



Heavy Minerals Distribution in the Sandstone Beds of the Tanjero Formation, Khalakan Valley, Dokan Area, Sulaimanyia Governorate, Northern Iraq.

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Received: 09 February 2025 Received in revised form: 30 May 2025 Accepted: 20 September 2025

Available online: 01 July 2026

Abstract

Mineralogical analysis of heavy minerals is done for ten sandstone samples of Tanjero Formation (Upper Cretaceous) at Khalakan Valley-Dokan Area. The data obtained from the analysis of heavy minerals indicate the dominance of opaque minerals and non-opaque minerals, represented by chlorite, pyroxene, amphibole, epidote, mica, garnet, chromium spinel, tourmaline, rutile, kyanite, zircon, and others. Opaque minerals may indicate the presence of multiple source rocks, and thus, opaque minerals are evidence of multiple rock sources, such as sedimentary, igneous, and metamorphic rocks. Significantly, high concentrations of both unstable and metastable heavy mineral assemblages indicate that these minerals originated directly from the primary provenance of igneous and metamorphic rocks located in northern Iraq. Tectonically, the high proportions of mafic minerals derived from mafic magmatic source rocks indicate that the study area was located within an active continental margin. Furthermore, the ZTR (zircon, tourmaline, rutile) maturity index in the investigated sandstone samples constitutes 7.9%, indicating the overall immaturity of the sandstone in the Tanjero Formation.

Keywords:

Tanjero Formation, Kurdistan, heavy minerals, Maturity index, Petrography.

DOI: [10.33899/injes.v26i3.56110](https://doi.org/10.33899/injes.v26i3.56110), ©Authors, 2026, College of Engineering, University of Kerbala.

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1. Introduction

Tanjero Formation is the last formation deposited within the Upper Cretaceous age (Campanian-Maastrichtian). After it, the deposition of the Kolosh Formation begins, which marks the beginning of the Tertiary period (Jassim and Goff, 2006). The Tanjero Formation is essential in the stratigraphic column of Iraq. According to Buday (1980), the rock unit found in northern Iraq's folded and overlapped regions originated during the Upper Cretaceous (Campanian-Maastrichtian) period. In addition to its extension as a range towards the northwest and southeast along the Iranian border, Abdul Kareem, (1986b), also described the possibility of discovering the formation in the Sulaimaniyah-Dokan area within the layers of the Upper Cretaceous and Lower Tertiary periods. Minas (1997) studied the sequence stratigraphy of the

formation and found that the Tanjero Formation is located in a deeper environment than the Shiranish Formation. As can be seen from the rocks at Rania, which range from gray silt and clay rocks to gray silt rocks and cross-layers of conglomerate, the formation's rocks are lithologically diverse (Bolton, 1954b). The Khalakan fold's development is nearly horizontal and roughly three hundred meters thick (Karim and Taha, 2012). Karim (2004) examined the lithology, sedimentary characteristics, and environment of the formation. He discovered that the formation could be divided into three parts based on the original rock distribution: (lower, middle, and upper parts). The lower part of the Tanjero Formation (lower regressive part) is primarily made up of thick sandstone aggradation (100–400 m), whereas on the shelf it is dominated by 500m thick succession of conglomerate, while the bluish-white marly limestone of about (100-300 m thick) forms the middle part is

Mesopotamian front basin south of the Zagros fold belt, which led to the forming of the Tanjero Formation. The research area is considered part of the Mesopotamian foreland basin, which continues to form due to the collision the Arabian plate with the Iranian plate, which led to the consumption of the New Tethys (Ali et al., 2013).

3. Methods of Study

Based on the rock lithological variations related to color and thickness, and interrelationships of the rock layers the sampling was made. Ten sand samples were collected from the sandstone strata in the study region (Fig. 2). To conduct the laboratory study, a heavy liquid with a density of 2.85 g/cm³ is used, and conventional Bromoform method is employed. By confirming the mineral composition of the heavy fragments and using conventional analysis and standard counting technique, the heavy mineral fractions are examined utilizing a polarizing microscope for a thorough petrographic analysis (Shehata et al., 2010; Webster et al., 2003; Carver, 1971). The results then are obtained by examining the prepared ten thin slides of the collected samples. In the lower part of the Tanjero Formation after the Shiranish Formation, a sandstone study is conducted through the separation and analysis of heavy minerals of sandstone layers, through a typical analysis of the sandstone composition by calculating the average of 300 points for each slide of the spacing between the largest particle sizes. (Hubert, 1971; Fleet, 1926; Griffiths, 1967; Müller, 1967). Additionally, the provenance and maturity of the Tanjero sandstones are ascertained, and the proportion and average of heavy minerals are calculated using Excel Software.

4. Results and Discussion

Heavy minerals are commonly used as indicators for provenance determination of the sandstone units (Hubert, 1971; Markevich et al., 2007). Table (1) exhibits an illustration of the mineral components of the source area (Hubert, 1971).

Table 1: Main heavy mineral constituents of the sandstone in the Tanjero Formation from the studied Dokan area.

Heavy Minerals	Samples Number										AV.G
	T 1	T 2	T 3	T 4	T 5	T 6	T 7	T 8	T 9	T 10	
Opauques	41.5	40.0	40.4	41.3	41.2	39.4	40.6	43.2	39.3	40.4	40.68
Chlorite	14.4	13.2	14.5	11.2	15.5	12.8	12.4	12.1	15.9	13.8	15.17
Chromium Spinel	1.6	2.4	2.3	1.7	2.4	2.9	1.8	2.3	2.6	1.5	2.15
Amphiboles	Hbl	6.1	6.3	7.5	7.1	6.5	9.7	7.2	8.5	8.3	7.43
	Actinolite	2.5	3.7	3.2	2.6	3.7	2.2	2.5	2.6	2.3	2.89
Pyroxenes	Opx	5.4	5.8	6.1	7.5	7.2	7.7	6.4	7.2	7.4	6.8
	Cpx	6.3	7.1	5.8	6.3	5.4	5.9	5.3	5.1	5.2	5.8
Mica	Biotite	3.4	3.3	2.6	3.2	2.2	3.5	2.5	2.3	2.1	2.73
	Muscovite	1.2	2.6	3.1	2.4	3.3	2.7	1.6	1.5	2.3	2.34
Epidote	6.4	5.1	5.4	6.3	5.5	5.8	6.1	4.2	4.8	5.7	5.53
Zircon	1.5	1.2	1.2	1.5	0.9	0.4	0.7	0.9	1.3	0.6	1.02
Tourmaline	2.7	1.8	1.3	1.4	2.3	1.6	1.3	1.4	1.1	3.2	1.81
Rutile	1.5	1.4	1.9	2.1	1.5	1.5	2.2	1.3	2.5	1.8	1.77
Garnet	3.6	2.9	3.2	3.2	2.2	3.3	3.1	3.4	2.4	1.4	2.87
Kyanite	1.3	2.8	2.3	1.2	1.3	1.7	1.5	2.3	1.3	1.8	1.75
Others	0.6	0.6	0.3	0.6	0.3	0.6	0.6	0.3	0.6	0.3	0.48

A. Opauques

The percentage of this group is the highest in comparison with the rest of the diagnosed heavy minerals; this is due to the fact that these minerals were crystallized and exist in all types of igneous, sedimentary, and metamorphic rocks (Neese, 2000). But in general, their presence in a high percentage indicates they were derived from

igneous or ultrabasic rocks. Their presence ranges in the samples under study (39.3–43.2%) with an average of (40.7%) (Table 1). The opaque minerals are present in darker-colored grains and have a subrounded form (Plate1-A). The high specificity of opaque minerals is associated with the iron content; the prevalence of opaque heavy minerals indicates that deposition occurred in an oxidizing (oxygen-rich) environment (Odumoso et al., 2013).

B. Transparent Heavy Minerals

Four subgroups of transparent heavy minerals are identified in the Tanjero sediment samples and examined depending on their stability (Folk, 1974); these are: ultra-stable, meta-stable, unstable, and flaky minerals (Plate 1 and Table 1).

Ultra Stable Heavy Minerals

This group of minerals is characterized by strong resistance to weathering and erosion. Three minerals are identified: zircon, tourmaline, and rutile (ZTR). Their existence may indicate their probable origin either from metamorphic and mafic igneous source rocks (Ruiz et al., 2007) or from acidic igneous source rocks (Chaodong et al., 2005). Table (1) shows that the average concentration of ultra-stable minerals is 4.6% of the total amount of heavy minerals.

Zircon is a common accessory mineral found in igneous rocks. Folk (1974) and Pettijohn (1975) reported that granitic rocks contain large amounts of zircon. In addition to being found in metamorphic rocks. It can be used to identify the source rock because its euhedral shape points to acidic igneous rock, and its rounded shape indicates high-grade metamorphism (Speer, 1982). Round grains are also commonly found in reworked sediment (Kerr, 1959; Pettijohn, 1975). Zircon is a prevalent component of most sandstones due to its hardness, endurance, and chemical inertness (Malone et al., 2008; Perrin, 1989). It can survive erosion and deposition events without breaking down (Klein, 2002; Al-Malabeh et al., 2017). The majority of the examined samples contain zircon, which has a relatively low percentage of 0.4–1.5% with an average ratio of 1.02% (Table 1). It is also colorless, has little gray hue, and has very high relief. Round to sub-rounded elongated grains is distinguished in the current study (Plate1–K).

Tourmaline has a variety of colors and intricate chemical compositions. It is obtained from acidic igneous source rocks (Kerr, 1959 in Pettijohn, 1975) and felsic igneous rocks, including granite and metamorphic rocks (Pettijohn et al., 1973; Tucker, 1985). Dravite, as a member of the tourmaline family, is represented by subrounded grains that were typically brown to yellowish brown in color (Elyas, 1988; Ismail, 1996). In this study, tourmaline appears as irregular, sub-rounded grains with a yellowish-brown color (Plate1–L), and its percentage is 1.1–3.2% with an average of 1.81 % (Table 1).

Rutile is one of the most stable and widespread heavy minerals in ancient and modern clastic sediments in the sedimentary cycle. It can be found in both acid-igneous and high-grade metamorphic rocks (Meinhold, 2010). In the current study, its percentage is between 1.3–2.5%, with an average of 1.77% Table 1. It is distinguished by dark red prismatic crystals; its high clarity and crystalline shape are characterized by elongation (Plate 1-M).

Metastable Heavy Minerals

This subgroup consists of kyanite (Plate1-O), garnet (Plate1-N), and epidote (Plate1-J). These minerals are identified in the sand fractions with low average percentages in the examined area: 1.75% for kyanite, 5.53% for epidote, and 2.87% for garnet. According to Table (1), their average proportion of heavy minerals in the study region is 10.16%.

Garnet is a metastable mineral (Morton and Hallsworth, 1994). Its origin is commonly from metamorphic rocks (Kerr, 1959; Folk, 1974). The chemical structure of garnet causes color variation; however, red, brown, yellow, green, white, and black are the most common colors. In this study, the garnet is observed to have an isotropic nature, better than engraving, sub-rounded, and colorless to pale gray (Plate1-N). The percentage is 2.2–3.6% with an average of 2.87 % (Table 1).

Epidote is primarily found in greenschist and epidote-amphibolite facies of the metamorphic rocks, also found in igneous rocks (Asiedu et al., 2000). Moreover, it is semicircular, prismatic, or semicircular crystalline, with color ranges from dark green to colorless in thin sections (Mange and Maurer, 1992). Its content range is 4.2 to 6.4% with an average of 5.73% (Table 1). In the current study, it is present in

rounded grains with yellowish-green color (Plate 1-J).

Kyanite is a metamorphic mineral found in gneiss, granulites, and pelitic schist. The content in the present study ranges between (1.2-2.8) %, with an average of 1.75 % (Table 1). Kyanite appears under the microscope in light semi-transparent colors having flat bladed shapes (Plate 1-O).

Unstable Heavy Minerals

A few actinolite, orthopyroxene, and clinopyroxene are representative of the unstable group of heavy minerals. Under weathering conditions, pyroxene and amphibole grains are susceptible to instability (Tucker, 1985). Mange and Morton (2007) stated that this group crystallizes under a range of conditions and is found in almost all types of igneous and metamorphic rocks. The average content is 22.92% (Table 1).

Pyroxene is found in nearly all types of metamorphic and igneous rocks (Deer et al., 1992; Mange and Morton, 2007). Orthopyroxene and clinopyroxene are the two minerals distinguished in the current study. Orthopyroxenes are common constituents of igneous rocks such as gabbro and pyroxenite, while some clinopyroxenes occur in igneous rocks such as basalt, gabbro, and pyroxenite, and others occur in metamorphic rocks (Hamilton et al., 1976). Orthopyroxene is found in this study in colorless and elongated shape (Plate 1-G), and the percentage is (5.4 -7.7) % with an average of 6.8 % (Table 1). Clinopyroxene, a mineral that crystallizes with a monoclinic system, is identified in the study samples with a green color (Plate 1-F). It has a slight color change, and its shapes are imperfect, and the content is (5.1-7.1) % with an average of 5.8% (Table 1).

Amphibole: There are several common and significant minerals in this group. They are the most significant category of transparent unstable heavy minerals under study; primarily, they are actinolite and hornblende. According to Hibbard (2002), amphibole is one of the major minerals that make up basic and intermediate igneous rocks, in addition to some metamorphic rocks as secondary minerals. Amphiboles are ranked second in abundance among the unstable transparent heavy minerals in the investigated section of the studied Tanjero Formation.

Hornblende is usually found in metamorphic rocks because it alters from pyroxene both during the early magmatic stages of crystallization of igneous rocks and during metamorphism (Pettijohn et al., 1973); and crystallizes in regionally metamorphic rocks under low-grade metamorphic conditions within greenschist interfaces (Raymond, 2010). The average percentage of hornblende and actinolite ranges between 7.43% and 2.89%, respectively, with a range between (6.1-9.7) % and (2.2-3.7) % respectively (Table 1). The green color of hornblende is characteristic (Plate 1-D), while actinolite appears colorless with some light grey flakes (Plate 1-E).

Flaky minerals (Mica Group)

The mica group belongs to phyllosilicate minerals, which are flaky in nature, and three minerals are identified: muscovite, biotite, and chlorite. The results show that 20.24% of the total heavy minerals content is flaky (Table 1).

Muscovite is found in the studied samples as angular to sub-angular, colorless to brown (Plate 1-I) with an average percentage of 2.34% (Table 1).

Biotite occurs in all types of igneous rocks and occurs in granite and granitic pegmatite; it is also widespread in gneisses and in amphibolite facies rocks (Al-Mukhtar, 2015). It is stable across a wide range of metamorphic temperatures and can withstand the highest metamorphism in the majority of rock types. It can be distinguished by its strong birefringence, brown, red-brown, or, in rare cases, green pleochroism, and micaceous habit. Because of its high birefringence, green biotite can be mistaken for chlorite (Ronald and Carol, 2014). The biotite grains in this study had a noticeable cleavage and a brown to light yellow appearance in high relief (Plate 1-H).

Chlorite is of secondary origin as alteration of ferromagnesian silicate minerals. Moreover, metamorphic rocks are the source of chlorite (Hibbard, 2002). In this study, the chlorite percentage is (11.2–15.9) % with a mean of 15.17% (Table 1); it is subrounded, green to pale green in color (Plate 1-C).

Chromium Spinel

Chromium spinel is a common mineral found in ultramafic igneous rocks (Mange and Maurer, 1992). According to Ronald and Carroll (2014), it is often the first mineral to crystallize in basaltic igneous rocks and is often found as

inclusions in olivine. Metamorphic rocks are known to contain chromium spinel, which is obtained from them as indicated in Table 1. In the present study, the chromium spinel grains are often dark in color and have a sub-angular form (Plate 1-B), with an average of 2.15% and a percentage ranging from 1.5 to 2.9% (Table 1).

Others

The mineral examination shows a very small percentage ranging between 0.3-0.6% with an average of about 0.48% for the minerals, whose optical properties could not be determined, and therefore their types are not exactly diagnosed, so for this reason they are listed under the heading ‘Others’.

Distribution of heavy minerals

The opaque mineral group dominated the studied heavy mineral groups, followed by chlorite, pyroxene, amphibole, epidote, and mica (including muscovite and biotite), followed by garnet, chromium spinel, tourmaline, rutile, kyanite, and zircon. Figure (3) shows the total average and distribution of heavy minerals in the Tanjero Formation using a Pie-Diagram, so it shows the average percentages of heavy minerals, which increase in of the opaques minerals content to about 40.68% indicating the presence of basic and ultrabasic igneous, and metamorphic rocks as well in the source area which means the different provenance of the sediments in addition to ancient oxidizing condition.

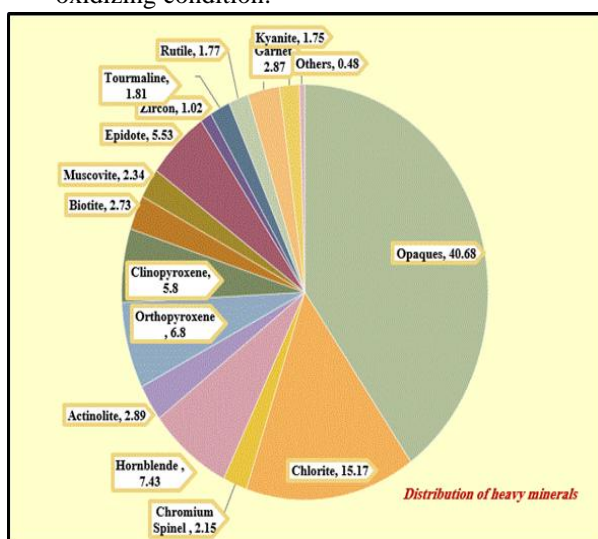


Fig. 3: Pie- Diagram of the total average and distribution of the heavy minerals in the Tanjero Formation.

Heavy Mineral Assemblages and Continental Margin Activity

The relationship between tectonic activity and sedimentation can influence heavy mineral assemblage configurations within the basin and depending on the rate and magnitude of the activity. Nechoev and Isphording (1993) compared the accumulation arrangement with potential sources of clastic sediments arising from different stages of the plate tectonic cycle in order to propose a plate tectonic interpretation of heavy mineral data. To connect the plate tectonic environment with the heavy mineral assemblage, they created the right-angle triangular diagram (MF, MT, and GM). Linking plate tectonic setting and the heavy mineral assemblages as follows:

- 1) MF (Common constituents of mafic magmatic rocks) = Total content of pyroxene and hornblende.
- 2) MT (Common constituents of basic metamorphic rocks) = Total content of pale-colored and blue-green amphiboles, epidote, and garnet.
- 3) GM (Accessory minerals of granites and sialic metamorphic rocks) = Total content of zircon, tourmaline, and kyanite.

The triangular diagram (MF, MT, and GM) is utilized to plot the heavy mineral data listed in Table (2) and Figure (4) of the Tanjero sediments in the study area. It has been known for a long time that the tectonic environment is linked to the formation of sediments and they are considered indicative signs of different tectonic environments (Pettijohn et al., 1987).

Table 2: Indices and proportions of certain heavy minerals used to determine the tectonic setting

Sample No.	MF%	MT%	GM%
T1	42.5	44.4	13.1
T2	44.8	42.2	13.0
T3	44.3	44.0	11.7
T4	47.3	43.6	9.1
T5	46.1	43.3	10.5
T6	46.7	44.7	8.6
T7	47.9	44.7	7.4
T8	46.3	42.4	11.3
T9	48.6	42.8	8.6
T10	47.3	40.0	12.7

The percentages of the obtained data for the heavy mineral group, plotted in the MF-MT-GM triangular diagram, clearly reflect the immaturity of the Tanjero Formation sandstone, as it is located in the active continental margin area with ratios (MF > GM) in the studied samples area (Fig. 4 and Table 2).

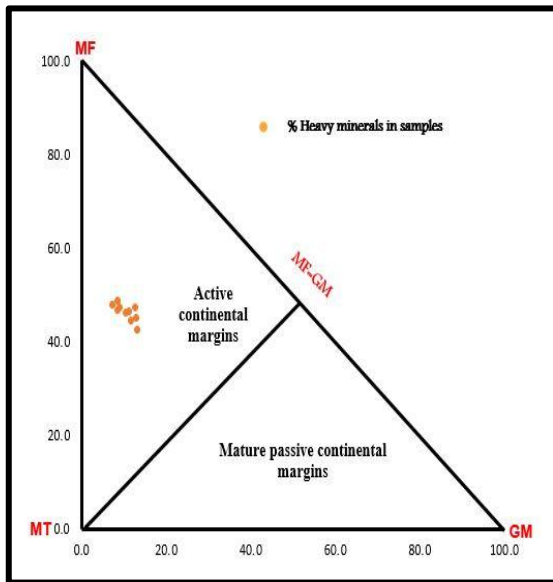


Table 3: Zircon (Z), Tourmaline (T) and Rutile (R) Index (ZTR Maturity Index).

Sample No.	Z	T	R	ZTR	Z%	T%	R%	ZTR INDEX%
T1	1.5	2.7	1.5	5.7	26.3	47.4	26.3	9.8
T2	1.2	1.8	1.4	4.4	27.3	40.9	31.8	7.3
T3	1.2	1.3	1.9	4.4	27.3	29.5	43.2	7.4
T4	1.5	1.4	2.1	5.0	30.0	28.0	42.0	8.6
T5	0.9	2.3	1.5	4.7	19.1	48.9	31.9	7.8
T6	0.4	1.6	1.5	3.5	11.4	45.7	42.9	5.8
T7	0.7	1.3	2.2	4.2	16.7	31.0	52.4	7.1
T8	0.9	1.4	1.3	3.6	25.0	38.9	36.1	6.7
T9	1.3	1.1	2.5	4.9	26.5	22.4	51.0	8.3
T10	0.6	3.2	1.8	5.6	10.7	57.1	32.1	9.8
Min.	0.4	1.1	1.3	2.8	14.3	39.3	46.4	5.8
Max.	1.5	3.2	2.5	7.2	20.8	44.4	34.7	9.8
Av.	1.0	1.8	1.8	4.6	22.0	39.0	39.0	7.9

Mim: Minimum, Max: Maximum, Av.: Average

The ZTR index, which is based on acidic igneous rocks, also shows how intensely weathering processes have occurred in humid conditions. They are highly resistant to weathering processes and can last lengthy transportation distances. Prothero and Schwab (2014) indicated that the ZTR index can be considered a valuable tool for assessing the degree of tolerance to weathering (chemical and mechanical). The low zircon, tourmaline, and rutile proportion (ZTR index), which is a measure of the sediments'

Fig. 4: Interrelationship of the MF-MT-GM suite of the studied Tanjero Formation sandstone samples after (Nechoev and Ispording, 1993).

Calculation of (ZTR Index)

The ZTR or mineral maturity index of the deposit is determined using the three heavy minerals, which are known as a ratio of zircon, tourmaline, and rutile minerals of the ultra-stable detrital heavy minerals group. The ZTR for every chosen sample is determined by applying the subsequent formula:

$$ZTR = \frac{Z+T+R}{Total\ no.\ of\ N.O} \times 100 \quad (Hubert, 1962).$$

where: N.O = non-opaque minerals, Z = Zircon, T = Tourmaline and R = Rutile; (see Table. 3).

maturity and a clue to their source identification, is seen in the heavy mineral assemblages in the research study area's sediments; this is shown by the calculated percentage of the ZTR indicator. According to Oni and Olatunji (2017), the ZTR index can also be utilized as a scale to estimate the level of alteration or maturity of the complete heavy mineral assemblage. Generally, the ZTR index rises with depth and age. When ZTR < 75%, this indicates immature to sub- maturity sediments; while ZTR > 75% indicates that the sediments are

minimally mature and originated in a high-energy environment (Hubert, 1962; Sulieman et al., 2015). Based on the proportions of analyses of ultra-stable group minerals for Tanjero sandstone samples, and according to what was reported by Hubert (1962), it appears that the sediments are mineralogically immature. This is clearly evident in Table 3, as it shows the average ZTR index value is low (7.9%), and the calculated ZTR index for the sand samples ranges from 9.8% to 5.8%, indicating that the Tanjero Formation sediments are immature and possibly re-deposited from older sediments (Aubrecht, 2001). Moreover, He et al. (2017) pointed out that heavy minerals are a critical factor in determining the type of source rock and origin of sediments. The relationship shown in Figure 5 between meta-stable minerals (garnet, epidote, kyanite) and ultra-stable minerals (zircon, tourmaline, rutile) indicates that most of the study area sandstone deposits are immature.

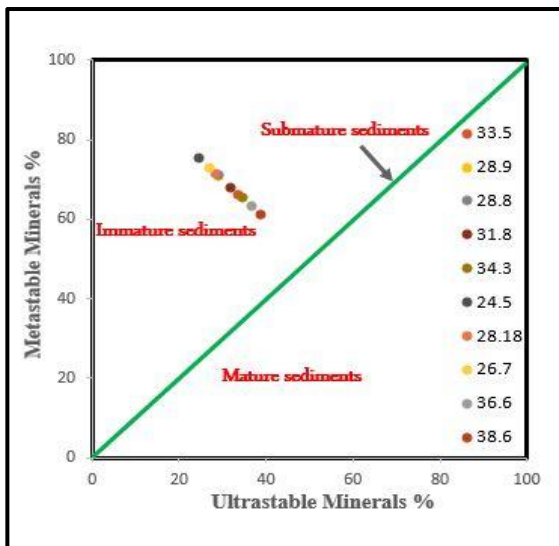


Fig. 5: Relationship between ultra-stable and metastable minerals in the study area after Pettijohn (1975).

Stability of Sediments

There are a great number of varieties of heavy minerals, and due to their properties, they are often used in determining the correct type of transport and provenance of sediment in many depositional environments (Morton and Hallsworth, 1999). As shown in Table (4) and Figure (6), the stability factor represents the stability of the content of heavy minerals in the study area, and it is represented using a formulated ternary diagram for unstable minerals (pyroxene and amphibole), moderately stable minerals (opacifiers), and ultra-

stable minerals (zircon, tourmaline, rutile) (Kasper-Zubillaga et al., 2008).

Table 4: Assemblages of heavy minerals by Kasper-Zubillaga et al. (2008) in Tanjero Formation.

Sample No.	Unstable (Pyroxene and Amphibole) %	Moderately stable (Opacues)%	Ultra stable (ZTR)%
T1	30.1	61.5	8.4
T2	34.8	58.7	6.5
T3	32.3	61.0	6.6
T4	34.0	58.8	7.1
T5	33.8	59.5	6.8
T6	35.6	59.2	5.3
T7	35.6	58.3	6.0
T8	31.4	63.3	5.3
T9	34.6	58.1	7.2
T10	33.5	58.4	8.1

The ternary diagram in Figure (6) illustrates how many sand samples are positioned near the moderately stable poles, indicating moderately stable of sediment owing to the high proportion of opaque minerals with the involvement of amphibole and pyroxene. Also, the ternary plot indicates that the sediments originating from granodiorites and ultramafic sources are likely the source of the unstable heavy minerals (pyroxene-amphibole), which are then transferred into the Tanjero Formation

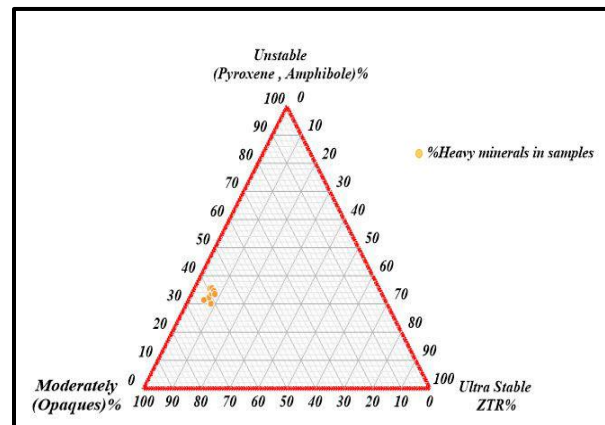


Fig.6: Ternary diagram with unstable (pyroxenes, amphibole), moderately stable(opaque), ultra-stable (zircon, tourmaline, rutile) poles after Kasper Zubillaga et al. (2008).

Mafic sources are most likely connected to the rather stable heavy mineral sites of opaque minerals (Cabrera-Ramírez and Carranza-Edwards, 2002). Certain sands contain ultra-stable heavy minerals, which could be attributed to the depletion of unstable and moderately stable heavy minerals during transportation and preservation of the ultra-stable heavy minerals. Additionally, it's

possible that the proximity of source rocks contributed to the grouping of some ultra-stable heavy mineral samples. For instance, before reaching the deposits, zircon and rutile most likely originated in felsic and schist sources (Kasper-Zubillaga et al., 2008).

5. Conclusion

The sandstone of the Tanjero Formation has been described as containing two main types of heavy minerals: opaque and transparent minerals, indicating multiple rock sources (sedimentary, igneous, and metamorphic). Opaque minerals dominated all other heavy minerals in the sandy portion studied, with an average rate of 40.68%, which indicates basic and ultrabasic igneous and metamorphic rocks, and it also indicates an ancient oxidizing condition. The presence of unstable heavy minerals marks proximity to the source rock, and the appearance of the ultra-stable heavy minerals suggests a mafic igneous source and indicates that they have high resistance to weathering processes. The MF- MT - GM ternary diagram indicates that the tectonic setting is mainly the active continental margin. Also, MF is larger than GM, and this indicates that the heavy minerals of the formation were derived from active tectonic plates as a result of the collision of the Iranian and Arabian plates. The Tanjero Formation appears to have stability in the study area, and this is reflected by the accumulation of heavy minerals, which indicates a transition from the moderately stable case. Additionally, Tanjero sandstone samples are Upper Cretaceous source rocks with equivalent levels of immaturity, so the ZTR averaging 7.9% equally corresponds to immature sediments.

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Plate 1

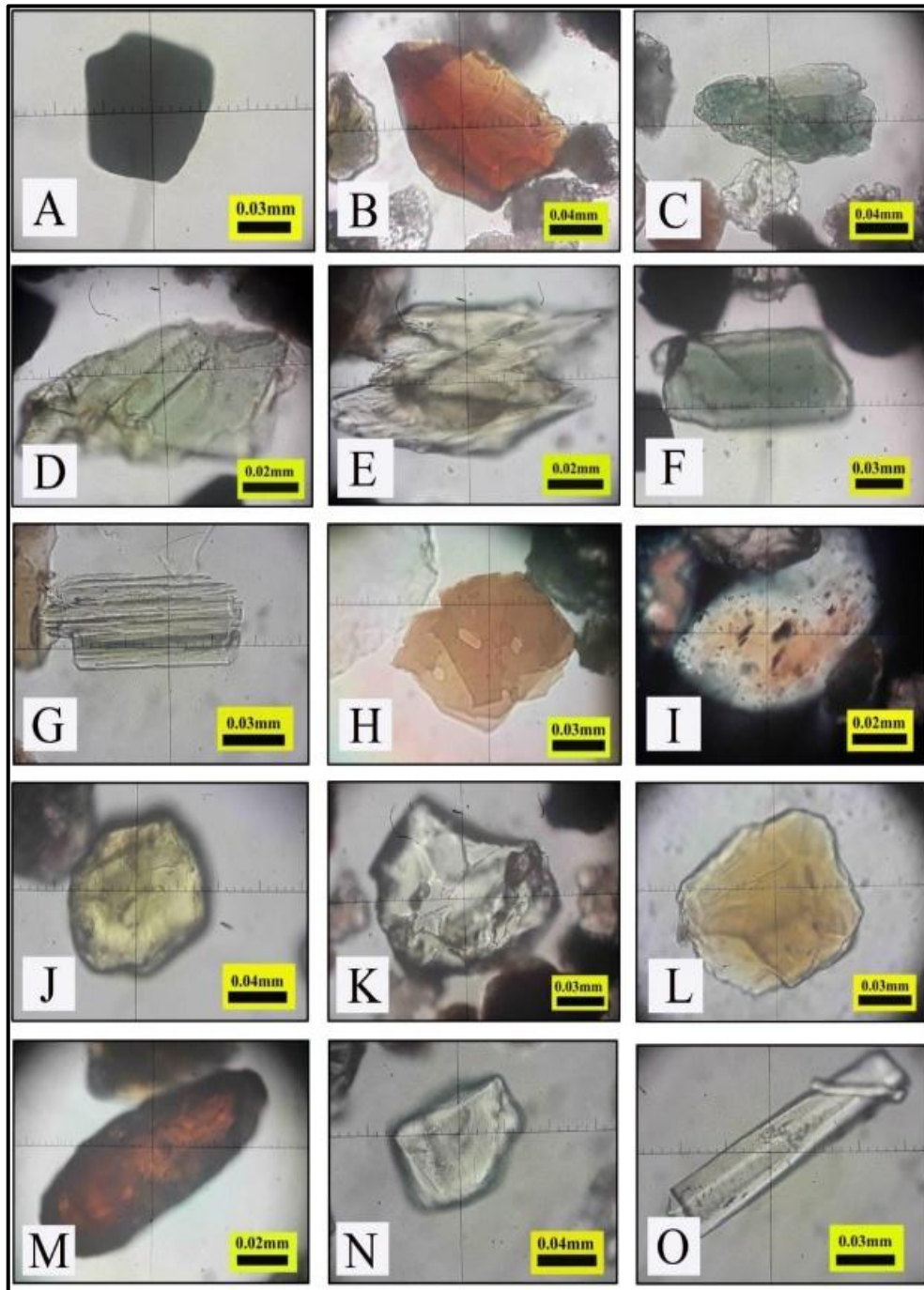
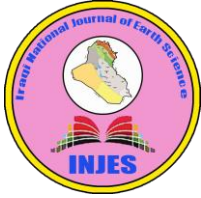


Plate 1: A: Opaques, B: Chromium Spinel, C: Chlorite, D: Hornblende, E: Actinolite, F: Clinopyroxene, G: Orthopyroxene, H: Biotite, I: Muscovite, J: Epidote, K: Zircon, L: Tourmaline, M: Rutile, N: Garnet, O: Kyanite.



توزيع المعادن الثقيلة في وحدات الحجر الرملي لتكوين تانجيرو في وادي خلاكان، منطقة دوكان، محافظة السليمانية، شمالي العراق.

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تاريخ الاستلام: 09 شباط 2025 تاريخ المراجعة: 30 ايار 2025 تاريخ القبول: 20 أيلول 2025

تاريخ النشر الإلكتروني: 01 تموز 2026

الملخص

أجرى تحليل معدني للمعادن الثقيلة على عشرة عينات من الحجر الرملي من العصر الطباشيري العلوي لتكوين تانجيرو في وادي خلاكان - منطقة دوكان. تشير البيانات المستمدة من تحليل المعادن الثقيلة إلى هيمنة المعادن المعتمة وغير المعتمة، ممثلة في الكلوريت، والبيروكسين، والأمفيبول، والإبيدوت، والميكا، والعقيق، وإسبنيل الكروم، والتورمالين، والروتيل، والكيانيت، والزركون، وغيرها. قد تشير المعادن المعتمة إلى وجود صخور مصدرية متعددة، وبهذا تعد المعادن المعتمة كدليل على تعدد مصادر الصخور مثل الصخور الرسوبية والنارية والمتحولة. وتشير التركيزات العالية بشكل كبير من المعادن غير المستقرة والمتوسطة الاستقرار في تجمعات المعادن الثقيلة إلى أن هذه المعادن نشأت مباشرة من الصخور المصدرية النارية والمتحولة الأولية التي تقع في شمال العراق. من الناحية التكتونية، تشير النسب العالية للمعادن المافية المشتقة من الصخور البركانية المافية المصدرية إلى أن منطقة الدراسة تقع ضمن حافة قارية نشطة علاوة على ذلك، يبلغ معدل مؤشر النضوج ZTR في عينات الرواسب الرملية 7.9% مما يشير إلى عدم نضج الحجر الرملي بشكل عام في تكوين تانجيرو.

الكلمات المفتاحية:

تكوين تانجيرو، كردستان، المعادن الثقيلة، دليل النضوج، الصخرية.

DOI: [10.33899/injes.v26i3.56110](https://doi.org/10.33899/injes.v26i3.56110), ©Authors, 2026, College of Engineering, University of Kerbala.

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