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Petrographic Characterization and Provenance of Sandstone from the Mukdadiya Formation, Eastern Iraq

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Abstract

Two surface sections of Mukdadiya Formation, Al-Band and Bajliah eastern Missan, were selected to conduct the petrography of sandstone units. Ten sandstone samples were analyzed using a polarized microscope on the thin sections prepared from all samples to determine their light mineral content for petrographic study. Petrographic analysis revealed that the Mukdadiya sandstone is primarily composed of rock fragments, along with quartz grains (both monocrystalline and polycrystalline), feldspars including K-feldspar (orthoclase and microcline), plagioclase, and is cemented with carbonates. Mukdadiya sandstone is classified as lithic Quartzarenite. The proposed provenance for Mukdadiya sandstone is mainly sedimentary and plutonic igneous rock, with a less dominant metamorphic source. These sandstones are considered to be mineralogically immature, and according to the stability of sandstone in both sections, are chemically and mechanically unstable. The QLF classifications, the tectonic provenance of the Mukdadiya sandstone is described as recycled orogeny, while the QmFLt classification is placed in the lithic recycled field. According to the paleoclimatic conditions affecting, all sandstone samples of Mukdadiya sandstone are fall in the semi-arid region. Mukdadiya Formation›s high percentage of carbonate rock fragments such as limestone and dolomite suggests that the parent rock is primally carbonate, indicating that the material was transported rapidly moved quickly within the area which occur only in areas with high relief and arid climate that the fragments could have originated in the overthrust belt, the Sanandaj-Sirgjan belt, or the northeastern Iraq in high Thrust belt, where the metamorphic fragments were most likely formed.

Keywords: *Mukdadiya, Sandstone, Igneous, Petrography, Weathering, Clastic, Mineralogy, Iraq*

1. Introduction

The study area is situated in the Al-Teeb District of the northeastern Missan Governorate, near the eastern international border between Iraq and Iran. The research area is situated within the Low Folded zone›s Hamrin Subzone-Foothill Zone of the Unstable Shelf (Al-Mutury and Al-Asadi, 2008). Iraq has significant exposure to the Upper Miocene-Pliocene Injana and Mukdadiya Formation. The Mukdadiya Formation consists of up to 2000 m of gravely sandstone, sandstone, and red mudstone. The sandstones are sometimes cross-bedded and contain channel lags and clay balls (Basi and Jassim, 1974). According to Jasim and Goff (2006), the Mukdadiya Formation was formed in a rapidly receding foredeep basin through river deposition. Sandstones constitute an important part of the Tertiary stratigraphic sequence in eastern and northeastern Iraq. Sandstone›s importance lies in its ability to be used primarily for construction. It is also used in varying proportions in the cement, ceramic, and glass industries, and is used in polishing, sharpening, and water purification processes. The Mukdadiyah Formation is one of the most important and widespread gravel formations in Iraq, containing sandstone and gravel. It is thick and contains quartz, feldspar, and other minerals such as barite and celestite, which are primary mineral sources of barium and strontium. They are also used to weigh drilling fluids in high- and medium-pressure oil wells.

Because of their widespread distribution, Mukdadiya Formations have been examined in a large number of publications, reports, papers, and scholarly dissertations (Bellen et al. 1959; Buday 1980; Al-Banna 1982). Most of which provide descriptions of the formations› lithofacies, sedimentology, and depositional environments, as well as geological overviews of the formations. Lower Bakhtiari Formation replaced with the Mukdadiya Formation and the Upper Bakhtiari Formation with the Bai Hassan Formation. Up to 2000 meters of fining upward cycles of gravely sandstone, sandstone, and red mudstone make up the Mukdadiya Formation. The sandstones are frequently heavily cross-bedded and are associated with clay balls and channel lags deposited in a rapidly subsiding foredeep basin (Jassim and Goff, 2006). The thickness of the formation in type section is 1411 meters, and it was measured close to Al-Mukdadiya City in the Diyala Governorate (Al-Rawi et al., 1992). Many previous investigations focused on the Mukdadiya Formation in different parts of Iraq, including Dohuk (Zawita and Amadya), Mosul, Tikrit, Dyala, and Wasit (Badra and Zurbatiya). These studies covered subjects such as : according to Al- Jassim (1969), the Mukdadiya formation was formed in central Iraqi flood plains and alluvial rivers; While Sadik (1977) examined the gravel content of the Mukdadiya and Dibdibba Formations, he discovered that the former had more quartz and chert gravels, whereas the latter had igneous rock fragments. Enad

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(2007) investigated the stratigraphy and sedimentology of the Mukdadiya Formation in the Badra area and proposed a fluvial environment there. Al-Shammary(2009) studied Mukdadiya Formation in south-east of Badra and shows that the conglomerate, sandstone, and mudstone facies repetitions in number of cycles with trough cross bedding and pebble size in all the studied section indication of typical variation of braided rivers activities through the deposition time. Al-Uqagdi (2011) compared the Mukdadiya and Injana Formations from the perspective of sedimentary sequences, stratigraphic environments and tectonic conditions in the northern Iraqi areas of Zakho and Ain Sefni. Al-Samaani (2011), in his study of mineralogy and geochemistry of the Mukdadiya Formation in northeast Missan, suggested that Mukdadiya Formation sediments sources primarily from the northeastern region of Iraq. Basi (2012) in his study of petrographic of the sandstones of Mukdadiya Formation indicates that they are immature, mostly poorly sorted and classified as litharenite. The predominant type of sedimentary fragments is carbonate. The source rocks, based on petrographical and heavy minerals studies, are interpreted to be composed essentially of sedimentary followed by igneous and metamorphic rocks , when studied in the Mukdadiya Formation in the central part of Iraq. Al-Salmani and Tamar-Agha (2018) in their study of Petrography and Provenance of the Sandstone of Injana and Mukdadiya Formations (Upper Miocene/Pliocene) at Duhok Governorate, Northern Iraq, 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. Al-Dabbagh (2018) reported that the sandstone of the Mukdadiya Formation in the Zurbatiya area (east Iraq) is classified as litharinite, sedarinite, and calclithite, and the tectonic provenance is a lithic recycled. Al-Kalidi (2014) studied the petrographic and geochemical analysis, suggesting the semi-arid to semi-humid environments of immature to sub-mature sediments of the Mukdadiya Formation in the Zawita and Amaadya areas, which indicate a near-source area in northeast Iraq. Mahdi and Sultan (2021) in their study of gravel of Mukdadiya in Al-Teeb area confirmed that the origin of the derived gravels is from the Qulqula Formation, because of their content of radiolaria and the other characterizing fossils. Sandstones› petrological characteristics are an important instrument for classifying them and can be used with other factors to address a variety of sedimentological problems (Boggs, 2009). The features of the source, the sedimentary processes occurring in the basin, and the types of channels connecting the source and the basin all affect the composition of sandstones (Demange, 2012). This study in two selected sections, eastern of Missan governorate namely Al-Band (A) and Al-Bajalia (B) with in latitude (32° 25› 51» N & longitude 47° 13› 03» E to latitude 32° 15› 36» N & longitude 47° 27› 18» E) respectively (Figure 1). The aim of study focuses on the petrographic description of sandstone to identify the Provence , paleclimate, and tectonic setting for these two selected sections :Al-Band and Al-Bajalia (Figure 1).

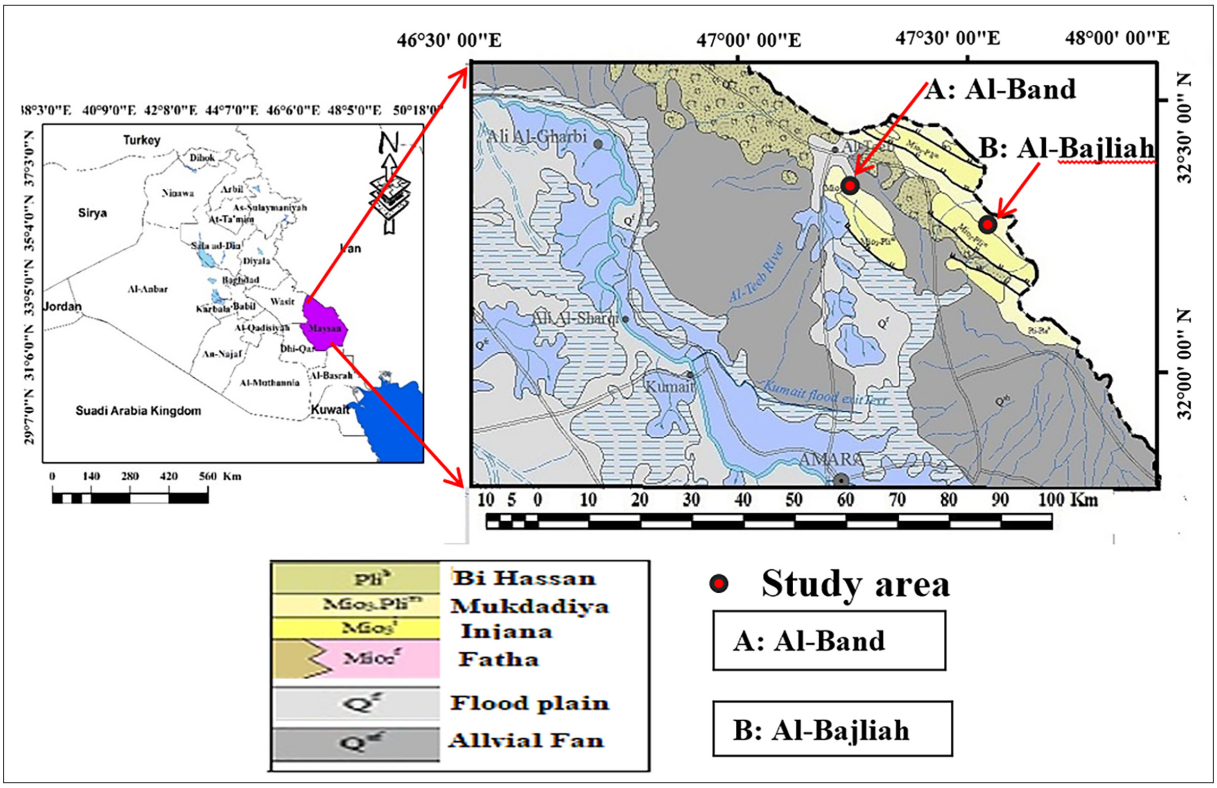


Figure 1. Geological map show the studied Area ***A:*** Al-Band and ***B:*** Al-Bajliah , modified after (Sissakian and Fouad,2012).

1.2. Geological and Tectonic Setting

According to Buday (1980), the Missan area is a part of the Makhul-Hemrine subzone (Low Folded Zone), which is sited outside the Arabian Plate form. According to Jassim and Goff (2006), Fouad (2008 and 2012), and Abdulnaby et al. (2021), the Mukdadiya Formation typically has a fluvial environment that quickly subsides in the foredeep basin. In late Miocene-Pliocene period, major thrusting occurred during collision of new Tethyan terranes and the Sanandaj-Sirjan zone with Arabian Plate resulting in the uplift of High Folded, Northern Thrust zones, and the NE part of Balambo-Tanjero zone (Figure 2). The Mukdadiya Formation in the Al-Teeb region (Figures 3 and 4) is made up of numerous sedimentary cycles, most of which consist of conglomerates, sandstone, and claystone arranged from bottom to top. Sand and gravel come in a variety of sizes, reflecting river environments and fining upward cycles. Range of sedimentary formations, such as load casts, trough cross-bedding, graded bedding, planer cross-bedding, and channeling that is periodically filled with gypsum. While Mukdadiya›s lower contact with Injana Formation is pebbly sandstone, the upper contact with Bai Hassan›s Formation is conformable and occasionally covered in Quaternary sediments. Most Quaternary sediments from the southern Iraqi Mesopotamian plain cover large areas of the unstable shelf (Al-Khafaji and Mhadi, 2019).

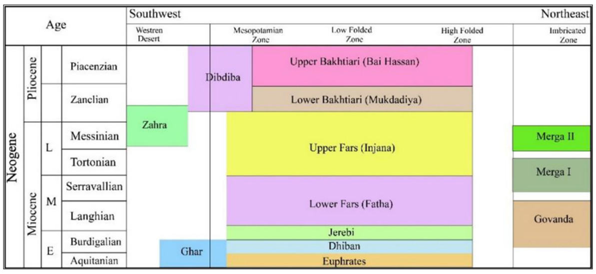
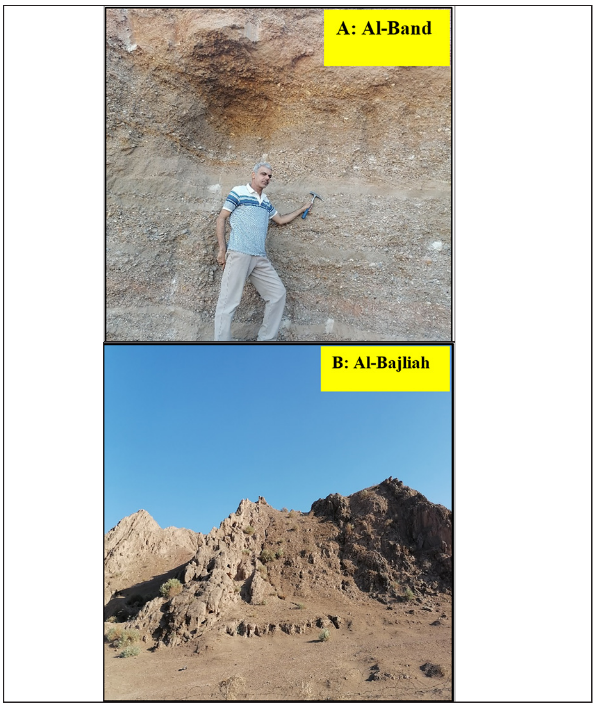


Figure 2. Correlation chart of the Neogene Period in Iraq (modified from Jassim & Buday, 2006; Jassim et al., 2006).



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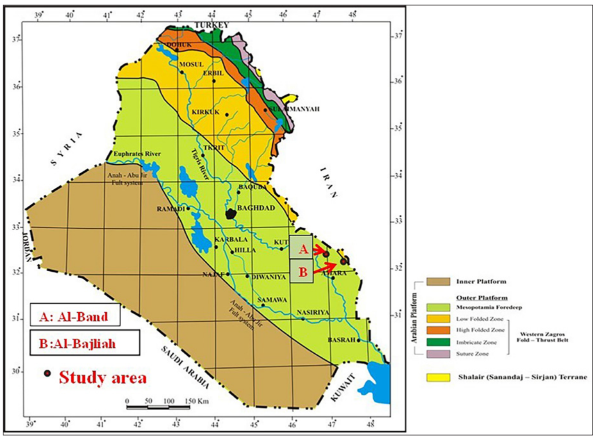

Figure 4. Location and tectonic map of the studied sections (after Fouad,2008; 2012 a and 2012 b)

2. Materials and Methods

The field work included the lithological description and measuring the thickness of sandstone units. Spot samples method were used for collections sandstone from the layers in the sections based on the variation in lithology, thickness, texture and color of the beds. Ten samples collected from both sections including five (5) samples of Al-Band section and five (5) samples of Al-Bajliah section (Figure 5) were chosen for preparing thin sections in the labratories of the Geology Department, College of Science, Baghdad University . The friable grains were consolidated on glass slide by saturated them with Araldite and Hardener materials (Moorland,1968). The components of thin section were counted according to the method of Gazzi-Dickinson (Dickinson, 1970), which is the most common method of counting point, using Polarized microscope (Type Optika) were used in order to identify the mineralogical components.

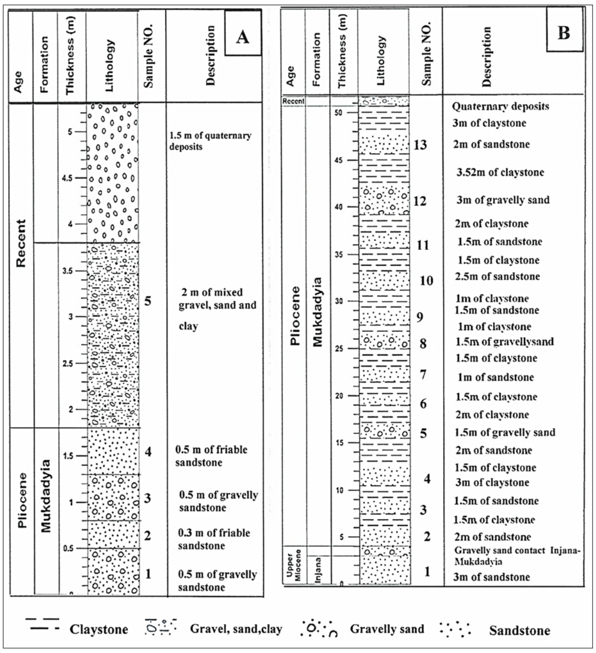

Figure 5. Stratigraphic column of Mukdadyia Formation in Al-Band (B), and Al-Bajliah (G).

3. Results and Discussion

3.1. Petrography of sandstone

Petrography is the most common geological method for understanding sediment formation, how sediments change during erosion, transport, deposition, and subsequent diagenesis. Morever , petrography is a fundamental method in sediment provenance studies (Dickinson et al. 1983; Garzanti, 2016, 2019; Augustsson, 2021). The only technique in sandstone provenance analysis that can give both mineralogical and textural data of the sandstone and its morphological components (small-scale original of the parent rock), enabling direct visualization and reconstruction of the source area (Garzanti, 2016). Sandstone fragmentation patterns can be connected to the plate tectonic setting of the sedimentary basins in which they were deposited (Dickinson & Suczek 1979; Dickinson et al. 1983; Dickinson 1985; Weltje & von Eynatten 2004; Weltje 2006); properties can be deduced to reflect source terranes and tectonic stratigraphic levels achieved through erosion in space and time. By examining the relative proportions of the three main constituents of sandstones: quartz (Q), feldspar (F), lithic or rock fragments (L), and carbonate cement, one can determine the modal composition of these rocks. Carbonate cement and matrix bind these components together (Boggs, 2009). Table 1 displays the averages and percentages of these components.

Table 1. Mineralogical components (%) of sandstone of Mukdadiya Formation Sandstone at Band (A) and Al-Bajalia

Components		Quartz			Feldspar				Rock fragments							Heavy Minerals	Opaque Minerals	Others
		Monocrystalline Quartz	Polycrystalline Quartz	Total Quartz	Orthoclase Feldspar	Microcline Feldspar	Plagioclase Feldspar	Total Feldspar	Carbonate Rock Fragments	Chert Rock Fragments	Igneous Rock Fragments	Metamorphic Rock Fragments	Mudstone Rock Fragments	Evaporites Rock Fragments	Total rock fragments			
Samples Number	A1	13.3	4.4	17.7	4.5	3.3	2.4	5.7	38.2	8.9	3.7	4.7	3.5	4.7	63.7	3.5	4.6	0.3
	A2	13.5	3.2	16.7	3.3	4.4	3.7	8.1	41.3	9.8	4.1	3.5	4.3	2.1	65.1	4.2	3.2	0.9
	A3	10.2	6.8	17	4.4	3.5	2.7	6.2	38.2	8.3	3.4	4.5	5.1	4.2	63.7	4.46	3.5	0.6
	A4	13.4	4.5	17.9	3.2	2.8	3.9	6.7	38.3	7.7	4.3	3.2	6.8	2.6	62.9	3.5	4.9	0.9
	A5	8.8	3.3	12.1	4.5	3.3	2.8	6.1	52.4	5.9	3.2	4.4	3.4	3.7	73	1.3	2.7	0.2
	mim	8.8	3.2	12	3.2	2.8	2.4	5.2	38.2	5.9	3.2	3.2	3.4	2.1	56	1.3	2.7	0.2
	max	13.5	6.8	20.3	4.5	4.4	3.9	8.3	52.4	9.8	4.3	4.7	6.8	4.7	82.7	4.46	4.9	0.9
	Av.	11.84	4.44	16.28	3.98	3.46	3.1	6.56	41.68	8.12	3.74	4.06	4.62	3.46	65.68	3.392	3.78	0.58
	B2	12.6	5.4	18	3.8	3.5	2.3	5.8	40.6	9.7	3.4	3.5	3.7	2.3	63.2	3.1	4.2	0.9
	B5	15.2	3.3	18.5	2.6	2.4	3.9	6.3	42.6	8.4	3.2	3.9	4.3	1.8	64.2	3.6	4.5	0.3
	B8	10.7	5.2	15.9	3.9	4.1	3.4	7.5	41.5	7.7	4.4	3.4	3.2	3.5	63.7	4.4	3.6	0.9
	B10	14.2	4.4	18.6	4.5	3.3	2.6	5.9	39.7	9.4	3.2	4.5	3.1	2.9	62.8	4.7	3.1	0.3
	B12	14.5	3.3	17.8	3.4	2.6	3.2	5.8	41.8	7.6	3.8	3.6	3.9	2.4	63.1	3.6	4.7	0.6
	min	10.7	3.3	14	2.6	2.4	2.3	4.7	39.7	7.6	3.2	3.4	3.1	1.8	58.8	3.1	3.1	0.3
	max	15.2	5.4	20.6	4.5	4.1	3.9	8	42.6	9.7	4.4	4.5	4.3	3.5	69	4.7	4.7	0.9
	Av.	13.44	4.32	17.76	3.64	3.18	3.08	6.26	41.24	8.56	3.6	3.78	3.64	2.58	63.4	3.88	4.02	0.6

Quartz is the main component of the Mukdadiya Formation sandstone is averaging 16.28% in the Band (A) section and 17.76% in the Al-Bajalia (B) section (Table 1). There are two types: polycrystalline quartz and monocrystalline quartz. The average monocrystalline type in the Band (A) section is 11.84%, and the average monocrystalline type in the Al-Bajalia (B) section is 13.4%. The crystals are angular to sub-angular with dominant straight and wavy extinction. The type of source rock is one of the major factors that affect the undulation of quartz (Conolly, 1965).

Wavy extinction resulted from the stress that was subjected to the quartz grain, which suggests that they are derived from plutonic igneous rock or metamorphic igneous rock (Asiedu et al., 2000; Folk, 1974). The occurrence of inclusions in monocrystalline quartz grains may reflect their derivation from plutonic igneous rock. (Figure 6-A).

These grains show polycrystalline type of quartz with an average in the Band (A) section is 4.44%, and the average polycrystalline type in the Al-Bajalia (B) section is 4.32%. It also has a sub-angular to sub-rounded shape, with a wavy extinction. Most of the quartz grains have a semi-angular shape, indicating that the transport distance is short to medium. Therefore, the probable source of polycrystalline quartz is metamorphic rocks, such as schist, gneiss, metaquartzite, and plutonic igneous rocks (Blatt, 1967; Folk, 1974). The amount of polycrystalline quartz presented in sandstones is a function of grain size and increases with increasing grain size (Conolly, 1965) (Figure 6-B).

Figure 6. A: Angular, monocrystalline quartz, sample number (A1), XPL. **B:** Sub Angular, Polycrystalline quartz, sample number (B2), XPL. **C:** Angular, potash Feldspar, sample number (A 3), XPL. **D:** Sub angular, Micocline, sample number (B5), XPL. **E:** Angular, Plagioclase, sample number (A2), XPL. **F:** Sub-rounded carbonate Rock fragment, sample number (B10), XPL. **G:** Sub-rounded carbonate Rock fragment, sample number (A1), XPL. **H:** Sub rounded Mudstone Rock fragment, sample number (B12), XPL. **I:** Angular chert fragment, sample number (A5), XPL. **J:** Angular chert fragment, sample number (B12), XPL. **K:** Angular Evaporite fragment , sample number (B8), XPL. **L:** Sub-rounded Zircon, sample number (A4), XPL.

Feldspars are common in sedimentary, igneous, and metamorphic rocks. They are less stable under the influence of surface conditions, especially in sedimentary environments. Mechanically, the stability of feldspar mineral is less than that of quartz in the process of erosion; on the other hand, Chemical weathering of feldspar may produce clay. Therefore, feldspar minerals refer to short distances of transportation (Pettijohn, 1975). Feldspars in Mukdadiya Formation sandstone have an averaging 6.5% in the Band (A) section and 6.26% in the Al-Bajalia (B) section (Table 1).

The occurrence of alkali feldspar (Potassium feldspars), including orthoclase and microcline, suggests semi-arid paleoclimate conditions or a high relief source area subjected to rapid erosion (Pettijohn et al., 1987). Orthoclase in the Band (A) section ranges from 3.2–4.5%, with an average of 3.98%. while in Al-Bajalia (B), sections ranged between 2.6-4.5%, with an average of 3.64%. Orthoclase grains are subangular to subrounded with dusty color due to decomposition into clay minerals.(Figure 6-C).

Microcline in the Band (A) section ranges between 2.8– 4.4%with an average 3.46 %. while in Al-Bajalia (B), sections ranged between 2.4-4.1%, with an average of 3.18%. Microcline grains show a cross-hatching twinning, and are observed as subangular, with degrees of alteration. A slight difference in percentages was observed in the sample of Band (A), and Al-Bajalia (B) (Figure 6-D). Plagioclase in the studied samples was observed as very angular to subangular. The fresh feldspars may indicate fragmentation from igneous rocks, accompanied by short-distance transport (Pettijohn, 1975) (Figure 6-D). Plagioclase in the Band (A) section ranges between 2.4– 3.9% with an average 3.1 %. While in Al-Bajalia (B) sections, ranging between 2.3-3.9%, with an average of 3.08%. Feldspar information alone is insufficient to identify source rocks; however, orthoclase and plagioclase may be derived from plutonic igneous rock or metamorphic rocks (Boggs, 2002). Microcline and perthite are more commonly found in the plutonic igneous rocks and metamorphic rocks, and are found to be rare in the formation of volcanic rocks. It can be said that the origin of the feldspar in the sandstones of the Mukdadiya Formation are from plutonic and metamorphic rocks (Figure 6-E).

The rock fragments include pieces of old source rocks that have been broken down and are indivisible into individual mineral grains. They are important in the study of the origin rocks because they are easy to distinguish and are a good indicator of the type of source rocks compared to individual minerals, such as quartz and feldspar (Boggs, 1995). Rock fragments are considered a material that indicates the clastic source. Location of the source rocks affects the percentage of rock fragments within the sandstone. This percentage increases when the source rock area was near the sedimentary basin or has high topography (Stephen, 2000). Rock fragments are common in the Mukdadiya Sandstone composition. The percentage ranges from 56% to 82.7.8% in the Band (A) section, with an average of 65.6%. It ranges from 58.8% to 69% in the Al-Bajalia (B) section, with an average of 63.4%.

A- Carbonate rock fragments

Carbonate rock fragments are common in clastic sedimentary rocks and clastic sediment in Iraq due to the widespread outcrops of these rocks in many areas of Iraq, these rock fragments represent special conditions of rapid mechanical erosion rather than chemical dissolution (Pettijohn et al., 1987). The Arabian shelf beneath Mesozoic carbonates is a likely source of carbonate fragments, which could have originated from adjacent areas. Carbonate source-rock fragments show a pattern of rapid mechanical erosion rather than chemical decomposition (Pettijohn et al., 1987). The presence of such fragments in the sediments indicates that the material was rapidly transported locally (Al-Juboury, 1994). Dickinson (1985) pointed out that high folds and thrusts in collision zones between colliding plates are formed, a process sometimes called recycling orogeny. Fold-thrust belts may expose igneous rocks, and the source rocks of the collision highs are sedimentary and metamorphic rocks that existed at the continental margin before the collision.

Carbonate rock fragments in the Band (A) section, ranges between 38.2– 52.4% with an average 41.6%, while in Al-Bajalia (B) section, it ranges from 39.7% to 42.9% with an average of 41.24% (Figures 6-F and -G).

B- Chert

The types of chert rock fragments, sub-rounded and rounded that were identified in the studied samples, including chalcedonic macrocrystalline and microcrystalline chert rock fragments in the Band (A) section,ranging between 5.9.– 5.8% with an average 8.1 %, while in Al-Bajalia (B) section, it ranges between 7.6-9. 7% with an average of 8.5% (Figures 6-I and -J).

C- Mudstone rock fragments

Mudstone rock fragments in the Band (A) section range between 3.4–6.8% with an average 4.6 %. While in Al-Bajalia (B) sections, ranging between 3.1- 4.3% with an average of 3.64% (Figures 6- H).

D- Igneous Rock Fragments:

Igneous rock fragments in the Band (A) section range between 3.2– 4.3%, with an average 3.74 %. While in Al-Bajalia (B) sections ranging between 3.2- 4. 4% with an average 3.6%

E- Metamorphic Rock Fragments

Metamorphic rock fragments in the Band (A) section range between 3.2– 4.7% with an average 4.07 %. while in Al-Bajalia (B) section, they range between 3.4- 4. 5% with an average of 3.78%.

F- Evaporates rock fragment

Evaporate rock fragments in the Band (A) section range between 2.1– 4.7% with an average of 3.46 %, while in Al-Bajalia (B) section, it ranges between 1.8- 3. 5% with an average of 2.58%. (Figures 6-K).

Opaque minerals

Opaque minerals in the Band (A) section range between 2.7– 4.9% with an average 3.78 %. while in Al-Bajalia (B) sections ranging between 3.1- 4. 7% with an average 4.028% (Figure 6-L)

3.2 Discussion:

Rock fragments are often unstable in the sedimentary setting, and their existence in sandstone provides good evidence of the original rock. (Boggs, 1995). It is clear that sedimentary rock fragments, particularly carbonate rock fragments, are the most abundant in the samples studied. This implies that they transformed from older layers with high carbonate content, which were exposed to the surface by tectonic activity such as folding and faulting (Dickinson, 1985); (Al-Juboury, 1994); and Zattin and Zuffa (2004). The presence of chert is attributed to the sediments of the chert that were subjected to the folding process or to the Chert nodules concretions located in the layers of carbonate rocks that were exposed (Dickinson, 1985; Blatt, 1987). AL-Juboury (1994) pointed out that the rocks of some Mesozoic formations in the thrust zone, possibly the Qulqula series, may be a source of chert. The chert fragments may be originated from carbonate deposits, containing chert nodules and chert in the northeastern overthrust belt sequence, in particular in the Qulqula Group (Al-Juboury, 1994). This shows that the Mukdadiya formation›s rocks, originated primarily from sedimentary rocks, with metamorphic and igneous rocks, contribute as secondary sources. The variety in mineral components reflects the diversity of their source rocks (Hendrix, 2000).

3.3 Classification of Sandstones

Based on the percentage of the main sandstone components, such as quartz, feldspar, and lithic pieces, the Mukdadiya Formation›s sandstone types (Table 1) were classified using Garzanti›s (2016). All of the Mukdadiya sandstone samples were classified as immature Quartzolithic sandstone as a result of this classification (Figure 7). Because sandstone is immature, this suggests that the sediments were deposited quickly and moved a short distance from their source (Garzanti, 2019). According to Boggs (1995), the lithic component of sandstone is compositionally immature sandstone formed by the production and deposition of several moderately unstable minerals. The predominance of carbonates and feldspars in the sections under study suggests that low-intensity physical and chemical weathering predominated in arid to semiarid climates, while tectonic uplift of thrust rocks and collisions between continents dominated the deposition of carbonates and solid rocks. Carbonate-rich sandstone indicated that the carbonate source was the primary source, with short-distance transportation and deposition occurring during the early stages of tectonic uplift. According to Arribas et al. (2000), dry and semi-dry climates preserve carbonate rocks, whereas wet climates reduce their abundance (Mack, 1981).

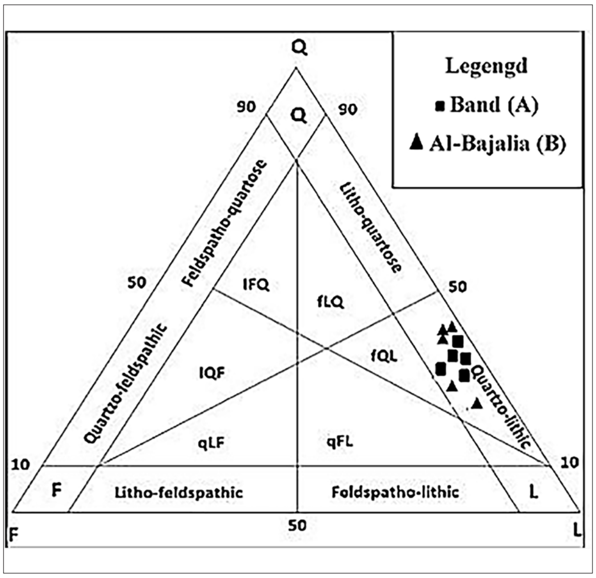

Figure 7. Classification of Mukdadiya Formation sandstone at Band (A) and Al-Bajalia (B) (Garzanti, 2016).

3.4 Stability of sandstone

Bjorlykke (1983) used a ternary diagram to classify sediment stability as chemical or mechanical (quartz-feldspar-rock fragments). He stated that a sandstone with a high percentage of quartz is chemically and mechanically stable, whereas a sandstone with a high percentage of feldspar is mechanically stable but chemically unstable, and a sandstone with a high percentage of rock fragments is chemically and mechanically unstable. According to this classification, Mukdadiya Formation sandstone in both sections is chemically and mechanically unstable due to the large percentage of rock fragments (Table 1and Figure 8).

3.5 Provenance of sandstone

The main aim of sediment provenance study is to remake and understand the geology of the source area, as well as to link the clasts› final burial to the host rock›s original erosion (Weltje & von Eynatten 2004). Most of the provenance investigations use petrographic analysis of quartz, feldspar, and rock fragments (Boggs, 2009). Due to its chemical stability, resistance to splitting, and relative hardness, quartz is a crucial mineral in the development of sandstones (Ibbeken & Schleyer 1991). Individual quartz crystals that exhibit wavy extinction, ranging from straight to oblique, are the primary means by which plutonic igneous rocks are identified in this study (Dickinson, 1985). Metamorphic rocks are indicated by wavy extinction > 5°, which is the greatest grade of wavy quartz (Folk, 1974). The wavy extinction of single quartz crystals and the disintegration of some of their grains under pressure could indicate that they originated in plutonic igneous and metamorphic rocks (Saftić et al. 2003). Polycrystalline quartz frequently displays straight or slightly curved intercrystalline borders, which suggests a plutonic origin (Tucker, 1985). Feldspar is seen as more relevant than quartz in detecting origin due to its less stable states (Boggs, 2009). Orthoclase and plagioclase can form from both plutonic and metamorphic igneous rocks, though microcline Microclene and plagioclase are more common in plutonic igneous rocks but uncommon in volcanic rocks (Garzanti, 2019). The presence of more feldspar could indicate that igneous rock fragmentation was accompanied by shorter transport routes (Pettijohn, 1975). According to Al-Jubоury (1994), the flint fragments might have come from carbonate deposits that contained flint nodules and flint in the Qulqula group and the northeastern overthrust belt sequence . Carbonate particles that may have come from nearby regions are most likely to have come from the Arabian shelf beneath Mesozoic carbonates. Fragments of carbonate source rock exhibit a distinctive pattern of quick mechanical erosion as opposed to chemical breakdown (Pettijohn et al., 1987). The Mukdadiya Formation›s high percentage of carbonate fragments suggests that the parent rock is naturally carbonate-rich. The presence of these shards in the strata suggests that the material was moved quickly within the area (Al-Jubоury, 1994). Volcanic fragments require quick erosion and incomplete weathering, which occur only in areas with high relief and arid climate (Pettijohn et al., 1973). Dickinson (1985) proposed that the fragments could have originated in the overthrust belt, the Sanandaj-Sirjan belt, or the northeastern overthrust belt, where the metamorphic fragments were most likely formed.

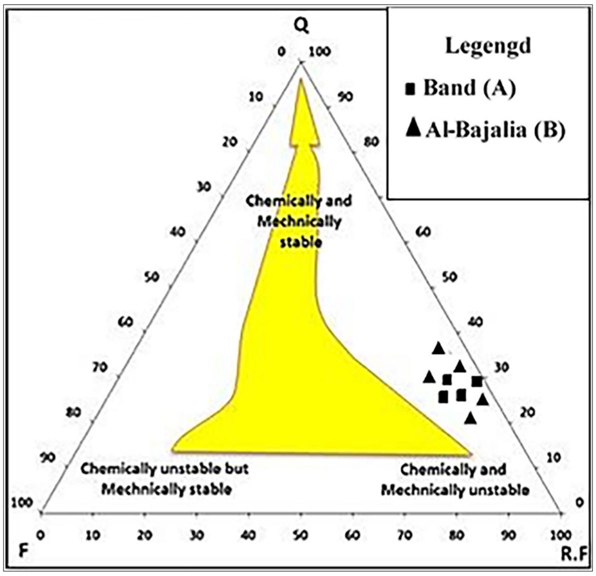

Figure 8. ternary diagram to classify sediment stability of Mukdadiya Formation sandstone at Band (A) and Al-Bajalia (B) Bjorlykke (1983) .

3.6 Tectonic setting

The source of the sandstone was identified in this work, using petrographical modal studies and QFL and QmFLt tectonec classification diagrams. The origin of Mukdadiya sandstone was explained using the ternary diagram of Ingersoll and Suczek (1979). The investigated samples plot in an undissected arc in this diagram (Figure 9). Additionally, the Dickinson and Suczek (1979) ternary diagram shows that the studied samples plot in lithic recycled (Figure 10). Uplifted terranes of folded and faulted strata, which are primarily composed of sedimentary and metamorphic rock, are the source of orogenic province deposits. However, igneous rock may be partially exposed (Dickinson and Suczek, 1979). The studied samples are lithic, recycled from transitional and undissected arcs, and show that the sand contains more rock fragments and less feldspar and quartz. In addition, the sand has a high concentration, due to the abundance of lithic fragments that are nearly solely volcanic clasts. The proportion of polycrystalline quartz and rock fragments and the low proportion of monocrystalline quartz and feldspar suggest that the sands may have derived from oceanic islands. High folds and thrusts develop in collision zones between colliding plates, a phenomenon often referred to as recycling orogeny, as noted by Dickinson (1985). Sedimentary and metamorphic rocks that were present at the continental margin before the collision are the source rocks of the collision highs, and fold-thrust belts may reveal igneous rocks (Dickinson1985). Tectonically uplifted, complex subduction zones behind volcanic arcs are the sources of transitional and lithospheric-recycled sediments. Sedimentary, metamorphic, and igneous rock exposed by thrust sheets and uplifting dominate these areas (Dickinson, 1970).

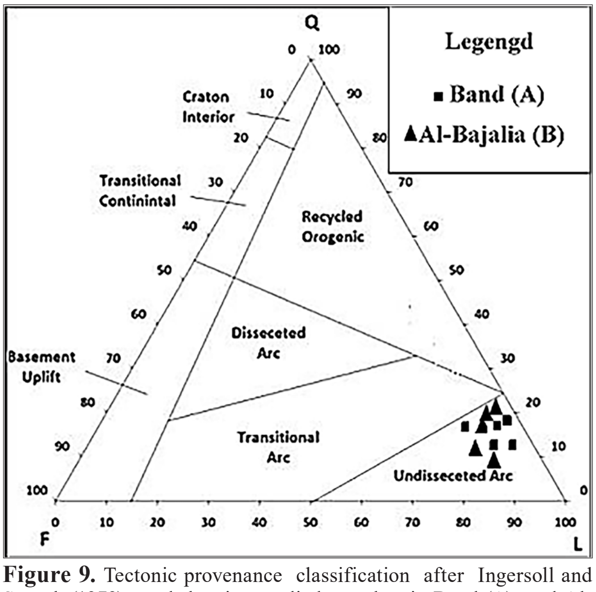

Figure 9. Tectonic provenance classification after Ingersoll and Suczek (1979) , and showing studied samples in Band (A) and Al-Bajalia (B) (after Garzanti, 2016).

3.7 Paleoclimate

Climate has a significant impact on skeletal mineralogy, even if tectonics is the primary determinant (Suttner and Dutta, 1986). According to Young (1975), the percentage of preservation in sands is a sensitive indicator of the type of paleoclimate. To identify the paleoclimatic circumstances that influenced the sandstones under study, the following is employed as a sensitive discriminator of sandstones with different climatic records. The ratios of Qt/F+R and Qp/F+R are low, indicating a low compositional maturity index and suggesting that the sandstone composition is immature. According to Suttner and Dutta›s (1986) bivariate double logarithmic plot of Qt/F+R and Qp/F+R, all of the Injana Formation›s sandstone samples are located in the semi-arid regions of the Tuz-Khurmatu and Basara sections (Figure 11 and Table 2). Tucker (1991) states that semi-humid conditions may contribute to the dominance of quartz and decrease the amount of feldspar and rock fragments, whereas dry conditions may support the dominance and stability of these unstable minerals.

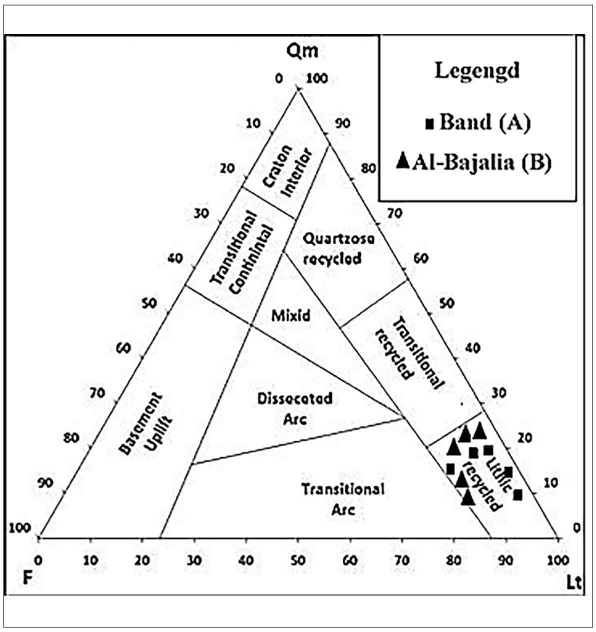

Figure 10. Tectonic provenance classification Dickinson and Suczek (1979), and showing studied samples in Band (A) and Al-Bajalia (B) . (Garzanti, 2016).

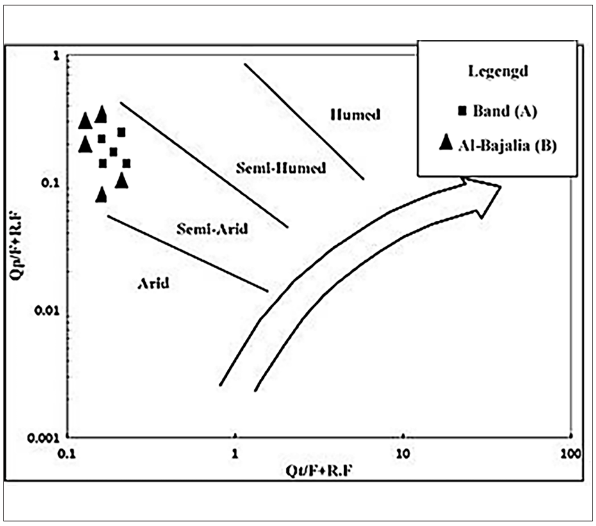

Figure 11. Bivariate log-log plot of Qt/F+R and Qp/F+R showing studied sample in Band (A) and Al-Bajalia (B) after (Suttner and Dutta, 1986).

Table 2. Main components (%) of sandstone of Mukdadiya Formation Sandstone at Band (A) and Al-Bajalia

	Total Quartz	Total Feldspar	Total rock fragments	F+RF	Q/F+RF
A1	17.7	5.7	63.7	69.4	0.25
A2	16.7	8.1	65.1	73.2	0.22
A3	17	6.2	63.7	69.9	0.24
A4	17.9	6.7	62.9	69.6	0.25
A5	12.1	6.1	73	79.1	0.15
min	12.1	5.7	62.9	68.6	0.17
max	6.8	3.9	4.7	8.6	0.79
Av.	16.28	6.56	65.68	72.24	0.22
B2	18	5.8	63.2	69	0.26
B5	18.5	6.3	64.2	70.5	0.26
B8	15.9	7.5	63.7	71.2	0.22
B10	18.6	5.9	62.8	68.7	0.27
B12	17.8	5.8	63.1	68.9	0.25
min	15.9	5.8	62.8	68.6	0.23
max	18.6	7.5	64.2	71.7	0.25
Av.	17.76	6.26	63.4	69.66	0.25

4. Discussion

The study area is situated in the Al-Teeb district in southern Iraq near the Iraqi-Iranian border. This study deals with the Mukdadiya Frmation in this area which Gravel, and sand sediments deposited by braided rivers make up these alluvial fans. The Mukdadiya Formation, located above the Fatha Formation and covered with Bai Hassan formations, which are found in the mountainous terrain along the border (Jassim and Goff, 2006). Field studies showed that the sediments consist mainly of gravel and sand, with the presence of clay. The changes in the grain size of sediments indicate that the differences in size are due to changes in the energy flow and sediment sorted in a relatively high energy environment. The large grain sizes indicate a high velocity for the current, which is strong enough to transport particles of this size (Friedman, 1967).

This study focuses on the petrographic description of sandstone to identify the Provence, paleoclimate ,and tectonic setting for Mukadya Formation in two selected sections: Al-Band and Al-Bajalia in Al-Teeb area by examining the proportions of the three main constituents of sandstones: quartz (Q), feldspar (F), lithic or rock fragments (L).

Most of the provenance investigations use petrographic analysis of quartz, feldspar, and rock fragments (Boggs, 2009).Sample of sandstone of Mukdadiya Formation shows quartz crystals with wavy extinction from straight to oblique, which means some of their grains› disintegration under pressure could indicate that they originated in plutonic igneous and metamorphic rocks (Saftić et al. 2003).Morover, Polycrystalline quartz frequently displays straight or slightly curved intercrystallite boundaries, which suggest a plutonic origin (Tucker, 1985). The presence of Feldspar could indicate that igneous rock fragmentation was accompanied by shorter transport routes (Pettijohn, 1975). Orthoclase and plagioclase can form from both plutonic and metamorphic igneous rocks, though microcline Microclene and plagioclase are more common in plutonic igneous rocks but uncommon in volcanic rocks (Garzanti, 2019). The presence of quartz and feldspar in the Muqdadiya Formation as clastic competes requires the presence of a nearby source containing igneous and metamorphic rocks that are exposed to weathering in order for the Muqdadiya Formation sediments to emerge from them, this source is located in northeastern Iraq in the high fold Zone . Moreover, the sandstone of Mukdadiya Formation›s high percentage of carbonate rock fragment and chert suggests that the source rock is consist of carbonate and chert that were subject to mechanical weathering and transport where Muqadiya Formation were deposited. This proposed source is the Qalqalah Formation, which consists of chert and limestone in northeastern Iraq and suggests that the material was moved quickly within the area (Al-Juboury, 1994). Mahdi and Sultan (2021) in their study of gravel of Mukdadiya in Al-Teeb area confirmed that the origin of the derived gravels is from the Qulqula Formation, because of their content of radiolaria and the other characterizing fossils.

Tectonically, The samples of current study are Lithic recycled and undissected arc which indicated the sand is high rock fragments and less quart and feldspar, moreover, the sand high in The proportion of polycrystalline quartz and rock fragments and low proportion of monocrystalline quartz and feldspar, that indicate the Sands may be derived from oceanic island due to abundant lithic fragments that are almost exclusively volcanic clasts. Lithic recycled sediments source refers to tectonically uplifted complex subduction zones behind volcanic arcs; these areas are dominated by sedimentary, metamorphic, and igneous rocks exposed due to tectonic uplift. (Dickinson,1970).

The collision between the Arabian Plate and the Eurasian Plate continued during the Pliocene. This convergence resulted in the formation of the Zagros Fold and Thrust Belt, where the Arabian Plate is colliding with the Iranian Plate. These events led to uplift and deformation of the

Plate as it is colliding with the Iranian Plate. These events led to significant uplift and deformation of the Zagros Mountains. Therefore, the origin of the deposits of the Mukdadya Formation in Iraq is believed to be from fluvial and alluvial fan environments that were active during the Miocene (Sissakian et al., 2021). Sediments were transported and deposited by rivers and streams that drained from the uplifted areas of the surrounding mountains. The formation is composed of gravel, sandstones, and mudstones that reflect a range of depositional environments, from braided river channels to floodplain deposits (Al-Juboury and McCann, 2008). This sedimentary deposit is a common type of molasse, which was formed in a rapidly sinking basin and is characterized by freshwater and lacustrine environments (Jassim and Goff, 2006).

5. Conclusion

1- Quartz is the main component of the Mukdadiya Formation sandstone. Two types of quartz, polycrystalline and monocrystalline, have angular to sub-angular with dominant straight and wavy extinction, that suggested they derived from plutonic igneous rock or metamorphic igneous.
2- The occurrence of Alkali feldspar (Potassium feldspars), including orthoclase and microcline, suggests semi-arid paleoclimate conditions or high relief source area, subjected to rapid erosion plagioclase in studied samples observed as very angular to sub angular. The fresh feldspars may indicate a fragmentation process from igneous rocks, accompanied by a short distance of transportation.
3- It is obvious that sedimentary rock fragments, particularly carbonate rock fragments, are the most abundant in the studied samples. This implies that they transformed from older layers with high carbonate content, which were exposed to the surface by tectonic activity such as folding and faulting with high relief.
4- Mukdadiya sandstone samples were determined to be quartzite. As a result, this sandstone is immature and suggests that the sediments were quickly deposited and moved a short distance from their source in the overthrust belt, the Sanandaj-Sirjan belt, or the northeastern overthrust belt, where the metamorphic fragments were most likely formed.
5- The stability of sandstone shows that the sediments are chemically and mechanically unstable.
6- Paleoclimate conditions indicate that all samples of Mukdadiya sandstone are semi-arid areas.

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