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# Comparison of Provenance of the Injana and Mukdadiya Formations in Zorbatiya area, Wasit Governorate, East of Iraq

**Neaam O.F. Al-Dabbagh, Mazin Y. Tamar-Agha***
Department of Geology, College of Science, University of Baghdad, Baghdad Iraq

**Abstract**

Petrographic, heavy mineral and clay mineral analyses are carried out for the sandstone and the mudstone units of Injana and Mukdadiya Formations in Zorbatiya area, Wasit Governorate, East of Iraq. The sandstones and the mudstones are nested as repeated fining–upwards successions, representing fluvial deposits. The sandstones of the Mukdadiya Formation is gravelly and on occasions becomes conglomerate. The sandstone of both formations comprises rock fragments, quartz and feldspars. The rock fragments are the dominant component consisting sedimentary, igneous and metamorphic rock fragments, accordingly these sandstone are classified as litharenite. The clay minerals of the mudstone units are mostly illite, kaolinite, chlorite and mixed-layered clay. The mineralogic and petrographic data suggest the derivation of Injana and Mukdadiya Formations from nearby sources with contribution from igneous, metamorphic and sedimentary provenance and deposited in arid climate. The Mukdadiya deposits are rich with Paleogene deposits, some of which are coarse and cobbly.

**Keywords**: Heavy mineral, Petrography, Upper Miocene-Pliocene, Iraq

# مقارنة أصل الصخور بين تكويني انجانة والمقدادية في منطقة زرباطية ، محافظة واسط ، شرق العراق

**نعم عمر فرحان الدباغ ، مازن يوسف تمراغا***
قسم الجيولوجي، كلية العلوم، جامعة بغداد، بغداد، العراق

**الخلاصة**

تمت دراسة بتروغرافية ودراسة المعادن الثقيلة للحجر الرملي ودراسة المعادن الطينية للحجر الطيني لكل من تكويني انجانة والمقدادية في منطقة زرباطية ، محافظة واسط ، شرق العراق. ان الحجر الرملي والحجر الطيني هذا يمثل ترسبات نهرية ذات دورات ترسيبية متنعمة نحو الاعلى. وجد ان الحجر الرملي لتكوين المقدادية هو حجر رملي حصوي وفي بعض الاحيان يكون متدملك. يتكون الحجر الرملي لكل من التكوينين من فتات صخرية، كوارتز و فلدسبار . الفتات الصخرية هي المكون الاكثر شيوعا وتتكون من فتات صخرية رسوبية، نارية ومتحولة واعتمادا على ذلك تم تصنيف هذا الحجر الرملي الى ليثأرينايت. كما وقد تم اجراء تحاليل الاشعة السينية للحجر الطيني لكل من التكوينين واتضح وجود المعادن الطينية الاتية: الالايت، الكاؤولينايت، الكلورايت والطين متعدد الطبقات. البيانات المعدنية و البتروغرافية افترضت اشتقاق صخور تكويني انجانة والمقدادية من مصدر قريب من الصخور النارية، الرسوبية والمتحولة.

*Email: mtamaragha@yahoo.com

**Introduction**

The Upper Miocene-Pliocene Injana and Mukdadiya Formations are widely exposed in Iraq. The Injana and Mukdadiya Formations represent the major molasse of the Neogene Zagros Foreland Basin . Recent study revealed that sediments of the Injana Formation are derived from the Paleozoic and Mesozoic rocks whereas sediments of the Mukdadiya Formation are derived from the Paleogene rocks [1]. This study aims to compare between Injana and Mukdadiya Formations in Zorbatiya area East of Iraq petrographiclly and mineralogically in an attempt to verify this finding.

**Geology of the studied area**

The studied area lies within two zones, Mesopotamian Zone (Tigris Subzone) which is a part of the Stable Shelf, and the Foothill Zone (Hemrin-Makhul Subzone) which is a part of the Unstable Shelf . The Mesopotamian Zone is the easternmost unit of the Stable Shelf. It is bounded in the NE by the folded ranges of Pesh-i-Kuh in the E, and Hemrin and Makhul in the N. The sedimentary column of the Mesopotamian Zone thickens to the east [2].

In late Miocene- Pliocene time major thrusting occurred during collision of the Neo-Tethyan terraines and the Sananadij-Sirjan Zone with the Arabian Plate. This event resulted in the uplift of the High Folded, Northern Thrust zone and the NE parts of the Balambo-Tangero zone and Mesopotamian zones. A major foredeep formed in the Foothill Zone [2]. The cycle is characterized by the progressive change from the marine sedimentation into the lacustarine and fluviatile one. This change was simultaneously accompanied by the gradational coursing of the clastics laid down during the cycle [3].

In the studied area the Fatha, Injana and Mukdadiya Formations, and Quaternary deposits are observed (Figures- 2 and 3). The Fatha Formation (middle Miocene) consists of numerous shallowing–upwards cycles of alternating greenish gray marl, limestone, gypsum and/or anhydrite, halite (in the center of the basin) and reddish brown mudstone. The clastics are found only in the upper member of the Fatha Formation from the dominant lithology in the marginal part of the basin [2].

The Injana Formation comprises fine grained pre-molasse sediments deposited initially in coastal area, and later in a fluvial system. The sandstones and the mudstones are nested as repeated fining–upwards successions, representing fluvial deposits. The Mukdadiya Formation comprises also stacked fining-upwards successions of gravely sandstone, sandstone and reddish-brown mudstone. The sandstones are often strongly cross-bedded and associated with channel lags and clay balls. The Mukdadiya Formation is deposited in fluvial environment in a rapidly subsiding foredeep basin [2].

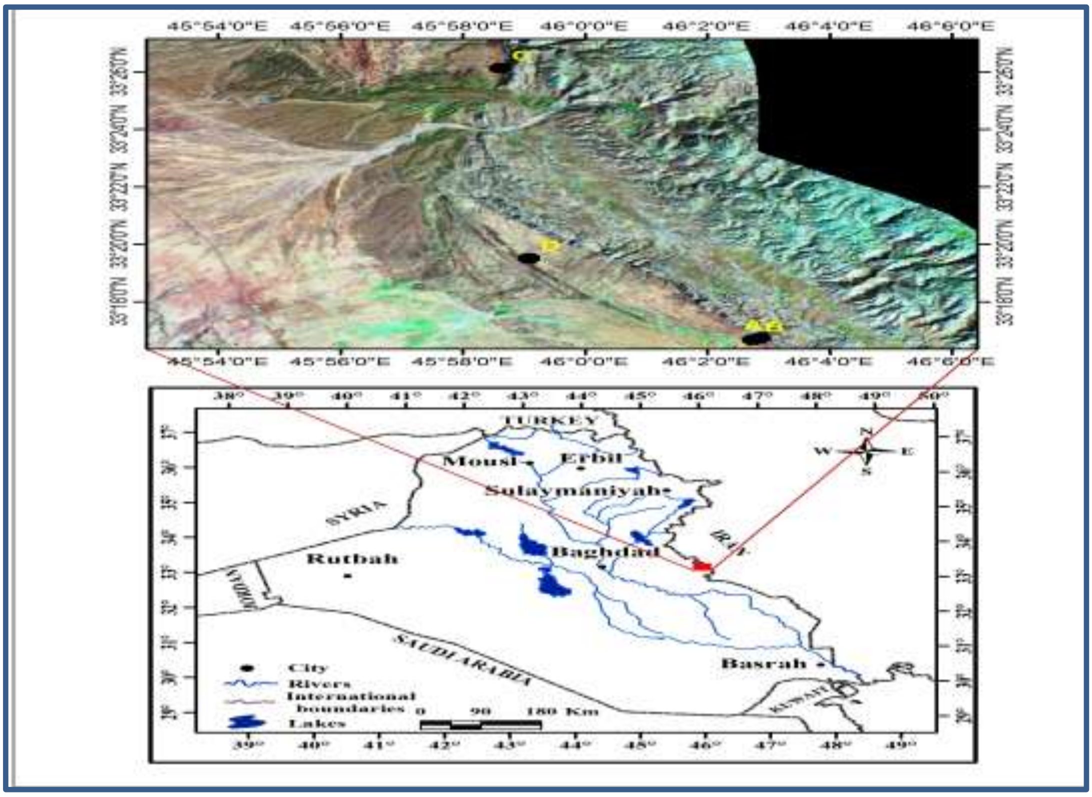


**Figure 1-**Location map of the studied area.

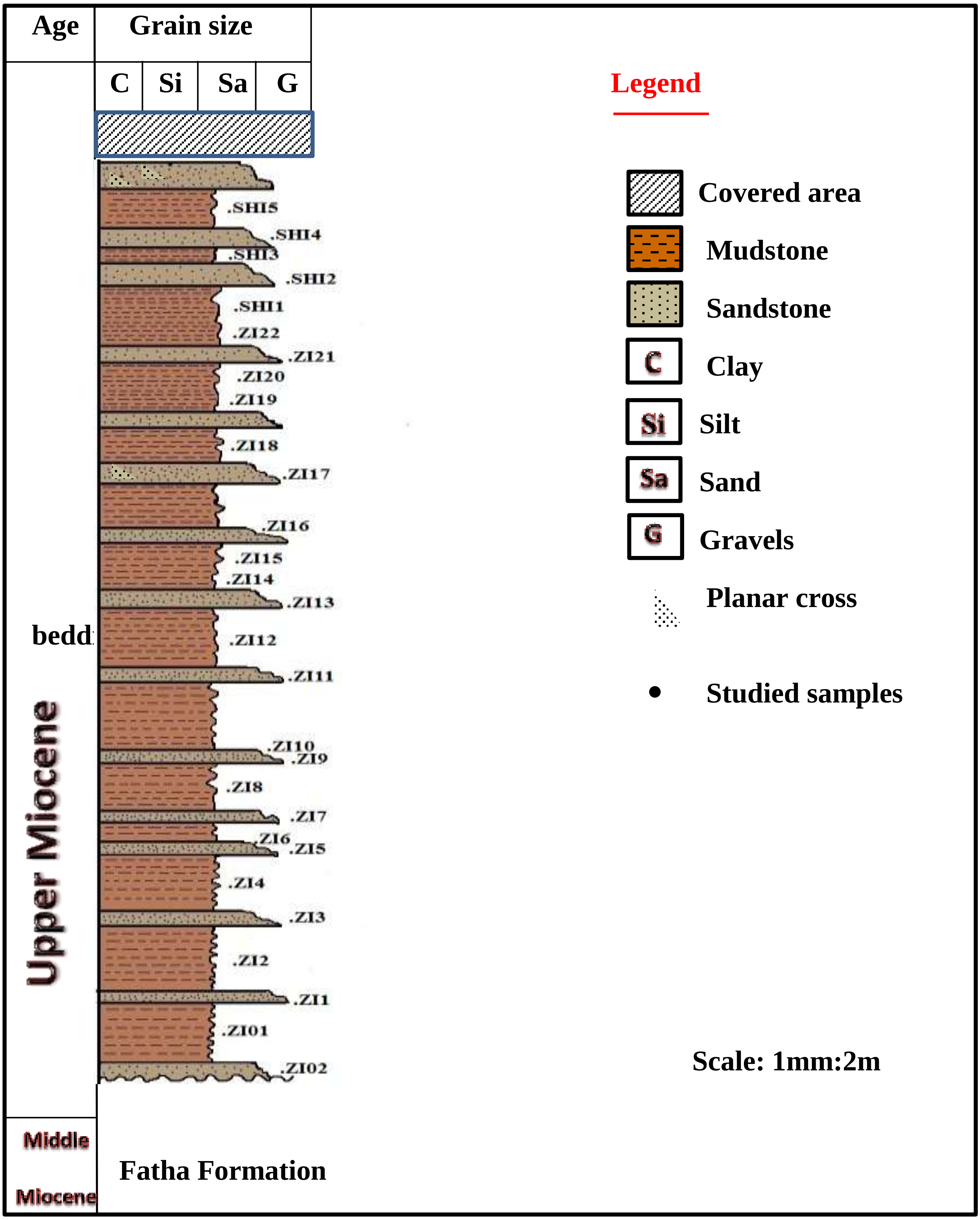


**Figure 2-**Vertical section of Injana Formation in the studied area.

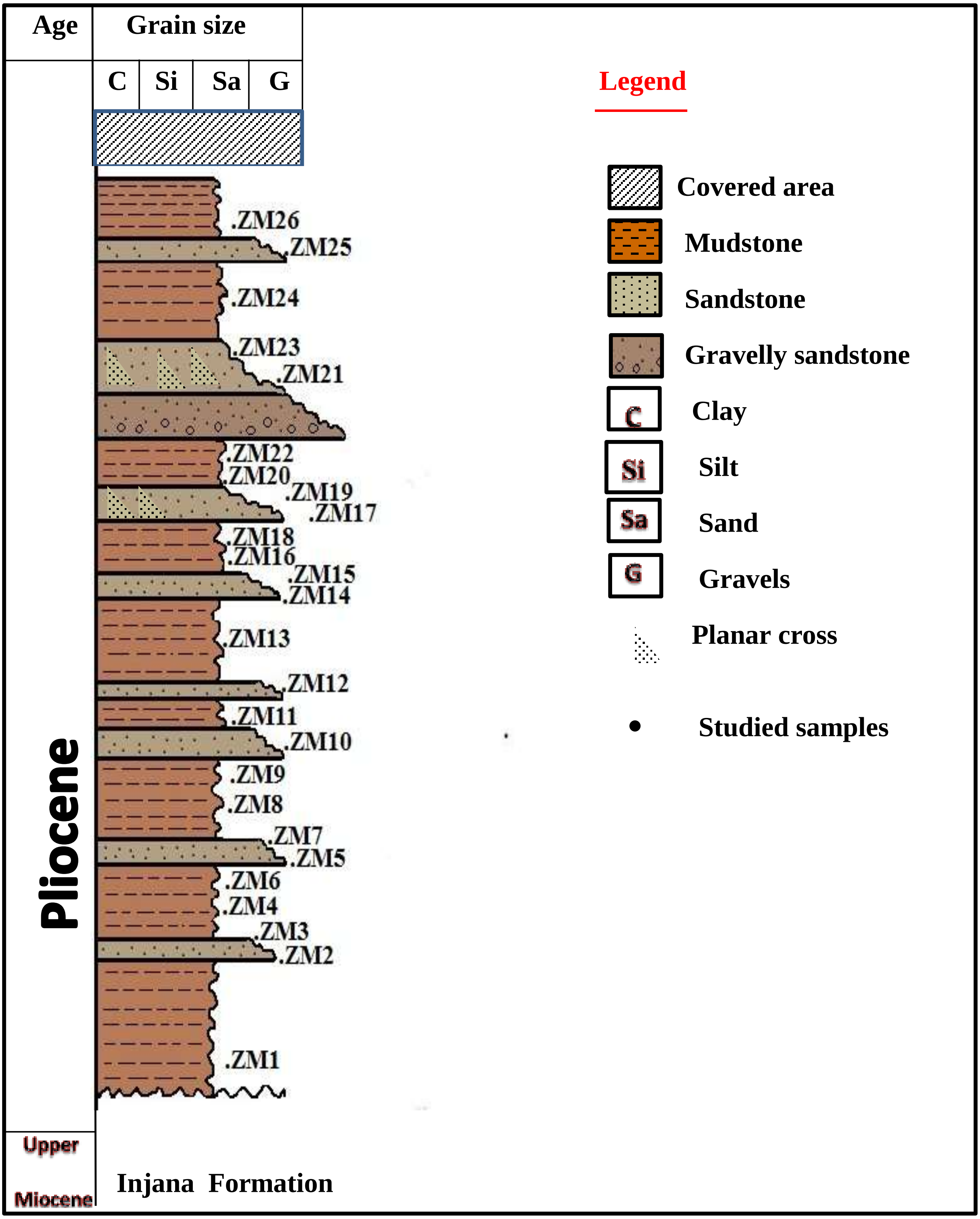


**Figure 3-**Vertical section of Mukdadiya Formation in the studied area.

**Materials and methods**

Twenty samples of sandstone are chosen to be examined by polarizing microscope (10 samples from each formation ). Modal analysis of the samples is carried out by mechanical stage point counter, as suggested by Chayes [4], 300 counts per slide are preformed covering 17 components.

Heavy minerals are separated from 20 sandstone samples (10 samples from formation) by the traditional gravity method using Bromophorm ($CHBr_3$, specific gravity 2.89). The heavy detrital accessories are studied petrographically.

For XRD analysis ten samples are chosen from successive mudstones (five samples from each formation) . Four oriented slides for the clay fraction (<2 µm) of each sample are prepared following the procedure suggested by Tucker [5]. Then the slides are subjected to various treatments (air dried, glycol solvated, heating to375$^{o}$ C, and heating to 550$^{o}$ C). The prepared samples are analyzed using X-Ray diffractometer at the Iraqi-German Laboratory, Department of Earth Sciences, College of Science - University of Baghdad.

**Petrographic results**

The sandstones of both Injana and Mukdadiya Formations are composed of three main detrital components, namely Quartz, Feldspars and Rock fragments (Table1):

**Quartz :** Quartz is not abundant in the studied samples, with an average of 14.2% in Injana Formation and 13.9% in Mukdadiya Formation. Both monocrystalline quartz and polycrystalline quartz occur in the samples. Monocrystalline quartzis usually in the form of rounded to subrounded grains indicating reworking from sedimentary origin. Most polycrystalline quartz grains consist of more than three crystals. The contacts between the subgrains are straight to sutured, the latter being more common. The subgrain size is variable, even within a single composite grain of polycrystalline quartz (Figure-4).

**Feldspars :** The percentage of feldspars in the sandstone of Injana Formation ranges between 3.2 and 5.4% with an average of 4.5% whereas its percentage in Mukdadiya Formation ranges between 4.0 and 6.2% with an average of 5.02%. Both plagioclase and K-feldspar are observed. Feldspar grains are usually replaced by carbonate or partially altered to sericite and clay minerals though some are strikingly fresh (Figure- 5).

**Table 1**-The range and average components of the sandstone of Injana and Mukdadiya Formations.

| Components | | Injana Formation | | Mukdadiya Formation | |
|---|---|---|---|---|---|
| | | **Range** | **Average** | **Range** | **Average** |
| Quartz | Monocrystalline | 8.6 -14.7 | 11.63 | 8.5 – 14.8 | 10.64 |
| | Polycrystalline | 1.5 -4.6 | 2.62 | 2.4 – 4.5 | 3.35 |
| Feldspar | Potash-Feldspar | 1.7 – 3.1 | 2.61 | 2.2 – 4.1 | 2.86 |
| | Plagioclase | 1.2 – 2.5 | 1.98 | 1.5 – 2.6 | 2.16 |
| Rock Fragments | Carbonates | 26.0 –36.3 | 31.17 | 22.5 – 38.0 | 31.14 |
| | Chert | 8.7 – 12.8 | 10.72 | 10.4 – 18.6 | 13.42 |
| | Argillaceous | 3.5 – 5.6 | 4.32 | 2.7 – 4.2 | 3.45 |
| | Sandstones | 1.5 – 2.8 | 1.96 | 1.4 – 2.6 | 1.99 |
| | Evaporites | 1.2 – 5.5 | 2.34 | 1.5 – 3.0 | 1.3 |
| | Metamorphics | 1.6 – 3.5 | 2.11 | 1.5 – 2.8 | 2.28 |
| | Igneous | 1.8 – 2.6 | 2.19 | 2.0 – 3.4 | 2.68 |
| Cement | Carbonate | 6.8 – 9.4 | 8.14 | 2.5 – 14.6 | 8.95 |
| | Evaporites | 3.0 – 9.4 | 3.59 | 1.3 – 9.4 | 2.93 |
| | Iron oxides | 1.6 – 3.5 | 1.27 | --------- | ----------- |
| Pores | | 3.8 – 5.4 | 4.3 | 3.0 – 4.3 | 3.57 |
| Matrix | | 5.0 – 8.7 | 6.29 | 5.2 – 9.4 | 7.03 |
| Others | | 1.1 – 2.0 | 1.49 | 0.8 – 1.9 | 1.22 |
| Unidentified | | 0.5 – 1.8 | 1.09 | 0.8 – 1.4 | 1.03 |

**Rock Fragments:** Rock fragments represent the major constituent in the sandstones of both Injana and Mukdadiya Formations, their percentage ranges between 49.6 and 58.2 % with an average of

54.81% in Injana Formation and a percentage ranges between 52.9 and 60.5 % with an average of 56.66% in Mukdadiya Formation. They are carbonates, cherts, mudstones, sandstones, igneous, and metamorphic rock fragments. The carbonate rock fragments are the most abundant amongst the other rock fragment types.

The percentage of matrix in the sandstone of Injana Formation ranges between 5.0 and 8.7 % with an average of 6.29 %, whereas its percentage in the sandstone of Mukdadiya Formation ranges between 5.2 and 9.4 % with an average of 7.03 %. Carbonate cement is the most common cement in both formations followed by evaporite cement whereas iron oxide cement is observed in Injana Formation only.

The gravels of Mukdadiya Formation are composed mainly of chert, carbonate, metamorphic and sandstone (Table 2). Chert gravels are the first in abundance in Mukdadiya Formation, with a percentage of 30%. Jasper gravels are the second in abundance after chert gravels in Mukdadiya Formation, the percentage of jasper gravels is 20%. Carbonate gravels represent 17% of the examined gravels, these gravels show yellow, gray, and light brown color, and react with HCl, some are weathered and fractured and others are fossiliferous.

**Table 2-**The average composition of Mukdadiya Formation gravels.

| Components | Average percentage |
|---|---|
| **Chert** | **30** |
| **jasper** | **20** |
| **Carbonate** | **17** |
| **Metamorphic** | **14** |
| **Sandstone** | **12** |
| **Hydrothermal quartz** | **4** |
| **Igneous** | **1** |
| **Unidentified** | **2** |

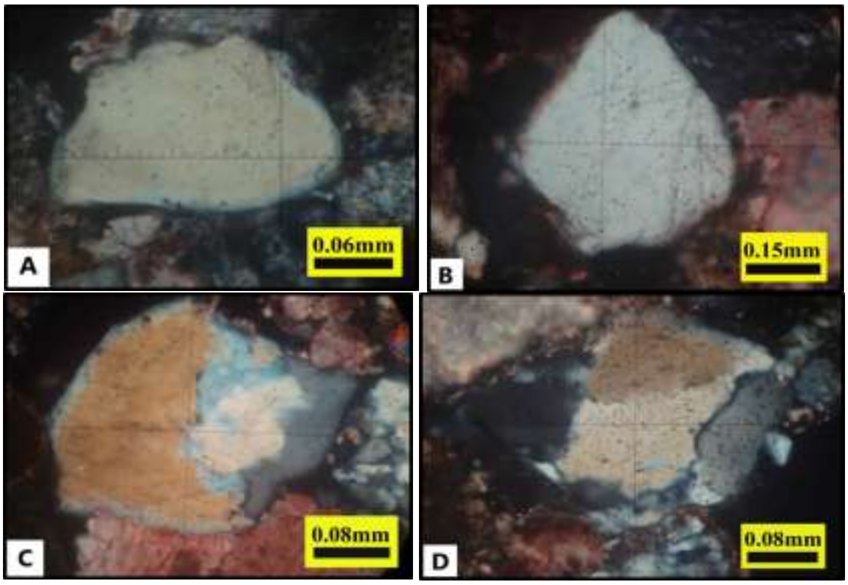


**Figure 4-** Types of quartz: A. Rounded monocrystalline quartz, Injana Formation, sample number ZI 7. B. Sub-angular monocrystalline quartz, Mukdadiya Formation, sample number ZM 9. C. Angular polycrystalline quartz, , Injana Formation, sample number ZI 17. D. Angular polycrystalline quartz, Mukdadiya Formation, sample number ZM 23.

According to the classification of Folk [6] which depends on the percentage of quartz, feldspar and rock fragments all the samples of both Injana and Mukdadiya Formations are Litharenite, with much higher percentages of rock fragments and exceedingly lower values of quartz and feldspar. According to the types of rock fragments (igneous, metamorphic and sedimentary) the sandstone of Injana and Mukdadiya Formations are classified as Sedarenite ( Figure- 7).

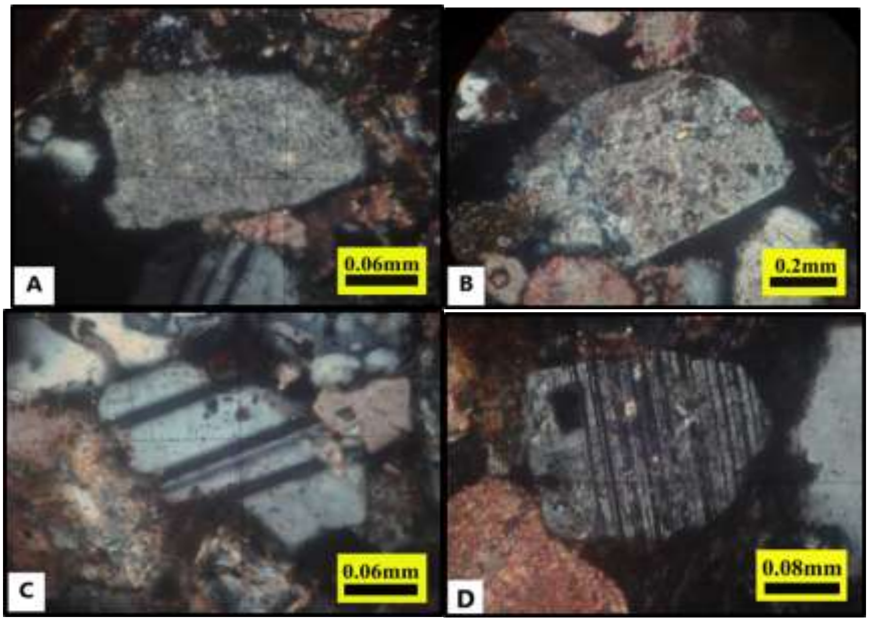


**Figure 5-**A. Altered Alkali Feldspar (orthoclase), Injana Formation, sample number SHI 4. B. Altered Alkali Feldspar (orthoclase), Mukdadiya Formation, sample number ZM 3. C. Fresh angular plagioclase Feldspar, Injana Formation, sample number ZI 7. D. Altered plagioclase Feldspar, Mukdadiya Formation, sample number ZM 14.

The sandstone of Injana and Mukdadiya Formations reclassified according to the type of the sedimentary rock fragments [6], and they are determined as Calclithite (Figure- 8). Folk [6] considered these carbonate-rich sandstones as a separated important group of the litharenite type. The source area of calclithite indicate a rugged relief, and deposits are laid down in alluvial fans and river channels, and the maturity is variable with frequent conglomerates .Most calclithites, (probably all) are cemented with calcite.

According to Al-Rawi [7] the sandstone of Injana and Mukdadiya Formations are classified as Carbonate arenite. The end members for his proposed classification are: [(quartz+ feldspar), (rock fragments excluding carbonates), and (carbonate rock fragment + carbonate cement)]. Figure- 9 illustrates the position of the sandstone samples of Injana and Mukdadiya Formations in this classification. Al-Rawi [7] suggested that the occurrence of carbonate rock fragments in the sandstone indicate short distance of transportation, intense tectonic uplift, and arid climate.

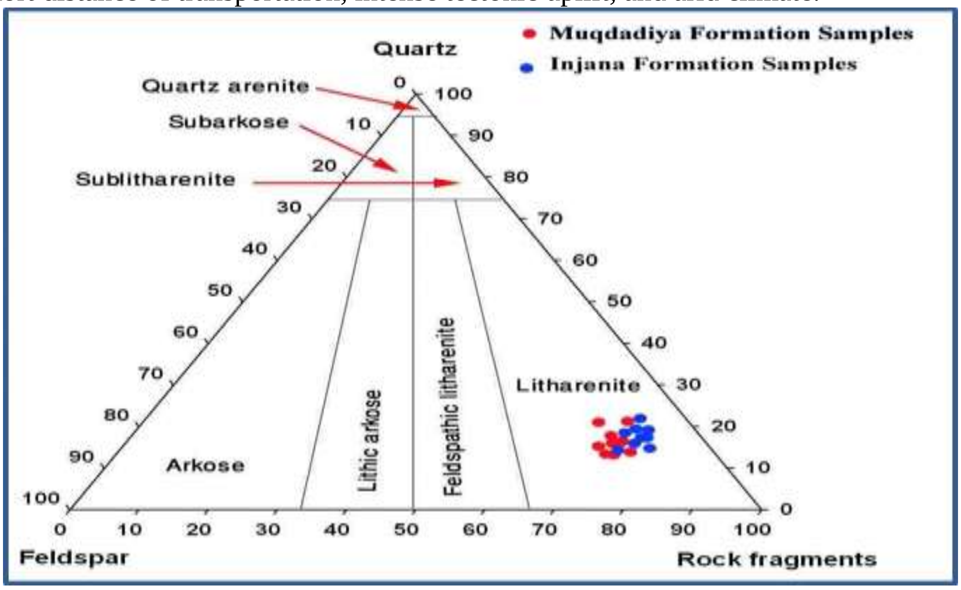


**Figure 6-** Classification of sandstone depending on the percentages of (quartz, feldspar, and rock fragments) in the samples of Injana and Mukdadiya Formations [6].

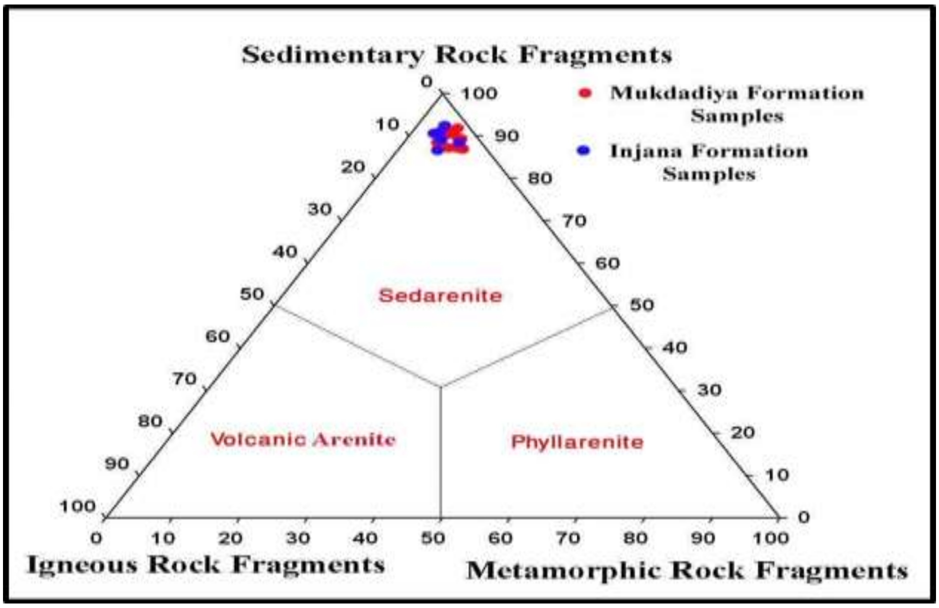


**Figure 7-** The relative percentage of types of rock fragments of Injana and Mukdadiya[6].

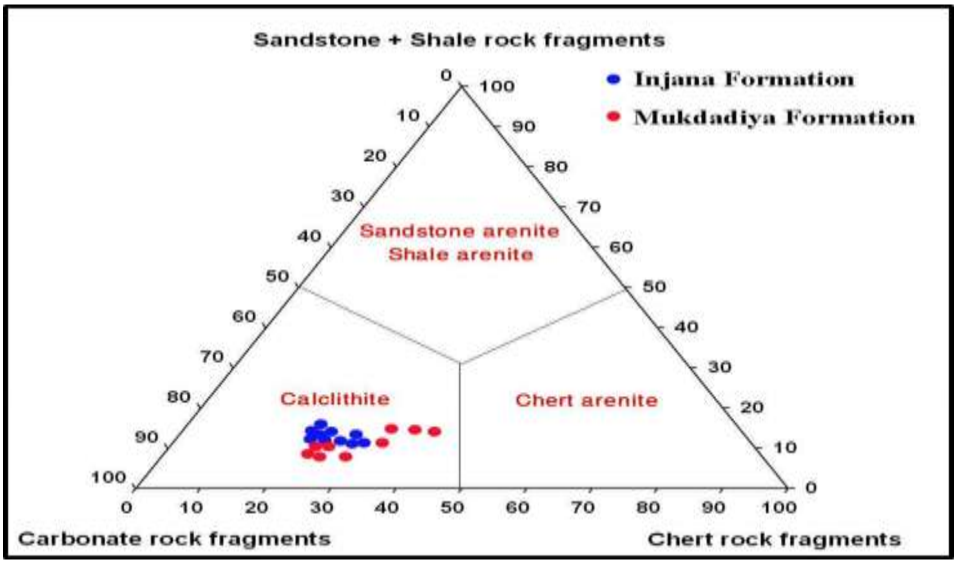


**Figure 8-** the relative percentage of sedimentary rock fragments of Injana and Mukdadiya Formations [6].

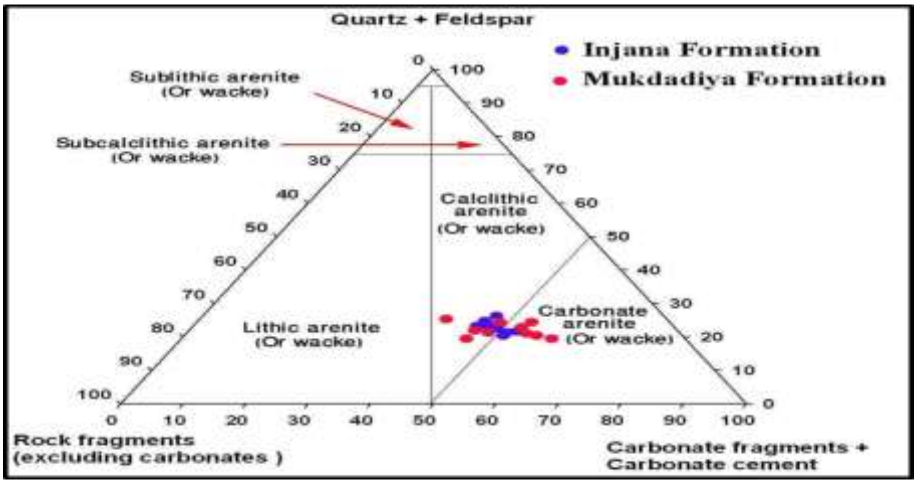


**Figure 9-** Classification of the sandstone of Injana and Mukdadiya Formations [7].

Dickinson and Suczek, [8] suggested a close relationship between sandstone composition and plate-tectonic. They proposed three principle types of tectonic setting, or provenance, namely (1) Continental block, (2) Magmatic arc, and (3) Recycled orogeny. They also proposed a ternary diagram showing framework compositions of [monocrystalline quartz, feldspar and (rock fragments+ polycrystalline quartz)]. The percentages of these components are taken from the modal analysis of the sandstone of both Injana and Mukdadiya Formations and plotted on this diagram. It is found that the sandstone samples of both of the two formations lie within the lithic recycled provenance (Figure- 10).

Suttner and Dutta [9] stated that the climate affect the composition of sand by influencing on pedogenic processes which brings about parent-rock destruction. To determine the paleoclimatic conditions, the following formula is used as a sensitive discriminator of sandstones with different climate heritage (Figure- 11): a log / log plot of [(total quartz / total feldspar + rock fragments ) / (polycrystalline quartz / total feldspar + rock fragments)] given by Suttner and Dutta [9].

The Injana and Mukdadiya sandstones plot in arid field. Arid conditions may favor the dominance and preservation of unstable lithic fragments and feldspars in the studied sandstones.

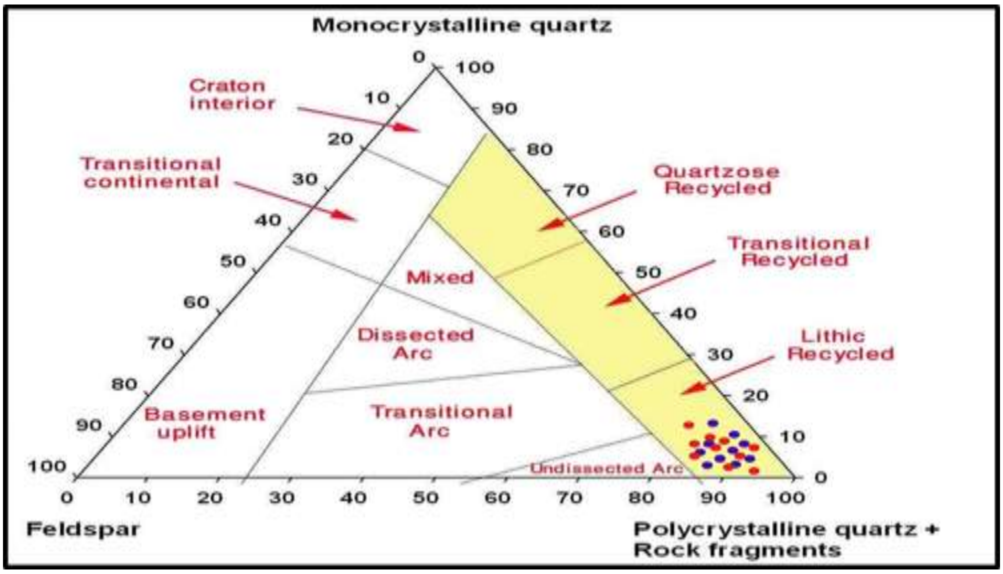


**Figure 10-** Provenance diagram showing the relationship between framework composition of the sandstone of Injana and Mukdadiya Formations and tectonic setting [10].

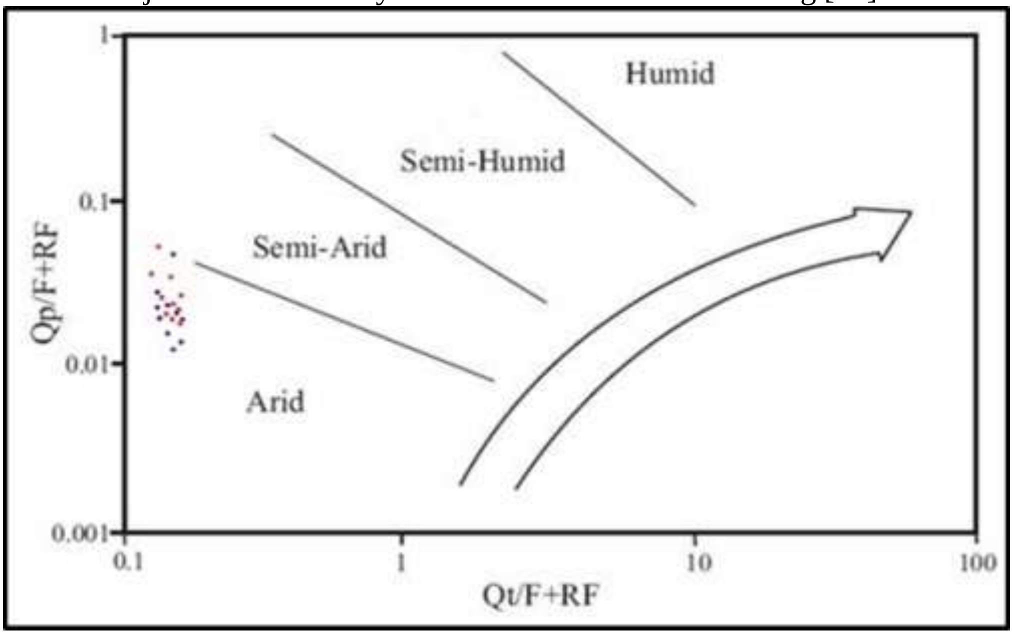


**Figure 11-** Bivariant log/log of the ratio [(polycrystalline quartz / feldspar + rock fragments) / (total quartz / feldspar + rock fragments)] in the Injana and Mukdadiya sandstone [9].

**Heavy mineral analysis**

The heavy mineral analysis of the studied samples showed that the sandstone of Injana and Mukdadiya Formations are mostly similar and are dominated by opaque minerals, chlorite, zircon, garnet, biotite, muscovite, pyroxene, amphibole, epidote, rutile, kyanite, tourmaline, and staurolite.

A collection of common heavy minerals from the sandstone of Injana and Mukdadiya Formations is illustrated in (Figures- 13, 14 and 15). The heavy minerals that found in the sandstone of the Injana and Mukdadiya Formations indicate a variety of probable source rocks including metamorphic, igneous and sedimentary.

The heavy minerals of Injana and Mukdadiya Formations are classified according to their relative stability to moderately stable (Figure- 16).

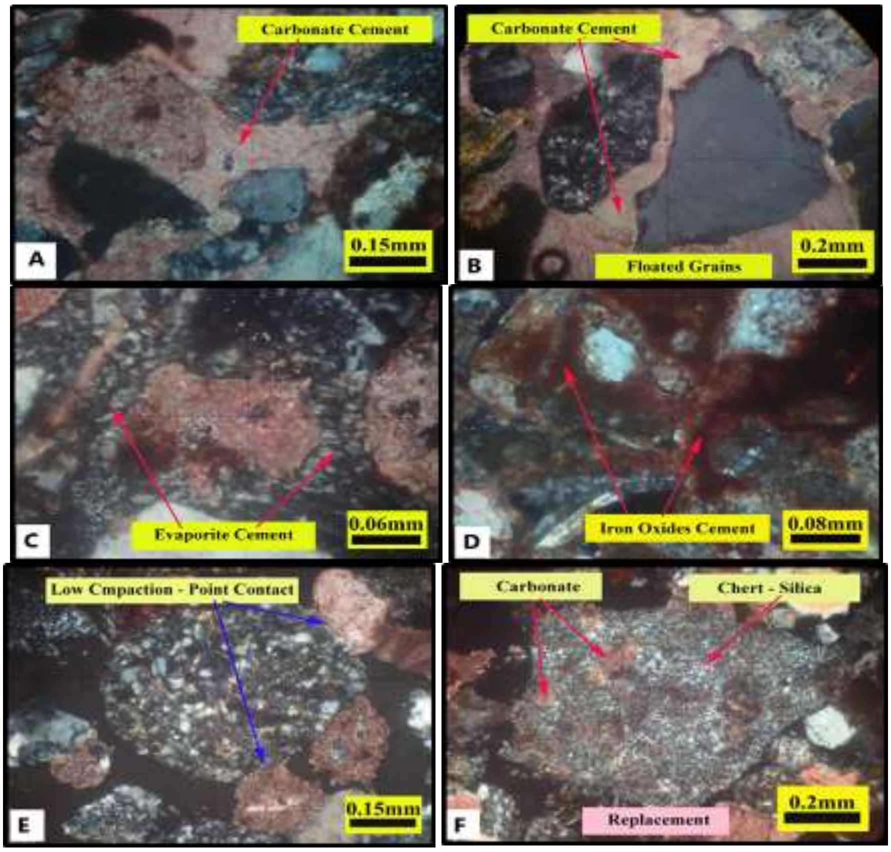


**Figure 12-** A. Cementation (carbonate cement), sample number ZI 6. B. Cementation (carbonate cement), Compaction (Floated grains in cement), sample number ZM 3. C. Cementation (evaporite cement), sample number ZM 12. D. Cementation (iron oxide cement), sample number SHI 2. E. Low compaction (point contact), sample number ZM 12. F. Replacement of carbonate materials on chert rock.

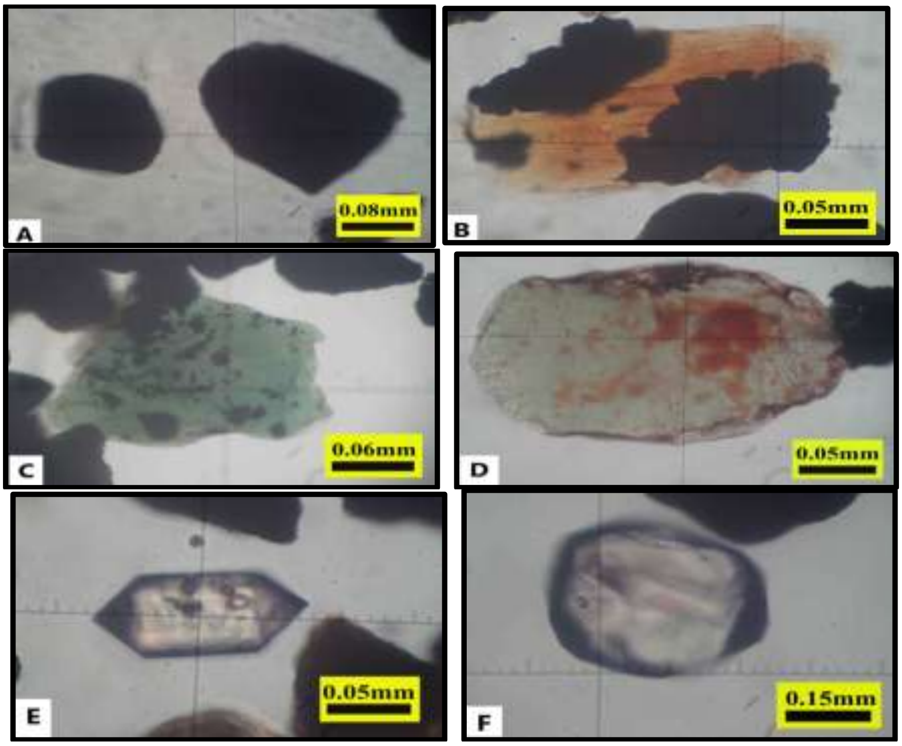


**Figure 13-** A. Subrounded opaque grains, sample number ZM 5. B. Brown chlorite with spots of iron oxides, sample number ZM 9. C. Green color with spots of iron oxides chlorite, sample number ZM 2. D. Green color flaky form chlorite, sample number ZM 7. E. Euhedral pink high relief zircon, sample number ZI 17. F. rounded colorless high relief zircon, sample number ZM 12.

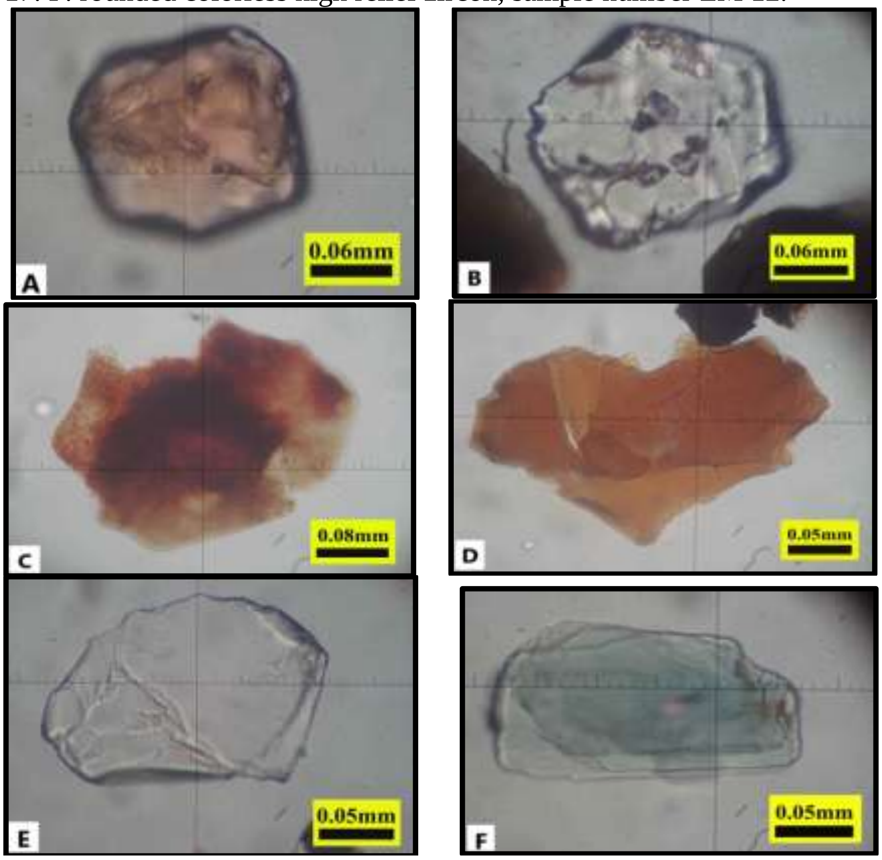


**Figure 14-** A. Brown color, high relief garnet, sample number ZI17. B. Subhedral, colorless garnet, sample number ZM 14. C. Flaky form biotite, sample number ZM 2. D. Flaky form brown color, pleochronic biotite, sample number ZI 16. E. Flaky form colorless Muscovite, sample number ZM 3. F. Green color, prismatic pyroxene, sample number ZI7.

Mixed-layered clay can form by weathering, involving the removal or uptake of cations, hydrothermal alteration, or removal of hydroxide interlayer, and in some cases may present an intermediate stage in the formation of swelling minerals from non-swelling minerals or vice versa [11].

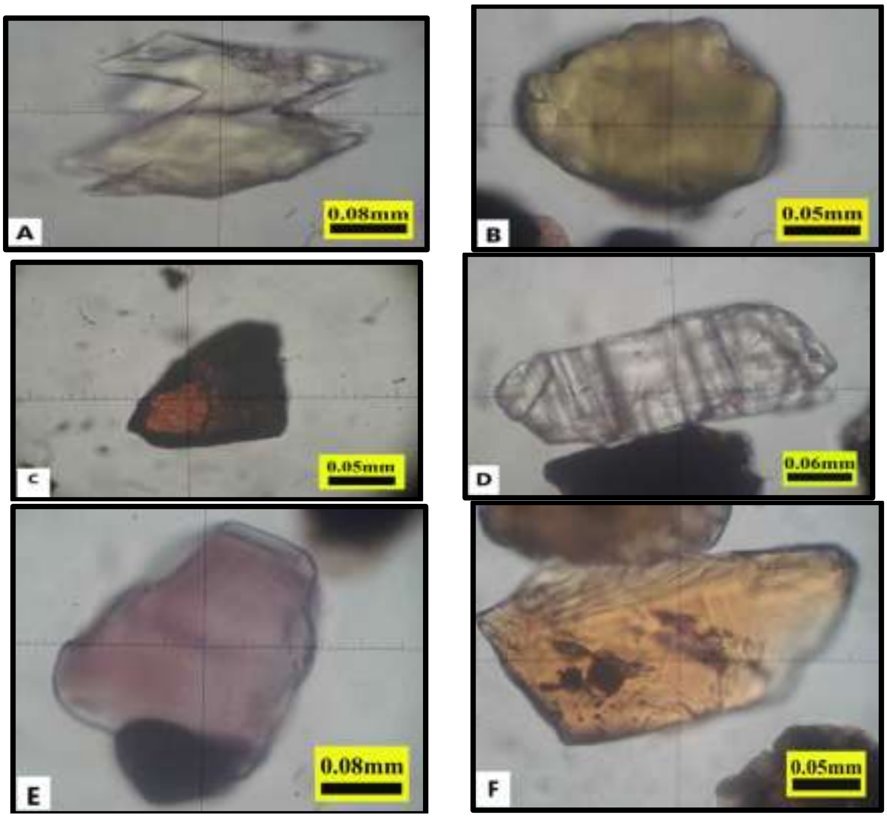


**Figure 15-** A. Cocks comb amphibole, sample number ZI 17. B. Sub rounded, yellowish green epidote, sample number ZM 12. C. Deep yellow, high relief rutile, sample number ZI 13. D. High relief, colorless kainite, sample number ZI 17. E. Pleochronic, honey color tourmaline, sample number ZM 7. F. Pleochronic, goldish color staurolite, sample number ZM 3.

**Clay mineralogy**

The clay minerals present in the mudstone samples of Injana and Mukdadiya Formations include illite, kaolinite, chlorite and mixed-layered clay. Illite could be formed as a result of alteration of muscovite, biotite and K-feldspar both in weathering zone. Kaolinite seems to be of detrital origin derived mainly from igneous rocks rich in potash feldspars and to lesser extent, from the reworking of older sedimentary rocks .

**Discussion and conclusions**

Percentages of the major framework fragments of Injana and Mukdadiya sandstones are approximately the same. These fragments are composed mostly of rounded, subrounded and subangular quartz grains, feldspar and rock fragments (sedimentary, igneous and metamorphic. There is marked difference in the size and composition of the rock fragments of the two formations.

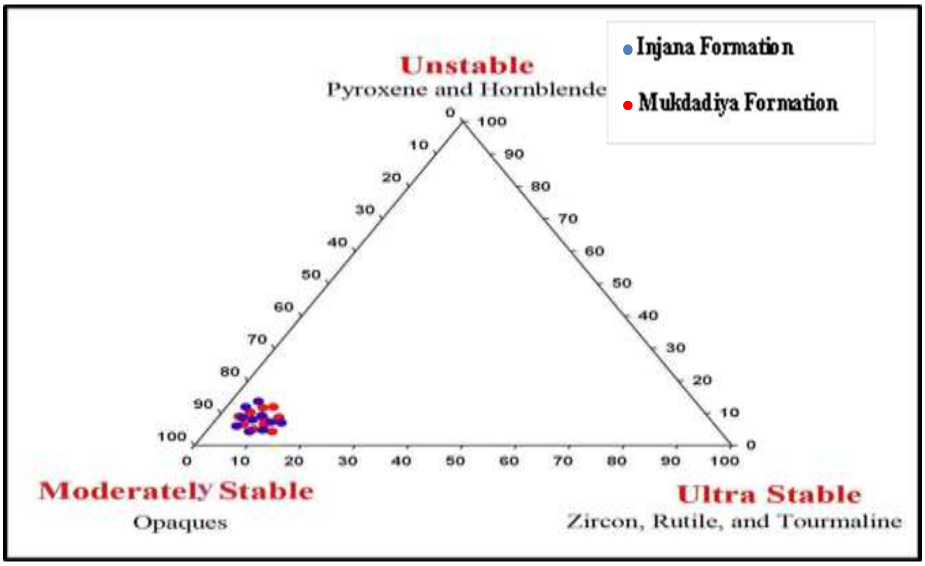


**Figure 16-** Ternary diagram of heavy mineral stability of Injana and Mukdadiya Formations [12].

Koshnaw and co-workers [1] concluded, based on U-Pb age spectra and petrologic data from the Injana Formation, that its sediments are derived from a variety of Eurasian, Pan-African, ophiolitic and Mesozoic-Cenozoic volcanic terranes, whereas the Mukdadiya and Bai-Hasan Formations show nearly exclusive derivation from the Paleogene Walash-Naopurdan volcanic complex near the Iraq-Iran border. They attributed the sharp cutoff in Eurasian, Pan-African, and ophiolitic sources is probably associated with drainage reorganization and tectonic development of the geomorphic barrier formed by the Mountain Front Flexure.

The petrographic data for the studied sandstones indicate that they are Calclithic arenite and Carbonate arenite (or wacke) and infer a recycled orogeny source terrain using the standard ternary diagrams. Within recycled orogens, sediment sources are predominantly sedimentary strata and subordinate volcanic rocks, partly metamorphosed, exposed to erosion by the orogenic uplift of foldbelts and thrust sheet [10].

The abundance of fresh grains of unstable components of feldspar, igneous and metamorphic rock fragments and unstable heavy minerals indicate intensive tectonism in the source area with rapid erosion and rapid transportation; it also indicates a nearby source area, which follows from the predominance of angular grains over rounded ones. Most of the sandstones are lithic arenites. These types of sandstones show that the rate of erosion must have greatly overbalanced the rate of chemical decomposition [6]. They also require rapid deposition in order to preserve unstable fragments from abrasion. It requires more rapid detrital influx due to active tectonism and high relief. The existence of such conditions is also supported by the fact that most of the studied sandstones are carbonate-rich sandstones.

The clay minerals of the studied samples of both Injana and Mukdadiya Formations are illite, kaolinite, chlorite and mixed-layer clay. Velde [13] invoked that the presence of illite with chlorite indicates that shale and metamorphic rocks are the main available source rocks. Illite may also be derived from the weathering of K-feldspar and disintegration of mica in continental environment [14]. Kaolinite may be formed from potash feldspar, this mineral form where solution has low silica and alkali cation activities [13]. The clay minerals present in the studied area suggest that the environment of their formation at the source area is likely to be characterized by arid climate which is dominated in the region at present. The clay minerals assemblage in the studied samples seems to be of detrital origin supplied by the source area with little effect of diagensis and or transformed during transportation.

In conclusion, it is proposed that Injana and Mukdadiya Formations, though they have some similitude in their composition the former represents the finer fraction and the latter, naturally, would be the coarser size. This indicates nearness of source and further elevation of source area. In addition the presence of the Paleogene carbonate gravels and sands supports the findings of Koshnaw [1].

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