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Mineralogical and Grain Size Analysis of Bai Hassan Formation Terraces in Al-Teeb Area, SE Iraq

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Abstract

Bai Hassan Formation is exposed as remnants of beds from previous formations due to severe erosion that were removed. Results from grain size analysis revealed that most of the studied sediments were coarse-grained sediments ranging from coarse sand to gravel. The study shows that the sediments are poorly sorted. The values of skewed coefficients ranged from fine to strongly skewed, and the negative values indicate the occurrence of hard changes in the environment. Meanwhile, the kurtosis values for the studied sediment indicate that the differences in these values are due to changes in the flow and sediment sorted in a relatively high energy environment. Light minerals like quartz, and feldspars, and rock fragments are identified. Heavy minerals such as chlorite, amphibole, pyroxene, mica, epidote, zircon, garnet, tourmaline, rutile, kyanite, and staurolite can provide information about the geological processes and environments that occurred in a particular area. These minerals can be indicative of specific rock types, metamorphic or igneous formations, that are derived from high Zagros mountains. The collision between the Arabian Plate and the Eurasian Plate resulted in the formation of the Zagros Fold and Thrust Belt, leading to the uplift and deformation of the Zagros Mountains. The Bai Hassan Formation in Iraq originated during the Miocene epoch from fluvial and alluvial fan environments. Sediments carried by rivers and streams from the elevated mountains in Iraq and Iran were deposited, forming conglomerates, sandstones, and mudstones that reflect various depositional settings such as braided river channels and floodplains indicating a rapidly sinking basin with freshwater and lacustrine environments.

Keywords: Bai Hassan Formation; Grain size analysis; Mineralogy; Al-Teeb geology; Iraq

1. Introduction

The surveyed formation is situated at the eastern part of the Al-Teeb area by the side of the south Hamrin in the Governorate of Missan, the formation is exposed as remains of beds from previous formations, because these beds were subjected to severe erosion, which led to the removal of most of the beds of this formation (Fig.1).

In 1918, Busk and Mayo (in Buday, 1980) published the first description of the Bakhtiari (Bai Hassan) Formation western Iran. The nomenclature had also been used in Iraq, where the formation was typically split into lower (Injana) and upper (Bai Hassan) formations that were both regarded as distinct formations (Jassim and Goff, 2006). The name Upper Bakhtiari Formation has been dropped in Iran, and it has been renamed Bakhtiari Formation (Sissakian and Al-Jiburi, 2012).

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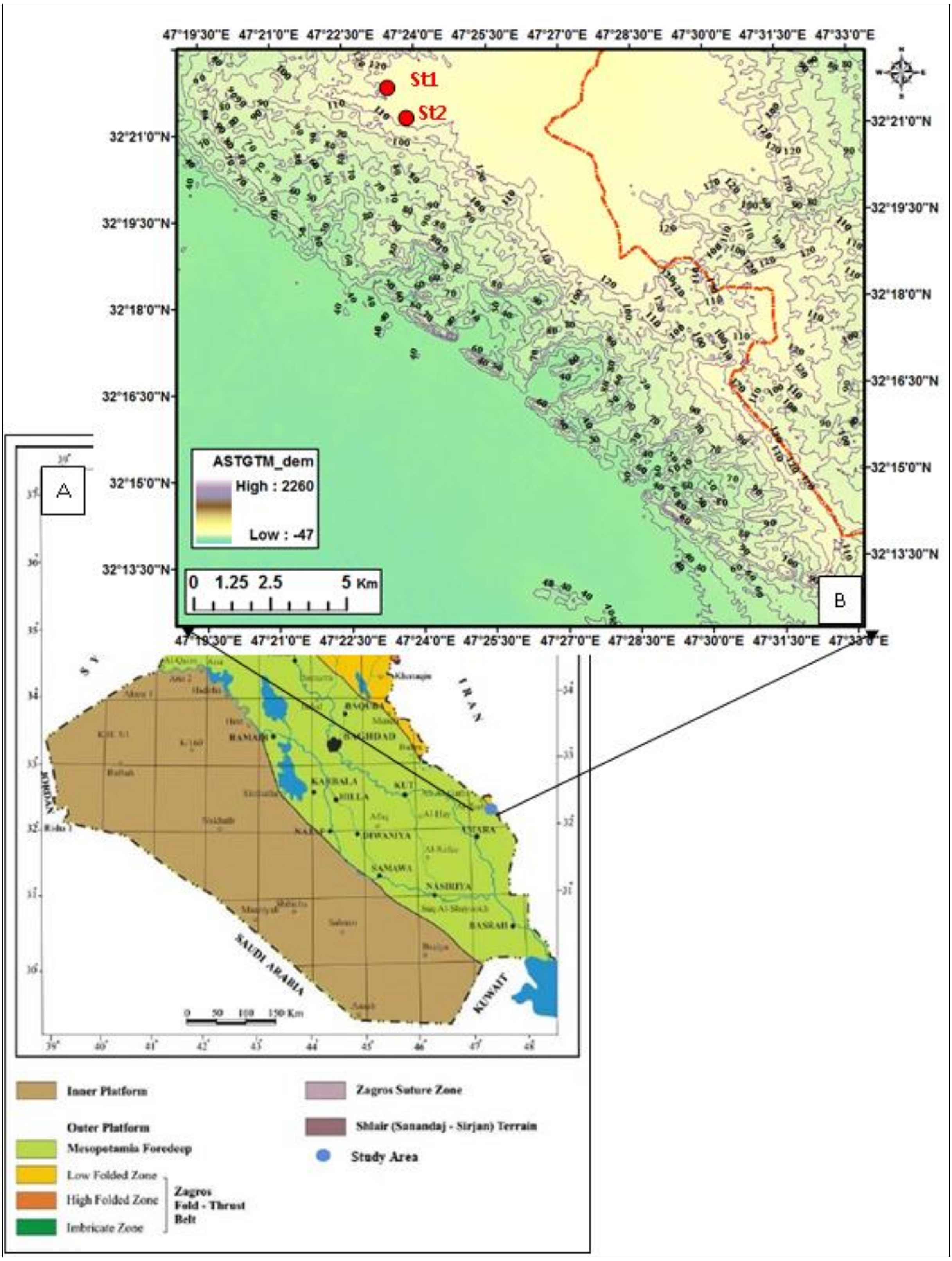

Fig.1. Studied area in Al-Teeb region, A. Tectonic location of current study within outer platform (Fouad, 2015), B. Topographic map for the study area, red circles present the studied outcrops at Alzubaydat region (Abdulnaby et al., 2021).

While there are many scholars confirmed that the two formations are one formation (Bellen et al., 1959). Generally, the name of the Upper Bakhtiari is changed into Bai Hassan Formation by Jassim et al.

(1984 in Jassim and Goff, 2006). However, Al-Rawi et al. (1992) formally established the name of the Bai Hassan Formation. Also, the presence of the studied formation in this area is questionable by some researchers, Nonetheless, Mukdadiya and Bai Hassan formations are reportedly exposed in the study region, according to geologists from the Iraq Geological Survey (e.g., Yacoub, 1993 in Abdulnaby et al., 2021). According to some researchers, only the Injana and Mukdadiya formations are exposed in the Al-Teeb area, and the Bai Hassan Formation is not recorded in the region (Alsamaani, 2011; Alsaad, 2014). Bai Hassan Formations, which is a part of the Pliocene sequences, extensively dispersed in the High Folded and Foothill zones. As of yet, the age of the Bai Hassan Formation is unknown. However, many scientists advocated for the Pliocene–Pleistocene age (Al-Rawi et al., 1992; Sissakian and Al-Jiburi, 2012). In the research region, the Bai Hasan Formation is hardly ever exposed. Only a 1 to 5 m thickness was found because the majority of the formation is eroded (Fig. 2).

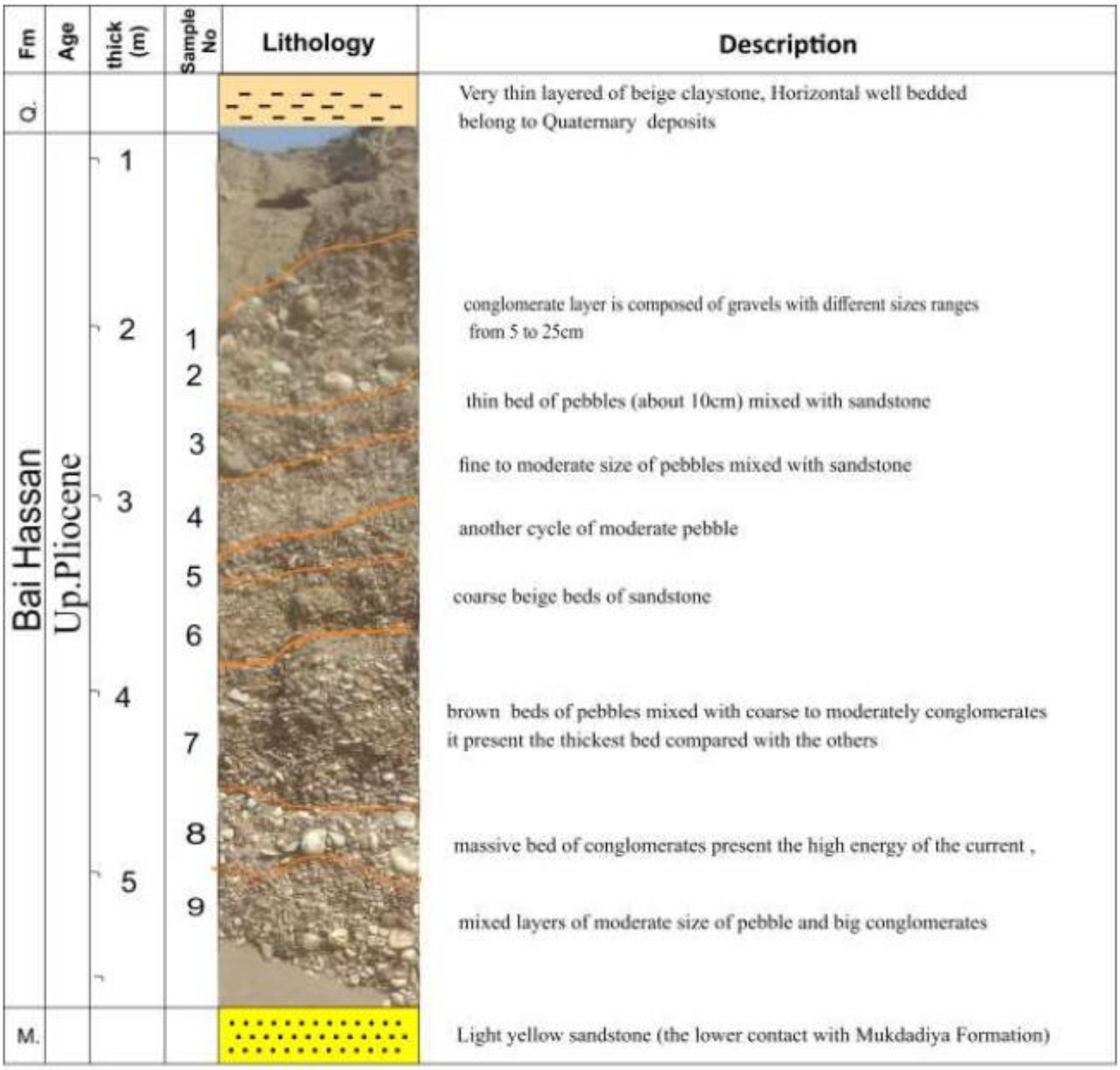

Fig. 2. Stratigraphic column of Bai Hassan Formation, illustrated the cyclicity of the gravels and sandstone

The Mukdadiya and Bai Hassan formations are in contact with one another through massive conglomerates. Conglomerate gravels range in size from 5 to 15 cm and make up the conglomerate layer. The gravels surrounding the conglomerates have well-rounded, elongated, semi-spherical shapes and are adhered to by coarse, light yellowish sandstone. Only the upper portion of the Bajalia anticline at the northwest limb had the formation exposed. Tectonically, the study area locates at the end of the low folded zone (Southern Hamrin) (e.g., Buday and Jassim, 1987; Numan, 1997; Jassim and Göff, 2006; Fouad, 2015), many anticlines along the NW-SE represent the contact between the Low Folded Zone and the Mesopotamia Foredeep, the most important of these anticlines are Makhul, North Himrin, South Himrin, Badra, Buzurgan anticlines (Abdulnaby et al., 2021) (Fig.1). The convergence of the Arabian plate with Iranian plate resulted in the subduction of the former beneath the latter, leading to a slight tilting of the Arabian plate towards the northeast. This geological process formed a sequence of folds and thrusts in the Zagros Mountains, while in the Middle Miocene period, evaporites of the Fat'ha Formation were deposited in the foreland basin, and with the end of the closure of the Tethys Sea, the subsequent formations came as clastic sediments such as Injana, Mukdadiya and Bai Hassan formations (Al-Mutury and Al-Asadi, 2008). Also, The High Folded Zone was raised with increasing strength during the Late Miocene and Pliocene. Erosion products were deposited in the neighboring molasse basin, which is distinguished by conglomerates dispersed within Mukdadiya and Bai Hassan formations (Jassim and Goff, 2006). There is no comprehensive geological study on Al-Teeb area. However, studies on the hydrogeology, sedimentology, and stratigraphy of Al-Teeb area were carried out generally (e.g., Alsamaani, 2011; Al-Abadi, 2011; Alsaad, 2014; Al-Abadi, 2015; Abdulnaby et al., 2021; Mahdi and Soltan, 2021; Shalal et al., 2022). Infrequent studies in the study area due to the existence of mines and unexploded bombs.

This research aims to study the sedimentology of the clastic beds that form Bai Hassan Formation in terms of sedimentary and mineralogical aspects and try to diagnose the types of light and heavy minerals that were studied for the first time in these deposits, collecting the sedimentary data (grain size) to identify the source rocks of this formation and to understand the sedimentary environment that accompanied this formation rocks with determine the direction for the movement of these deposits to new sedimentary basins that accumulated in southern Iraq

2. Methodology

Field and laboratory works were conducted to study the mineralogy of the Bai Hassan Formation in two stations in the Al-Teeb area near the Iraq-Iran border. The fieldwork was represented by choosing suitable places for sampling. As above mentioned, the outcrops of the studied formation are rare and needed a careful survey. The maximum thickness reaches 5 m (station 1). Over two days, field work was carried out, with the primary goal of describing the lithology, structure, and stratigraphy of the geological formations. Accurate sampling was conducted to the studied column for each sedimentary cycle. 11 total samples were taken from the studied formation. Nine samples were chosen from station 1 for grain size analysis at the coordinates 47° 23´ 30″ E, 32° 22´ 45″ N and two only from station 2 because of the small thickness (1 m.) (Plates 1 and 2) at the coordinates 47° 23´ 50″ E, 32° 21´ 54″ N, then taken to the laboratories of the Marine science center and Engineering College (University of Basrah). Five samples were chosen for determining and calculating the light and heavy minerals, which diagnosed at the Geology Department- Baghdad University.

The grain size analysis was conducted depending to Folk (1974), the detail of this method as following: The dry sieving method was used by several sieves which are 1, 2, 2.83, 4.75, 9.5, 12.5, 16, 19, 25.37.5, 63, 75 mm. The sieves were arranged vertically from the large sieve to the smaller (1 to 75 mm). Under the last sieve is a pan to collect the mud in case there are grains less than the size of the sand. The sieves were installed using the electric shaker through belts, then the shaking time was set for 10-15 minutes. After that, the contents of each sieve are emptied separately on clean paper, and then the cumulative percentage is calculated for each of the parts separated by the sieves, by adding the percentage of each part to the next.

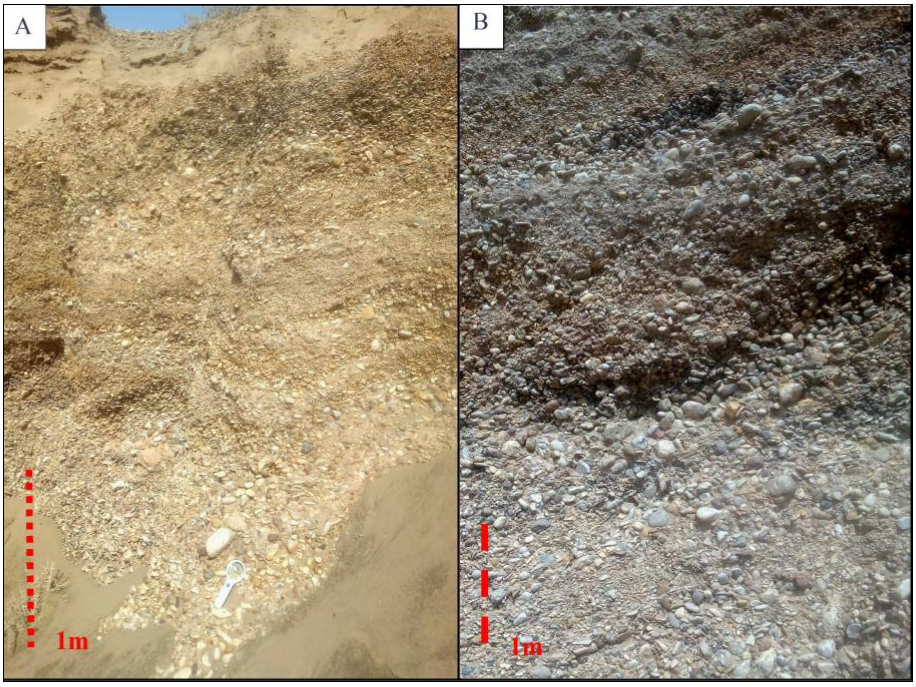

Plate 1. (A and B) the outcrops of the maximum thickness (5m) for the studied formation (station1), the alternation of the sandstone and gravel cycles are common.

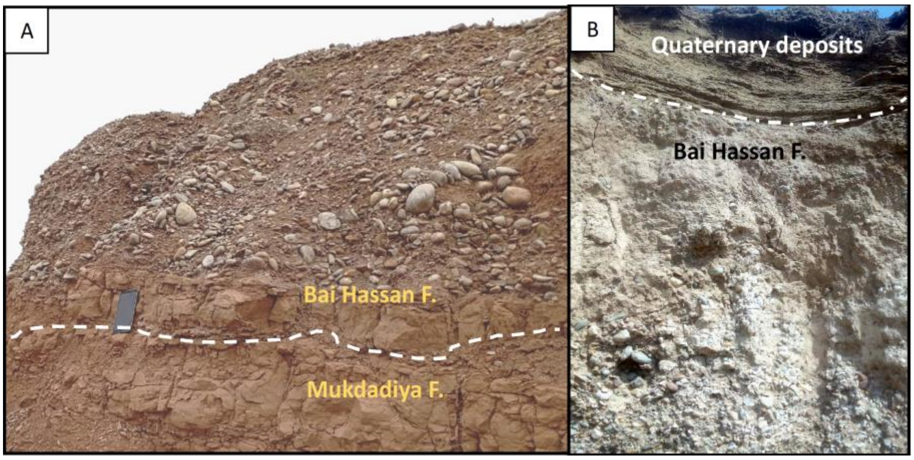

Plate 2. A. Studied section (2) with the contact with Mukdadiya Formation (white dotted line), it appears as thin pebble layer. B. The upper contact of Bai Hassan Formation with Quaternary deposits, it appears as thin horizontal clayey beds.

3. Stratigraphy

Bai Hassan Formation is one of the most widespread formations in the Low Folded Zone. It is spreading from the North (east and west) until south at Amara, along the Iraqi-Iranian border, to the Tigris River (Sissakian and Al-Jiburi, 2012). The Low Folded Zone at Al-Teeb region exposes three formations: Injana, Mukdadiya, and Bai Hassan formations (Upper Miocene-Pleistocene). Furthermore, Quaternary deposits encompass a wide range of locations, most of which are characterized by alluvial fans produced by seasonal waterways that traveled from Iran to Iraq (Abdulnaby et al., 2021). Al-Rawi et al., (1992) describe the lithology of Bai Hassan Formation in the type locality as a succession of main cycles which are conglomerate, claystone and sandstone (Plates 1 and 2).

The terrace conglomerates include a significant proportion of carbonate pebbles (more than 70% of the rock), whereas the Bai Hassan conglomerates contain just 30% carbonate pebbles (Jassim and Goff, 2006). A thin bed of pebbles (about 10cm) represents the contact between the two Injana and Bai Hassan formations in some places (Plate 2A). Bai Hassan Formation was observed with a thickness of 1 to 5m and a sharp contact with quaternary sediments. The Bai Hassan Formation is made up of cycles of boulders, conglomerates, and pebbles with a sand matrix. The size of gravel is varied from limited millimeters to 25 cm; however, 5 cm is the most typical size.

Whereas, the top of the formation overlaid by a very thin sheet of claystone, different of texture and direction of Bai Hassan Formation, it located with horizontal setting (Plate 2B).

4. Results

4.1. Grain Size Analyses

Grain size analysis is mainly used to identify and understand the grain size characteristics and texture of sediments, as this information is necessary to estimate the sedimentation environment (Ghsoub et al., 2020). Folk's classification (1974) was used to determine the types of sediments that were recorded in the study area.

4.2. Cumulative Curves

These curves are useful for analyzing and comparing sediment samples, as they provide a quick and intuitive way to visualize the overall grain size distribution of sediment. The results of the cumulative and passing curves of the grain size are illustrated in Figs. 3 and 4.

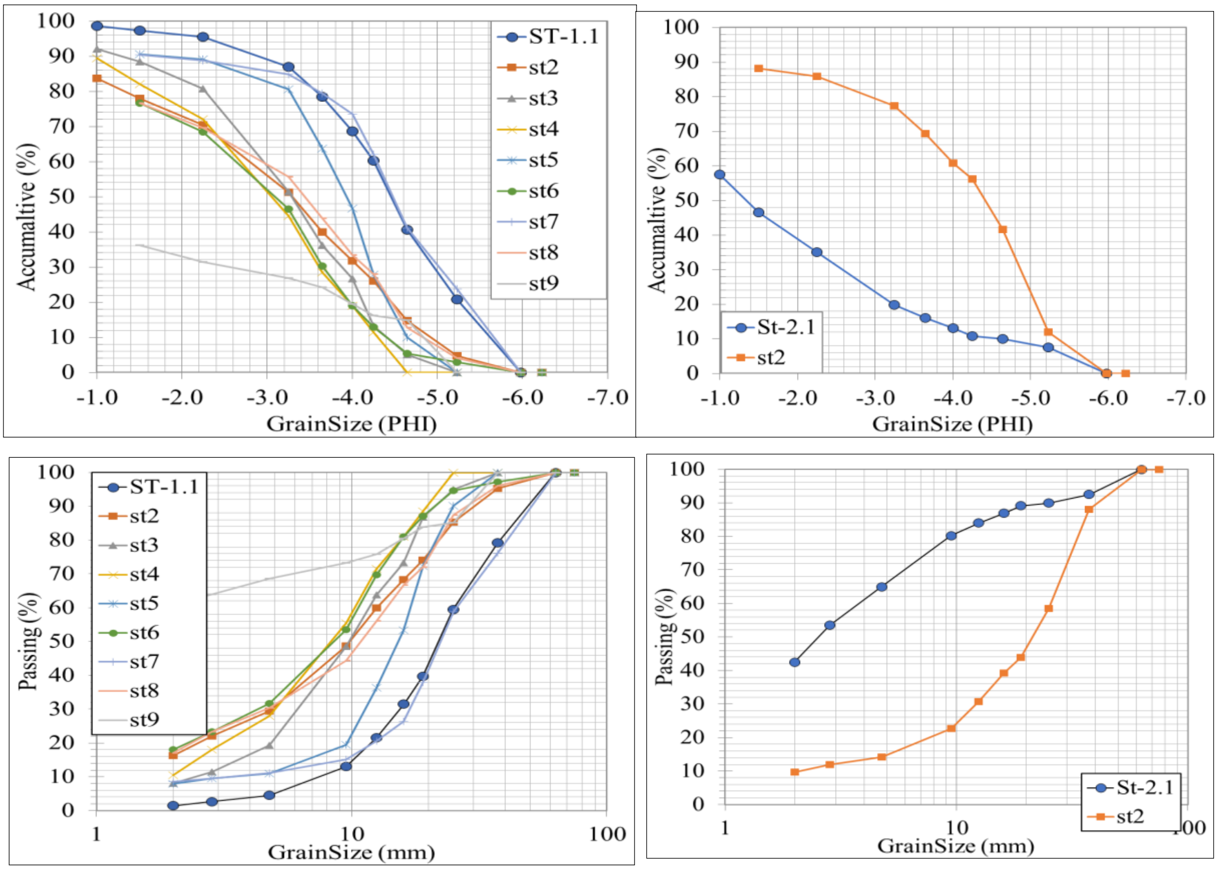

Fig. 3. Cumulative curve of studied samples of Bai Hassan Formation (Cumulative and Passing), stations 1 and 2, Al-Teeb region.

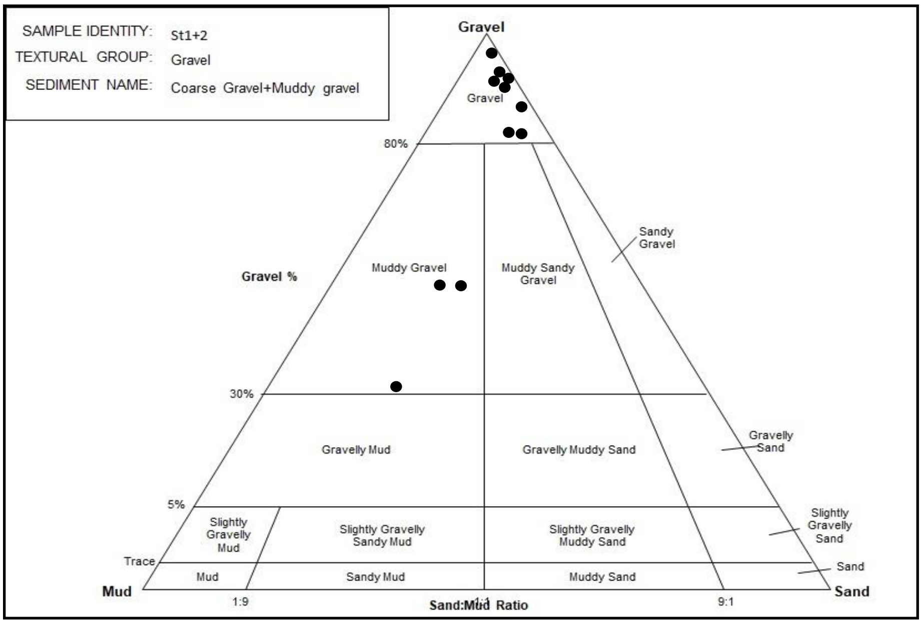

Fig. 4. Classification of the studied samples according to Folk's classification of clastic sediments.

The gravel presents the highest percentage in the studied section, and the clay and silt were wholly lost from the analyzed samples. The result of the studied area is located within two zones; Gravel and Muddy gravel. Most of the samples comprise of gravel and coarse sand.

4.3. Light and Heavy Minerals

This study recorded many light and heavy minerals illustrated in Tables 1 and 2 with the percent for each component (Plates 3 and 4) (Fig. 5).

Table 1. Range of light minerals in Bai Hassan Formation at Al-Teeb region

Light components		Samples number				
		St1-9	St1-10	St1-11	St2-1	St2 -2
Quartz	Monocrystalline Quartz	21.5	20.9	23.3	20.5	26.1
	Polycrystalline Quartz	3.7	2.2	3.5	2.6	2.5
Feldspars	Potash Feldspar Microcline	2.9	2.4	3.7	2.8	2.2
	Potash Feldspar Orthoclase	2.2	4.4	3.2	4.5	3.2
	Plagioclase Feldspar	4.5	3.8	3.8	3.7	4.9
Rock fragments	Carbonate rock fragments	38.8	36.5	36.3	40.2	37.5
	Chert rock fragments	7.9	9.4	8.2	10.6	7.1
	Mudstone rock fragments	4.4	6.8	5.4	4.5	3.2
	Evaporites (Gypsum)	4.3	5.3	3.5	2.3	4.6
	Igneous rock fragment	4.7	3.7	2.2	3.4	2.5
	Metamorphic rock fragments	2.2	2.8	3.3	2.5	3.4
Coated grains by clay		2.6	1.2	2.7	1.8	1.9
Others		0.3	0.6	0.9	0.6	0.9

The following light minerals were distinguished: Quartz, Feldspars and rock fragment, while the Heavy minerals are composed of opaque minerals that formed the highest percentage compared to the rest of the minerals (46.4%). The other heavy minerals are chlorite, amphibole, pyroxene, mica, epidote, zircon, garnet, tourmaline, rutile, garnet, kyanite, staurolite.

Table 2. Range of heavy minerals in Bai Hassan Formation at Al-Teeb region

Mineral components		Samples number				
		St1-9	**St1-10**	**St1-11**	**St2-1**	**St2-2**
Opaques		46.4	42.1	44.2	39.9	45.4
Chlorite		8.1	6.5	7.3	6.7	7.5
Pyroxenes Group	Orthopyroxene	2.7	2.2	2.4	2.8	2.8
	Clinopyroxene	2.2	5.4	4.3	5.4	4.3
Amphiboles Group	Hornblende	4.5	4.9	5.1	6.5	5.4
	Glaucophane	1.1	1.5	0.4	0.6	1.5
	Actinolite	1.6	1.3	2.6	2.3	0.6
Mica Group	Biotite	4.2	5.5	4.3	5.3	3.6
	Muscovite	4.6	5.3	4.7	5.7	4.1
Epidote		6.4	6.4	4.4	6.8	6.4
Zircon		4.7	3.2	4.0	3.0	3.5
Tourmaline		3.5	3.5	4.5	4.3	3.3
Rutile		2.9	4.6	3.2	3.4	3.6
Garnet		4.7	2.8	3.4	4.3	3.5
Staurolite		0.5	2.4	2.8	1.3	2.2
Kyanite		1.3	1.5	2.1	1.1	1.4
Others		0.6	0.9	0.3	0.6	0.9

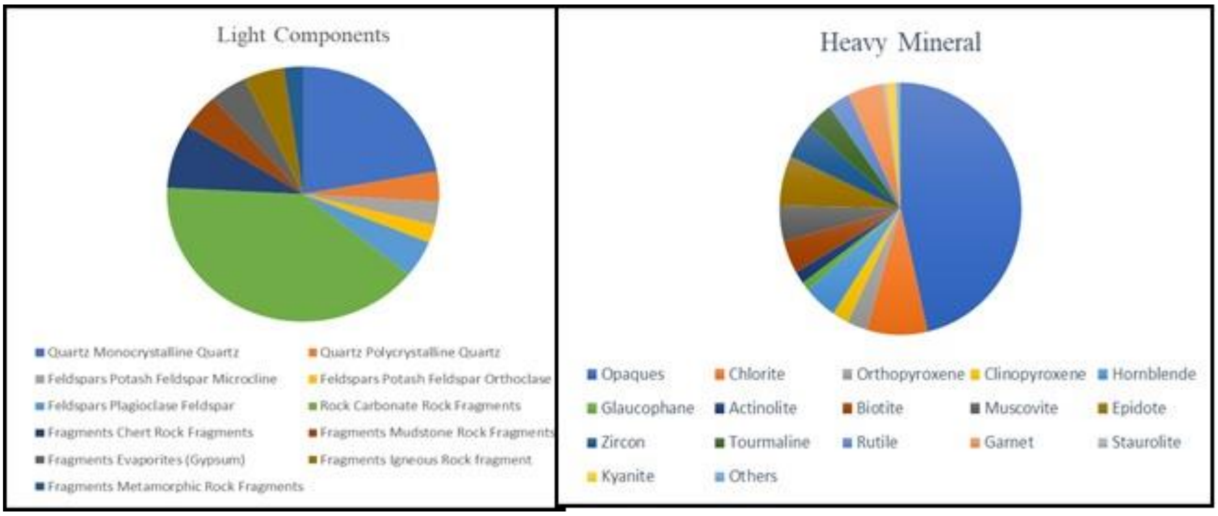

Fig. 5. Diagram for the percent of light and heavy minerals of Bai Hassan Formation

The geological indication for the existence of light minerals such as quartz, feldspars and rock fragments in rocks can vary depending on the specific context, but there are some common indicators of the origin of these light and heavy minerals. Quartz is one of the most common minerals on Earth, and can often be found in many types of rocks, including granite, sandstone, and quartzite.

Feldspars are also common in many types of rocks, including granite, gneiss, and basalt. Rock fragments can be derived from the erosion and weathering of other rocks, and their presence in a rock can indicate the type of rock that was eroded (Blatt et al., 2006). The presence of heavy minerals such as chlorite, amphibole, pyroxene, mica, epidote, zircon, garnet, tourmaline, rutile, kyanite, and staurolite can be indicative of specific geological processes or environments. For example, chlorite and amphibole are commonly found in metamorphic rocks, particularly those formed under conditions of low to moderate pressure and high temperature (Bushmin and Glebovitsky, 2008). Pyroxene is often found in igneous rocks, especially those with a mafic composition (Klein and Philpotts, 2017).

Mica is also commonly found in metamorphic rocks, particularly those formed under high pressure and temperature conditions (McCann and McCann, 2021). Zircon is a common accessory mineral found in igneous and metamorphic rocks, and is often used for radiometric dating of rocks (Valley et al., 2014).

Garnet is a common mineral in metamorphic rocks, and its composition can provide information about the pressure and temperature conditions under which the rock was formed (Xia and Zhou, 2017). Tourmaline is often found in pegmatites and hydrothermal veins, and can provide information about the conditions under which these rocks were formed (Simmons et al., 2005). Rutile is commonly found in metamorphic rocks, and can provide information about the oxidation state of the rocks during metamorphism (Harlov and Förster, 2013).

Kyanite is typically found in metamorphic rocks that have undergone high-pressure, low-temperature conditions, and its presence can be indicative of the original sedimentary or volcanic protolith (McCann and McCann, 2021). Staurolite is also commonly found in metamorphic rocks, particularly those formed under high-pressure conditions (Bushmin and Glebovitsky, 2008). Overall, the presence of these heavy minerals can provide valuable information about the geological history and processes that have occurred in a given area, and can be useful in geological exploration and resource evaluation.

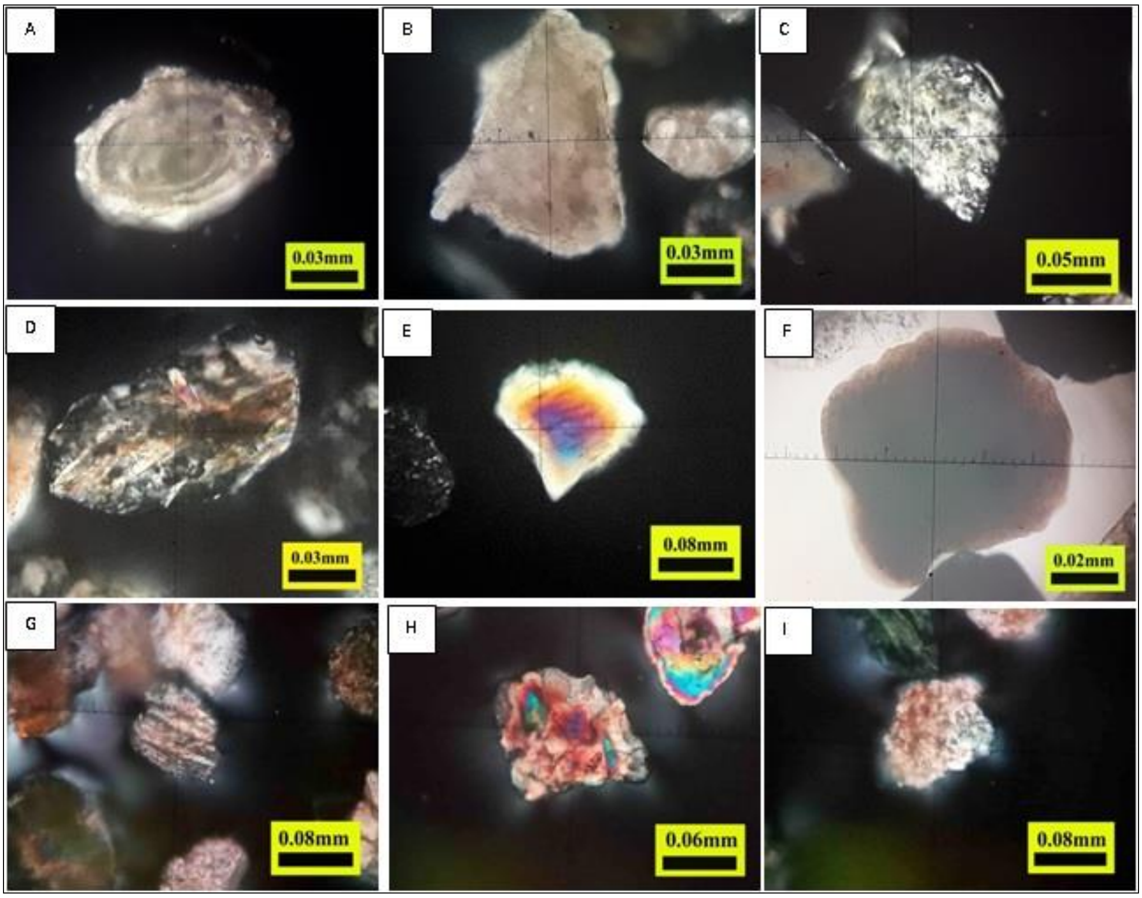

Plate 3. The light minerals that recorded in the studied section; A- Carbonate rock fragment, _XPL; B. Carbonate rock fragment; C. chert rock fragments XPL; D. Metamorphic rock fragment, XPL; E. Monocrystalline quartz, XPL; F. mudstone rock fragment, XPL; G. plagioclase feldspar, XPL.; H. Polycrystalline quartz, XPL; I. Potash feldspar – orthoclase, XPL.

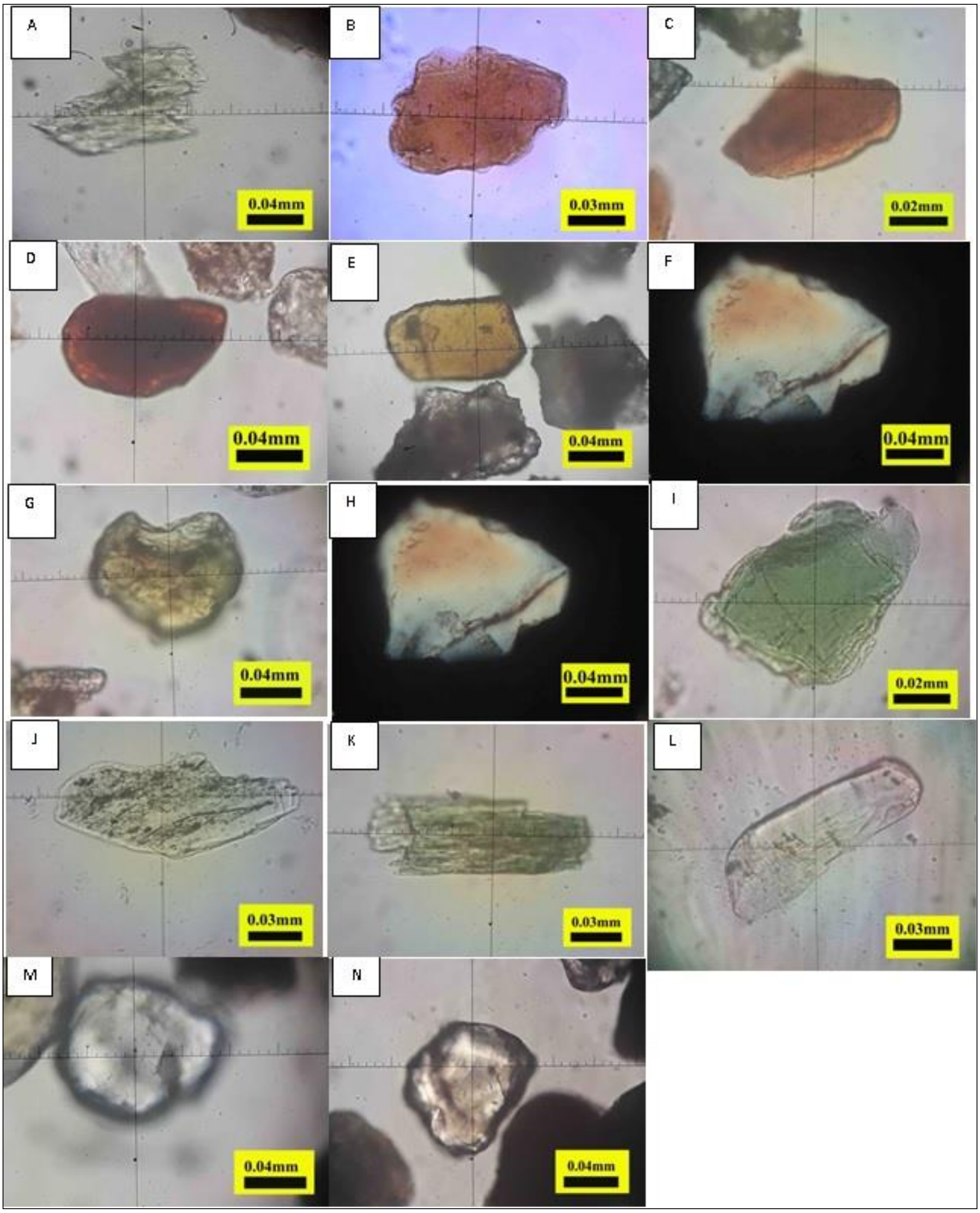

Plate 4. Heavy minerals that recorded in the studied section; A- Colorless actinolite amphibole, PPL; B-Brown color biotite, PPL;C- Deep yellow color staurolite, PPL; D- red high relief rutile, PPL; E- Honey color tourmaline, PPL; F- Flaky habit, muscovite mica, XPL; G- Green color epidote, PPL; H- Flaky habit, muscovite mica, XPL; I- Green color, flaky habit chlorite, PPL; J-Green color hornblende amphibole, PPL; K-Green color, clinopyroxene, PPL; L-High relief, kyanite, PPL; M- High relief, Equant form garnet, PPL; N High relief colorless zircon, PPL

5. Statistics analysis

Median, mean, sorting, kurtosis and skewness are several important measures used in statistical analysis to describe the shape of a distribution of data (Cooksey and Cooksey, 2020), which are used in many geological applications, including sedimentary environments. The results of the statistical analysis are shown in Table 3.

Table 3. Statistical analysis of the studied samples

S. No.	Median	Mean	Sorting		Skewness		Kurtosis	
St1.1	-4.4	-4.4	1.06	Poorly sorted	1.2	Fine skewed	1.08	Very leptokurtic
St1.2	-3.2	-2.96	1.48	Poorly sorted	0.13	Fine skewed	0.48	Very platytokurtic
St1.3	-3.3	-3.13	1.12	Poorly sorted	0.24	Fine skewed	1.12	Leptokurtic
St1.4	-3.1	-2.86	1.20	Poorly sorted	0.22	Fine skewed	0.84	platytokurtic
St1.5	-3.9	-3.73	1.01	Poorly sorted	0.39	Fine skewed	1.77	Very leptokurtic
St1.6	-3.1	-4.1	1.32	Poorly sorted	0.26	Fine skewed	0.70	platytokurtic
St1.7	-4.5	-4.43	1.21	Poorly sorted	0.22	Fine skewed	1.50	Very leptokurtic
St1.8	-3.4	-0.33	1.51	Poorly sorted	0.25	Fine skewed	0.66	platytokurtic
St1.9	-1.0	-0.83	1.48	Poorly sorted	-1	Coarse skewed	0.65	platytokurtic
St2.1	-1.3	-2	1.34	Poorly sorted	-0.82	Strongly Coarse skewed	0.94	Mesokurtic

6. Discussion

The Mandali-Badra-Al-Teeb alluvial fans are found in southern Iraq near the Iraqi-Iranian border. The gravelly and sandy sediments deposited by braided rivers make up these merging alluvial fans. These are located above the Injana, Mukdadiya, and Bai Hassan formations, which are found in the mountainous terrain along the state border (Jassim and Goff, 2006).

Through the grain size analysis and the statistical coefficients obtained from the studied samples, the results revealed that most of the studied sediments are coarse-grained sediments ranging from coarse sand to gravel. The statistical results showed the median ranged between -4.4 to -0.1 and the amount of mean ranged between -4.4 to -0.33. The studied sediment was characterized by a large variation in the sizes of the grains, this variation gives the area a high permeability, therefore, this area is very rich in groundwater, which is present within these layers. Muhardi et al. (2022) stated that the poor sorting is due to the size of the grains that accumulated randomly and that the bad sorting is affected by the speed of the current that is not constant most of the time (Rifardi, 2012).

The values of the skewed coefficient of the sediments of the study area ranged between 1.2 and 0.082. It represents fine to strongly skewed and the negative values indicate the occurrence of hard changes in the environment, such as tidal changes and high energy waves in the region (Elsherif, et al., 2020). While the values of kurtosis for the studied sediment varied between 1.77 and 0.48 and it represents very leptokurtic to very platytokurtic. The changes in the kurtosis value indicate that the differences in these values are due to changes in the flow and sediment sorted in a relatively high energy environment.

The large grain sizes present in the region indicate a high velocity for the carrying current, which is strong enough to transport particles of this size. By using size analysis, the particle sizes, the energy and environmental conditions of the transport can be determined. Relationships between different size parameters have been established by researchers to understand the deposition process, distinguish between different types of sediments (whether riverine or marine), and determine the velocity of currents present in the environment (Friedman, 1967).

Based on the relationship between sorting and shape parameters, it can be observed that the average grain size is large, indicating coarse and poorly sorted grains. This is evidence that the transport process is close to the source despite the high current velocity due to the presence of coarse particles. However, the relationship between skewness and the arithmetic mean can be seen in Fig. (6).

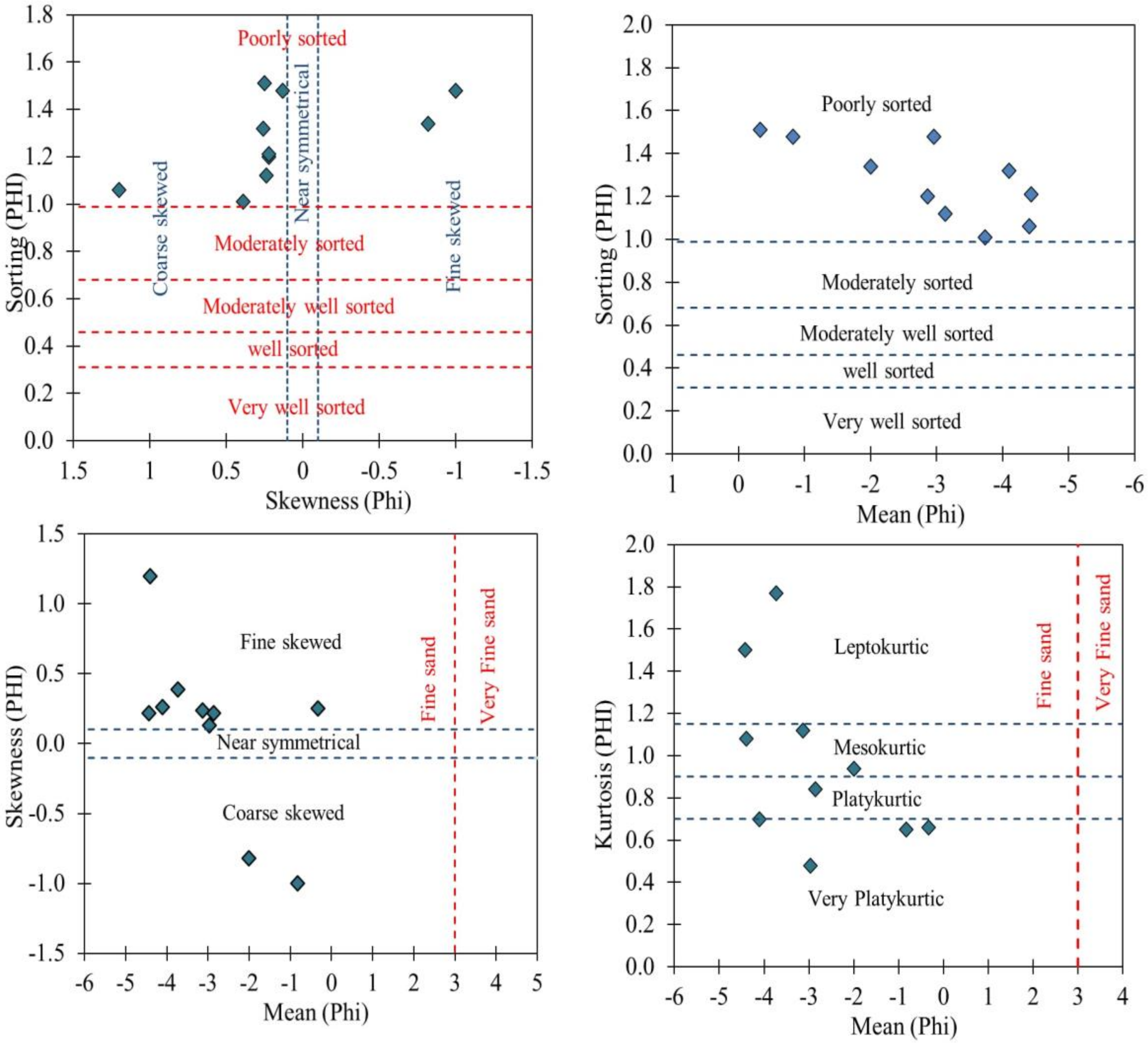

Fig. 6. The statistical analysis results of Bai Hassan Formation, stations 1 and 2.

The study finds a difference between the sediments in the process of skewness distribution, which is evidence of the large mixing process between sediment layers in the study area. The fluctuation between different current velocities indicates the relationship between sorting and distortion. Most sediments in the area have poorly sorted coarse sand due to their coarse volumes, which the current cannot rewash and deposit with good sorting again.

Poor sorting in gravel grains indicates that the grains have a wide range of sizes and are not well-sorted according to size. This can be due to a variety of factors, such as the energy of the transporting medium (e.g., water or wind) or the distance that the sediment has been transported. Poor sorting can occur when the transporting medium is not strong enough to sort the grains effectively or when the transport distance is short, allowing a wide range of sizes to be deposited together (Mulder and Alexander, 2001). This can result in a mixture of different-sized particles, ranging from large boulders to small pebbles, that are not well-sorted according to size. Similarly, Flemming (2011) states that poorly sorted gravel can indicate a high-energy transport environment, such as a river channel or a beach subjected to wave action. In these environments, the sediment is constantly being reworked and mixed, resulting in a wide range of grain sizes and poor sorting.

Overall, poorly sorted gravel indicates a dynamic and constantly changing sedimentary environment, where sediment is constantly being transported and mixed with the action of water or wind. Most of the statistical results for the sand indicated that the majority of the results fell within Platykurtic (Fig. 6). Platykurtic is a statistical term used to describe the shape of a distribution of data in statistics. It refers to data that is very close to a normal distribution, but has a tendency to be shorter and more open at the tails than a normal distribution (Tucker, 2003). Therefore, data in a platykurtic distribution contains values that are very close to the mean, and extreme or rare values (outliers) have less impact on the shape of the distribution compared to other distributions such as leptokurtic distributions. Sediments deposited in a high-energy environment such as a beach or steep mountain stream may show a platykurtic distribution due to the sorting and selective transport of sediment particles by waves or currents (Davis, 1986).

The occurrence of feldspar grains in their natural state suggests incomplete chemical weathering processes, pointing towards a semi-arid climate where mechanical weathering prevails over chemical weathering and indicating a limited distance of transportation (Tucker, 1991). During the Pliocene epoch in the northeastern Arabian Plate, several tectonic events and processes shaped the region, The ongoing collision between the Arabian Plate and the Eurasian Plate continued during the Pliocene. This convergence resulted in the formation of the Zagros Fold and Thrust Belt in the west, where the Arabian Plate is colliding with the Iranian Plate. These events led to significant uplift and deformation of the Zagros Mountains. The Pliocene witnessed the continued uplift and folding of these mountains, creating the characteristic structures and topography seen today (Beydoun et al., 1992; Al-Kaabi et al., 2023). The mountain heights from both directions Iraq and Iran (Allen and Talebian, 2011). Therefore, the origin of the deposits of the Bai Hassan Formation in Iraq is believed to be from fluvial and alluvial fan environments that were active during the Miocene epoch (Sissakian et al., 2021). Sediments were transported and deposited by rivers and streams that drained from the uplifted areas of the surrounding mountains. The formation is composed of conglomerates, sandstones, and mudstones that reflect a range of depositional environments, from braided river channels to floodplain deposits (Al-Juboury and McCann, 2008). This sedimentary deposit is a common type of molasse, which was formed in a rapidly sinking basin and is characterized by freshwater and lacustrine environments (Jassim and Goff, 2006). It was deposited in a foredeep that was rapidly sinking (Al-Sharahan and Narin, 1997).

7. Conclusions

The grain size analysis and statistical coefficients obtained from the samples in the Mandali-Badra-Al-Teeb alluvial fans of southern Iraq suggest that most of the sediments are coarse-grained sediments ranging from coarse sand to gravel. The poor sorting in the sediments indicates the occurrence of hard changes in the environment, such as tidal changes and high energy waves in the region. Very Leptokurtic sediment deposits exhibit a peaked and narrow grain size distribution curve with a higher concentration of particles around the mean size. Very leptokurtic sediment deposits would indicate an environment characterized by high energy: Sediments are likely to be transported by strong currents, which selectively sort and concentrate particles of similar sizes. This can occur in environments such as steep mountain streams and high-energy beaches, due to the selective transport of sediment particles by waves or currents. The Pliocene epoch in the northeastern Arabian Plate was marked by significant tectonic events and processes. The ongoing collision between the Arabian Plate and the Eurasian Plate led to the formation of the Zagros Fold and Thrust Belt (origin of light and heavy minerals), resulting in the uplift and deformation of the Zagros Mountains. The deposits of the Bai Hassan Formation in Iraq originated from fluvial and alluvial fan environments during the Miocene epoch. Sediments were transported and deposited by rivers and streams draining from the uplifted mountains in Iraq and Iran. The formation comprises conglomerates, sandstones, and mudstones, reflecting a range of depositional environments, including braided river channels and floodplains. The Bai Hassan Formation represents a molasse deposit, formed in a rapidly sinking basin characterized by freshwater and lacustrine environments. Overall, these tectonic and sedimentary processes have had a significant impact on the geological history and landscape of the region.

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