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Geochemical Parameter Indicators of Origin and Sediment Type, Paleoclimate, and Source Rocks of Al-Teeb River Sediments in the Missan Governorate, Eastern Iraq

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Abstract

This geochemical study concerns the Al-Teeb River sediments that accumulate in the river course or river basin. The river is one of the seasonal rivers in Iraq, located in the Missan Governorate in southeastern Iraq, northeast of Amara City. It originates from the Himrin mountains near the Iranian border and flows into Hor Al-Snnaf. It has a maximum length of about 63 km and runs through the Al-Teeb District. Eight samples were collected and subjected to geochemical analyses by XRF. Numerous geochemical parameters and major and trace element relationship diagrams have been used to infer the origin and type of sediments, paleoclimate, and source rocks. The average chemical alteration index (44.12) indicates that the sediments have undergone low to moderate weathering. Results obtained from the chemical index of weathering (55.043), plagioclase index of alteration (50.5), and index of chemical variability (2.37) support this conclusion and confirm the low weathering of the source rocks and low maturity. The climate of source rocks is semi-arid to sub-humid and mean annual temperature is 15.22°C. The chemical classification of Al-Teeb river sediments is greywacke and originated from continental arc or oceanic arc environments.

Keywords: Al-Teeb river; Provenance; Paleoclimate; CIA; Tectonic setting

1. Introduction

Al-Teeb River is one of the seasonal rivers in Iraq. It originates from the Iranian border within the Himrin mountains and ends in Hor Al-Snnaf. It has a maximum length of about 63 km within Iraq. It is located in the Missan Governorate in southeastern Iraq and flows through the Al-Teeb District, northeast of Amara City. The river's seasonal, cyclical flow brings in quantities of sediment representing eroded material transported from upstream and deposited in the river basin and estuary as alluvium sediments. River sediments offer a valuable record of the Earth's surface processes, reflecting interactions between different rock lithologies, weathering, sediment maturity, and climate in their source area of the river (Nesbitt and Young, 1982). The major and trace elements geochemical analysis of alluvial deposits can clarify the composition of the source area and supply valuable information about the source rocks and the conditions of formation, such as weathering, climate, etc. (Ahmad et al., 2014; Awadh et al., 2024). Trace elements are often utilized to investigate sediment source areas because they exhibit relatively low mobility during sedimentary transportation and deposition (Cullers et al., 1979).

Many literature reviews studied Al-Teeb river sediment, such as Hussain et al. (1977) investigated the aquifer system of alluvial fans in the Al-Teeb area. They noted that alluvial fans are hydraulically

connected to the Mesopotamian aquifer system. Al-Ghanimy et al. (2019) studied groundwater in the Al-Teeb area and concluded that all the groundwater that was studied is oversaturated to calcite. Al-Moozani (2008) conducted a geomorphological and hydrological study of the eastern Missan Governorate, including the Al-Tayeb River. Mahdi and Soltan (2021) studied the source rock of the Mukdadiya Formation in the Al-Teeb area and revealed, depending on petrography and paleontology, that the source rock is the Qulqula Formation. Kadhim and Ali (2022) studied the mineral content of Al-Teeb sediment, and their study showed that they are moderately stable and mature. In the Al-Teeb area, Sedkhan et al. (2023) revealed that sediments of the Bi Hassan Formation originated from mountains in Iraq and Iran and were transported by river and stream waters.

The main goal of this study is to identify the parent rocks and origin of the seasonal Al-Teeb River sediments, determine the prevailing climatic conditions in the source area that affected their maturation, and determine their type.

2. Geological Setting

The study area is located in the northeastern part of Missan Governorate (Eastern Iraq), where the topography varies in elevation from flat to high hills parallel to the border between Iraq and Iran. The Hamrin Hills are low, southeast-trending folds in the form of a chain parallel to and adjacent to the Zagros Mountains. The folds were formed as a result of tectonic movements accompanying the collision of the Arabian and Iranian plates. Thrust faults and the upward thrust of the Fatha Formation above the Injana Formation accompanied this process (Jassim and Goff, 2006). The topographic elevation varies from 7 to 325 m above sea level. The study area's land surface is relatively flat in its central part, increasing in elevation to the north and northeast, where the Himrin Hills are located (Fig. 1).

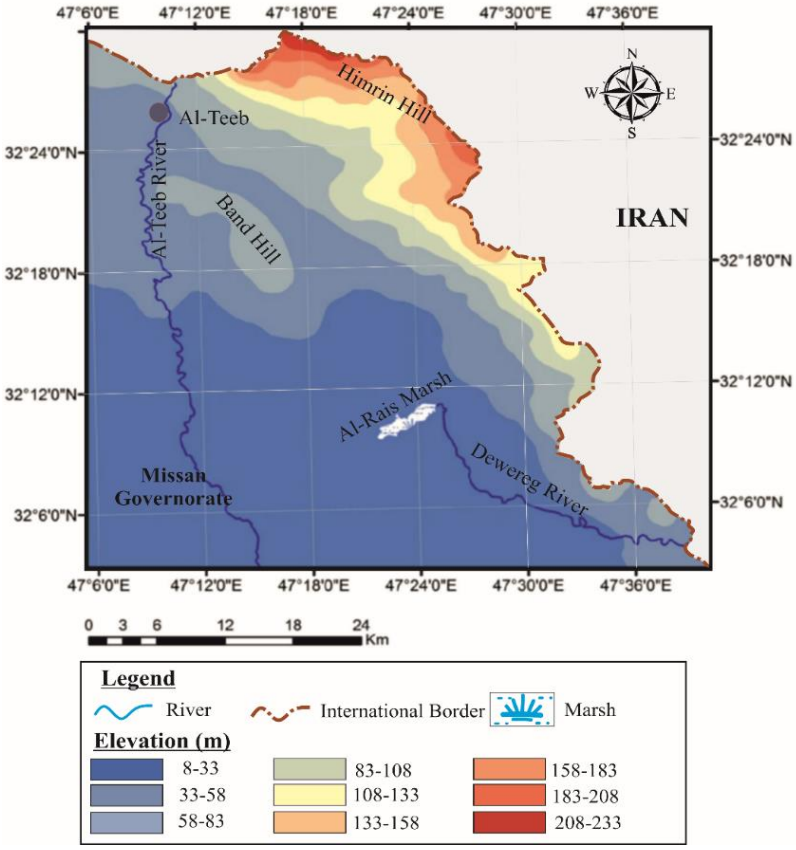

Fig. 1. Topographic map with ground levels of the study area

Band Hell is located on the left side of the Al-Teeb River, close to Al-Teeb District. Due to the prolonged drought period and irregular intervals of surface drainage, the population in the study area depends on groundwater, which is the main water source. Many groundwater wells are spread throughout the area.

One of the geomorphological features is that valley networks are common landforms, especially in Teeb. After heavy rain, these valleys fill with water, significantly contributing to groundwater recharge. This is accompanied by erosion, which transports sediments from the tops of the hills to the flat plain behind them. Valleys are either mountainous or flat, depending on their occurrence. The impact of the great slope of the terrain and the intensity of the water flow coming during the rainy season from the Iranian side of the Iranian border have made the valleys of the mountainous regions rugged and dissected. In flat areas, shallow valleys are shallow channels with gentle slopes, often ending in swamps and their sediments consisting of a clastic mixture of gravel, sand and silt.

As a result of the rush of rainwater from the tops and foothill zone of the Hamrin Hills, several alluvial fans established and spread in the study area along the boundaries of the foothill zone in the study area towards the northeast; the surface of the fans is usually eroded by weathering and consists of a layer of red clay and coarse sediment particles (Jassim and Goff, 2006). Newer fans often cut into the bodies of older fans. Their deposits are composed of lenticular bodies of poorly sorted fine to coarse sand and gravel, with varying portions of clay. Many seasonal swamps form as a result of water accumulating in flat areas, while sabkhas form as a result of water evaporation during the hot summer. Many dunes are also found in the region, which are derived from alluvial fans, and they are often rich in grains belonging to the older Mio-Pliocene molasse (Buday and Jassim, 1987). In addition, several major normal and thrust faults are identified in the study area (Sissakian and Fouad, 2015).

The stratigraphic succession in the study area started with Quaternary deposits of recent and Pleistocene age, which include sands, silts, and silty clays, covering the majority of the Al-Teeb River Basin in Iraqi territory. Tertiary rocks are only found in the region's eastern and northeastern regions. The tertiary sediments cover more than 28% of the studied region, and quaternary deposits make up roughly 72% of it (Kadhim, 2022).

Bi Hassan (Upper Miocene–Pliocene) and undifferentiated Mukdadiya Formations (Late Miocene–Pliocene) comprise the stratigraphic column in the research region. Claystone and sandstone interbedding in monotonous stages with minor siltstone intercalation make up the Mukdadiya Formation. The Mukdadiya Formation was formed in a rapidly subsiding fluvial basin. Since the sandstone layers frequently have stones of various lithologies and forms, they are regarded as typical freshwater. The Bai Hassan Formation is composed of interbedding conglomerate, claystone, and sandstone (Buday, 1980) (Fig. 2).

The facies change, which represents the beginning of the appearance of the coarse conglomerate layer, is considered the conformity surface between the upper boundary of Muqdadiyah and the base of Bai Hassan formations.

The Mukdadia Formation overlies the Injana Formation (Late Miocene). It is a clastic sequence comprised of subcontinental to continental coarse and medium-grained, carbonate-rich sandstone, interbedded with brownish-red siltstones, mudstones, marls, and rare freshwater limestone (Jassim and Goff, 2006). The formation outcrops in the Himrin foothill. Underlies the Injana Formation gradationally contact, the Fatha Formation (Middle Miocene) was deposited in the lagoon basin. It is comprised of alternative layers of clay, limestone, and gypsum (Al-Juboury, 2009). The research area's central region has a comparatively flat land surface, while the northeastern Himrin Hills enclose it. The Al-Teeb River, which originates in Iran, flows through the study area (Fig. 1).

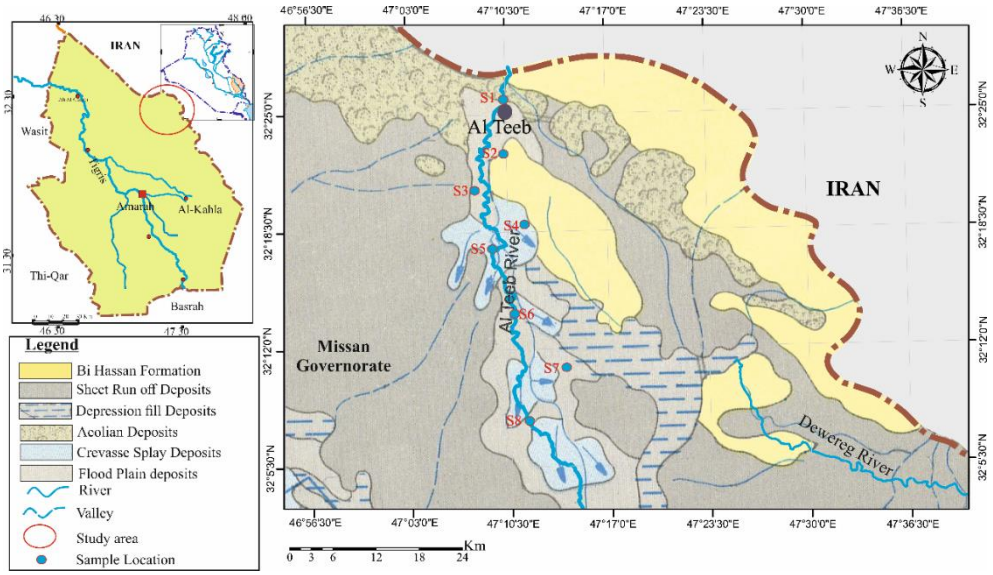

Fig. 2. Geological and location map of the studied area (modified after Sissakian and Fouad, 2015)

Al-Teeb River Basin is located in east Missan Governorate, south Iraq. Between the latitudes 32° 15' 00" - 32° 30' 00" N and longitude 46° 55' 00"- 47° 25' 00" E. The study region, which covers 1790 km^2, is bounded by the eastern Iraqi-Iranian border. The terrain is situated between 14 and 200 m above sea level.

3. Study Methods

Eight samples were gathered from eight positions representing recent sediment deposited in and around the Al-Teeb River course: four from the river bottom and four from the adjacent area (Fig. 2). The samples were collected from the riverbed and adjacent areas within the river basin using a metal shovel and a sediment container and preserved in polyethylene bags. To reduce variability and increase reliability, the composite sampling method was used to determine the spatial variability of river sediments. Five samples were gathered from each location in a square shape, one from each corner and one from the centre. They were collected together, homogenized well, and a representative sample was taken. Rock pieces and coarse material were removed without screening, and sediment samples were air-dried before laboratory analysis.

The coordinates of the sample locations were fixed by GIS (Garmin eTrex 10 portable) and are listed in Table 1.

Table 1. Sample coordinates in the Study Area

Samples No.	Latitude	Longitude
S1	32°26′19″	47°10′15″
S2	32°22′35″	47°11′35″
S3	32°21′30 ″	47°08′52″
S4	32°20′39″	47°13′50″
S5	32°19′44″	47°09′32″
S6	32°17′50″	47°10′55″
S7	32°16′54″	47°11′12″
S8	32°15′45″	47°10′23″

The X-ray fluorescence spectroscopy (XRF) technique was used to identify the concentrations of major (SiO_2, CaO, MgO, Al_2O_3, Fe_2O_3, MnO, Na_2O, K_2O, P_2O_5, SO_3, and TiO_2, in addition to LOI) and

trace elements (Th, Rb, Sr, V, Ni, and U) in the Iraqi Germany Laboratory at the Department of Geology/ University of Baghdad. Several geochemical parameters and equations are utilized to interpret the geochemical analysis results. The Suttner and Dutta (1986) bivariant plot SiO_2 versus Al_2O_3+ K_2O + Na_2O is used to identify the climate. Equations 1 calculate climatic parameters such as the prevailing Annual Temperature (MAT) (Sheldon and Tabar, 2009).

$$MAT(°C) = -18.516 \times ln(CIA) + 85.319 \quad (1)$$

The Chemical Index of Alteration (CIA) equation is used to quantify the chemical weathering degree of the rocks and sediments of the Al-Teeb River. This equation was offered by Nesbitt and Young (1982). The equation molar proportions of major oxides (Eq. 2).

$$CIA = Al2O3 / (Al2O3 + CaO* + Na2O + K2O) \times 100 \quad (2)$$

Where the scale of weathering intensity, depending on Fedo et al. (1995), below 50 refers to unweathered rocks (plagioclase and K-feldspar are unaltered), between 50 and 60 refers to the low weathered and first cycle of sedimentation, between 60–80 refers to moderately weathered, while greater than 80 is intensely weathered.

The CaO* is represented by silicate minerals within samples (in moles) calculated in Equation 3, and non-silicate sources (carbonates or phosphates) are excluded, and when CaO* exceeds Na_2O, then CaO* is set equal to Na_2O (McLennan et al., 1993).

$$CaO* = 0.35 * 2(Na2O\%)/62 \quad (3)$$

There are other geochemical parameters used to support the weathering degree, such as the Chemical Index of Weathering (CIW) (Harnois, 1988) (Eq. 4) which refers to weathering intensity. When between 50 and 60 refers to unweathered to low weathered, between 60–80 refers to moderately weathered, while greater than 80 is extremely weathered rocks (Harnois,1988). Plagioclase Index of Alteration (PIA) (Eq. 5) evaluates the weathering process, with a specific emphasis on the alteration of plagioclase feldspar (Fedo et al., 1995). The PIA scale when 50 to 60 refers to a minimal weathering of plagioclase, between 60 and 80 refers to moderate plagioclase weathering, which is frequently observed in sediments associated with temperate climates, and > 80 to 100 refers to extreme plagioclase breakdown (e.g., residual clays) (Sheldon and Tabor, 2009). Index of Chemical Variability (ICV) (Eq. 6) (Cox et al., 1995) as a scale for the maturity of sedimentary. When ICV is higher than 1, it means immature sediments, but when lower than 1 means the sediment is mature.

$$CIW = [Al_2O_3/ (Al_2O_3 + CaO* + Na_2O)] * 100 \quad (4)$$

$$PIA = (Al2O3 - K2O)/(Al2O3 + CaO* + Na2O - K2O) * 100 \quad (5)$$

$$ICV = (Fe2O3 + K2O + Na2O + CaO* + MgO + MnO + TiO2)/Al2O3 \quad (6)$$

All values of oxides in these equations (4, 5, and 6) are following molar proportions.

To identify the provenance of Al-Teeb River sediments, Pettijohn et al. (1972) and Herron (1988) geochemical bivariate plots are used. These plots are based on the geochemical composition of sediments to infer the classification of clastic sediments. They used the relationship between SiO_2/ Al_2O_3 vs. log Na_2O/K_2O and log-log SiO_2/ Al_2O_3 vs. log Fe_2O_3/K_2O, respectively.

4. Results and Discussion

The bulk of Al-Teeb River sediment samples are analyzed for major oxides and some trace elements. The geochemical analysis results performed on selected sediment samples from Al-Teeb River are presented in Table 2.

The sediment samples are characterized by their lower percentage of Al_2O_3 (average 3.69%), which reflects a low content of clay minerals. The low content of SiO_2 (average 20.2%) implies the presence of quartz and silicate minerals. The high percentage of CaO (average 34.779) points out the presence of

minerals enrichment by CaO minerals of carbonate and feldspar; this may mean less recycling and a lower degree of weathering processes.

Table 2. Analysis result for major oxides and trace elements of Al-Teeb river sediments

Oxide	S3	S2	S8	S1	S6	S7	S4	S5	Ave.
					%				
Na_2O	2.355	2.6180	2.7270	1.8130	2.8610	1.3420	2.3450	2.3730	2.304
MgO	2.348	3.7710	1.4960	3.2270	1.8800	3.6180	1.9010	1.8140	2.507
Al_2O_3	3.588	3.8910	2.9890	4.9900	2.8790	5.2540	2.9680	2.9730	3.692
SiO_2	19.12	19.480	21.040	23.950	16.8500	24.3900	17.4100	19.3600	20.200
P_2O_5	0.1205	0.1392	0.1002	0.1345	0.0955	0.1743	0.1070	0.0992	0.121
SO_3	7.6380	7.1710	7.0940	5.8760	8.8260	2.4800	7.7560	5.7180	6.570
K_2O	0.6586	0.8993	0.5712	0.8820	0.5497	1.1080	0.5430	0.5302	0.718
CaO	36.18	36.280	30.770	32.590	38.5500	32.5400	36.3600	34.9600	34.779
MnO	0.0458	0.0463	0.0359	0.0507	0.0480	0.0565	0.0431	0.0429	0.046
Fe_2O_3	2.3580	2.5210	1.9990	2.9900	2.2290	3.2220	2.1880	2.2400	2.468
TiO_2	0.4047	0.4085	0.3163	0.4778	0.3787	0.4801	0.4224	0.4250	0.414
LOI	25.183	22.775	30.861	23.019	24.853	25.335	27.956	29.465	25.183
V_2O_5	0.011	0.0103	0.0082	0.0106	0.01	0.0121	0.0084	0.0091	0.00996
NiO	0.00623	0.00815	0.00555	0.00925	0.00513	0.01046	0.00543	0.00492	0.0069
Rb_2O	0.00291	0.00323	0.00323	0.0038	0.00267	0.00438	0.00261	0.00298	0.00323
SrO	0.1492	0.1682	0.07145	0.124	0.1512	0.1063	0.143	0.1159	0.12866
Th	0.00028	0.00034	0.00034	0.00037	0.00027	0.00045	0.00031	0.00028	0.00033
U	0.00026	0.00035	0.00014	0.00019	0.0002	0.00006	0.00021	0.00022	0.0002
Sum	75.12	78.05	69.5	77.26	75.64	75.1	72.36	71.09	74.265
					Geochemical indices				
CIA	43.63	42.17	36.67	55.66	34.94	60.47	39.77	39.64	44.12
PIA	54.89	52.79	46.39	68.91	44.32	75.13	50.25	50.13	55.35
CIW	59.83	59.26	51.69	72.92	49.6	79.29	55.29	55.02	60.36
ICV	2.28	2.64	2.39	1.89	2.76	1.87	2.51	2.5	2.35
Rb/Sr	0.021	0.021	0.049	0.033	0.019	0.045	0.020	0.028	0.029

Pearson correlation coefficients show the strength of the correlation between the main oxides, whether negative or positive, ranging from -1 to 1. The number of samples (N)=8, so Pearson's correlation degrees of freedom are N-2=6. This implies that the critical value is approximately ±0.707. An absolute value greater than ±0.707 is statistically notable (Table 3).

Table 3. Pearson correlation coefficients between major oxide of Al-Teeb River sediments

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_3	TiO_2	LOI
SiO_2	1									
Al_2O_3	0.87	1								
Fe_2O_3	0.80	0.98	1							
CaO	-0.81	-0.40	-0.31	1						
MgO	0.58	0.85	0.84	-0.11	1					
K_2O	0.78	0.94	0.92	-0.36	0.94	1				
Na_2O	-0.81	-0.87	-0.89	0.47	-0.60	-0.76	1			
SO_3	-0.83	-0.75	-0.77	0.61	-0.54	-0.74	0.88	1		
TiO_2	0.52	0.76	0.85	-0.04	0.67	0.65	-0.85	-0.64	1	
LOI	-0.2	-0.60	-0.63	-0.34	-0.79	-0.62	0.27	0.03	-0.54	1

SiO_2 positively correlates with each Al_2O_3 (0.87), Fe_2O_3 (0.80), and K_2O (0.78) reflecting the presence of clay minerals, mica and feldspars and indicating mineralogical linkages in felsic weathering profiles(Nesbitt and Young, 1982). The strong negative correlations of SiO_2 with each CaO (-0.81), Na_2O (-0.81), and SO_3 (-0.83) indicate high silica and low calcium, sodium, and sulfur oxides. High SiO_2 may indicate the presence of quartz-rich rocks, while high CaO could indicate carbonate rocks. Al_2O_3 has a positive correlation with each Fe_2O_3 (0.98) and K_2O (0.94), inferring association with clays, micas, or potassium feldspars ($KAlSi_3O_8$) (Ali, 2012). The positive correlation of MgO with each K_2O (0.94) and Fe_2O_3 (0.84) can reflect mafic mineral assemblages such as biotite, and amphiboles, where Mg, Fe, and K coexist and are common in mafic minerals. Na_2O vs. Al_2O_3 (-0.87) indicates Na may substitute for Al in certain minerals such as albite vs. potassium feldspar. The Loss on ignition (LOI) has a lower positive correlation with MgO-rich rocks, implying fewer clay minerals (Nesbitt and Young, 1982; Rollinson, 1993; Tucker, 2001).

Numerous factors, such as weathering, sediment transport, and the depositional environment, control the chemical composition of clastic sedimentary rocks. The most important factors include the composition of the parent rocks, chemical weathering during the sedimentary process, and formations' outcrop exposure, in addition to diagenesis and metamorphism (Nesbitt and Young, 1982; Fedo et al., 1995).

4.1. Geochemical Parameter Indicators

4.1.1. Geochemical index of alteration and palaeoweathering

The geochemical index chemical index of alteration (CIA) is used to quantify the chemical weathering degree of rocks and sediments. As chemical weathering of rocks happens, the alkali and alkaline earth elements are broken and leached away because of their high mobility; in contrast, Al_2O_3 tends to remain. So, the CIA values are an indicator of the degree of weathering (Sheldon et al., 2022). The calculation is based on the molecular proportions of major oxides (Al_2O_3, CaO, Na_2O, and K_2O) (Nesbitt et al., 1997) in the sample by Equation 3.

The CIA ranged from 34.9 (sample S6) to 60.5 (sample S7), with an average of 44.12. The CIA values suggest that the source areas are subjected to a low to moderate degree of chemical weathering processing. This may be interpreted by arid or cold climates, indicating limited chemical weathering. Fresh and relatively uneroded source rocks also mean rapid erosion and transport, limiting the time and amount of weathering overall (Wang et al., 2013).

The Sr/Rb ratio is an important geochemical proxy for chemical weathering and inferring paleoclimate. Rb and Sr behave differently during weathering, making their ratios an important indicator of weathering intensity and climate. Rubidium is relatively immobile during less severe weathering and is enriched in weathered residues. Strontium is more mobile than Rb and is leached from rocks and soils during weathering (Chang et al., 2013; Wei and Algeo, 2020). When Rb/Sr >1 means intense weathering, warm/humid climate, Rb/Sr 0.5–1 means moderate weathering, temperate climate, and Rb/Sr <0.5 means weak weathering, cold/arid climate. The Rb/Sr value of the studied samples is 0.0294, which confirms that the source area is subjected to weak weathering and a cold/arid climate, and it may be mafic rocks as Rb is low concentrated in it. The sediment was deposited in a region with low mean annual precipitation and temperature.

The CIA is represented as a ternary plot using the weight percent of Al_2O_3-(CaO + Na_2O)-K_2O diagram. When plotting the sample data in this chart, it appears as shown in Fig. 3).

In Fig. 3, the samples plotted a parallel trend close to the Al_2O_3–CaO + Na_2O line, which suggests less weathering of the source rocks. In contrast, CaO and Na_2O are leached during intense weathering because of their mobility. As a result, the samples trend towards the Al_2O_3 and K_2O line, indicating K

enrichment (Fedo et al., 1995). Despite all the benefits of CIA, a drawback of this index is the remobilization of K during the sedimentation.

The CIW can help minimize such a complication (Harnois, 1988), which is widely used. Practically, CIW reflects the extent to which soluble elements (like Ca and Na) leach from a rock or sediment during chemical weathering compared to the more resistant element (Al).

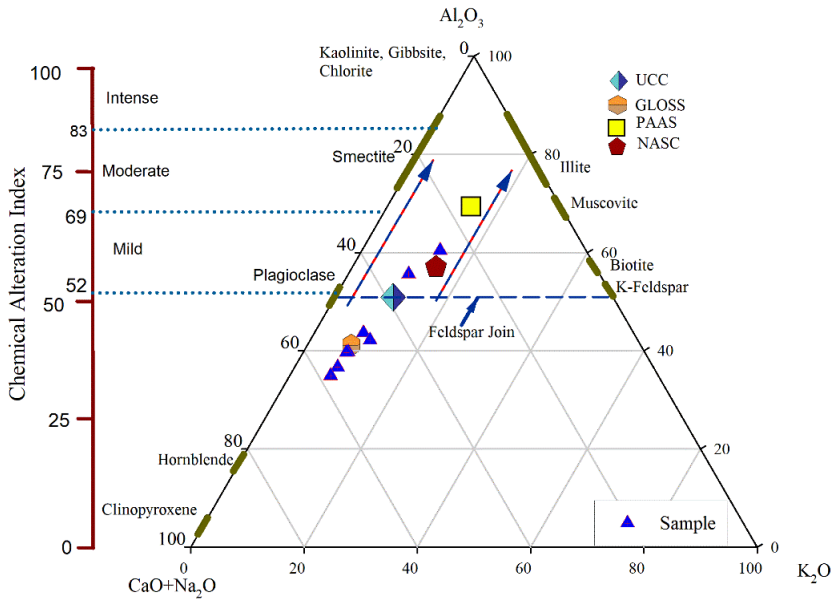

Fig. 3. Al_2O_3-(CaO + Na_2O)-K_2O diagram after Nesbitt et al. (1997)

The CIW is calculated by Eq. 4 (Nesbitt and Young, 1982; Harnois, 1988). The average CIW value attained for the studied samples is 60.36 (ranging from 49.6 to 79.3), which indicates a low to moderate degree of chemical weathering and an arid climate in the source area.

Fedo et al. (1995) assessed the grade of the CIA by computing the PIA, which was modified from the CIA. The source sedimentary rocks can be estimated using a triangular plot Al_2O_3-CaO+Na_2O-K_2O, Eq. 5 helps to assess the PIA values (Fedo et al. 1995).

Sediment PIA values can provide insights into the weathering conditions of the source areas (Abedini and Calagari, 2017) where the sediment of the Al-Teeb River originated. The PIA values ranged from 44.3 to 75.1, averaging 55.35. This value indicates minimal plagioclase weathering, reflected in a low weathering degree associated with an arid climate.

The CIW and PIA values are consistent with the CIA value in that they reflect the same degree of chemical weathering of the source of the Al-Teeb River sediments.

Cox et al. (1995) introduced the ICV, another geochemical parameter used to assess sediment or sedimentary rock maturity. ICV evaluates the extent of chemical weathering and alteration of sediments by linking the abundance of more mobile oxides and leaching during weathering (CaO, Na_2O, and K_2O) to stable and immobile oxides (Al_2O_3); essentially, it indicates how much weathering processes have changed the original mineral composition of the sediment. ICV values above 0.84 indicate the presence of pyroxenes, amphiboles, and feldspars, while values below 0.84 suggest an alteration to kaolinite, illite, or muscovite. The ICV value can be calculated according to the Eq. 6.

The ICV value of Al-Teeb sediments ranges from 1.87 to 2.77, with an average of 2.35. These values demonstrate that Al-Teeb River sediments are immature, low-recycled, and low-weathered, and the sediments are derived from less-weathered metamorphic or igneous sources in addition to arid climates (Nesbitt and Young, 1982; Fedo et al., 1995; Hossain et al., 2010). The CIV gives tectonic

implications, as its high value indicates continental arcs and/or collision zones (Cox et al., 1995). The bivariant plot CIA versus ICV diagram (Fig. 4) reveals low chemical weathering and low sedimentary recycling for Al-Teeb River sediment samples (Lee, 2002; Potter et al., 2005).

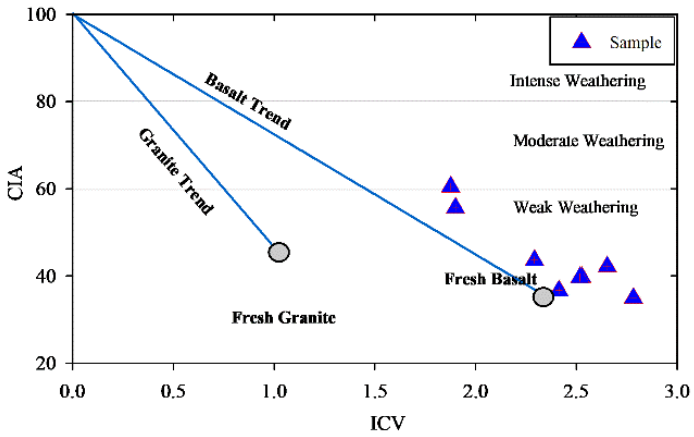

Fig. 4. Bivariant plot CIA vs. ICV diagram of Al-Teeb River Sediments after (Lee, 2002)

4.1.2. Paleoclimate

When the bivariate plot SiO_2 versus Al_2O_3+ K_2O + Na_2O (Suttner and Dutta, 1986) is used, the climate in the study area is arid to semi-arid (Fig. 5a).

This conclusion is supported by using the connection between CIA (as log) vs. K_2O/Na_2O proposed by Goldberg and Humayun (2010) as a paleo-humidity indicator. The sample results are plotted in the arid to the subtropical field (Fig. 5b).

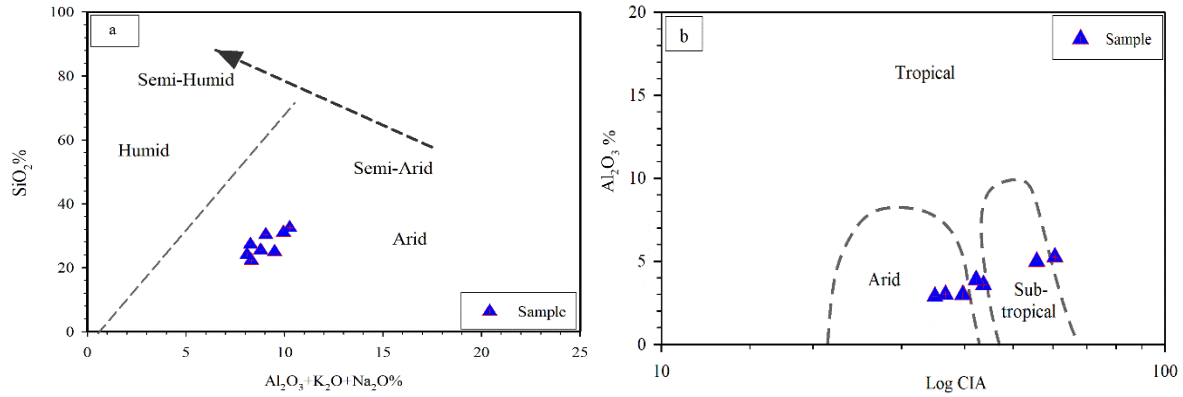

Fig. 5. Paleoclimate by a) bivariate plot SiO_2 vs. Al_2O_3+ K_2O + Na_2O (Suttner and Dutta, 1986), b) CIA (as log) vs. K_2O/Na_2O (Goldberg and Humayun, 2010)

Where reinforces this belief that the environment is dry to semi-dry is the expected the prevailing temperature at a rate according to Eq. 1. Sheldon et al. (2002) also established an empirical relationship between CIA and Mean Annual Temperature (MAT) depending on geochemical data by the optimal method for calculating MAT (Eq. 1).

MAT≈ 15.22°C

The MAT value suggests the climate is semi-arid to sub-humid. This result value is consistent with Low-moderate chemical weathering, as revealed by the relatively low CIA value (44.12) and low value of Rb/Sr.

4.1.3. Maturity of Al-Teeb river sediments

The geochemical properties of sedimentary rocks can retain details about their provenance, even when sedimentary processes destroy primary structures and alter minerals (Roser and Korsch, 1988; McLennan et al., 1993). Both Pettijohn et al. (1972) and Herron (1988) suggested geochemical bivariate plots based on the major elemental geochemical composition of sediments to infer the classification of clastic sediments, especially mudrocks, shales, and sandstones. In addition, these diagrams can help to identify the tectonic setting, provenance, and environment of deposition. Based on a bivariate log-log diagram of Pettijohn et al. (1972), the relationship of SiO_2/ Al_2O_3 vs. log Na_2O/K_2O (Fig. 6a) was used.

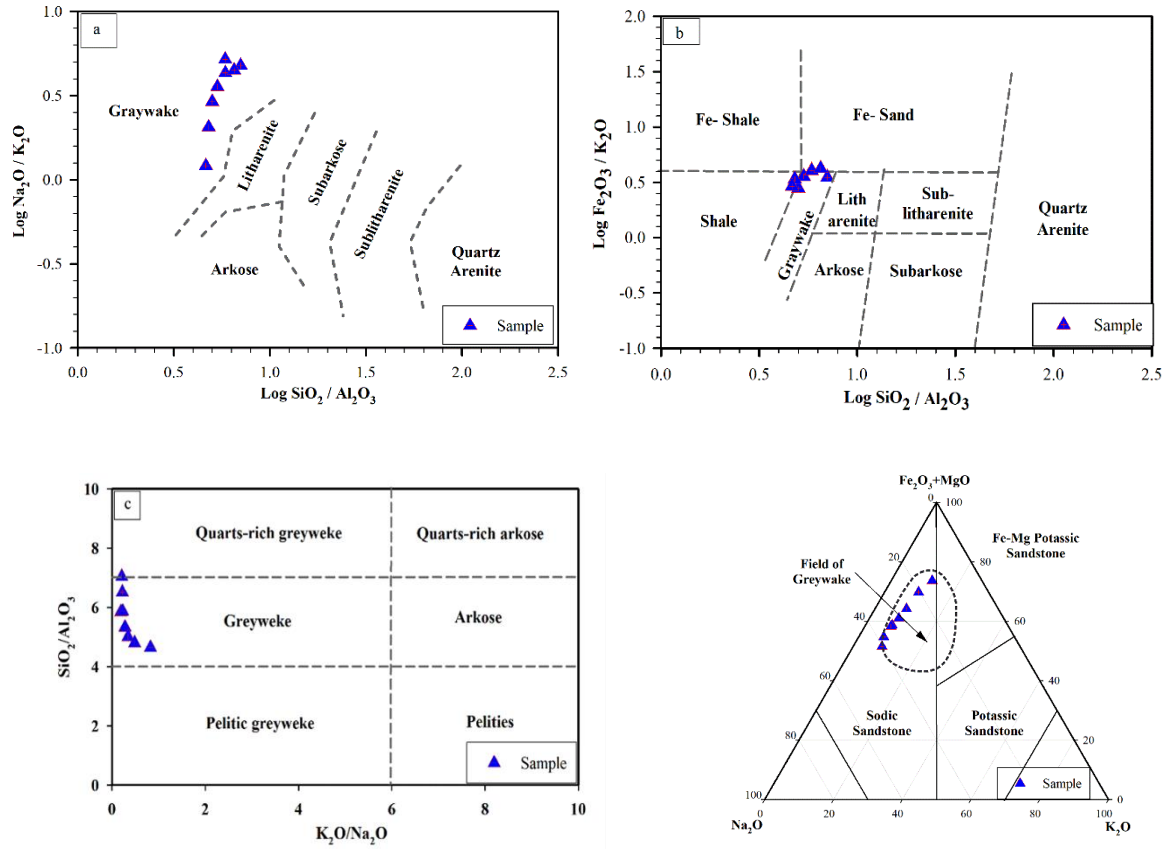

Fig. 6. Chemical classification of Al-Teeb river sediments

As shown in Fig. 6a, b, c, and d, the geochemical analyses of sediments collected from the Al-Teeb River exhibit greywacke-type sediments. The data depicted in these figures likely illustrate key geochemical relationships, such as the relative abundances of major and trace elements and mineralogical compositions, which align with the diagnostic properties of Greywacke. These sediments are immature and poorly sorted, typically comprising a mix of quartz, feldspar, lithic fragments, and a significant clay matrix, as inferred from geochemical signatures.

The greywacke of Al-Teeb river sediments can provide important evidence about the region's geological history, sediment source area, and transportation processes. These supported that it derived from a tectonically active environment. with tectonic activity near mountainous areas, the immaturity of the sediments, and the relative proximity of the source rocks, where the sediments have not been subjected to weathering or transporting on a large scale (Pettijohn et al., 1987; Miall, 2014; Ali et al., 2022).

Employing the diagram representing the relationship between CIA and ICV (Nesbitt and Young, 1982) confirms that the sediments are immature (Fig. 7).

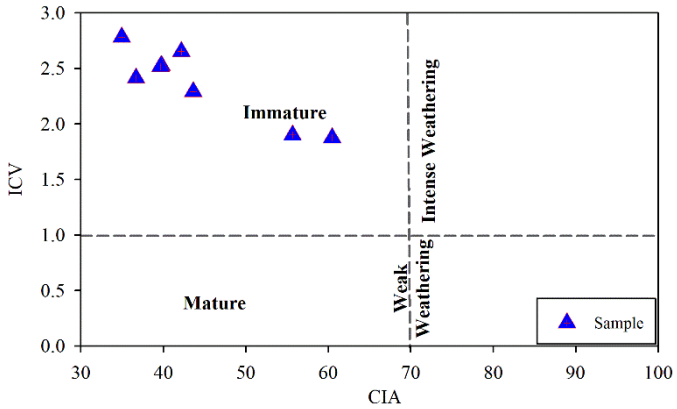

Fig. 7. Bivariate plot CIA and ICV of maturity (Nesbitt and Young, 1982)

4.1.4. Tectonic setting

According to Bhatia (1983), the source rock of the Al-Teeb river originated from the active continental margin and continental arc (Fig. 8a). The source rocks are from the collision between the Arabian and Iranian plates. The river sediments may result from eroding and reworking older sedimentary rocks that contain greywacke (Miall, 2014).

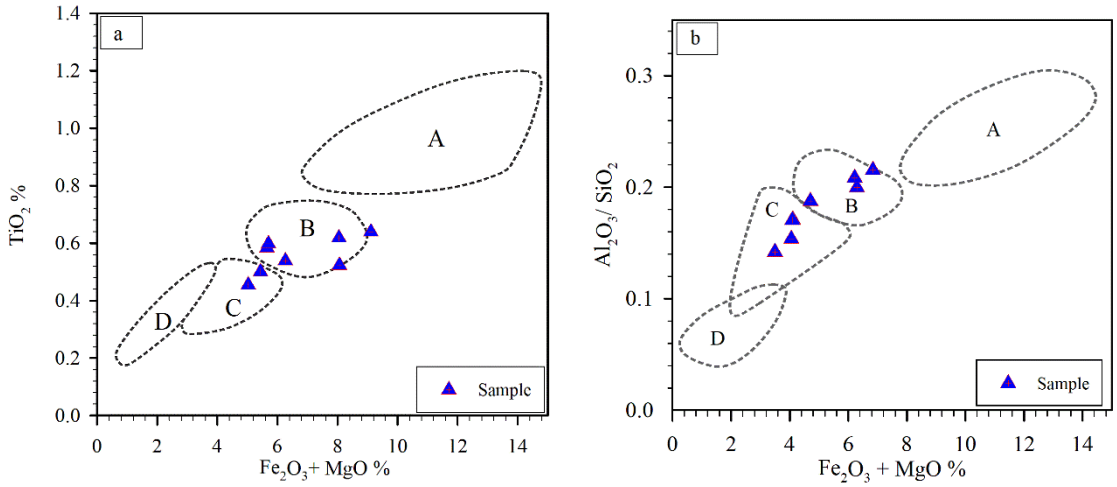

Fig. 8. Bivariant discrimination tectonic setting between A, Passive margin. B, Active continental margin. C, Continental arc. D, Oceanic arc after Bhatia (1983)

The tectonic setting of ancient basins is widely interpreted using two bivariant discrimination diagrams. The first uses K_2O/Na_2O vs SiO_2/Al_2O_3 provided by Maynard et al. (1982) (Fig. 9a), where PM passive margin and ACM active continental margin, including A1 is basaltic and andesitic detritus, and A2 evolved arc. The second uses K_2O/Na_2O (as log) vs. SiO_2 proposed by Roser and Korsch (1986), which revealed the samples originated from the island arc (Fig. 9b).

To delineate the tectonic setting, a discriminant bivariate plot of the first and second discriminant functions (F1 and F2) calculated by Equations 7 and 8 was plotted. The major element analysis of the Al-Teeb River sediment was also plotted. The plot demonstrated that the sediment was plotted within the Oceanic Island arc Field (Fig. 10a).

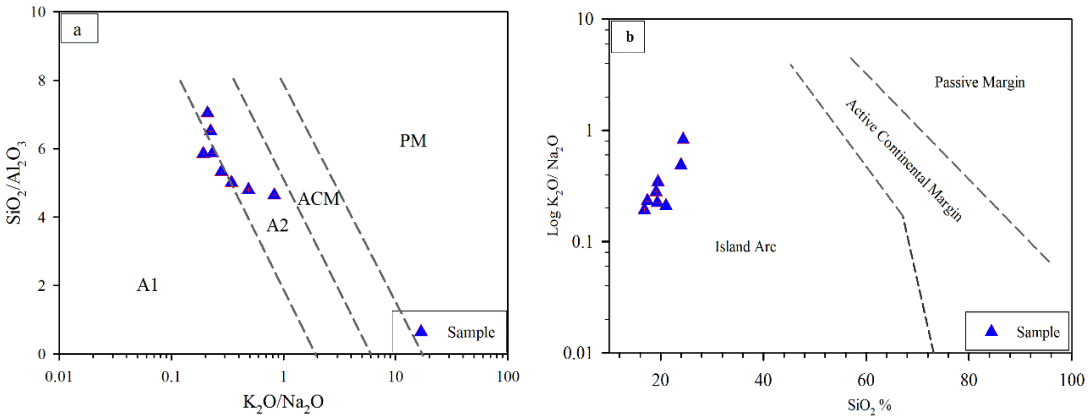

Fig. 9. Bivariant plots tectonic setting between a. K_2O/Na_2O vs SiO_2/Al_2O_3 (after Maynard et al., 1982), b. K_2O/Na_2O vs SiO_2 (after Roser and Korsch, 1986)

$$F1 = -0.0447 * SiO2 - 0.972 * TiO2 + 0.008 * Al2O3 - 0.267 * Fe2O3 + 0.208\, FeO - 3.082 * MnO + 0.140 * MgO + 0.195 * CaO + 0.719 * Na2O - 0.032\, K2O + 7.510 * P2O5 + 0.303, \quad (7)$$

$$F2 = -0.421 * SiO2 + 1.988 * TiO2 - 0.526 * Al2O3 - 0.551 * Fe2O3 - 1.610\, FeO + 2.720 * MnO - 0.907 * CaO - 0.177 * Na2O - 1.840 - K2O + 7.244 * P2O5 + 43.57, \quad (8)$$

Trace elements are characterized by their low mobility and insolubility during various sedimentary processes. Their presence as minor elements in host minerals can provide more trustworthy information about their source than major elements, so they can be considered a fingerprint of the sedimentary rock's provenance (Bracciali et al., 2007). Bracciali et al. (2007) create a triangle diagram by using V–Ni–Th*10 trace elements to identify the provenance. In Fig. 10b, the al-Teeb River samples plot close to the mafic source field.

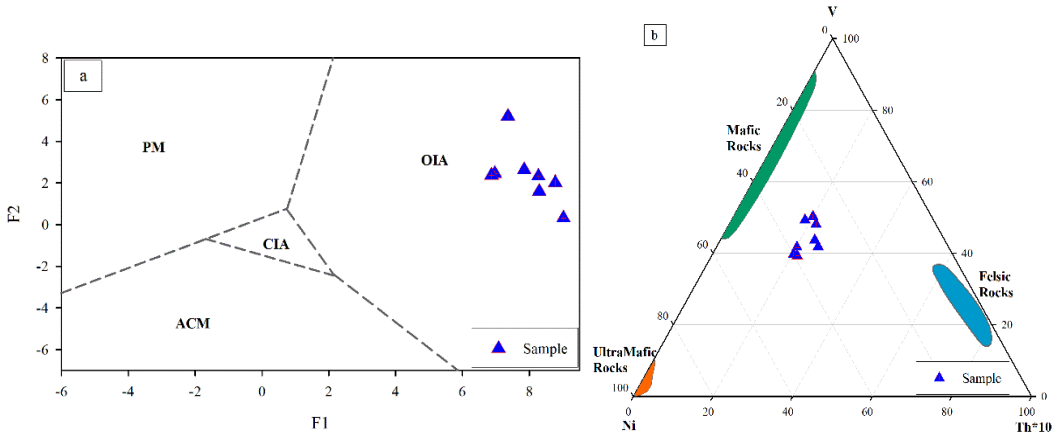

Fig. 10. (a) Discrimination function plot of tectonic setting of Al-Teeb river sediments (Bhatia, 1983), where PM (Passive Margin), ACM (Active Continental Margin), CIA (Continental Island Arc), OIA (Oceanic Island Arc); (b) V-Ni-Th*10 plot after Bracciali et al. (2007)

5. Conclusions

The seasonal Al-Teeb River originates in the Hamrin Highlands, northeast of the city of Amara. The source area is located within the Thrust Zone according to the tectonic division of Iraq based on Fouad (2015).

The Teeb River sediments are characterized by their high content of silica (20.2%) and calcium oxide (34.779%). The Chemical Alteration Index (CIA) indicates that the sediments have undergone low to moderate weathering. Results obtained from the Chemical Index of Weathering (CIW), Plagioclase Index of Alteration (PIA), and Index of Chemical Variability (ICV) support this conclusion and confirm the low weathering of the source rocks. The ICV values for all analyzed sediments revealed immature characteristics, which indicate low recycling levels and minimal weathering of the parent rock source area.

Geochemical relationships revealed that the source area of the Al-Teeb River sediments is characterized by an arid continental climate with relatively high temperatures and moderate rainfall, which decreased chemical weathering. The low clay content and the presence of significant proportions of unstable minerals with a low clay mineral content can be attributed to the proximity of the supply area and the dry climate.

The result reveals that the Al-Teeb River sediments are greywacke type with a low percentage of maturation. The source area may be a continental arc or an oceanic arc environment.

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