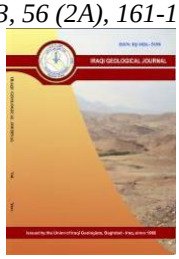
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# Sedimentology, Mineralogy of Al-Dujaila River Sediments Project, Southeastern Kut City, Iraq

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## Abstract

A sedimentological and mineralogical study was carried out on sediments of Al-Dujaila River Project, one of the branches of the Tigris River, southeastern Kut City, Iraq. The study aims to identify the nature and maturity of sediments in order to deduce the provenance of these sediments and the source area. The results of grain size analysis of ten river sediment samples indicated that the averages are: silt (44.97%), clay (34.06%), and sand (20.96%). According to Folk's classification (1974), the sediments are classified as sandy mud. A microscopic study of five sand fraction samples has shown the presence of light and heavy minerals. Light minerals (average 94.6%) include on average: a major share of rock fragments (64.8% including dominant carbonate, chert, igneous, metamorphic, and mudstone), quartz (24.1% including dominant monocrystalline and polycrystalline), feldspars (5% including orthoclase and plagioclase) while evaporates, and coated clays are subordinate. Heavy minerals (average 5.4 %) include opaques (average 54.2%) and non-opaques (average 45.8%) including pyroxene, amphibole, epidote, garnet, staurolite, chlorite, biotite, muscovite, zircon, tourmaline and rutile. Based on the mineralogical signatures, light and heavy minerals reflect metamorphic, mafic and felsic igneous rocks of the active margin of the unstable shelf in addition to carbonate, evaporate and mud of sedimentary rocks that could be sourced from the floodplain. According to sediment diversity and very poor grain sorting in the study area, as well as the values of indices of mineral maturity MI (0.34), MMI (0.76), and the ZTR (23.5%), all these results indicate that sediments are immature to extremely immature, which means the source area represents rather elevated topography, rapid erosion and transport in arid to the semi-arid environment and a short distance of transportation. The tectonic provenance of Al-Dujaila River sediments can be characterized as a lithic reworked of the recycled orogen as a result of the collision range of Taurus and Zagros Mountain range.

**Keywords:** Sedimentological and mineralogical study; Light and heavey minerals, maturity; Provenance; Al-Dujaila River;; Kut City

## 1. Introduction

Al-Dujaila River Project is one of the branches of the Tigris River from its right bank before Kut Barrage. The river offers the water share for 1372 $km^3$ southeastern Kut City with discharge rate about 42.15 $m^3$/sec (DWRW, 2010 and Al-Khafaji, 2014). This river represents the primary water source for agriculture and public requirements has a particular impact on the socio-economic aspects of that area

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(DWS, 2009). In 1974 was attached to the major development project and completed in 1979 in two stages, the first stage was implemented by the English company Marbles Riga and the second stage was implemented by Yugoslav companies (Al-Rikabi, 1999).

The key factors in sedimentology are grain size and grain size distribution. These factors specify the mechanical properties of sediment and provide indicators about the origin of these sediments (Goossens, 2008). Mineral compositions are generally used to determine the source rocks, the character of the sedimentary provenance and the nature of the sedimentary processes within the depositional basin. Heavy mineral component in river sediments closely refer the nature of the source area, and their composition is sensitive to the processes occurring during the sedimentary cycle (Morton and Johnsson, 1993). Grain size analyses, mineral compositions and petrographic studies were achieved to determine the provenance of the Al-Dujaila River Project sediments.

## 2. Location of Study Area

Geographically, the study area is located in the southeastern Kut City in Wasit Governorate, Iraq.It lies between the latitude 32°10'-32° 35' N and longitude 45° 50'-46° 27' E. The Dujaila River has a length of about 69.45 km, a width of 15 m, and a depth of 2.8 m, while its water share is 1372 $km^3$ (DWRW, 2010).

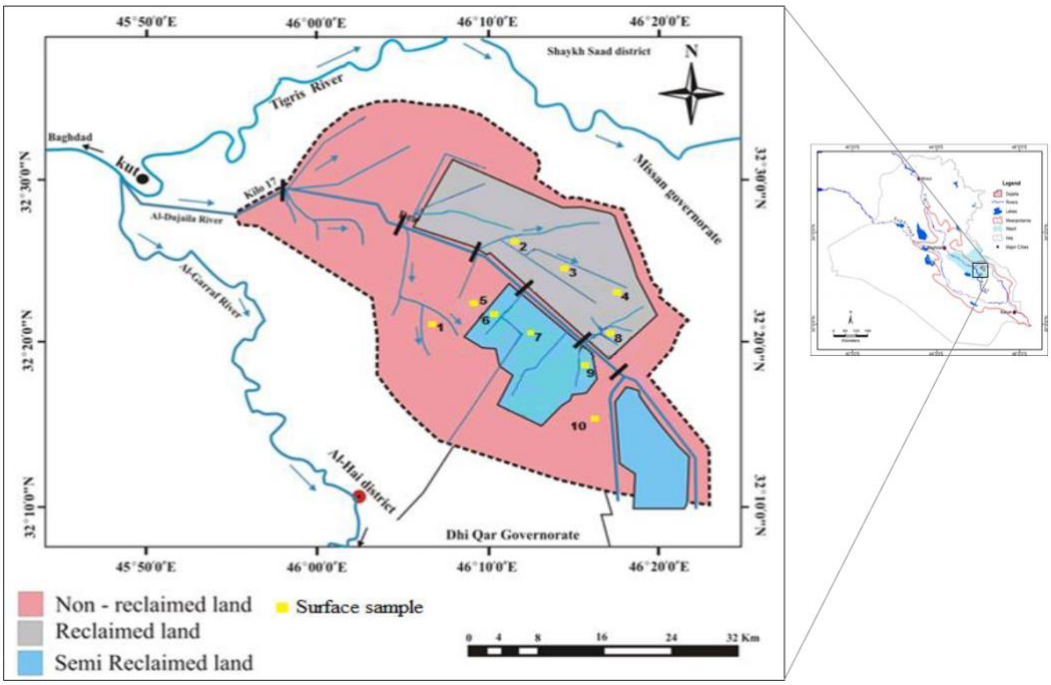



**Fig. 1.** Location map of 10 surface sediments in the study area, (Directorate of Water Resources in Wasit, Ministry of Water Resources, 2010)

## 3. Geology of Study Area

The study area is located within the stable shelf, as a part of the Mesopotamian Zone (Jassem and Goff, 2006). Quaternary depositsmostly covered study area, these deposits divided into Pleistocene deposits and Holocene deposits (Fig. 2).

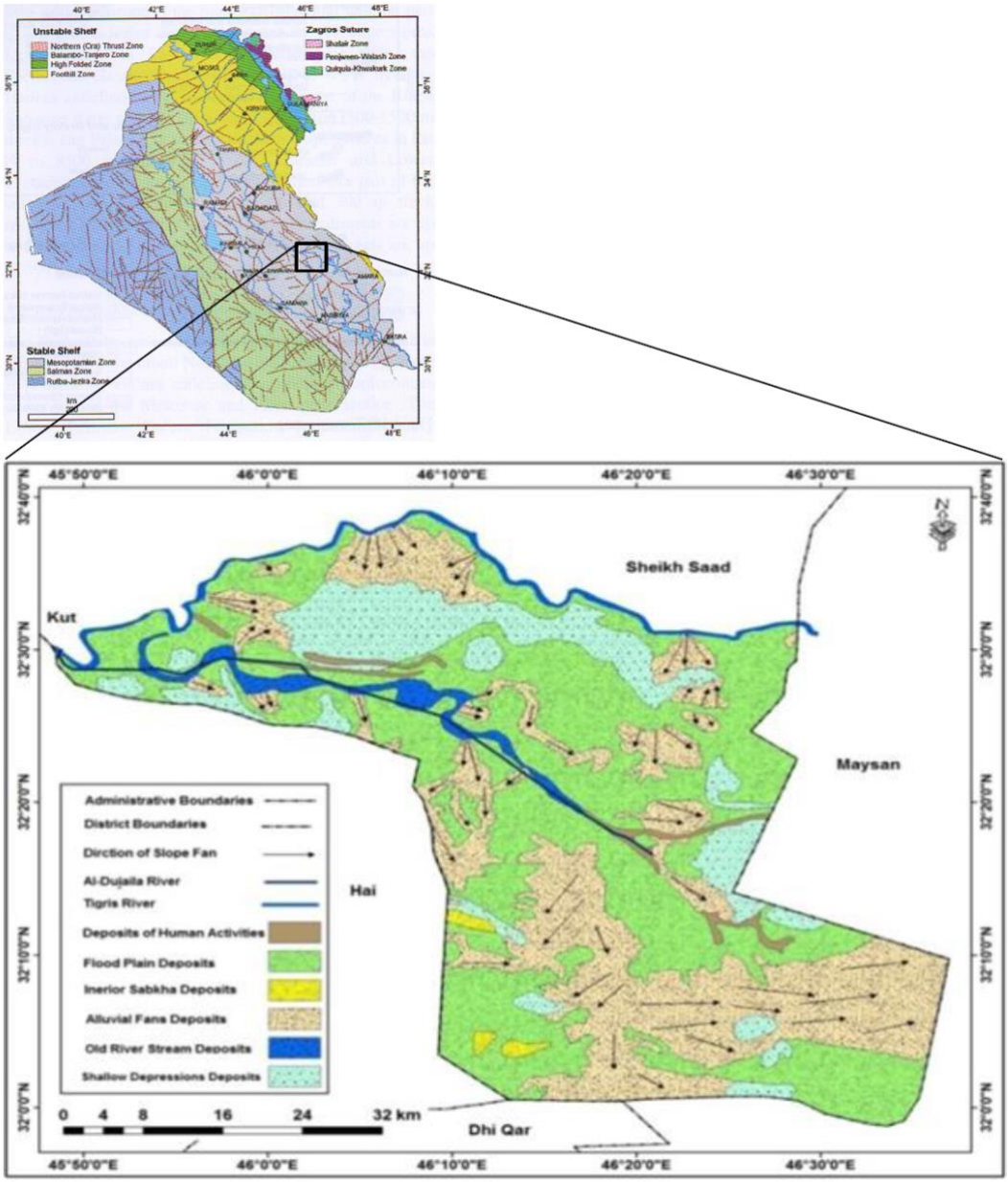



**Fig. 2.** Geological maps of the study area (A-Jassem and Goff, 2006; B-Geological Survey & Mining 1993)

### 3.1. Pleistocene Deposits

These deposits covering the study area and, the upper limit of this sediment could be up to1.5 m. Below the surface of the ground and up to a thickness of 174 m and consists of sand, silt, clay interfering with each other (Barwary and Yaakob, 1993).

### 3.2. Holocene Deposits

Holocene sediments that are spread widely in the study area and cover most of the surface by surface sediments that above the Pleistocene sediments of the basin of the alluvial plain sediments and are as follows:

*3.2.1. River Deposits*

They are deposited by Tigris River water, thickness of 10-15 m. The overlap of these deposits with deposits of the irrigation consisting flood plain of the Tigris River (Salih and et al., 2018). They include deposition shoulders of the river and crevices formed by stopping the natural shoulders of the river during the flood as well as the deposits of the former course of the Tigris River in the study region, and often overlapping these sediments of sand, silt, clay with thickness ranges from 1 to 2.5 m (Barwary and Yaakob, 1993).

*3.2.2. Deposits of Shallow Depressions*

Extensions of these deposits are different in the study area and the origin of these deposits is from the old network of irrigation canals. These depressions are dry for long periods and are filled with water through irrigation at high water levels in the Dujaila River Project (Al Jiburi, 2009).

*3.2.3. Marshes Deposits*

These deposits are either on the surface or buried under other sediments, and their thickness ranges from a few centimetres to 2 m. The color of these sedimentsis black or dark grey as it is built up of the remnants of roasted plants and the other organic mixed with mud represents sediment Al-Saadia Marsh, (Al Jiburi, 2009).

## 3. Materials and Methods

Grain size analyses defined as the method to distinguish pieces of sedimentary sample into many forms with different sizes and classify it for names according to these sizes (Wentworth, 1922). Ten recent clastic surface sediment samples were taken from the study area that represent fluvial deposits (Fig. 1). Fifty grams of each sample were separated by wet sieving analysis according to Folk (1974), while mud fraction was carried out by pipette and hydrometer analysis. Laboratory techniques are performed to separate ten grams of these sizes were used for heavy mineral separation, using heavy liquid (bromoform) with a specific gravity of 2.89 depend on Carver (1971).

Petrographic investigation was achieved by polarizing microscope on five samples 1, 3, 6, 9 and 10 to identify the light and heavy minerals. These samples were chosen depending on the spreading of sediment across the branches of the river (Fig.1). The statistical parameters of the results of the grain size analysis (median, mean and standard deviation) were calculated to know the type of the dominant sediment, in addition to calculate the maturity of these sediments by IM and IMM indices according to Pettijohn (1957 and 1975). Heavy minerals were described and analyzed statistically and calculated maturity by ZTR index according to Hubert (1962) and Ikhane (2013). The values of the light minerals (quartz; feldspar and rock fragments) are represented in ternary diagrams of Dickinson et al. (1983) and Dickinson and Suczek (1979) to determine the tectonic region of the sediment source.

## 4. Sedimentological Study

The results of grain size analysis of Al-Dujaila River Project sediments show that the silt and clay are a major part. Silt is in average 44.97%, it ranges between 35.8% and 56.4%. Clay comes in the second rank in terms of the relative distribution with an average 34.06%, ranging between 25.3% and 39.3%, and sand average 20.96%, which ranges between 10% and 33.1%, see (Table 1). According to Folk's classification of grain size (1974), sandy mud (sM) is the type of Al-Dujaila River sediments as shown in (Fig. 3).

**Table 1.** Percentages of sand, silt, clay and an average of median, mean and standard deviation.

| Sample No. | Sand% | Silt% | Clay% | Type of texture |
|---|---|---|---|---|
| 1 | 25.1 | 36.7 | 38.2 | sM |
| 2 | 33.1 | 35.8 | 31.1 | sM |
| 3 | 26.7 | 39.0 | 34.3 | sM |
| 4 | 17.1 | 43.6 | 39.3 | sM |
| 5 | 27.8 | 35.9 | 36.3 | sM |
| 6 | 19.2 | 55,5 | 25.3 | sM |
| 7 | 17.5 | 45.2 | 37.3 | sM |
| 8 | 12.1 | 52.9 | 35.0 | sM |
| 9 | 10.0 | 56.4 | 33.6 | M |
| 10 | 21.0 | 48.7 | 30.2 | sSi |
| Average | 20.96 | 44.97 | 34.06 | sM |
| Av. of median grain size (Ø) | 4.5 | Coarse silt | | |
| Av. of mean grain size (Ø) | 4.7 | Coarse silt | | |
| Av. of standard deviation (Ø) | 2.9 | Very poorly sorted | | |

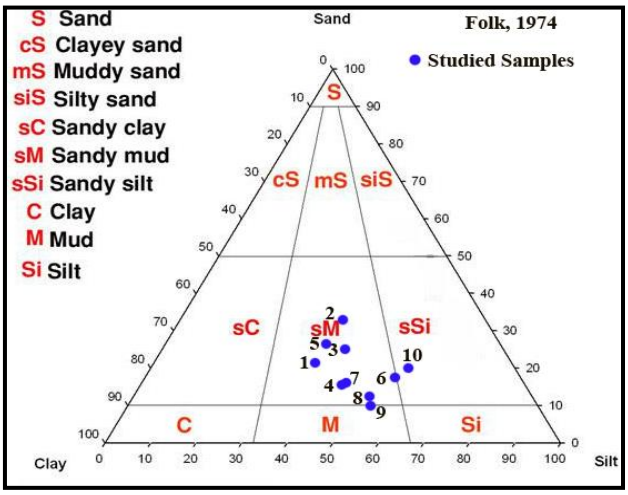



**Fig. 3.** Grain size classification of the ten scattered site samples in the study area after (Folk, 1974).

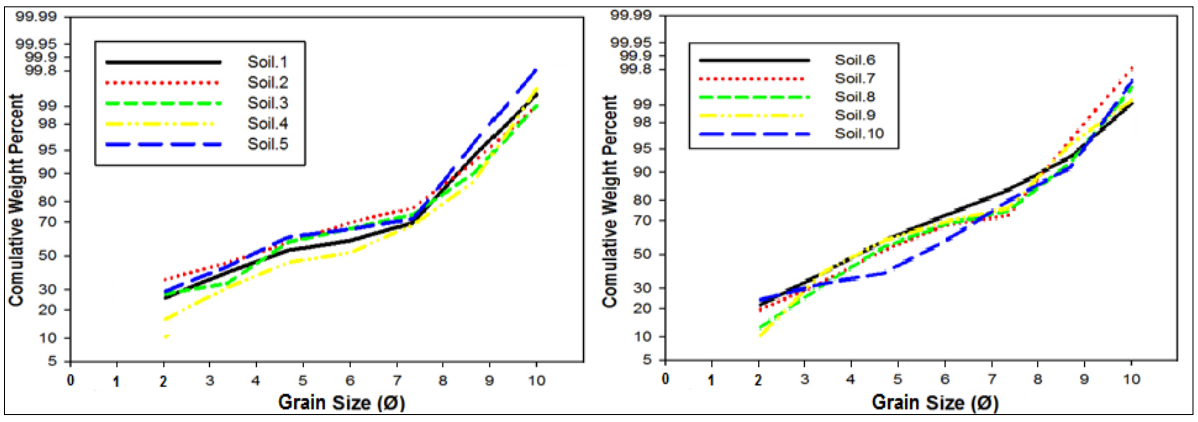



**Fig. 4.** Cumulative frequency curve of ten sediment samples of Dujaila River Project introducing the mean, median and standard deviation of grain size (Folk, 1974)

## 5. Mineralogical Study

Using a polarizing microscope, five samples (10 grams each) of sand fraction were examined to determine the mineral composition of the sediments. The mineral composition is divided into:

### 5.1. Light Minerals

The sediment of Al-Dujaila River Project is composed of quartz (both monocrystalline and polycrystalline), feldspar (alkali feldspar and plagioclase), and rock fragments (sedimentary, igneous, and metamorphic rock fragments). The sedimentary rock fragments include: carbonate, chert, argillaceous, evaporate and other clay (coated clay) (Table 2).

**Table 2.** The percentage of ranges and averages of the sand fraction of Al-Dujaila River Project sediments, MI:Maturity Index (Pettijohn, 1975), MMI: Mineral maturity index (Pettijohn, 1957)

| Light Components | | Weight of samples (%) | | | | | Av. % | Total Range % | Total Av.% |
|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 3 | 6 | 9 | 10 | | | |
| Quartz (Q) | Monocrystalline | 20.4 | 21.6 | 22.4 | 21.7 | 21.7 | 21.6 | 22.5 - 24.9 | 24.1 |
| | Polycrystalline | 2.1 | 2.8 | 2.5 | 2.8 | 2.5 | 2.5 | | |
| Feldspar (F) | Alkali | 3.2 | 3.2 | 2.9 | 3.7 | 3.3 | 3.2 | 3.7 - 5.7 | 5.0 |
| | Plagioclase | 1.8 | 1.5 | 1.8 | 2.0 | 1.7 | 1.8 | | |
| Rock Fragments (RF) | Carbonate | 40.3 | 39.4 | 39.8 | 40.8 | 39.7 | 40.0 | 61.4 – 66.6 | 64.8 |
| | Chert (Ch) | 17.7 | 19.0 | 13.6 | 15.9 | 16.9 | 16.6 | | |
| | Igneous | 2.9 | 2.7 | 2.0 | 2.7 | 2.5 | 2.5 | | |
| | Metamorphic | 2.0 | 2.1 | 1.9 | 1.7 | 1.9 | 1.9 | | |
| | Mudstone | 3.7 | 3.2 | 4.1 | 3.8 | 3.8 | 3.7 | | |
| Evaporates | | 3.8 | 3.0 | 2.0 | 3.4 | 3.7 | 3.2 | 2.0 – 3.8 | 3.2 |
| Others (Coated Clay) | | 2.1 | 1.5 | 2.0 | 0.5 | 1.3 | 1.5 | 0.5 – 2.1 | 1.5 |
| Maturity Index (MI) | | 0.31 | 0.34 | 0.37 | 0.34 | 0.35 | 0.34 | Extremely Immature | |
| Mineral Maturity Index (MMI) | | 0.76 | 0.83 | 0.73 | 0.73 | 0.77 | 0.76 | Extremely Immature | |

- Quartz

The percentage of quartz is ranging between 22.5 and 24.9 % with a total average of 24.1% (Table 2). Monocrystalline and polycrystalline quartz were determined in the sand fraction of Al-Dujaila River Project. The first type is ranging between 20.4 and 22.4% with an average of 21.6%, and it is generally coarse to fine grained, and angular in shape (Fig.5-A). These features may indicate the shortest length for transportation from the source area (Pettijohn, 1975). The polycrystalline quartz ispresent in a little, ranging between 2.1 and 2.8% with an average of 2.5%, but it increases with an increase in grain size (Conolly, 1965). The polycrystalline quartz is generally medium sized, angular in shape with more or less one-dimensional shape in the sand fraction (Fig. 5-B). Quartz could be originated from metamorphic rocks or plutonic igneous rocks (Blatt, 1967; Folk, 1974; Basuet al., 1975).

- Feldspars

Feldspars are present in the sand fraction ranging between 3.7 and 5.7% with a total average of 5.0% (Table 2). Feldspars identified include: plagioclase (Fig. 5-C) with an average of 1.78 % and orthoclase with an average of 3.2%. Some of the feldspars appeared to be altered (Fig. 5-D), which may reflect multi-sources. Feldspars are detected in a wide variety of igneous and metamorphic rocks (Al-Zubaidi and et al., 2021) which have crystallized at intermediate to low temperature (Hibbard, 2002).

- Rock Fragments

Rock fragments constitute the biggest share in the sediments of Al-Dujaila River Project, and their percentage ranges between 61.4 and 66.6% with a total average of 64.8% (Table 2). The location of the parent rocks has an effect on the percentage of rock fragments within the clasts. The percentage increasedin two cases, when the source rock area was near the sedimentary basin and\or had high topography (Nelson, 2000). Amongst the rock fragments in the sandstone, carbonates have the highest percentage ranges between 39.4 and 40.3 % with an average of 40.0% (Fig. 5-E). Rock fragments of carbonate rocks represent special conditions of rapid physical erosion rather than chemical dissolution (Pettijohn et al., 1987) refers to the parent rocks that are rich in carbonate rocks and, traveled short distances with prevailed arid to semi-arid climates.

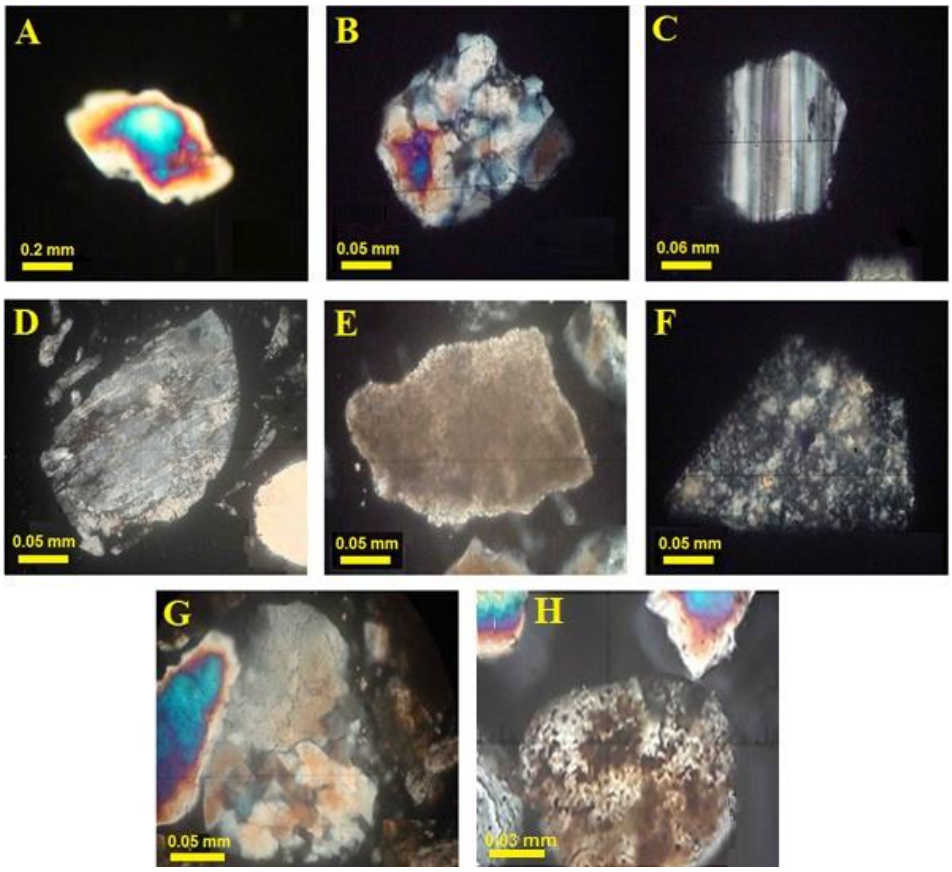



**Fig. 5.** Microphotographs of light minerals grains using XPL technique including: (A) Angular to sub-angular monocrystalline quartz grain, sample number 6. (B) Angular polycrystalline quartz grain, sample number 3. (C) Sub-angular plagioclase grain, sample number 9. (D) Angular orthoclase grainaffected by alteration, sample number 9. (E) Angular carbonate rock fragment grain, Sample Number 1. (F) Angular chert fragment grain, Sample Number 10. (G) Igneous Rock Fragments, sample number 10. (H) Sub-rounded evaporite grain, sample number 1.

Chert rock fragments rank third in terms of abundance, ranging between 13.6 and 19 % with an average of 16.6 %. Chert fragments are angular in shape, very coarse to fine grained in size (Fig. 5-F). The percentage of the igneous rock fragments which are mainly volcanic rock such as andesite, ranges between 2 and 2.9 % with an average of 2.5 %, while the percentage of the metamorphic rock fragments ranges between 1.7 and 2.1 % with an average of 1.9 %. The grains of both rocks are sub-angular in shape, medium to fine-grained in size (Fig. 5-G). Mudstone rock fragments are present in a range between 3.2 and 4.1% with an average of 3.7%.

Other components are evaporates and coated clay. The first is ranging between 2 and 3.8 % with an average of 3.2 % (Fig. 5-H), that could be due to chemical weathering along transportation. The last one is coated clay which its percentage ranges between 0.5 and 2.1% and an average of 1.5% (Table 2). The sedimentary carbonate, evaporate and mud rocks that could be sourced it form the flood plain (mostly excluded from Euphrates, Fatha and Injana Formations).

### 5.2. Heavy Mineral

Heavy minerals of clasticsedimentary rocks are nongenetic mineral group. These minerals are of parent rock surviving destruction by weathering, abrasion or intrastriatal solution and, that have a specific gravity greater than 2.85 (Pettijohn et al., 1987). Heavy minerals are important constituents of sandstones; most sands contain a small (1-2 %) but an often diverse suite of heavy minerals (Selly, 2000). Five samples of Dujaila project were determined in order to use them as indicators for the source rocks and the nature of the source area. The procedure for heavy mineral separation was followed after (Carver, 1971; Griffiths, 1967; Muller, 1967). The heavy minerals in the sediments of the study area are very low percentage than light mineral, they constitute about 4-7 % of the total minerals in the sand fraction (Table 3).

**Table 3.** Weight and percentage of light and heavy minerals in the sand fraction of sediments

| Samples Number | Sand Samples (gm) | Light Minerals (gm) | Light Minerals (%) | Heavy Minerals (gm) | Heavy Minerals % |
|---|---|---|---|---|---|
| 1 | 10 | 9.4 | 94 | 0.6 | 6 |
| 3 | 10 | 9.5 | 95 | 0.5 | 5 |
| 6 | 10 | 9.5 | 95 | 0.5 | 5 |
| 9 | 10 | 9.3 | 93 | 0.7 | 7 |
| 10 | 10 | 9.6 | 96 | 0.4 | 4 |
| Average | | | 94.6 | | 5.4 |

The heavy minerals characterized in Al-Dujaila River Project were detected by using point counter mechanical stage following the method of fleet (1926; in Carver, 1971). A summary of these results, consist of the average and ranges of each heavy mineral is given in the Table (4).

**Table 4:** Ranges and averages in percentageof heavy minerals groups for five samples of sand fraction, ZTR: (zircon, tourmaline, and rutile) Maturity Index (Hubert, 1962**;** Ikhane, 2013).

| Heavy Minerals | | Sample Numbers (%) | | | | | Range (%) | Average (%) |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 3 | 6 | 9 | 10 | | |
| Opaques | | 55.7 | 53.8 | 55.4 | 53.9 | 52.4 | 52.4 -55.7 | 54.2 |
| Unstable Minerals | Pyroxene | 6.5 | 6.0 | 5.8 | 5.4 | 6.5 | 5.4 - 6.5 | 6.04 |
| | Amphibole | 5.8 | 6.0 | 6.3 | 6.1 | 6.4 | 5.8 - 6.4 | 6.12 |
| Metastable Minerals | Epidote | 5.8 | 5.8 | 5.9 | 6.5 | 6.2 | 5.8 - 6.5 | 6.04 |
| | Garnet | 3.3 | 3.9 | 3.8 | 4.5 | 4.1 | 3.3 - 4.5 | 3.92 |
| | Staurolite | 2.0 | 2.3 | 0.9 | 1.7 | 1.4 | 0.9 – 2.3 | 1.66 |
| Flaky Minerals | Chlorite | 7.5 | 9.2 | 8.0 | 8.4 | 8.6 | 7.5 - 9.2 | 8.3 |
| | Biotite | 3.2 | 3.5 | 3.1 | 3.0 | 3.8 | 3 - 3.8 | 3.32 |
| | Muscovite | 4.9 | 4.0 | 4.5 | 5.2 | 4.8 | 4 - 5.2 | 4.68 |
| Ultrastable minerals | Zircon | 4.7 | 5.1 | 4.7 | 4.3 | 4.1 | 4.1 - 5.1 | 4.58 |
| | Tourmaline | 1.3 | 1.0 | 1.3 | 1.6 | 1.4 | 1 - 1.6 | 1.26 |
| | Rutile | 1.3 | 1.7 | 1.5 | 1.1 | 1.7 | 1.1 - 1.7 | 1.46 |
| ZTR Index % | | 23.8 | 24.5 | 24.4 | 22.4 | 22.6 | 22.4 – 24.4 | 23.5 |

*5.2.1. Opaque Minerals*

These represent the major constituent in the heavy mineral assemblage. The high specific of opaque minerals relates with the iron content (Folk, 1974). The percentage of the opaque minerals is ranging between 52.4 and 55.7% with an average of 54.2% (Table 4). The opaque minerals are generally sub-angular to angular and some grains are sub-rounded, their shape is generally sub equal to slightly elongated (Fig. 6-A). Opaque minerals refer to metamorphic, mafic and acidic igneous rocks, in addition to reworked sedimentary rocks (Pettijohn et al., 1987).

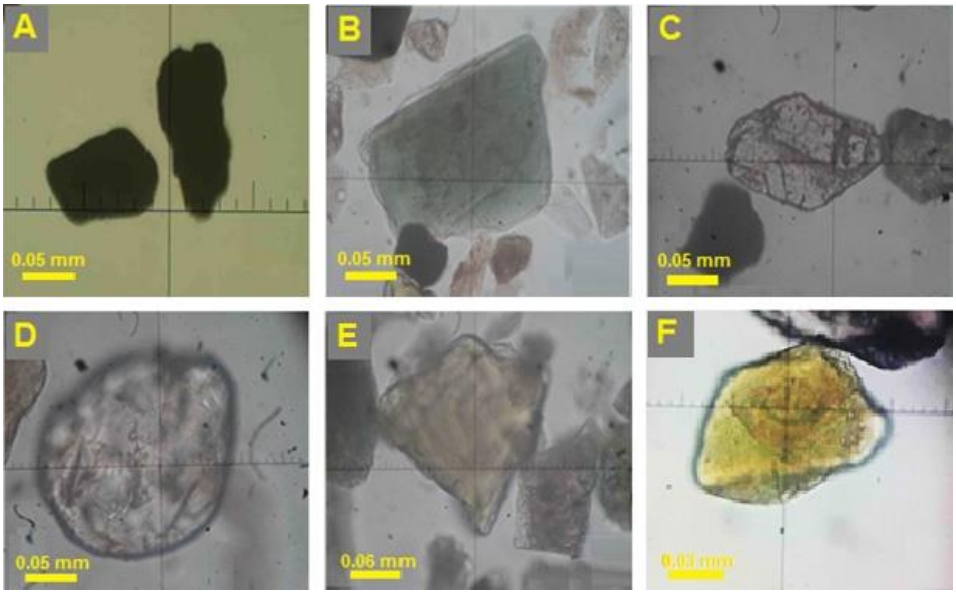



**Fig. 6.** Microphotographs of heavey minerals grains using PPL technique including: (A) Sub-rounded opaque grain, sample 1. (B) Pyroxene, sample 9. (C) Amphibole, sample 1. (D) Colourless, rounded garnet, sample 3. (E) Pale green to brown colored epidote, sample 3. (F) High relief, yellowish color subangularstaurolite grain, sample 6.

*5.2.2. Unstable Minerals*

- Pyroxene

Pyroxene is the most important group of ferromagnesian rock forming minerals. It occurs in almost every type of igneous and metamorphic rocks (Mange and Morton, 2007; Deer et al. 1992) The percentage of the pyroxene is ranging between 5.4 and 6.5% with an average of 6.04% (Table 4), pale green, yellowish color showing a prismatic habit (Fig. 6-B), the grains are both orthopyroxene and clinopyroxene.

- Amphibole

Pettijohn et al. (1973) concluded that amphiboles compose of complex group of minerals that form in many types of metamorphic andigneous rocks. They are the most common group in the studied transparent unstable heavy minerals, ranging between 5.8 and 6.4% with an average of 6.12% (Table 4), green, mostly fresh showing some degree of alteration, euhedral to subhedral in shape (Fig. 6-C).

*5.2.3. Metastable Minerals*

- Garnet

The percentage of the garnet is ranging between 3.3 and 4.5% with an average of 3.92% (Table 4), colorless and rounded garnet shape, mostly fresh grains (Fig. 6-D). Garnet is especially characteristic of metamorphic rocks (Mason and Berry, 1968; Kerr, 1959).

- Epidote

The percentage of the epidote is ranging between 5.8 and 6.5% with an average of 6.04% (Table 4), light green colored and sub-rounded to rounded in shape (Fig. 6-E). Epidote is common in low to medium grade metamorphic rocks (Mange and Maurer, 1992).

- Staurolite

The percentage of the staurolite is ranging between 1.5 and 2.7% with an average of 1.96% (Table 4), high relief, light yellowish color and sub-angular to sub-rounded in shape (Fig. 6-F). It is usually detected in metamorphic rocks due to regional metamorphism in intermediate to high grade (Elsner, 2010).

*5.2.4. Flaky Minerals:*

- Biotite

The percentage of the biotite is ranging between 3 and 3.8% with an average of 3.32% (Table 4), brown flaky, irregular in shape, platy grains are common (Fig. 7-A), with few long platy grains, and usually altered to chlorite. Biotite group are recognized in many igneous and metamorphic rocks (Nesbitt and Young, 1984).

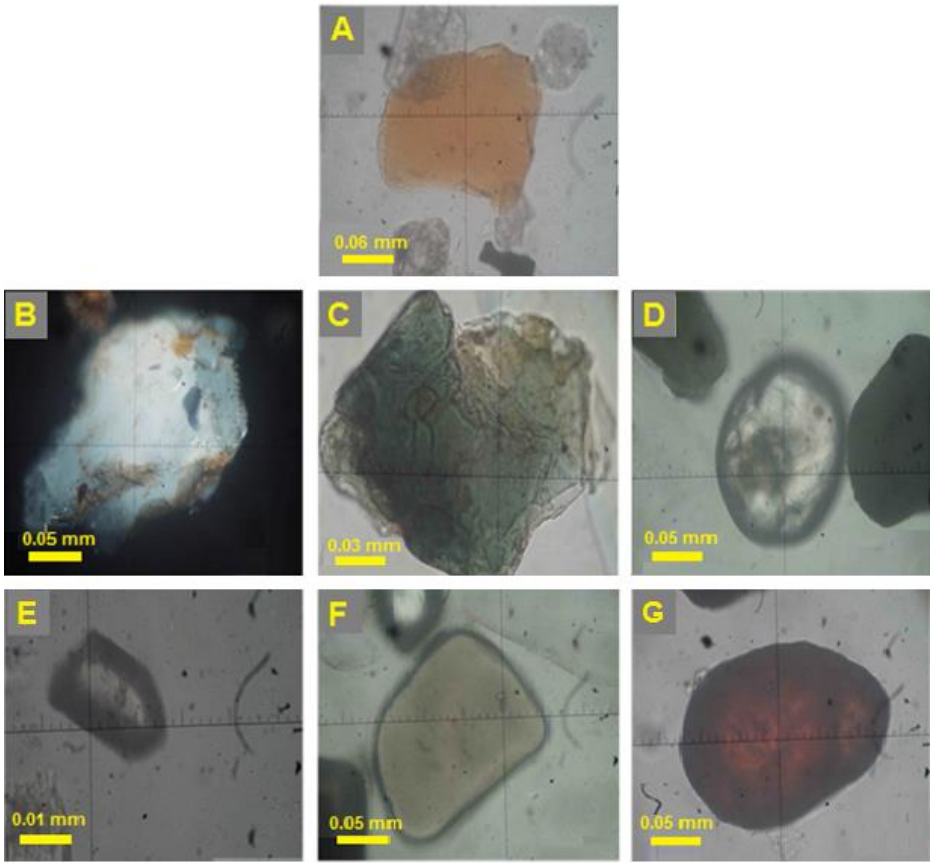



**Fig. 7.** Microphotographs of heavey minerals grains using PPL, (except B is XPL) technique including: (A) Platy brown flaky Biotite, sample 10. (B) Muscovite, sample 10. (C) Subrounded green chlorite, sample 10. (D) Well-rounded zircon, sample 1. (D) Prismatic zircon, sample 6. (E) Sub-rounded pleochroic tourmaline sample 6. (F) Rutile sample 1.

- Muscovite

The percentage of the muscovite ranging between 4 and 5.2% with an average of 4.68% (Table 4), colorless, basal flakes, rounded to irregular outline. Most of the observed muscovite grains are clear and fresh (Plate 3-B). Muscovite is common mica, foundin a contact metamorphic rocksalso in granites,

pegmatites,and as or a secondary mineral resulting from the alteration of topaz, feldspar, kyanite, etc. (Blatt and Robert, 1996).

- Chlorite

Chlorite formed as result of alteration ferromagnesian silicate minerals and can be derived from metamorphic rocks (Hibbard, 2002). The percentage of chlorite is ranging between 7.5 and 9.2% with an average of 8.3% (Table 4). Chlorite second in abundance, it shows a deep bluish green and yellow green (Plate 3-C), the shape of the chlorite grains varies from platy to sub-rounded as well as irregular outline.

*5.2.5. Ultrastable Minerals*

- Zircon

The percentage of the zircon is ranging between 4.1 and 5.1% with an average of 4.58% (Table 4). Colorless, sometimes with shades of deep blue and purple tints euhedral, subhedral prismatic grains are common rarely sub-angular, zircon grains, mostly occur with inclusions (Plates 2-D and 2-E). Euhedral shape zircon is pointing to the acidic igneous rock where the rounded shape is indication for the high grad metamorphic rocks (Speer, 1982).

- Tourmaline

The percentage of the tourmaline is ranging between 1 and 1.6% with an average of 1.26% (Table 4), pleochroic, sub-rounded, equant shape and mostly fresh grains (Plate 3-F). Tourmaline derived from granite, and metamorphic rocks (Petijohn et al., 1972 and Tucker, 1985).

- Rutile

The percentage of the rutile is ranging 1.1- 1.7% with an average of 1.46% (Table 4), rounded,dark red color, and cleaved (Plate 3-H). Rutile is widely distributed as accessory mineral in metamorphic and felsic igneous rocks (Boggs, 1995; Tucker, 1991).

## 6. Provence of Sediments

### 6.1. Maturity of Sediments

There are two types of sedimentary maturity – textural and mineralogical. The textural maturity of sediment depends on the content of fine-grained material, the sorting and the roundness of the grains (Adams et al., 1988). The sediments in the study area are classified as sandy mud (sM), very poorly-sorted (with an average standard deviation of 2.9) (Table 1), and the framework grains are mostly angular to sub-angular, and thus can be classified as immature (Folk, 1974). The compositional maturity refers to the relative abundance of stable and unstable framework grains (Boggs, 1995). Depending on the proportions of light minerals in the sediments, the average mineral maturity indices (MI and MMI) were 0.35 and 0.58 (Table 4). These results indicate that the sediments were extremely immature (Nwajide and Hoque, 1985; Igwe et al., 2013). On other hand, the mineral maturity of the heavy mineral assemblages of the sediments is quantitatively defined by the ZTR index (Hubert, 1962). The calculated index is expressed in percentage to ascertain the mineralogical maturity of the sediment. The ZTR values (Table 4) show low percentages implying that these sediments are immature according to Hubert's (1962) scheme. These results indicate that the source area represents rather high topography, rapid erosion and transport in arid to semi-arid environment and a short distance or a little more of transportation.

### 6.2. Tectonic Provenance of Sediments

To differentiate sediment derived from the three main tectonic provenances, it is proposed the use of ternary composition diagrams QFL and QmFLt (Dickinson and Suczek, 1979; Dickinson et al., 1983). On QFL diagram, all five samples were fallen in the field of the recycled orogen (Fig. 5-A), while

on QmFLt diagram of the samples fall in the field of lithic recycled (Fig. 5-B). Many recycled orogens formed by the collision of terrains that were once separate continental blocks; this resulted the collision range of the Taurus and Zagros mountain ranges (Al-Salmani and Tamar-Agha, 2018).

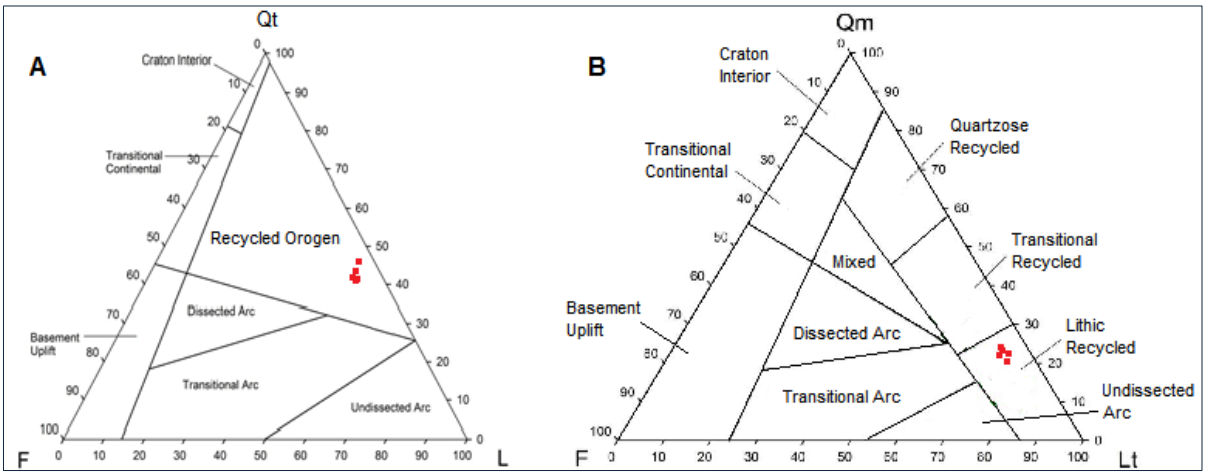



**Fig. 8.** A and B. All five samples clotted in the field of lithic recycled orogen in the study area.

## 7. Conclusions

Grain size analysis of Al-Dujaila River Project sediments showed that the silt represents the major part and clay in second rank then sand. According to Folk's classification (1974), these sediments are classified as a sandy mud. Sedimentology study illustratethat averages of light and heavy minerals are 94.6% and 5.4% respectively: The light minerals are: quartz (monocrystalline and polycrystalline), feldspar and rock fragments which represent the biggest share in the sediments of Al-Dujaila River Project that refers to the source rock area was near the sedimentary basin or has high topography. On other hand, carbonates rock fragments have the highest percentage (40%), pointed to the source rocks are rich in carbonate rocks, traveled short distance with prevailed arid to semi-arid climate. Opaques represent the major share of heavy minerals with average 54.2%, while ultrastable minerals represent the less share 7.3%. Light and heavy minerals reflect metamorphic, mafic and felsic igneous rocks of the active margin of unstable shelf in addition to carbonate, evaporate and mud of sedimentary rocks that could be sourced it form the flood plain (Euphrates, Fatha and Injana Formations).

The petrographic results of sediment samples (diversity percentages of sediment components, angularity shape and very poorly sorting of grains) in the studied area and values of MI, and MMI as well as the ZTR indices, all these indicate that sediments of the Dujaila River Project are immature to extremely immature. It refers that the source area represents rather high topography, rapid erosion and transport in arid to semi-arid environment and a short distance or a little more of transportation. According to major tectonic provenances of Dickenson et al. (1979; 1983), the QFL and QmFLt diagramsof five sediments samples fallen in the lithic reworcedregion of recycled orogen provenancedue to the collision range of the Taurus and Zagros mountain ranges.

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