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Petrography and Provenance of the Sandstone of Injana and Mukdadiya Formations (Upper Miocene/Pliocene) at Duhok Governorate, Northern Iraq

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Abstract

A total of 23 samples are collected from Injana and Mukdadiya Formations representing: sandstone (14 samples from Injana Formation and 9 samples from Mukdadiya Formation). 19 sandstone samples are thin sectioned for petrographic study (10 thin sections from Injana and 9 thin sections from Mukdadiya) and 23 sandstone samples are selected for heavy minerals study (14 samples from Injana and 9 samples from Mukdadiya). The petrographic investigations revealed that the sandstone of Injana and Mukdadiya Formations are composed primarily of rock fragments (sedimentary, igneous and metamorphic), quartz (monocrystalline and polycrystalline) and feldspars (orthoclase, microcline and plagioclase). The matrix is subordinate and the cement is mostly carbonate. The amount of quartz in Injana sandstone is more than of that in Mukdadiya sandstone and the amount of rock fragment in Injana sandstone is less than of that in Mukdadiya sandstone. Provenances of the Injana and Mukdadiya Formations consist primarily sedimentary and igneous rocks and subordinate metamorphic rocks. These sandstones are classified as Litharenites and are mineralogically immature. The heavy minerals assemblages include opaque minerals as major component, epidotes, garnet, amphiboles, clinopyroxenes, orthopyroxenes, chromian spinal, zircon, tourmaline, rutile, chlorite, biotite, muscovite and others (kyanite and staurolite). These assemblages indicate that the heavy minerals are derived from mafic igneous and metamorphic rocks mainly as well as acidic igneous and reworked sediments. The tectonic provenances of both Injana and Mukdadiya Formations can be described as transitional and lithic recycled of recycled orogen.

Keywords: Litharenite**,** Heavy minerals, Provenance, Injana Formation, Mukdadiya Formation. Recycled Orogen

بتروغرافية واصل تكوينيي انجانة والمقدادية (المايوسين الاعلى\بلايوسين) في محافظة دهوك شمالي العراق

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الخلاصة

جمعت (23) عينة من تكوينيي انجانة والمقدادية ممثلة: صخور رملية (14 عينة من تكوين انجانا و 9 عينات من تكوين المقدادية). 19 عينة عملت منها شرائح رقيقة لغرض الدراسة البتروغرافية (10 شرائح من تكوين انجانة و 9 شرائح من تكوين المقدادية) و 23 عينة من الحجر الرملي اختيرت لغرض دراسة المعادن الثقيلة (14 عينة من تكوين انجانة و9 عينات من تكوين المقدادية).
الملاحظات البتروغرافية أظهرت ان الصخور الرملية لتكوينيي انجانة والمقدادية مؤلفة بصورة أساسية من القطع الصخرية (الرسوبية ، النارية والمتحولة)، الكوارتز(الأحادي التبلور و المتعدد التبلور و الفلدسبارات (اورثوكليز، مايكروكلين و البلاجيوكليز). الحشوة تكون ثانوية والسمنت غالبا كاربوناتي. كمية الكوارتز في الصخور الرملية لتكوين انجانة اكثر من تلك الموجودة في الصخور الرملية لتكوين المقدادية وكمية القطع الصخرية في الصخور الرملية لكتوين انجانة اقل من كمية القطع الصخرية في الصخور الرملية لتكوين

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المقدادية. اصل تكوينيي انجانةوالمقدادية يتالف بصورة أساسية من صخور رسوبية ونارية وبصورة ثانوية صخور متحولة. هذه الصخور الرملية تصنف على انها ارينايت صخري و غير ناضجة معدنيا.
تجمعات المعادن الثقيلة تضم المعادن المعتمة كمكون رئيسي، ابيدوت، كارنت، امفيبول، كلاينوبايروكسين، اورثوبايروكسين، كروميان سبنل، زركون، تورمالين، روتايل، كلورايت، بايوتايت، مسكوفايت و أخرى تشمل (كيانايت، شتورولايت) هذه التجمعة تشير الى انه المعادن الثقيلة مشتقة بصورة أساسية من صخور نارية قاعدية وصخور متحولة بالإضافة الى الصخور النارية الحامضية والرسوبية القديمة. الأصل التكتوني لكلا من تكويني انجانة والمقدادية اظهر بانها تقع ضمن نطاق الاوروجيني معاد الترسيب.
الكلمات المفتاحية: الارينايت الصخري، المعادن الثقيلة، الاصل، تكوين انجانة، تكوين مقدادية، الاوروجيني المعاد.

1-Introduction

Injana and Mukdadiya Formations (previously called Upper Fars and Lower Bakhtiari Formations respectively) are of Upper Miocene-Pliocene age and are widely exposed throughout Iraq. They were described for the first time by Busk and Mayo in 1918 [1]. The Injana Formation represents the lower fine-grained molasses sediments deposited at the beginning in marine and progressively in fluvial and lacustrine environment [2]. The Mukdadyia Formation comprises fining-upward succession of gravelly sandstone, sandstone and mudstone and it deposited in a fluvial environment in rapidly subsiding foredeep basin [3]. The names of the Upper Fars and Lower Bakhtiari Formations respectively are replaced by Injana and Mukdadiya Formations [4]. Injana and Mukdadiya are extensively studied by workers because of their extension and good exposure. Such studied are [5], [6], for Injana Formation and [7], [8] for Mukdadiya Formation. The aim of this study is, first, to give a detailed petrographic description of the sandstones of Injana and Mukdadiya Formations at Amadiya area and second to interpret the provenance and tectonic setting of the provenance area using the petrography and heavy minerals data. The coordinates for the study area are Longitude 43° 31′ 55″ E, Latitude 37° 03′ 26″ N for Injana Formation and Longitude 43° 31′ 55″ E, Latitude 37° 04′ 01″ N for Mukdadiya Formation Figure-1.

2-Geological Setting

The studied area is located at the High Folded Zone (Outer Platform, Western Zagros Fold-Thrust Belt of [9] Figure-1. Injana (Upper Miocene) and Mukdadiya (Lower Bakhtiari) Formations is part of Arabian Plate Tectonostratigraphic Megasequnce AP11 of [10]. This megasequence is defined as the package of sediments representing the latest Eocene-Recent and is associated with the collision of Neo-Tethyan terrains along the N and E side of the Arabian Plate, and the opening of the Gulf of Aden and the Red Sea on the S and W side of the plate**.** The N and NE drift of Arabia and the closure of the Neo-Tethyan terranes along the NE margin of the Arabian Plate.

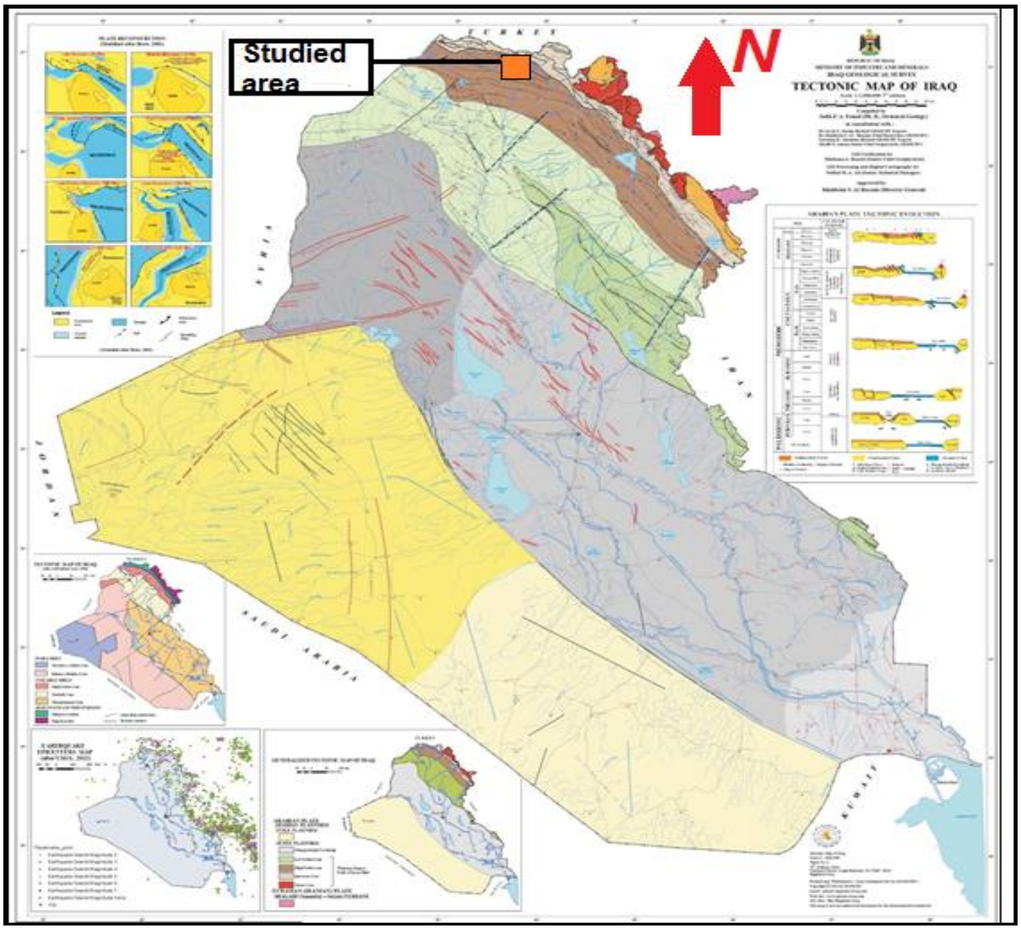

Figure 1- Tectonic and location map of the study area [9]

In N and NE Iraq in the Foothill and High Folded Zones, the megasequence is dominated by Mio-Pliocene molasse up to 3000 m thick in the foredeep basin located to the SW of the Zagros Suture [11]. Upper Miocene-Pliocene cycle is characterized by the progressive change from the marine sedimentation into the lacustrine and fluviatile. This change was accompanied by the gradational coarsening of the clastics laid down during the cycle. The main source area of the clastics was the rising mountain in the northeast of Iraq [2]. The lower contact of the Injana Formation with the underlying Fatha (previously called Lower Fars Formation) is gradational, marked by the termination of the last gypsum bed. The upper contact with the Mukdadiya Formation is gradational too, marked by appearance of gravely sandstone [4]. The lower contact of Mukdadiya Formation can be detected on the first appearance of gravel in the sandstone, and the upper contact grades into Bai-Hassan Formation on the basis of the first appearance of conglomerate [1]. In Late Miocene-Pliocene time, major thrusting occurred during collision of the Neo-Tethyan terranes and the Sanandaj-Sirjan Zone with the Arabian Plate. This event resulted in the uplift of the High Folded, Northern Thrust Zones and the NE part of Balambo-Tanjero Zones and Mesopotamian zones. During the Late Miocene and especially in the Pliocene, the High Folded Zone was uplifted with increasing intensity; the products of erosion were deposited in the nearby molasses basin.

3-Methods of Study

A total of 23 samples are collected from Injana and Mukdadiya Formations, representing sandstone (14 samples from Injana Formation and 9 samples from Mukdadiya Formation). 19 sandstone samples are thin sectioned, stained with Alizarin red S and studied petrographically under transmitted polarizing microscope (10 thin sections from Injana and 9 thin sections from Mukdadiya) and 23 sandstone samples are selected for heavy minerals study (14 samples from Injana and 9 samples from Mukdadiya). The percent of different constituents are obtained by counting 300 grains counts per thin section using the point-counter mechanical stage as suggested by [12]. The heavy minerals are separated by the standard method of heavy liquid [13] using Bromoform of density 2.89, mounted on glass slide and point contend using 300-500 grains per slide following the method of Fleet (1926: in [13]).

4-Results and discussion

4.1. Petrography and mineralogy

In general, The Injana and Mukdadiya sandstones are similar, but there are slight differences in the original texture and proportion of component. Grains are mostly subangular to subrounded. The grains of the Injana sandstone are less angular and finer than the Mukdadiya sandstone. The main detrital constituents of Injana and Mukdadiya sandstone are: rock fragments (L) quartz (Q), feldspar (F) and subordinate matrix. These constituent are bound by carbonate cement. The percentage of quartz in Injana Formation is more than of that in Mukdadiya Formation, and the percentage of rock fragment in Injana Formation is less than that in Mukdadiya Formation. The percentage, range and average of these constituents are shown in Table-1.

Table 1-Percentage, range and average of constituents of Injana and Mukdadiya sandstone at Amadiya area

Location	*Formations*	*Sample No.*	*Quartz % (Q)*	*Feldspar % (F)*	*Rock fragments % (L)*	*Others*		
						Carbonate Cement %	*Matrix %*	*Others %*
Amadiya	**Injana**	A.I.1	19.2	8.1	43.0	22.7	2.3	3.9
		A.I.2	18.4	8.6	42.8	21.6	3.6	4.4
		A.I.3	20.7	8.5	40.7	23.9	2.3	4.1
		A.I.4	23.1	6.8	41.4	18.9	4.2	6.0
		A.I.5	18.7	11.2	36.9	24.0	3.7	5.1
		A.I.7	20.5	8.9	41.0	21.5	4.3	4.0
		A.I.8	17.7	9.9	34.6	24.6	4.1	6.9
		A.I.9	19.2	10.2	37.2	20.1	4.8	6.7
		A.I.10	21.7	12.7	32.6	24.7	3.1	4.1
		A.I.11	15.4	4.7	44.8	25.5	3.2	5.8
		Range	15.4-23.1	4.7-12.7	32.6-44.8	18.9-25.5	2.3-4.8	3.9-7.2
		Average	***19.46***	***8.96***	***39.5***	***22.8***	***3.6***	***5.4***
	Mukdadiya	A.M.1	13.2	6.9	47.9	24.8	2.5	4.8
		A.M.2	17.1	7.9	47.3	15.6	4.3	6.7
		A.M.3	15.0	9.6	46.1	23.0	1.2	5.5
		A.M.4	15.7	4.7	58.6	14.3	0.9	4.8
		A.M.5	8.7	10.4	48.5	25.8	2.1	4.1
		A.M.6	11.0	6.3	50.6	21.1	4.1	6.6
		A.M.7	9.5	5.4	54.7	23.3	2.2	5.1
		A.M.8	11.5	3.8	51.3	22.3	4.6	6.4
		A.M.9	20.2	8.0	44.9	15.6	3.8	5.9
		Range	8.7-20.2	3.8-10.4	44.9-58.6	14.3-25.8	0.9-4.6	3.8-6.6
		Average	***13.5***	***7.0***	***50.0***	***20.6***	***2.9***	***5.2***

Rock fragments (L) - Rock fragments are the most abundant of all detrital components of Injana and Mukdadiya sandstones, ranging from 20.6-53.4% (average 39.7%) in Injana sandstone and ranging from 28.2-71.3% (average 49.9%) in Mukdadiya sandstone. The sedimentary rock fragments (chert, carbonate, argillaceous, sandstone) represent the largest proportion among the other rock fragments forming the sandstone of Injana and Mukdadiya Formations. The other rock fragments (igneous (volcanic and plutonic) and metamorphic) are less common. The most common rock fragments in Injana and Mukdadiya sandstones are chert rock fragments. The rock fragments are generally coarser than the other component in both formation sandstone and generally subangular to subrounded in shape Figures-2(F, G, H, I, J, K, L and M).

Quartz (Q) - Quartz is the second common detrital component in the present sandstones. The quartz grains are mostly monocrystalline with straight extinction. Most of the quartz grains show a clear rim with sharp outline and their percentage ranges from 13.7-20.9% (average 19.4%) in Injana sandstone and ranging from 5.9-15.0% (average 9.7%) in Mukdadiya sandstone. Polycrystalline quartz grains range from 0.9-5.2% **(**average 2.5%**)** in Injana sandstone and ranges from 2.1-5.1% (average 3.8%) in Mukdadiya sandstone**.** The quartz grains are generally subangular in shape Figures-2(A and B) which indicates short transport distance.

Feldspar (F) - Feldspar is the least abundant framework component of Injana and Mukdadiya sandstones. Its percentage ranges from 2.6-12.9% (average 8.9%) in Injana sandstone and from 3.7-10.9% (average 7.0%) in Mukdadiya sandstone. The feldspar is dominated by alkali feldspar (orthoclase and microcline) and less abundant plagioclase in both formations. The feldspar grains are mostly fresh indicates arid to semi-arid climate Figures-2(D and E).

Matrix -The percentage of matrix in Injana sandstone ranges from 2.3 to 4.8% (average 3.6%) and ranging from 0.9-4.6% (average 2.9%) in Mukdadiya sandstone. The matrix consists of very fine material of silt to clay and micritic materials Figure-2(N).

Cement - The percentage of cement in Injana Formation ranges from 18.9 to 25.5% (average 22.8%) and in Mukdadiya sandstone ranging from 14.3-25.8% (average 20.6%). The present study shows that the carbonate cement in highly concentrated filling the void spaces between the detrital constituent Figure-2(O).

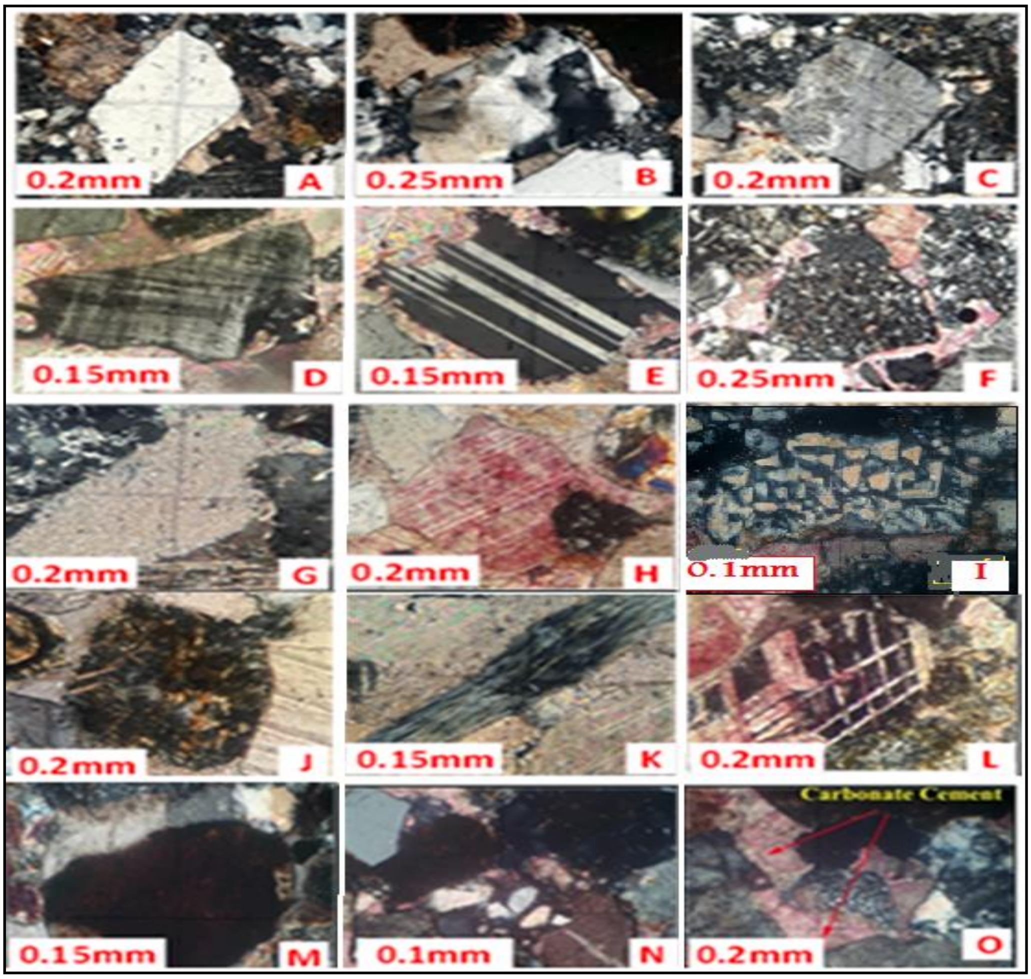

Figure 2-Crossed Nicol (XPL) photomicrograph of detrital grains of the Injana and Mukdadiya sandstone at Amadiya area, showing: A: straight extinction monocrystalline quartz, B: polycrystalline quartz, C: orthoclase, D: microcline, E: plagioclase, F: chert, G and H: carbonate fragments, I and J: igneous fragments, K and L: metamorphic fragments, M: argillaceous fragment, N: matrix, O: carbonate cement.

Heavy minerals - Depending on the transparency, two groups of heavy minerals are recognized in Injana and Mukdadiya sandstones Table (2): opaque minerals and transparent minerals Figure-3**.** The opaque minerals represent the major constituents ranging from 59.0 to 75.1% (average 62.9%) in Injana sandstone and 49.2-69.7% (average 58.1%) in Mukdadiya sandstone. The transparent heavy minerals assemblages includes both stable and unstable, average as follows: epidotes 7.96% in Injana sandstone and 3.73% in Mukdadiya sandstone, garnet 6.26% in Injana sandstone and 3.7% in Mukdadiya sandstone, chromian spinel 3.9% in Injana sandstone and 0.03% in Mukdadiya sandstone, zircon 2.3% in Injana sandstone and 1.7% in Mukdadiya sandstone, amphiboles 2.1% in Injana sandstone and 1.9% in Mukdadiya sandstone, clinopyroxenes 1.7% in Injana sandstone and 3.0% in Mukdadiya sandstone , orthopyroxenes 1.3% in Injana sandstone and 0.9% in Mukdadiya sandstone, tourmaline 0.4% in Injana sandstone and 0.3% in Mukdadiya sandstone, rutile 0.3% in Injana sandstone and 0.1% in Mukdadiya sandstone , others (kyanite and staurolite) 0.3% in Injana sandstone and 0.1% in Mukdadiya sandstone and unidentified 6.3% in Injana sandstone and 24.1% in Mukdadiya sandstone.

In brief, there is marked difference between the average heavy mineral content in the two studied formations. Epidote and garnet are almost double the average percentage in Injana than in the Mukdadiya sandstones. On the contrary, clinopyroxene is double the average percentage in the Mukdadiya than in the Injana sandstone whereas the opaques, amphibole, orthopyroxene and zircon have approximately similar percentage. The heavy minerals assemblages are varying in stability from unstable to ultra-stable. They also vary in form from prismatic (euhedral to unhedral) to subrounded.

Table 2- Range and average of heavy minerals in Injana and Mukdadiya sandstone at Amadiya area.

Location	***Amadiya***			
Formations	***Injana***		***Mukdadiya***	
	Range	*Average*	*Range*	*Average*
Opaque %	59.0-75.1	***62.9***	49.2-69.7	***58.1***
Epidote %	4.0-13.8	***7.96***	2.4-5.3	***3.7***
Garnet %	3.2-9.1	***6.3***	1.7-5.3	***3.7***
Amphibole %	0.2-4.7	***2.1***	0.7-4.0	***1.9***
Clinopyroxene %	0.2-4.5	***1.7***	1.2-4.6	***3.0***
Orthopyroxene %	0.2-2.8	***1.3***	0.3-1.7	***1.0***
Zircon %	0.8-4.0	***2.3***	0.0-2.6	***1.7***
Chromian Spinal %	1.1-7.4	***3.9***	0.0-0.2	***0.04***
Rutile %	0.0-0.8	***0.3***	0.0-0.5	***0.1***
Tourmaline %	0.0-1.4	***0.4***	0.0-0.5	***0.3***
Chlorite %	0.4-5.7	***1.9***	0.0-1.0	***0.3***
Biotite %	0.2-2.7	***0.96***	0.0-0.9	***0.2***
Muscovite %	0.0-1.6	***0.7***	0.0-1.9	***0.9***
Others %	0.0-1.6	***0.3***	0.0-0.9	***0.1***
Unidentified %	2.6-9.8	***6.3***	11.1-33.8	***24.2***

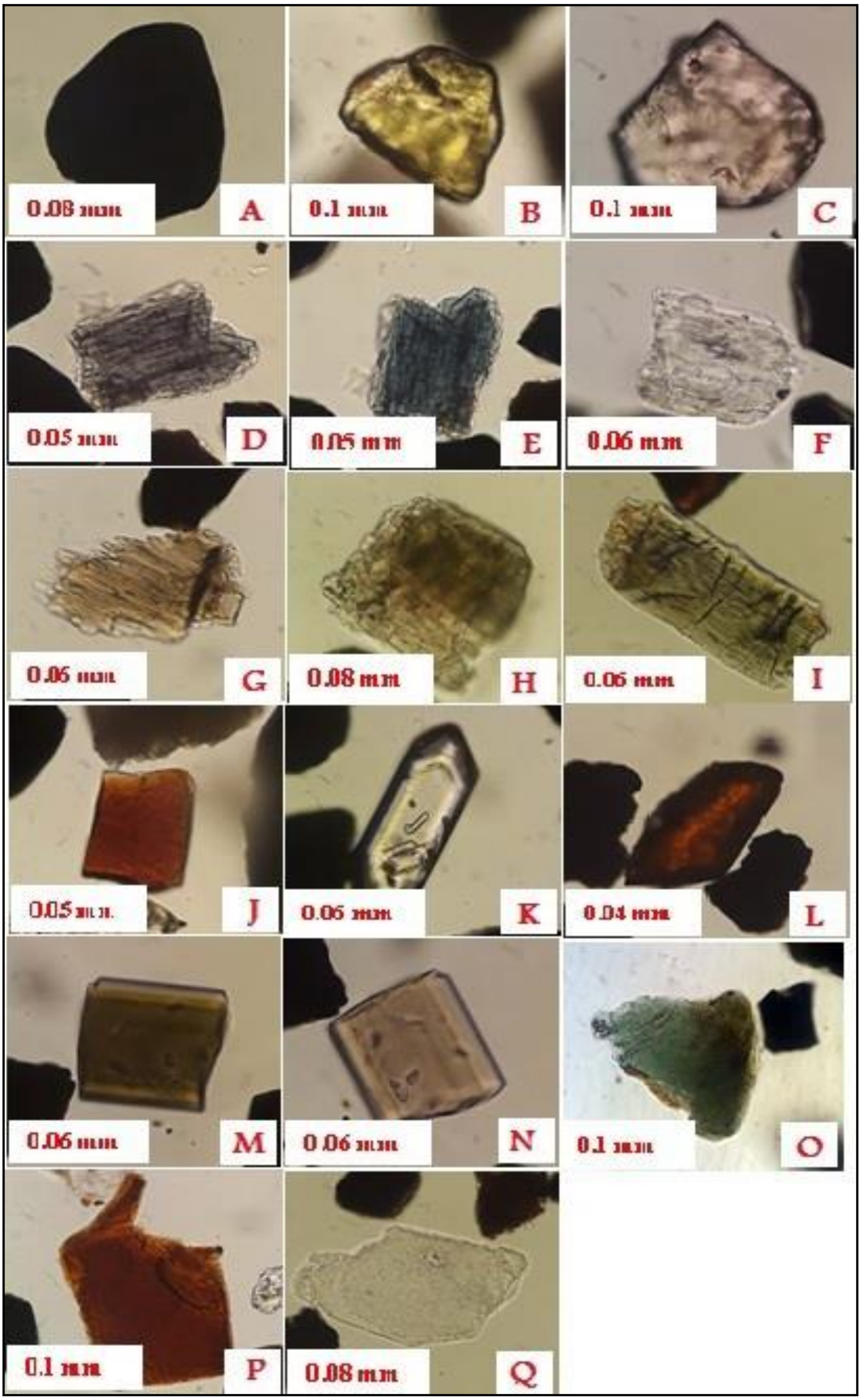

Figure 3- Photomicrograph of heavy minerals of Injana and Mukdadiya sandstones: A- Opaque mineral, B- Epidote, C-Garnet, D and E- Pleochroic amphibole (Glaucophane), F- Amphibole (Tremolite), G- Brown amphibole (hornblende), H and I- pyroxene, J- Chromian Spinal, K- Zircon, L- Rutile, M and N- Pleochroic tourmaline, O- Chlorite, P- Biotite and Q- Muscovite.

5. Classification of sandstone

Classification of Folk, 1974 [14] is used to classify the Injana and Mukdadiya sandstones. The classification is based on the percentage of basic component of sandstones (quartz, feldspar and rock fragments). Accordingly all samples of Injana and Mukdadiya sandstones are classed as Litharenite Figure-4. Such litharenites are of immature composition that implies high rates of sediment production from supra-crustal sources followed by short transport distance [15]. [16] Stated that the "Litharenites are compositionally immature sandstones that originate under conditions favoring the production and deposition of large volume of relatively unstable materials".

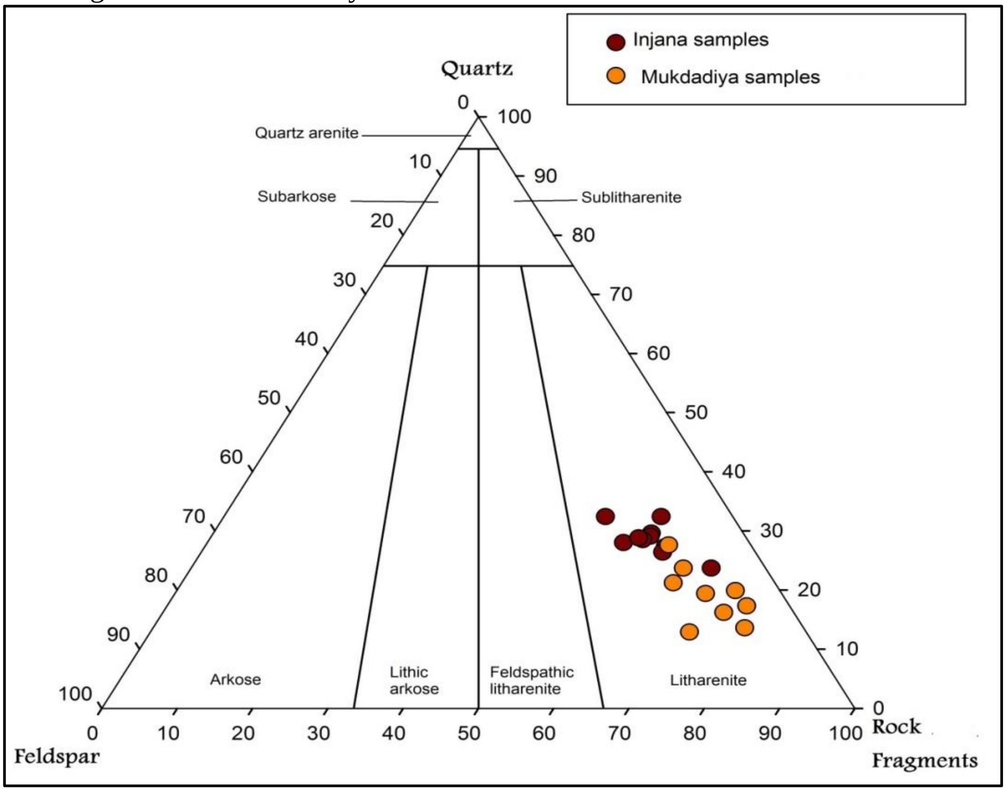

Figure 4- Classification of the Injana and Mukdadiya sandstone at Amadiya sections, after [14].

6. Maturity

The compositional maturity refers to the relative abundance of stable and unstable framework grains [17]. In this study two formulae are used to calculate the mineralogical maturity of Injana and Mukdadiya sandstone as below:

Maturity index (MI) = Quartz / Feldspar + Rock Fragments………………………………….. (1) [18]

Mineral maturity index (MMI) = (Quartz + Chert) / (Feldspar + Rock Fragments)………….. (2) [19]

The use of the 1st formula showed that the mineral maturity values for Injana sandstone ranging between 0.30 and 0.45 (average 0.37) and for Mukdadiya sandstone ranging from 0.15 to 0.38 (average 0.24). Due to the high percentage of the chert, the 2nd formula are used and it shows that the mineral maturity values in the Injana sandstone ranging between 0.77 and 1.30 (average 1.04) and for Mukdadiya sandstone ranging from 0.72 to 1.31 (average 0.98). Consequently the Injana and Mukdadiya sandstones are mineralogically immature. Indicating that the source area had high relief, rapid erosion and transport, and short transport distance. The presence of stable and unstable rock fragments and minerals together, occurs in areas with high relief, fast flowing rivers and dry climatic conditions, which is a feature of unstable tectonic crusts [20].

ZTR Maturity index - The mineralogical maturity of the heavy mineral assemblages of the sediments is quantitatively defined by the ZTR index. The ZTR index is the percentage of the combined zircon, tourmaline and rutile grains among the transparent, non micaceous and detrital heavy mineral [21]. ZTR maturity index is determined for all samples of Injana and Mukdadiya sandstone according to the formula below [21].

ZTR INDEX=zircon + tourmaline + rutile / total number of non-opaque heavy minerals.

The ZTR maturity index values of Injana sandstone are ranging from 5.4 to 15.7 (average: 11.0) and from 0 to 20.1 (average 12.4) in Mukdadiya sandstone. These values are considered very low and thus the sandstones are immature.

7. Provenance

The character of sedimentary provenance, the nature of sedimentary processes within the depositional basin and the kind of dispersal paths that link provenance to basin, influence the sandstone composition [22]. The modes of detrital constituent of sandstone provide information about the composition and tectonic setting of the provenance [23]. In the present study the provenance of sandstone are determined on the basis of petrographic modal analysis including heavy minerals analysis and the QFL and QmFLt tectonic discrimination diagrams for provenance determination.

***Determination of provenance from Petrographic analysis* -** Petrographic analysis of quartz, feldspar and rock fragment forms the most provenance studies [24]. Quartz is one of the main mineral components of sandstone due to its relatively high hardness, chemical stability and lack of cleavage.

In this study the presence of monocrystalline quartz with straight to slightly undulose extinction Figure -2(A) mostly indicates plutonic igneous rocks [25]. Most highly undulose quartz is (undulose extinction >5° degree) diagnostic of metamorphic rocks [26], [14]. The monocrystalline quartz with undulose extinction has been subjected to stresses that have led to this type of extinction and break down some of its grains; this may give evidence of its derivative from plutonic igneous and metamorphic rocks [27]. The polycrystalline quartz is mostly straight to slightly curve intercrystalline boundaries Figure-2(B), indicating the plutonic origins [15], [14]. Some grains show suture intercrystalline boundaries indicating the metamorphic origin [14].

Several properties of feldspar make them useful as provenance indicators, because feldspar is chemically and mechanically less stable than quartz, they are less likely to be recycled [24]. According to [28] orthoclase and plagioclase Figures-2(C and E) may be derived from plutonic igneous and metamorphic rocks whereas microcline, perthite and graphic texture derived from granite Figures -2(C, D, E and I) are more common in the plutonic igneous rocks and rare in the volcanic rocks. The presence of fresh feldspar Figures-2(C, D and E) may indicate a fragmentation process from igneous rocks accompanied by short distance of transportation and arid climate in the source area [18].

The rock fragments are important in the study of source rocks and more reliable than the study of single minerals such as quartz and feldspar it can be derived from different type of rocks [29]. Chert rock fragments Figure-2(F) may be derived from radiolarian chert in the Thrust zone sequence, especially Cretaceous Qulqula Series [5], as well as it may be derived from carbonate formations which include chert nodules [5].

The source of carbonate rock fragment Figures-2(G and H) is believed to be derived from nearby areas, most probably from underlying Mesozoic carbonate rocks of the Arabian Shelf. Carbonate rock fragments represent special condition of rapid mechanical erosion rather than chemical dissolution. The presence of high amount of carbonate rock fragment in Injana and Mukdadiya sandstone indicates that the source rocks are rich in carbonate rocks, travelled short distance and prevailed in arid to semi-arid climate. The presence of volcanic rock fragments Figure-2(J) requires rapid erosion and incomplete weathering. Such weathering and erosion occurs only in areas with high relief and arid climate [30]. According to [31] these fragments may be derived from the Thrust Zone. According to [32] the metamorphic rock fragments Figures-2(K and L) are most probably derived from Northeast Thrust Zone and Sanandaj-Sirjan Zone.

***Provenance from heavy minerals* -** The analysis of heavy minerals is carried out in order to determine the provenance and tectonic setting of the source area. In this study the presence of opaques originate from mafic igneous and metamorphic rock mainly, as well as acidic igneous and reworked sedimentary rock. Pyroxene is widely distributed in the basic igneous rocks [20], chromian spinel is a common accessory mineral of ultramafic igneous rocks [33], hornblende is common in mafic igneous and metamorphic rocks [30], glaucophene characteristic of metamorphic rocks such as schist and gneiss [16], tremolite-actinolite are metamorphic provenance [34], Biotite are derived from acidic igneous and metamorphic rocks [35], [36], the euhedral form of zircon indicate acid igneous rock, zircon occurs in acid and intermediate igneous rocks [37]. Epidote, garnet, chlorite, amphibole (tremolite-actinolte and glaucophane), kyanite, staurolite and silimanite are indicating metamorphic source [37]. Presence of rutile is characteristic of a provenance of metamorphosed of argillaceous sediments of high grade schist as well as acidic igneous rock [38]. Presence of the tourmaline indicates to the granitic pegmatites and acidic igneous sources [38]. The presence of rounded to subrounded grains such as some opaques, zircon, and tourmaline indicates reworked sedimentary source [34], [39]. The results of heavy minerals analysis for the studied samples of the Injana and Mukdadiya Formations indicate that the source rocks are basic, ultra-basic and metamorphic rocks, essentially, in addition to reworked sedimentary and acidic igneous rocks.

8-Tectonic setting of provenance

[22], [23] divided clastic sedimentary rocks into three broad provenance classification namely, continental block, magmatic arc and recycled orogen. This classification is based mainly on the petrographic characteristics of rocks derived from particular provenance. To differentiate sediment derived from the three major tectonic provenance they suggested the use of ternary composition diagrams QFL (Q: total quartzose, F: feldspar, and L: total unstable lithic fragment) and QmFLt (Qm: monocrystalline quartz, F: feldspar, and Lt: total unstable lithic fragment plus polycrystalline quartz). On QFL diagram, all the samples of Injana and Mukdadiya sandstone clotted in the field of recycled orogen Figure-5. On QmFLt diagram some of the samples of Injana fall in the field of transitional recycled and other fall in the field of lithic recycled and all samples of Mukdadiya are fall in the field of lithic recycled Figure-6. Recycled orogen which are the source orogen created by upfolding or upfaulting of sedimentary or metasedimentary terrains, allowing detritus from these rocks to be recycled to associated basin. Many recycled orogen were formed by collision of terrains that were once separate continental blocks, this corresponds to what exists in the collision range of Taurus and Zagros mountain ranges.

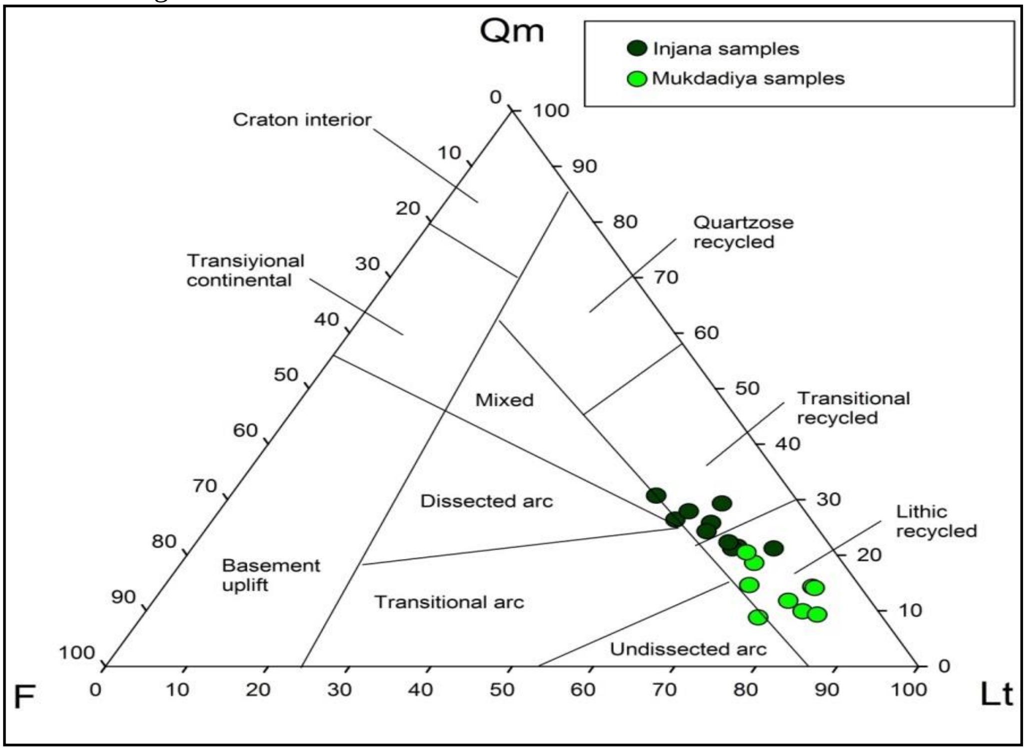

Figure 5- QFL ternary diagram of Injana and Mukdadiya sandstone tectonic region provenance after [23] in Amadiya area**.**

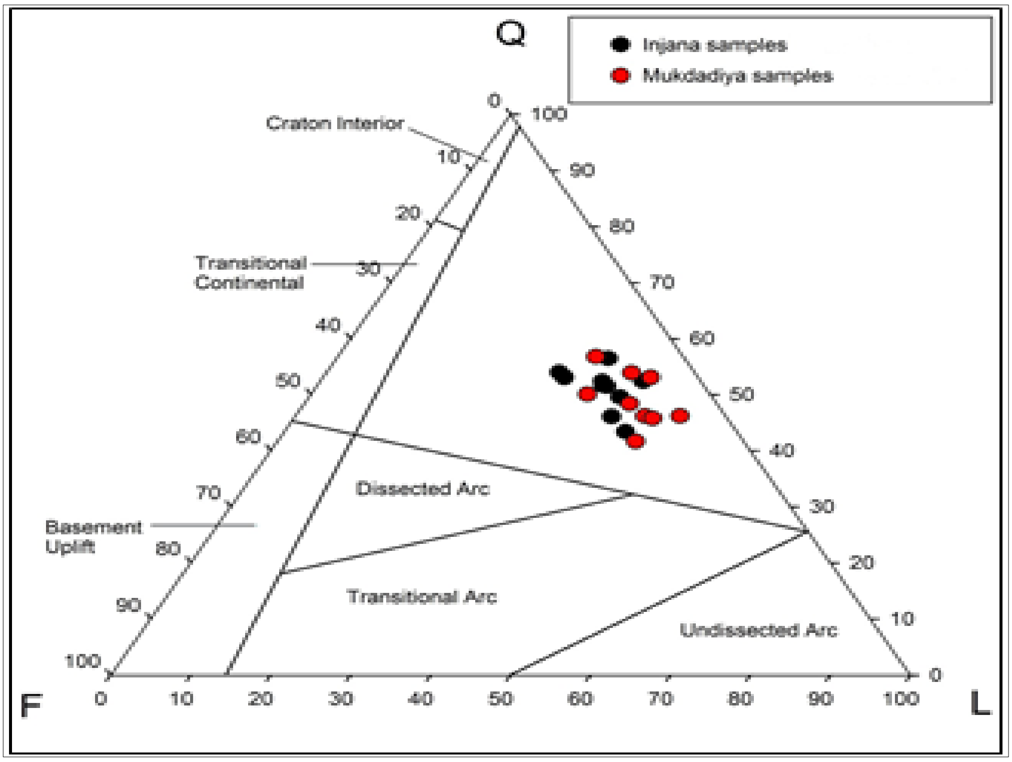

Figure 6- QmFLt Ternary diagram of Injana and Mukdadiya sandstone tectonic region provenance after [23] in Amadiya area.

9. Conclusions

There is marked variation between the Injana and Mukdadiya sandstones. The quartz content in Injana sandstone is almost double than that in Mukdadiya sandstone. By contrast the percentage of rock fragments in Injana sandstone is less than that in Mukdadiya sandstone. The monocrystalline quartz is more common than the polycrystalline quartz in both formations; the characteristic of this quartz indicates that it is derived from plutonic igneous and metamorphic mainly as well as the reworked sediment origin. The amount of K-feldspar (orthoclase and microcline) is higher than of the amount of plagioclase in both formations, the feldspar is generally plutonic igneous and metamorphic origin. The high percentage of the sedimentary rock fragments compared with the igneous and metamorphic rock fragments indicate the recycled sediments. The sandstone of Injana and Mukdadiya Formations is classified as litharenite that led to high relief, rapid erosion and near the source area.

The presence of different type of heavy minerals indicates various source rocks. There is marked difference in the content of heavy mineral species between the two studied sandstones, which indicate that they are from slightly different sources. The heavy minerals assemblages comprise very high percent of opaques relative to the other heavy minerals that are indicated to derive mainly from mafic igneous and metamorphic sources, as well as acidic igneous and reworked sediments sources. The presence of unstable heavy minerals indicates the proximity sources rock.

The calculated mineral maturity (MMI and MI) indicates mineralogical immature of Injana and Mukdadiya sandstones. The ZTR indices suggest that the sandstone of Injana and Mukdadiya are mineralogical immature.

Major framework mineral composition of Injana sandstone indicates that the sediments are derived from transitional recycled and lithic recycled region of recycled orogen provenance. Major framework mineral composition of Mukdadiya sandstone indicates that the sediments derived their detritus from lithic recycled region of recycled orogen provenance.

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