Iraqi National Journal of Earth Science

www.earth.mosuljournals.com

Heavy Mineral Study of Gercus Formation in Darbandi Basara Anticline, Sulaymaniyah Area, North-Eastern Iraq.

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Article information

Received: 23- Oct -2023

Revised: 04- Feb -2024

Accepted: 06- Mar -2024

Available online: 01- Apr – 2025

Keywords:
Sources Rocks
Gercus Formation
Heavy Minerals
Sandstone

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ABSTRACT

The heavy minerals analysis of the Gercus Formation at the Darbandi Basara anticline in Sulaymaniyah City, Northern Iraq was conducted in this study. Twelve samples were collected from different beds within the Gercus Formation. These samples were divided into two groups: fine-grain sandstone (6 samples) and very fine-grain sandstone (6 samples). The heavy metals identified in the selected sandstone samples from the Gercus Formation were categorized into five main groups: opaque, unstable, metastable, ultrastable minerals, and flaky minerals. These minerals point to presence of metamorphic, mafic igneous rocks, and acidic igneous, as well as reworked sedimentary rocks in the feeding region. The stability of the heavy minerals was evaluated using a ternary scheme, and the results showed that the heavy minerals in the Gercus Formation are relatively stable. This stability can be attributed to the presence of an opaque mineral group, which has a significant influence on the overall stability of the heavy minerals. Based on the findings, it can be inferred that the sandstones in the Gercus Formation originated from active continental edges. This suggests that the sedimentary rocks were deposited in a tectonically active environment.

DOI: 10.33899/earth.2024.144127.1166,

دراسة المعادن الثقيلة لتكوين جركس في طية دربندي باسرة، منطقة السليمانية، شمال – شرقي العراق

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معلومات الارشفة

تاريخ الاستلام: 23- اكتوبر -2023

تاريخ المراجعة: 04- فبراير -2024

تاريخ القبـول: 06- مارس -2024

تاريخ النشر الالكتروني: 01- ابريل -2025

الكلمات المفتاحية:
الصخور المصدرية
تكوين جركس
المعادن الثقيلة
الصخور الرملية

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الملخص

تتضمن الدراسة الحالية تحليل المعادن الثقيلة لتكوين جركس الواقع ضمن طية دربندي باسره المحدبة في مدينة السليمانية شمالي العراق. تم جمع اثنا عشر عينة من الصخور الرملية من مواقع مختلفة من الطبقات. شملت العينات المختارة (6 عينات) من الحجر الرملي الناعم و(6 عينات) من الحجر الرملي الناعم جدا. صنفت المعادن الثقيلة في تتابعات الدراسة الحالية الى خمس مجاميع وهي: مجموعة المعادن المعتمة، مجموعة المعادن غير المستقرة، مجموعة المعادن شبه المستقرة، مجموعة المعادن فوق المستقرة ومجموعة المعادن الصفائحية. ويستدل من هذا التجمع المعدني على ان أصل الصخور المدروسة هي الصخور المتحولة والصخور النارية بنوعيها (المافية والحامضية)، فضلا عن الصخور الرسوبية المعادة الترسيب. وتشير الدراسة من خلال المخطط الثلاثي لاستقرار المعادن الثقيلة بان المجموعة المعدنية في الصخور المدروسة مستقرة نسبيا. ويمكن أن يكون ذلك الاستقرار بسبب وجود نسبة كبيرة من المعادن الثقيلة المعتمة نسبة الى بقية المعادن. تشير النتائج إلى أن الصخور الرسوبية الرملية في تكوين جركس نشأت من الحواف القارية ذات البيئة النشطة تكتونيا.

DOI: 10.33899/earth.2024.144127.1166,

Introduction

Heavy metals are very substantial in provenance identification and knowing the role of diagenetic action especially in clastic rock. The type of heavy metals depends on the lithology of the source rocks and sedimentary environment conditions (Osuwake and Francis, 2020). Also, heavy metals are generally utilized to know the path and origin of deposits, and movement trends, and determine the nature of the paleogeography of the feeding region (Chmielowska and Salata, 2020). Mostly, heavy minerals form secondary components in clastic rocks and they are less than %3 in sands when extremely affected by weathering processes. The accuracy of heavy minerals analyses is influenced by the climate of provenance, weathering, and diagenesis processes in the feeding area (Garzanti *et al.*, 2013). Overall, the heavy mineral assemblages in the sandstone sediments support important evidence about the composition of the feeding region and the tectonic environment.

Generally, the successions of Gercus Formation in Iraq consist of highly thick red clastic rocks (Molasse sediments of the intra-Eocene Orogeny) represented by claystone, sandstone, marl, conglomerate, and gypsum rocks, which formed after the closing of the Neo- Tethys Ocean (Buday, 1980; Numan, 1997). The Gercus Formation was first described in Southern Turkey, in Batman governate - Gercüş village by (Bellen *et al.*, 1959).

In northern Iraq in the Dohuk area, a supplementary type section for Gercus Formation was defined by (Bellen *et al.*, 1959). The thickness of the Formation in the Dohuk region reaches (850 m.), while it decreases in the Diyala region in Southern East Iraq (Jassim and Goff, 2006). The exposed thickness of the formation in the section of the Duhok Dam area is about 94 meters (Al-Talib *et al.*, 2021). According to (Bellen *et al.*, 1959), the age of Gercus Formation was the Middle Eocene. Al Naqib (1980), investigated the type of the sandstone in Gercus Formation and concluded its lithic arenite and sublithic arenite. Al-Aany (2010) studied Gercus Formation sedimentologically in Northern Iraq and indicated the river, delta, sabkha, and tidal flat depositional environments for the Gercus Formation. The current study's main objective is to determine the provenance and tectonic setting of the sandstones of Gercus Formation based on heavy minerals investigation.

Geological Setting

The present research region is situated in the Sulaymaniyah area, Northern Iraq, which is represented by one section (Delija village) pointed by latitude, (35º, 26º, 00º N) and longitude (45º, 11º, 07º E) as shown in (Fig. 1). Geologically, study area located within Darbandi Basara anticline, Sulaymaniyah area, Northern Iraq, which belong to folded zone and unstable shelf (Fig. 1).

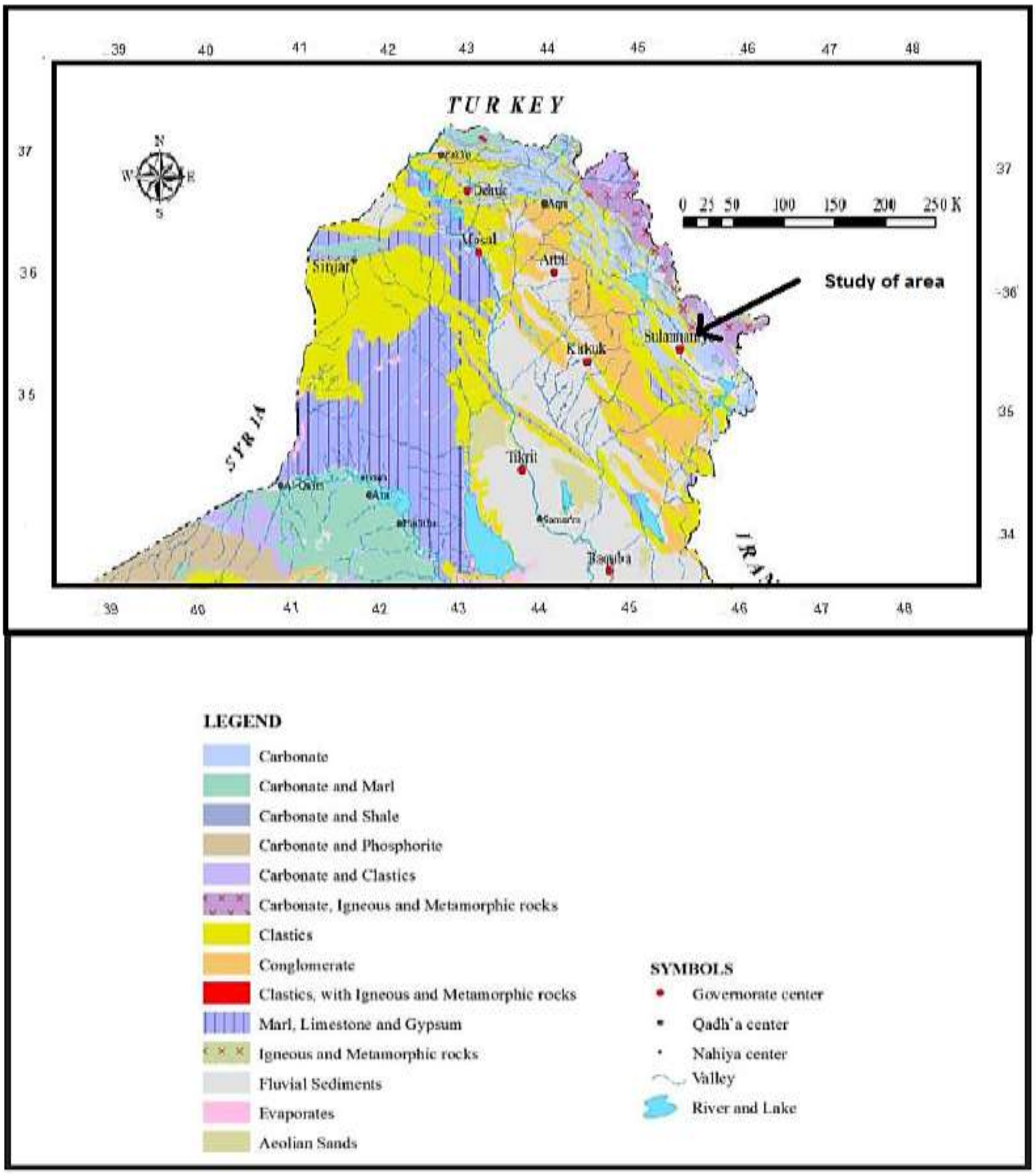

Fig.1. Geological map of NE Iraq displaying the chosen region location. Modified from (Sissakian and Fouad, 2015).

The Gercus Formation is a portion of the Arabian plate Tectonostratigraphic Megasequence (Sharland *et al.*, 2001), this formation is represented by Molasse sediments which were deposited after the uplift in the Middle Eocene age (Zaid *et al.*, 2019). In Iraq, the Gercus Formation extends from high folded to Foothill zones in the unstable shelf (Numan, 2000). The Gercus Formation thickness in the research region is (100m.) and consists of massive thick beds from conglomeratic sandstone of (3m.) thick (plate1, A) and followed by massive sandstone beds. The thickness of massive sandstone beds (10m.), recognize by cross bedding (plate1, B), and followed by thin beds of sandstone (30m.thickness) with fining upward (plate1, C). The lower part from succession composes from laminated clay strata with thick (30m.) (plate1, D). According to (Al-Khtabey, 2012), the lower contact with Sinjar Formation is unconformable which determined by beds from brecciated limestone (plate1, E), while the upper contact with Pila Spi Formation is covered, (plate1, E), (Fig. 2).

Plate 1. A. massive thick beds from conglomeratic sandstone. B. massive sandstone with cross bedding. C. thin beds of sandstone and finning upward D. laminated claystone beds. E. brecciated limestone between Gercus and Pila spi Formations.

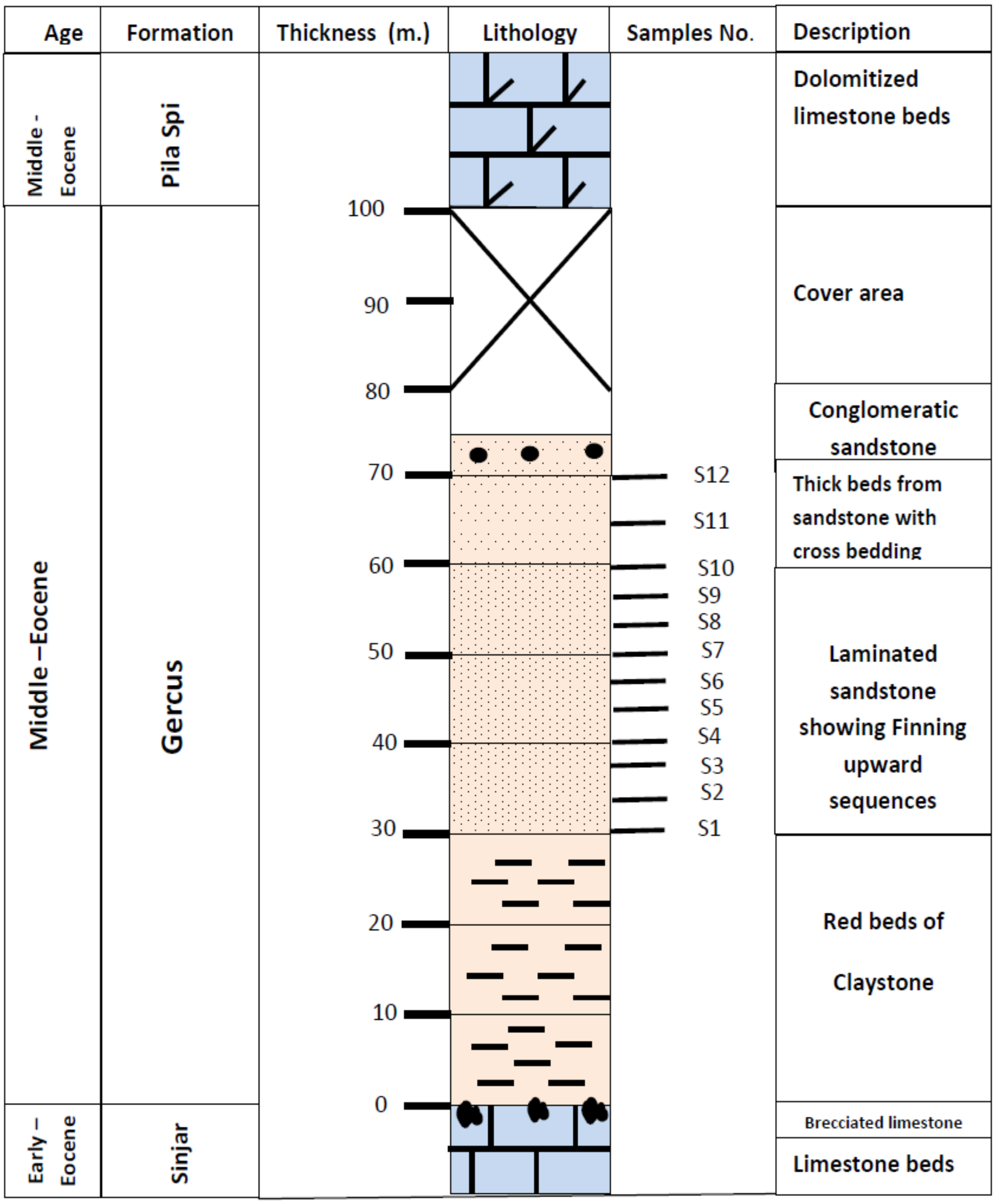

Fig.2. Stratigraphic column of the studied formation in the chosen region section.

Materials and Methods

Twelve fresh Specimens were chosen from the outcrop in the study area (Fig. 2), and they were studied in detail under a polarizing microscope. Heavy minerals were separated according to the Fleet's method (Carver, 1971). Employ sieves with different sizes fractions of 2mm, 1mm, 0.5mm, 0.25mm, 0.125mm, and 0.063mm, various sand fractions were isolated. The 3Ø (0.125 mm) fine-grain sand and 4Ø (0.063 mm) very fine-grain sand were collected by dry sieving. Five grams of fine-grain sand and very fine-grain sand were used for heavy minerals segregation, using a Bromoform liquid with a density of 2.89, then spread and fixed on thin slides using Fleet's method (Carver, 1971).

Results and Discussion

Heavy Minerals Petrography:

The studied sandy specimens from Gercus Formation involved two sets of heavy minerals (Table 1), as described below:

Table 1: Percentage, maximum - minimum limits, and average of petrographic composition in Gercus Formation at selected section.

Sample No.	Monocry-Quartz	Polycry-Quartz	K. Felds-Par	Plagioclase	Carbonate R.F.	Chert R.F.	Igneous Metamor. R.F.	Heavy Min	Cement	Matrit Pgres
S1	6.3	3.5	3.6	2.8	24.4	11.2	3.9	11.4	15.9	16.8
S2	8.7	1.7	4.9	1.3	22.8	14.6	5.9	14.3	17.2	8.5
S3	6.6	2.9	5.5	1.9	29.6	8.4	3.2	14.2	12.9	14.7
S4	9.3	0.4	13.8	2.1	22.5	19.6	5.5	8.9	12.3	5.5
S5	8.6	2.8	8.9	2.6	19.3	9.2	6	12.6	14.2	16.8
S6	4.3	3.4	6.6	2.4	18.5	18.3	5.9	5.1	18.9	16.4
S7	7.1	4.8	6.3	1.4	18.9	17.6	6.2	10.4	9.8	17.5
S8	9.5	1.6	7.1	1.9	20.9	20.1	5.4	11.3	14.9	7.3
S9	5.6	3.8	6	2.1	26.9	12.3	5	13.8	8.8	15.7
S10	7.1	3.2	3.9	1.4	19.9	13.6	6.3	8.9	18.6	17
S11	6.7	4.3	2.6	1.6	35.9	10.3	3.3	10.5	9.3	15.5
S12	4.8	2.1	2.4	2.2	30.6	9.1	3.1	8.6	17.9	19.2
AV	6.9	2.9	6	2.1	24.4	13.7	5	10.6	14.3	13.4

1. Opaque minerals group

Opaque minerals appear in high ratios in heavy minerals because of their crystallization in all kinds of rocks (Ali *et al.*, 2022). In the current research, the opaque minerals of iron oxides suit consist of two types: opaque black–dark brown minerals and hematite (Plate 2: a and b). The particles of these minerals are angular to sub-angular and sub-rounded. The Opaque minerals were identified in the studied samples with ranges from (40.1-48.3%) and an average of 43.06% (Table 2). Generally, the presence of dark metals in the studied specimens refers to acidic and mafic igneous rocks, metamorphic rocks also, and reworked sedimentary rocks in the feeding area (Tucker, 1991; Ali, 2021).

Table 2: Percentage, maximum - minimum limits, and average of heavy minerals ratios in Gercus Formation at selected section.

	Samples No.	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	Range	AV.
Minerals	Opaque%	48.3	46.7	41.6	40.8	42.7	45.7	42.1	42.7	40.1	41	40.7	43.8	40.1-48.3	43.06
	Chromian spinel%	2.7	4.3	3.6	3.5	5.8	3.3	2.7	2.8	5.9	4.7	2.3	5.6	2.3-5.9	3.93
	Glaucophane %	4.5	6.5	4.9	5	5.9	4.7	3.8	5.6	5.5	6.3	5.4	6.1	3.8-6.3	5.35
	Hornblende	6.2	4.2	5.7	4.4	6.8	3.9	5.9	5.8	4.9	5.8	5.5	4.8	3.9-6.8	5.32
	Clinopyroxene%	3.5	5.3	4.5	4.9	3.5	4.9	3.7	4.9	2.7	3.9	4.4	3.8	2.7-5.3	4.16
	Orthopyroxene%	3.2	2.2	4.2	5.5	3.8	4.3	3.9	3.7	5.8	4.9	3.5	3.1	2.2-5.8	4.00
	Epidote%	10.3	7.5	9.8	8.9	8.7	7.6	8.1	6.9	7.5	5.9	6.7	8.2	5.9-10.3	8.00
	Garnet%	6.5	5.2	5.7	5.4	4.4	5.5	6.3	3.9	7.7	5.5	5.7	5.3	3.9-7.7	5.59
	Tourmaline%	4.4	6.8	3.5	5.7	4.5	3.9	4.8	5.9	3.7	4.8	5.4	3.6	3.5-6.8	4.75
	Zircon%	3.7	5.5	5.6	4.5	4	3.1	4.7	3.8	2.9	4.7	4.3	3.6	2.9-5.6	4.2
	Rutile%	2.2	1.8	4.3	3.3	2.8	4.4	3.7	5.1	4.8	5.2	4.8	4.5	1.8-5.2	3.90
	Chlorite %	4.2	3.3	6.2	7.3	6.9	7.9	8.9	7.8	7	6.1	9.8	7.3	3.3-9.8	6.89
Others %		0.3	0.7	0.4	0.8	0.2	0.8	1.4	1.1	1.5	1.2	1.5	0.3	0.2-1.5	0.85

Also, Chromian spinel was found in all studied samples within the selected section. Chromian spinel grains generally have angular to subangular shapes and brown color. The percentage of Chromian spinel ranges between 2.3-5.9 % and an average of 3.93% (Plate 2: c), (Table 2). Chromian spinel is common in ultramafic igneous rocks and high-grade metamorphic rocks (Tucker, 1991).

2. Unstable minerals group: which are represented by the following minerals:

A. Glaucophane mineral: This mineral was identified in all samples of Gercus Formation. The particles are blue-colored and irregular in shape (plate 2: d). The percentage of glaucophane ranges between 3.8-6.3% and an average reach of 5.35% (Table 2). (Zhen *et al.,* 2021) proved that glaucophane is mostly, derived from metamorphic rocks, especially schist and gneiss.

B. Hornblende mineral: Hornblende is the most abundant mineral within studied unstable minerals. The hornblende grains are green in color and tabular to subangular shapes (Plate 2: e). Hornblende ranges between 3.9-6.8% with an average ratio of 5.32% (Table 2). According to (Topaz *et al.*,2023) hornblende minerals can be formed in different igneous and metamorphic rocks.

C. Clinopyroxene mineral: Clinopyroxene mineral is recorded by all studied samples. Clinopyroxene is colorless to light yellowish green and prismatic to subangular grain shapes (Plate 2: f). The percentage of clinopyroxene ranges from 2.7-5.3% and an average of 4.16 % (Table 2). Pyroxene minerals occur generally in basic igneous rocks and metamorphic rocks (Chmielowska and Salata, 2020).

D. Orthopyroxene mineral: Orthopyroxene is found in all examined samples. This mineral is commonly observed as light green color to colorless and subangular shapes (Plate 2: g). The percentage of orthopyroxene ranges between 2.2-5.8% and an average of 4 % (Table 2). Pyroxene minerals occur generally in basic igneous rocks and metamorphic rocks (Chmielowska and Salata, 2020).

3. **Metastable minerals group:** which included the following minerals:

A. Epidote mineral: This mineral is too common in the studied samples. Epidote mineral is shown as angular to subangular grains and appears as a yellowish green to pale brown color (Plate 2: h). Epidote minerals at most exist in parent and metamorphic rocks (Asiedu *et al.*, 2000; Kamil *et al.*,2023). The ratio of mineral grains extends between 5.9-10.3% and an average of 8 % (Table 2).

B. Garnet mineral: This mineral is observed in all studied samples. Garnet is shown as angular to subangular grains and diagnosed as colorless to brown color (Plate 2: i). The garnet mineral is found in metamorphic rocks (Zhang *et al.*, 2022). The percentage of garnet mineral grains ranges between 3.9-7.7% and an average of 5.59 % (Table 2).

4. **Ultrastable minerals group**: which consists of below minerals:

A. Zircon mineral: Zircon is diagnosed in all the studied samples, with generally little content ranging between 3.5-6.8 % with an average ratio of 4.75% (Table 2), (Plate 2: j). Zircon is widely distributed in igneous and metamorphic rocks (Elawi, 2005; Osuwake and Francis, 2020).

B. Tourmaline mineral: Tourmaline is found in all samples in different ratios, the percentage of tourmaline ranges between 2.9-5.6% and an average of 4.2 % (Table 2). Tourmaline mineral has a brown color and subrounded shape (Plate 2: k), Tourmaline minerals come from igneous and metamorphic rocks (Boggs, 2006; Guo *et al.*, 2023).

The association of tourmaline with zircon in small amounts refers to the low representation of felsic igneous rocks at the feeding region (Khorsheed and Ali, 2015).

C. Rutile mineral: This mineral is observed in all examined samples. Rutile generally occurs as a common mineral in metamorphic and acidic rocks (Bondje *et al.*, 2020). The percentage of Rutile ranges between 1.8-5.2% with an average ratio of 3.90% (Table 2), rutile is recorded as elongated to irregular grains, with dark red color and high in relief (Plate 2: I).

5. **Flaky minerals group:** represented by chlorite mineral only.

Where all examined samples contain chlorite. Chlorite almost occurs in a green color and several from irregular to subangular shapes (Plate 2: m). The percentage of chlorite ranged between 9.8-3.3% with an average ratio of 6.86% (Table 2). The origin of chlorite is the changing of some silicate metals (like olivine, pyroxenes, amphiboles, mica biotite, and phlogopite), as well as chlorite mineral can also originate from low-grade metamorphic rocks (Hibbard, 2002).

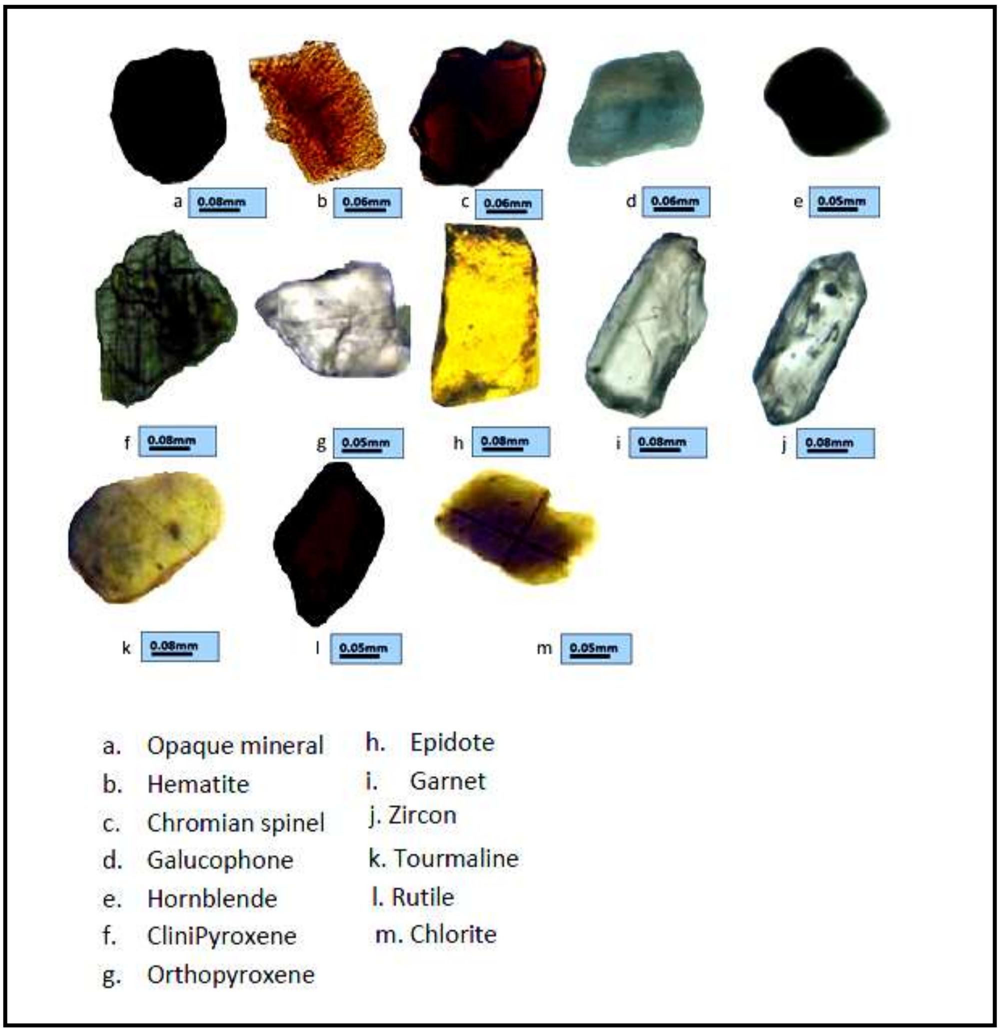

Plate 2. Types of heavy metals identified in Gercus Formation.

Provenance of the Gercus Formation Sediments

Heavy minerals investigation is too accurate method of knowing the origin of sediments. The current research diagnosed the existence of opaque minerals, which come from mafic igneous rocks, metamorphic rocks, and redeposited sedimentary rocks (Ali *et al.*, 2022). The petrographic study of examined samples diagnosed the presence of glaucophane, hornblende, Clinopyroxene, orthopyroxene, and epidote in a high ratio within non-opaque minerals, which proves that these minerals come from near source areas (Prothero and Schwab, 2014; Chmielowska and Salata, 2020; Zhen *et al.*, 2021; Ali *et al.*, 2022; Topaz *et al.*, 2023; Kamil *et al.*, 2023). The variety of minerals suggests a complex source area and a mixture of different rock types, indicating to complicated geological history.

Using (Hubert, 1962) diagram it was recognized that the tourmaline mineral is mainly metal amid the ZTR minerals (Fig. 3). Where tourmaline is found in many rock types. Generally, the assemblage of zircon, tourmaline, and tourmaline indicates to igneous and metamorphic source (Cyglicki and Remin, 2023). The ZTR index for studied specimens ranges from (0.10 – 0.29) and an average of 0.17 (Table, 2). This indicated that the rocks of the investigated region are immature and also may be possibly redeposited by older rocks near from feeding region.

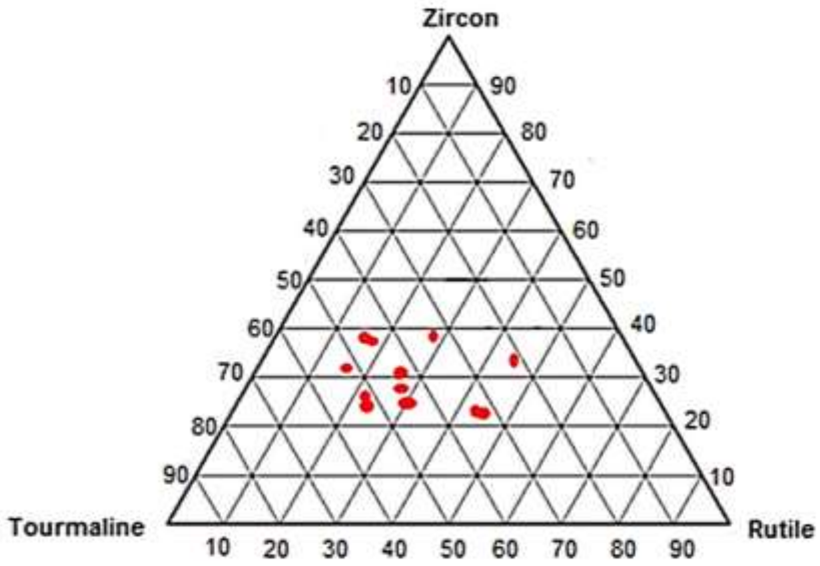

Fig. 3. Triangular plotting of zircon –Tourmaline- Rutile of the Gercus Formation Samples based on (Hubert, 1962).

Table 2: The ZTR index value in the investigated region

Samples	ZTR index
1	0.13
2	0.10
3	0.17
4	0.12
5	0.18
6	0.19
7	0.15
8	0.11
9	0.18
10	0.22
11	0.29
12	0.23
Average	0.17

Using the ternary diagram proposed by (Kasper *et al.*, 2008), all the examined specimens were situated within the moderately stable as displayed in (Fig. 4), which refers to the moderate stability of Gercus Formation sediment as a result of the big ratio of dark minerals besides the presence of glaucophane, hornblende, with epidote, this supports that these minerals come from near source area could not be carried from long distance.

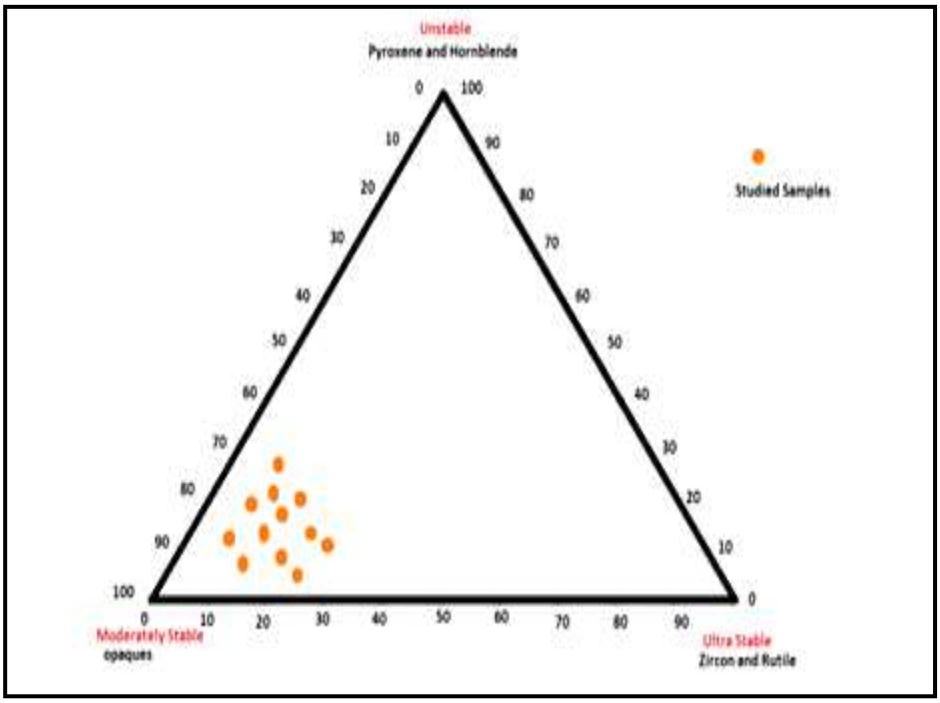

Fig.4. Ternary scheme for heavy metals stability of the Gercus Formation specimens depends on Kasper *et al.*, (2008).

Nechaev and Isphording (1993), proposed a plate tectonic analysis of heavy metals information by contrasting the accumulation and probable origin of clastic sediments that formed by various levels of the plate tectonic events. The samples plotted to obtain data on the ternary diagram displayed that most minerals fall within the active continental margins zone (Fig. 5), where these minerals have a comparatively high percentage of minerals originating from mafic rocks. All samples of sandstone are derived from active continental margins; thus, the moderate stability of the heavy minerals suggests relatively short-distance transport and assemblage near the source area, indicating a localized sedimentary environment. The tectonic setting, as determined by a ternary diagram, suggests an active continental margin, further supporting the idea of tectonic activity in the source area. The subangular of most heavy metals in study region refer to the near of feeding area, where after the collision between the Arabian plate and Turkey - Iranian plates at the Eocene sediments of Gercus Formation may be eroded and transported from Turkey plate to the Arabian plate in north and north eastern Iraq and situated as Gercus Formation.

The abundance of opaque metals refers to the transport by river and deltaic environments (Tucker, 1991). The existence of stable – ultrastable metals in studied samples as a result of depletion of most unstable and moderately unstable metals during transport. Zircon and rutile grains (elongate shapes) are perhaps originated from felsic and schist origins were carried by river currents from close by region adjacent to the study region and situated as alluvial deposits.

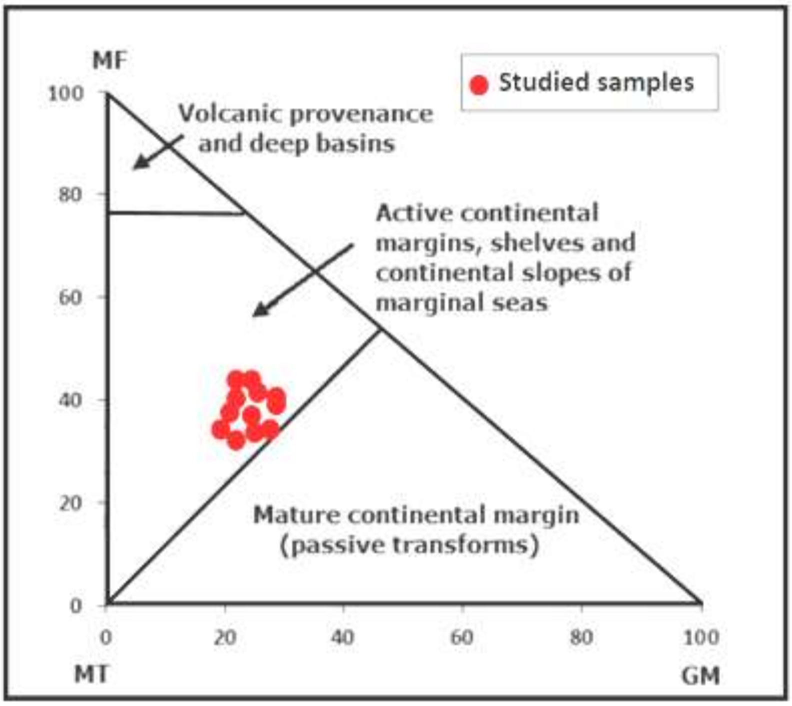

Fig. 5. Ternary plot of the MF (accessory metals elements to the metamorphic and granitic rocks, MT (accessory metals elements to the basic metamorphic rocks) GM (accessory metals elements to the marine mafic magmatic rocks) suite of the examined Gercus Formation specimens (Nechaev and Isphording, 1993).

Conclusion

The heavy metals groups in the studied sandstone specimens of Gercus Formation primarily consist of opaque minerals (opaque black–dark brown metals, hematite, and Chromian spinel), unstable minerals (glaucophane, hornblende, clinopyroxene, orthopyroxene), metastable minerals (epidote, garnet), ultrastable minerals (zircon, tourmaline, rutile), flaky minerals (chlorite) and other minerals.

In the Eocene, after the total depletion of Tethys Ocean crust, collision happened between Arabian plate and Turkey - Iranian plates therefore the two plates riding and thrusted above the Arabian plate. Consequently tectonic uplift and thrusted faults formed in the north and north eastern Iraq. After the collision event and finishing of flysch stage the Gercus basin received the clastic sediments. This sediment transported from Turkey plate exactly from Bitlis Metamorphic rocks and ophiolite complex, where these areas represent typical origin to the diagnosed heavy metals.

The diversity of heavy minerals refers to a variety of the rocks in source area. Depending on the high ratio of opaque minerals the studied succession is derived basically from acidic and mafic igneous rocks, metamorphic rocks and reworked sedimentary rocks. Rivers are a main origin of supply of opaque metals, accordingly the rates of these metals rise in fluvial and deltaic environments. The low presence of unstable metals group minerals in the studied section proves the proximity of feeding area. The existence of meta - stable metals (garnet and epidote) indicate to river environment. The study showed that most of heavy metals grains are angular-subangular to sub- rounded shapes, which corroborate the near of feeding area.

According to the nature of the relation between ultrastable and metastable heavy metals, the sediments of the Gercus have modest stability. Mainly, the sediments of the Formation moved from little distances and assemblage near the feeding region. The tectonic situation of the studied region was determined through a ternary diagram which represents the active continental margin.

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