

Petrography, heavy mineral study and tectonic setting of Walsh Naopurdan Series Sandstones, Qalander area, Northeastern Iraq

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Abstract

The Petrography and Heavy mineral study of Walsh-Naopurdan Series Sandstone (Middle-Late Eocene) at Qalander area is carried out.

Thin section study of twenty seven samples showed that these sandstones consist of quartz, feldspar, rock fragments (lithics), matrix, and cement. The rock fragments are of sedimentary, igneous, and metamorphic types as an indication of multiple source rocks originated from the complex thrust zone of northeastern Iraq.

The Heavy mineral analysis also showed different types, dominated by opaques and transparent minerals as a further indication of multiple source rocks.

The main constituents of the studied sandstones (quartz, feldspar, rock fragment and matrix) are used in their classification which showed that the sandstones are of lithic greywacke type. The provenance indicating triangular diagrams (QtFL and QmFLt) showed that the Walsh-Naopurdan Series Sandstone is of recycled orogen sources shared between transitional, mixed, dissected and transitional arcs tectonic settings. These represent a complex convergent boundary with dissected transitional volcanic arc which was subjected to uplift and erosion.

Keywords: Petrography, Provenance, Walsh-Naopurdan Series, Qalander area, lithic greywacke.

Introduction

The study area is located between Longitudes $44^{\circ} 27' 00'' - 44^{\circ} 27' 30''$ E and Latitudes $36^{\circ} 48' 30'' - 36^{\circ} 49' 30''$ N in Iraqi Kurdistan region at Erbil governorate, about 100km to the Northeast of Erbil city (Fig.1).

Many studies such as those of (Underwood and Bachman ,986) (Dickinson 1985), (Uddin, *et al*, 2007) and (Garzanti and Ando 2007) (Pindell, *et al*. 2009). have indicated the importance of the lithology and

heavy minerals content of sandstones as a tool to predict their provenance and tectonic setting (Table 1).

Crook (1970b) has recognized three major classes of greywacke and has attributed their differences to provenance: the quartz-poor (under 15 percent quartz) being of volcanic provenance, the quartz-rich (over 65 percent and commonly 80 percent) being of sedimentary provenance, and the intermediate class (15 -65 percent quartz) being of mixed provenance. So the greywacke sandstones of Walash-Naopurdan Series at Qalander area (35, 5 percent quartz) are intermediate class.

Recycled orogens refers to several tectonic settings such as tectonically uplifted complexes, subduction zones, thrust sheets situated behind volcanic arc islands and suture belts, collisions represented by foreland fold - thrust belts. (Dickinson and Suczek, 1979). These areas are dominated by sedimentary strata with subordinate volcanic rocks and their metamorphic derivatives exposed to deformation due to uplifting and erosion by orogenic uplifting of fold belts and thrust sheets. Recycled orogens of greywacke sandstones in present study refers to tectonically uplifted complexes subduction zones and thrust sheets situated behind volcanic arc islands.

Table (1) Major provenance types and key compositional aspects of derivative sands (Dickinson, 1985)

Provenance Type	Tectonic Setting	Derivative Sand Composition
Stable craton	Continental Interior or passive platform	Quartzose sands (Qt-rich) with high Qm/Qp and K/P ratios
Basement uplift	Rift shoulder or transform rupture	Quartzofeldspathic (Qm-F) sands low in Lt with Qm/F and K/P ratios similar to bedrock
Magmatic arc	Island arc or continental arc	Feldspatholithic (F-L) volcanoclastic sands with high P/K and Lv/Ls ratios grading to quartzofeldspathic (Qm-F) batholith-derived
Recycled orogen	Subduction complex or fold-thrust belt	Quartzolithic (Qt-Lt) sands low in F and Lv with variable Qm/Qp and Qp/Ls ratios

A. Quartzose Grains ($Qt = Qm + Qp$) Qt = total quartzose grains Qm = monocrystalline quartz (>0.625 mm) Qp = polycrystalline quartz (or chalcedony).

B. Feldspar Grains ($F = P + K$) F = total feldspar grains. P = plagioclase grains. K = Kspar grains .

C. Unstable Lithic Fragments ($L = Lv + Ls$) L = total unstable lithic fragments Lv = volcanic/metavolcanic lithic fragments Ls = sedimentary/metasedimentary lithic fragments.

D. Total Lithic Fragments ($Lt = L + Qp$) Lt = extrabasinal detrital limeclasts (not included in L or Lt).

Aim of study

The goal of this study is firstly to give a detailed petrographic description of the sandstone unit of Walsh-Naopurdan Series at Qalander area, and secondly to interpret the provenance and tectonic environment of this area using the petrography and heavy minerals data.

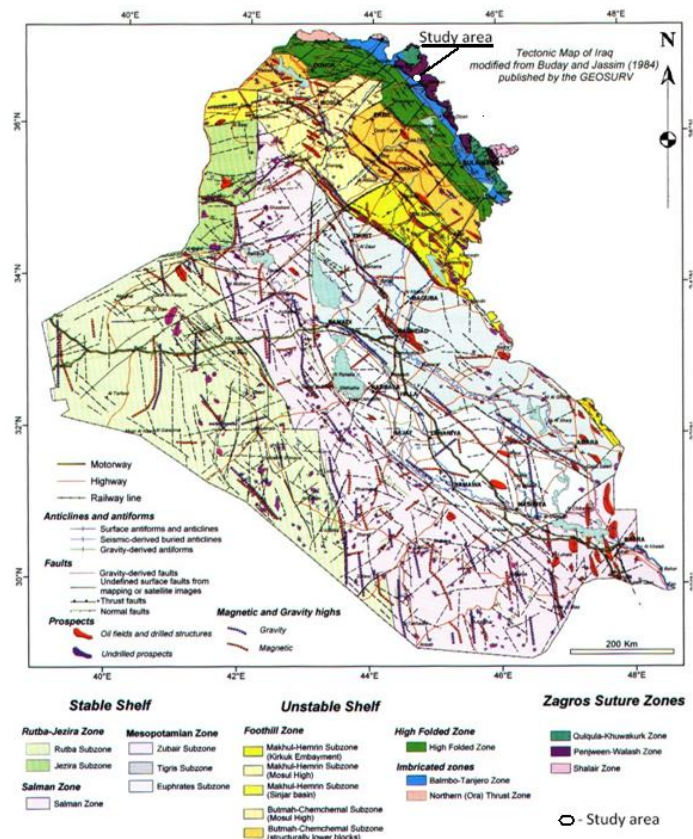


Figure 1: Tectonic map of Iraq showing the study area
(S. Z Jassim and J.C.Goff. 2006)

Geology of the study area

Topographically, the area consists of complicated and rugged mountains with scarps and valleys; the drainage of the studied area is of irregular dendritic type where the valley slopes are generally very steep, this complication is probably attributed to the tectonic setting of the area which is dominated by folding and thrusting. (Al-Chalabi 2004). Geologically the study area composed of Naopurdan Group and Walash volcanic Group. (Jassim and Goff. 2006) (Fig.2): Stratigraphically the lithofacies that occur in the study area are:

- A. Naopurdan Shaly Rock Group (Oligocene): This group is composed mainly of gray shale beds with green sandstone and coralline limestone, tuffaceous slaty shales and felsitic volcanics

and some conglomerates, (Buday and Jassim, 1987). (5 samples taken from green sandstone).

B. Walsh Group: According to (Buday 1980), the lithological sequence of this group in ascending order is:

1. Red mudstone, cherty siltstones and shales
2. The lower volcanics, which are mostly closely associated with basal red beds and composed of basic and acidic lavas, often pillow lava and associated pyroclastics.
3. Lower sediments which are composed of red mudstone, red and grey shale, sandstone, conglomerates and limestone (8 samples taken from sandstone).
4. The upper volcanic which are composed mainly of basic and intermediate lavas with andesite and pyroclastic sediments.
5. The sequence overlain by the upper sediments which consists of red mudstone in addition to conglomerate (mainly agglomerate), siltstone and greywackes sandstone (14 samples taken from sandstone).

The age of Walsh Series is Middle-Late Eocene (Koiy, 2006) which is thrust over Red Bed Series (Early-Middle Miocene).

Tectonically Qalander area is situated within the Penjwin-Walsh zone of the Iraqi Zagros suture Zone (Jassim and Goff. 2006) (Fig.1).

This zone is divided vertically to three thrust sheets

(Buday and Jassim, 1987):

Naopurdan (Oligocene) (Lower sheet).

Walsh (Middle-Late Eocene) (Middle sheet).

Penjewin – Qandil (Upper sheet).

Sampling and Methodology

Twenty seven sandstone samples were collected from massive and blocky sandstone rock beds (12 m) which are alternated with claystone. The samples were taken along traverse starting in ascending order.

The thin sections were studied petrographically under transmitted polarizing microscope and the percent of different constituents were

obtained by counting 400 grains using point counter (Table 2). Similarly, the heavy mineral percentages were obtained by counting 300 grains using grain slides prepared according to Hutchison's (1974) method for the heavy minerals fraction separated from the sandstones by bromoform as heavy liquid (Table 4).

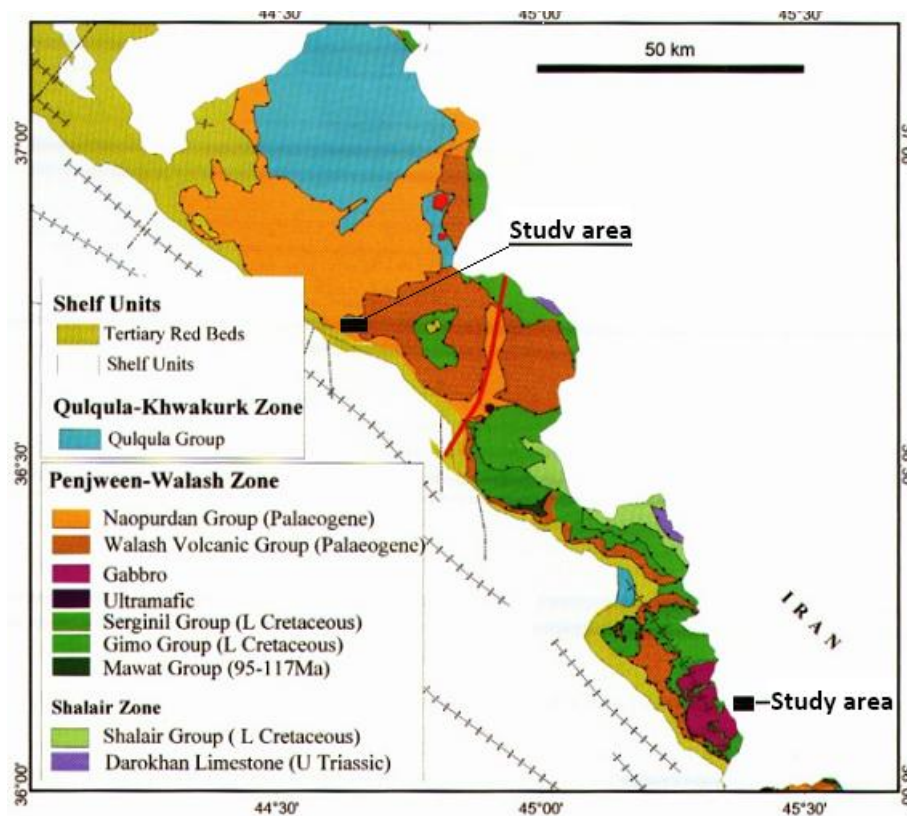


Figure (2) Geological map of the NW part of the zagros suture showing the study area (S. Z Jassim and J.C.Goff. 2006)

Results and Discussion

The studied Walsh-Naopurdan sandstones consist of quartz, feldspars and lithics of various rock types.

1. Quartz.

Quartz forms the main constituent in the studied sandstones ranging between 23-49% with an average of 35.5% (Table 2). Two types of quartz grains were recognized, monocrystalline and polycrystalline. Monocrystalline quartz is angular to sub-rounded in shape, usually have straight extension and occasionally with wavy extension indicating metamorphic origin (Folk, 1974)

(Plate 1-1). The amount of monocrystalline quartz is between 16-32 % with an average of 23.8%. Polycrystalline quartz grains contain some aggregate crystals of quartz which have sub-angular to sub-rounded shape (Plate 1-2). The amount of polycrystalline quartz is between 7–18 % with an average of 11.6%. The amount of polycrystalline quartz is less than monocrystalline quartz which is due to the lesser stability of the former, while increasing amount of monocrystalline quartz is due to the remoteness of their source rocks. The contacts between quartz crystals are mostly elongate indicating plutonic source rocks; while fewer contacts are of sutured type as an indication of metamorphic origin (Folk, 1974).

2. Feldspar.

Feldspar grains are present in minor amounts ranging between 5-18% and averaging 10%. Two types of feldspars exist in the studied sandstones, Na- and K-feldspars.

The Na-feldspar (plagioclase) is sub rounded and angular in shape with albite twinning (plate 1-3) , partially altered to clay minerals.

The amount of Na-feldspar ranges between 4 – 14% with an average of 7.8%, albite type indicating its derivation from granitic acidic igneous source rocks (Thoreau, 1982).

The K-feldspar is orthoclase which has platy form and dusty appearance due to the decomposition to clay minerals (Plate 1- 4). The amount of K-feldspar ranges between 1-4% with an average of 2.2%, Feldspars are less stable than quartz and can be altered to clay *minerals* (Boggs, 1997). The presence of orthoclase and plagioclase indicates plutonic igneous or metamorphic source rocks (Pittman, 1970).

3. Rock fragments (Lithics).

Most of the rock fragments are terrigenous grain that were derived from older source rocks and survived destruction. They are very important for studying the source rocks and more reliable than individual minerals such as quartz and feldspar that could be derived from different source rocks (Boggs, 1997). The amount of

total rock fragments are between 17-33% averaging 25.5%. They consist of the following types:

3 – 1 Sedimentary rock fragments.

Sedimentary rock fragments are the most abundant lithics ranging in amount between 11-24% with an average of 17.7%. They are of different types including chert, carbonates and clastics. The chert lithics are probably derived from the radiolarian chert beds of Qulqula Series exposed in the thrust zone of northeastern Iraq. The carbonate lithics are mostly composed of sparry calcite (Plate 1- 5); they indicate carbonate source rocks (Al- Juboury, 1994). The clastics are abundant and exist as sandstone grains (Plate1-6), siltstone (Plate 1-7), clay (Plate 1-8). The sandstones are of medium grain size and consist of quartz in clay matrix; while the siltstones are smaller in size and consist of tiny dark colored quartz crystals in clay matrix.

3 – 2 Igneous rock fragments.

These clasts are usually rare ranging in amount between 3-8% with an average of 5.7% (Table 1). They are mostly dark colored grains of basalt (Plate 1-9). The existence of these lithics is attributed to igneous source rocks (Al-Juboury, 1994).

3 – 3 Metamorphic rock fragments.

The metamorphic lithics are present in minor amounts ranging between 1-3% with average 2.6% (Table 2). They are mostly serpentines and schist.

The serpentine lithics are derivatives of peridotites exposed in ophiolite complexes of northeastern Iraq. The schist lithics shows foliation with fine grained texture (Plate 1-10). The metamorphic rock fragments are derived from the thrust zone area which represents exposed uplifted fold belts and thrust sheets.

4. Matrix.

The matrix represents ligament materials that are filling void between particles which generally consists of formed clay and micritic materials (Dickinson, 1970). It is produced as a result of disintegration and decomposition of unstable constituents

especially rock fragments and feldspars. The matrix amount is relatively high ranging between 15-28% and averaging 20.3% (Table 2).

The matrix are of two types, first is of autochthonous origin which was created by diagenesis, the second is allochthonous in origin which was transported from the source area and deposited in the basin (Tucker, 1985). The matrix has been considered as an essential characteristic of greywacke and was noted by some as the essence of the greywacke problem. Wherever the matrix is mainly friable clay material (Plate 1-11), this means that most of this matrix is autochthonous (Selley, 1982).

5. Cement.

Cement represents binding material which is deposited from chemical solutions present between grains. It ranges between 5-12% with an average of 8.7% (Table 2). The main kinds of cements in the studied sandstones are carbonates (Sparry calcite cement) (Plate 1- 12).

Table (2) modal analyses percentage and average of Walash-Naopurdan Series Sandstone constituents in Qalander area

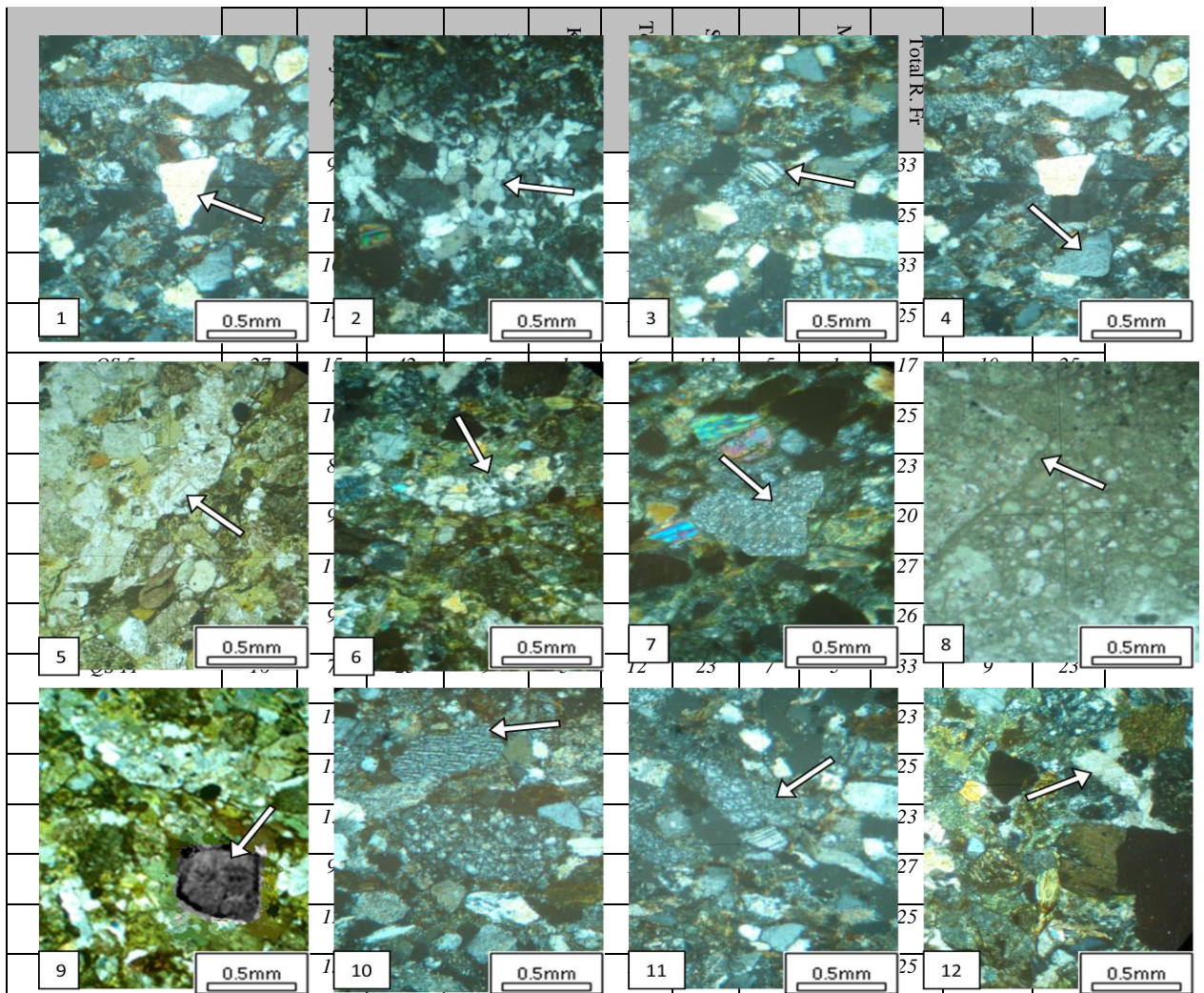
Sample No.	Quartz (Mono.+Poly.)	Feldspars	Rock Fragment	Matrix
QS1	26	13	33	20
QS 2	40	14	25	16
QS 3	29	14	33	17
QS 4	34	10	25	20
QS 5	42	6	17	25
QS 6	42	10	25	15
QS 7	26	15	23	25
QS 8	31	18	20	22
QS 9	38	8	27	20
QS 10	32	9	26	23
QS 11	23	12	33	23

QS 12	31	14	23	21
QS 13	42	7	25	18

Sample No.	Quartz	Feldspar	Rock Fragment	Cements	Matrix
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QS 14	42	8	23	21
QS 15	25	14	27	25
QS 16	35	8	25	20
QS 17	37	10	25	18
QS 18	41	9	23	20
QS 19	40	12	21	17
QS 20	27	10	33	21
QS 21	49	5	23	16
QS 22	37	5	28	19
QS 23	34	11	25	22
QS 24	42	6	22	20
QS 25	33	6	26	28
QS 26	44	9	20	20
QS 27	36	7	33	16
Average	35.5	10	25.5	20.3

Table (3) percetage and average of walash-Naopurdan series sandstone constituents in qalander area plotted on (Pettijohn *et al* ., 1973) equilateral tringle



QS 18	28	12	40	8	1	9	18	4	1	23	8	20
QS 19	27	13	40	9	3	12	16	3	2	21	10	17
QS 20	19	8	27	8	2	10	22	8	3	33	9	21
QS 21	32	17	49	4	1	5	16	4	3	23	7	16
QS 22	26	11	37	4	1	5	18	7	3	28	11	19
QS 23	21	13	34	8	3	11	17	6	2	25	8	22
QS 24	32	10	42	4	2	6	18	4	2	22	10	20
QS 25	21	11	33	4	2	6	18	5	3	26	7	28
QS 26	27	17	44	8	1	9	12	6	2	20	7	20
QS 27	28	8	36	6	1	7	23	7	3	33	8	16
Average	23.8	11.6	35.5	7.8	2.2	10	17.7	5.7	2.6	25.5	8.7	20.3

Plate (1) Petrographic images for the main constituents of the studied sandstones

1. Angular monocrystalline quartz, with straight extension (crossed nicols).
2. Polycrystalline quartz surrounded by quartz aggregate(crossed nicols).
3. Subrounded plagioclase grain showing albite twinning (crossed nicols).
4. Dusty orthoclase with platy form decomposed to clay minerals.
5. Sparry calcite as carbonate rock fragments (crossed nicols).
6. Sandstone rock fragments (quartz grain in clay matrix) crossed nicols.
7. Siltstone rock fragments with small size of quartz in clay matrix.
8. Clay rock fragment in sandstone(crossed nicols).
9. Igneous Rock fragments usually found as dark color grains of (basalt).
10. Metamorphic rock fragments (schist) that shows oriented crystals.
11. Autochthonous friable clay matrix which is deposited in the basin.
12. Sparry calcite cement between sand grains (crossed nicols).

Classification of Sandstones

The data given in Table 3 are plotted on the equilateral triangle of Pettijohn et.al., (1973) in order to name the type of the studied sandstones. This triangle depends on the main constituents of the sandstone, i.e., quartz, feldspar, rock fragment and matrix. It showed that

most of the studied samples are situated in lithic greywacke field (Figure 3).

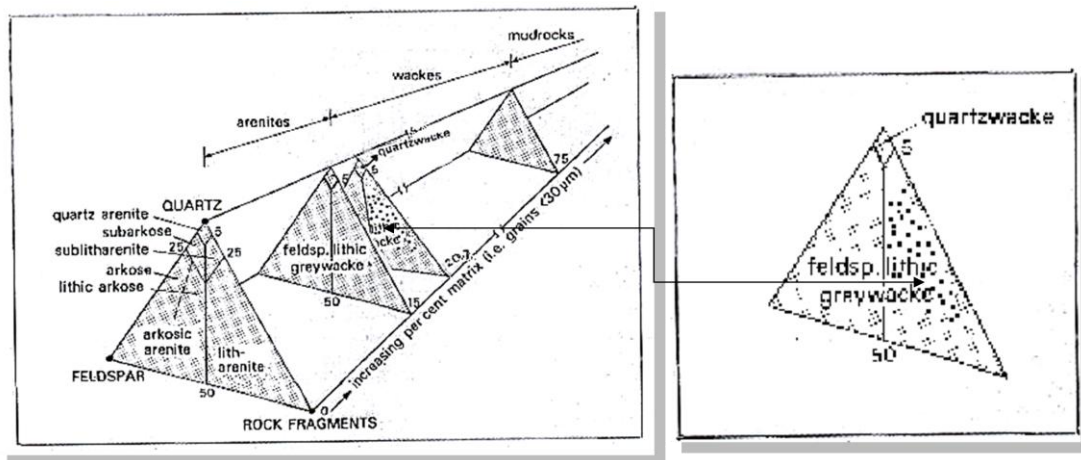


Figure (3) Classification of Walash-Naopurdan Series Sandstone in Qalander area after (Pettijohn et al., 1973)

Heavy Minerals

The heavy minerals are very important group of minerals which exist in clastic sedimentary rocks because they are provenance indicators (Markevich, *et al.*, 2007).

The general properties of heavy minerals depend on many factors including the source rocks. Usually this group of minerals is divided into two types, the opaques and the transparent minerals. Twenty seven grain slides were used in this study for the identification and counting heavy minerals in the sandstones of Walash-Naopurdan Series.

Opagues

The studied grain slides showed that the opaque heavy minerals comprise the highest percentage with an average of %69.45 (Table 4).

The identification of opaques depended on Kerr's (1959) classification in such a way that the black colored grains are magnetite (Plate 2-1), reddish weak brown is Goethite (Plate 2-2), and dark with metallic luster is chromite (Al-Chalabi. 2004) (Plate 2-2). These opaques are usually derived from mafic igneous rocks (Pettijohn, 1975). Chromite is an evidence of the proximity to the source rocks (Dill, 1998).

Transparent Heavy Minerals

This group of heavy minerals is usually positively identifiable under the polarizing microscope because they can transmit light in thin sections. These heavy minerals can be classified according to their stability into three subgroups: ultrastable, metastable and unstable heavy minerals (Folk, 1974).

1. Ultra Stable Heavy Minerals

They include zircon, rutile and tourmaline. Their presence is an evidence of metamorphic rocks which were derived from acidic igneous source rocks (Chaodong *et al.*, 2005), or metamorphic and igneous mafic source rocks (Ruiz *et al.*, 2007).

Zircon

Zircon is found as subrounded grains or prisms with pyramidal endings (Plate 2-3). It can be derived from metamorphic and acidic igneous source rocks. The rounded grains are abundant in reworked sediment (Kerr, 1959; Pettijohn, 1975).

Zircon is characterized by its colorless, pale yellow or pale pink colors and high relief. The amount of zircon is between 2- 8 % with an average of 4.44 % (Table 4).

Tourmaline

Tourmaline is a group of minerals with complex chemical compositions and various colors. The variation in colors is due to the complexity of chemical composition and they all show pleochroism. The subrounded grains are usually brown to yellowish brown representing dravite (Elyas 1988; Ismail, 1996).

The percentage of tourmaline is between 3-6 % with an average of 4.1 % (Table 4). It is derived from metamorphic and igneous source rocks while the rounded grains are derived from reworked sediment source (Kerr, 1959; Pettijohn 1978).

Rutile

Rutile is found as subrounded grains (Plate 2-4). The rounded grains are derived from reworked sediments source (Pettijohn, 1978)

while the platy forms are derived from mafic igneous rocks (Pettijohn,1975).

Rutile can be identified by its high relief, red or brown to yellowish orange color , pleochroism from yellow to reddish brown (Kerr, 1959). The amount of rutile is between 1-6% with an average of 3.5 % (Table 4).

2. Metastable Heavy Minerals

This subgroup includes garnet, epidote and kyanite which were recognized in the studied sandstones.

Garnet

Garnet includes two mineral groups, pyrospite and grandite (ugrandite) with a general composition $X_3Y_2(SiO_4)_3$, where X site is occupied by Ca^{2+} with possible extensive substitution by Mg, Fe, and Mn; while Y site is occupied by Al^{3+} (Nesse, 2000). Garnet with a general formula $(Mg,Fe,Ca)_3Al_2(SiO_4)_3$ is an intermediate composition between the two groups. Garnet is characterized by distinct optical properties such as high relief, isotropy, pitted appearance, subrounded form and pale brown to dark brown color (Plate 2-5). The subrounded form of garnet is attributed to its crystallization in cubic system (Al-Sayegh, and Al-Jubouri, 2002).

The percentage of garnet is between 2-6% with an average of 3.6% (Table 4). Garnet is derived from dynamothermal metamorphic source and igneous source rocks (Kerr, 1959; Folk, 1974), (Pettijohn, 1975; Pettijohn, 1978).

Epidote.

The amount of epidote is between 4-12% with an average of 7.6% (Table 4). It has a dusty appearance, subrounded form, pistachio green to yellowish green colors and weak pleochroism (Plates 2- 6).

Epidote has multiple source including metamorphic and igneous rocks (Kerr, 1959), dynamothermal metamorphic rocks (Pettijohn, 1978), and metamorphic rocks (Asideu *et al.*, 2000).

3. Unstable Heavy Minerals

The unstable heavy minerals recognized in the studied sandstones are pyroxene, hornblende, and serpentine.

Pyroxenes: are colorless or pale green in color, prismatic or irregular in shape, and have eroded surfaces which are evident on the corroded outer rim of the grains (Plate 2-7). The amount of pyroxenes is between 1-3% with an average of 1.6% (Table 4). Pyroxene minerals are derived from mafic igneous rocks.

Amphibole: group is represented by hornblende grains which are prismatic or subrounded in forms, green in color, and have rhombohedral cleavages (Plate 2-8). The amount of hornblende is between 1-3% with an average of 1.3% (Table 4). It is derived from metamorphic and acidic igneous source rocks (Folk, 1974; Pettijohn, 1975).

Serpentine: minerals are yellowish green in color and have fibrous forms (Antigorite –Lizardite) (Plate 2-9). The amount of serpentine is between 2-7% with an average of 3.97% (Table 4). Serpentine forms as a result of hydration of peridotite and also can be derived from mafic igneous rocks, or hydrothermal metamorphic source rocks (Pettijohn, 1978).

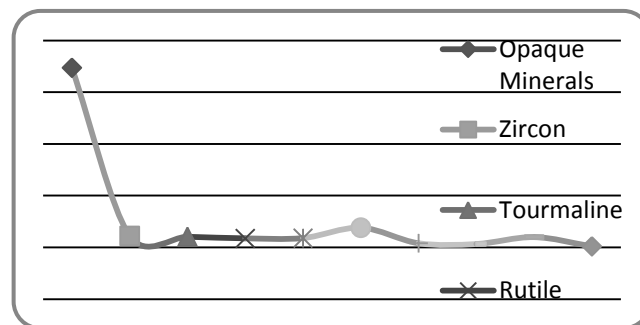


Figure (4) Percentages of heavy minerals in Walash-Naopurdan Series Sandstone at Qalander area

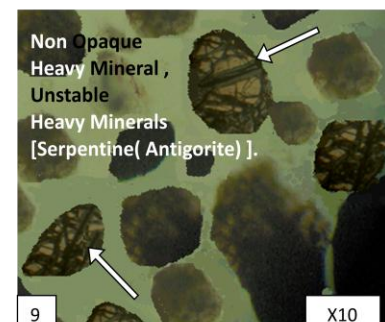
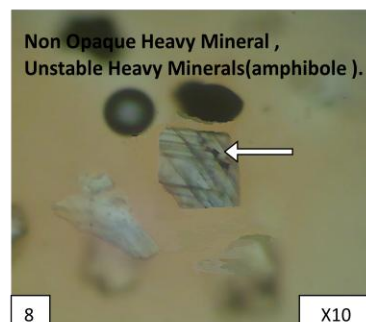
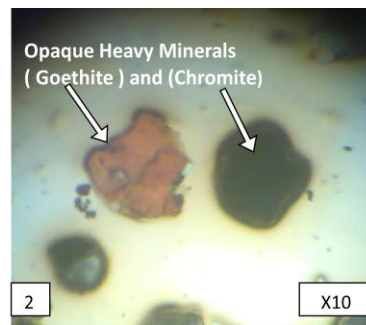
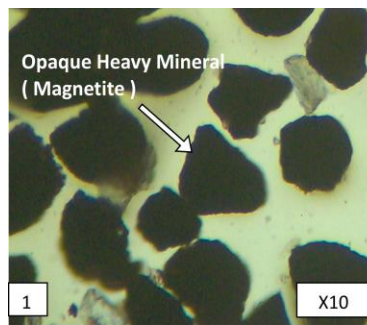
Table (4) percentage and average of heavy minerals inWalash-

<i>Sample NO.</i>	<i>Heavy Mineral (Wt%) in Bulk sample</i>	<i>Opaque Minerals</i>	<i>Zircon</i>	<i>Tourmaline</i>	<i>Rutile</i>	<i>Garnet</i>	<i>Epidote</i>	<i>Pyroxene</i>	<i>Amphibole</i>	<i>Serpentine</i>	<i>Others</i>
<i>QS1</i>	<i>8.51</i>	<i>73</i>	<i>4</i>	<i>3</i>	<i>3</i>	<i>2</i>	<i>6</i>	<i>2</i>	<i>1</i>	<i>5</i>	<i>0</i>
<i>QS 2</i>	<i>7.52</i>	<i>68</i>	<i>3</i>	<i>4</i>	<i>2</i>	<i>4</i>	<i>10</i>	<i>1</i>	<i>2</i>	<i>5</i>	<i>1</i>
<i>QS 3</i>	<i>4.36</i>	<i>57</i>	<i>7</i>	<i>6</i>	<i>4</i>	<i>5</i>	<i>11</i>	<i>2</i>	<i>1</i>	<i>7</i>	<i>0</i>
<i>QS 4</i>	<i>9.10</i>	<i>80</i>	<i>2</i>	<i>3</i>	<i>2</i>	<i>3</i>	<i>5</i>	<i>1</i>	<i>1</i>	<i>3</i>	<i>0</i>
<i>QS 5</i>	<i>7.51</i>	<i>72</i>	<i>3</i>	<i>5</i>	<i>3</i>	<i>3</i>	<i>6</i>	<i>1</i>	<i>1</i>	<i>5</i>	<i>1</i>
<i>QS 6</i>	<i>7.92</i>	<i>78</i>	<i>3</i>	<i>4</i>	<i>2</i>	<i>3</i>	<i>5</i>	<i>1</i>	<i>1</i>	<i>3</i>	<i>0</i>
<i>QS 7</i>	<i>7.32</i>	<i>67</i>	<i>6</i>	<i>4</i>	<i>4</i>	<i>4</i>	<i>6</i>	<i>1</i>	<i>1</i>	<i>6</i>	<i>1</i>

Naopurdan Series Sandstones in Qalander area

QS 8	8.72	77	2	3	1	3	8	1	1	4	0
QS 9	6.53	63	5	5	5	5	10	1	1	5	0
QS 10	6.23	63	6	4	5	4	9	1	3	4	1
QS 11	6.03	57	8	5	6	4	12	1	1	6	0
QS 12	6.71	81	2	3	2	3	4	1	1	2	1
QS 13	3.62	53	7	6	6	6	12	3	1	6	0
QS 14	4.72	68	5	3	3	4	11	1	1	3	1
QS 15	7.32	71	4	4	3	3	7	1	2	4	1
QS 16	7.51	74	4	3	3	3	6	2	1	4	0
QS 17	8.53	73	5	4	3	4	5	1	1	3	1
QS 18	4.31	57	7	5	6	5	11	3	2	4	0
QS 19	7.53	68	6	5	4	3	7	2	1	3	1
QS 20	8.02	78	3	3	4	2	5	2	1	2	0
QS 21	7.61	73	3	5	4	4	5	1	1	3	1
QS 22	7.81	77	4	4	3	3	5	1	1	2	0
QS 23	7.42	67	7	3	4	4	6	3	2	3	1
QS 24	8.72	76	2	3	1	3	8	3	1	3	0
QS 25	6.51	63	5	5	5	4	10	1	1	6	0
QS 26	6.33	70	4	4	3	3	9	3	1	3	0
QS 27	5.12	71	3	5	4	4	7	1	2	3	0
Average	6.95	69.45	4.44	4.1	3.5	3.6	7.6	1.6	1.3	3.97	0.4

Plate (2) Heavy Mineral images for the studied sandston



e

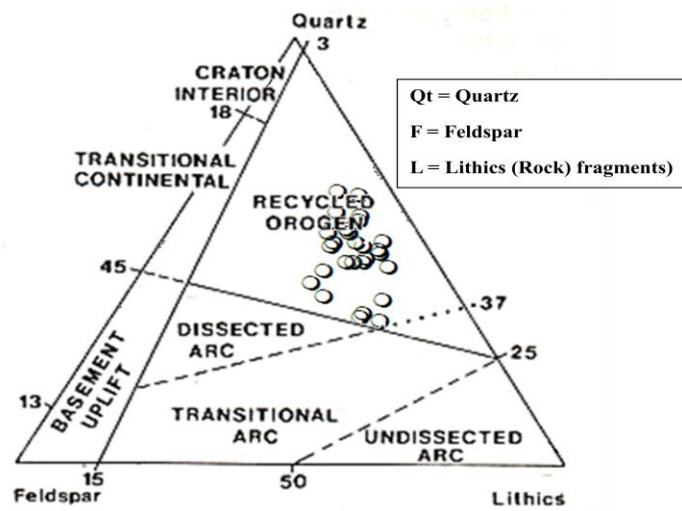


Figure (5) (Qt F L) triangle scheme of Walash-Naopurdan Series Sandstone tectonic region provenance after (Dickinson *et al*, 1983) in Qalander area.



Figure (6) (Qm F Lt) triangle scheme of Walsh-Naopurdan Series Sandstone tectonic region provenance after (Dickinson *et al*, 1983) in Qalander area

Tectonic setting and provenance

1. Petrography provenance

Source rocks component, dispersal path types and nature of depositional process are among the important factors affecting sandstone constituents (Garzanti and Ando, 2007), (Dickinson and Suczek, 1979). Terrigenous sediments are useful for determining provenance (Dickinson, 1970). QtFL triangular plot shows that all sandstones are located within the recycled orogen provenance (Figure 5). This means that these sediments were derived from recycled source rocks that were subjected partially to metamorphic process (Dickinson, 1985), The QmFLt triangular plot also showed that the studied sandstones are of recycled orogen source represented mainly by transitional field in addition to the occurrence of some samples in the mixed, dissected and transitional arc fields (Figure 6). Recycled orogens refers to several tectonic settings, the greywacke sandstones components (QmFLt) triangular plots in present study refers to tectonically uplifted complexes subduction zones and thrust sheets situated behind volcanic arc islands. These areas are dominated by sedimentary strata with subordinate volcanic rocks and their metamorphic

derivates exposed to deformation due to uplifting and erosion by orogenic uplifting of fold belts and thrust sheets.

2. Heavy Mineral provenance

Opaque's comprise very high percent (average 69.45 %) of heavy minerals in the studied sandstones suggesting mafic igneous source rocks which presence in volcanic arcs islands before complexes subduction zones and thrust sheets. Meanwhile the ultrastable heavy minerals (ZTR) are generally derived from reworked sediments source, because these areas are dominated by sedimentary strata with subordinate volcanic rocks and their metamorphic derivates exposed to deformation. Noticeable increase in the ratio of epidote and serpentine among the metastable and unstable heavy minerals (Figure 4) as an indication of dynamothermal and hydrothermal metamorphic source rocks presence in thrust sheets. The presence of different kinds of heavy minerals is by itself an indication of multiple source rocks (Sedimentary, Igneous, and Metamorphic) which are exposed in the complex subduction and thrust zones of northeastern Iraq.

Conclusions

1. The studied Sandstone rocks are classified as lithic greywacke.
2. The amount of sedimentary rock fragments is higher than those of igneous and metamorphic lithics; and the amount of monocrystalline quartz is relatively higher than the polycrystalline quartz. This indicates that the studied sandstones were mainly derived from sedimentary source rock with contributions from Igneous and metamorphic sources.
3. The provenance of Walash-Naopurdan Series Sandstone at Qalander area is recycled orogen.
4. The tectonic setting mainly is transitional recycled, which transition between quartzose recycled and lithic recycled represent deferent tectonic sources, several samples located in mixed tectonic represent mixed between transitional recycled and transitional continental , and few samples located in dissected and transitional arcs which

represents magmatic arcs presence in volcanic arcs islands before complexes subduction zones and thrust sheets.

5. The opaques comprise very high percent (69.6 % in average) relative to the other heavy minerals in the studied sandstones suggesting mafic igneous source rocks which presence in volcanic arcs islands before complexes subduction zones and thrust sheets uplifted and exposed to erosion.
6. The unstable heavy minerals indicate the proximity of source rock.
7. The presence of different kinds of heavy minerals indicates multiple source rocks (sedimentary, igneous and metamorphic) which all are exposed in the complex thrust zone of northeastern Iraq.

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دراسة بتروكرافية ومعادن الثقيلة لصخور الرملية في سلسلة والاش -

ناوبردان (النيسين الأوسط-المتاخر) في منطقة قلندر - شمال شرق

العراق

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تضمنت الدراسة جمع (٢٧) نموذجاً من الصخور الرملية في سلسلة والاش- ناوبردان (الثيوسين الأوسط-المتأخر) في منطقة قلندر وحضرت منها (27) نموذجاً من الشرائح الرقيقة لدراسة بتروكرافيتها والعدد مثله من الشرائح الرقيقة الخاصة بالمعادن الثقيلة لدراسة المعادن الثقيلة وتبين إنها تحتوي على المكونات المعدنية الآتية : الكوارتز، الفلدسبار، القطع الصخرية ، الحشوة والسمنت ، ان وجودانواع مختلفة من القطع الصخرية (الرسوبية،النارية والبركانية) يدل على إن تلك الصخور الرملية قد اشتقت من مصادر صخرية مختلفة في منطقة الفوالق الزاحفة ، ودراسة المعادن الثقيلة تبين وجودانواع مختلفة من المعادن الثقيلة وباشكال مختلفة في البعض منها والذي يؤكد تلك الصخور قد اشتقت من مصادر صخرية مختلفة ايضاً. التصنيف الذي يعتمد على المكونات الرئيسية لصخور الرملية : الكوارتز، الفلدسبار، القطع الصخرية ، الحشوة تبين انها من نوع (لتك كريبواكي) ، وبعد إسقاط النسب على المثلثين (كوارتز، الفلدسبار ،القطع الصخرية) و(الكوارتزالأحادي، الفلدسبار ،القطع الصخرية) تبين ان اصل الصخور الرملية من نوع معاد الترسيب و الوضع التكتوني يدل على وجد الاقاليم التكتونية مختلفة و المتمثلة بانطقة الزحف لقوس البركانية المنفصلة والزاحفه ومعقدات التصادم في منطقة الفوالق الزاحفة التي تعرضت للنهوض والتعرية .