm, compared to a primary threshold value of 1.3 ppm U for the total Desert Terrain soil (Al-Bassam and Yousif, 2014). These results are comparable to the results obtained in the recent study of the Al-Batin Alluvial Fan sediments by Alkinani and Merkel (2018) who report mean uranium concentration of 2.1 ppm (range 0.6 – 6.9) ppm. They report U concentrations in the fine fraction ranges between 1.2 and 14.1 ppm with an average of 2.85 ppm. High uranium concentrations are also reported by Alkinani *et al.* (2016) in groundwater of the Al-Batin aquifer, reaching up to 98 ppb.

Statistical processing of chemical analyses results of 36 samples collected from the Al-Batin Alluvial Fan sediments (Alkinani and Merkel, 2018) show U, SO_3, Sr and Na grouped in a single factor in the statistical factor analysis and is explained by the authors as an indication of authigenic formation of secondary gypsum, celestite and U concentration under hot arid climate and shallow groundwater. These elements show the same trend of increasing concentration in the distal part of the fan and Alkinani and Merkel (2018) related this to the increase of the fine fraction (clay and silt) and organic matter in the distal part of the fan which is the same trend noticed in the groundwater analysis (Alkinani *et al*., 2016).

DISCUSSION

The main anomalous zones in the soils of the Desert Terrain (red color in Fig.4) are those related to the Paleocene phosphorite exposures in the Akashat and Nukhaib regions and they coincide with the radiometric anomalies identified by the CGG (1974). Another group of uranium anomalies is found at the west bank of the Euphrates River, related to the uranium enrichment in the Miocene rocks and radioactive springs and seepages associated with the Anah – Abu Jir fault system. The largest spatial coverage of uranium soil anomalies is found in the soils and clastic sediments of the Dibdibba Sand Domain (Fig.3). In view of the lack of air-borne radiometric results in this area, which constitutes most of the Basrah Governorate, it is not possible to make any comparison between the radiometric and geochemical results.

Uranium in soil is usually strongly related to parent rocks unless when introduced by anthropogenic factors. It is found in various concentrations in all rock types; among which are marine phosphorites, sandstones and black shale. Its concentration in soil shows a wide range; the world average of U concentration in soil was reported as (1) ppm by Hawkes and Webb (1962). In a later estimate the background range was reported as (0.3 – 11.7) ppm by the UNSCEAR (1993), whereas, Kabata-Pendias (2011) estimated the world average for U concentration in soil by 3 ppm. Uranium may be introduced geogenically to soil by the chemical weathering of and mobilization from uraniferrous parent rocks or introduced by uranium-bearing groundwater.

The source of the clastic sediments of the Dibdibba Formation and the Al-Batin Alluvial Fan is believed to be from the igneous complexes of the Northern parts of the Arabian Shield, fluvial transported by huge valleys, such as Wadi Al-Batin, in the wet periods of the Pliocene and Pleistocene, and were deposited, as the slope breaks, near the gulf, forming alluvial fans (Ma'ala, 2009). These clastic sediments are composed mainly of monocrystalline quartz with significant content of feldspar minerals as grains and pebbles (Sadiq, 1977, Alkinani and Merkel 2018). The feldspars are fresh and coarse in size which indicates mechanical erosion from the igneous parent rocks and short transportation to the depositional site. The presence of monocrystalline quartz and fresh feldspars suggest significant contribution of acidic igneous rocks to the clastics of both the Dibdibba Formation and the Al-Batin fan sediments. Acidic igneous rocks are expected to be rich in zircon, which is an ultrastable mineral under weathering and transportation and contains appreciable amounts of uranium in the structure.

Noticeable increase in the uranium concentrations is reported by Alkinani *et al*. (2016) in the eastern parts of the Al-Batin Alluvial Fan and they attributed this increase to the lowering of redox conditions under the influence of organic-rich fine sediments in the marshes located in that part of the area. The anthropogenic factor in creating the discussed uranium anomaly in the soil and sediments of the Dibdibba Domain can be excluded, since the regional geochemical survey was carried out about 40 years ago, when uranium pollution by military action (such as depleted uranium) was not a possibility. This possibility was also excluded by Alkinani and Merkel (2018) in their post war survey of the area, based on isotopic analysis of uranium.

There is no conclusive evidence to explain the source of the U anomaly in the soil and sediments of the Dibdibba Domain. However, in their recent study of Al-Batin Fan sediments, Alkinani *et al.* (2019), using sequential extraction method, reported about 40% of U concentration is located in the residual fraction (resistant minerals), followed by 23.2% in Fe – Mn oxides, 16.5% in acid-soluble elements fraction, 15.8% in organic matter, 4.3% in the exchangeable fraction and 1% in the water-soluble fraction. These results, although cover a minor part of the Dibdibba Domain area, indicate that about 80% of U in the fan sediments is retained in its parent minerals and about 20% is mobilized. These U-bearing minerals may partly account for the U-anomaly detected in the regional soil survey, assuming a similar trend in the Dibdibba Formation clastics, but it stops short of explaining the extension of this anomaly over the carbonates of the Dammam, Ghar and Nfayil formations exposed in the western part (compare Figs.2 and 4).

The possibility that uranium was transported from the Arabian Shield as soluble uranium phases, suggested by Khwedim *et al*. (2017) and Alkinani and Merkel (2018), requires deep and intense chemical weathering of the parent rocks, believed to be acidic igneous complexes (Sadiq, 1977), which is not likely due to the available facts and observations. U-mobilization on land requires chemical weathering of source rocks, which lacks evidence in the mineralogy and texture of the studied clastics. The soils covering the Dibdibba Domain, as with almost all soils of the Desert Terrain, are immature and often represent residual products of mechanical disintegration of the underlying rocks or transported by water to the depositional site with negligible alteration as is the case in the Dibdibba Domain.

The heterogeneous clastic sediments of both the Dibdibba Formation and the Al-Batin fan are rich in fresh and coarse grained feldspar, reaching up to 10% of the constituents (Sadiq, 1977, Alkinani and Merkel, 2018). Under weathering conditions and soil formation, the feldspars are unstable and usually altered to a variety of minerals (Churchman and Lowe, 2012). The most common of these minerals are kaolinite (Calvert *et al*., 1980, Anand and Gilkes, 1984), mica (Caroll, 1970) and smectite (Allen and Hajek, 1989). Moreover, the sequential analysis carried out by Alkinani *et al.* (2019) show that the majority of U is residing in the resistates and acid-soluble minerals. Kaolinite is not reported in the clay minerals assemblage of the studied clastic sediments; the main clay minerals reported are palygorskite and smectite; the former is found in concentrations >10% of the constituents in some samples (Alkinani and Merkel, 2018). Palygorskite indicates arid climate and increased salinity (Singer, 1984), hence; it cannot develop in tropical weathering conditions. Moreover, gypcrete and gypsiferous crust are dominant in the whole terrain; reaching up to 1.5 m in thickness (Al-Sharbati and Ma'ala, 1983), which point towards the aridity and hot climate of the region. The development of gypcrete requires near-surface sulfate-rich groundwater and arid and hot climate, which dominate the area since the Holocene. The present day pan evaporation exceeds 3000 mm/year and annual precipitation less than 100 mm/year (Iraq Meteorological Organization, 2000).

There is no evidence of laterite formation in Northern Arabia (including the Iraqi desert) since the Upper Cretaceous, when the climate turned generally arid with intermittent rainy periods. Northern Arabia was already at high latitude (~30^{o} N) by the Late Neogene (Popov *et al*., 2006). It should be noted that wet periods do not necessarily induce chemical weathering; on the contrary, heavy rain may assist in the physical disintegration of rocks and their fluvial transportation. Moreover, the Pleistocene witnessed several ice ages in the Northern hemisphere, which was witnessed in Arabia as cold intervals with frequent freezing and thawing episodes that further promoted physical disintegration of the parent rocks.

Alkinani and Merkel (2018) explained the grouping of U with sulfate, sodium and strontium in a single factor as an indication of authigenic formation of secondary gypsum, celestite and U concentration under hot arid climate and shallow groundwater. This association is significant and may suggest epigenetic enrichment of uranium in the gypsiferous surface sediments, originated from uranium-rich and sulfate-rich groundwater during the Holocene. This suggestion is challenged, however, by the very low U concentration in the water-soluble phases (Alkinani *et al*., 2019).

The epigenetic U-enrichment in the sediments and soils of the Dibdibba Domain may be compared to areas influenced by uraniferrous groundwater springs and seepages along the Anah – Abu Jir fault system, where uranium (and radium) is concentrated in the sediments of these seepages. Al-Atia *et al.* (1976, 1977) and Mahdi *et al.* (2005) reported up to 250 ppb U in the groundwater flowing from the uraniferrous springs between Hit and Shithatha areas and up to 24 ppm U in the sediments around these springs. The source of uranium in the groundwater seepages and springs along the Anah – Abu Jir fault system is controversial. Al-Atiya *et al.* (1977) suggested subsurface magmatic igneous rocks as source of uranium in the groundwater; leached by hydrothermal fluids, whereas, Al-Bassam *et al*. (2006) suggested deep-seated old (Paleozoic) uraniferrous formations. Al-Qwaizi (1977) found anomalous U concentrations in the subsurface Paleozoic units of the Western and Southern deserts. He reported for the Ordovician sandstone (46 – 124 ppm), Ordovician shale (23 – 76 ppm), Silurian black shale (46 – 124 ppm) and Permocarboniferous sandstone (71 – 99 ppm).

The Dibdibba Domain is influenced by the Anah – Abu Jir fault system and intersected by several transversal faults (Ma'ala, 2009). These can form conduits for the deeper uranium-rich groundwater to feed shallow aquifers with U-rich waters and reach the earth surface when the hydraulic gradient is zero forming springs and seepage. Sulfate-rich groundwater can also migrate upward by capillary action, when the water table is at shallow depth, and form uraniferrous gypsiferous crusts, enhanced by high permeability of the clastic sediments and high evaporation rate in the region. Alkinani *et al*. (2016) reported up to 98 ppb U in the groundwater of Wadi Al-Batin Fan aquifer, whereas Khwedim *et al*. (2017) reported up to 64 ppb U in the groundwater aquifer of the Dibdibba Formation in the area. The enrichment of U in the groundwater of Al-Batin aquifer is suggested to be due to mobilization of U from surface to the groundwater (Alkinani *et al*., 2016). An alternative possibility is presented in this study that U was introduced to the shallow aquifers from deep sources via faults and conduits, same as many uraniferrous groundwater aquifers along the Anah – Abu Jir fault system.

The groundwater aquifers in the area, which have been shown to contain anomalous concentrations of dissolved U (Alkinani *et al.*, 2016 and Khwedim *et al*., 2017), can carry anomalous concentrations of dissolved U to the surface by hydraulic pressure and/or by capillary action induced by evaporation, similar to numerous groundwater discharge areas along the Anah – Abu Jir fault system, where uranium is concentrated in the surrounding sediments forming significant uranium anomalies (Fig.3). Uranium, dissolved in shallow groundwater, will precipitate with the evaporate minerals on the surface forming crusts and cementing material to the sandy sediments. In the pluvial periods of the Pliocene and Pleistocene, the groundwater recharge becomes extremely high creating high subaerial flow at the discharge zone, along the Euphrates faults, flooding the whole area of influence, where a gypcrete zone is developed now (Sissakian and Ibrahim, 2005). In the dry periods, the salts carrying high concentrations of U, precipitated in the studied region as gypsum and formed a crust of uraniferrous gypcrete and gypsiferous soil, which was developed over successive wet and dry periods of the Pliocene and Pleistocene and finally matured during the dry and hot climate of the Holocene to form up to 1.5 m thick sandy and pebbly gypsiferous sandy horizon at the surface (Krasny, 1982, Al-Sharbati and Ma'ala, 1983, Jassim and Al-Jiburi, 2009). The largest, most continuous and thickest non-pedogenic gypcrete and calcrete are those developed within the capillary fringe or overlapping vadose subzones above a shallow groundwater where some of the world class economic uranium deposits are found (Carlisle, 1980).

Some uranium that may account for the anomaly in the Dibdibba Domain is expected to be incorporated in the detrital U-bearing primary minerals such as zircon and/or monazite, but this may account for the uranium anomaly recorded in the clastic-covered part only. The regional geochemical survey (Al-Bassam and Yousif, 2014) shows the uranium anomaly covering the whole of the Dibdibba Domain including clastics- and carbonates-covered areas and not restricted to the clastics-covered part (see Fig.4). Alkinani and Merkel (2018) suggested that uranium in the Al-Batin Alluvial Fan deposits is linked to organic-rich fine sediments, despite the lack of any significant correlation between U and Al, Fe, Mg and K, which are usually enriched with clay minerals in the fine fraction. On the contrary, U is shown by these authors to be linked to evaporate minerals and grouped in one factor with SO_3, Sr and Na. Uranium may form its own minerals in the secondary environment; such as carnotite and tyuyamunite; common as weathering products of phosphate deposits (Al-Bassam, 2007) and in calcrete and gypcrete deposits (Carlisle, 1980). In addition, several hydrated uranium sulfate minerals; identified in the early decades of the past century, may also form in the secondary environment (e.g. uranopilite, zippeite and johannite; c.f. Frondel (1958). It is worth mentioning in this respect that almost all the uranium present in the phosphogypsum waste at Al-Qaim Fertilizer Plant is present as water-soluble U-sulfate (Jalhoom *et al*., 2017).

CONCLUSIONS

Uraniferrous groundwater aquifers may have contributed to the U enrichment in the surface soils and sediments of the Dibdibba Domain and neighboring area in the west. The source of uranium in these shallow aquifers may have originated from deeper aquifers which have been feeding shallow aquifers (via faults) and the Earth surface (via springs, ponds, and seepages). In addition, primary, unaltered and resistant U-bearing minerals present in the fine fraction of the clastics can be another source of the U anomaly.

There is no direct evidence to support the mobility of U, from the source area in the Arabian Shield, in dissolved free ionic forms to feed the groundwater in the area. Such mobilization requires intense chemical weathering of the primary U-bearing igneous rocks at the source area, which is not supported by any evidence. All observations indicate physical erosion of source rocks and short distance and time of transportation for the clastics of the Dibdibba Formation and Wadi Al-Batin fan, illustrated in the considerable content of fresh feldspars, lack of kaolinite, dominant palygorskite and development of thick gypsiferous and gypcrete horizons.

ACKNOWLEDGMENTS

Thanks are due to Dr. Majid Alkinani, Senior Chief Geologist at Iraq Geological Survey, for reading the manuscript and providing useful comments that helped in improving the context of the article. Thanks are also due to Mr. Hayder H. Taha, Senior Technical Director at the survey, for the technical editing of the article.

REFERENCES

Al-Atiya, M.J., Mahdi, M.A. and Al-Abbousi, M., 1976. Geochemical exploration for uranium in the Qalat Diza area. GEOSURV, int. rep. no. 1671 (in Arabic).

Al-Atiya, M., Mahdi, M.A., Al-Aboosy, Al-Delaimi, M. and Ali, K.M., 1977. Geochemical investigation of Hit and Shithatha radioactive thermal springs. GEOSURV, int. rep. no. 1686 (in Arabic).

Al-Azzawi, S.A., 2015. Depleted uranium and radioactive contamination in Iraq: An overview. Global Raesearch, Vol.1, p. 1 – 10.

Al-Azzawi, S. and Al-Naemi, A., 2002. Risk assessment related to radiological contamination resulted from the use of DU ammunition in al-Basrah war zone", proceedings of the conference on the effects of the use of DU weaponry on human and environment in Iraq, March 26 – 27, 2002, Baghdad, Iraq.

Al-Bassam, K.S., 2007. Uranium in the Iraqi phosphorites. Iraqi Bull. Geol. Mining., Vol.3, No.2, p. 13 – 31.

Al-Bassam, K. and Yousif, M., 2014. Geochemical distribution and background values of some minor and trace elements in Iraqi soils and recent sediments. Iraqi Bull. Geol. and Mining, Vol.10, No.2, p. 109 – 156.

Al-Bassam, K.S., Mahdi, M.A. and Al-Delaimi, M., 2006. Contribution to the origin of the syngenetic uranium enrichment in the Early Miocene carbonates of the Euphrates Formation, Iraq. Iraqi Bull. Geol. Min., Vol.2, No.2, p. 1 – 21.

Al-Hadithi, T.M.S. and Al-Mehaidi, H.M., 1982. Photogeological – Hydrogeological survey of the Southern Desert (Blocks 1, 2, 3). GEOSURV, int. rep. no. 1251.

Al-Hadithi, T., Al-Diwan, J.K., Saleh, A.M. and Shabila, N., 2012. Birth defects in Iraq and the plausibility of environmental exposure. Conflict and Health, Vol.6, No.3, p. 1 – 7, doi: 10.1186/1752-1505-6-3.

Al-Hamdany, M.Z., 2020. Post-war environmental pollution as a risk of congenital disorders in Iraq. A study review. Iraqi National Journal of Medicine, Vol.2, No.1, p. 32 – 47, doi:10.37319/iqnjm.2.1.1.

Al-Janabi, Y., Al-Sa'adi, N., Zainal, Y., Al-Bassam, K.S. and Al-Delaimi, M., 1992. Work Procedures of Iraq Geological Survey: Part 12: Chemical Laboratories. GEOSURV, int. rep. no. 2002.

Al-Jiburi, H.K. and Al-Basrawi, N.H., 2009. Hydrogeology. In: The Geology of the Iraqi Southern Desert, Iraqi Bull. Geol. Min., Special Issue no.2, p. 77 – 91.

Alkinani, M. and Merkel, B., 2017. Hydrochemical and isotopic investigation of groundwater of Al-Batin Alluvial Fan aquifer, Southern Iraq. Environ. Earth Sci., Vol.76, No.7, p. 301 – 322, doi:10.1007/s12665-017-6623-8.

Alkinani, M. and Merkel, B., 2018. Geochemistry of sediments of the Al-Batin alluvial fan, southern Iraq. Environ. Earth Sci., Vol.77, No.7, p. 282 – 296, doi.org/10.1007/s12665-018-7461-z.

Alkinani, M., Kanoua, W. and Merkel, B., 2016. Uranium in groundwater of the Al-Batin Alluvial Fan aquifer, Southern Iraq. Environ. Earth Sci., Vol.75. No.10, p. 869 – 881, doi.org/10.1007/s12665-018-7461-z.

Alkinani, M., Wiche, O., Kanoua, W. and Merkel, B., 2019. Sequential extraction analysis of U, Sr, V, Ni, Cr, B, and Mo in sediments from the Al-Batin Alluvial Fan, Southern Iraq. Environ. Earth Sci., Vol.78, No.24, p. 684 – 696, doi.org/10.1007/s12665-019-8730-1.

Allen, B.I. and Hajek, B.F., 1989. Mineral occurrencein soil environments. In: J.B. Dixon and S.B. Weed (Eds.); Minerals in Soil Environments. 2nd Edition. Soil Society of America, Madison, Wisconsin, U.S.A.
Al-Muslih, S., 2012. Hydrogeological and hydrochemical study of Al-Basrah quadrangle (NH-38-8) and Abadan quadrangle (NH-39-5) scale 1: 250 000. GEOSURV, int. rep. no. 3402.
Al-Sharbati, F. and Ma'ala, K., 1983. Report on the regional geological mapping Al-Sharbati F, Ma'ala K (1983) Report on the regional geological mapping of west of Zubair area. GEOSURV, int. rep. no. 1345.
Anand, R.R. and Gilkes, R.J., 1984. Weathering of ilmenite in lateritic pallid zone. Clays and Clay Minerals, Vol.32, No. 5, p. 363 – 374, doi.org/10.1346/CCMN.1984.0320504.
Al-Qwaizi, M., 1977. Geochemistry, mineralogy and sedimentology of Paleozoic rocks in deep wells, western Iraq. Ph.D. Thesis, University of Baghdad, 190pp (in Arabic).
Altschuler, Z.S., Clarke, R.S. and Young, E.J., 1958. The geochemistry of uranium in apatite and phosphorite. USGS Prof. Paper no. 314D, p. 45 – 90.
Buday, T. and Jassim, S.Z., 1984. Tectonic Map of Iraq (scale 1: 1000 000), 1st ed. GEOSURV, Baghdad.
Calvert, C.S., Boul, S.W. and Weed, S.B., 1980. Mineralogical transformation of a vertical rock-saprolite-soil sequence in the North Carolina Piedmont. Soil Science Society of America Jourvnal, Vol.44, issue 5, p. 1096 – 1112, doi.org/10.2136/sssaj1980.03615995004400050044x.
Carlisle, D., 1980. Possible variations on the calcrete-gypcrete uranium model. United States Department of Energy, report, 38pp.
Caroll, D., 1970. Rock Weathering. Monograph in Geoscience. Plenum Press, New York, 168pp.
Companie General de Geophysique (C.G.G), 1974. Aeromagnetic and aerospectrometric Survey of Iraq Interpretation report. GEOSURV, int. rep. no. 2642.
Churchman, G.J. and Lowe, D.J., 2012. Alteration and occurrence of minerals in soil. In: P.M. Huang, Y. Li and M.E. Sumner (Eds.). Handbook of Soil Sciences, 2nd edition, Vol.1: Properties and Processes. CRC Press (Taylor and Francis), Boca Raton, F1, p. 1 – 72.
Fouad, S.F, 2004. Contribution to the structure of Abu Jir Fault Zone, West Iraq. Iraqi Geol. Journal, Vol. 32 – 33, p. 63 – 73.
Fouad, S.F., 2012. Tectonic Map of Iraq (scale 1: 1000 000) 3rd. ed. GEOSURV, Baghdad.
Fouad, S.F., Al-Marsoumi, A.M., Saleh, F., Hasan, F.A. and Nano, H.O., 1986. Detailed geological survey of Anah area. GEOSURV, int. rep. no. 1527.
Frondel, C., 1958. Systematic Mineralogy of Uranium and Thorium. U.S.G.S. Bull. no. 1064, 397pp.
Hawkes, H.E. and Webb, J. S., 1962. Geochemistry in Mineral Exploration. Harper and Row, 377pp.
Iraq Meteorological Organization, 2000. Climatic Map of Iraq. Ministry of Transportation, Iraq.
Jalhoom, M.G., Al-Bassam, K. and Humaidi, A., 2017. Recovery of some trace elements from Iraqi phosphate products. Iraqi Bull. Geol. Min., Special Issue No.7, p. 79 – 92.
Jassim, S.Z., Karim S., Al-Mubarak M.A., Basi, M. and Munir, J. 1984. Final report on the regional geological survry of Iraq. Vol.3: Stratigraphy. GEOSURV, int. rep. no. 1447.
Jassim, R.Z. and Al-Jiburi, B.S., 2009. Stratigraphy. In: The Geology of the Iraqi southern Desert. Iraqi Bull. Geol. Min., Special Issue no.2, p. 53 – 76.
Kabata-Pendias, A., 2011. Trace Elements in Soil and Plants, 4th ed. CRC Press, Boca Raton, 520pp.
Khwedim, K. H., Al-Ansari, H.R. and Al-Bassam. K.S., 2009a. A study of heavy elements distribution in mollusk shells at the shores of Abi Alkhasib and Alkhora River, Basrah City, South Iraq. 3rd Sccientific Conference of the College of Science, University of Baghdad, 24 – 26 March, 2009. Proceedings, p. 1685 – 1692 (in Arabic).
Khwedim, K.H., Al-Ansari, H.R. and Al-Bassam. K.S., 2009b. A study of some heavy elements in the soil of the Basrah City, South Iraq. Iraqi Journal of Science, Vol.50, No.4, p. 533 – 542 (in Arabic).
Khwedim, K.H., Schneider, M., Ameen, N., Abdulameer, A. and Winkler, A., 2017. The Dibdibba aquifer system at Safwan – Zubair area, southern Iraq, hydrogeology and environmental situation. Environ Earth Sci., Vol.76, No. 4, p. 155 – 167, doi.org/10.1007/s12665-017-6469-0.
Krasny, J., 1982. Hydrogeology of Al-Basrah area. GEOSURV, int. rep. no. 1337.
Mahdi, M.A., Al-Atiya, M.J. and Al-Bassam, K.S., 2005. Factors controlling uranium distribution in the main uranium-bearing bed of Abu Skhair deposit, Najaf area. Iraqi Bull. Geol. Min., Vol.1, No.2, p. 23 – 35 (in Arabic).
Mahdi, M.A., 2019. Uranium deposits and occurrences in Iraq. In: K. Al-Bassam and V. Sissakian (Eds.). The Geology and Economic Potential of Mineral Deposits and Occurrences of Iraq. Iraqi Bull. Geol. Min., Special Issue no.8, p. 1 – 18.
Ma'ala, K.A., 2009. Tectonic and structural evolution of the Iraqi Southern Desert. In: The Geology of the Iraqi Southern Desert. Iraqi Bull. Geol. Min., Special Issue no.2, p.35 – 52.
Popov, S., Shcherba, I., Ilyina, L., Nrvesskaya, L., Paramonova, N., Khondkarian, S. and Masgyar, I., 2006. Late Miocene to Pliocene palaeogeography of the Paratethys and its relation to the

Mediterranean. Palaeogeography, Palaeoclimatology, Palaeoecology, Vol.238, No. 1 – 4, p. 91 – 106, doi.org/10.1016/j.palaeo.2006.03.020.

Singer, A., 1984. Pedogenic palygorskite in the arid environment. p. 169 – 175. In: Palygorskie-Sepiolite: Occurrences, Genesis and Uses; A. Singer and E. Galan (Eds.). Development in Sedimentology, Vol.37. Elsevier, Amsterdam.

Sissakian, V., 2000. Geological Map of Iraq (scale 1 000 000), 3rd ed. Iraq Geological Survey, Baghdad.

Sissakian, V. and Ibrahim, F.A., 2005. Geological Hazards Map of Iraq (scale 1: 1000 000), 1st ed. GEOSURV, Baghdad.

Sissakian, V., Shihab, A., Al-Ansari, N. and Knutsson, S., 2014. Al-Batin Alluvial Fan, southern Iraq. Journal of Earth Sciences and Geotechnical Engineering, Vol.6, No.11, p. 699 – 711. doi:10.4236/eng.2014.611069.

Sadiq, J.M., 1977. Sedimentological investigation of the Dibdibba Formation, southern and central Iraq. M.Sc. Thesis, University of Baghdad.

UNSCEAR, 1993. Sources and effects of ionizing radiation. UN Scientific Committee on the Effects of Atomic Radiation, ISBN 92-1-142200-0.