IRAQI BULLETIN OF GEOLOGY AND MINING (IBGM)\
IRAQ GEOLOGICAL SURVEY (GEOSURV-IRAQ)

*IBGM (**2025**, Vol 21; Issue 2)* *473-488*

HEAVY MINERAL DISTRIBUTION IN THE MUKDADIYA FORMATION AT AL-TEEB AREA, MISSAN GOVERNORATE, SE IRAQ

Hasan Kattoof Jasim

Department of Geology – College of Science - University of Baghdad – Iraq; e-mail: hasan.jasim@sc.uobaghdad.edu.iq

Type of the Paper (Article)
Received: 07/04/2025
Accepted: 19/10/2025
Available online: 27/12/2025

Abstract

In the current study, eight samples were collected from gravely sandstone and sandstone units of the Mukdadiya Formation, which is deposited within the Late Miocene-Pliocene sedimentary cycle and exposed in Al-Taeeb area in Missan Governorate, southeastern Iraq, and on the southwestern flanks of Bajalia and Band Folds in Al-Teeb area. The formation consists of sedimentary cycles deposited as a fining-upward sequence. Heavy minerals were separated from light minerals using heavy fluids. It was found that the heavy mineral content consists of opaque minerals (43.66%), chlorites (8.91%), orthopyroxene (3.43%), clinopyroxene (3.08%), hornblende (4.31%), tremolite-actinolite (2.23%), glaucophene (1.81%), biotite (5.61%), muscovite (4.53%), grossularite (2.68%), almandite (2.15%), zircon (2.17%), tourmaline (2.71%), rutile (2.30%), epidote (5.06%), staurolite (1.31%), kyanite (1.54%), and chromian spinel (0.91%). The results obtained indicate that the sediment of Mukdadiya Formation is unstable due to its high content of unstable minerals, including opaque and ferromagnesian minerals, including chlorites, pyroxenes, amphiboles, and biotite, as well as a low percentage of stable minerals (zircon, tourmaline, and rutile) (ZTR). Tectonically, the sediment of the Mukdadiya Formation in the studied locality is considered to have been deposited within an unstable and active tectonic environment. This is due to the low content of stable minerals (ZTR), which does not indicate that the formation's sediment was transported over long distances or subjected to recycling. The main source rocks of the Mukdadiya Formation deposits in Al-Teeb area are basic igneous rocks, regionally metamorphic rocks, and sedimentary rocks originating from the rocks found within the Zagros Mountains in northeastern and eastern Iraq. This is due to the high percentage of basic igneous minerals. In addition, there is a minor influence of other sources, namely acidic igneous rocks, which is evident due to the low percentage of stable minerals such as zircon, tourmaline, and rutile.

ISSN 1811-4539, EISSN 3005-3714
https://doi.org/10.59150/ibgm2102a26
IBGM: http://ibgm-iq.org/
Academic Scientific Journals: www.iasj.net

Keywords: Heavy Minerals, Source Rocks, Mukdadiya Formation, Tectonic Setting, Subduction Zone.

1. Introduction

Heavy minerals are dense mineral grains with specific gravities significantly higher than the average density of most common rock-forming minerals. They typically exhibit densities greater than 2.9 g/cm³ and are commonly composed of minerals such as garnet, tourmaline, zircon, rutile, and magnetite. Heavy minerals are often concentrated in sedimentary deposits through various sedimentary processes, such as erosion, transportation, and sedimentation (Vikas Swarnkar et al., 2024).

Heavy mineral analysis is one of the most important and often used techniques for determining the provenance of sand and sandstone. Heavy mineral accumulation is affected not only by the source area's mineralogical composition but also by a variety of other processes that occur during the sedimentation cycle, such as the stability of minerals and chemical weathering processes during transportation (Folk, 1974; Nichols et al., 2007; Tucker, 1988). The geological records found in sediments are unparalleled. In source locations, along transport routes, and in depositional basins, they document and conserve the traces of past geological occurrences. The characteristics of the source location are the primary determinants of the mineralogy and chemical composition of sediments, although burial circumstances and the hydraulic regime during transportation also have a role. The more significant characteristics of the source area include the vegetation, slope, climate, relief, source-rock composition, and fluvial environment dynamics. Additionally, weathering and erosion are crucial in controlling the sediment composition. According to (Folk,1974), heavy minerals are those of a parent rock that have a specific gravity of more than 2.89 and have withstood deterioration due to weathering, abrasion, or intrastratal solution. One of the most popular and sensitive methods for determining the provenance of sediments is heavy mineral analysis. High-density auxiliary minerals found in siliciclastic deposits are known as heavy minerals. They can be found in a wide range of rock types in their parent rocks as accessory components like zircon, apatite, and tourmaline, or as necessary rock-forming minerals like amphiboles and pyroxenes. Numerous factors, such as origin, sedimentary processes, and post-depositional dissolution, can produce significant variations in the concentration of heavy mineral grains in sand-sized terrigenous sediments (Mange and Wight, 2007). Heavy minerals include various silicates and oxides that are found in small quantities in sandstones. These minerals are derived from the very stable minor accessory minerals of the parent rock. Despite their small amount, they are of great value in studying provenance, transportation, and weathering history of sediments. Heavy mineral analysis is a sensitive and well-proven technique for determining the provenance of clastic sediments.

2. Previous Works

The Mukdadiya Formation (Late Miocene - Pliocene) is widely exposed in Iraq. This formation is composed of gravely sandstone, sandstone, and mudstone in a fining-upward sequence (Jassim and Goff, 2006; Al-Salmani and Tamar-Agha, 2018). There are many previous studies of Mukdadiya Formation including; (Jasim, 2009; Al-Khalidi, 2014), (Ali, 2021), (Al-Salmani and Tamar-Agha, 2018), (Mahdi and Soltan, 2021), and (Al-Rawi and Razzak, 2020), All previous studies indicated that the formation was deposited in a fluvial environment in the form of sedimentary cycles whose sediments fining upward sequence, and the formation sediments are unstable, and the proportion of unstable heavy minerals is dominant. The Mukdadiya Formation was deposited in an unstable tectonic environment resulting from the collision process between the Arabian and Iranian Plates within the Zubduction Zone (Mahdi and Soltan, 2021) and (Ali, 2021). The present study includes the heavy minerals distribution of the Mukdadiya Formation in Al-Teeb area, southeastern Iraq.

3. Materials and Methods

3.1. Location of the Studied Area

The present study is located in Al-Teeb area in Missan Governorate, Southeastern Iraq, near the Iraq-Iran border, between longitudes (47° 35' 00" E and 47° 05' 00" E) and latitudes (32° 10' 00" N and 32° 25' 00" N). The study area consists of five folds: Al-Teeb, Band, Bajalia, Abu Gharab, and Fawq Anticlines (Abdulnaby et al., 2021). The samples for the current study were collected from the outcrops of Mukdadiya Formation within the southwestern flanks of Bajalia and Band folds (Figure 1).

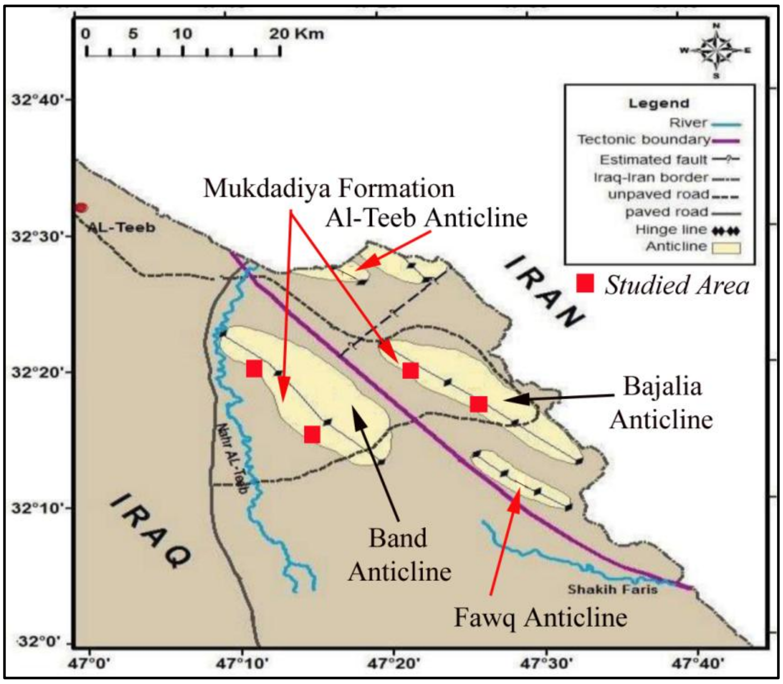

Figure 1. Location map of the studied area (Abdulnaby et al., 2021).

3.2. Methodology

Eight samples of gravely sandstone and sandstone units are collected from the outcrops of Mukdadiya Formation that are exposed in Al-Teeb area. The heavy mineral distribution of these samples was separated by using heavy liquid (Bromoform). Heavy mineral analysis is one of the most important and often used techniques for determining the provenance of sand and sandstone. Heavy mineral accumulation is affected not only by the source area's mineralogical composition, but also by a variety of other processes that occur during the sedimentation cycle, such as the stability of minerals and chemical weathering processes during transportation (Folk, 1974; Nichols et al., 2007; Tucker, 1988).

The main methods used in this work included: Collection of samples from the outcrops of Mukdadiya Formation in the studied area, separating the sand fraction from the friable gravely sandstone and sandstone and performing a grain size analysis by sieving the sand fraction and separating the fine and very fine sand for separation of the heavy mineral part (Tucker, 1988), and (Folk, 1974), separation heavy minerals from the gravely sandstone and sandstone using heavy liquid (Bromofirm), (Folk, 1974), and (Tucker, 1988), prepararing of mounted slides using Canada Balsam, and determination of types and percentage of heavy minerals by point counting technique using Leitz polarized transmitted microscope.

3.3. Geological Settings

The area of study comprises (Late Mocene-Pliocene) deposits, represented by Injana, Mukdadiya, and Bai Hassan formations, which are exposed in the Low Folded Zone represented by five anticlines in the studied area: Bajalia, Band, Al-Teeb, Abu Gharab, And Fawq Anticlines.

The Mukdadiya Formation occupies the southwestern flank of Bajalia and Band Anticlines. It is composed of gravely sandstone, sandstone, and mudstone, which were deposited according to the fining upward sequence (Figure 2). The study area also contains recent sediments of Quaternary Deposits of the Mesopotamian Plain (Pleistocene and Holocene). It includes flood plain, valley-fill sediments, and aeolian sediments represented by deposits of sand dunes (Aqrawi in Jassim and Goff, 2006).

The Mukdadiya Formation in the studied area was deposited in the form of sedimentary cycles with a fining-upwards sequence in each sedimentary cycle. Each sedimentary cycle begins with gravely sandstone, then sandstone, and ends with mudstone to begin a new sedimentary cycle. This model falls within the fluvial sedimentary environments.

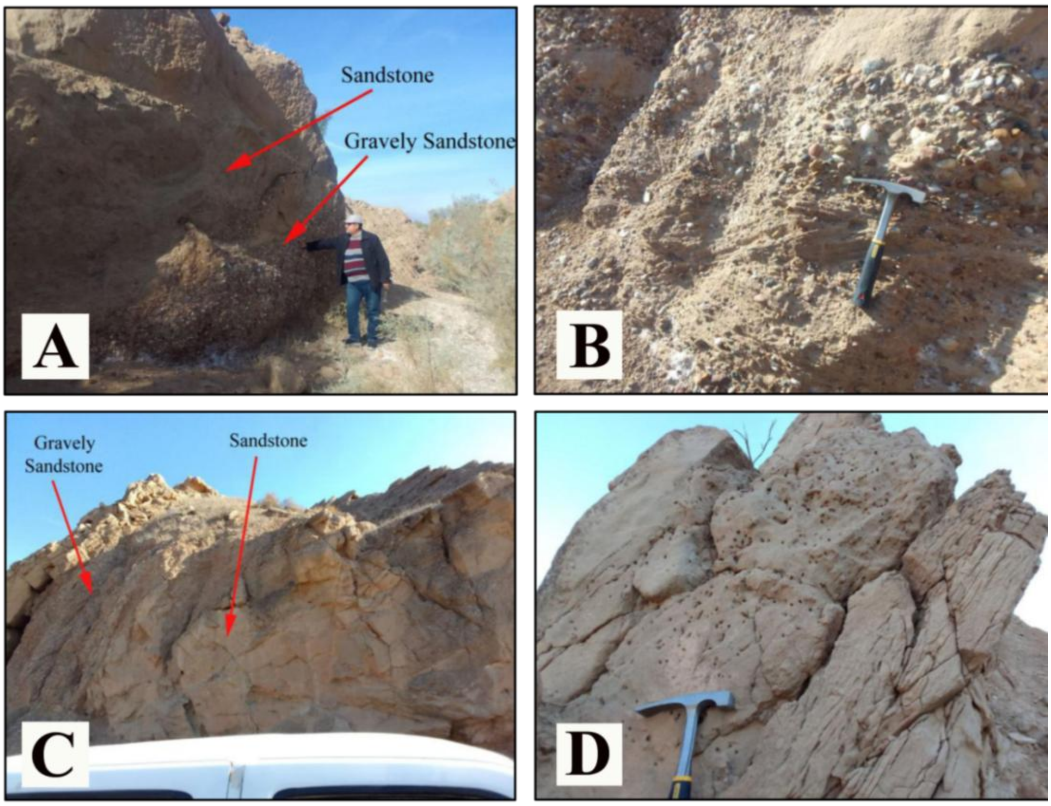

Figure 2. Outcrops of Mukdadiya Formation in the studied area were: A: Outcrops of Mukdadiya Formation in the southwestern flank of Band Anticline, B: Cross-bedded gravely sandstone of Mukdadiya Formation in the southwestern flank of Band Anticline, C: Outcrops of Mukdadiya Formation in the Southwestern flank of Bajalia Anticline, and D: Cross-bedded sandstone of Mukdadiya Formation with boring sedimentary structure of Mukdadiya Formation in Bajalia Anticline.

Tectonically, the area of study is located within the platform, in the Low Folde Zone (Fouad, 2015 (Figure 3). The Low Folded Zone is characterized by many long anticlines with Neogene cores and broad synclines composed of thick Mocene – Pliocene formations that are represented by molass deposits (Jassim and Goff, 2006). The Neogene rocks are exposed in the Foot Hill Zone or Low Folde Zone in Iraq within the flanks of anticlines trending North-West to South-East (Jassim and Goff, 2006). During the Miocene-Pliocene, major thrusting occurred during the collision of the Neo-Tethyan terranes (Arabian Plate) with the Sanandaj-Sirjan Zone, causing the end of the marine phase and beginning of the continental phase in Iraq. A major foredeep formed in the Zagros Foreland, which was filled by continental molasse sediments that increased in size continuously, due to continuous and intense uplifting of the High Folded Zone; the erosion products, which were laid down in the foredeep, represent Injana, Mukdadiya, and Bai Hassan formations (Sissakian and Al-Jibouri, 2012). The Low Folded Zone forms the first topographic and morphological front of the Western Zagros Fold Thrust belt. The boundary between the Mesopotamin Foredeep and the Low Folded Zone is taken along the slopes of the Hamrin-Makhul mountain range and its continuation northwestwards. The zone consists of a series of widely spaced, low-amplitude, gentle folds. The folds trend NW – SE. The topography is dominated by Middle Miocene to Pliocene sediments (Fouad, 2015).

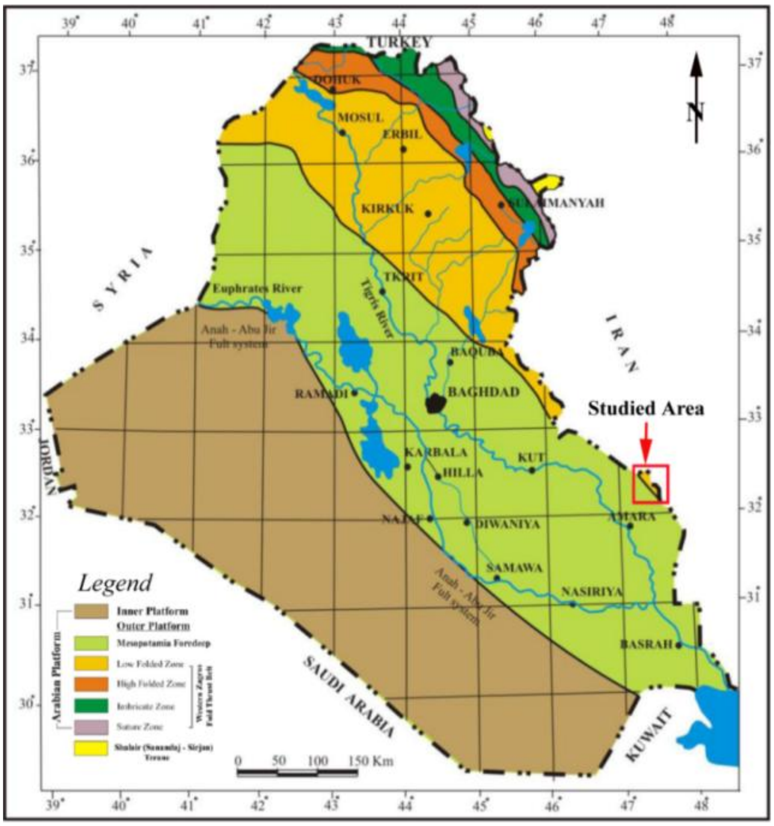

Figure 3. Tectonic map of Iraq (Fouad, 2015).

4. Results and Discussion

4.1. Heavy Minerals Analysis

The present results of heavy minerals analyses in the samples of the Mukdadiya Formation show that the heavy minerals are divided according to the light transparency into two main groups: opaque and non-opaque minerals (transparent minerals). The proportion of opaque minerals is predominant in all samples studied. This is because the source rocks for these minerals are diverse, including igneous, metamorphic, and sedimentary rocks (Folk, 1974). Table 1 shows the proportions of the separated heavy minerals, as well as the proportions of opaque minerals to transparent minerals from the total heavy minerals.

The heavy minerals identified in the studied samples of the Mukdadiya Formation included two main groups: the opaque minerals group and the non-opaque or transparent minerals group. Opaque minerals are minerals that are not transparent to light and include many mineral groups, including native elemental minerals, oxides, hydroxides, sulfides, etc (Barker, 2014). The non-opaque or transparent minerals identified from the studied sample include: chlorites, pyroxenes (orthopyroxene and clinopyroxene), amphiboles (hornblende, tremolite-actinolite, and glaucophene), mica minerals (biotite and muscovite), garnet (grossularite and almandite), zircon, tourmaline, rutile, epidote, staurolite, kyanite, and chromian-spinel. The mineral identification was based on the optical properties of the minerals under polarized light (Nesse, 2000; Barker, 2014). The percentage and average of heavy minerals are shown in Table 2 and Figures 4 and 5.

Table 1. Percentage of heavy minerals and percentage of opaque to non-opaque minerals from the studied samples.

Samples Number	Weight percentage of heavy minerals from samples	Percentage of opaque minerals %	Percentage of non-opaque minerals (Transparent minerals) %
MT1	3.85	41.2	58.8
MT2	4.15	45.1	54.9
MT3	4.75	44.9	55.1
MT4	3.82	40.4	59.6
MT5	3.06	45.3	54.7
MT6	4.45	43.8	56.2
MT7	5.80	43.2	56.8
MT8	4.25	45.4	54.6

Table 2. Percentages and average of heavy minerals of Mukdadiya Formation in the studied samples.

Heavy Minerals		Samples Number								Average %
		MT1	**MT2**	**MT3**	**MT4**	**MT5**	**MT6**	**MT7**	**MT8**	
Opaques		41.2	45.1	44.9	40.4	45.3	43.8	43.2	45.4	43.66
Chlorites		9.2	8.6	8.4	9.5	8.6	9.5	9.4	8.1	8.91
Pyroxenes	Orthopyroxene	3.3	2.7	4.2	3.6	3.4	3.6	2.8	3.8	3.43
	Clinopyroxene	2.7	3.8	3.2	3.3	2.6	3.7	2.5	2.8	3.08
Amphiboles	Hornblende	5.2	3.3	4.5	4.1	3.7	4.9	3.4	5.4	4.31
	Tremolite-Actinolite	2.5	1.8	2.2	2.1	2.8	2.5	2.1	1.8	2.23
	Glaucophane	2.1	1.2	2.5	2.9	1.6	1.5	1.2	1.5	1.81
Mica	Biotite	5.2	5.6	5.3	6.5	5.6	4.7	6.8	5.2	5.61
	Muscovite	4.3	4.7	3.2	4.3	5.1	4.8	5.9	3.9	4.53
Garnet	Grossularite	2.9	3.5	2.7	2.6	2.4	2.2	2.8	2.3	2.68
	Almandine	2.5	2.9	1.8	1.5	3.2	1.5	2.6	1.2	2.15
ZTR	Zircon	3.5	2.6	2.4	3.2	2.6	4.1	2.8	4.2	2.17
	Tourmaline	2.7	2.5	3.2	2.5	2.4	3.4	2.6	2.4	2.71
	Rutile	2.6	2.3	2.6	2.1	1.8	1.9	2.5	2.6	2.30
Epidote		5.6	5.2	4.3	5.8	4.8	4.1	5.2	5.5	5.06
Staurolite		1.8	1.5	0.9	2.3	1.7	0.6	0.8	0.9	1.31
Kyanite		1.5	0.6	2.5	2.1	0.9	1.7	1.2	1.8	1.54
Chromian Spinel		0.9	1.2	0.6	0.3	1.2	0.6	1.6	0.9	0.91
Others		0.3	0.9	0.6	0.9	0.3	0.9	0.6	0.3	0.60

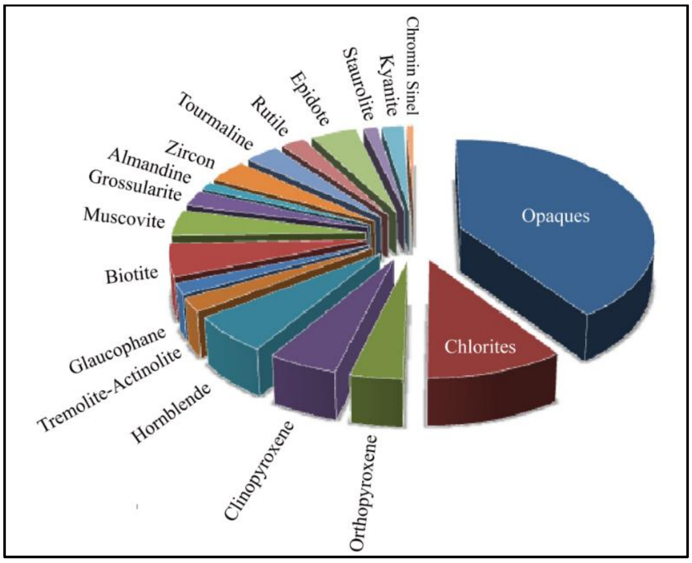

Figure 4. Pie chart showing the percentage of average heavy minerals in the studied samples.

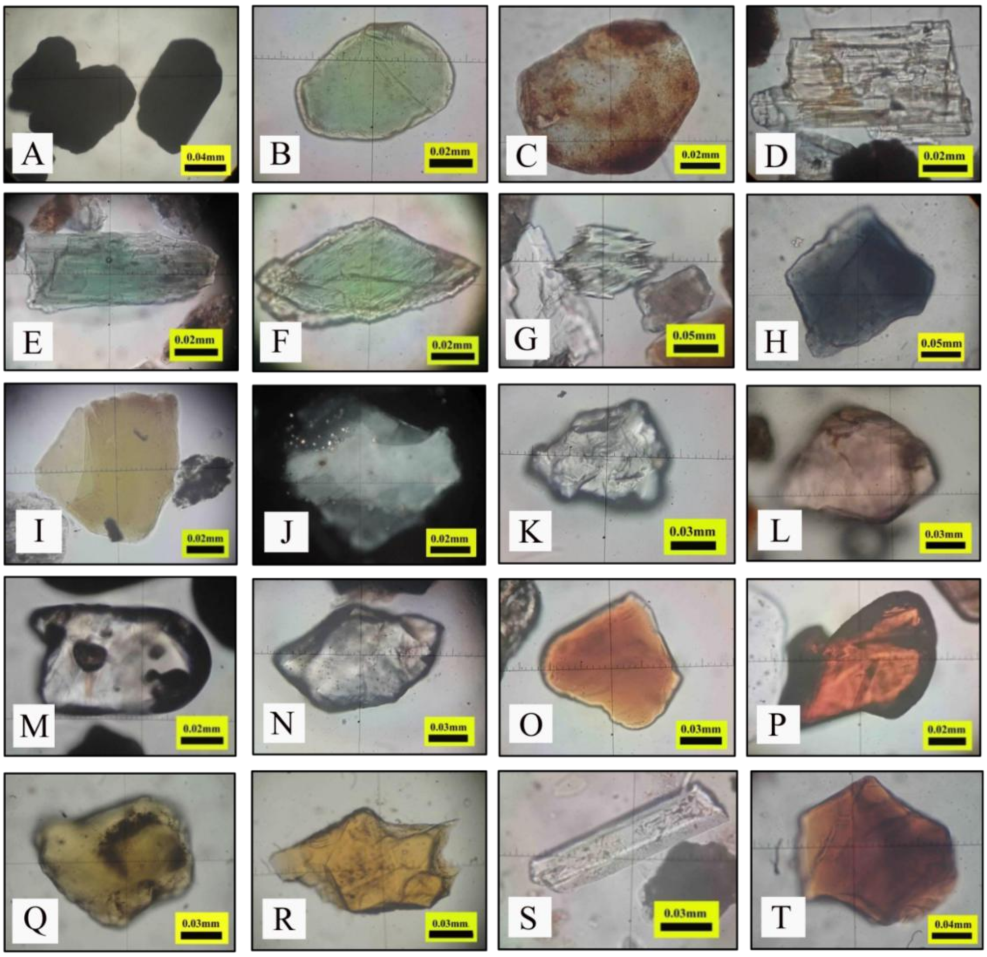

Figure 5. Photomicrograph of heavy minerals were by; A: opaque minerals, B, and C: chlorites, D: orthopyroxene, E: clinopyroxene, F: hornblende, G: tremolite-actinolite, H: glaucophane, I: biotite, J: muscovite, K: Almandite, L: Grossularite, M, and N: zircon, O: tourmaline, P: rutile, Q: epidote, R: staurolite, S: kyanite, and T: chromian spinel.

According to Folk (1974), who divided heavy minerals into four groups according to their stability. These groups are: A- Opaques, B- Mica (Phyllosilicates), C- Ultra-Stable, and D- Meta-Stable.

The heavy minerals identified from the Makdadiya Formation are grouped according to this classification (Table 3).

Table 3. Classification of heavy minerals according to their stability (Folk, 1974).

Opaques	Mica	Ultra-Stable	Meta-Stable
	Biotite	Zircon	Orthopyroxene
	Muscovite	Tourmaline	Clinopyroxene
	Chlorite	Rutile	Hornblende
			Tremolite-Actenilite
			Glaucophane
Opaques			Grossularite
			Almandite
			Epidote
			Staurolite
			Kyanite
			Chromian-Spinel

4.2. Description of Heavy Minerals

The following represents the description of identified heavy minerals from the studied samples:

4.2.1. Opaques Group

Opaque minerals represent the essential components of the heavy minerals in the studied samples; they are not transparent to light and do not exhibit any optical properties through a polarized transmitted microscope. They belong to several mineral groups, the most prominent of which are: native elements, oxides, hydroxides, phosphates, and sulfides (Nesse, 2000). The percentage of opaque minerals in the studied samples ranges from 40.4% – 45.4%, with an average of 43.66% of the total heavy minerals. The shape of these minerals varies from angular to sub-angular, euhedral to unhedral, and moderate to low sphericity (Figure 6).

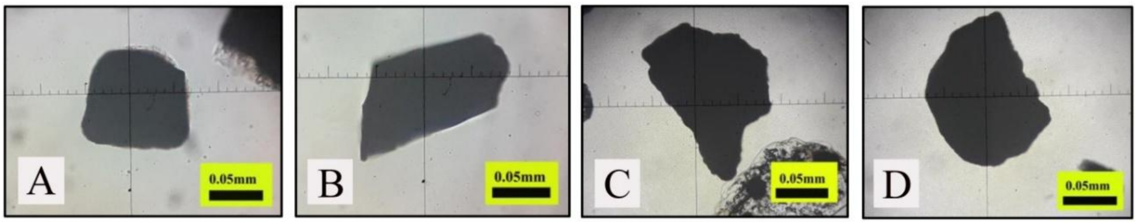

Figure 6. The form and shape of opaque minerals in the studied samples were A: equant and subhedral, B: subhedral with elongated habit, C: angular grain, and D: sub-rounded and unequant form.

4.2.2. Phyllosilicate Group

Biotite is a member of the mica group of minerals, which is a group of sheet-silicate or phyllosilicate minerals (Barker, 2014). The percentage of this mineral ranges between 4.7% – 6.8%, with an average of 5.61%. The color of biotite is brown with strong pleochroism. The mineral habit is flaky, medium relief, some grains are fresh while others are altered, the second mineral in the mica group is muscovite, muscovite is colorless with flaky habit, the percentage of muscovite in the studied samples ranges between 3.2% – 5.9%, with an average of 4.53%. About chlorites, two types of chlorite were identified in the studied samples: green and brown chlorites. The percentage of chlorites ranges between 8.1% – 9.5% with an average of 8.91%.

Chlorites are the second most abundant phyllosilicate minerals after opaque minerals in the studied samples. The habit of these minerals is flaky, and some grains have some degree of alteration. Chlorites refer to low-grade metamorphism within the chlorite schist facies and are sometimes an alteration product of ferromagnesian minerals (Best, 2003).

4.2.3. Ultra-Stable Group

Zircon was observed in all studied samples. It is mainly colorless with very high relief. The form of this mineral is usually prismatic. Zircon mostly occurs with some inclusions; the shape of this mineral is angular to sub-angular and subhedral to unhedral. The percentage of zircon ranges from 2.4 % – 4.2% with an average of 2.17%. Tourmaline has a honey color with strong pleochroism and high relief (Barker, 2014). The shape of this mineral is subrounded to angular and unhedral to subhedral, and the percentage of tourmaline ranges between 2.4% – 3.2% with an average of 2.71%. Rutile shows very high relief with deep red color, and the form is angular to sub-angular, and unhedral to subedral. The percentage of rutile ranges between 1.8% – 2.6% with an average of 2.30%.

4.2.4. Meta-Stable Group

Orthopyroxene is a subgroup of the pyroxene minerals group that crystallizes in the orthorhombic crystal system; therefore, the extinction of these minerals shows parallel extinction (Barker, 2014). The percentage of these minerals in the studied samples ranges between 2.7% – 4.2%, with an average of 3.43%. This mineral is colorless, has a high relief, sub-hedral, and has two sets of cleavage at right angles, the second group of pyroxene in the clinopyroxene subgroup, clinopyroxene represent a pyroxene crystallized in the monoclinic crystal system. This group contains several minerals that differ in the value of the extinction angle (Nesse, 2000). The percentage of these minerals ranges between 2.5% – 3.8%, with an average of 3.08%. These minerals have high relief, a prismatic habit, and two sets of right-angled cleavage.

Hornblende: Hornblende is the main mineral in the amphibole group and was observed in all studied samples of Mukdadiyah Formation. The percentage of this mineral ranges between

3.3% – 5.4%, with an average of 4.31%. The color of the mineral is green with moderate pleochroism, and the mineral has two directions of cleavage with obtuse and acute angles (Barker, 2014; Nesse, 2000). The second mineral of the amphibole group is tremolite-actinolite. Tremolite-actinolite is a mineral of the amphibole group, which crystallized in metamorphic rock under a low grade of metamorphism. The optical properties of these minerals are colorless to very light green, the form of these minerals is prismatic with rhombic shape, and they have two sets of cleavage with acute and obtuse angles (Barker, 2014). The percentage of trmolite-actenolite ranges between 1.8% – 2.8%, with an average of 2.23%. The third mineral of the amphibole group is glaucophane. Glaucophane represents one of the amphibole minerals, representing an index mineral of metamorphism. It crystallizes under special conditions of high pressure and low temperature, so it is considered a mineral that indicates metamorphic conditions (Nesse, 2000). The color of the mineral is distinctive; it is blue to purple with strong pleochroism and high relief (Barker, 2014), the percentage of glaucophane ranging between 1.2% – 2.9%, with an average of 1.81% .

The identified garnet mineral group includes grossularite and almandine. Grossularite is an isotropic mineral that crystallizes in the isometric system, and it is one of the rock-forming minerals of metamorphic rocks (Best, 2003). The main optical properties of this mineral are colorless, a high relief, an angular, equant shape, and optically isotropic (Nesse, 2000). Almandite, crystallized in a cubic system, represents one of the rock-forming minerals of metamorphic rocks (Gill, 2010). The mineral is a light rose color, high relief, angular to sub-angular shape, and isotropic (Barker, 2014**;** Bucher and Graper, 2011).

Epidote mineral was recorded in all studied samples with high relief and light green color. The percentage of epidote ranges between 2.8% – 5.6%, with an average of 4.31%. Epidote is a metamorphic mineral with a low to medium transitional grade of metamorphism (Bucher and Graper, 2011).

Staurolite mineral was identified in all studied samples; the main optical properties of staurolite are a yellowish color with pleochroism, high relief (Nesse, 2000; Barker, 2014). Staurolite represents one of the rock-forming minerals of metamorphic rocks (Best, 2003). The percentage of staurolite ranges between 0.6% – 2.3%, with an average of 1.31%. Staurolite crystallizes in medium-grade metamorphism (Bucher and Graper, 2011). The form of staurolite grains is angular and unequilateral in shape.

Kyanite mineral represents one of the rock-forming minerals of regional metamorphism (Mange and Maurer, 1992). The main optical properties are colorless, high relief, and elongated habit (Barker, 2014). The shape of kyanite grains that were identified in the studied sample is not equivalent to an elongate habit. The percentage of kyanite ranges between 0.6% – 2.5%, with an average of 1.54%.

Chromian-Spinel mineral represents one of the spinel group crystallized in the isometric system (isotropic mineral), the color of the mineral is deep red, and high relief, and with concoidal fractures (Mange and Maurer, 1992), (Bucher and Graps, 2011), the shape of mineral that was identified in the studied samplesis angular, and equant in form with cconcoidal fractures. The percentage of chromian-spinel ranges between 0.3% – 1.6%, with an average of 0.91%.

5. Provenance of Heavy Minerals

Heavy mineral analysis is one of the most sensitive and widely used techniques in the determination of sand and sandstone provenance. The heavy mineral assemblage is not only controlled by the mineralogical composition of the source region but is also modified by several other processes that operate during the sedimentation cycle (Mange and Wight, 2007). The heavy mineral assemblage found in the Mukdadiya Formation samples shows that igneous, metamorphic, and sedimentary rocks are all possible sources The result of heavy mineral analysis is to determine the result source rock of: The presence of opaques minerals suggests that the source rocks may include all types of rocks include: sedimentary (clastic and carbonates), igneous, and metamorphic rocks as a source rock (Tucker, 2001). The presence of zircon, tourmaline, muscovite, and biotite represent the acidic igneous rock as a source rock (Best, 2003; Bucher and Graps, 2011; Gill, 2010). The presence of pyroxene and hornblende refers to the basic igneous rock as a source rock (Best, 2003; Sen, 2014). The presence of chlorites, glaucophane, tremolite-actinolite granets, sturolite, and kyanite represent metamorphic rocks as a source rock (Bucher and Gfraps, 2011; Sen, 2014; Best, 2003). The presence of chromin-spinel refers to mafic and ultramafic igneous rock sources (Al-Juboury et al., 2009) and serpentinite (Hisada et al., 1999). This mineral represents an accessory mineral in these rocks and is a good indicator of mafic and ultra-mafic rocks, especially alpine-type peridotite (Uysal et al., 2014).

6. Tectonic Setting

The linkage between tectonic setting and sediment composition has long been recognized (Nichols et al., 2007; Nichols, 2009; Nechaev and Isphording, 1993), suggesting a plate tectonic interpretation of heavy mineral data by comparing the assemblage configuration with the possible sources of clastic sediments resulting from different stages of the plate tectonic cycle. Nechaev and Isphording (1993) constructed the right-angle triangular diagram (MF, GM, and MT) linking plate tectonic setting and the heavy mineral assemblage, where MF: common constituents of mafic magmatic rocks = total contents of pyroxene, hornblende, and olivine. MT: common constituents of basic metamorphic rocks = total contents of pale-colored and blue-green amphibole, epidote, and garnet, and MG: accessory minerals of granites and sialic metamorphic rocks = total content of zircon, tourmaline, staurolite, kyanite, andalusite, monazite, and sillimanite. Plotting of the studied samples of Mukdadiya Formtion on the classification (Figure 7), The Mukdadiya Formation sediments samples fall within the field of active continental margins which are characterized by a relatively high percentage of minerals derived from regional metamorphic rocks and basic igneous rocks (chlorites, pyroxenece, hornblende, epidote, kyanite, garnet, and mica) as a result of sediment not reworking and deep weathering in regions with active tectonic events. This is evident from the decrease in the proportion of stable minerals (ZTR) or (zircon, tourmaline, and rutile), The sediments of the Mukdadiya Formation in the studied site are derived from the igneous**,** metamorphic and sedimentary rocks of the Zagros Suture Zone exposed in the east and northeast of Iraq as well as the sedimentary rocks of the High and Low Folded Zones north and northeast of the studied area.

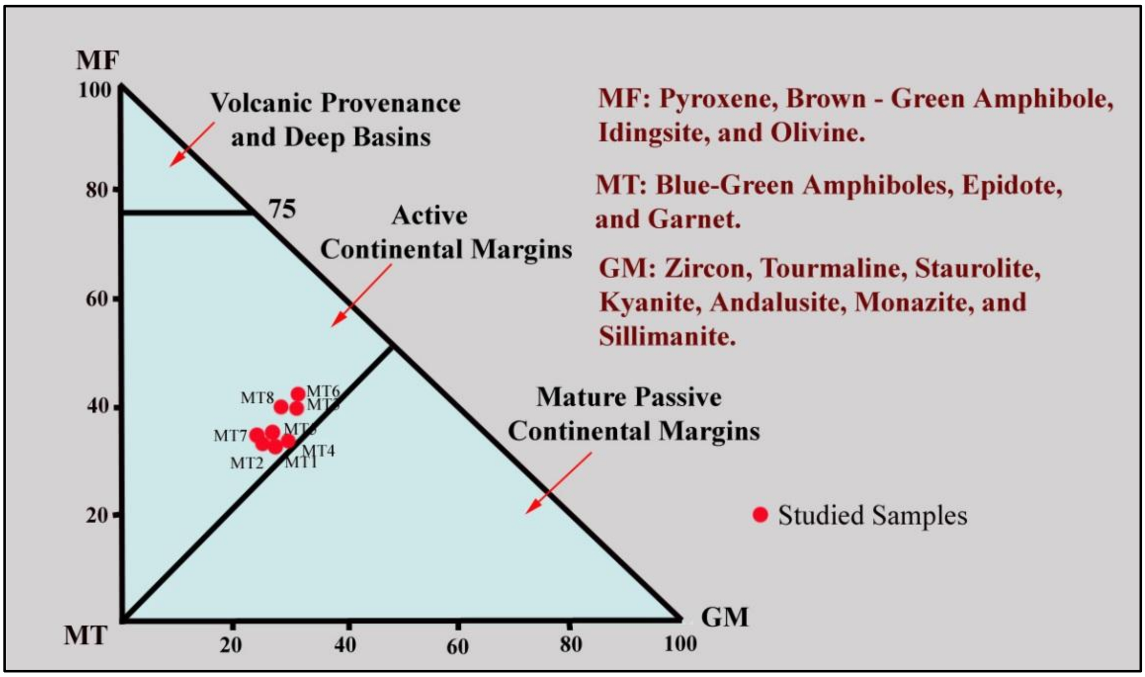

Figure 7. Relationship between heavy mineral distribution of Mukdadiya Formation and tectonic setting (Nechaev and Isphording, 1993).

Markevich et al. (2007) developed a triangular three-component classification that links tectonic setting and heavy mineral content consisting of hornblende, orthopyroxene, and clinopyroxene. The classification was applied to the heavy mineral content of the studied samples of the Mukdadiya Formation (Figure 8), The studied samples fall within the field of active continental margins, with one sample falling within the field of continental arcs related with normal subduction, this result is due to the close proportions of heavy minerals hornblende, orthopyroxene, and clinopyroxene, when there is an increase in one of these minerals, the result of applying the classification will change. This result is related to the source rocks associated with these minerals, which are the basic and ultrabasic igneous rocks that are common in eastern and northeastern Iraq.

A continental arc is generated when an oceanic plate collides with a continental plate, resulting in a subduction zone (Best, 2003), which explains why one of the samples falls within the field of the continental arc in the classification.

Through the application of the classifications of (Markevich et al., 2007), and (Nechaev and Isphording, 1993), there is a match between the application of the two classifications, and this confirms that the sediments of Mukdadiyah Formation were deposited in a tectonically active environment resulting from the collision of the Arabian and Iranian Plates associated with uplifting, rapid erosion and short transportation distance.

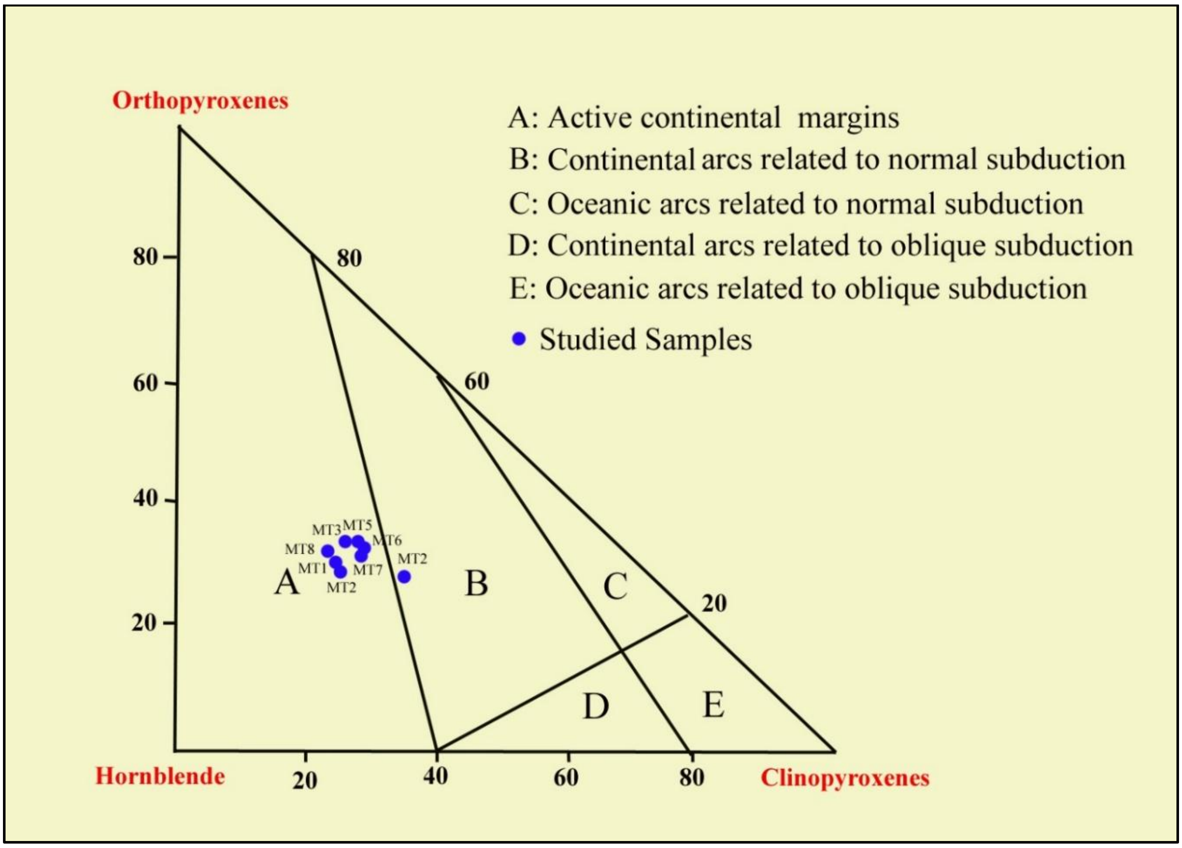

Figure 8. Linkage between heavy mineral distribution of Mukdadiya Formation (Hornblende, orthopyroxene, and clinopyroxene) and tectonic setting (Markevich et al., 2007).

7. Conclusion

The Mukdadiya Formation occupies the southwestern flanks of Bajalia and Band anticlines in Al-Teeb area. The formation consists of fining-upward sedimentary cycles within a fluvial sedimentary environment. The sediment of Mukdadiya Formation is unstable due to the low content of stable minerals (zircon, tourmaline, and rutile), and a high percentage of metastable minerals (opaques, biotite, pyroxenes, hornblende, epidote, staurolite, and chromian-spinel). The opaque minerals represent the main component of heavy minerals in the sediments of Makdadiya Formation, as they show the highest percentage in all studied samples compared to other heavy minerals. This is due to the diversity of source rocks that contain these minerals, including igneous, metamorphic, and sedimentary rocks. The main source rocks Mukdadiya Formation sediment are basic igneous rocks originating from the east and northeastern Iraq due to the high percentage of pyroxenes, hornblende, and other sources. These are metamorphic rocks due to the high percentage of chlorites, and presence of index minerals of metamorphism such as: tremolite-actenolite, epidote, kyanite, garnet, chromian-spinel, and glaucophane. Tectonically, Mukdadiya Formation sediment was deposited under an active tectonic environment. This is due to the low content of stable minerals (ZTR) and the high percentage of unstable minerals, which indicates short transportation distances and active tectonic margins.

Most of the mineral grain shapes were angular to sub-angular, and a low degree of roundness and sphericity, which indicates that the distance of sediment transport was short and that the sediments of Mukdadiya Formation are close to the source rocks.

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About the Author

Name: Dr. Hasan Kattoof Jasim
Occupation Position Held: Geology Department Staff
Scientific Degree: Lecturer
Field of Specialization: Petrology and Mineralogy
Address of Employer: University of Baghdad
College of Science - Department of Geology

e-mail: hasan.jasim@sc.uobaghdad.edu.iq

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