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TECTONIC SETTING INTERPRETATION FOR THE INJANA FORMATION IN SELECTED SITES OF THE CENTRAL AND EASTERN PARTS OF IRAQ BY HEAVY MINERALS ASSEMBLAGES

Farqad Zora Al-Hameedawi[1*], Salam Ismael Al-Dulaimi[1], Hasan Kattoof Jasim[1]

[1] Department of Geology, College of Science, University of Baghdad, Baghdad, Iraq.
***** Correspondence: e-mail: ferqad.zawra2308@sc.uobaghdad.edu.iq; ORCID: 0009-0009-2363-6048

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Abstract

The present study aims to determine the tectonic setting of the Injana Formation (Late Miocene) by using heavy mineral assemblages, which are also considered to be one of the most important indicators of the tectonic environments. Eighteen samples of the Injana Formation have been collected from four different sites. These are Al-Hasheema section in Wasit Governorate, Al-Bajalia section in Missan Governorate, the Tar Al-Sayyed in Karbala Governorate, and the Tar Al-Najaf in Al-Najaf Governorate, all of which represent the eastern and western ends of the sedimentary basin of the formation, respectively. To notice the degree of the influence of sediment supply from these two sides and the influence of the different tectonic settings, heavy minerals were separated from light minerals through heavy liquid (Bromoform), then recognized under polarized microscopy. Consequently, two groups have been identified: opaque minerals and transparent minerals. Transparent minerals include: chlorites, pyroxenes, amphiboles, mica, garnet, zircon, tourmaline, rutile, epidote, staurolite, kyanite, and chromian spinel. The percentages of heavy minerals were found to be different in the studied sites; this may be due to the different sources of sediment supply of the Injana Formation, the first one is from the east and northeast, whereas the second one is from the southwest, represented by the Arabian Shield. Therefore, the effect of the tectonic setting on the formation is also diverse, so that the eastern and northeastern sides of the sedimentary basin represent a subduction zone of the Arabian-Iranian plates. Whilst the craton tectonic setting represents the southwest side.

Keywords: Heavy Minerals; Provenance; Tectonic Setting; Chromian Spinel; Injana Formation.

1. Introduction

Heavy mineral analysis is one of the most important and often used techniques for determining the provenance of sand and sandstone. The accumulation of heavy minerals is influenced not only by the mineralogical composition of the source area but also by other

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factors, including mineral stability and chemical weathering during transportation (Folk, 1974; Tucker, 1988; Nichols et al., 2007). Heavy mineral assemblages of continental margins differ significantly from those of the intraoceanic, island-arc, and deep marginal sea assemblages by possessing relatively high contents of zircon, tourmaline, garnet, epidote, amphibole, and less common minerals, derived mainly from metamorphic and sialic intrusive rocks (Nechaev & Isphording, 1993). Numerous studies have been conducted on the Injana Formation with various objectives, such as (Al-Juboury et al., 2009; Al-Salmani & Tamar-Agha, 2018; Al-Bayaty & Alhazaa, 2024; Al-Salmani et al., 2024), have indicated that the heavy mineral assemblages of the Injana Formation are dominated by opaque minerals alongside transparent minerals such as epidotes, garnet, amphiboles, pyroxenes (both orthopyroxene and clinopyroxene), zircon, tourmaline, rutile, biotite, muscovite, and chlorite. Minor occurrences of kyanite and staurolite were also noted. These assemblages suggest a derivation from mafic igneous and metamorphic rocks, with subordinate contributions from acidic igneous sources and reworked sediments. The presence of unstable heavy minerals, such as amphiboles and pyroxenes, indicates proximity to the source area. This study aims to demonstrate the tectonic situation of the Injana Formation sediments between the eastern and western ends of its sedimentary basin by studying the heavy minerals assemblages.

1.1. Geological Settings

Stratigraphically, the Injana Formation was formed and deposited during the period of the collision of the Sanandaj-Sirjan Zone with the Arabian Plate, which led to the transition from the marine to the continental phase. It is a clastic sediment of marine origin, followed by fluvial deposits. The Injana Formation is widely exposed in the low Folded Zone and the Jazira area of the Mesopotamian foredeep, as well as in the Mesopotamian plain. It has a constant lithology: sandstone, claystone, thin evaporate, and very thin beds of freshwater limestone (Sissakian et al., 2016). The Injana Formation represents part of the megasequence AP11, which has lasted 34 my (Sharland et al., 2001; Aqrawi et al., 2010).

Tectonically, intense tectonic subsidence occurred in response to compression deformation and overthrusting of allochthonous units along the NE margin of the Arabian Plate (Aqrawi et al., 2010). Generally, according to Fouad (2015), the study area is located within the Outer Platform, where Al-Hasheema and Al-Bajalia sections in the eastern part of Iraq lie within the Low Folded Zone/ Kirkuk Subzone, whereas the central part of Iraq (Tar Al-Sayeed and Tar Al-Najaf sections) lies within the Mesopotamian Zone/ Mesopotamia Subzone (Figure 1).

1.2. Location of the studied area

The current study is represented by four locations in the eastern and central parts of Iraq (Figure 2); their latitudes and longitudes are listed in Table 1.

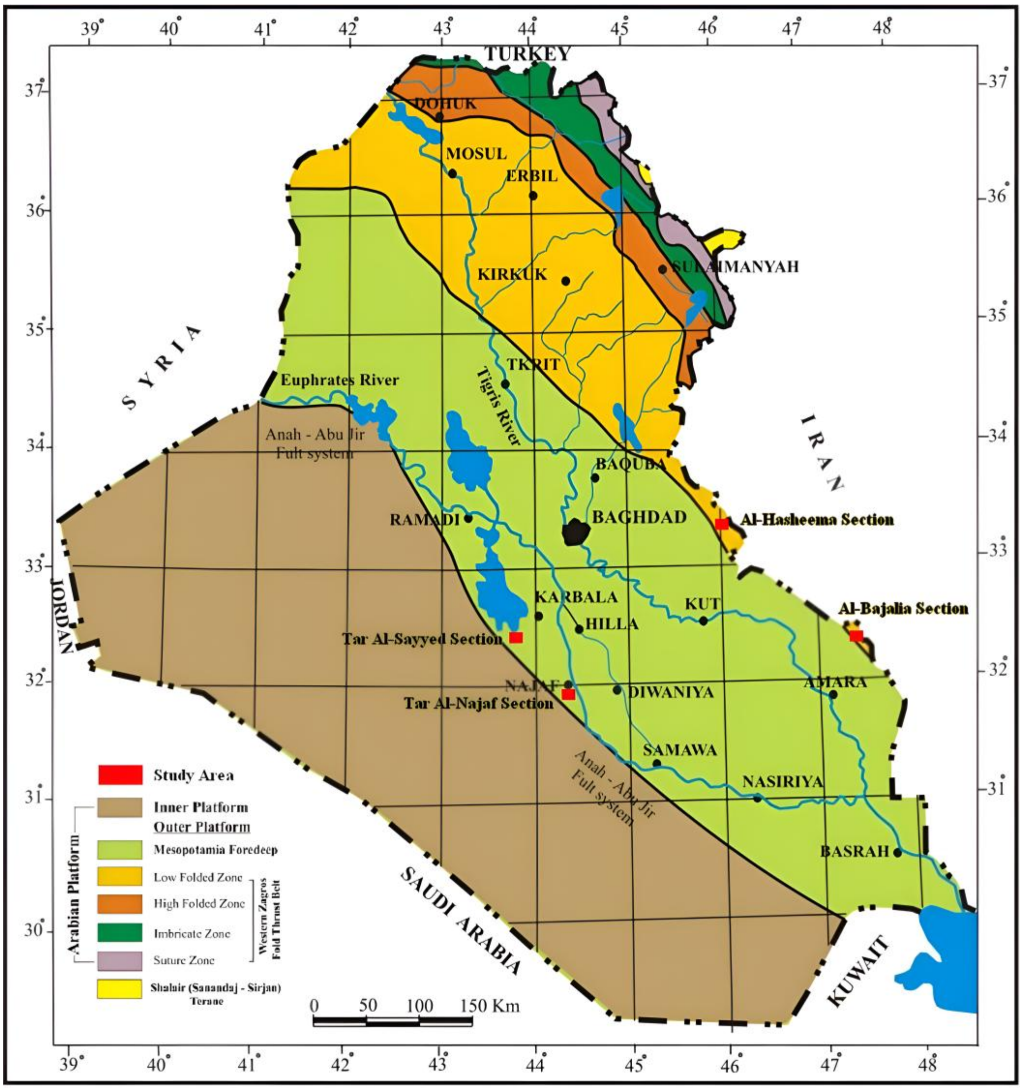

Figure 1. Tectonic map of Iraq (after Fouad, 2015).

Table 1. The coordinates of the study area.

Governorate	Section Name	Latitude	Longitude
Zurbatiya-Wasit	Al-Hasheema	33° 16′ 46″ N	46° 02′ 50″ E
Al-Teeb-Missan	Al-Bajalia	32° 19′ 03″ N	47° 24′ 10″ E
Karbalaa	Tar Al-Sayyed	32° 28′ 54″ N	43° 46′ 45″ E
Al-Najaf	Tar Al-Najaf	32° 04′ 20″ N	44° 11′ 10″ E

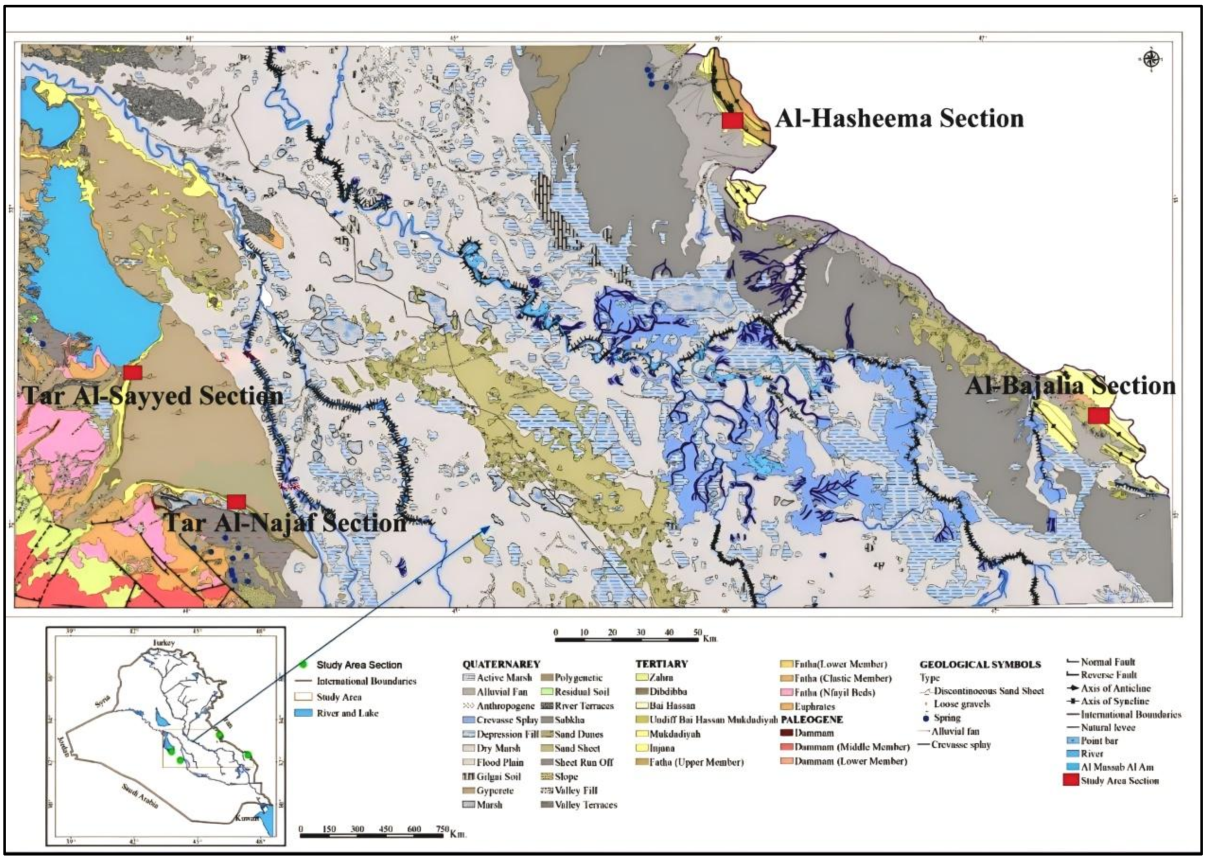

Figure 2. Location map of the studied area (modified after Sissakian & Fouad, 2015).

2. Materials and methods

This study was conducted using the methodology represented by fieldwork and laboratory work, where the fieldwork included four fieldtrips to four Injana Formation outcrops and collecting 18 rock samples of sandstone units from them (Figure 3).

Then a laboratory work has been done by separation the heavy mineral assemblages, this is done by; disintegrating the rock samples and removing carbonate materials by reacted them with 10% hydrochloric acid (Folk, 1974), then separating the fine and very fine sand grains by dry sieving (Folk, 1974; Tucker, 1988), and separation them from the light minerals by using heavy liquid (Bromoform) 2.89 g/cm3 (Folk, 1974; Tucker, 1988).

Finally, preparing mounted slides by using Canada Balsam, and identifying the different types of heavy minerals and their percentages by the point-counting technique using a Leitz polarizing microscope.

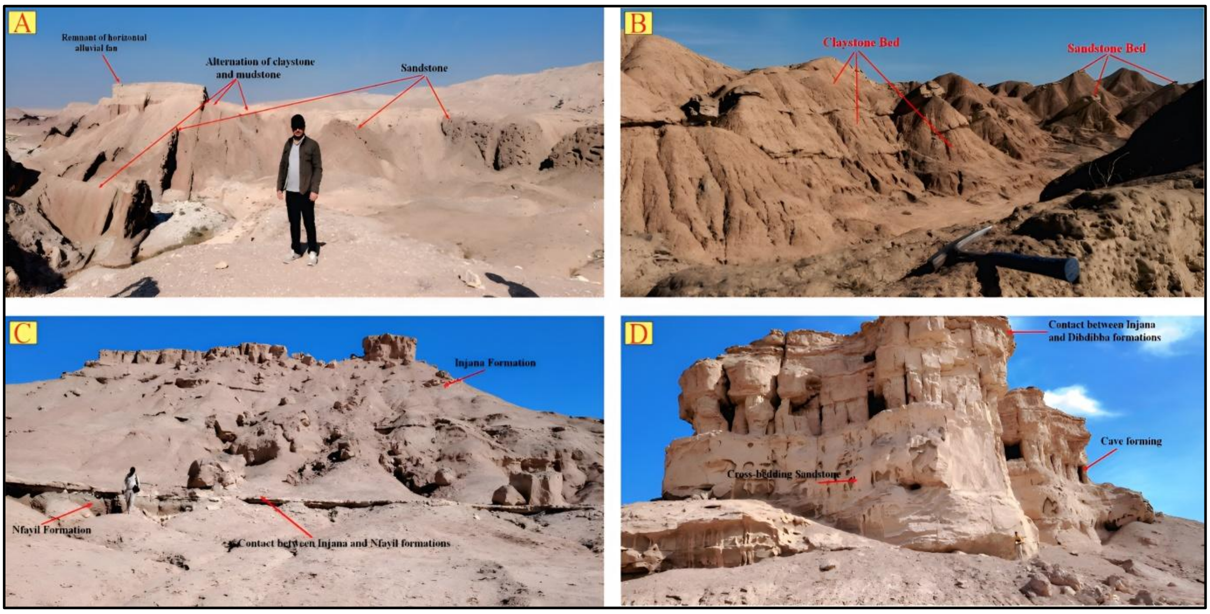

Figure 3. Outcrops of the Injana Formation in the studied area. A: Succession of the Injana Formation in Al-Hasheema section, B: Outcrops of the Injana Formation in Al-Bajalia section at the southwestern limb of Al-Bajalia anticline, C: Outcrops of the Injana Formation in Tar Al-Najaf section, and D: Outcrops of the Injana Formation in Tar Al-Sayyed section.

3. Results and Discussion

3.1. Heavy Minerals

The heavy minerals in the studied sandstones are divided into two major groups, depending on the light transparency: opaque and non-opaque minerals (transparent minerals). The opaque minerals represent the predominant percentage in all studied samples (Table 2), which reflects the diversity of source rocks, including sedimentary, metamorphic, and igneous rocks (Folk, 1974).

The Opaque minerals are defined by their inability to transmit light and include various groups, such as oxides, native elements, sulfides, and hydroxides (Barker, 2014). The transparent or non-opaque minerals identified from the analyzed samples include: pyroxenes (orthopyroxene and clinopyroxene), chlorites, amphiboles (hornblende, glaucophane, and tremolite-actinolite), mica minerals (muscovite and biotite), garnet (almandine and grossular), zircon, tourmaline, epidote, rutile, kyanite, staurolite, and chromian spinel. The identification of minerals was conducted using their optical characteristics when examined under a polarized light microscope (Barker, 2014; Al-Shakeri et al., 2016). Tables (3 and 4) show the percentage and average of heavy minerals, and Figure (4) shows the heavy minerals and their percentages as pie diagrams, and Figure (5) shows the photomicrograph of the determined heavy minerals of the studied samples.

Table 2. Percentage of opaque to non-opaque minerals from the studied samples.

Section Name	Samples Number	Percentage of opaque minerals %	Percentage of non-opaque minerals (Transparent minerals) %
Al-Hasheema	H1	42.1	57.9
	H4	43.3	56.7
	H6	40.3	59.7
	H7	45.3	54.7
	H9	41.6	58.4
	H10	40.6	59.4
Al-Bajalia	B1	42.6	57.4
	B4	43.7	56.3
	B5	39.9	60.1
	B6	40.8	58.9
	B8	45.7	54.6
	B10	40.5	59.5
Tar Al-Najaf	N1	38.6	61.4
	N2	42.6	57.4
	N3	40.2	60.7
Tar Al-Sayyed	S1	37.6	62.4
	S2	39.3	60.7
	S3	40.6	59.4

Table 3. Heavy minerals percentages of the Injana Formation in the eastern part of the studied area.

Heavy Minerals		**Samples Numbers**											
		Al-Hasheema section						**Al-Bajalia section**					
		H1	**H4**	**H6**	**H7**	**H9**	**H10**	**B1**	**B4**	**B5**	**B6**	**B8**	**B10**
Opaques		42.1	43.3	40.3	45.3	41.6	40.6	42.6	43.7	39.9	40.8	45.7	40.5
Chlorites		7.9	9.3	8.6	10.4	7.9	9.3	8.5	9.3	8.9	8.3	9.6	8.3
Pyroxenes	Orthopyroxene	3.4	3.6	3.6	5.6	3.9	3.1	3.1	3.1	4.3	4.1	3.3	3.6
	Clinopyroxene	3.6	4.6	5.1	3.9	4.6	5.3	3.2	4.1	3.3	4.3	5.3	5.3
Amphibole	Hornblende	3.3	4.9	5.3	5.3	4.9	5.1	4.3	4.1	3.6	4.6	4.3	5.6
	Tremolite-Actinolite	5.7	3.6	3.1	2.5	4.3	3.1	2.1	2.1	3.4	3.6	4.3	4.6
	Glaucophane	2.3	2.3	1.6	1.3	1.6	1.1	0	0	1.3	0.9	0	0.6
Mica	Biotite	5.6	2.6	3.3	1.3	2.6	2.6	5.3	5.3	5.6	4.9	1.1	3.1
	Muscovite	2.3	2.3	1.9	3.9	2.9	3.3	3.3	4.1	3.1	2.9	3.6	2.6
Garnet	Grossular	2.1	3.3	3.6	2.6	4.1	3.3	3.2	4.1	3.3	3.6	3.3	3.6
	Almandine	3.1	3.3	2.6	5.6	2.9	2.3	4.3	2.1	3.1	1.9	2.6	2.6
ZTR	Zircon	2.6	3.6	4.1	4.6	4.3	4.2	4.3	5.3	4.5	4.3	3.3	4.1
	Tourmaline	3.3	2.3	2.6	0.9	2.6	2.3	3.2	3.1	3.1	2.6	2.3	2.3
	Rutile	0	0	1.1	0	1.1	2.3	0	0	0	0.6	0	0.6
Epidote		5.3	4.6	6.1	4.9	5.3	6.1	5.3	5.3	4.3	6.1	5.6	6.1
Staurolite		2.6	2.3	2.6	0	1.1	2.2	5.3	0	3.1	1.9	2.6	2.1
Kyanite		1.6	1.3	2.3	1.3	2.1	1.1	1.1	1.3	2.3	2.1	0.6	1.9
Chromian Spinel		2.3	2.2	1.6	0	1.3	2.1	0	2.1	2.3	1.6	1.6	1.9
Others		0.9	0.6	0.6	0.6	0.9	0.6	0.9	0.9	0.6	0.9	0.6	0.6

Table 4. Heavy minerals percentages of the Injana Formation in the western part of the studied area.

Heavy Minerals		Samples Numbers					
		Tar Al-Najaf			Tar Al-Sayyed		
		N1	N2	N3	S1	S2	S3
Opaques		38.6	43.2	40.5	37.6	39.3	40.6
Chlorites		5.3	4.3	4.6	6.6	5.3	4.6
Pyroxenes	Orthopyroxene	3.1	4.1	3.3	3.6	3.6	3.3
	Clinopyroxene	3.3	3.3	3.6	3.9	3.3	2.6
Amphiboles	Hornblende	4.3	5.1	4.6	3.3	4.1	3.9
	Tremolite-Actinolite	1.3	2.1	1.9	2.3	3.1	2.3
	Glaucophane	0	0	0	0	0	0
Mica	Biotite	8.6	6.6	7.6	6.9	5.6	4.9
	Muscovite	8.6	4.9	5.9	4.1	4.3	4.6
Garnet	Grossular	3.1	3.3	3.3	2.1	2.3	3.1
	Almandine	1.3	2.1	1.6	4.4	4.1	4.3
ZTR	Zircon	10.3	8.6	8.9	9.2	8.6	8.9
	Tourmaline	4.2	2.9	3.6	5.3	4.6	3.9
	Rutile	2.6	2.6	2.1	4.2	2.9	3.6
Epidote		4.3	4.1	4.9	4.3	5.1	5.3
Staurolite		0	1.1	0.6	0	1.1	1.3
Kyanite		0.6	1.1	2.1	1.3	2.1	1.9
Chromian Spinel		0	0	0	0	0	0
Others		0.5	0.6	0.9	0.9	0.6	0.9

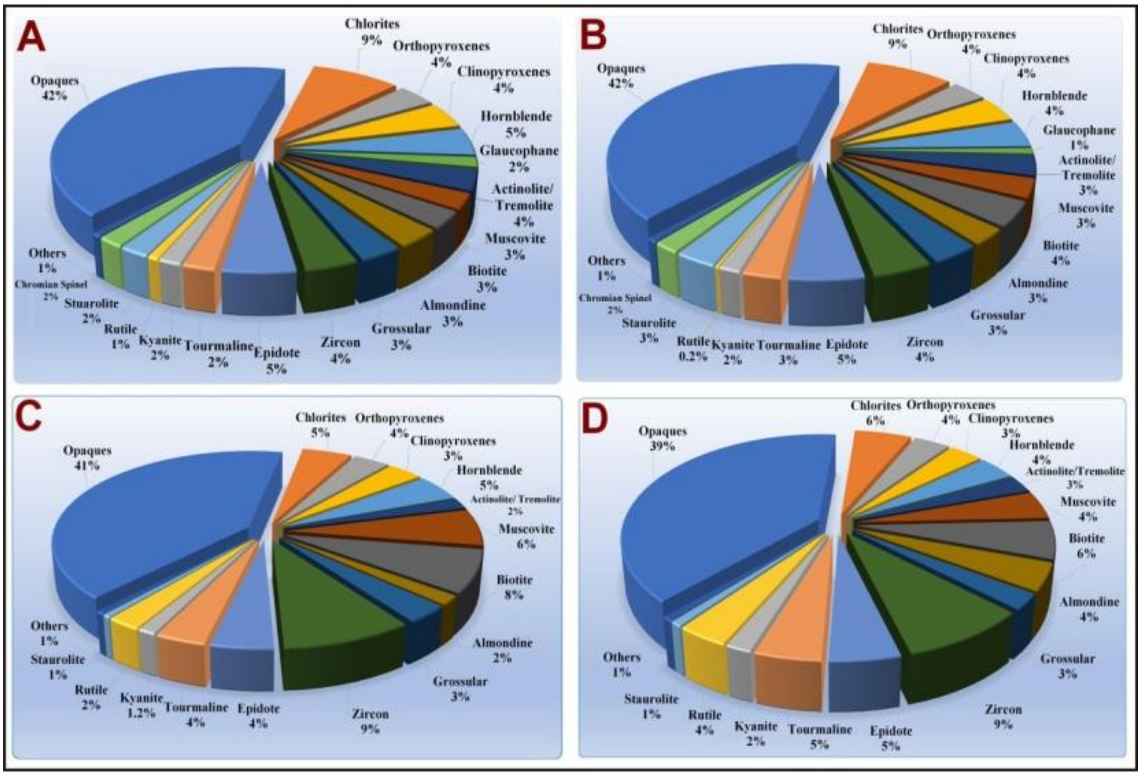

Figure 4. Pie Diagram showing the percentage of average heavy minerals of four studied sections, where A: represents the studied sandstone of Al-Hasheema section, B: represents the studied sandstone of Al-Bajalia section, C: represents the studied sandstone of Tar Al-Najaf section, and D: represents the studied sandstone of Tar Al-Sayyed section.

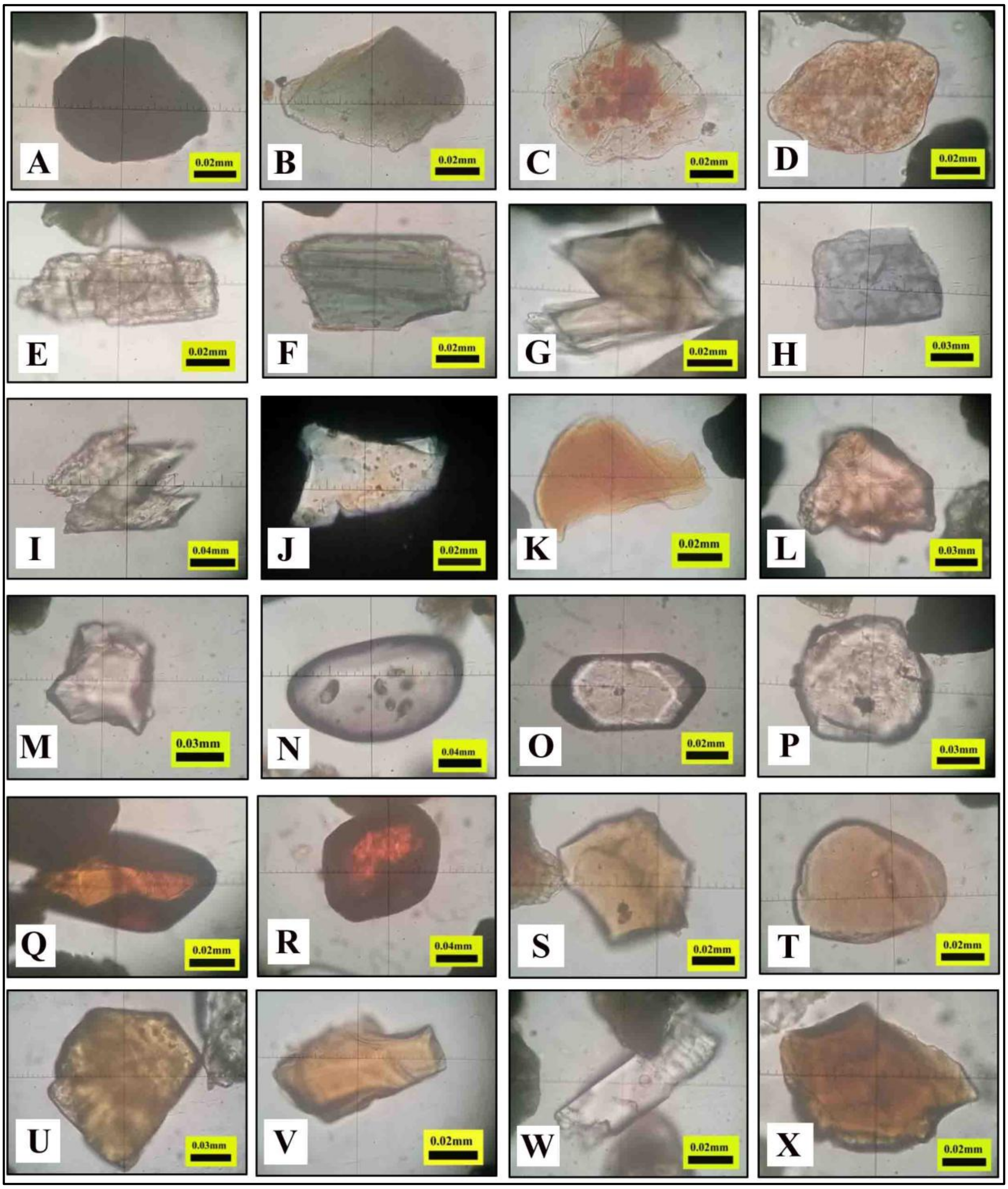

Figure 5. Photomicrograph of heavy minerals were by; A: opaque minerals, B, C and D: chlorites, E: orthopyroxene, F: clinopyroxene, G: hornblende, H: Glaucophane, I: tremolite-actinolite, J: muscovite, K: biotite, L: almandine garnet, M: Grossular garnet, N, O, and P: zircon, Q, and R: rutile, S, and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

The heavy minerals have been divided into four groups based on their stability according to Carver (1971): Ultra-stable, stable, semi-stable, and unstable groups, as illustrated in Table 5.

Table 5. Classification of heavy minerals according to their stability (Carver, 1971).

Heavy Minerals Groups			
Ultra-stable	**Stable**	**Semi-stable**	**Unstable**
Zircon	Chlorite	Staurolite	Biotite
Tourmaline	Muscovite	Kyanite	Amphibole
Rutile	Chromian Spinel	Epidote	Pyroxene
			Garnet
			Opaque

3.2. Description of Heavy Minerals

3.2.1. Ultra-Stable Group

Zircon: It is considered an ultra-stable mineral for its resistance to weathering processes (Alsudani et al., 2022). It is of great significance for the source rock (Figure 5) because its euhedral shape is an indication of acidic igneous rock, and the rounded shape is an indication of high-grade metamorphic rocks (Bela et al., 2024). The average percentage of zircon in Al-Hasheema, Al-Bajalia, Tar Al-Sayyed, and Tar Al-Najaf sections is 3.9%, 4.3%, 8.9%, and 9.3%, respectively.

Tourmaline: It is derived from felsic igneous rocks, especially granite, and metamorphic rocks (Garzanti, 2017). Its optical properties are rounded to sub-rounded shapes with a high relief and characterized by a honey colour with strong pleochroism (Figure 5). The average percentage of tourmaline in Al-Hasheema, Al-Bajalia, Tar Al-Sayyed, and Tar Al-Najaf sections is 2.3%, 2.7%, 4.6%, and 3.6%, respectively.

Rutile: It is an accessory mineral in igneous rocks, but is more common in schists and gneisses. Its optical properties show very high relief with deep red color, and the form is angular to sub-angular, and unhedral to subhedral (Figure 5). The average percentage of rutile in Al-Hasheema, Al-Bajalia, Tar Al-Sayyed, and Tar Al-Najaf sections is 0.75%, 0.2%, 3.6%, and 2.4%, respectively.

3.2.2. Stable Group

Chlorites: It refers to low-grade metamorphism within the chlorite schist facies and is sometimes an alteration product of ferromagnesian minerals (Best, 2003). Its optical properties show various colors from light green to light brown (Figure 5). The average percentage of chlorite in Al-Hasheema, Al-Bajalia, Tar Al-Sayyed, and Tar Al-Najaf sections is 8.9%, 8.8%, 5.5%, and 4.7%, respectively.

Muscovite: It is the most common mica group. Its optical properties are colorless with a flaky habit (Figure 5). The average percentage of Muscovites in Al-Hasheema, Al-Bajalia, Tar Al-Sayyed, and Tar Al-Najaf sections is 2.7%, 3.3%, 4.3%, and 6.5%, respectively.

Chromian Spinel: It represents one of the spinel group crystallized in the isometric system (isotropic mineral) (Mange & Maurer, 1992; Bucher & Grapes, 2011). Its optical properties are deep brown to deep red with high relief, and equant in form with conchoidal fractures (Figure 5). The average percentage of chromian spinel in Al-Hasheema, Al-Bajalia, Tar Al-Sayyed, and Tar Al-Najaf sections is 2.7%, 3.3%, 4.3%, and 6.5% respectively.

3.2.3. Semi-stable Group

Staurolite: The main optical properties of staurolite are a yellowish golden color with slightly pleochroic (Figure 5), with high relief (Nesse, 2012; Barker, 2014). It is crystallization in medium-grade metamorphism (Bucher & Grapes, 2011). The average percentage of staurolite in Al-Hasheema, Al-Bajalia, Tar Al-Sayyed, and Tar Al-Najaf sections is 2.1%, 2.1%, 0.8%, and 0.6%, respectively.

Kyanite: It represents one of the minerals that form in the regional metamorphism (Mange & Maurer, 1992), where its main optical properties are colorless (Figure 5), high relief, and elongated habit (Barker, 2014). The average percentage of kyanite in Al-Hasheema, Al-Bajalia, Tar Al-Sayyed, and Tar Al-Najaf sections is 1.6%, 1.6%, 1.7%, and 1.3%, respectively.

Epidote: It is a metamorphic mineral with a low to medium transitional grade of metamorphism (Bucher & Grapes, 2011). It has the main optical properties of high relief and pale brown color (Figure 5). The average percentage of epidote in Al-Hasheema, Al-Bajalia, Tar Al-Sayyed, and Tar Al-Najaf sections is 5.3%, 5.4%, 4.9%, and 4.4%, respectively.

3.2.4. Unstable Group

Biotite: It represents a sheet silicate or phyllosilicate mineral (Al-Shakeri et al., 2016), where it has a brown color with strong pleochroism, and flaky habit (Figure 5), and it shows two types: fresh and altered biotite. The average percentage of biotite in Al-Hasheema, Al-Bajalia, Tar Al-Sayyed, and Tar Al-Najaf sections is 3.0%, 4.2%, 5.8%, and 7.6%, respectively.

Hornblende: It represents the main mineral of the amphibole group. The main optical properties are green color with moderate pleochroism, and it has two directions of cleavage (Figure 5), with obtuse and acute angles (Nesse, 2012; Barker, 2014). The average percentage of hornblende in Al-Hasheema, Al-Bajalia, Tar Al-Sayyed, and Tar Al-Najaf sections is 4.8%, 4.4%, 3.7%, and 4.6%, respectively.

Tremolite-Actinolite: It is one mineral of the amphibole group, which crystallized in metamorphic rock under low-grade metamorphism, where its optical properties are colorless, with cockscomb structure (Figure 5), and has a two-set of cleavage with acute and obtuse angles (Barker, 2014; Al-Shakeri et al., 2016). The average percentage of actinolite-tremolite in Al-Hasheema, Al-Bajalia, Tar Al-Sayyed, and Tar Al-Najaf sections is 3.7%, 3.3%, 2.6%, and 1.7%, respectively.

Glaucophane: It represents one of the amphibole minerals, and it is an index mineral of metamorphism (Nesse, 2012). The main optical properties of it are buish to bluish green color with strong pleochroism (Figure 5), and high relief (Barker, 2014). The average percentage of glaucophane in Al-Hasheema and Al-Bajalia sections is 1.7% and 0.9%, whereas the mineral does not exist in Tar Al-Sayyed and Tar Al-Najaf sections.

Orthopyroxene: They are a subgroup of minerals belonging to the pyroxene group of minerals, which have an orthorhombic crystal system (Barker, 2014). The main optical properties are colorless, with high relief, and two sets of cleavage (Figure 5). The average percentage of orthopyroxene in Al-Hasheema, Al-Bajalia, Tar Al-Sayyed, and Tar Al-Najaf sections is 3.9%, 3.6%, 3.5%, and 3.5%, respectively.

Clinopyroxene: They are a subgroup of minerals belonging to the pyroxene group minerals (Figure 5), which have a monoclinic crystal system (Al-Shakeri et al., 2016). The main optical properties are light green color, high relief, with pleochroism, and two sets of cleavage. The average percentage of clinopyroxene in Al-Hasheema, Al-Bajalia, Tar Al-Sayyed, and Tar Al-Najaf sections is 4.5%, 4.3%, 3.3%, and 3.4%, respectively.

Grossular: It is one of the garnet mineral group; it has an isometric system. The main optical properties of grossular are colorless, high relief, equant shape (Figure 5), and optically isotropic (Nesse, 2012). The average percentage of grossularite in Al-Hasheema, Al-Bajalia, Tar Al-Sayyed, and Tar Al-Najaf sections is 3.1%, 3.5%, 2.5%, and 3.2%, respectively.

Almandine: It belongs to the garnet minerals group too, which has a cubic system, and it represents one of the minerals that form the metamorphic rocks (Gill, 2010). The main optical properties of almandine are rose color, high relief, and equant shape (Figure 5). The average percentage of almandine in Al-Hasheema, Al-Bajalia, Tar Al-Sayyed, and Tar Al-Najaf sections is 3.3%, 2.7%, 4.3%, and 1.7%, respectively.

Opaque group: They represent the predominant components and have the highest percentage. They have different shapes (Figure 5), and they may belong to native elements, hydroxides, sulfides, oxides, or phosphates (Nesse, 2012). The average percentage of the opaque group in Al-Hasheema, Al-Bajalia, Tar Al-Sayyed, and Tar Al-Najaf sections is 42.2%, 42.2%, 39.1%, and 40.7%, respectively.

4. Provenance of Heavy Minerals

It is possible to trace the detrital grains of sandstones to specific source rocks by using distinct mineral types of heavy minerals; this represents a successful method for lithic and arkosic sandstones that were deposited in fluvial environments close to their source (Carver, 1971). The heavy mineral assemblages in the studied samples of the Injana Formation indicated that igneous, metamorphic, and sedimentary rocks are all possible sources. The following results confirm this belief: The presence of opaque minerals indicates diverse sources of rocks; sedimentary (clastic and carbonates), metamorphic, and igneous rocks (Tucker, 2001; Al-Shakeri et al., 2016). The presence of zircon, tourmaline, muscovite, and biotite indicates a source of acidic igneous rock (Gill, 2010; Bucher & Grapes, 2011), whilst the presence of pyroxene and hornblende refers to a source of basic igneous rocks (Sen, 2014). The presence of chlorites, glaucophane, tremolite-actinolite, garnets, staurolite, and kyanite refers to metamorphic source rocks (Bucher, K., 2011; Sen, 2014). The source of mafic and ultramafic igneous rocks is indicated by the presence of chromian-spinel (Al-Juboury et al., 2009).

5. Tectonic Setting

The heavy minerals' assemblages can serve as reliable indicators of major plate-tectonic settings (Nechaev & Isphording, 1993). There is a close relationship between the sediment compositions and the tectonic setting (Nichols, 2009). The studied samples were plotted on the triangle diagram prepared by Nechaev & Isphording (1993) to determine the tectonic setting of the study area.

According to Nechaev & Isphording (1993), the MF represents common constituents of mafic magmatic rocks (total contents of pyroxene, hornblende, and olivine), and MT represents common constituents of basic metamorphic rocks (total contents of pale-colored and blue-green amphibole, epidote, and garnet). GM represents accessory minerals of granites and sialic metamorphic rocks (total content of zircon, tourmaline, staurolite, kyanite, andalusite, monazite, and sillimanite).

By plotting the achieved results of the studied samples on the ternary of Nechaev & Isphording (1993), it was found that the sediments of the Injana Formation in western side of the depositional basin are all located within the mature passive continental margin, which resulting from derivation from source regions lacking active tectonic events (Nechaev & Isphording, 1993), while most of the studied samples of Injana Formation from Eastern Iraq are located within the active continental margin, which reflects different volcanic contributions to sediments (Nechaev & Isphording, 1993), except for some samples that were within the mature passive continental margin, and in general all the studied samples were close as shown in Figure (6).

(Markevich et al., 2007) developed a triangular three-component classification that links tectonic setting and heavy mineral content by hornblende, orthopyroxene, and clinopyroxene. From the plotting the results on the classification of (Markevich et al., 2007), it has been found that all the studied samples of the Injana Formation in western side of the depositional basin are located within field A, which represents the active continental margin, while the studied samples of the Injana Formation from Eastern Iraq are located within fields A and B, which represent the active continental margin and continental arcs related to normal subduction, respectively (Figure 7). This result is due to the similar proportions of hornblende, orthopyroxene, and clinopyroxene. Any increase in one of these minerals would change the classification 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.

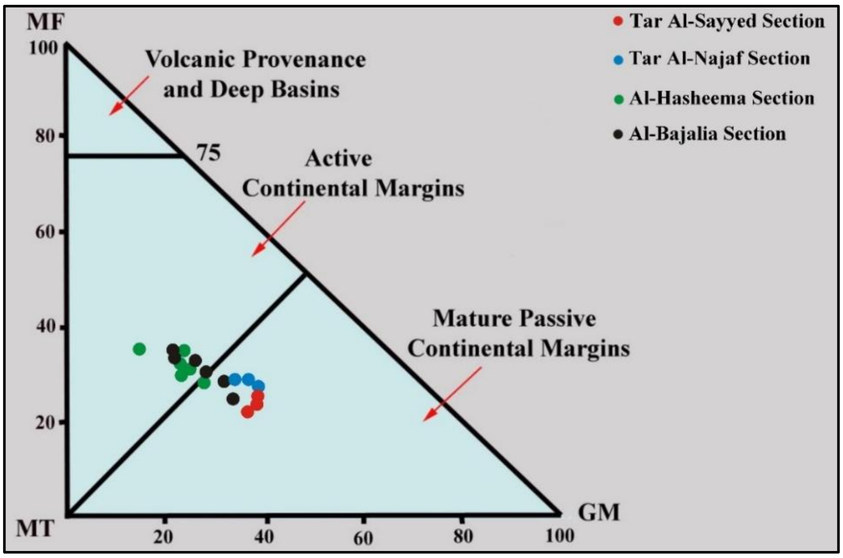

Figure 6. Relationship between heavy mineral assemblage of the Injana Formation and tectonic setting (after Nechaev & Isphording, 1993).

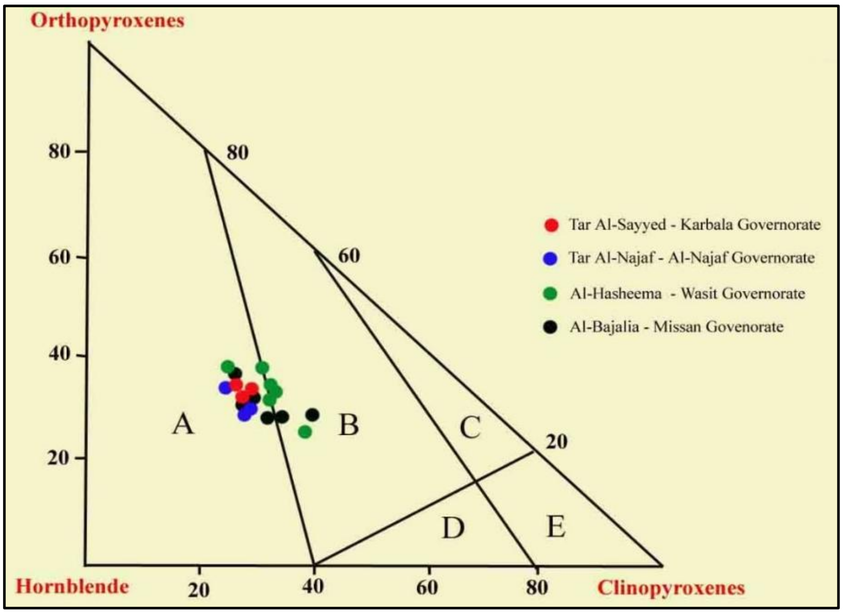

Figure 7. Linkage between heavy mineral distribution of the Injana Formation (Hornblende, Orthopyroxene, and Clinopyroxene) and tectonic setting (Markevich et al., 2007).

Where: A (Active continental margins), B (Continental arcs related to normal subduction), C (Oceanic arcs related to normal subduction), D (Continental arcs related to oblique subduction), and E (Oceanic arcs related to oblique subduction).

5. Conclusions

The conclusions indicate that the results revealed variations in heavy mineral assemblages across the studied sections, reflecting sensitivity to changes in sedimentary environments and tectonic setting, as follows;

The low percentage of ultrastable minerals (Zircon, Tourmaline, and Rutile, collectively known as ZTR), relative to the high percentage of unstable and semistable minerals (opaque, biotite, Pyroxenes, Hornblende, epidote, staurolite, chromian spinel), indicates that the Injana Formation represents unstable sediments.

Ultra-stable minerals (ZTR): The proportions of these minerals west of the Injana sedimentary basin (Tar Al-Sayyed and Tar Al-Najaf sections) were relatively higher than at the east of the sedimentary basin (Al-Hasheema and Al-Bajalia sections). This difference may be due to the difference in transport distance and the far distance from the source area, as well as the difference in the type of source rocks that supply the basin with sediments.

Unstable minerals: Their proportions are nearly similar in all studied sections, with the highest portion being altered.

By applying the percentages of heavy mineral assemblages to tectonic classifications, it became clear that the four sites exhibit differences in their tectonic settings, according to the type of classification and the minerals on which the classification is based. The classification of Nechaev & Isphording (1993) showed that the studied samples of the east sedimentary basin (Al-Hasheema and Al-Bajalia sections) were plotted within the active continental margins, while the studied samples of the west sedimentary basin (Tar Al-Sayyed and Tar Al-Najaf sections) were plotted within the mature passive continental margins. Likewise, the classification (Markevich et al., 2007) showed most of the studied samples have been plotted within the Active continental margins field, while some samples have been plotted within Continental arcs related to the normal subduction field.

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