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Heavy Minerals Contents in Sandstone Beds from Tanjero Formation (late Campanian - Maastrichtian) in Sulaimaniyah Governorate Northeast of Iraq

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Abstract

Tanjero Formation (late Campanian – Maastrichtian) mainly occurs in the balambo-tanjero zone, it also occurs in the high folded zone. Twelve sandstone samples were collected from two section of Tanjero Formation (Dokan and Qamchuqa) from Sulaimaniyah governorate northeast of Iraq. According to the collected information, opaque heavy minerals are the most common, followed by pyroxene, chlorite, amphibole, epidote, garnet, mica, Staurolite, tourmaline and rutile. According to heavy minerals assemblage, the source rocks are interpreted to be composed essentially of sedimentary followed by acidic and basic igneous and metamorphic rocks and the high contents of unstable and stable minerals confirm their direct derivation from the adjacent primary source. The relationship between an ultra-stable and a meta-stable heavy mineral indicated the immaturity of the Tanjero Formation sandstone and its moderate stability, proving that these minerals cannot be transported over extremely long distances close to the source rocks area. The heavy mineral assemblage demonstrated that the studied area is distinguished by high tectonic activity. In addition, according to the MF- MT-GM ternary diagram, the analyzed sandstone samples lie within the active continental margins field, which is distinguished by a higher percentage of MF minerals than GM minerals generated from mafic magmatic source rocks.

Keywords: Tanjero Formation, heavy minerals, Sandstone, Sulaimaniyah governorate

Introduction

According to [1], [2], and [3], Tanjero Formation (Late Campanian-Maastrichtian) is primarily composed of clastic sediments, such as marl, siltstone, sandstone, shale, and conglomerate. In a basin that was rapidly subsiding, these clastic sediments developed as flysh deposits. At the type section in Sirwan Valley, southeast of Sulaimaniyah, it is divided into two sections: the lower section is made up of 484m thick basinal marl, with some beds of limestone and siltstone, and the upper section is made up of alternating bedding of silty marls, siltstone, conglomerates, and detrital limestone, with a thickness of up to 2010m. But while you move southwest, it becomes finer grained and thinly bedded, however, it becomes thinly bedded and finer grained southwestward. Tanjero Formation is restricted to Balambo-Tanjero Zone and some parts of the Low Folded Zone of the Unstable Shelf. In these areas, the formation widely exposed; sometimes it fills the synclines troughs between the anticlines [4]. [5] Separated the formation in Dokan area into three units. Marl, siltstone, and fine sandstone are alternately layered in the lower unit, with a thickness of about 460 m. The middle layer is represented by 209 m of chalky marl, while the upper unit is made up of 124 m of sandstone, shales, and sandy limestone. According to [6], the lowest part of the formation could be a lowstand system tract, especially a lowstand wedge that was deposited in a deep environment. The transgressive system tract (TST) is represented by the thin strata of marly limestone in the middle section in Dokan area. The Highstand System Tract (HST) is just about 130 m thick. While the upper boundary of the Tanjero Formation is unconformable with Kolosh, the lower boundary is conformable and gradational with Shiranish formation.

Heavy minerals play a crucial role within the composition of sandstones, constituting an essential component. While sands generally comprise a minor proportion (1-2%) of heavy minerals, this assortment is often quite varied [7]. The significance of heavy minerals stems from dual perspectives: their potential economic worth and their capacity to unveil the provenance of sandstones or sands [8]. These minerals are valuable for two primary reasons: first, they could possess commercial viability, and second, they can serve as indicators pinpointing the origin and composition of the source area, thereby facilitating their utilization as markers for source rock identification and source location characterization.

The objective of this research is to analyze the composition and distribution patterns of heavy mineral assemblages. Furthermore, the study aims to establish connections between these assemblages and their respective sources, including the identification of the originating source rocks for these minerals.

Geological setting

The study location lies in high folded zone of the unstable shelf. This zone is strongly affected by Cretaceous and Tertiary deformation. Mesozoic-era limestones are found in the anticlines' cores, whereas Tertiary-era limestones and clastic are found in their flanks. According to [1], the anticlines of this zone tend to extend in a trend of NW-SE in northeast Iraq and EW in north of Iraq. Major marine transgression occurred during Late Campanian-Maastrichtian, this transgression was due to the closure of the Neo-Tethys. The obduction of ophiolite and closure of Neo-Tethys led to formation NW-SE extensional basins. Ophiolite sheets that had been raised above sea level were eroded and left behind as flysh deposits, which are represented by Tanjero Formation, in a foredeep basin that was subsiding at the time. Tanjero Formation hence covers a large portion of the Balambo-Tanjero, high folded, and some low folded zone. Hadiena, Aqra, and Bekhma Formations, which were deposited to the southwest in shallow environments, pass laterally into the carbonate and basinal marl of shiranish deposited.

Materials and Methods

Twelve rock samples (6 from Dokan and 6from Qamchuqa) of Tanjero Formation were collected from Dokan and Qamchuqa areas with latitudes (35°57’53.00, 35°53'29.39") N and longitude (44°54'7.00, "45° 0'45.51"E), Figure 1 to establish the heavy mineral suites composition in order to use that information as a source rock marker. Heavy minerals were recognized by using transmitted light polarized microscope in the samples of Tanjero Formations and estimated by using point counter mechanical stage. According to [9], [10], and [11], (50) Grams of the sandstone samples were disintegrated by mortar and pistol into pea size chips and then (10 % HCI) acid was added to each sample in order to remove the carbonate cement, after that each sample was washed by water through a (230 mesh sieve) or (63 microns) in order to remove all the silts and clays (2.5, 3, 3.5, and 4Ø) size grades which were obtained by dry sieving were mixed together. Five grams of these sizes were used for heavy minerals separation, using heavy liquid (bromoform) with a

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specific gravity of (2.89). Heavy minerals fraction was then washed on filter paper with acetone, dried out and part of them mounted on glass slides with Canada balsam for petrographic study. The Preparation and separation heavy minerals were achieved at department of Geology- College of Science- University of Baghdad.

Result

Heavy minerals of Tanjero formation are grouped based on their relative stability into four groups according to the classification of [12],

Table 1: Approximate relative stability of the heavy minerals of the Tanjero sandstone [11].

Heavy minerals groups			
Ultra-stable	**stable**	**Semi-stable**	**Un-stable**
Rutile Zircon Tourmaline	Chlorite Muscovite	Staurolite Kyanite Epidote Clinozoisite Glaucophane	Biotite Garnet Amphibole Pyroxene Opaque

Un-stable heavy mineral

A. Opaque minerals:

Opaque minerals have high specific gravity and strongly attracted to magnets [13], because they are primarily iron oxides, Minerals in this category are thought to be moderately stable [12]. The opaque minerals typically exhibit a subangular to angular shape, with certain grains appearing subrounded to rounded .The percentage of opaque minerals in the sandstone of Tanjero Formation ranging between 38- 42.2% with an average (40.68%) in Dokan section, and 37.1 – 39.4 % (average 38.2%) in Qamchuqa section (Plate 1 A and B).

1. Pyroxene group:

The pyroxene group stands out as the predominant collection of ferromagnesian minerals that play a pivotal role in the composition of various rock types. Scholarly references [14] and [15] propose that pyroxenes are ubiquitous across nearly all categories of igneous and metamorphic rocks, having formed under a diverse spectrum of conditions. They are prominent constituents in the parent materials of basic and ultrabasic igneous rocks [16], [17], and [18]. This group encompasses a wide range of variations and compositions.

- **Orthopyroxene**

It is One of the sources of magnesium in sediments is pyroxene and It is found in igneous rocks that are both basic and ultrabasic [16] and [17].It has a limited resistance to weathering [19]. Orthopyroxene crystallizes in a specific based system and is usually of light colorless. It has prismatic habit (Plate 1E). Its percentage in Dokan sandstone ranges between (6.4-8.1%) with an average of (7.18 %), while in Qamchuqa section, the range is (5.4-7.8%) with an average (7.08%).

- **Clinopyroxene**

Clinopyroxene crystallizes in a monoclinic system and usually of light green color. It is observed as prismatic shape and green color (Plate 1F). Its percentage in Dokan section ranged between (5.1-5.8%) with an average of (5.3%), while in Qamchuqa section the range is between (5.1-6.4%) with an average of (5.7%).

2. **Amphibole group:**

As per reference [20], amphiboles make up a highly intricate collection of minerals that emerge within a diverse range of igneous and metamorphic rocks. In reference [21], it is demonstrated that amphibole suggests a primarily igneous origin for the source rock. These minerals primarily encompass hornblende, accompanied by lesser amounts of tremolite-actinolite and the infrequent presence of glaucophane.

3. **Hornblende**

Hornblende is the common mineral of this group in the sections of Qamchuqa and Dokan sandstone. It has green color, prismatic subhedral, and an elongation (Plates 2A). Its percentage of in Qamchuqa sandstone ranged between (6.3-7.7%) with an average of (7.1%), while in Dokan section, the range is (7.1-9.9%) with an average of (8.16%). It is used to define acidic igneous rocks as well as metamorphic rocks like schist and gneiss [20], [22], and [23].

4. **Actinolite**

It is found in all samples of Qamchuqa and Dokan sandstone and was found as colorless to pale green colored grains, it occurs in long prismatic crystal and columnar to fibrous aggregate shape (Plates 2C). Its percentage in Dokan ranged between (2.1- 3%) with an average of (2.5%), while in Qamchuqa section the range is (2.4- 3.5 %) with an average of (2.91 %). Metamorphic rocks like schist and gneiss exhibit this particular trait [24]. Diagnostic features of Actinolite extinction angle and form.

5. **Garnet**

It is observed in all the studied samples of Tanjero sandstone. It occurs in equant shape with high relief colorless, the grain is mostly fresh and the percentage of garnet in Dokan sandstone ranges between (3.2- 4.3%) with an average(3.66%) while the range (3.2- 5.3%) with an average (4.25) in Qamchuqa sandstone (Plate 3 D).

6. **Biotite**

It is recorded in all the examined samples of Tanjero sandstone. It occurs as flaky form and angular to irregular shape, reddish and brown pleochroic colors. The percentage of Biotite in Dokan section ranging between (1.2-2.3%) with an average (2.01%) while the range (2.2-3.7%) with an average (2.91%) in Qamchuqa section, (Plate 2D).

B. Semi-stable heavy minerals

- **Staurolite**

Staurolite is found in all samples of Tanjero sandstone, Staurolite grains show rounded shape with yellowish color. The percentage of Staurolite in Dokan section (1.3-2.9%) with an average (2.25%), while it range (1.3-2.9%) with an average (2.11%) in Qamchuqa section (Plate 3) . It is commonly encountered within metamorphic rocks due to the effects of regional metamorphism occurring in intermediate to high-grade conditions [25].

- **Kyanite**

It is recorded in all examined samples of Tanjero sandstone. kyanite grains are colorless, high relief, subhedral with elongated habit, prismatic form. The percentage of kyanite in Dokan sandstone ranges between (1.1 – 2.5) % with an average (1.53%), and 1.1-1.8% with an average (1.51 %) in Qamchuqa section plate (3F).

- **Epidotes**

Epidotes are found in all samples of Tanjero sandstone. It is usually present as subangular to subrounded shape, high relief, and green to olive green color. It is percentage in Dokan sandstone is ranging between (4.3-6.2%) with an average (5.35%), while it range between (5.1-6.5%) in Qamchuqa section, (Plate 2 F)

- **Glaucophane**

Basic some samples of Qamchuqa and Dokan sandstone sections contain glaucophane. It has blue green to violet color, occurs in prismatic crystals or columnar aggregates. (Plates 2B). Its percentage in Qamchuqa section ranged between (0.9-1.9%) with an average of (1.48%), while in Dokan section, the range is (0.6-1.8%) with an average of (1.2%).

C- stable heavy minerals

- **Chlorite**

According to [26] Chlorite primarily originates as a secondary mineral formed through the alteration of ferromagnesian silicate minerals. Additionally, chlorite is a byproduct of metamorphic processes. The percentage of chlorite in Tanjero sandstone ranging between10.1-14.9 % with an average (12.5) in Dokan section, and11.6-14.7% with an average (13.05%) in Qamchuqa section. Its show green to altered brown color with flaky form, (Plate 1 C and D).

- **Muscovite**

It is found in metamorphic rocks, particularly schist and gneisses, as well as plutonic rocks [27]. It is occurs as flaky form, irregular to subangular shape, transparent colorless with low relief. The percentage of muscovite in Dokan sandstone ranging between (1-2.3%) with an average(1.5%) while it range (2.2-3.7%)with an average (2.6)in Qamchuqa sandstone, (Plate 3 E).

D- Ultra-stable heavy minerals

- **Zircon**

The presence of zircon grains is recorded in all of the examined samples of Dokan and Qamchuqa sandstone. Zircon occurs as clear colorless, very high relief, some grains show inclusions. The percentage of zircon in Dokan sandstone ranging between (0-1.2%) with an average (0.3%) while it ranging between (0.3-1.6%) with an average (1.05%) in Qamchuqa sandstone, (plate 3A). Zircon is extensively found in granites and syenites [12], [17]. Its presence serves as a reliable indicator of the source rock; therefore, its well-formed euhedral crystals indicate an origin in acidic igneous rocks, while rounded crystals suggest association with high-grade metamorphic rocks [27].

- **Tourmaline**

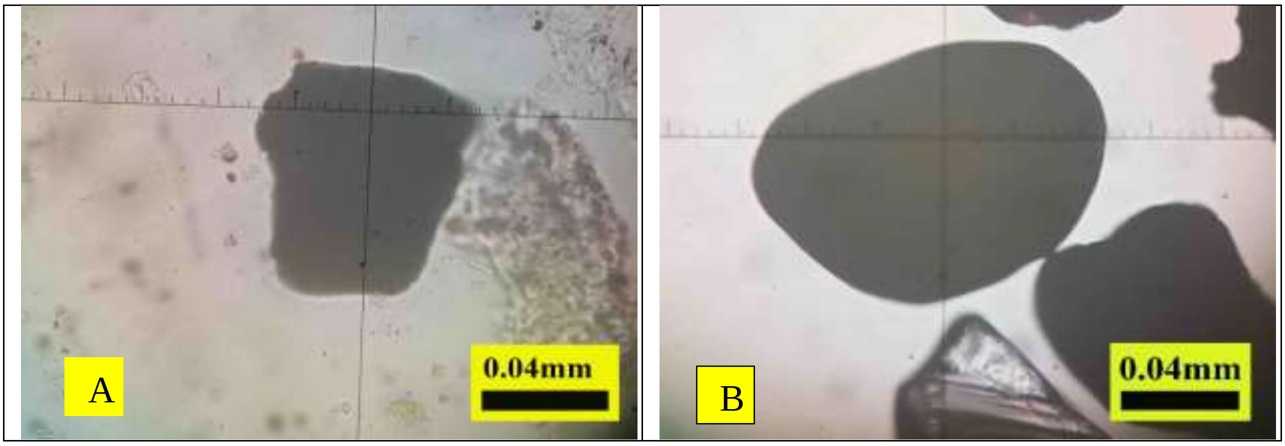
Tourmaline originates primarily from felsic igneous rocks, notably granite, as well as from metamorphic rocks [20, 28] . However, the presence of tourmaline and zircon in trace amounts may suggest a limited influence of acidic rocks in the source area, as indicated in reference [29]. Tourmaline grains have honey color with pleochroic, high relief, Subrounded to round form with inclusion these grains are mostly fresh. Subhedral grains are also observed in some samples. The percentage of tourmaline in Dokan sandstone ranges between (0.8-3.2%) with an average (1.58%) while it range between (1.2-2.6%) with an average (1.75%) in Qamchuqa sandstone, (plate 3B).

- **Rutile**

Rutile is commonly found as an accessory mineral in metamorphic and felsic igneous rocks [18], [24]. It is found in all samples of Tanjero sandstone, rutile occurs as elongated subhedral and irregular grains, deep red color, and very high relief. The percentage of rutile in Dokan sandstone ranges between (1.7-2.9%) with an average (2.1%), while it range between (1.5-1.9%) with an average (1.78%) in Qamchuqa sandstone, (Plate 3C).

- **Others**

This group includes the minerals that recorded in rare percentages and difficult or cannot be identified by the microscope because of their large size and thickness in addition to the grains that show high alteration. There percentage in Dokan sandstone ranges between (0.3-0.9%) with an average (0.63%) and (0.2-0.9%) with an average (0.58 %) in Qamchuqa section.



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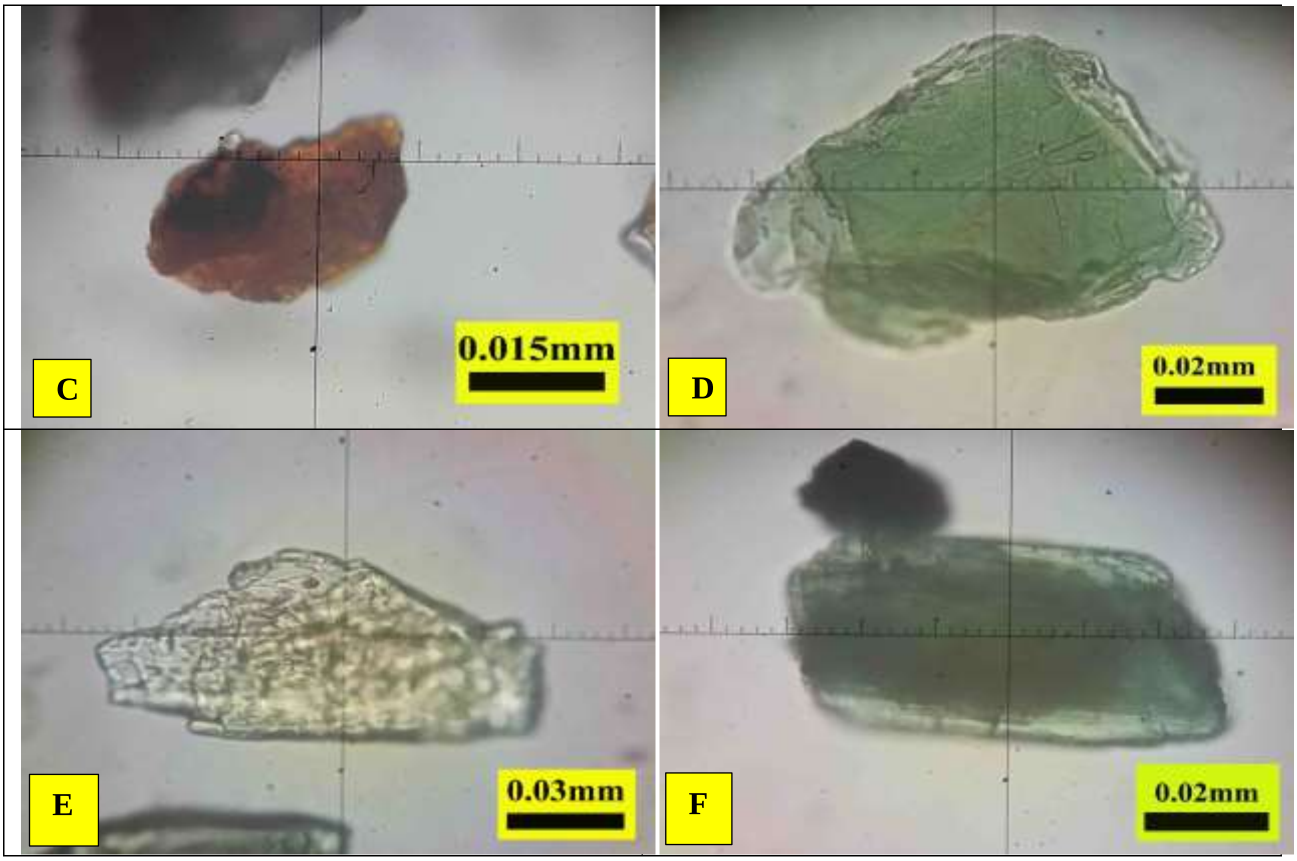

Plate 1A: Opaque grain, Iron oxide, subhedral, sample number Q9, ppl.

Plate 1B: Rounded Opaque's, (iron oxides), sample number D13, ppl.

Plate 1C: Altered brown color chlorite, sample number Q19, ppl.

Plate 1D: Flaky form, green color chlorite sample number D13, ppl.

Plate 1E: Prismatic habit, Colorless orthopyroxene Enstatite, sample number

Plate 1F: Prismatic habit, green color clinopyroxene, sample number D9, PPL

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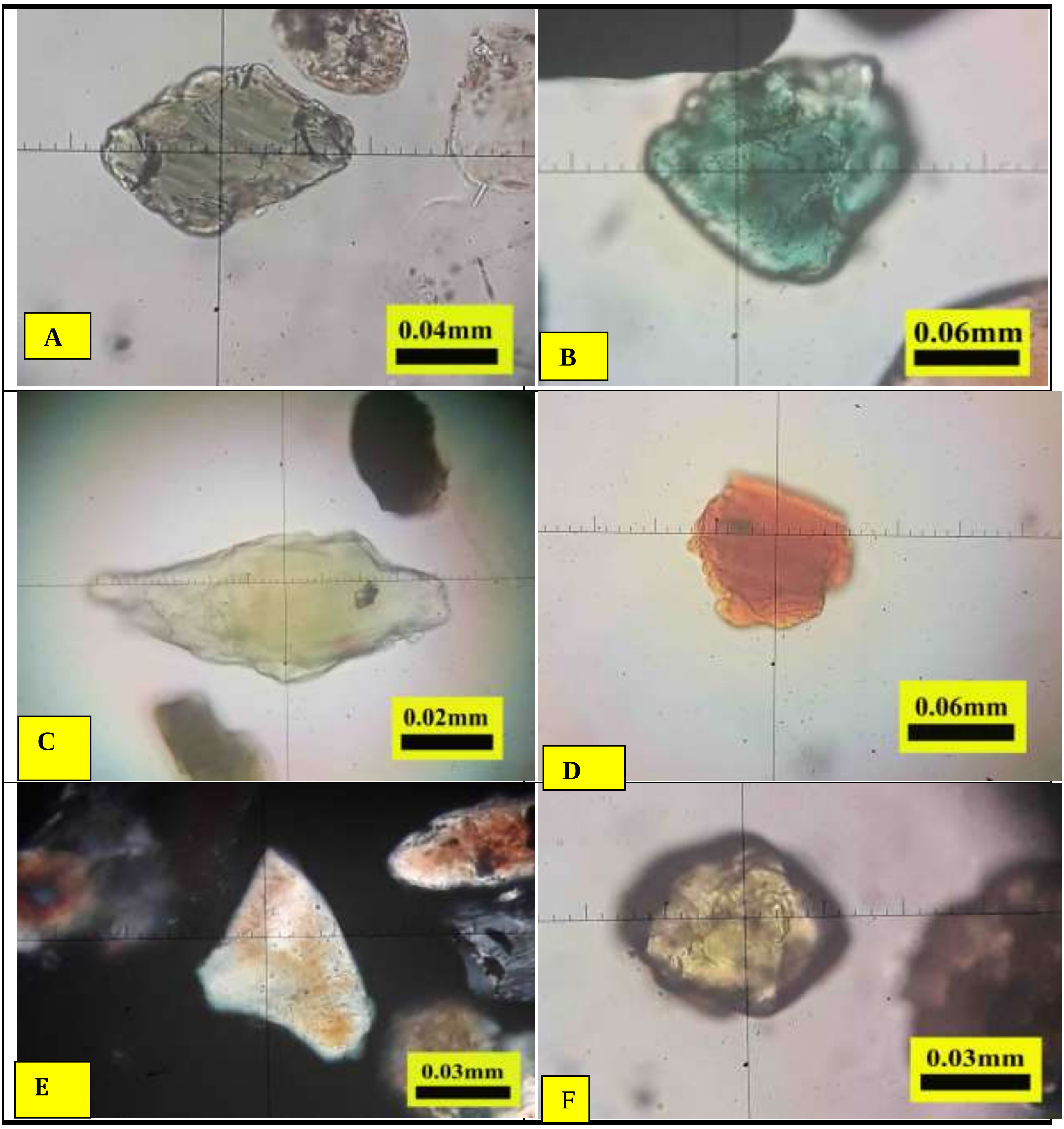

Plate 2 A Green Hornblende m sample number Q2, PPL
Plate 2 B blue_green_color_glaucophane_amphibole, sample_number_Q5, PPL
Plate 2C Prismatic habit, light green color actinolite amphibole sample.
Plate 2D Flaky form, brown color biotite mica, sample number Q5, PPL
Plate 2E Flaky form, colorless muscovite mica, sample numberD23, PPL
Plate 4FHigh_relief, light_brown_color_epidote, sample_number_D16, PPL

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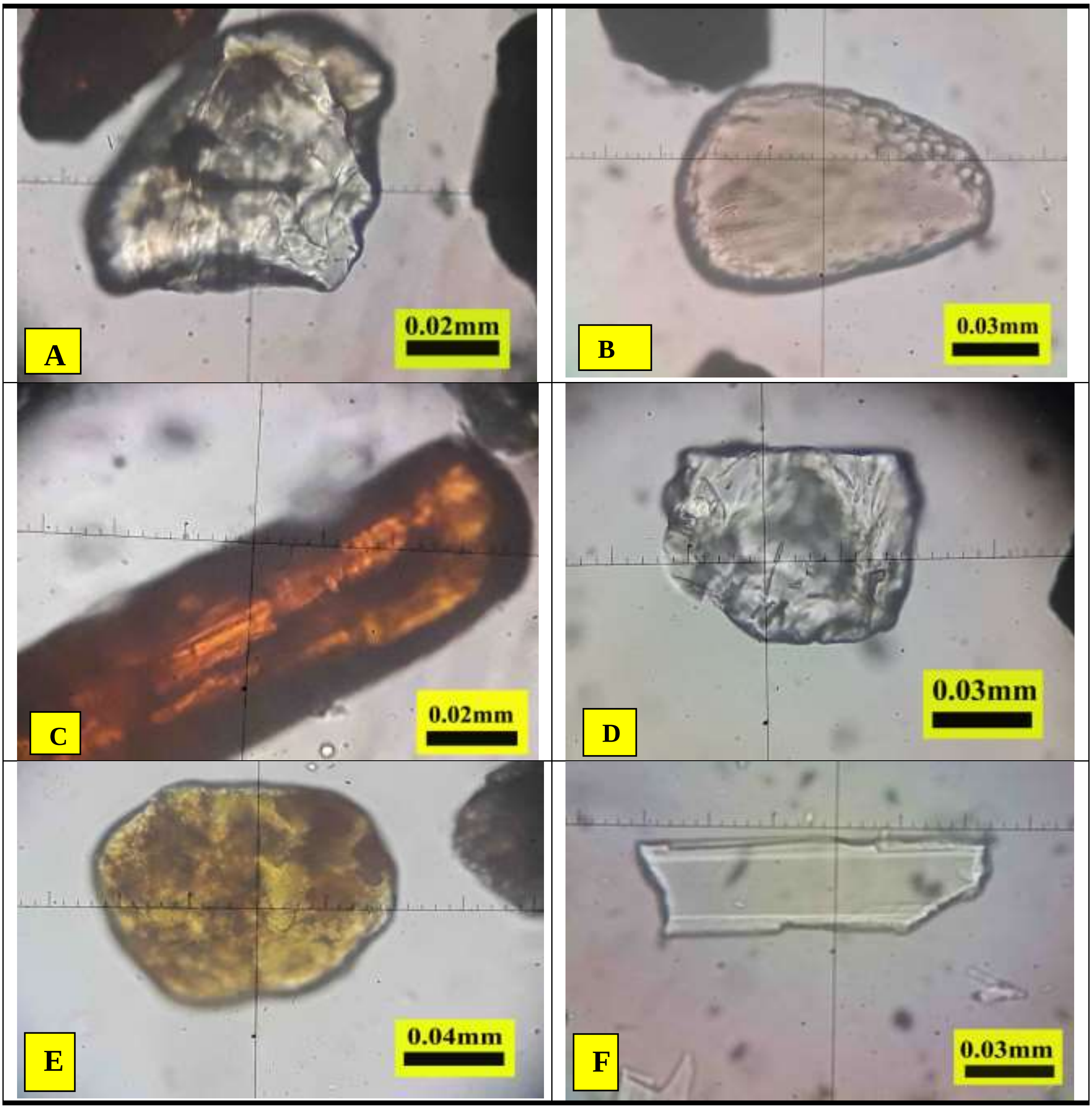

Plate 3A: High relief, colorless zircon, sample number D23, PPL
Plate 3 B: High_relief, rounded,_honey_color_tourmaline_,_sample_number_D4
Plate 3C: High relief, deep Ref color rutile, sample number D4, PPL
Plate 3D: High_relief, colorless_equant_habit_garnet_,_sample_number_D13,
Plate 3E: Rounded yellowish color staurolite, sample number D13, PP
Plate 3F: Elongated habit, colorless kyanite, sample number Q2, PPL

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Table 2: Range Percentages of Heavy Minerals of Tanjero formation (Dokan section)

Dokan Section									
Heavy Minerals		**Samples Number**						**Range**	**Average**
		D4	**D6**	**D9**	**D13**	**D16**	**D23**		
Opaques		**40.3**	38	42.1	40.2	42.2	41.3	38-42.2	40.6833
Chlorite		**12.3**	13.4	12	12.3	14.9	10.1	10.1-14.9	12.5
Pyroxenes	Orthopyroxene	**7.1**	7.7	6.4	7.1	6.7	8.1	6.4-8.1	7.18333
	Clinopyroxene	**5.1**	5.2	5.3	5.5	5.8	5.4	5.1-5.8	5.38333
Amphiboles	Hornblende	**8.1**	8.2	7.1	9.9	7.5	8.2	7.1-9.9	8.16667
	Actinolite	**2.4**	2.1	2.5	2.4	2.7	3	2.1-3	2.51667
	Glaucophane	**0.6**	1.8	1.2	1.5	0.9	1.2	0.6-1,8	1.2
Mica	Biotite	**2.1**	2.2	2.1	2.3	1.2	2.2	1.2-2.3	2.01667
	Muscovite	**2.1**	1.6	1.1	2.3	1.2	1	1-2,3	1.55
Epidote		**5.7**	4.7	4.7	6.5	4.3	6.2	4.3-6.2	5.35
Zircon		**0.4**	1.2	0	0.2	0	0	0-1.2	0.3
Tourmaline		**3.2**	1.2	1.8	0.8	1	1.5	0.8-3.2	1.58333
Rutile		**1.8**	2.9	1.7	2.2	2.1	1.9	1.7-2.9	2.1
Garnet		**3.4**	4.3	3.2	3.6	4.2	3.3	3.2-4.3	3.66667
Staurolite		**1.3**	2.9	2.4	1.6	2.8	2.5	1.3-2.9	2.25
Kyanite		**1.5**	1.3	2.5	1.3	1.5	1.1	1.1-2.5	1.53333
Others		**0.6**	0.3	0.8	0.3	0.9	0.9	0.3-0.9	0.63333

Table 3: Range Percentages of Heavy Minerals of Tanjero formation (Qamchuqa section).

Qamchuqa Section									
Heavy Minerals		**Samples Number**						**Range**	**Avarge**
		Q2	**Q5**	**Q9**	**Q16**	**Q18**	**Q19**		
Opaques		39.4	37.1	37.3	39.3	37.7	38.4	37.1-39.4	38.2
Chlorite		14.1	13.2	14.7	11.6	12.4	12.3	11.6-14.1	13.05
Pyroxenes	Orthopyroxene	5.4	7.8	6.1	7.7	7.7	7.8	5.4-7.8	7.083333
	Clinopyroxene	6.2	5.1	5.5	6.4	5.3	5.7	5.1-6.4	5.7
Amphiboles	Hornblende	7.5	7.1	6.4	7.7	7.6	6.3	6.3-7.7	7.1
	Actinolite	2.5	2.7	3.2	2.4	3.2	3.5	2.4-3.5	2.916667
	Glaucophane	1.6	1.9	0.9	1.8	1.2	1.5	0.9-1.9	1.483333
Mica	Biotite	2.2	3.3	2.9	3.1	2.3	3.7	2.2-3.7	2.916667
	Muscovite	2.2	2.2	3.1	2.2	3.3	2.9	2.2-3.1	2.65
Epidote		6.3	5.5	5.1	6.5	5.5	5.9	5.1-6.5	5.8
Zircon		1.6	1.2	1.5	1.1	0.6	0.3	0.3-1.6	1.05
Tourmaline		2.4	1.5	1.4	1.4	2.6	1.2	1.2-2.6	1.75
Rutile		1.8	1.7	1.5	2.1	1.7	1.9	1.5-1.9	1.783333
Garnet		3.8	4.6	5.2	3.2	5.3	3.4	3.2-5.3	4.25
Staurolite		1.3	2.4	2.2	1.7	2.2	2.9	1.3-2.9	2.116667
Kyanite		1.4	1.8	2.3	1.2	1.1	1.3	1.1-1.8	1.516667
Others		0.3	0.9	0.6	0.6	0.2	0.9	0.2-0.9	0.583333

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Discussion

The predominant composition of heavy minerals in sandstone sediments from the Tanjero Formation consists of opaque mineral, followed by pyroxene, chlorite, amphibole, epidote, garnet, mica, grant, Staurolite, and tourmaline and rutile. To determine the relative stability of heavy minerals, an alternative classification of [32] suggested a ternary classification considering unstable, moderately stable, and ultrastable groups. The unstable are pyroxene and hornblend, the moderately stable are opaque, and the ultrastable are zircon, rutile, and tourmaline (Fig. 1). According to this classification, sandstone samples from the Dokan and Qamchuqa trends are moderated stable. Due to the significant abundance of opaque minerals, along with the presence of amphibole and epidote, it can be inferred that these minerals likely did not undergo extensive transportation over long distances. Instead, they appear to have been deposited in proximity to the source area, indicating a lack of polycyclic grain representation [33].

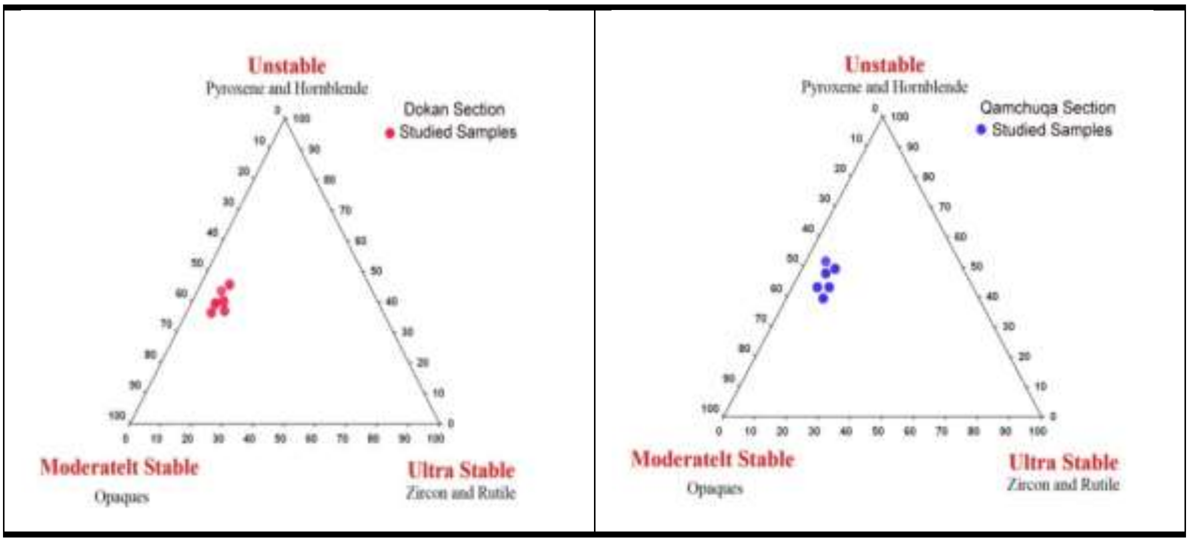

Figure 1: Ternary diagram of heavy mineral stability of Dokan and Qamchuqa sandstone [30].

The relationship between sediment composition and tectonics has long been known [20]. Through a comparison of the assemblage with potential sources of clastic sediment originating from various phases of the plate tectonic cycle. [33] proposed a plate tectonic interpretation of heavy mineral data and produced a triangular diagram (MF, GM, and MT) that connects plate tectonic setting and heavy mineral assemblage where:

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MF: Common composition of mafic igneous rocks.

MT: Common constituents of basic metamorphic rocks.

GM: Associated minerals of granite and sialic metamorphic rocks.

The basic metamorphic, mafic magmatic, and granites, as well as the sialic metamorphic rocks (MF, GM, and MT) have been recalculated to 100%. Plotting the studied Tanjero Formation samples on the ternary diagram in both sections (Dokan and Qamchuqa) reveals that all of the samples fall within the field of active continental margins Fig. (2), which are characterized by a relatively high percentage of minerals derived from basic rocks. Both sandstones come from active continental margins. Taurus and Zagros Mountains may represent these source rocks.

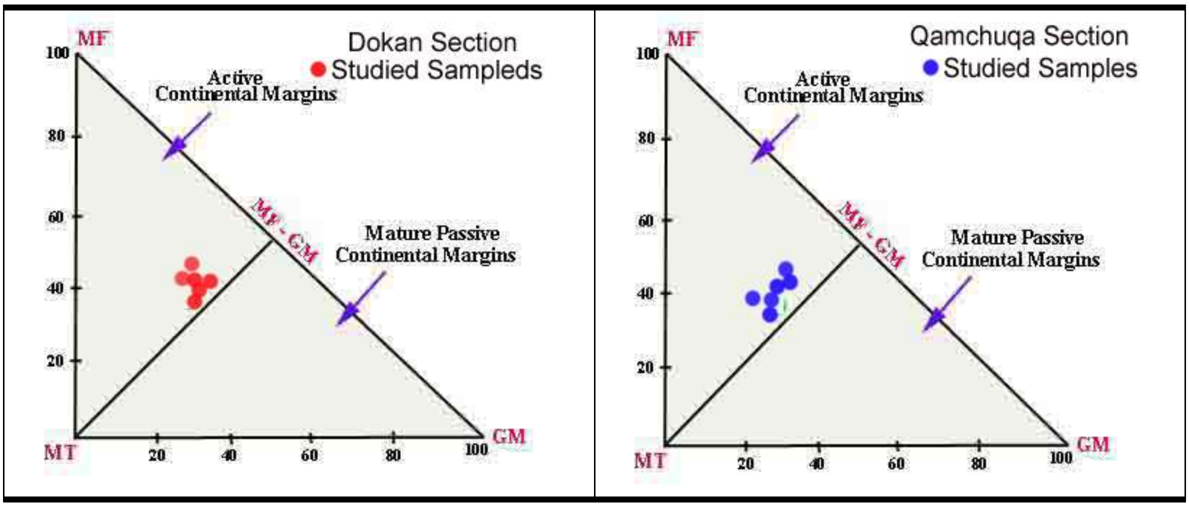

Figure 2: interrelationship of the MF-MT-GM suites of Dokan and Qamchuqa sandstone [33].

Conclusions

- The heavy mineral assemblages in sandstone sediments from Tanjero formation are mainly represented by opaque mineral, chlorite, amphibole, pyroxene, epidote, garnet, mica and rutile.
- The sediment's composition is primarily influenced by the diversity of heavy minerals present, with a notable predominance of those originating from sedimentary rocks, followed by contributions from igneous and metamorphic rock sources. The significant presence of unstable and metastable minerals within these sediments serves as compelling evidence of their direct derivation from nearby primary sources.

- The relationship between ultra-stable and metastable heavy minerals, indicates immature and moderate stability of sandstone sediments of the Tanjero Formation. Generally, they were transported from short distances and accumulated close to their source area and not represents polycyclic grain.
- The studied sandstone samples are located in the active continental margins field, which is defined by a higher proportion of MF minerals than GM minerals derived from mafic magmatic source rocks, according to the MT-MF-GM ternary diagram.

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Conflict of interest: none

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