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Mineralogy and Geochemistry of Al-Na'ma area Sand Dunes, Southeastern Tikrit, Northern Iraq

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Abstract

Surface sediment characters and understanding the earth's surface processes are very interesting global research topics. The region in southeastern Tikrit city is characterized by the spread of large surface sediment from aeolian deposited types and dunes. These dunes were investigated to understand the origin of these dunes. For this purpose, grain size analysis, XRD, XRF, and heavy mineral analyses were conducted. Results indicate that these sand dunes in the study area are mainly composed of coarse particles such as sand (especially fine sand) with a percentage more than fine particles (mud), and the fine sand fraction is the predominant class. The sand grains are characterized by also negative value of skewness (strongly coarse skewed), moderately sorted, and leptokurtic. The normal distribution curve shows a unimodal type for most samples, reflecting one potential sediment source.
Mineralogically, quartz is the main mineral composition of this sand, in addition to other minerals such as feldspar, clay minerals, calcite, dolomite, and gypsum. The identified heavy minerals in these samples were tourmaline, garnet, zircon, kyanite, chlorite, rutile, hornblende, and olivine. Regarding the geochemistry, the distribution of major oxides and trace elements in these samples area showed high SiO_2 and TiO_2 and low content of Na_2O. UCC-normalization reveals enrichment of CaO, Cr, and Cl and depletion of other trace elements.

Keywords: sand dune; grains size; geochemistry; Mineralogy; Tikrit

معدنية وجيوكيميائية الكثبان الرملية في منطقة الناعمة، جنوب شرق مدينة تكريت، شمال العراق.

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الخلاصة

تعد خصائص الرواسب السطحية وفهم عمليات سطح الأرض موضوعات بحثية مثيرة للاهتمام عالميا. تتميز المنطقة الواقعة في الجنوب الشرقي من مدينة تكريت بانتشار مساحات كبيرة من الرواسب السطحية من نوع الرواسب الريحية والكثبان الرملية. تم دراسة هذه الكثبان لفهم أصل هذه الكثبان. لهذا الغرض، تم إجراء تحليل الحجم الحبيبي، XRD، XRF ، وتحليل المعادن الثقيلة. تشير النتائج إلى أن هذه الكثبان الرملية في منطقة الدراسة تتكون أساسًا من حبيبات خشنة الحجم (الرمل ، خاصة الرمل الناعم) بنسبة أعلى من الحبيبات

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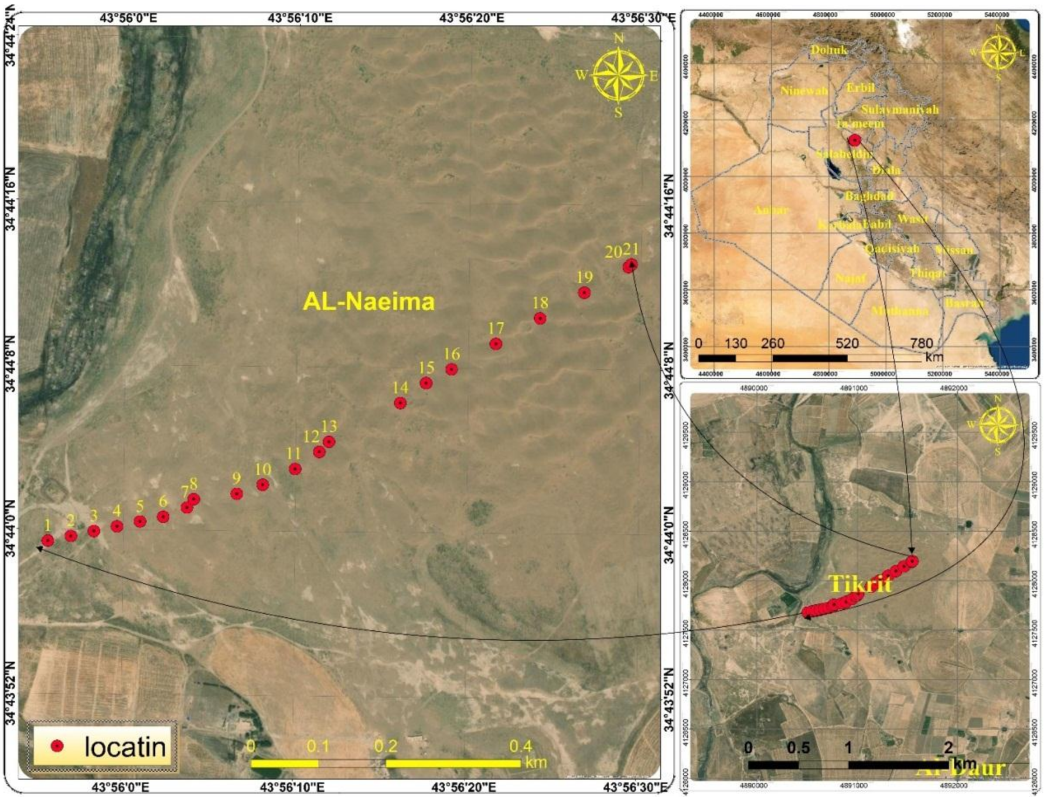
الناعمة (الطين) ، وجزء الرمل الناعم هو الصنف السائدة. تتميز حبيبات الرمل أيضًا بالقيمة السلبية للانحراف (strongly coarse skewed)
، وفرزًا معتدلًا، وLeptokurtic . يُظهر منحنى التوزيع الطبيعي نوعًا أحادي النسق (unimodal) لا غلب العينات والذي يعكس مصدرًا محتملاً واحدًا للرواسب.
من الناحية المعدنية، يعتبر الكوارتز هو المكون المعدني الرئيسي لهذا الرمل بالإضافة إلى المعادن الأخرى مثل الفلسبار والمعادن الطينية والكالسيت والدولوميت والجبس. المعادن الثقيلة التي تم تحديدها في هذه العينات هي التورمالين ، العقيق ، الزركون ، الكيانيت ، الكلوريت ، الروتيل ، الهورنبلند ،والاوليفين. من الناحية الجيوكيميائية ، أظهر توزيع الأكاسيد الرئيسية والعناصر النزرة في العينات هذه محتوى عاليًا من SiO_2 و TiO_2 ومحتوى منخفض من Na_2O. ويكشف نمط المعايرة مع محتوى القشرة القارية العليا (UCC)عن اغناء في CaO و Cr و Cl وشح في العناصر النزرة الأخرى.

1. Introduction

Sand dunes represent the product of intense wind erosion, and one of the soil degradation processes led the transport of fine grains by air while coarse grains remain in a position [1]. The formation and development of sand dunes are controlled by wind regimes, sediment provenance and earth surface properties [1]. The most amazing natural feature on earth is the aeolian sand dune, and the understanding of how aeolian deposits (sand dunes) form and move is an important research topic in the earth's surface processes[2]. Sand dunes in Iraq have been studied from various aspects within different locations[3-10]. Aeolian sand deposits are distributed in other parts of Iraq [6]. In southeastern Tikrit city, north Iraq, there are sand dunes. Generally, scattered and isolated mobile dune or dune groups are distributed in the area. These sand dunes are consistent with the predominant wind direction (NW-SE) parallel to the Himrain fold transport and sorting of Aeolian deposits. This study tries to determine the provenance of these dunes in the study area through the mineralogical composition and major and trace elements geochemistry of these sand dunes.



Figuer 1: Location of the study area and samples location.

2. Geological setting

The study area is located on the eastern Tigris River and south of Hemrin Mountain near the Na’ama Village, about (24km) from Tikrit city in Salah- Alddin governorate. Tectonically it is located in the Hemrin - Makhul Subzone within Foothill Zone, part of the Unstable Shelf [11]. Geologically Many types of rocks are outcropped in the study area. The exposed sedimentary sequence (from older to younger) is composed as follows [11]; Injana Formation: This formation has a widespread distribution in the study area and is overly the Fat’ha Formation. This formation is composed of an alternation of reddish brown, calcarea, claystone, siltstone and sandstone and deposited in a fluvial environment, and it belongs to the Late Miocene[12]. Quaternary deposits: These deposits overly the Injana Formation unconformably, and they consist of intermixed sand, clay, gravel and silt. Flood plain deposits, slope sediments, valley fillings, gypseous soil and gypseous represent the main types of Quaternary deposits in the study area. The age of these deposits is Pleistocene-Recent[13]. Barchan dunes characterize the site, have a crescent shape and comprise only a small percentage of the world's dune areas and tend to develop where limited amounts of sand are available[14]. These sand dunes are extended to the northwest-southeast direction in the study area[15].

3. Materials and Methods

3.1 Filed Work and Sampling

The fieldwork included measurement of the height and orientation of the sand dunes and the slopes of the wind and less side to indicate their type and extension in the study area (Figure 1). The dune type was from sand sheet. Collecting samples were along the transect shape perpendicular to the sand sheet. Twenty-two (22) samples were collected as longitudinal transect with East-west direction,. The coordination of each location has been determined using GPS.

3.2 Laboratory Work

Grain size distribution was measured using a standard sieving procedure as depicted by[16]. The statistical parameters of grain size were computed based on[16], including mean particle diameter, sorting, skewness, and kurtosis. These parameters have been used to get a good description of the sand particles and distribution. They were calculated by using spreadsheet programs developed by [17]. Three (3) samples were selected from different locations (No. 1, 12, and 22) for mineralogical and geochemical study using X-ray fluorescence (XRF) and X-ray diffraction (XRD) techniques. These analyses were carried out at the Geochemistry Laboratory- Geology Department at the University of Baghdad; XRD analysis was used to determine the mineralogical constituents of bulk sediments. 5g of sample oven-dried to 24 h at 45 ◦C. Then they grinded to ≤200 mesh size by agate mortar. About 1 g of powder sample was used for XRD analysis. Semi-quantitatively interpretation of the results, implemented by Jade 6.0 software. To determine element composition and variation among the different locations, three samples were examined by automated X-ray fluorescence. The sand was crushed to <75 μm to reduce the granular effect during the X-ray analysis process, improve analysis results, and be more accurate. Another important role of grinding is to completely remove the impact of sample heterogeneity on analytic outcomes [1], [18]. The samples containing more than 10 gr from very fine sand (0.125–0.063 mm or 3.0–4.0 Φ) were selected for heavy mineral analysis. Very fine sand is selected to carry out mineral separation from light minerals by traditional gravity methods using Bromoform liquid ($CHBr_3$, Specific Gravity 2.89). A magnet separates the magnetic particles from the heavy part. Thin sections were prepared to identify the heavy mineral by polarizing microscope based on optical properties parameters.

4. Result
4.1. Grain Size Discretion
4.2 Mineralogy of Bulk Sand

The particle size properties are shown in Figure 2 and Table 1. The samples show obvious spatial heterogeneity, but all samples have a general trend, containing a high percent of sand size and a low percent of silt and clay sizes. The coarse sand in the surface sediment ranges from 0.00 to 12.61% with an average of 2.13%; medium sand ranges from 15.48 to 70.18 % with an average of 41.80%. The fine sand is (13.17 to 74.38 %) with an average (45.02 %), and the very fine sand range (2.52 to 16.04%) with an average (8.81%). Mud ranging (0.14 to 4.31%) with an average (2.18%). The fine sand fraction is the predominant particle size in the samples of the study area. Figure 3 shows the histogram graph of the studied samples to determine grain size distribution. Seven samples show unimodal type histogram, which reflects a common probable provenance of sediment, whereas the others, representing a large part of samples, have bimodal histogram shape. The obtained grain size statistical parameters are presented in (Table 1). Grain-size parameters (i.e. mean, standard deviation, skewness and kurtosis) have been calculated from the grain-size distribution cumulative curves. These parameters are used to identify the grain-size characteristics of the sand dune in the study area. The mean size of studied samples falls between 0.18Ø (coarse sand) and 2.44Ø (fine sand), with an average of 1.93Ø (fine sand). Standard deviation values ranged between 0.56 (moderately well sorted) and 1.36 (poorly sorted), with an average of 0.89 (moderately sorted). The skewness ranged from -5.34 (strongly coarse skewed) to 7.04 (strongly fine skewed), with an average of -0.56 (strongly coarse skewed). The kurtosis values are from 0.53 (very platykurtic) to 2.25 (very leptokurtic), with an average of 1.24 (leptokurtic). As a result of wind velocity variation on the sand dunes, the mean particle size and sorting degree vary [19].

Table 1: Grain-size content in percent and statistical parameters.

	Grain size class					Statistical parameters			
Sample No.	course sand	medim sand	fine sand	very fine sand	Mud	mean size (Φ)	standard deviation (Φ)	skewnes s	kurtosis
1	1.97	44.24	44.56	7.60	1.64	2.12	0.63	0.64	1.05
2	5.84	35.27	46.29	10.56	2.04	2.16	0.75	0.28	1.04
3	6.72	35.00	42.10	12.69	2.63	2.20	0.84	0.58	1.07
4	12.61	53.53	22.11	7.68	4.05	1.86	0.90	1.96	1.28
5	0.00	33.32	54.08	10.08	2.53	1.73	1.28	-4.13	0.55
6	0.00	24.47	60.31	12.51	2.69	1.80	1.31	-4.74	2.00
7	0.00	22.53	57.99	16.04	3.44	1.87	1.36	-4.95	1.87
8	1.33	27.99	55.75	11.54	3.36	2.35	0.68	0.50	1.17
9	1.45	45.86	41.53	8.63	2.54	2.16	0.67	1.04	1.09
10	2.96	48.36	38.80	7.45	2.41	2.08	0.69	0.98	1.12
11	0.00	19.02	64.32	14.87	1.79	1.84	1.31	-5.34	2.04
12	0.00	53.51	38.47	5.88	2.16	1.55	1.19	-2.50	0.57
13	1.73	70.18	13.17	10.60	4.31	2.04	0.79	2.64	1.62
14	0.00	63.19	33.70	2.52	0.57	0.81	1.04	7.04	0.53
15	1.01	36.99	54.30	6.51	1.19	2.20	0.56	0.27	1.07

16	2.79	48.48	40.50	6.64	1.59	2.05	0.64	0.73	1.08
17	2.55	59.85	31.48	4.70	1.41	1.95	0.59	0.68	1.15
18	1.83	49.97	39.01	6.83	2.36	2.09	0.65	0.98	1.10
19	0.00	26.47	66.33	6.49	0.70	1.64	1.14	-4.87	2.01
20	4.16	54.96	31.03	7.03	2.81	2.00	0.72	1.35	1.16
21	0.00	51.02	40.33	7.01	1.64	1.57	1.19	-2.74	0.56
22	0.00	15.48	74.38	9.99	0.14	2.44	0.71	-2.71	2.25
min	**0.00**	**15.48**	**13.17**	**2.52**	**0.14**	**0.81**	**0.56**	**-5.34**	**0.53**
max	**12.61**	**70.18**	**74.38**	**16.04**	**4.31**	**2.44**	**1.36**	**7.04**	**2.25**
average	**2.13**	**41.80**	**45.02**	**8.81**	**2.18**	**1.93**	**0.89**	**-0.56**	**1.24**

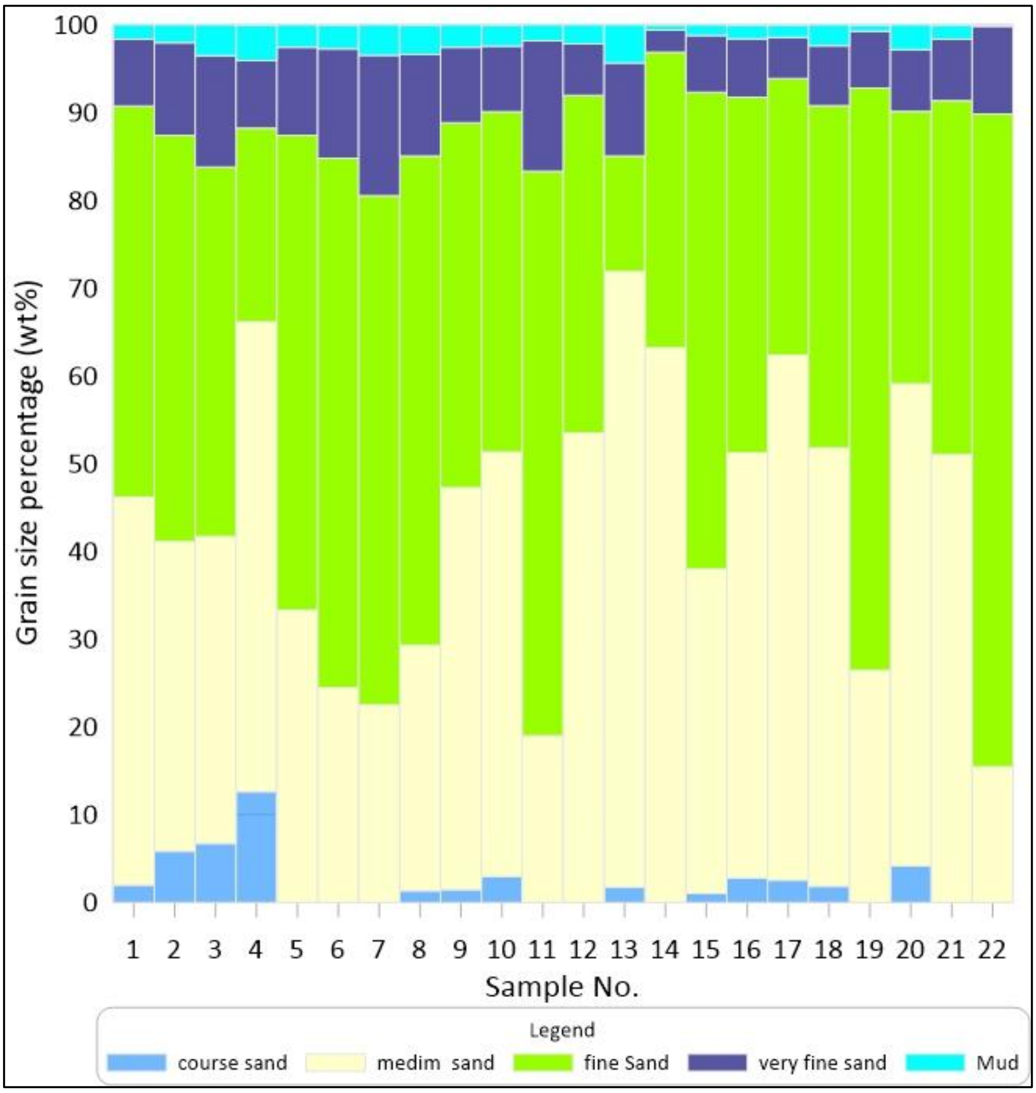
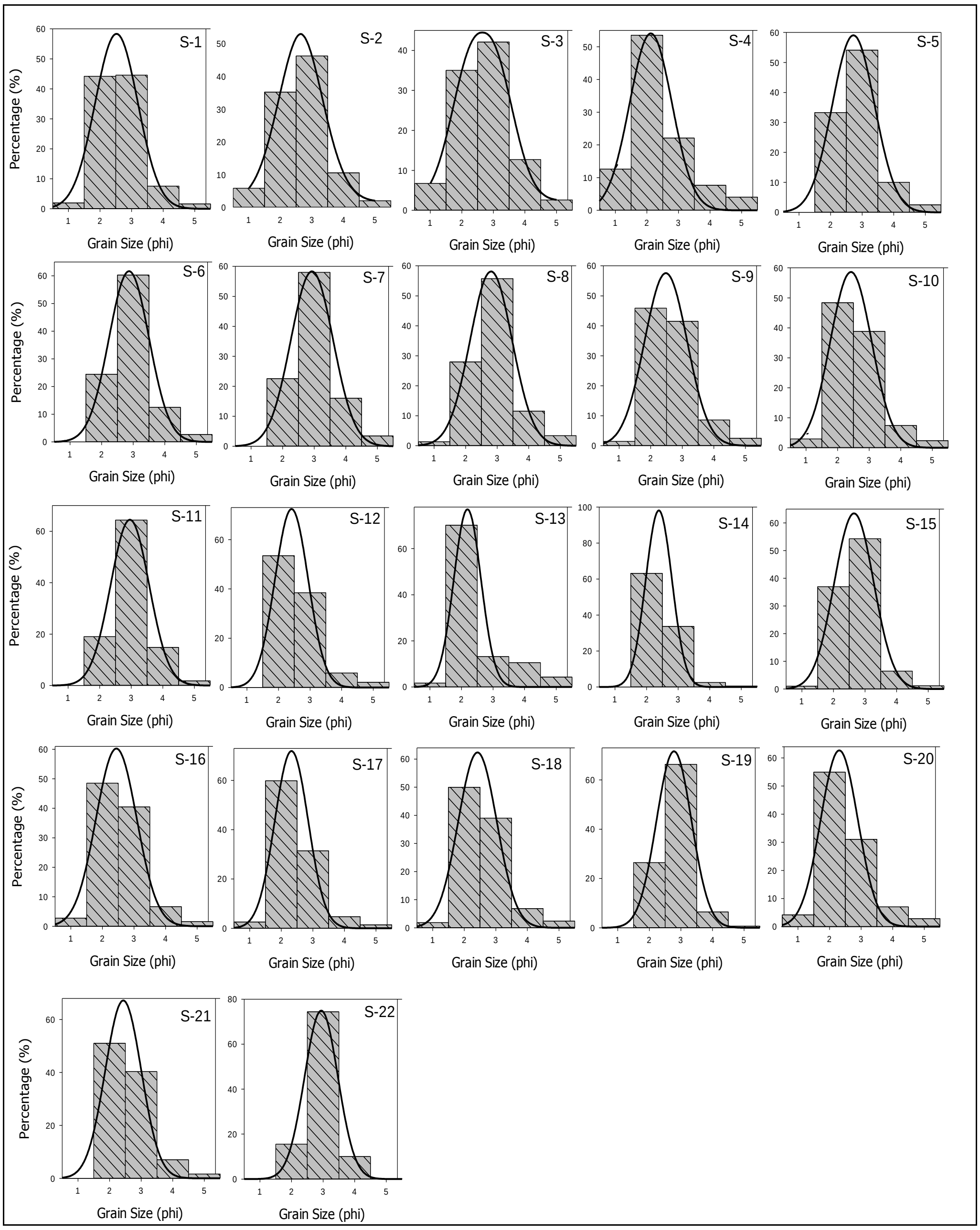


Figure 2 Distribution of particles size percentage in the studied samples (n=22).



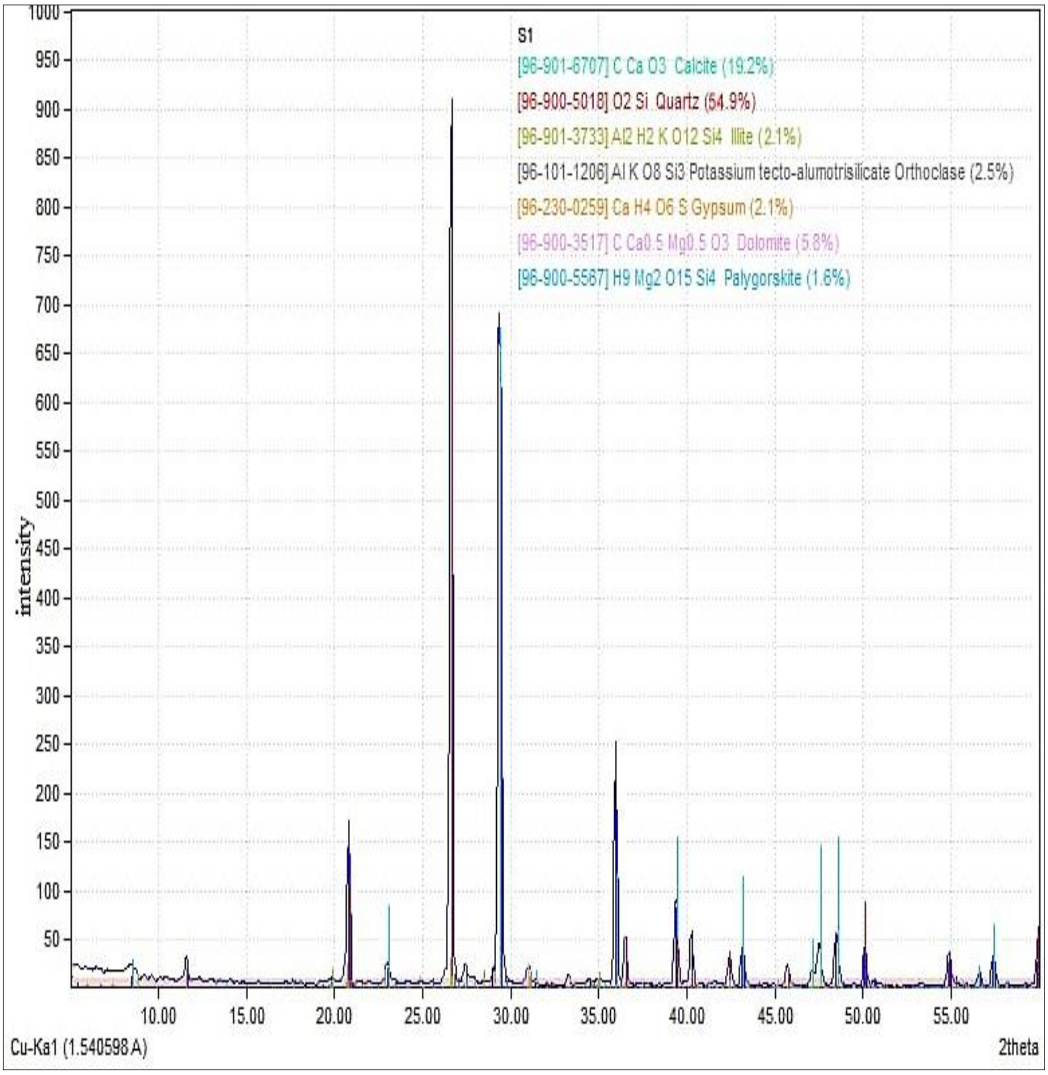
Figuer 3: Histogram of the studied samples (n=22).

3.2 Mineralogy of Bulk Sand

The X-ray diffraction patterns show the mineral composition of the present study samples. The semi-quantitative analysis of these samples is presented in Table 2 and Figure 4. These minerals are quartz, feldspar (orthoclase and albite), clay minerals (Illite, chlorite, and palygorskite), carbonate minerals (calcite and dolomite), and gypsum. Among these groups of minerals, quartz is the dominant mineral, with an average of 55.43wt %, followed by calcite (21.83wt %), clay minerals (8.73wt %), feldspar (5.53wt %), dolomite (3.67wt %), and gypsum (0.77wt %). The palygorskite appears in all samples, chlorite in samples (S-12&22), and illite in (S-1) only. The feldspar type is orthoclase in (S-1&22) and albite (S-1) only. The difference in the polytype of each group leads to variation in the sediment's geochemical composition, especially in major oxides. The mineralogy of sand dunes in the study area can divide into three groups, silicate minerals group (quartz, feldspar, and clay minerals), carbonate group (calcite and dolomite), and evaporite (gypsum). The silicate is the predominant group in the studied samples. The type of heavy minerals that occur in the study area was tourmaline, garnet, zircon, kyanite, chlorite, rutile, hornblende, and olivine (Figure 5). In detrital sediment, the distribution of heavy mineral is controlled by some factors such type and size of crystals of the parent rocks, sorting by hydraulic, density of minerals, and mineral fragmentation [20]. Understanding heavy mineral preservation is important for interpreting sediments' generation, pathways, provenance and geochemistry [21]. Heavy minerals are a varied and nongenetic mineral grouping found in detrital sediment and sedimentary rocks [22].

Table 2: Semi-quantity of minerals phases percentages in bulk samples of study area.

Minerals Name	Content in percentage(%) per samples			
	S-1	S-12	S-22	Average
Quartz	54.9	49.6	61.8	55.43
Feldspar	2.5	5.8	8.3	5.53
Clay Minerals	3.7	11.1	11.4	8.73
Calcite	19.2	27.8	18.5	21.83
Dolomite	5.5	5.5	-	3.67
Gypsum	2.1	0.2	-	0.77



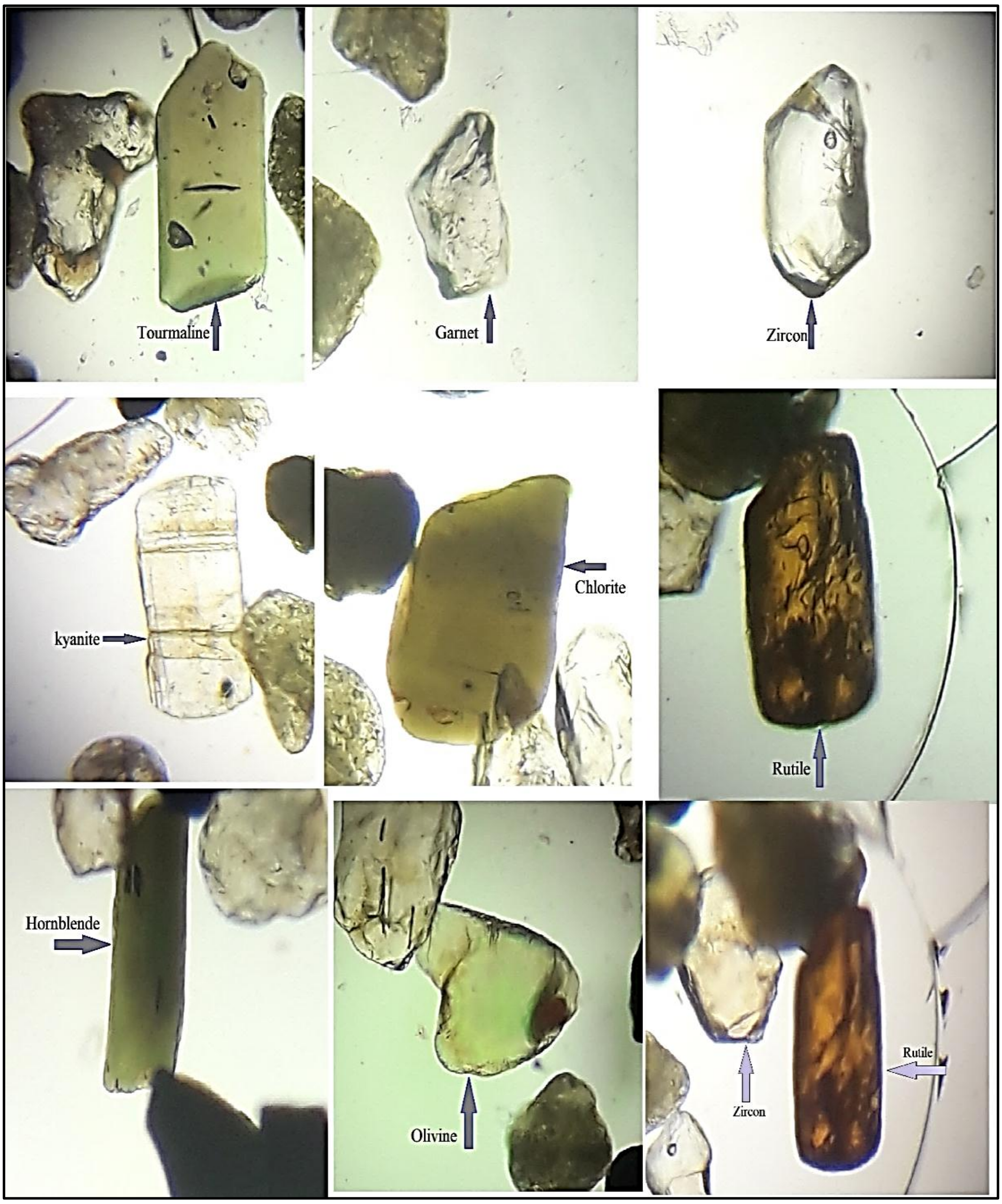


Figure 4: XRD plot of the sediments from sand dune under study (Sample-1).

Figure 5: Microscopy photo (X10) for heavy minerals species occurrence in the studied samples.

3.3 Geochemistry of Major Oxide and Trace Elements

The major oxide content and trace elements concentration for sand dune sediment in the study area are shown in Table (3) and Figure (6). In the studied samples, SiO_2 concentration was highest (ranging from 49.33 to 58.85 wt%, with an average 55.06 wt%), while the Na_2O had the lowest concentration (ranging from 0.56 to 1.02wt%, with average 0.84 wt%). For trace elements, Ti is the highest concentration among trace elements (ranging from 1887.23wt% to 2851.82 wt% on average 2208.76 wt%), whereas As has the lowest concentration in the study area (ranging from 2.88wt% to 3.56wt% with average 3.11wt%). Figure (6) C and D show the normalization of the trace elements and major oxides compared to their abundance in the upper continental crust (UCC:[23]). Major oxides are enriched with calcium oxide (CaO), and depleted in the other oxides compared with an average upper continental crust value (UCC). Most trace elements are depleted compared to UCC, whereas Cl and Cr were enriched. The high content of SiO_2 in studied samples refers to the high content of silicate minerals, especially quartz. This finding is consistent with the mineralogical study, which showed that quartz is the main mineral composition of these dunes. Al_2O_3 and K_2O contents are relatively low, indicating that the content of clay minerals is low in the sediment. The Na_2O was lower than K_2O in the studied samples, referring to the abundance of K-bearing minerals such as K-feldspar (orthoclase, $KAlSi_3O_8$) more than albite in the analysed samples. The low iron oxide (Fe2O3) content is possibly attributed to the low presence of Fe-bearing phases (i.e., hematite, goethite) in the sediment. MgO is present in both carbonate and silicate minerals (clay mineral specially, palygoriskite). The high content of CaO oxide in the studied samples was correlated with the silicate fraction in sediment in addition to carbonate (calcite and dolomite) and gypsum minerals.

Table 3: Major oxide and trace elements content in percentage for studied samples (n=3).

Samples No.	S-1	S-12	S-22	average
Major Oxides weight percentage (wt %)				
SiO_2	58.85	49.33	57.01	**55.06**
Al_2O_3	5.29	5.32	6.39	**5.67**
Fe_2O_3	1.79	2.66	2.10	**2.18**
CaO	13.17	21.44	15.50	**16.70**
MgO	1.26	1.29	1.43	**1.32**
Na_2O	0.65	0.84	1.02	**0.84**
K_2O	1.37	1.11	1.53	**1.34**
SiO_2/Al_2O_3	11.1	9.3	9	**10**
Trace elements concentration (ppm)				
Cl	284.50	284.50	290.60	**286.53**
P	214.83	214.83	247.04	**225.56**
Ti	1887.23	1887.23	2851.82	**2208.76**
V	46.49	46.49	56.58	**49.85**
Cr	108.80	108.80	445.31	**220.97**
Mn	243.08	243.08	303.09	**263.08**
Co	8.02	8.02	9.91	**8.65**
Ni	34.73	34.73	47.07	**38.84**
Cu	12.22	12.22	14.38	**12.94**
Zn	25.79	25.79	14.46	**22.01**
Ga	6.80	6.80	9.00	**7.53**
As	2.88	2.88	3.56	**3.11**
Rb	47.82	47.82	49.47	**48.37**
Sr	177.66	177.66	207.76	**187.70**
Y	9.60	9.60	11.20	**10.13**
Zr	72.62	72.62	76.84	**74.03**
Nb	9.30	9.30	10.91	**9.83**
Ba	283.03	283.03	287.78	**284.61**

Ce	46.40	46.40	2.00	**31.60**
Pb	6.31	6.31	7.24	**6.62**

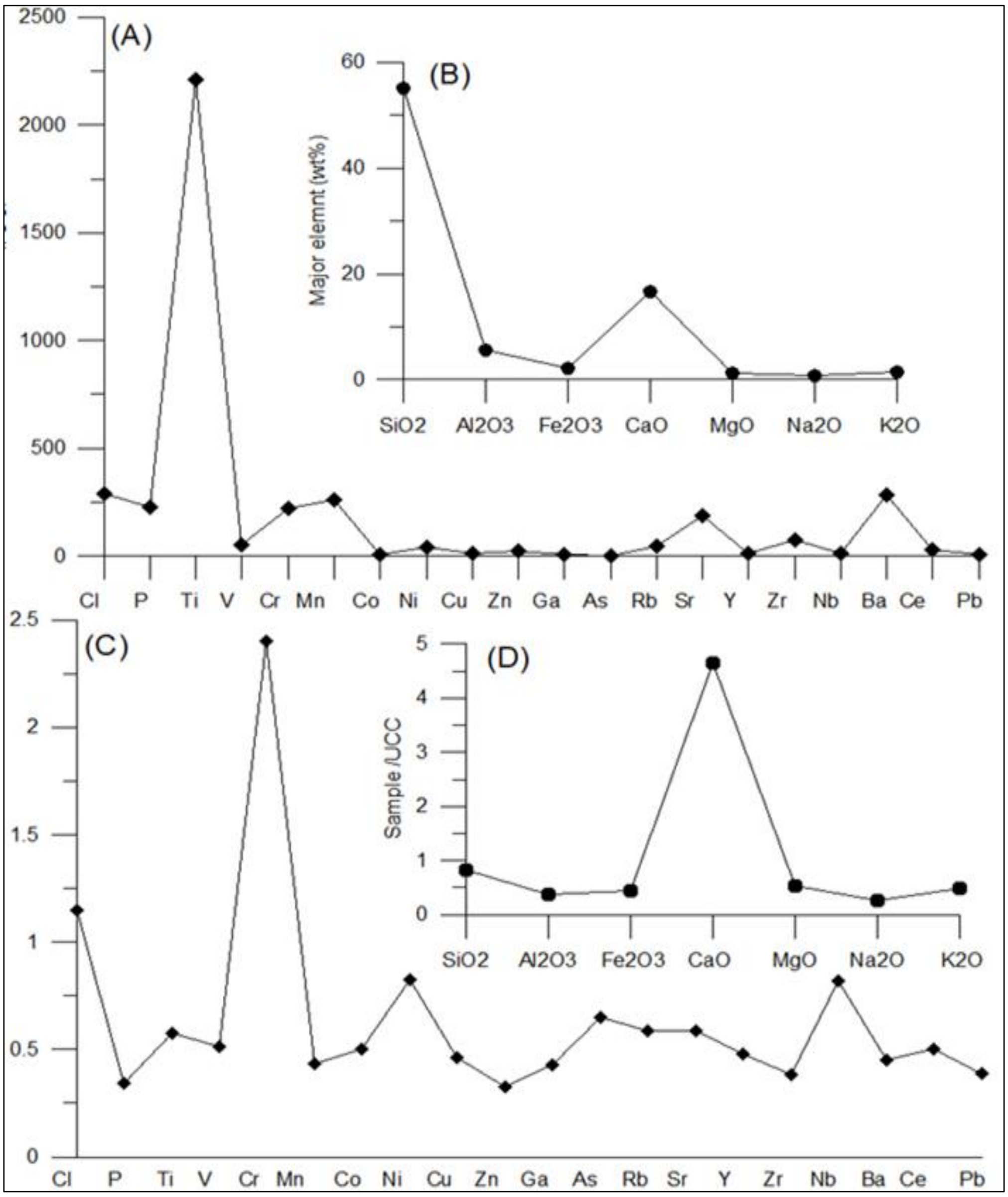


Figure 6: Trace element concentration (ppm) (A) and weight percentage of major oxides (B); UCC-normalization of trace elements (C) and major oxides (D) in the studied samples.

4. Discussion

4.1 Grain Size Characters

Grain size properties in the study area's sediment represented spatial heterogeneity. Significant variation in the particle size is a consequence of the differences in landform surface type, wind velocity, nature of provenance materials, and intensity of the earth's surface process. The general trend in studied samples is increasing sand percentage against mud (silt and clay) fraction. Production of clay fraction is insignificant in dry sediment or soils because of the low damp content. A chemical weathering process controls the clay product in waterish circumstances [24]. Therefore, low humidity has a negligible impact on clay production in this dry area.

For this reason, clay content was very low when these sand dunes were stabilized [25]. Some clays are assumed to be added as secondary quantities to the sand dune [26]. Thus, the sand fraction reveals medium and fine sand more abundant than coarse and very fine sand. The low proportion of coarse sand in sand dunes may be attributed to their too-heavy weight, while the fine particles can be removed by wind and deposited on the dune, causing increased proportion. Generally, the variation in mean grain size values refers to fluctuations in energy circumstances during the deposition of this sediment. Furthermore, the prevalence of fine grains in sediments and the absence of coarse grains refer to moderately low energy sedimentation conditions [27]. The particle size distribution of the studied samples showed significant bimodal distributions for most samples. The grain size distribution of sand dunes is typically unimodal type; it usually has narrow peaks and good sorting [28]. The multimodal distribution of the sediments is assumed to refer to the presence of unstable and varied sedimentary depositional environments such as playa or low depressions, wadi fill deposits, and stream channel deposits with different grain size deposits[29]. The variation in wind breeze-up direction may clarify some of the diverge in the grain size parameters[30]. Most of the samples have moderate to poor sorting. This represents the most instant difference in the spatial heterogeneity of the variation in landform surface kind [28]. The diversity in particle size distribution can result from spatial differences in the nature and intensity of surface aeolian activity. The dominance of poorly sorted sand refers to near-source regions. Most of the studied samples are characterized by strongly coarse skewed skewness value, while kurtosis shows variation mesokurtic, leptokurtic, and very platykurtic. The grain mixture is dominantly medium sand and subordinate fine sand. The variation in the quantity of very fine sediment with a dominant medium sand modem, reducing in the degree of sorting, particularly in the tail of the dune, thus the leptokurtic to very platykurtic conditions exits the variation in grain size statistics parameters may be attributed primarily to the sediment grains size characteristics of the parent rocks, but may also be an indicator to the air direction over years [30].

4.2 Mineral Composition of the Sand Dunes

Mineral composition investigation can give discernment to the provenance and evolution of aeolian sand dunes[31], [32]. The main mineral constituents of dune sands are quartz and feldspar, with the total content of these minerals can reach up to 90% in some deserts[33], [34]. Sand dune deposits in the study area are a mixture of various minerals in different content such as carbonate (calcite and dolomite), gypsum, silicate minerals such as quartz feldspar, clay minerals with the following abundance sequence quartz > calcite > clay minerals < feldspar < dolomite < gypsum. These groups of minerals refer to the dominance of physical weathering over chemical weathering. The result of Physical weathering is coarse grains, composed mainly of quartz, calcite, and feldspar, whereas chemical weathering produces fine particles from clay minerals [35]. Generally, quartz content is highly higher than feldspar. This is because of the high percent of quartz in silicate part from sediment, but mostly because quartz characters are physically hard and chemically stable [33]. Three clay minerals types were identified in the study samples with different content. Palygorskite is the most common, followed by chlorite, then illite, while kaolinite is absent. Kaolinite is mainly considered to form in tropical conditions from well-developed ferritic soils in a plain environment with active hydrolysis processes [36]. Palygorskite is an indicator of sediment that forms in arid and semi-arid areas.[37] Pointed out that the palygorskite mineral is present in all dry areas of the Middle East and Africa and is the major provenance of atmospheric dust in Asia because it is composed of fibrous crystals and can be loaded by air and transported by the wind away from the source. In addition, it is formed during high Mg and alkali conditions[37]. The presence of calcite and dolomite in the sediment suggests that sediment was exposed to significant chemical weathering from the soil-forming process, while the presence of aragonite indicates the verses (less effect of chemical weathering on the sediment). In other words, it reflects the long transport path and residence time in the aeolian environment[33]. The rare gypsum mineral may represent a secondary gypsum derived from Fat'ha Formation that was exposed in the east part of study area on the west flank of Hamrin fold. Tourmaline, garnet, and olivine reflect the variation of the source rocks of the sediment. Zircon, tourmaline and rutile would originate in source areas consisting of igneous and/or reworked sedimentary rocks[38]. Kyanite refer to metamorphic rock especially gneisses, chlorite and hornblende are found in vary range of igneous and metamorphic rocks[39]. The provenance or source rocks are usually determined using heavy minerals [22], [40].

4.3 Major and Trace elements composition

The major and trace element is used to identify the source of sand dune deposits [1]. The variation in the geochemical composition of sand dune sediment is related to the nature of the sediment source, mean grain size, and chemical alteration processes[41]. The chemical composition of studied samples reflects normal distribution for trace elements and significant oxide, but the UCC- normalized major oxides show CaO is enriched, while other oxides are depleted. Most UCC-normalized trace elements show depletion, while Cl and Cr are enriched. The studied samples' particle size ranged from 0.18Φ to 2.44Φ (coarse to fine sand), which may be due to moderate action for both chemical and physical weathering processes on the parent rocks from which these sediments were derived. This means long transport of very fine size grains. SiO_2/Al_2O_3 ratio can be used to infer the maturity of sediments (Table 3). The high value for this ratio reflects compositionally mature sediments, and exhibits the nature of components, which was toward stable minerals, such as quartz[42]. For origin rocks, if the SiO_2/Al_2O_3 ratio value of 3 refers to basic rocks, 5 refers to acid igneous rocks. SiO2/Al2O3 value of the studied samples is > 5. This indicates mature sediments and acidic igneous source rock.[43] Pointed out that Injana Formation contains carbonate lithic fragments as common sedimentary rock fragments. Therefore, the high content of CaO in the study area refers to derive this sediment directly from Injana Formation that exposure in the study area.

5. Conclusions

The main conclusions of this study are:

1- Generally, the grain size analysis of sand dune sediments reveals a high percent of coarse grains (sand) size relative to fine grains (mud), and fine sand is dominant. In addition, most of the sand dune sediment shows unimodal grain size distribution.

2-The average sorting of all sediment samples is 0.89 (moderately sorted), with strongly coarse skewed for most samples. The sediment that contains moderately sorted could be due to fine and coarse sediment mixing by winnow action. Generally, both peaks and tails are equally sorted to terminate in the leptokurtic in grain–size pattern.

3-The sediments' mineral compositions show high silicate minerals content relative to non-silicate minerals. Quartz is the most dominant mineral, followed by feldspar (orthoclase > albite), clay minerals (palygoriskite > chlorite > illite), calcite, dolomite, and gypsum. These groups of minerals refer to the dominance of physical weathering. The presence of palygorskite is a good indicator for arid and semi-arid regions.

4-The major heavy minerals that were identified in the sand dune sediments were tourmaline, garnet, zircon, kyanite, chlorite, rutile, hornblende, and olivine. These minerals refer to igneous and metamorphic rock sources (specially gneisses).

5-Major and trace element concentrations of sand dunes sediments show a high percentage of SiO_2 % and Ti and low content of Na_2O and As. The UCC- normalized revealed CaO, Cr, and

Cl, while other elements were depleted. Enrichment, while. SiO_2/Al_2O_3 value indicates moderately mature sediments derived from acidic igneous rock.

6-The high content of CaO refers to derived sediment directly from the Injana formation.

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