DOI: 10.24996/ijs.2022.63.9.12

ISSN: 0067-2904

Study of Light and Heavy Minerals and Their Effect on Oil Aggregation in the Zubair Formation for the Rumaila Oil Field in Southern Iraq

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Received: 23/9/2021 Accepted: 12/12/2021 Published: 30/9/2022

Abstract

Zubair Formation is the most productive reservoir in southern Iraq, which is comprised of sandstones, interbedded with shale sequences and sometimes carbonate rock. It is an important formation in the lower Cretaceous cycle in Iraq. Rumaila oil field is the largest oil field in Iraq and the 6th in the world. Two wells were studied for three depths, one in the southern Rumaila and the other in the north. The study focused on light and heavy minerals in sand fractions and their relationship with hydrocarbon assemblages. For the survey to be complete, the sedimentological study of the cores was also conducted. This research aims to determine the effect of the amount of heavy and light minerals on the generation and production of oil in the reservoir layers. The sedimentological results were the prevalence of sand for all depths, especially in Southern Rumaila. The sand ratio ranged from 62% to 98%. The rate of heavy minerals in southern Rumaila was greater than in Northern on average at 1.17%. Light minerals were the most in Northern Rumaila up to 99.3% represented in quartz with a high percentage and a little part of feldspar represented in orthoclase. Heavy minerals were represented in Opaque (24%), zircon (27.6%), tourmaline (18%), rutile (11%), biotite (3%), chlorite (3.6%), muscovite (3.6%), staurolite (2%) and hornblende (3.6%). The proportion of quartz was the most in light minerals. The average of minerals is ultra-stable, and Opaque is the most dominant over the other minerals. Ultra-stable minerals in the sand that contain hydrocarbon assemblage are an index to mineralogical maturity for sandstone rocks. The SEM images showed deformations in quartz grains due to the high energy; on the other hand, the roundness and sphericity of the grains were evident, especially in Southern Rumaila sands.

Keywords: Zubair Formation, sedimentological, heavy minerals, Rumaila oilfield, light minerals, ultra-stable, SEM study, and texture.

دراسة المعادن الثقيلة والخفيفة وتأثيرها على تجمع البترول في تكوين الزبير لحقل الرميلة النفطي جنوب العراق

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الخلاصه

يعتبر تكوين الزبير هو الخزان الأكثر إنتاجية في جنوب العراق ، والذي يتألف من أحجار رملية متداخلة مع تتابعات السجيل الصفائحيٍ(Shale) وأحيانًا صخور كاربونية. الزبيرتكوين مهم في دورة العصر الطباشيري الاسفل في العراق. حقل الرميلة النفطي هو أكبر حقل نفط في العراق والسادس في العالم. تمت دراسة بئرين لثلاثة أعماق أحدهما في الرميلة الجنوبية والآخر في الشمالية. ركزت الدراسة على المعادن الخفيفة والثقيلة في أجزاء الرمال وعلاقتها بتجمعات الهيدروكربونات. ولكي تكتمل الدراسة ، أجريت أيضًا الدراسة الرسوبية للكورات. الهدف من هذا البحث هو تحديد تأثير كمية المعادن الثقيلة والخفيفة على توليد وإنتاج النفط في طبقات المكمن. وأظهرت النتائج الرسوبية انتشار الرمال لكافة الأعماق وخاصة الرميلة الجنوبية. تراوحت نسبة الرمل بين (62٪ – 98٪) ، وكان معدل المعادن الثقيلة في الرميلة الجنوبية أكبر منه في الشمالية بمعدل (1.17٪) ، بينما كانت المعادن الخفيفة هي الأكثر في الرميلة الشمالية حتى (99.3٪) ممثلة في الكوارتز بنسبة عالية وجزء ضئيل من الفلسبار ممثل في الاورثوكليز. تمثلت المعادن الثقيلة في المعادن المعتمة (24٪) ، الزركون (27.6٪) ، التورمالين (18٪) ، الروتيل (11٪) ، البيوتايت (3٪) ، الكلوريت (3.6٪) ، المسكوفيت (3.6٪) ، الشترولايت (2 ٪) وهورنبلند (3.6 ٪). الكوارتز هو الأكثرنسبة في المعادن الخفيفة. تعتبر المعادن فوق الثابتة Ultra stable والمعادن المعتمة Opaque هي الأكثر انتشارًا بين بقية المعادن. تعتبر المعادن فوق الثابتة في الرمال التي تحتوي على تجمعات هيدروكربونية كمؤشرللنضوج المعدني في الصخور الرملية. اظهرت دراسة صور SEM تشوهات في حبيبات الكوارتز بسبب الطاقة العالية ؛ من ناحية اخرى كانت الاستدارة والتكور واضحة في حبيبات رمال الرميلة الجنوبية.

1- Introduction

The most important economic application for heavy mineral analysis is the correlation of hydrocarbon reservoir sandstones. Studying Zubair Formation was in 1984 in the south of Iraq by drilling the first oil well. Buday,1980 [1], confirmed that Zubair Formation offered to specify the prevalent oil-bearing sequences and terrigenous clastics south of Iraq, and it is vastly distributed in the Arabian Gulf zone besides in Iran and Syria.

The Zubair Formation has been studied by many authors [2], [3], [4], [5], [6], and [7], but they have not dealt with the heavy minerals. Al-Sayab, 1989 [8], pointed out that Zubair Formation is the main formation of the Lower Cretaceous depositional cycle in Iraq. The main component of the sandstone in Zubair Formation is quartz with a minor percentage of silt and clay minerals. Sand grain size ranges from very fine to medium, with roundness ranging from sub-angular to sub-rounded [9] and [10]. Hounslow and Morton [11], Proved that Opaque minerals that are excluded from the count (e.g. ilmenite, magnetite...), minerals that are potentially unrepresentative (carbonates, authigenic minerals) or minerals whose specific density is influenced by containment of another mineral of greater density (magnetite, ilmenite, etc.) than that of the host mineral. The grains of monocrystalline sand is a grain that consists of a single crystal [12]. Heavy mineral correlation is one of a family of provenance-based tools that also includes chemo stratigraphy [13]. Assemblages of heavy minerals in the Zubair Formation reflect a combined source, pegmatite, acidic plutons, and older sedimentary rocks. It is assured by studying these minerals under the microscope [14]. Generally, a high percentage of quartz has greater potential reservoir quality [15]. Stability values are assigned according to the relative-stability pattern for heavy minerals during burial diagenesis [16]. Since the heavy minerals form a tiny fraction of sand, their persistence is significant only in terms of hardness and durability relative to the major granular components present, which in the case of the study area consist of quartz, feldspar, and lithic grains [17] and [18]. Morton and Milne, 2012 [19], referred to that heavy mineral data are used in the decision-making process in a variety of situations, including picking of casing and coring points, whether to maintain or alter the good trajectory and when to terminate drilling. Heavy minerals have also been used to monitor stratigraphy and to pick formation tops when logging tools have failed, allowing drilling to continue and avoiding tripping to change the bottom-hole assembly. Al-Mayyahi, 2018 [20] indicated that the oil production in the southern Rumaila field is more than in the northern Rumaila because the proportion of silt and clay (matrix) in the north is more than in the south. Also, Gkay and Rex, 1966 [21] mentioned that the clay minerals in the Mica group where illite may enter within spaces between grains, narrowing or closing this space, resulting in decreased permeability. This research aims to determine the effect of the amount of heavy and light minerals on the generation and production of oil in the reservoir layers.

2- Study area

The study area is located in the Rumaila oil field, northwestern Basra, Southern Iraq. Two wells were selected from the group of wells in the field, one in North Rumaila and the other in South Rumaila. Approximately the field lies between 47º14` 47 Longitude and 30º13` 03 Latitude. Well T represents North Rumaila and lies between (30 º27 `9.5) Latitude and (47º20` 55) Longitude. The well R represents South Rumaila lies between (30 º9 `34.15) Latitude and (47º22` 53.55) Longitude (Figure 1).

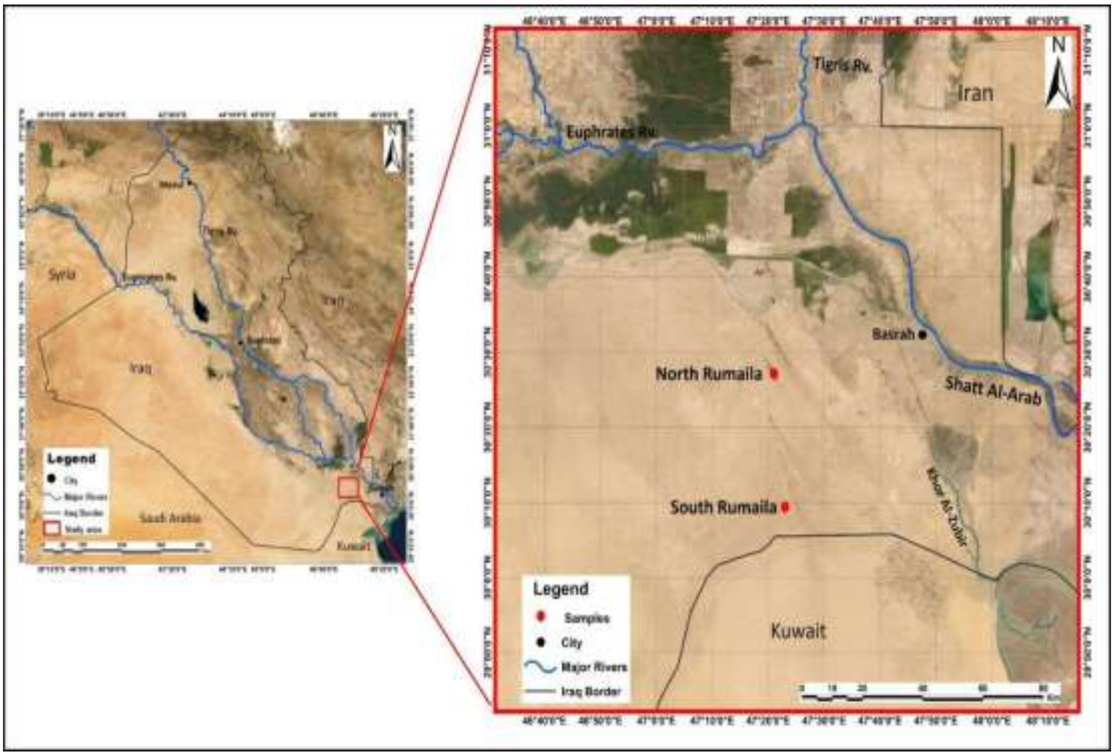

Figure 1- The location map shows the Rumaila Oil field.

3- Geological setting

According to Buday and Jassim, 1987 [22], the Mesopotamian zone lies within an unstable shelf of the Arabian platform. In these divisions, Jassim and Goff, 2006 [23], depend on classical geosynclinal theory. The study area lies in the sagged basin within the Mesopotamian zone of the qusiplatform foreland belt of the Arabian plate. Rumaila Oil field Structure is laying within Zubair Subzone. Jassim and Goff, 2006 [23], mentioned that the Zubair Subzone is constrained from the north by the Takadid-Qurna Transversal Fault. These subzone structures are long and relatively narrow anticlines separated by broader synclines, particularly in the east. The huge sandstone amount of Zubair formation (reservoir) results from erosion of the western Arabian Shield and the uplift in the Early Cretaceous [24]. It is difficult to determine the exact contact location of the rock outcrops in the extreme southeast of Iraq because of the thick layers that cover these outcrops from the Quaternary sediments [25], (Figure 2).

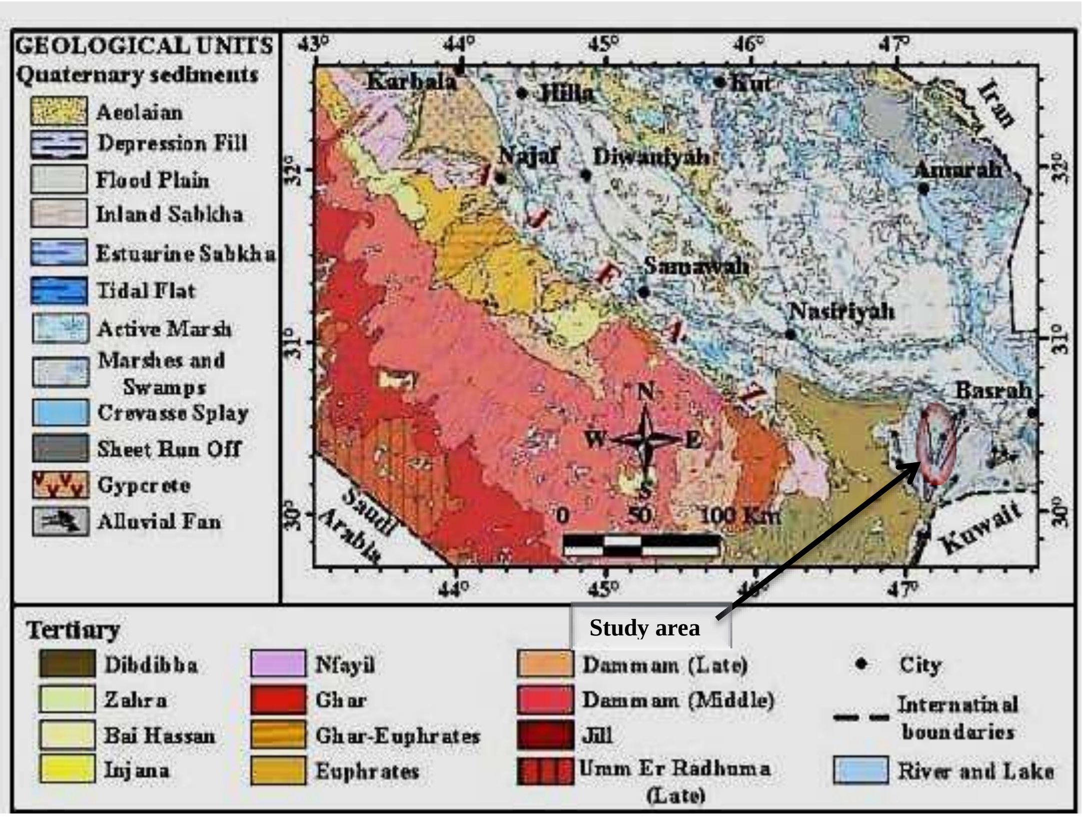

Figure 2- Outcrops map Southern Iraq according [25**].**

4- Methods and Materials

The Pipet method was used to calculate grain size analysis [26]. The sediment texture is different for samples, and most samples' sand content is predominant. The Pipet method was carried out in the sedimentology Laboratory in the Marine Sciences Center at the University of Basrah.

Total sand sieved with 0.063 mm sieve. The light minerals were separated from the heavy by the bromoform liquid with a specific weight of 2.9, utilizing the separation funnel and filter paper, and then washed with the acetone [27]. Heavy and light minerals were separated in the Sedimentology Laboratory in the Marine Sciences Center at the University of Basrah. Grains of sand are placed on a glass slide of about 200-300 granules using the polarized microscope (Olympus BH2), and then diagnose the kinds and percentage of the minerals in each sample in the Laboratory of Rocks and Minerals at the Marine Sciences Center at the University of Basrah.

Analyses and SEM images were carried out in the Electron Microscope Laboratory at the College of Pharmacy at the University of Basrah by a ZEISS (SUPRA 55VP) device.

5- The Results and discussion:

A-Sedimentological study

The sedimentary study showed a variation in the granulation texture of the two wells, but the sand was prevalent in a percentage of 61% to 98%, Table 1. This refers to predominating the quartzite rocks, especially in south Rumaila as the average of 91%. In explorations of the petrography, sandstone is of great importance for many reasons: First, obtaining information on the sorting, size, and roundness of Sandston grains that is useful in determinations of the depositional environment of the sediment and transportation mechanisms. Second, it supplies great detailed value information on composition of sedimentary rock, and this can be deduced from the lithology, as well as a prediction of the response of such units to a variety of subsurface diagenetic environments, and third, information acquired by post-depositional modification, history of sedimentary rocks. This may include cementation, compaction, fracturing, and porosity types. Scholle, 1981 [28] confirmed that the essential factors for properly understanding reservoir rocks petrography provide the only technique for gathering accurate data on such diagenetic factors. A high proportion of sand with a small percentage of clay indicates to high-energy environment represented by pro-delta, as confirmed by Al-Ameri and Batten, 1997 [29]. The grains of monocrystalline are grains that consist of a single crystal [12]. Monocrystalline quartz is a major type served in all studied samples (Figures 3 A, B).

Table 1- The texture and percentage of grains of cores**.**

Sample name		Depth(m)	Sand%	Mean	Silt%	Clay %	Texture
T3	North Rumaila	3211	85	79.6	10	5	Silty sand
T7		3271	62		22	16	Muddy sand
T6		3281	92		7	1	Sand
R2	South Rumaila	3146	88	91	11	1	Silty sand
R3		3194	98		2	-	Sand
R1		3215	87		10	3	Silty sand

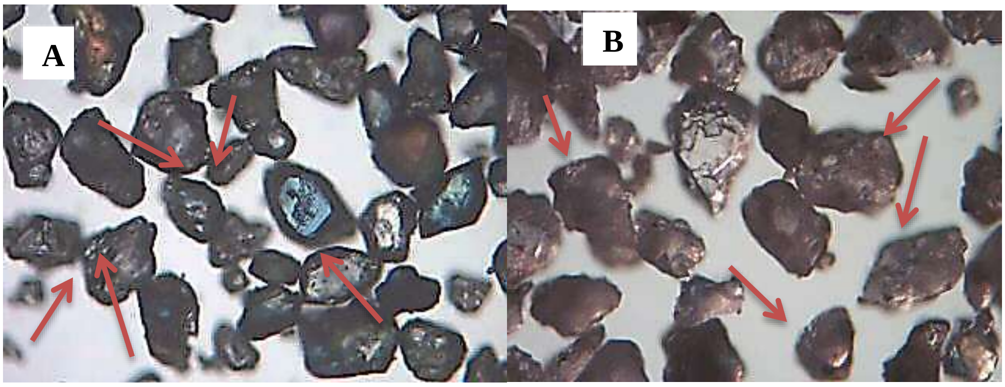

Figure 3- Monocrystalline quartz in Sandstone grains under polarizing microscope 10X.

This was confirmed by Al-Auweidy, 2019 [30], in his study of the high proportion of sand, especially monocrystalline quartz and, the textural analysis shows that monocrystalline grains are rounded to sub-rounded, medium to very fine-grained, and well-sorted grains. Most monocrystalline quartz grains are derived from undeformed igneous sources; quartz monocrystalline grains were probably reworked [26].

The samples were sieved in three sizes of sieves (0.075, 0.090, and 0.150 mm), and the big weights were 0.150mm (Table 2).

Table 2- The sand grain sizes (%).

Sample name		Depth(m)	0.075mm	0.090mm	0.150mm
T3	North Rumaila	3211	4	35	61
T7		3271	9	43	48
T6		3281	1	7	92
R2	South Rumaila	3146	8	48	44
R3		3194	5	43	52
R1		3215	10	65	25

B- Mineralogical study

One important economic, practical application for analysing heavy and light minerals is the correlation between sandstone rocks and oil and gas reservoirs [31]. Heavy minerals were separated from light minerals by bromoform liquid using a separating funnel, and the percentages were recorded as shown in Table 3. The mineralogical study showed the presence of different types of minerals represented with opaque, Zircon, Tourmaline, and Rutile as s heavy minerals in good percent (Table 4 and plate 1) Figure 4 and 5. Light minerals were dominated in cores containing quartz and feldspar, and quartz was the most present (Table 5, and Plate 2). Heavy mineral assemblages are exceptions placed to identify such changes since they are highly sensitive indicators of origin. However, care must be considered to ensure that heavy mineral variations are not related to differences in hydrodynamic conditions at the deposition time or too deep burial diagenesis [31].

Table 3- The light and heavy minerals (%) in the sand fraction.

Sample name		Depth(m)	Light minerals	Mean	Heavy minerals	Mean
T3	North Rumaila	3211	98	**99.3**	2	0.96
T7		3271	99.5		0.5	
T6		3281	99.6		0.4	
R2	South Rumaila	3146	99.46	**98.81**	0.533	1.17
R3		3194	97.52		2.47	
R1		3215	99.47		0.523	

Table 4- Heavy minerals (%) in each depth

		North Rumaila				South Rumaila			
	Heavy minerals %	T3	T7	T6	Mean	R2	R3	R1	Mean
	Opaque	26	24	22	**24**	22	21	23	**22**
Ultra-stable minerals	**Zircon**	27	27	29	**27.6**	32	30	29	**30.3**
	Tourmaline	18	19	17	**18**	19	16	13	**16**
	Rutile	9	11	13	**11**	13	11	11	**11.6**
Mica group	**Biotite**	4	2	3	**3**	2	4	3	**3**
	Chlorite	4	5	2	**3.6**	5	5	6	**5.3**
	Muscovite	7	4	4	**3.6**	3	5	6	**4.6**
Meta-stable group	**Staurolite**	1	3	2	**2**	1	1	2	**1.3**
Un-stable group	**Hornblende**	3	4	4	**3.6**	3	5	5	**4.3**
	Others	1	1	2	**1.3**	1	2	2	**1.6**

Table 5- Light minerals (%) in each depth.

	North Rumaila				South Rumaila			
Light minerals	**T3**	**T7**	**T6**	**Mean**	**R2**	**R3**	**R1**	**Mean**
Quartz	92	88	97	**92.3**	97	95	99	**97**
Feldspar	8	12	3	**7.6**	3	5	1	**3**

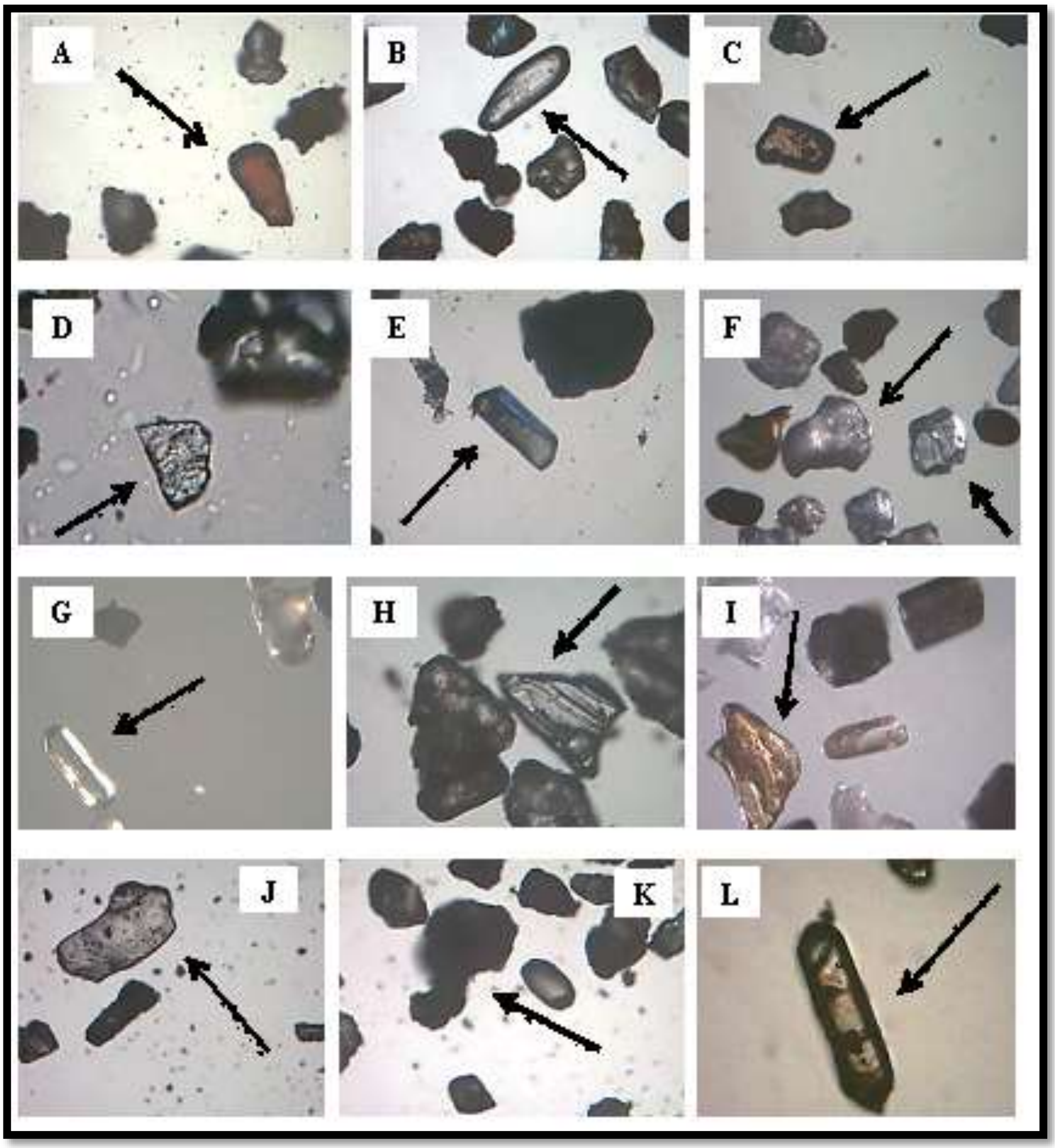

Plate 1- Heavy minerals under polarizing microscopic (Olympus BH2): A- Rutile 10X, B- Zircon 10X, C- Biotite 10X, D- Chlorite 10X, E- Tourmaline 10X, F- Sub rounded Zircon 10X, G- Hornblende 10X, H- Chlorite 10X, I- Staurolite 20X, J- Muscovite 10X, K-Opaque 10X and L- Brown Tourmaline 20X.

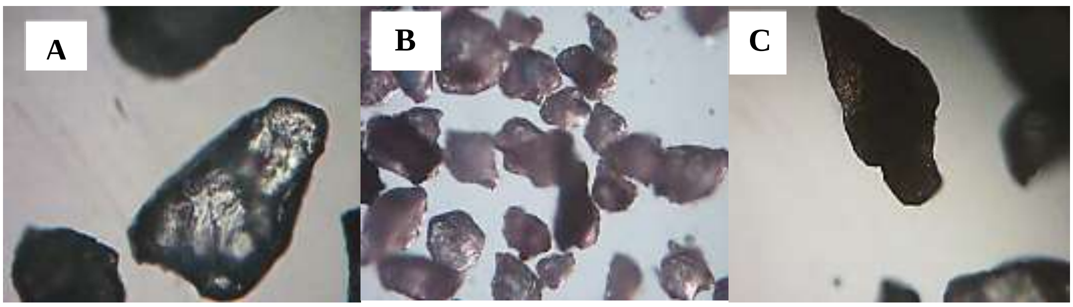

Plate 2- Light minerals under polarizing microscopic (Olympus BH2):A and B- Quartz, C- Feldspar

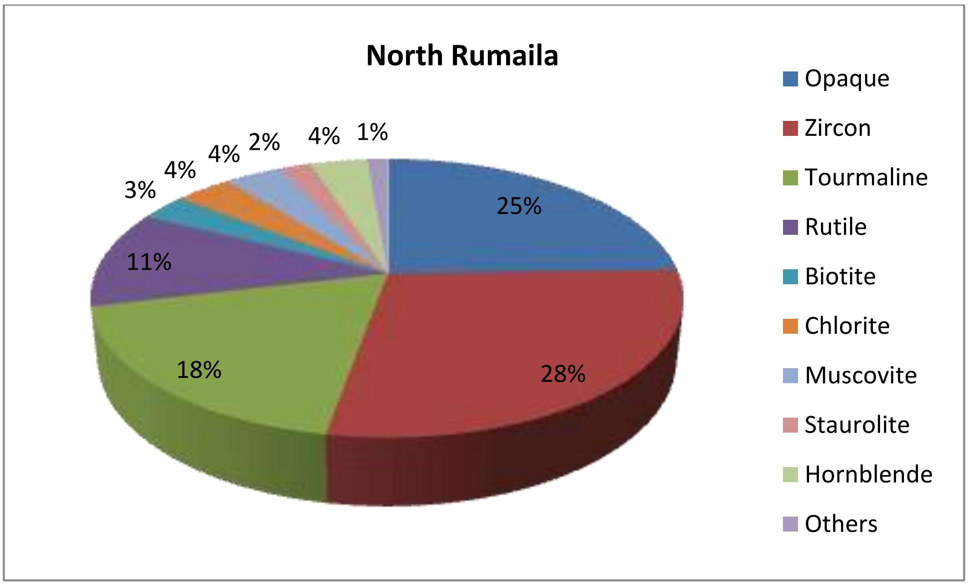

Figure 4- Distribution of Heavy minerals in the Rumaila North.

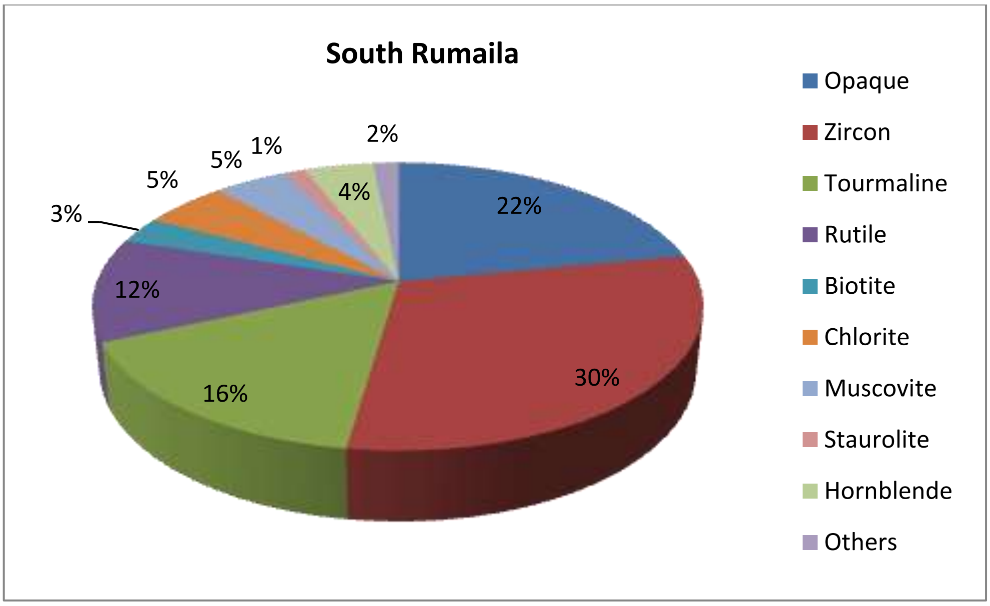

Figure 5- Distribution of Heavy minerals in the Rumaila South.

Heavy minerals group types have been identified on core dissociate observation of this section as follows:

1- Ultra-stable minerals

This group is characterized by its high resistance to corrosion and weathering. The results of the mineralogical study showed an increase in the proportion of ultra-stable minerals, including zircon (Z(, tourmaline (T), and rutile (R). The total rate of the ZTR in the North Rumaila is 56.6, and in South Rumaila is 57.9 (Table 4).

Zircon: It ranges between 27 and 32% (Plate 1B, F), because zircon is very resistant to heat and corrosion. Zircon occurs in many colors, brown, yellow, blue, green, gray, and colorless. Its color can be changed by heat treatment [32].

Tourmaline: It characterized by rounded shapes to semi-rounded. It has light brown, blue and green; tourmaline forms 13-19% (Plate 1E, L) as prismatic, rounded or subrounded grains and irregular fractured grains [14]. Kaminsky et al., 2008 [33] clarified that zircon, rutile, and ilmenite have been observed concentrated in the froth during the extraction of bitumen from oil sands.

Rutile: It is found ranging from 9 to13% (Plate 1A). Rutile diagnosis in different forms in samples fractured and subrounded with reddish brown, blood red, and dark brown colors. It is widely distributed as an accessory mineral in metamorphic and felsic igneous rocks [34] and [35]. Ultra-stable minerals are increasing in south Rumaila more than in north Rumaila. On the other hand, the average sand content in Southern Rumaila is 91%, which is evidence of the increase in heavy minerals in Southern Rumaila, as was confirmed by Al-Mayyahi, 2018 [20].

2- Opaque minerals

They are considered moderately stable minerals. The high specify opaque minerals relate to the iron content [26]. Opaque minerals have a good percentage of heavy sand samples ranging between 21-26% plate 1 (K), including hematite, magnetite, ilmenite, and Limonite. Opaque grains are generally dark grey strains black color and subangular to subrounded. The wide occurrence of opaque minerals in the study area may be connected to the nature of the environment of deposition like marshes, distributary mouth bar, subaerial levee, inter distributary bay, shelf, and prodelta [36].

3- Mica group

The study area was represented in biotite, chlorite, and muscovite and ranged between 2-4%, 2-6%, and 3-7% plate 1(C, D, and J), respectively.

Staurolite: It is considered from the meta-stable group. It can be identified in metamorphic rocks. It ranges between 1 and 3% (Plat 1- I). Staurolite is also an index mineral used to evaluate the temperature, pressure, and depth at which a rock undergoes metamorphism [37].

4- Un-stable group

Hornblende: The percentage of this mineral was between 3-5% (Plate 1-G). Amphibole groups typically occur with quartz, plagioclase, feldspar, and biotite, as well as with oxide minerals and chlorite. Kasper-Zubillaga et al., 2010 [38] formulated a ternary classification for determining the stability of heavy minerals content, in which unstable, moderately stable, and ultra-stable groups are considered in Figure 6, the ultra-stable represented in (zircon, tourmaline, and rutile) and unstable represented in hornblende and moderately stable represented in opaque minerals.

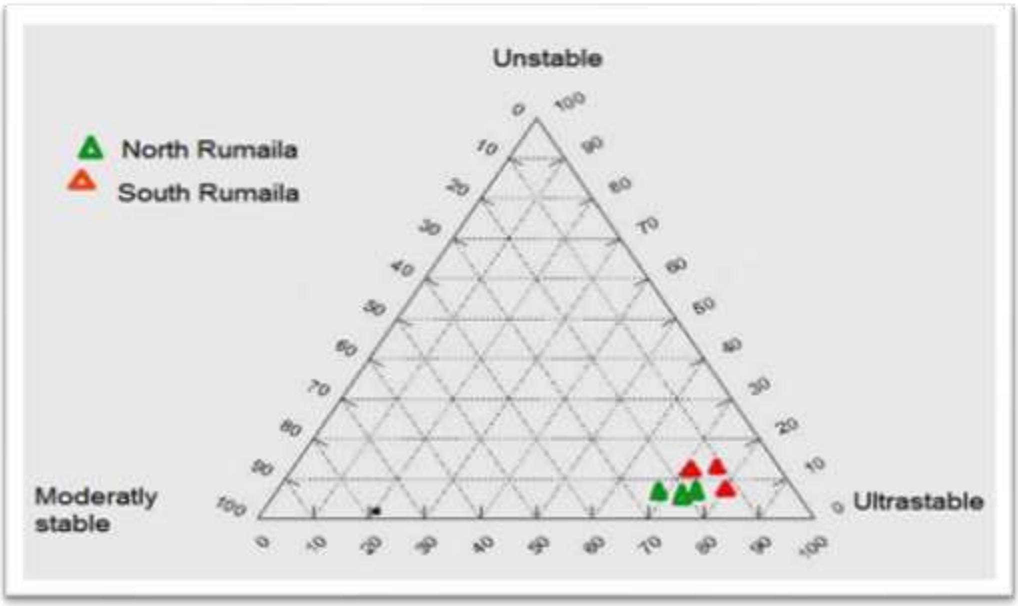

Figure 6- Ternary diagram of heavy mineral stability of southern and northern Rumaila based on Kasper-Zubillaga et al., 2010 [38].

- **Light minerals**

Quartz and feldspar are the main light minerals in the studied cores. Quartz is highest compared with feldspar. The shape of the quartz grains in the south Rumaila is rounded to sub-rounded (Figure 7A), while in the north Rumaila, the shape of grains is sub-angular to sub-rounded (Figure 7 B).

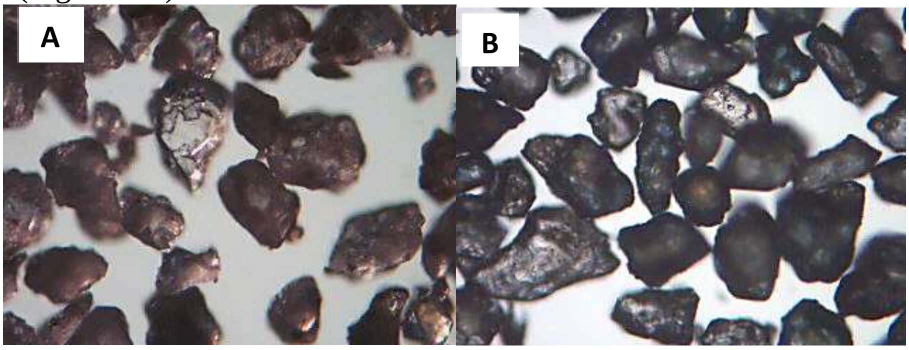

Figure 7- (A) light minerals (10X) in South Rumaila, (B) light minerals (10X) in North Rumaila.

***Quartz*:** The average percentage of quartz in the northern Rumaila oilfield is 92.3%, and the southern Rumaila oilfield is 97% Table 5. It is highly resistant to both mechanical and chemical weathering. In the study area, most of the quartz was found in small grains with dark color and crude oil smell. The high dominance of quartz in the Rumaila oilfield is due to the breakdown and degradation of the un-stable minerals. The sediments are subjected to heavy erosion and weathering in addition to the far transportation distance from the source area, resulting in high sorting and the remainder of quartz which is more stable. In Zubair Formation, quartz mineral is the major sandstone component with a small proportion of feldspar and quartz arenite as uncommon rock fragments [39].

***Feldspars*:** The feldspar percentages are restricted between 1-12% (Table 5). It is lowest in the south Rumaila compared with the north. The stability mechanism of feldspar grains is lower than quartz, which crashes upon one cycle of erosion.

6- Quartz Micromorphology and indication

Quartz is commonly considered the most appropriate material to record the surface textural features produced in each environment. Different surface textures are produced by the grinding and sliding motion of glaciers, the collision and abrasion of grains in breaking waves of the beach surf zone, and the traction and saltation movement of grains by wind or river water [40]. Most of the surface texture types on the studied quartz are V-shaped pits which index to high-energy subaqueous environments (Figures 8, 9, 10, and 11). This environment reflected the higher content of quartz and more outstanding potential reservoir quality [15], especially in the South of Rumaila Oilfield.

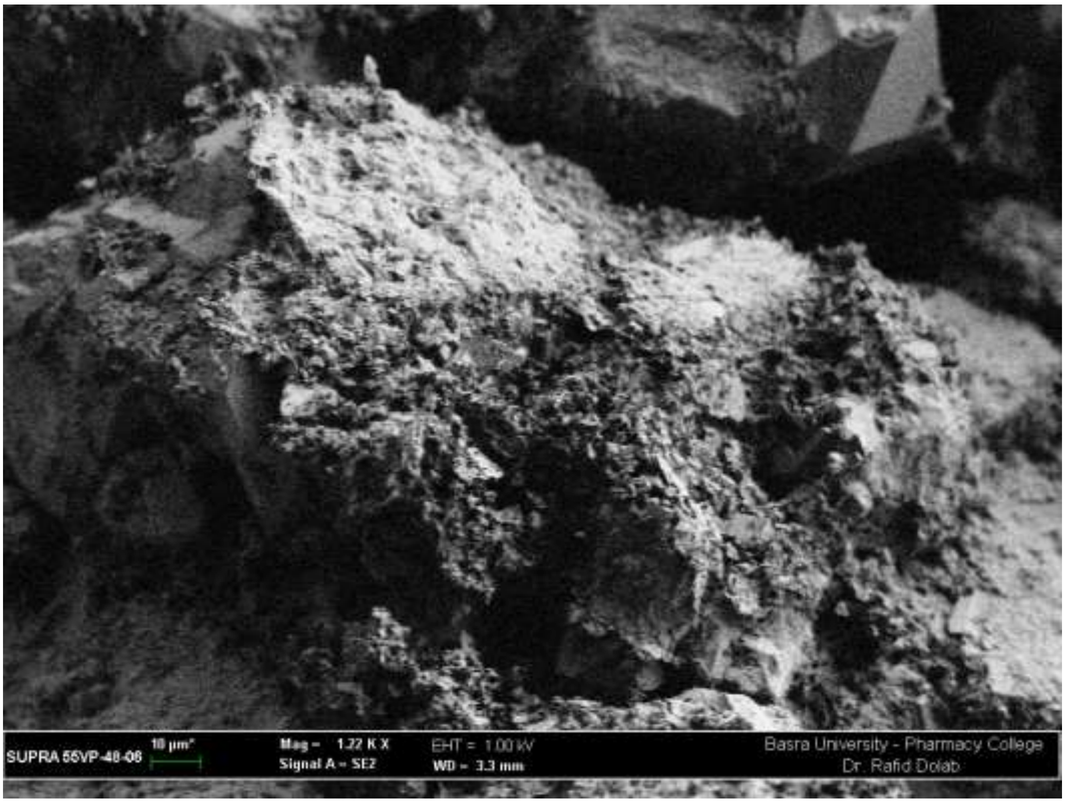

Figure 8- SEM image explains the malformation of quartz grains in south Rumaila.

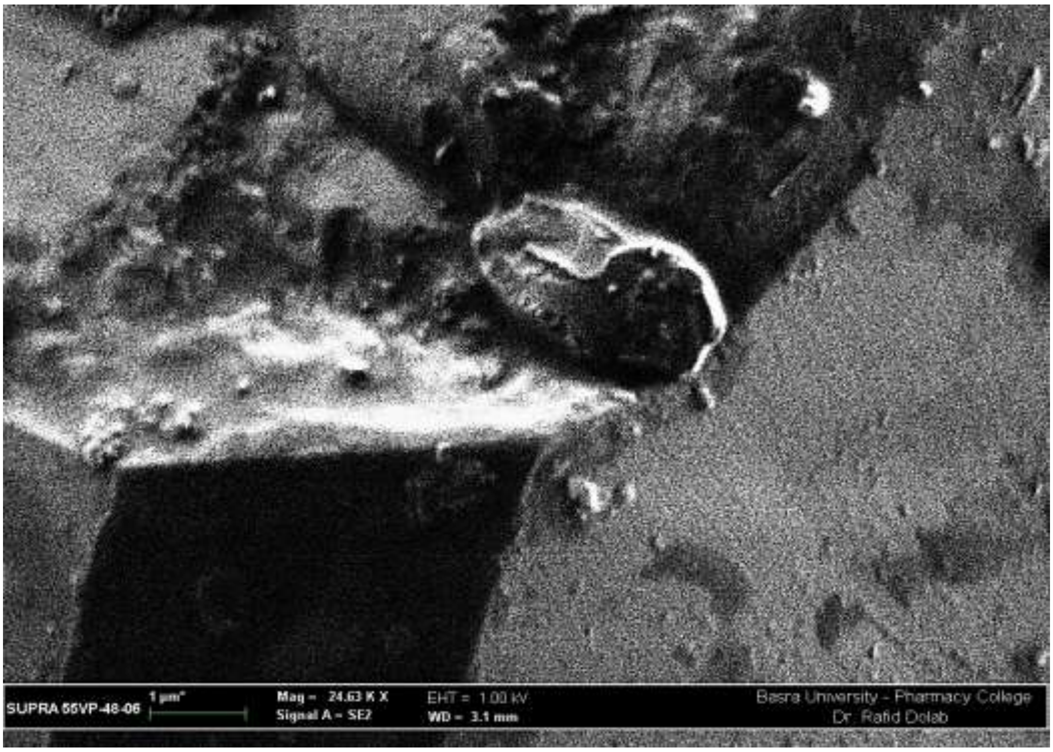

Figure 9- SEM image explains the malformation of quartz grain covered with clay minerals in north Rumaila.

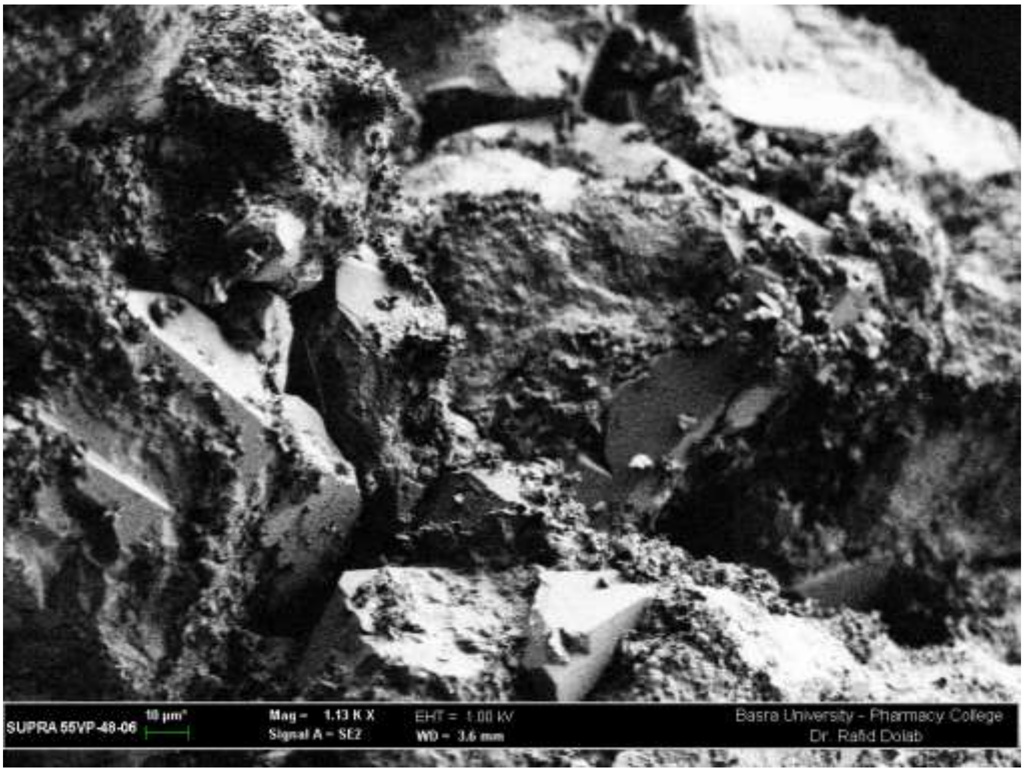

Figure 10- SEM image explains the sub-rounded grains of quartz covered with clay minerals in southern Rumaila.

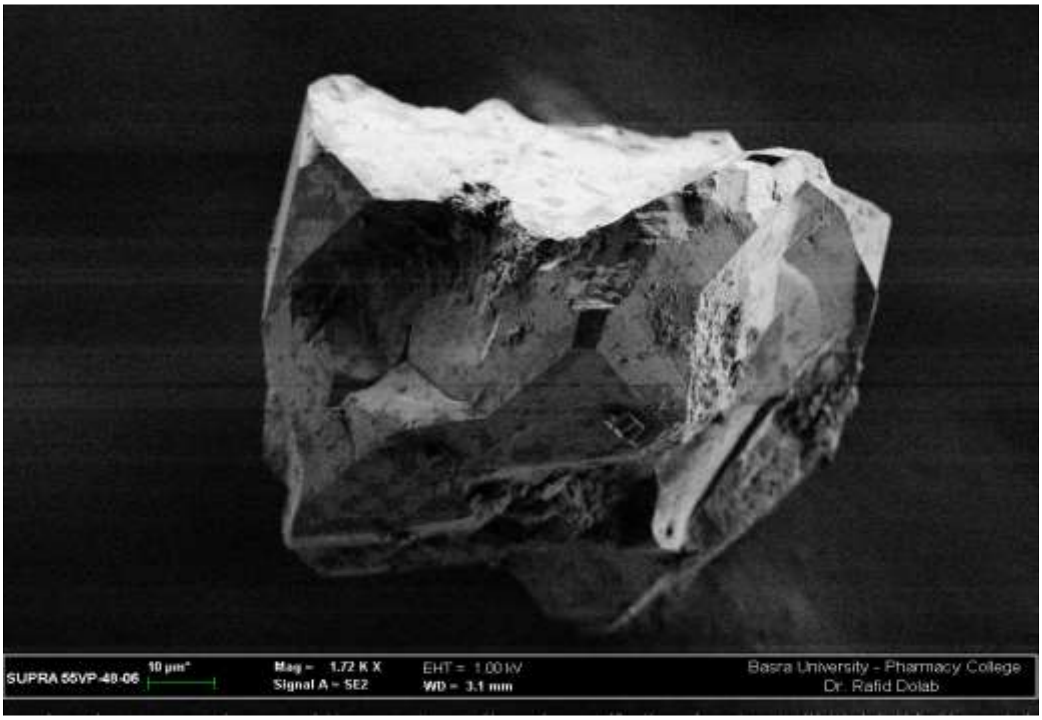

Figure 11- SEM image explains the subangular grain of quartz in northern Rumaila.

7- Conclusions

1- The sedimentological study showed that sand content in the South Rumaila is increasing than in North Rumaila, where the sand rate reached 91% compared to the North Rumaila 79.6%. The texture of cores varied from silty sand to sand and muddy sand .

2- Monocrystalline quartz is a significant type observed in all studied samples, explaining quartz resistance to weathering and erosion over long distances.
3- The shape of quartz grains in south Rumaila is rounded to sub-rounded while in north Rumaila is sub-angular to sub-rounded; this interpreted the increase in crude oil productivity in South Rumaila in addition to previous results.
4- The mineralogical study explained an increase in light minerals 98.81% in south Rumaila, while 99.3% in northern represented quartz and feldspar with a high percentage of quartz.
5- Increasing in heavy minerals reaches 1.17% in south Rumaila and 0.96% in southern and this is evidence of crude oil productivity.
6- The dominance of ultra-stable minerals represented in (Zircon, Tourmaline, and Rutile), especially in south Rumaila. On the other hand, increasing in opaque minerals indicates the resistance of these minerals to weathering, erosion, and many sedimentary cycles in Zubair formation.
7- SEM images showed deformations in quartz grains due to high energy; on the other hand, the roundness and sphericity of the grains were evident, especially in Southern Rumaila.

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