



<https://jssr.ui.ac.ir/?lang=en>

Journal of Stratigraphy and Sedimentology Researches

E-ISSN: 2423-8007

Vol. 41, Issue 4, No. 101, 2025, 27-42

Received: 09.05.2025

Accepted: 25.08.2025

Research Paper

Sedimentological Study of Sand Dunes in the Al-Najaf Province, Central Iraq

Mohammed L. Hussein

Department of Medical Physics, College of Sciences, Al-Mustaqbal University, Babylon, Iraq
mohammed.lateef@mustaqbal-college.edu.iq

Mohanad R. A. Al-Owaidi * 

Department of Applied Geology, College of Science, University of Babylon, Iraq
sci.mohanad.rasim@uobabylon.edu.iq

Hamid A. A. Alsultan 

Department of Applied Geology, College of Science, University of Babylon, Iraq
sci.hamid.ali@uobabylon.edu.iq

Abstract

This study focused on the sedimentological attributes of the dunes in the Najaf Governorate, southern Iraq. Twelve spot samples were collected from two areas, the first was approximately 3 km from Madhlum Village, and the other was west of Al-Manathera District. Several analyses were performed, including grain-size analysis, XRD, petrography using a polarized microscope, magnifying lenses to distinguish light minerals, and SEM-EDS survey. These sediments are compound of silt, sand, and mud fractions, with sand particles predominating in the dune fields. Muddy sand was categorized according to this pattern. According to XRD, quartz is the predominant mineral at the studied locations, followed by feldspars, calcite, and gypsum. Petrographic analysis reveals that monocrystalline quartz is more abundant than polycrystalline quartz. The various types of rock fragments include metamorphosed, igneous, carbonate, mudstone, and chert fragments. Alkaline feldspar is more than plagioclase. The mineral content was classified as litharenite to feldspathic litharenite. The provenance of the sand dunes indicates recycled orogeny. The paleoclimate in the source area ranged from semi-humid to semi-arid.

Keywords: Sand dunes; Sedimentology; Quartz; Al-Najaf; Petrogenesis

Introduction

Approximately 20% of the Earth's surface is covered by deserts, of which only 20% sand cover (Watson 1997). Sand is formed through weathering and erosion, which break down rocks into smaller particles. Durable minerals such as quartz and feldspar dominate in sands because of their resistance to chemical and physical weathering. Environmental forces such as wind, water, and ice are primary agents that control sands geometry and composition, which vary based on the original rock source and weathering degree (Pye & Toser 2009). Over the past 40 years, global climate change has resulted in a scarcity of rain and water, significantly affecting Iraq. The Iraqi Mesopotamian Plain has suffered from desertification, which has turned large agricultural regions into expanses of sand dunes.

The Najaf dunes are located west and southwest of Najaf City and are oriented in the direction of the predominant wind regime, prevailing in the NW–SE direction in the region (Rasheed & Al-Ramahi 2021). The morphological types of dunes

include barchan, barchanoid, longitudinal, and sand sheet dunes. Various sedimentary structures include ripple marks, burrows, borings, cross-strata, and lamination (Hussein et al. 2021).

Aeolian dunes are composed of several minerals and various rock fragments. These loose particles originate from natural breakdown and erosion of source rocks, wind-borne transportation, and deposition in arid regions (Padmakumar et al. 2012).

The Pleistocene and Holocene Quaternary deposits in the study area include ravine drains, flooded areas, marshlands, and aeolian deposits. Aeolian sediments are widely dispersed throughout the study area. The regional stratigraphy, from Eocene to Recent includes, the Dammam, Ghar, Euphrates, Nfayil, Injana, Zahra, and Dibdibba formations (Jassim & Goff 2006) (Fig. 1).

Approximately 20% of the Earth's land

*Corresponding author

Hussein M., Al-Owaidi M. and Alsultan H. (2025). Sedimentological Study of Sand Dunes in the Al-Najaf Province, Central Iraq. *Journal of Stratigraphy and Sedimentology Researches*, 41(4):27-42. <https://doi.org/10.22108/jssr.2025.145207.1312>

2423-8007 / © 2025 University of Isfahan

This is an open access article under the CC BY-NC-ND 4.0 License (<https://creativecommons.org/licenses/by-nc-nd/4.0/>).



<https://doi.org/10.22108/jssr.2025.145207.1312>

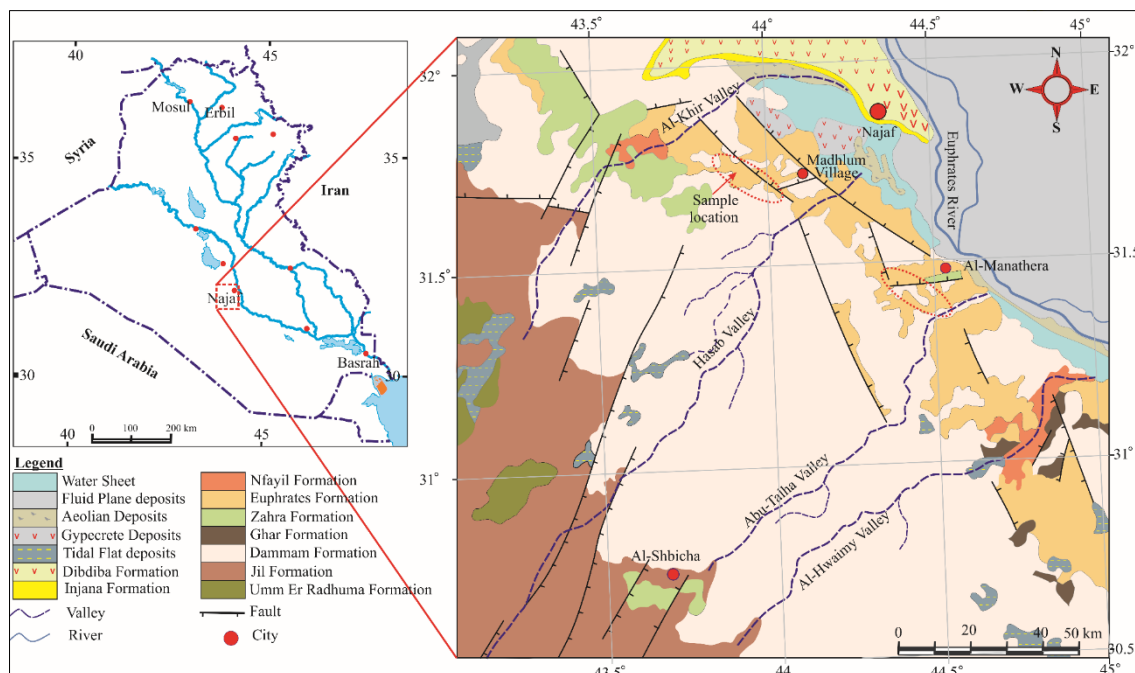


Fig 1- Geological map of the studied area

Temperature, precipitation, wind direction and strength, dust storms, and other climatic factors exert a primary control on sediment availability and the transport capacity of wind (Rasheed and Al-Ramahi 2021). Iraq is located in a dry to semi-dry climatic region with a predominantly continental climate characterized by hot summer and cold winter. This region experiences low precipitation, rapid evaporation, and limited water sources. The amount of available sediments and their capacity to be transported by aeolian processes are significant factors in this climate (Hussein et al. 2021).

Numerous researchers, notably Buday and Jassim (1987); Al-Janabi et al. (1988); Hassan et al. (2007); Al-Shakeri et al. (2017); Jassim (2017); and Al-Naji and Al-Shammery (2019), have conducted comprehensive geological surveys, including geotechnical, geochemical, and geophysical analyses in the region. Al-Enezi et al. (2008) conducted a study on the movement of dunes, their economic significance, and an analysis of their mineralogical characteristics to determine the source of the dunes' sand and their characteristics.

The main goal of this study is to understand the sedimentological features of the dunes in the Al-Najaf area by utilizing grain size analysis, mineralogical analyses, to determine the provenance of the sand sediments, in addition to petrogenesis and paleoclimate.

Materials and Methods

Two dune fields in the Al-Najaf province were selected for this study: the first is situated in the western region of Najaf City adjacent to Madhlum Village, between latitudes 31°32'57"-31°33'27" N and longitudes 44°35'04"-44°35'26"E. The second area lies in the southwestern region of Najaf City, west of Al-Manathera District, between latitudes 31°57'36"-31°57'39"N and longitudes 44°08'17"-44°08'29"E (Table; Fig. 2).

A GPS device was used to georeference the sample locations. Ten of the 12 samples were selected for various analyses. Each sample represented a single dune. A composite sampling method was employed. For each dune, one sample was taken from the dune crest, two from the sheltered sides (steep slopes), and one from the windward side (gentle slope). Equal weights of the samples were combined and mixed thoroughly, and a single sample was selected to represent each dune.

Table 1- The coordinates of the sampling locations

Sample No.	Longitude (N)	Latitude (E)
S 1	44° 35' 12''E	31° 32' 57''N
S 2	44° 35' 24''E	31° 33' 00''N
S 3	44° 35' 26''E	31° 33' 04''N
S 4	44° 35' 08''E	31° 33' 07''N
S 5	44° 35' 15''E	31° 33' 11''N
S 6	44° 35' 27''E	31° 33' 14''N
S 7	44° 35' 04''E	31° 33' 17''N
S 8	44° 35' 13''E	31° 33' 18''N
S 9	44° 35' 11''E	31° 33' 27''N
S 10	44° 08' 29''E	31° 37' 36''N
S 11	44° 08' 17''E	31° 57' 39''N
S 12	44° 08' 22''E	31° 57' 38''N



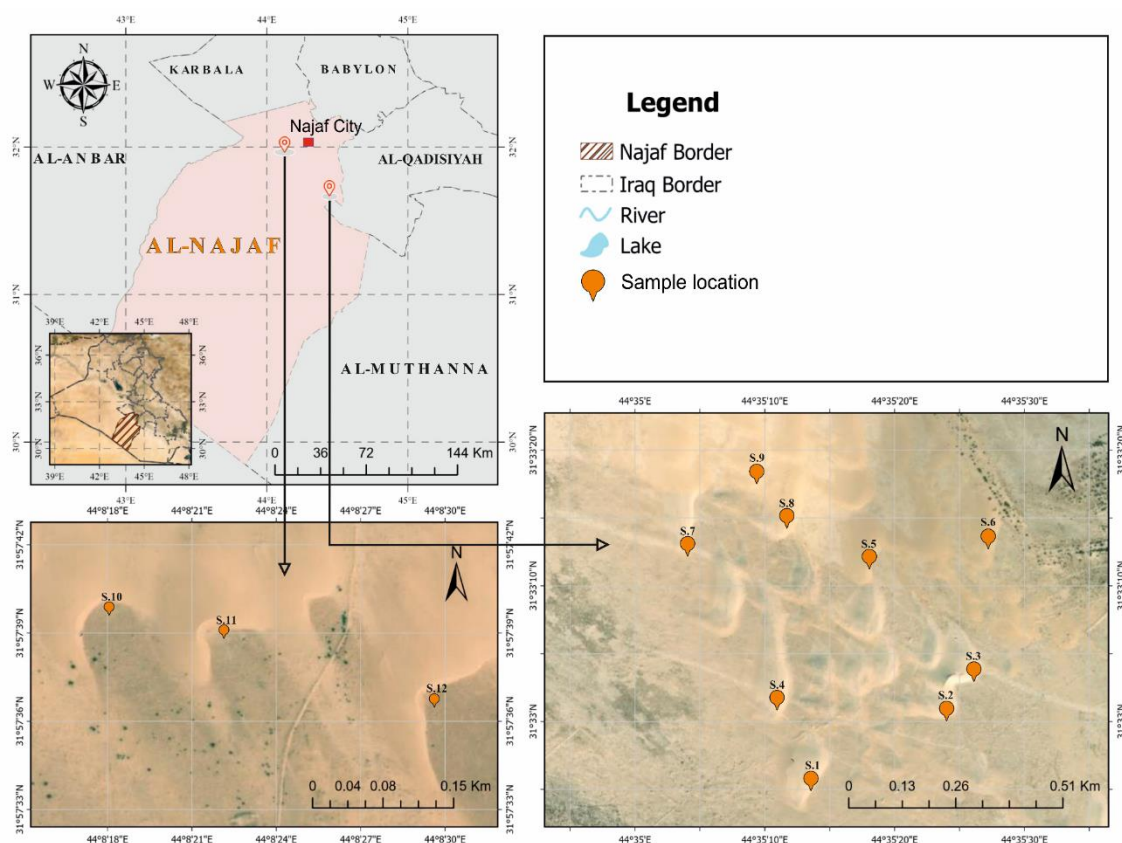


Fig 2- A satellite map showing the site locations of the investigated area.

For grain size analyses, the coarse to very fine-grained sandstone sample, with a grain size 1.000 mm to 0.063 mm, was prepared. A total of 400 grains per sample were counted. Each grain that fell under a predetermined grid point was identified and classified. The results are presented as the percentage of each grain (Ingersoll et al. 1984). The obtained samples were analyzed for grain size at the Department of Applied Geology, College of Science, University of Babylon, using the Wentworth (1922) scale as employed by Folk (1980). The sand and mud fractions were separated by sieving the samples, which ranged in size from 2 mm to 63 μ m (Allen 1981). To determine the mineralogical specifications of the sediments, bulk samples were analyzed using X-ray diffraction (XRD) (Del Valle et al. 2008). This method identifies light minerals by analyzing the mineral content of the entire sample. The analytical procedures in the Materials Laboratory of the Ministry of Science and Technology followed the Thorez method (1976). To analyze the chosen samples petrographically, under a transmitted polarized microscope, light minerals were separated from heavy minerals according

to (Carver 1971; Mange & Maurer 1992). The separation was performed by using heavy liquid (bromoform of a specific weight 2.9) for sand fractions of grain size from 0.0625 to 0.250 mm in the Applied Geology Department/ University of Babylon.

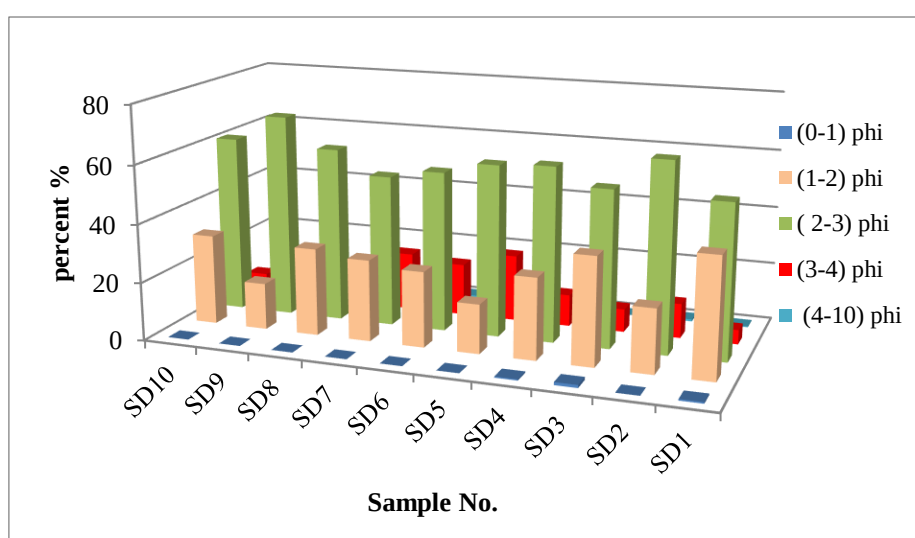
Results and Discussion

Grain size analysis

The grain size and grain size distribution determine the mechanical properties of sediments and provide insights into their history and origin (Goossens 2008). Krumbein (1941) devised the phi scale as a logarithmic scale of Wentworth (1922). Modern data are typically reported in phi because the mathematical computations are simplified (Folk 1974). Furthermore grain-size patterns provide significant clues about the source, transportation history, and depositional conditions of sediments (Sierra et al. 2013). grain size analysis and distribution for the study area are presented in detail in Table 2 and Fig. 3. These samples ranged, dominantly from very fine- to medium-grained sand, with few coarse-grained sands.

Table 2- Grain size analysis in the investigation area, based on Wentworth (1922)

Sample No.	Coarse (0-1 Ø)	Medium (1-2 Ø)	Fine (2-3 Ø)	V. fine (3-4 Ø)	(4-10 Ø)	Texture
	1000-500 µ	500-250 µ	250-125 µ	125-63 µ	63-1 µ	
SD1	0.5	41	53	5	0.3	sand
SD2	0	22	65	12	0.7	sand
SD3	1	37	54	8	0	sand
SD4	0.4	28	60	11	0.5	sand
SD5	0	17	59	23	0.9	sand
SD6	0	26	55	18	1	Muddy sand
SD7	0	28	52	20	0.8	sand
SD8	0	30	60	10	0.6	sand
SD9	0	16	70	13	1	Muddy sand
SD10	0	31	61	7	0.8	Sand
Average	0.19	27.6	58.9	12.7	0.66	

**Fig 3-** Bar chart shows the grain size distribution in the study area.**Statistical Parameters**

The statistical parameters applied in this study included mean size, median, standard deviation, skewness, and kurtosis, based primarily on the method of Folk and Ward (1957). The mean size is considered the average grain size (Tucker 1988).

The mean size values concentrate in the class interval of 2.2-2.67 Ø corresponding to the fine sand class. The median size is the diameter corresponding to the 50% mark on the cumulative curve (Fig. 4).

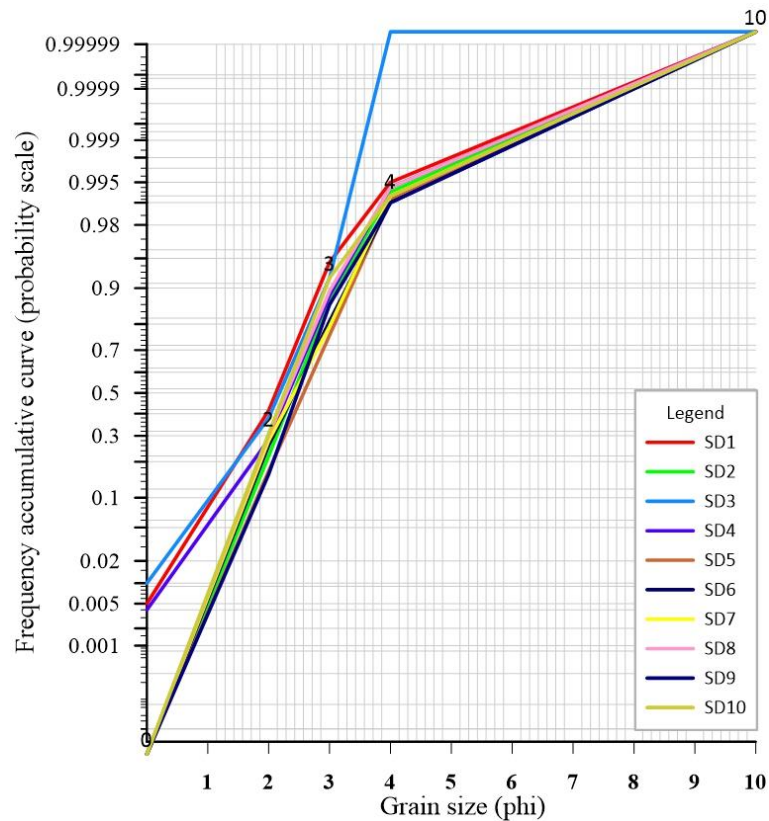


Fig 4- Frequency cumulative curve of studied samples

The median values exhibited a clustering distribution around the 2.0-2.8 ϕ class interval, which also falls within the fine sand limit. The inclusive graphic standard deviation (σ_I) values provide insight into the kinetic energy and sedimentation rate. The sorting values cluster in the class interval of 0.44 ϕ to 0.6 ϕ corresponding to well to moderately well-sorted sediments. Skewness represents the degree of symmetry in a distribution (Pettijohn et al. 1973). The sands in the study area have skewness values clustering in the -0.64 ϕ to 0.65 ϕ class interval, indicating positive skewness in average. Sample SD5 has more negatively skewed due to the very fine particles ratio then the rest samples. Kurtosis

indicates the degree of peak of the grain distribution. It is a numerical statistic that characterizes the deviation from a normal distribution (Folk 1974), as shown in Tables 3 and 4, as well Figs. 5, 6, and 7. The kurtosis values of sands were concentrated in the interval of 0.4 ϕ to 0.86 ϕ (very platykurtic to platykurtic), and -1.23 ϕ (leptokurtic).

The texture parameters, which include well to moderately well sorted, fine mean grain size, and positive skewness, indicate an aeolian depositional environment characterized by unidirectional wind transport and gradual grain sorting, which are typical of active dune fields in arid to semi-arid climates.

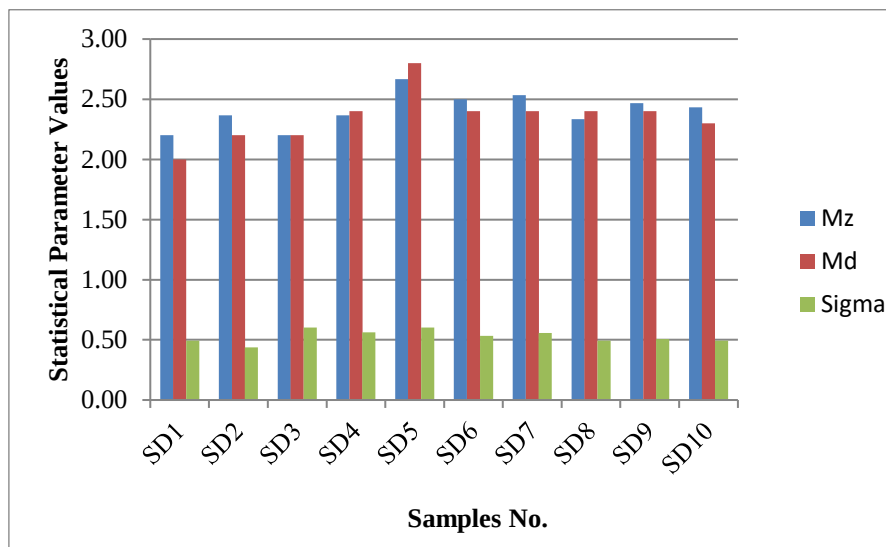


Fig 5- The bar chart displays the statistical parameter values (Mz, Md, and σI) in the study area

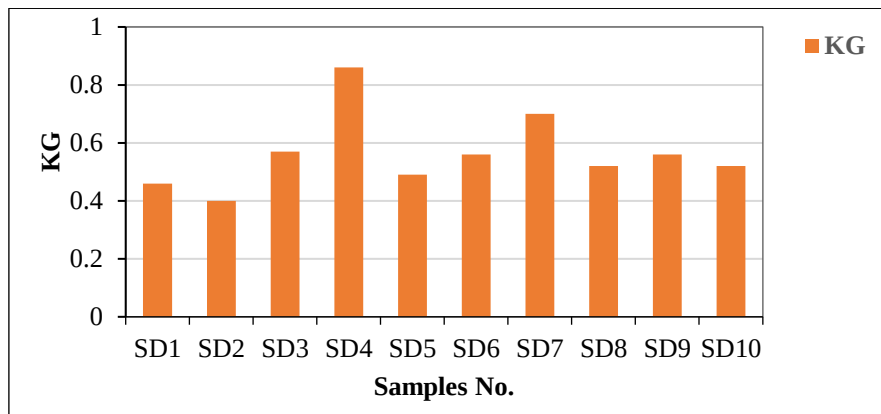


Fig 6- Exhibits the statistical parameter of KG in the studied samples.

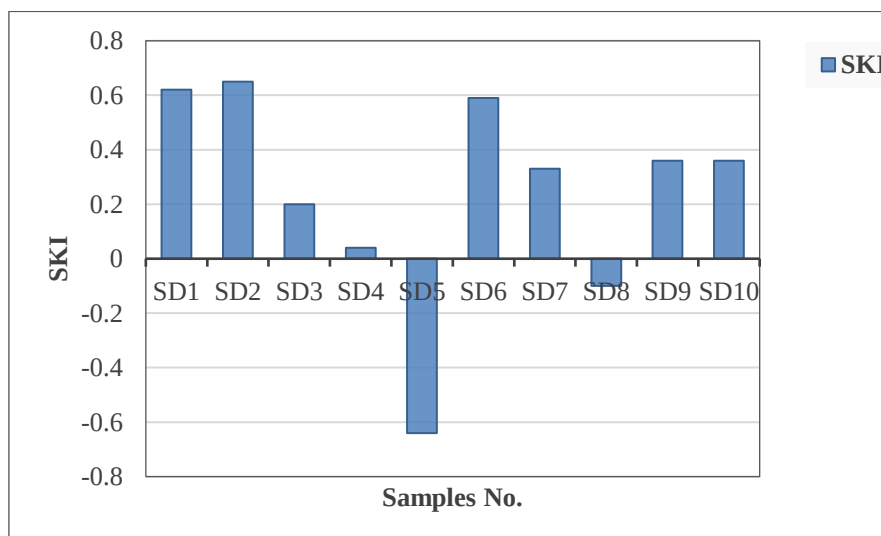


Fig 7- Shows the statistical parameter of SKI in the studied samples.

The equations used for the calculations are as follows (Folk & Ward 1957):

- Median (MdZ)= Ø50
- Mean Size (Mz)= (Ø16 + Ø50 + Ø84)/ 3
- Standard Deviation (σ I) = $[(\text{Ø}84 - \text{Ø}16) / 4] + [(\text{Ø}95 - \text{Ø}5) / 6.6]$
- Skewness (SKI)= $[(\text{Ø}16 + \text{Ø}84 - 2 \text{Ø}50) / 2 (\text{Ø}84 - \text{Ø}16)] + [(\text{Ø}5 + \text{Ø}95 - 2 \text{Ø}50) / 2 (\text{Ø}95 - \text{Ø}5)]$
- Kurtosis (KG) = $(\text{Ø}95 - \text{Ø}5) / [2.44 (\text{Ø}75 - \text{Ø}25)]$

Table 3- Statistical parameters for Al-Najaf sand dunes

Sample No.	Mz	Md	GI	SKI	KG
SD1	2.20	2.00	0.49	0.62	0.46
SD2	2.37	2.20	0.44	0.65	0.40
SD3	2.20	2.20	0.60	0.20	0.57
SD4	2.37	2.40	0.56	0.04	0.86
SD5	2.67	2.80	0.60	-0.64	0.49
SD6	2.50	2.40	0.53	0.59	0.56
SD7	2.53	2.40	0.56	0.33	0.70
SD8	2.33	2.40	0.49	-0.10	0.52
SD9	2.47	2.40	0.51	0.36	0.56
SD10	2.43	2.30	0.49	0.36	0.52

Table 4- The terminology applied to the graphical statistical parameter values (after Folk & Ward 1957).

Standard Deviation Inclusive Graphic Standard Deviation or Phi Sorting (σ)		Skewness Inclusive Graphic Skewness or Phi Skewness (Ski)		Kurtosis Inclusive Graphic Kurtosis or Graphic Kurtosis (Kg)	
Very Well Sorted	> 0.35	Very positively Skewed	0.3 to 1.0	Very platykurtic	> 0.67
Well Sorted	0.35 – 0.5	Positively Skewed	0.1 to 0.3	Platykurtic	0.67 – 0.9
Moderately Well Sorted	0.5 – 0.7	Symmetrical	0.1 to -0.1	Mesokurtic	0.9 - 1.11
Moderately Sorted	0.7 – 1.0	Negatively Skewed	-0.1 to -0.3	Leptokurtic	1.11 – 1.5
Poorly Sorted	1.0 – 2.0	Very Negatively Skewed	-0.3 to -0.1	Very Leptokurtic	1.5 – 3.0
Very poorly Sorted	2.0 – 4.0				

Bivariate Discriminates Plots

Bivariate plots illustrating the relationships between various textural factors offer valuable insights into the sedimentary environment and help distinguish between closely related depositional ecosystems (Venkatraman et al. 2011). These plots are crucial for determining the source and environment of

sand. Following the approach of Friedman (1967) and Moiola and Weiser (1968), bivariate discrimination diagrams using the mean size and standard deviation and standard deviation plot versus skewness were employed in this study. The dune samples analyzed in this study were characteristic of terrigenous river sediments, as shown in Figs. 8 and 9.

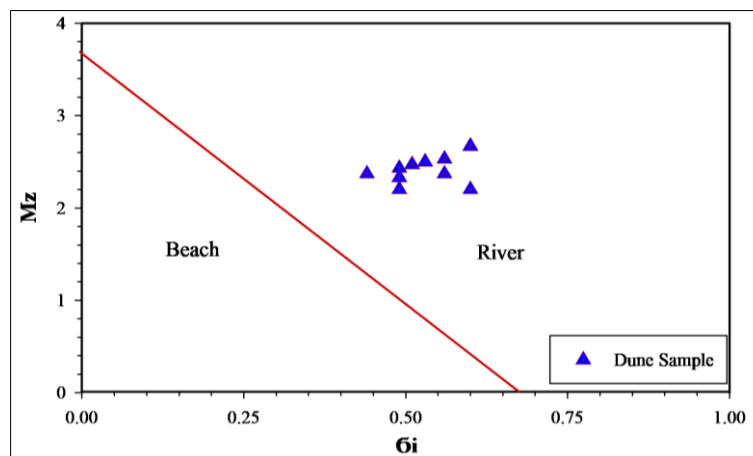


Fig 8- Bivariant standard deviation plot versus mean (Mz) (after Moiola and Weiser 1968).



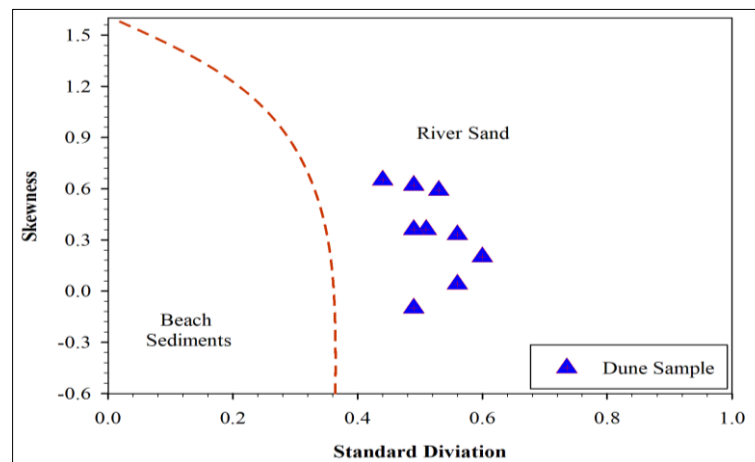


Fig 9- Bivariate standard deviation plot versus skewness (SKI) (after Muiola and Weiser 1968).

The studied dune samples exhibited textural characteristics that may reflect a reconstituted fluvial and alluvial paleoenvironment as shown in Figs. 8 and 9. However, based on the dune morphology, sedimentary structures, and prevailing aeolian patterns supported by the presence of barchan and longitudinal dune morphologies, these sands are interpreted as having an aeolian agent, having been transported, deposited, and accumulated by wind.

Mineralogical Components

The light minerals of dune fields in thin sections were studied using transmitted polarized microscopes. Quartz, feldspar, and rock fragments are the main components. These minerals are discussed in detail below.

Quartz

Quartz is the predominant constituent of the field dune sandstones, comprising an average of 55.4%. Petrographically, two types of quartz were identified: monocrystalline and polycrystalline. Monocrystalline quartz, consisting of a single crystal, is the dominant type in the examined samples, ranging from 48.75% (SD5) to 57.3% (SD1), with an average of 52.79% (Table 5). These grains are typically rounded, subrounded and angular to subangular, and exhibit straight extinction (Figs. 11 and 12). Monocrystalline quartz originated from acidic igneous rocks and often indicates multicycle sedimentation (Hussain & Al-Jaberi 2020).

Table 5- Mineralogical stations in the study area.

Light Components	Samples Number										Average
	SD1	SD2	SD3	SD4	SD5	SD6	SD7	SD8	SD9	SD10	
	%										
Monocrystalline Quartz	57.3	51.5	53.5	54.4	48.7	55.7	52.3	48.9	54.8	50.8	52.79
Polycrystalline Quartz	2.5	1.6	2.3	2.6	3.5	2.8	1.9	3.6	2.5	3.1	2.64
K Feldspar	6.8	5.3	5.9	7.6	7.4	6.5	7.2	7.7	6.8	7.4	6.86
Plagioclase Feldspar	3.4	2.5	2.6	2.8	2.5	3.1	3.5	3.2	2.7	2.9	2.92
Carbonate Rock Fragments	11.5	16.4	15.3	12.7	15.2	13	15.7	14.1	13.9	15.5	14.33
Chert Rock Fragments	2.5	3.7	3.5	3.8	2.5	2.9	2.4	3.3	2.7	3.6	3.09
Igneous Rock Fragments	2.6	2.8	2.5	2.8	2.6	2.2	2.5	3.0	2.8	2.5	2.63
Metamorphic Rock fragments	1.8	2.6	2.2	1.5	2.8	2.5	1.9	2.4	1.8	1.6	2.11
Evaporates	7.4	9.7	9.1	8.6	9.6	6.9	8.3	9.2	7.7	8.4	8.49
Mudstone Rock Fragments	2.8	2.5	1.9	2.7	3.5	3.1	2.7	3.2	3	3.2	2.86
Others	1.2	1.4	0.9	0.6	1.5	1	1.3	0.8	1.1	0.9	1.07
Total percent.	99.8	100	99.7	100.1	99.8	99.7	99.7	99.4	99.8	99.9	



Polycrystalline quartz grains exhibit rounded, subrounded, and angular shapes, with slightly undulatory extinction (Figs. 11 and 12). A polycrystalline quartz grain comprises two or more quartz crystal components with distinct intergranular boundaries and optical orientations (Tucker 1985), ranging from 1.6% (SD2) to 3.6% (SD8), averaging 2.64% (Table 5). This quartz type in the samples is primarily derived from metamorphic rocks such as schist, gneiss, and metaquartzite, as well as plutonic igneous rocks (Folk 1974). Notably, polycrystalline quartz is susceptible to weathering and breakdown.

X-ray diffraction (XRD) analysis revealed that quartz constitutes a significant portion of the sandstone, ranging from 68.8% (SD7) to 73.9% (SD1). The sharp diffraction peaks indicate high crystallinity, with prominent reflections at [101]

with a d-spacing of 3.34 Å (highest intensity) and (100) at $d=4.26$ Å (Table 6; Fig. 10). Scanning electron microscopy (SEM) observations confirmed the abundance of angular quartz grains with pitted surfaces (Fig 13).

In the study area, quartz was distinguished, predominantly by rounded, subrounded shapes; whereas subangular, and angular forms are less than the others, that refers to long distances through wind transportation. The angularity of quartz grains results by broken-down of its due to the collision between each one with others through high wind in the situ. This feature was supported by angular and pitted particles as shown SEM technique. Dibdibba Formation is believed the source of quartz and other clastic sediments, contributed with Inaja Formation. The mother rocks of them are from Arabian Shield and Zagros with Torus Mountain belts.

Table 6- Averages for the non-clay minerals in the investigated areas.

Sample No.	Quartz (%)	Calcite (%)	Feldspar (%)	Gypsum (%)	Celestite (%)
SD1	73.2	13.9	6.7	3.4	2.6
SD5	69.6	17.2	5.3	6.3	0.9
SD7	68.8	15.5	8.5	6.1	1.8
SD10	69.2	16.1	6.0	8.0	0.1
Average	70.2	15.7	6.6	5.9	1.3

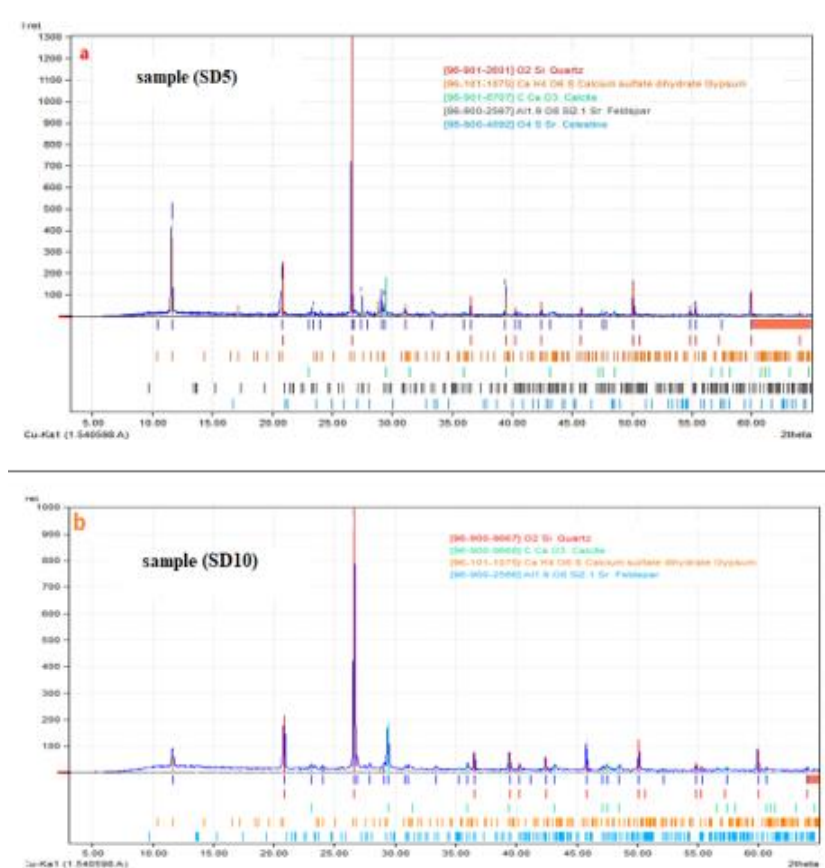


Fig 10- XRD diffractogram of a bulk sample SD5 and SD10 from the dune field of the study area.

The dominance of quartz is likely attributed to the quartz-rich nature of the source rocks in the surrounding area (Ammar

et al. 2013).



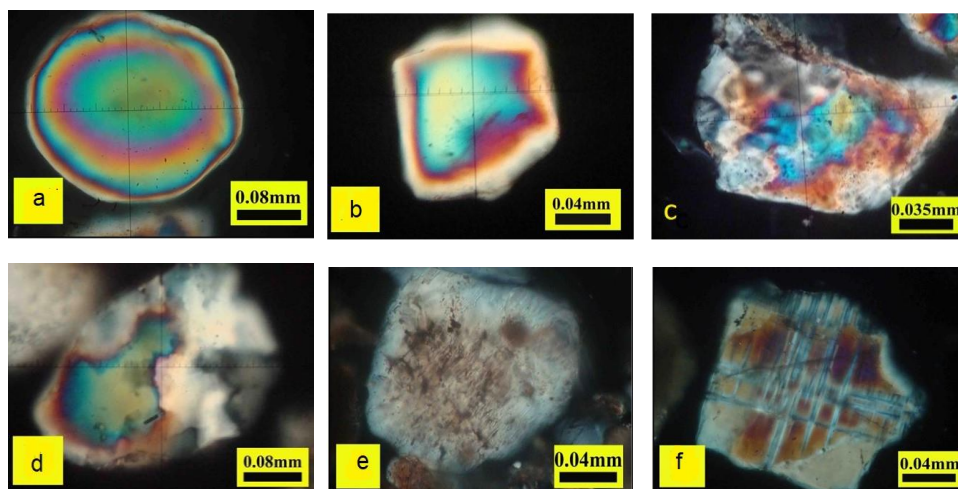


Fig 11- Light mineral microscopy images from the sand fields in the study area: a- Monocrystalline quartz, rounded form, SD4, seen under XPL. b- Monocrystalline quartz, subrounded shape, SD3, according to XPL. c- Polycrystalline quartz, with angular shape, SD6, using XPL. d- Polycrystalline quartz, rounded form, SD2, due to XPL. e- Potash feldspar (Orthoclase) rounded, altered, SD10, used XPL. f- Potash feldspar (microcline), sub angular, cross hatched twining, SD2, by XPL

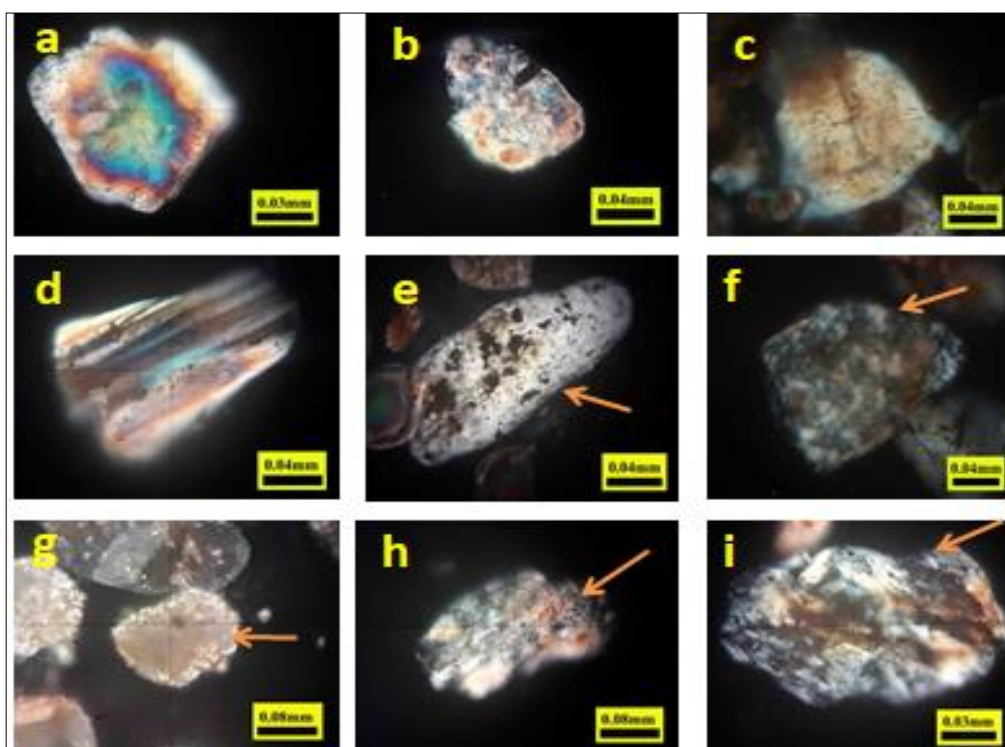


Fig 12- Light mineral microscopy images from the sand fields in the study area: a- Monocrystalline quartz, angular form, SD3, seen under XPL. b- Polycrystalline quartz, subrounded shape, SD5, according to XPL. c-, Altered orthoclase, with angular to subangular shape, SD4, using XPL. d-, Plagioclase, with carles bad twining, subangular, SD8, due to XPL. e-, Elongated igneous rock fragment, subrounded form, SD10, used XPL. f- Chert rock fragment, subrounded, SD2, by XPL. g- Carbonate rock fragment, subrounded shape, SD5, by XPL. h- Subrounded, altered orthoclase, SD3, seen by XPL. i- Metamorphic rock fragment with schistose structure, subangular, SD6, using XPL.

Feldspar

The feldspar proportions in the field dunes of the study area ranged from 2.5% to 7.7%. The K feldspar is more abundant than plagioclase between 5.35 (SD2) and 7.7% (SD8), with a mean of 6.86%. A rounded, altered form of the orthoclase grain was observed (Fig. 8). The plagioclase content ranged from 2.5% (SD2) to 3.5% (SD7), with an average of 2.78%. The shape of the grain is subangular and slightly altered, with Carlsbad twinning. The [100] reflection identified feldspar: $d = 3.2 \text{ \AA}$, $2\theta = 27.8$. According to the XRD investigation, feldspar ranged between 5.3% (SD5) and 8.5% (SD7) (Table 6; Fig. 10).

SEM-EDS analysis confirmed that the orthoclase and plagioclase grains with irregular shapes were highly weathered and altered (Figs. 13, 14, 15, and 16). The variations in feldspar composition among the different dune zones suggest differences in the source rock. A semiarid paleoclimate and/or a high-relief source area

with rapid erosion may be effective on in altering the degree of feldspar alteration (Pettijohn 1973). Based on Folk's classification (1980), the sand samples in this study are categorized as litharenite to feldspathic litharenite (Fig 17).

Rock Fragments

The studied dunes contained sedimentary, igneous, metamorphic, and evaporite rock fragments from 25.8% to 35.2%, with an average of 30.65%. Sedimentary rock fragments (average 25.91%) constitute almost all types of sedimentary rock (Table 5; Fig. 8). The carbonate rock fragments ranged from 11.5% (SD1) to 16.4% (SD2) and displayed a subrounded shape (Fig 8). Calcite was restricted between 13.9% (SD7) and 17.2% (SD5), with an average of 15.7% by the XRD method. Chert, a type of quartz, is the second most abundant sedimentary rock fragment, averaging 3.09% with a subangular shape (Table 5; Fig. 8).

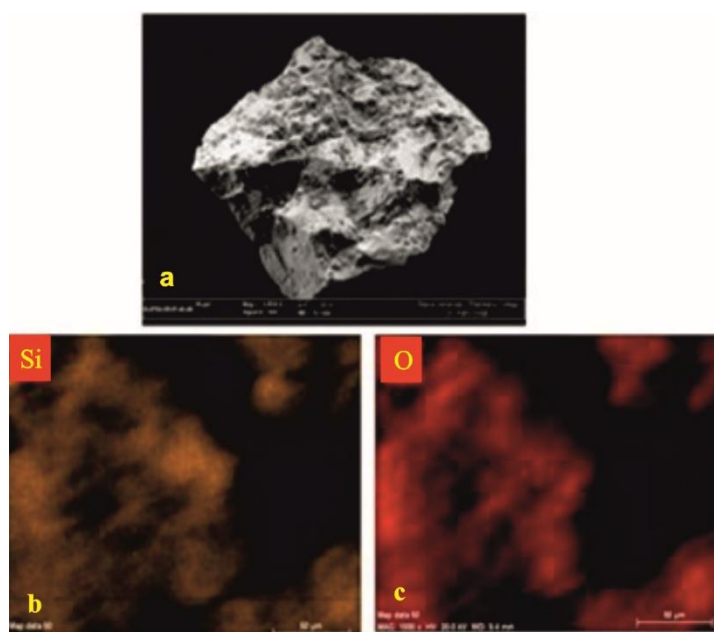


Fig 13- a, c, and c: The backscattered image supported with the elemental map using the SEM-EDS technique (scale of 20 and 50 micrometers) showed quartz grains of pitted and angular form, SD5.

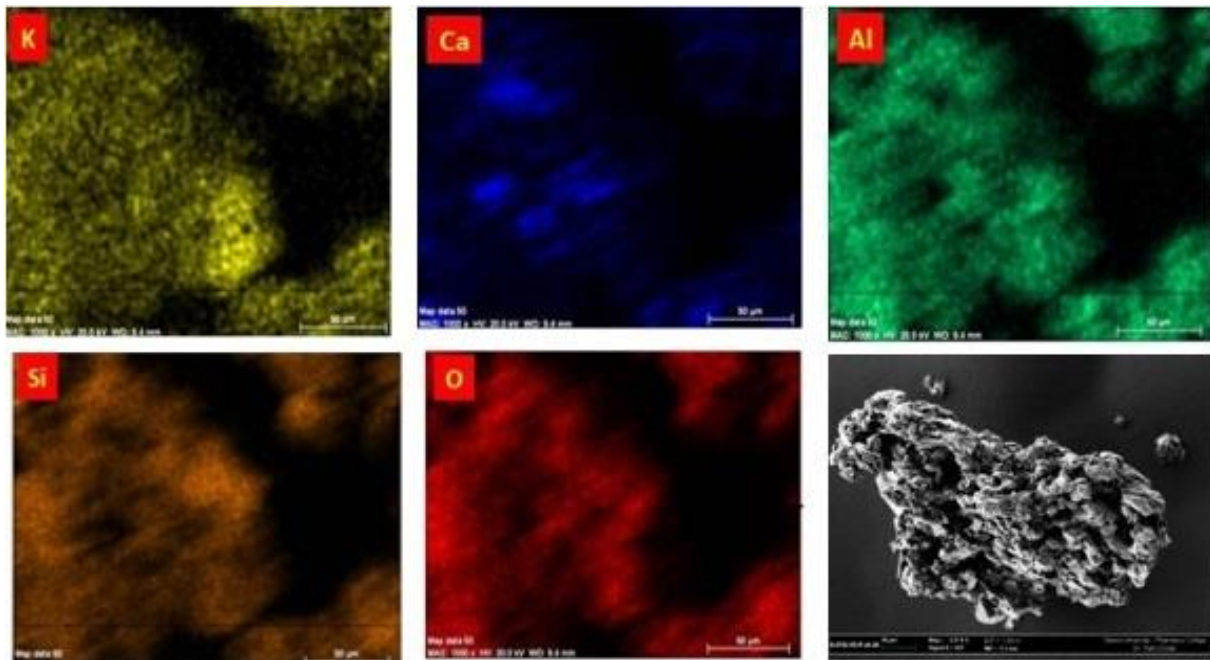


Fig 14- a, b, c, and d: The backscattered image and elemental pattern produced by the SEM-EDS technique (scale of 10 and 50 micrometers) explain the weathered, altered, and unangular shape of orthoclase form SD3.

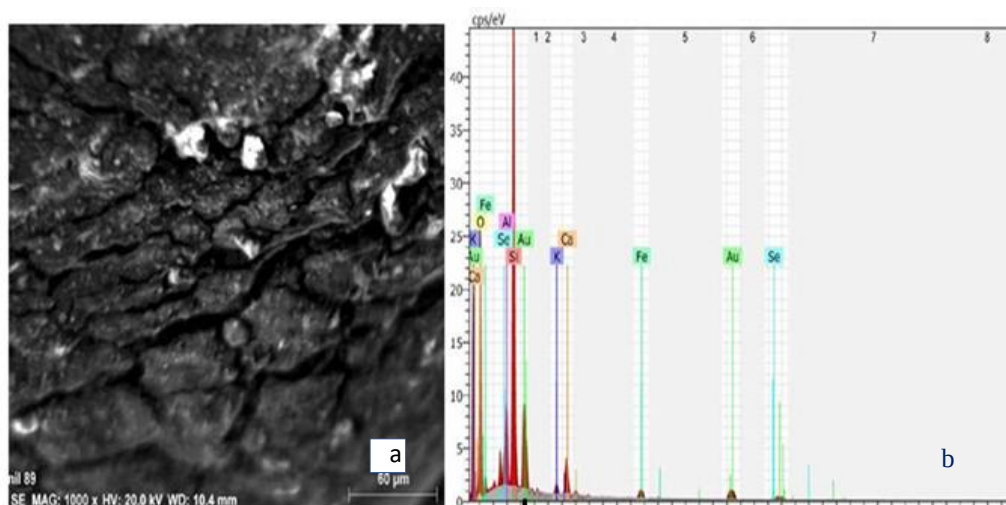


Fig 15- a, and b: The scattering image, in addition to the spot chemical spectrum utilizing the SEM-EDS approach (scale of 60 micrometers), illustrates Ca—Na plagioclase, SD6.

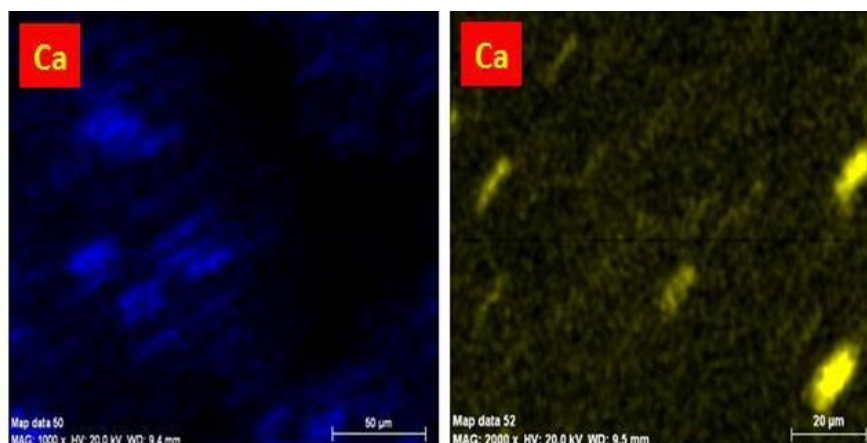


Fig 16- Elemental mapping of calcium shows the predominant calcite (SD10)

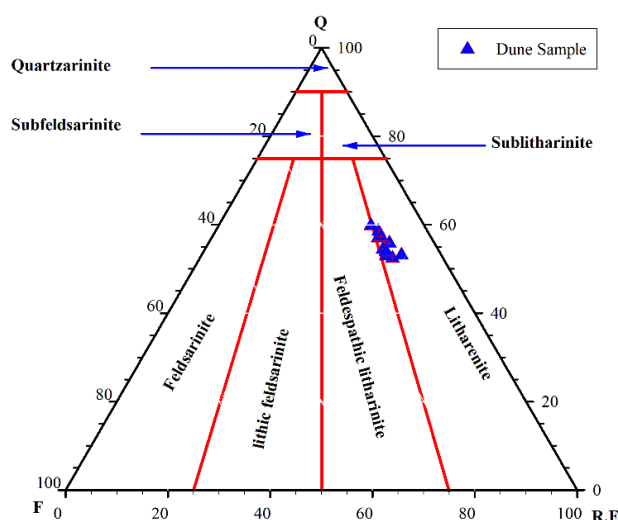


Fig 17- The dune field's classification of sand in the investigation region according to Folk (1980).

The dominance of carbonate rock fragments, particularly calcite, can be attributed to the older carbonate formations in Iraq's western desert. Regional wind patterns likely contributed to the dispersion of calcite grains. The prevalence of carbonate-rich rock fragments in clastic sedimentary rocks adjacent to the study area, as documented by Mohsain and Al-Khalidy (2022), indicates a source area characterized by rapid mechanical erosion rather than extensive chemical weathering (Pettijohn et al. 1987).

Evaporite rock fragments, predominantly composed of rounded and elongated gypsum, ranged from 6.9% (SD6) to 9.7% (SD2), with an average of 8.49% (Fig. 8). XRD analysis confirmed the presence of gypsum, with concentrations ranging from 3.4% (SD1) to 8.0% (SD10) (Table 6; Fig. 7). This gypsum is primarily attributed to formation by secondary processes, likely originating from the neighboring outcrops in the study area, where similar gypsum deposits have been identified.

The abundance of secondary gypsum in the Najaf dune field is likely linked to the prevalence of gypcrete soil in the

surrounding area and its occurrence in nearby outcropping formations. Gypcrete is a calcium sulfate-rich soil or rock formed by accumulation of calcium sulfate minerals in the soil in a dry climate. The regional arid climate facilitates the precipitation and accumulation of evaporite minerals, including gypsum, in plant root systems.

The subrounded altered igneous rock fragments are restricted between 2.2% (SD6) and 3.0% (SD8), with a mean of 2.63% (Fig. 8). The metamorphic rock fragments ranged from 1.5% (SD4) to 2.8% (SD5), with a mean of 2.11%. These subrounded grains display schistose fabric (Fig. 8). Mudstone rock fragments range from 1.9% (SD3) to 3.5% (SD5), with an average of 2.86%.

Other components: Grains that were difficult to identify or that the microscope was unable to detect the high alteration were included in this unknown group.

Petrogenesis

Based on the QFL ternary diagram of Dickinson et al. (1983), the data plot falls into the recycled quartzose field, tending to the boundary of the transitional recycled field. This suggests a

recycled orogenic provenance for the Al-Najaf sand dunes (Table 7; Fig. 18).

The petrographic composition, rich in monocrystalline quartz and lithic fragments, along with feldspathic components, indicates a recycled orogenic origin, consistent with sediment derived from the Arabian Shield. The petrographic composition of the Al-Najaf dune sediments, characterized by the dominance of monocrystalline quartz, feldspar, and diverse lithic fragments (including carbonate and chert), indicates a recycled quartzose provenance. According

to Dickinson and Suczek (1979) and Dickinson et al. (1983), such sediment compositions are typically derived from recycled orogenic belts, where older sedimentary and metamorphic rocks are uplifted, eroded, and redeposited. The Arabian Shield, composed primarily of Precambrian crystalline basement rocks, contributes quartz-rich detritus through fluvial and aeolian processes. The presence of well-rounded quartz and recycled carbonate/chert fragments further supports multiple sedimentary cycles and long-distance aeolian transport.

Table 7- Total quartz-feldspar-lithic rock fragments at the current study sites.

Sample No.	SD1 %	SD2 %	SD3 %	SD4 %	SD5 %	SD6 %	SD7 %	SD8 %	SD9 %	SD10 %
Total Q (Qm)	59.8	53.1	55.8	57	52.2	58.5	54.2	52.5	57.3	53.9
Total F (F)	10.2	7.8	8.5	10.4	9.9	9.6	10.7	10.9	9.5	10.3
Total RF (Lt)	29.8	39.1	35.4	32.7	37.7	31.6	34.8	36	33	35.7

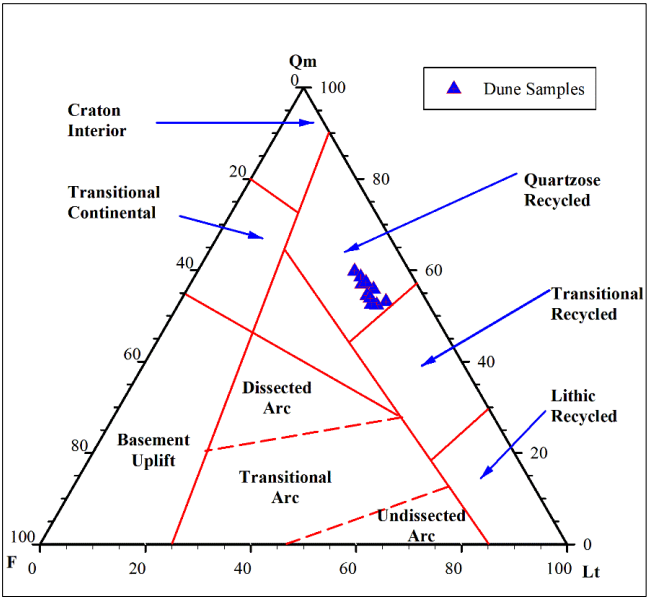


Fig 18- The quartz-feldspar-lithoclastic ternary diagram (Dickinson and Suczek 1979) displays the dune field data distribution.

The QFL ternary diagram of Dickinson et al. (1983) reveals that the sand samples plot within the recycled quartzose field; however, the significant proportion of carbonate lithic fragments (Lc) indicates a strong first-cycle input from the calcareous Dammam and Euphrates formations. This indicates a mixed provenance, where the sediments reflect both local derivation from adjacent carbonate outcrops and distal, recycled quartzose input—likely reworked from older fluvial or aeolian deposits such as Dibdibba Formation.

Paleoclimate

To infer paleoclimatic conditions in the dune field's source area, the diagram of Suttner and Dutta (1986) was used. This approach is based on the principle that climatic conditions can influence the relative abundance of these minerals during weathering and erosion; the data on the Suttner and Dutta diagram fall within the semi-humid to semiarid field. The results indicate that the source area experienced semi-humid to semiarid conditions (Fig. 19).

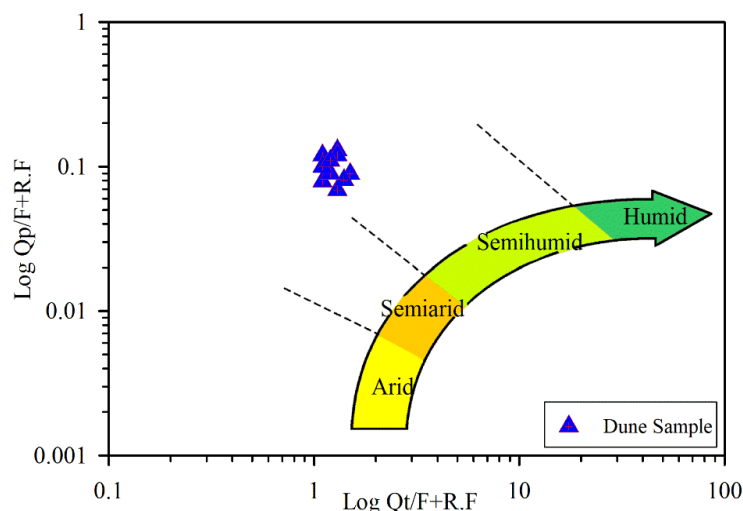


Fig 19- Paleoclimate conditions in the source area of Al-Najaf sand dunes (after Suttner and Dutta 1986).

The inferred semi-humid to semi-arid paleoclimate aligns with regional paleogeographic maps (Jassim & Goff 2006), which show an increasing aridity trend across central and southern Iraq during the Late Pliocene–Pleistocene due to tectonic uplift and retreat of marine incursions.

Conclusions

Fine to medium sand is the dominant component of the dunes. It is primarily composed of quartz grains that are often covered with clay minerals.

Based on statistical parameters, the dunes exhibited predominance of moderate to well-sorted fine sand particles. The grain size distribution is characterized by varying degrees of skewness, ranging from negative to positive, and kurtosis, typically platy to very platy. While these characteristics are commonly associated with terrigenous river sediments as paleoenvironment in the past, approximately at the last period of Cenozoic, which the transportation agent was the water energy at the first, as illustrated from grain size analysis and statistical parameters relationships. Clastic sediments, after that, may be, since Quaternary suffered of aeolian transportation proxy. The forms of grains with rounded to subrounded and other shapes, in addition to pits on the quartz grains concluded from transmitted microscopy and SEM investigation, that indicate to wind agent to move and transport dunes in the study area, other potential sources, such as coastal dunes or reworked fluvial deposits, should also be considered.

Physical weathering is evident in dune deposits, as observed through mineral assemblages and petrographic analyses. Quartz, predominantly monocrystalline, is the primary constituent and reflects multiple cycles of sediment transportation, in addition to textural properties as mentioned above. Carbonate rock fragments constitute a significant portion of the mineral composition of the rock. The overall litharenite to feldspathic litharenite classification is characterized by rounded, subrounded, and subangular grains.

The paleoclimate may be considered semi-humid to semi-arid. The petrogenesis of the sands in the dune fields shows a recycled quartzose origin.

The most significant source of sand forming the dune fields of Najaf is the Dibdibba Formation (Pliocene–Pleistocene) found in the Tar Al-Najaf. The dominance of quartz, feldspar, and lithic fragments—particularly

sedimentary and metamorphic—reflects a recycled orogenic source where sediments eroded from uplifted blocks of the Arabian Shield were received during Late Neogene to Quaternary tectonism.

The Arabian Shield is the source location from which sediments are transported. The sediments studied originated from a mature continental source, specifically the Arabian Shield (Saudi Arabia), with contributions from the Zagros Belt in northeastern Iraq. This conclusion depends on the origin of clastic source sediments of Dibdibba and Injana Formations with oldest carbonate formation (Dammam, Ghar, Euphrates, Nfayil, and Zahra).

Acknowledgements

The authors would like to express their gratitude to the University of Babylon, especially the Department of Applied Geology, for their assistance. They are also extremely grateful to the Journal Secretary and Technical Editors for their great work and helpful support in this study.

References

- Al-Naji A.J. and Al-Shammery T.A. 2019. Mineralogical study of sand dunes fields in Najaf Governorate, Southern Iraq. *Iraqi Journal of Science*, 60 (2): 239-254. <https://doi.org/10.24996/ij.s.2019.60.2.6>
- Ammar RA. Al-Ansari NA. and Al-Jubouri MA. 2013. Mineralogical and geochemical characteristics of the Upper Cretaceous–Paleocene sediments in the southern part of the Mesopotamian Basin, Iraq. *Journal of Petroleum Geology*, 36(2): 143–160. <https://doi.org/10.1111/jpg.12015>
- Shakir A.M. Foti S. Flora G. Hijab B.R. and Laftah A.A. 2013. Laterally constrained inversion of surface wave data at Najaf City (Iraq). *Soil Dynamics and Earthquake Engineering*, 45: 89-95. <https://doi.org/10.1016/j.soildyn.2012.11.003>
- Al-Enezi A. Pye K. Misak R. and Al-Hajraf S. 2008. Morphologic characteristics and development of falling dunes, Northeast Kuwait. *Journal of Arid Environments*, 72(4): 423-439. <https://doi.org/10.1016/j.jaridenv.2007.06.017>
- Al-Janabi K.Z. Ali A.J. Al-Taie A. and Jack T.J. 1988. Origin and nature of sand dunes in the alluvial plain of southern Iraq. *Journal of Arid Environments*, 14: 27-34.



- [https://doi.org/10.1016/S0140-1963\(18\)31093-0](https://doi.org/10.1016/S0140-1963(18)31093-0)
- Allen T. 1981. Particle Size Measurement. New York: Chapman and Hall.
- Al-Shakeri A.J. Jasim H.K. Abdullah H.H. Kadhum A.K. and Thwani H.H. 2017. Uses of sand dunes as building materials. *Iraqi Journal of Science*, 58 (4A): 1874-1887. <https://doi.org/10.24996/ij.s.2017.58.4A.11>
- Buday T. and Jassim S.Z. 1987. The Regional Geology of Iraq, Tectonism, Magmatism and Metamorphism, 2. GEOSURV, Iraq.
- Carver R.E. 1971. Procedures in Sedimentary Petrology. New York: Wiley-Inter Science, 653p.
- Del Valle H.F. Rostagno C.M. Coronato F.R. Bouza P.J. and Blanco P.D. 2008. Sand dune activity in North-Eastern Patagonia. *Journal of Arid Environments*, 72 (4): 411-422. <https://doi.org/10.1016/j.jaridenv.2007.07.011>
- Dickinson W.R. Beard L.S. Brakenridge G.R. Erjavec J.L. Ferguson R. Inman K.F. Knepp R.A. Lindberg F.A. and Ryberg P.T. 1983. Provenance of North American Phanerozoic sandstones in relation to tectonic setting. *Geological Society of America Bulletin*; 94: 222-235. <https://doi.org/10.1016/j.jaridenv.2007.07.011>
- Dickinson W.R. and Suczek C.A. 1979. Plate tectonics and sandstone compositions. *AAPG Bulletin*, 63(12): 2164-2182. <https://doi.org/10.1306/2F9188FB-16CE-11D7-8645000102C1865D>
- Folk R. 1974. Petrology of Sedimentary Rocks. Texas: Hemphill, 170p.
- Folk R.L. 1980. Petrography of Sedimentary Rocks. Texas: Hemphill Publishing Company, Austin, 182p.
- Folk R.L. and Ward W.C. 1957. Brazo River Bar; A study in the significance of grain size parameters. *Journal of Sedimentary Research*, 27: 3-26. <https://doi.org/10.1306/74D70646-2B21-11D7-8648000102C1865D>
- Friedman G.M. 1967. Dynamic processes and statistical parameters compared for size frequency distribution of beach and river sands. *Journal of Sedimentary Research*, 37: 327-354. <https://doi.org/10.1306/74D716CC-2B21-11D7-8648000102C1865D>
- Goossens D. 2008. Techniques to measure grain size distribution of Loamy sediments; a comparative study of ten instruments for wet analysis. *Journal of Sedimentology*; 55: 65-96. <https://doi.org/10.1111/j.1365-3091.2007.00893.x>
- Hassan K.M. 2007. Stratigraphy of Karbala-Najaf area, Central Iraq. *Iraqi Bulletin of Geology and Mining*, 3(2): 53-62.
- Hussein M.L. Menshed M.A. Al-Owaidi M.R.A. and Abdulla M.D. 2021. Sedimentological properties of the sand dunes and valley sediments in Al-Muthanna, Southern Iraq. *Iraqi Geological Journal*, 54 (1F): 70-71. <https://doi.org/10.46717/igj.54.1F.7ms-2021-06-27>
- Hussein M.L. and Al-Jaberi M. 2020. Comparison the bed sediment contamination of the southern part of Euphrates River with Shatt Al-Arab, Iraq. *Iraqi Geological Journal*, 53 (1C):68-71. <https://doi.org/10.46717/igj.53.1C.5Rx-2020-04-05>
- Hussien M.L. Fadhil L.A. and Hasan A.A. 2021. Geochemical study of Injana Formation and its tectonic significances in selected areas, Iraq. *Iraqi Geological Journal*, 54 (1C): 41-42. <https://doi.org/10.46717/igj.54.1C.4Ms-2021-03-24>
- Ingersoll R.V. Bullard T.F. Ford R.L. Grimm J.P. Pickle J.D. and Sares S.W. 1984. The effect of grain size on detrital modes: a test of the Gazzi-Dickinson point-counting method. *Journal of Sedimentary Research*, 54(1): 103-116. <https://doi.org/10.1306/212F83B9-2B24-11D7-8648000102C1865D>
- Jassim S.Z. and Goff J.C. 2006. Geology of Iraq. Prague: Moravian Museum, Brno, 341p.
- Jasim H.K. 2017. The Sedimentology, Industrial, and Environmental Studies of the Dune Fields in Missan, Thi-Qar, and Samawa Districts, Southern Iraq. Ph.D. thesis, Department of Geology, College of Science, University of Baghdad, 257p.
- Krumbein W.C. 1941. Measurement and geologic significance of shape and roundness of sedimentary particles. *Journal of Sedimentary Research*, 11: 64-72. <https://doi.org/10.1306/D42690F3-2B26-11D7-8648000102C1865D>
- Mange M.A. and Maurer H.F.W. 1992. Heavy Minerals in Color. London: Chapman Hall, 147p.
- Mohsain A.F. and Al-Khalidy A.A.L. 2022. Geotechnical assessment of Dar Al Salam complex in Hilla City, Babylon using the seismic refraction. *Iraqi Geological Journal*, 55(1F):95-101. <https://doi.org/10.46717/igj.55.1F.8Ms-2022-06-23>
- Moiola R.J. and Weiser D. 1968. Textural parameters, an evaluation. *Journal of Sedimentary Research*, 38: 45-53. <https://doi.org/10.1306/74D718C5-2B21-11D7-8648000102C1865D>
- Padmakumar G.P. Srinivas K. Uday K.V. Iyer K.R. Pathak P. Keshava S.M. and Singh D.N. 2012. Characterization of aeolian sands from Indian Desert. *Engineering Geology*, 139(6): 38-49. <https://doi.org/10.1016/j.enggeo.2012.04.005>
- Pettijohn F.J. Potter P.E. and Siever R. 1987. Sand and Sandstone. Springer-Verlag, 553p.
- Pettijohn F.J. Potter P.E. and Siever R. 1973. Sand and Sandstone. New York: Springer-Verlag, 618p.
- Pye K. and Tsoar H. 2009. Aeolian Sand and Sand dunes (2nd ed.). Berlin: Springer Press, 458p.
- Rasheed M.J. and Al-Ramahi F.K.M. 2021. Detection of the impact of climate change on desertification and sand dunes formation east of the Tigris River in Salah Al-Din Governorate using remote sensing techniques. *Iraqi Geological Journal*, 54 (1A):69-83. <https://doi.org/10.46717/igj.54.1A.7Ms-2021-01-28>
- Sierra J.R. Munoz J.J. and Pons M.N. 2013. Influence of sieving time on the efficiency and accuracy of grain-size analysis of beach and dune sands. *Sedimentology*, 60: 1484-1497. <https://doi.org/10.1111/sed.12040>
- Suttner L.J. and Dutta P.K. 1986. Alluvial sandstone composition and paleoclimate; I, Framework mineralogy. *Journal of Sedimentary Research*, 56: 326-345. <https://doi.org/10.1306/212F8909-2B24-11D7-8648000102C1865D>
- Thorez J. 1976. Practical Identification of Clay Minerals: A Handbook for Teachers and Students in Clay Mineralogy. Editions G. Lelotte. 90 p.
- Tucker M.E. 1985. Sedimentary Petrology, an Introduction. Oxford: Blackwell Scientific Publ, 252p.
- Tucker M.E. 1988. Techniques in sedimentology. Blackwell Scientific Publ, 394p.
- Venkatramanan S. Ramkumar T. Anitha Mary I. 2011. Grain size statistical parameters of coastal sediments around Tirumalairajana River Mouth, Tamilnadu, East Coast of India. *Indian Association of Sedimentologists*, 30 (I): 65-73.
- Watson J.M. 1997. Desert Features. USGS. <http://pubs.usgs.gov/gip/deserts/features/>.
- Wentworth C.K. 1922. A scale of grade and class term for clastic sediments. *The Journal of Geology*, 30: 377-392. <https://doi.org/10.1086/622910>

