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Grain size and mineralogical studies of sandy sediments in southwestern Iran

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Abstract

The objectives of this study were to determine the nature (aeolian vs. alluvial) and origin of sandy sediments in southwestern Iran (Khuzestan province) were collected in two transects across (NW-SE directions) and perpendicular to the Karkheh River, by using grain sized distribution characteristics, and the mineralogy and micro-texture of quartz grains of forty-five surface samples (0-30cm) at interval distances of ~1.5km. Standard sieves (0.5phi-intervals) were used for determining sand fractions. Silt and clay fractions were measured using the pipette method. Mineralogical composition and surface micro-texture of quartz grains of the selected samples were examined using a polarizing microscope and a scanning electron microscope, respectively. Mz (mean grain size) varied between 1.82 to 4.56ϕ. The variations of Mz indicated the directional particle size fining the NW-SE transect. Sorting (δI) was 0.46 to 2ϕ and with an average of 0.97ϕ was poorly to well sorted. The mean value of skewness (SKI) was 0.12 which ranged from -0.24 to 0.46 and skewed to fine particles. Kurtosis with mean values of 1.21 varied between 0.85 to 2.25, which indicated a slight leptokurtic. Grain size characteristics showed a disturbance near the river due to the fluvial processes. Quartz grains were rounded and evidences of both aeolian and fluvial processes were observed on the grains' micro-texture. The mineralogy of sediments were similar to those in Saudi Arabia. This mineralogical similarity, as well as prevailing wind direction and grain size variations, indicates the possibility of the sediments to have likely originated from the Arabian plate.

Keywords: Quartz micro-texture; Grain size characteristics; Sand mineralogy; Aeolian sand

1. Introduction

Aeolian deposits cover 36% of the world's continents, commonly in the arid environments. Arid and semi-arid regions with long-term dry seasons occupy more than half of the world, which is affected by sandstorms and active sand dunes (Wang *et al.*, 2003; Yang and William, 2015). Sand containing areas are naturally developed into arid regions with low sparse vegetation. The formation and accumulation of sand dunes are resulted from a set of geomorphic processes, source area characteristics and environmental setting (Farahi *et al.*, 2013). However, they are sensitive landforms and human activities which lead to degradation being a major environmental problem. These features make the sand deposits important for both the environmental concerns, as well as the landscape evolution (Pye and Tsoar, 2009).

Grain size characteristics and mineralogy are important characteristics used in identifying the nature and origin of sand deposits (Kasper-Zubillaga and Zolezzi-Ruiz, 2007; Li *et al.*, 2015; Wang *et al.*, 2017). Grain size distribution is one of the most important features of aeolian deposits, which is primarily influenced by the distance from its origin and the characteristics of its source area (Zhang *et al.*, 2015). The grain size of the aeolian deposits reflect the direction of the transportation of particles (Zhu and Yu, 2014; Wang *et al.*, 2017). Sediments in arid environments may accumulate by aeolian or alluvial processes. Mean grain size, sorting, skewness, and kurtosis are the parameters of

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particle size distribution, which indicate both sedimentary processes and the origin and distance from the source (Sun and *et al.*, 2007; Wang *et al.*, 2017).

The accumulation source and processes of sediments are two frequent questions in sedimentology research. The sand deposits' mineralogical composition is the commonly used property in determining sediment sources (Wakindiki and Ben-Hur, 2002; Kasper-Zubillaga and Zolezzi-Ruiz, 2007). Quartz is a resistant mineral which is usually found in all sediments. Microtexture of quartz grains indicates the features of the sedimentation environment (e.g. aeolian, fluvial and glacial) (Mahaney, 2002; Cardona *et al.* 2005; Vos *et al.*, 2014). During transportation, sediments may experience different sedimentation processes which are revealed by micro-texture analysis (Mahaney *et al.*, 2001; Rusk and Reed, 2002; Vos *et al.*, 2014). For example, troughs and gouges, are the evidences glacial grinding and randomly oriented v-shaped cracks and edge rounding fracturing are the result of aeolian abrasion (Sweet and Soreghan, 2010).

Iran is located in the mid-latitude desert belt and sand deposits are common landscapes found in the arid environment of the country. Although there have been some attempts to characterize the sand dunes in the recent decade (Vosoo *et al.* 2015; Karimi *et al.*, 2009), the nature and origin of sand deposits in Iran's desert areas are still unknown. Khuzestan province in southwestern Iran, which borders the Persian Gulf and Iraq, has a total of 39,400km^2 of aeolian deposits. The objectives of this study were to find the nature and origin of sand deposits in northwestern Khuzestan province, by determining the grain size characteristics, mineralogy, and the micro-texture of its quartz grains.

2. Materials and Methods

2.1. Study Area and Sampling

The study area was located 30km into the northwestern city of Ahwaz and extended from the Karkheh river to border of Iraq. It covered 64,000 hectares of the lands between 31˚ 27' to 31˚ 47' N and 48˚ 09' to 48˚ 37' E (Figure 1). Karkheh river flowed through the study area and sediments were found on both side of the river. The mean annual rainfall was 193.2m with a maximum and minimum of 42.3 and 0mm in February and August, respectively. The mean annual temperature was 24.1°C and the maximum and minimum temperatures were 45.5 and 5.9°C in August and February, respectively. According to the De Martonne classification, the climate was hot and dry. Based on the Annual Wind Rose (Figure 2), the prevailing wind had a maximum speed of 60km/h with a western direction.

2.2. Sampling and Particle Size Analysis

Forty-five samples were collected from a depth of 0-30cm and interval distance of about 1.5km in two transects across and perpendicular to the Karkheh River (Figure 1).

To determine the particle size distribution, 50g of an air-dried sample was sieved to separate the sand fraction (>63µm). The sand fraction separated using a series of sieves with an interval of 0.5ϕ units. The fractions of 20-50, 5-20, 2-5 and <2µm were measured using the pipet method. The mean grain size (Mz), sorting (δI), skewness (SKI) and kurtosis (K) were calculated with the GRADISTA program (Blott and Pye, 2001). These parameters were calculated in accordance to the graphical measurement method

$$MZ = \frac{\phi16 + \phi50 + \phi84}{3} \quad (1)$$

with the following equations (Folk and Ward, 1957).

$$\sigma I = \frac{\phi84 - \phi16}{4} + \frac{\phi95 - \phi5}{6.6} \quad (2)$$

$$SKI = \frac{\phi16 + \phi84 - 2\phi50}{2(\phi84 - \phi16)} + \frac{\phi5 + \phi95 - 2\phi50}{2(\phi95 - \phi5)} \quad (3)$$

$$K = \frac{\phi95 - \phi5}{2.44(\phi75 - \phi25)} \quad (4)$$

2.3. Mineralogy and Micro-texture Analysis

In order to determine the mineralogy of sand fraction, calcium carbonate was removed by hydrochloric acid. The sand particles were mounted on glass slides which were hardened by resin and thinned to a 30µm size. The thin sections were analyzed using a hp-PL20 polarizing microscope.

The micro-texture of quartz grains were examined by a scanning electron microscope (SEM), model VP-1450 made by a German company, LEO. For this purpose, the sand fraction was treated with hot HCl 6N to remove impurities from the surfaces of the grains.

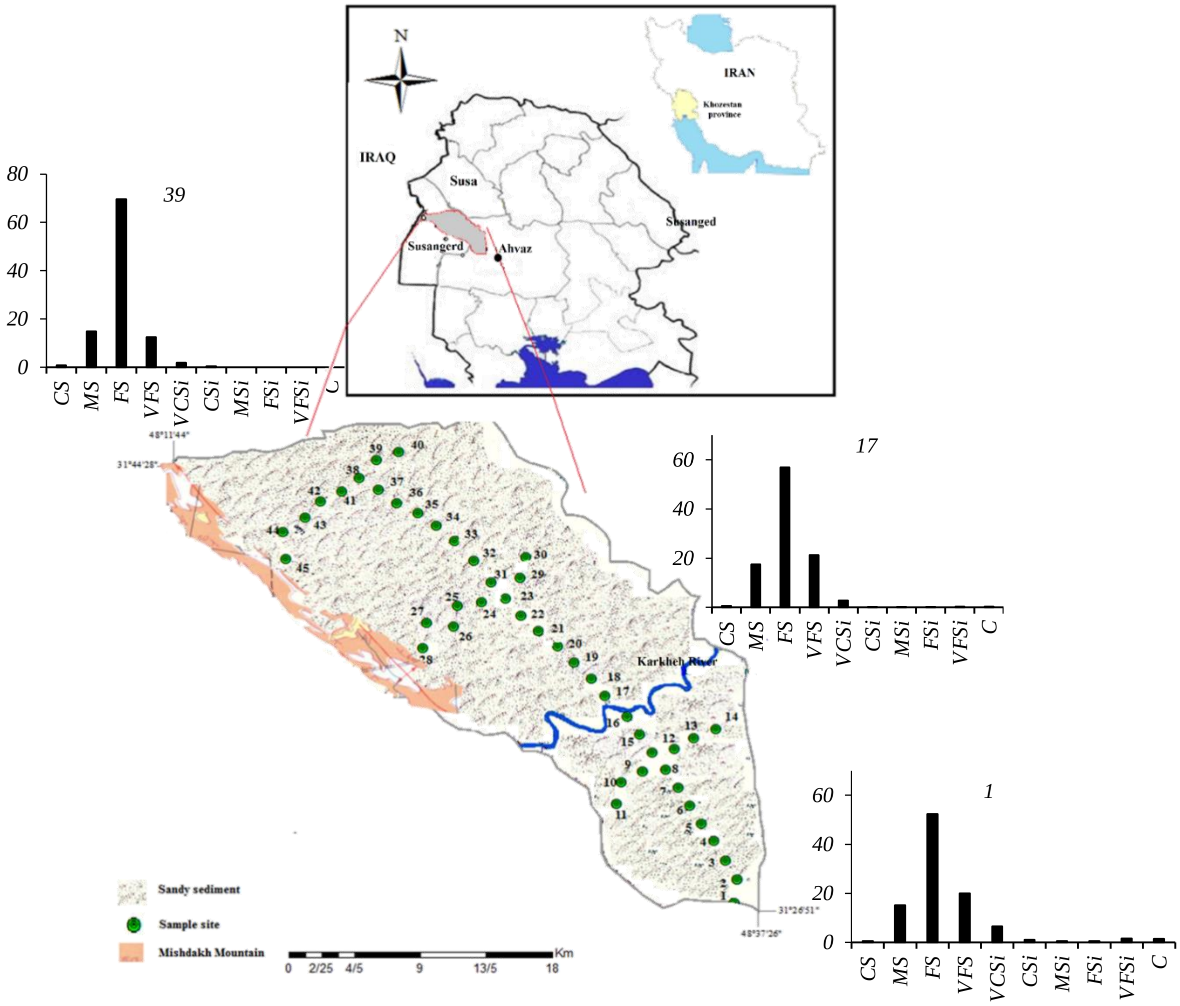

Fig. 1. Study area in southwestern Iran and location of sampling points area in studied sandy sediments; The histograms indicated frequency of particle size fractions of three representative samples

MS: Medium sand, FS: Fine sand, VFS: Very fine sand, VCSi: Very coarse silt, CSi: Coarse silt, MSi: Medium silt, FSi: Fine silt, VFSi: Very fine silt.

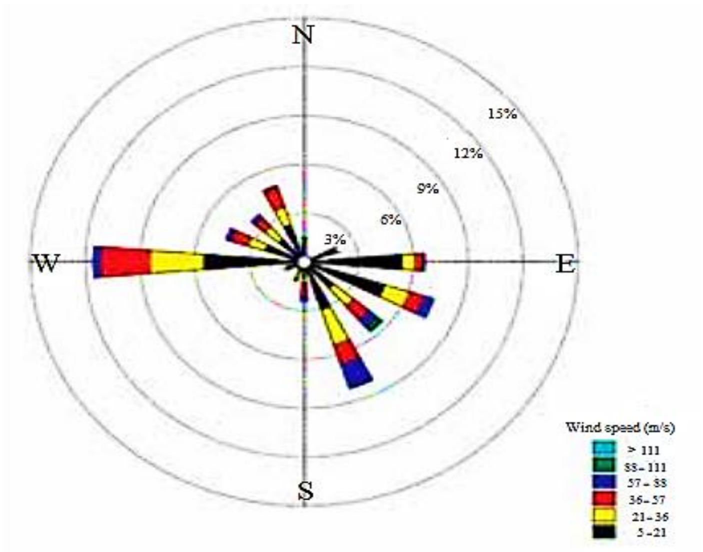

Fig. 2. Wind rose of study area

3. Results and Discussion

3.1. Grain size distribution

The sand content comprised 79 to 98.1% of the samples, with an average of 88.6%. The range of silt content was 1.6 to 66.2%. The clay content had an average of 0.8% and a maximum of 6.2% as the lowest fraction (Table 1).

Fine sand with an average of 49.7% was the highest amount of sub-fraction in the sediments. The medium and very fine sand were considerably higher than other fractions (Table 1). Fine and medium sand are the main constituent of the sand deposits of the world. For example, fine to medium sands were the dominant fractions of the Ejina desert in China (Zhu *et al.*, 2014) and the Toshka desert in Egypt (Hamdan *et al.*, 2015).

Table 1. Summary of particle size distribution and grain size characteristic

Parameter	Sand	Silt	Clay	CS	MS	FS	VFS	VCSi	CSi	MSi	FSi	VFSi	Mz	δI	SKI	K
	%												(ϕ)			
Mean	88.6	10.6	0.8	2.3	19	49.7	17.6	6.4	2.7	0.4	0.5	0.6	2.66	0.97	0.14	1.21
Sd	12.2	11.3	1	3	10.5	12.5	7	5.3	6.8	0.6	0.6	1	0.45	0.34	0.12	0.21
Max	98.1	31	6.2	13.9	52	81.3	43.2	19.1	9.8	3.7	3.6	6.4	3.7	2.00	0.46	2.25
Min	79	1.6	0	0	2.7	25.8	6.5	0.9	0	0	0	0	1.82	0.46	-0.24	0.85

MS: Medium sand, FS: Fine sand, VFS: Very fine sand, VCSi: Very coarse silt, CSi: Coarse silt, MSi: Medium silt, FSi: Fine silt, VFSi: Very fine silt, Mz: Mean grain size, δI: Sorting, SKI: Skewness, K: Kurtosis

The Mz average was 2.66ϕ (0.18mm) (Table 1), which was similar to the Mz for the Kumtagh desert (0.19mm) (Dong *et al.*, 2011), Tengger (0.17mm) (Hasi and Wang, 1996), Badain Jaran (0.21mm) (Qian *et al.*, 2011) and in China and the southwestern Kalahari (0.21mm) (Lancaster, 1986). The frequency curves of the grain size distribution of four representative samples along the transect (Figure 3) indicated a unimodal distribution with a mode at 2.5ϕ (fine sand).

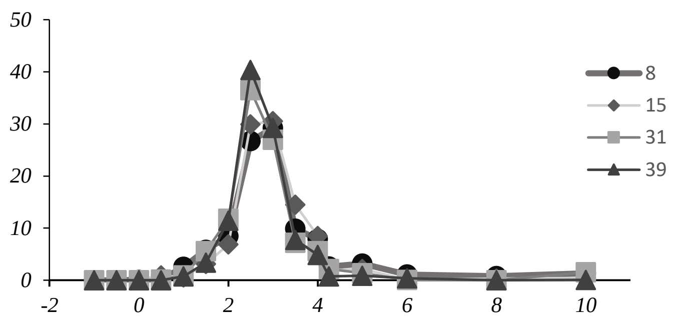

Fig. 3. Frequency distribution curves of grain size distribution of selected samples

The average values of δI was 0.97ϕ which ranged from 0.46 to 2ϕ, which according to the Folk and ward (1957) classification, indicated a well to poorly sorted studied sediments. The broad range of SKI values from -0.24 to 0.46 (mean 0.14) indicated the coarse to very fine skewed sediments. The K range was 085-2.25, with an average value of 1.21, hence the sediments were mostly leptokurtic**.**

3.2. Spatial Variations of Grain Size Distribution

Spatial variations of grain size distribution of aeolian sediments provide insights to the sedimentary environments and processes. Figure 4 shows the grain size characteristics along the sampling transect. On both sides, the Mz decreased towards the river. This means that the sediments are coarser near the river. Furthermore, the Mz on the right side of the river was 2.75ϕ which is finer than the sediments on the left side which have a value of 2.58ϕ.

The grain size distribution frequency histograms of samples 1, 17, and 39 along the transect are shown in Figure 1. Sample 39 to 1 have a decrease in fine sand, with an increase in the amount of very fine sand and coarse silt. The δI on the left side of the river did not show any distinct variations. However there was a slight increase on the right side, farther away from the river. The K and SKI did not indicate distinct variations along the transect, however, the mean values of these parameters were slightly higher on the right side of the river.

3.3. Bivariate Plots

Bivariate plots illustrate the relationship between two properties of a sample. In sedimentology, bivariate plots of grain size characteristics are used to understand and describe the sedimentation processes (Zhu *et al.*, 2014; Zhu and Yu; 2014; Zhang and Dong; 2015; Karimi *et al.*, 2017).

A positive correlation was observed between Mz and δI (Figure 5a) which was indicated worsening the sorting by fining of the sediments,. By increasing Mz (fining the sediments) the particles distribute among the fractions and cause worsening the sorting.

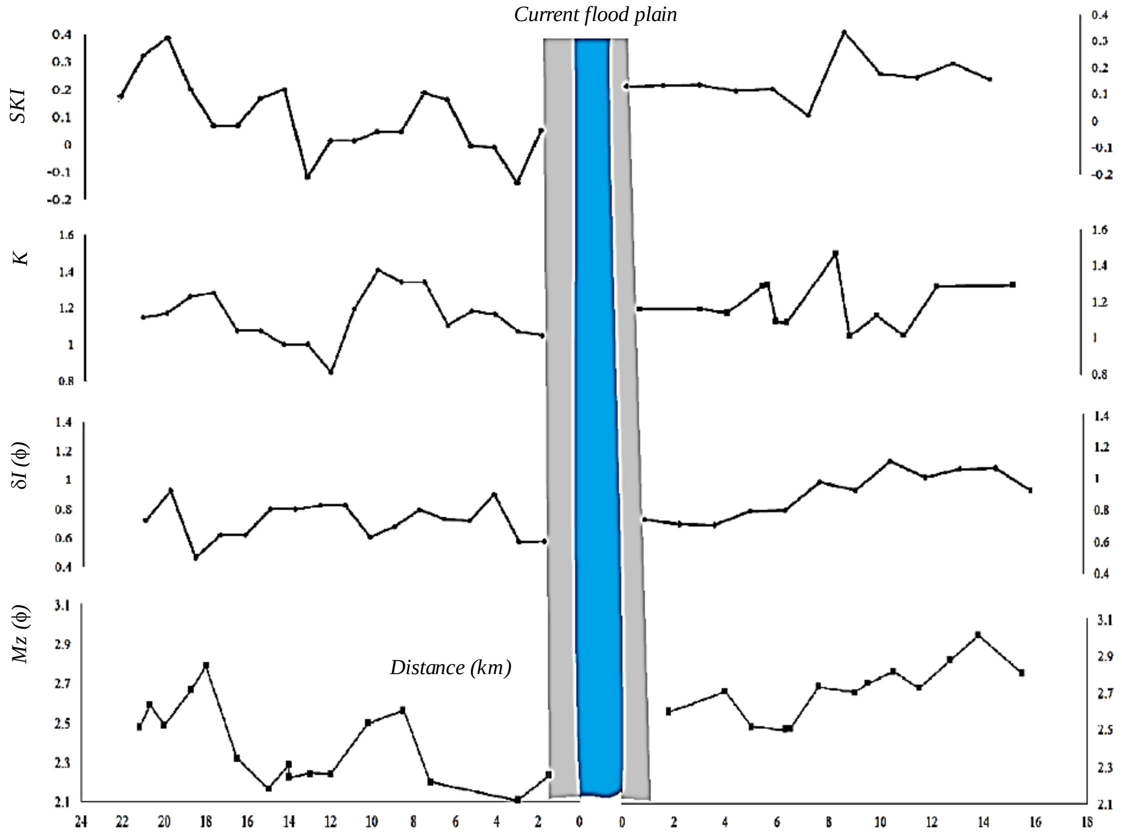

Fig. 4. Variations of grain size characteristics along the studied transect on both sides of the Karkheh river

Usually, at a short distance from the source, the δI value is low, due to an accumulation of the particles at a narrow range particle size. By distance, the portion of the finer particle increases, and consequently, the δI increased. Sorting slightly improves in distant area from the origin due to decreasing the coarser and increasing the finer fractions, (slight decrees the δI) (Karimi e*t al.*, 2017). This is confirmed by studies of Qian *et al.* (2011) and Chen (1993). Blount and Lancaster (1990) showed that coarse particles near the origin are moderately to poorly sorted and improve by distance from the origin. Zhu and Yu (2014) showed that in the Ejina Desert (China), sediments with dominating medium and fine fraction were sorted best, and with an increase of the coarser or finer particles, the sorting tended to be worse. The dominance of fine sand in the studied sediments indicate a far distance from the origin and therefore explain the worsening of the sorting of the fining sediments. By increasing the Mz, SKI increased and K decreased (Figures 5b and 5c). In aeolian deposits usually by increasing distance from the source, the particles distribute in broader size range which causes both decreasing the K and increasing skewness (Purkait, 2010; Karimi *et al.*, 2017; Chen, 1993; Li *et al.*, 1998).

As stated by the increase of the Mz (fining the sediments), the particles in coarser fractions decreased and finer fractions increased, which therefore led to a regular K decrease and δI and SKI increase.

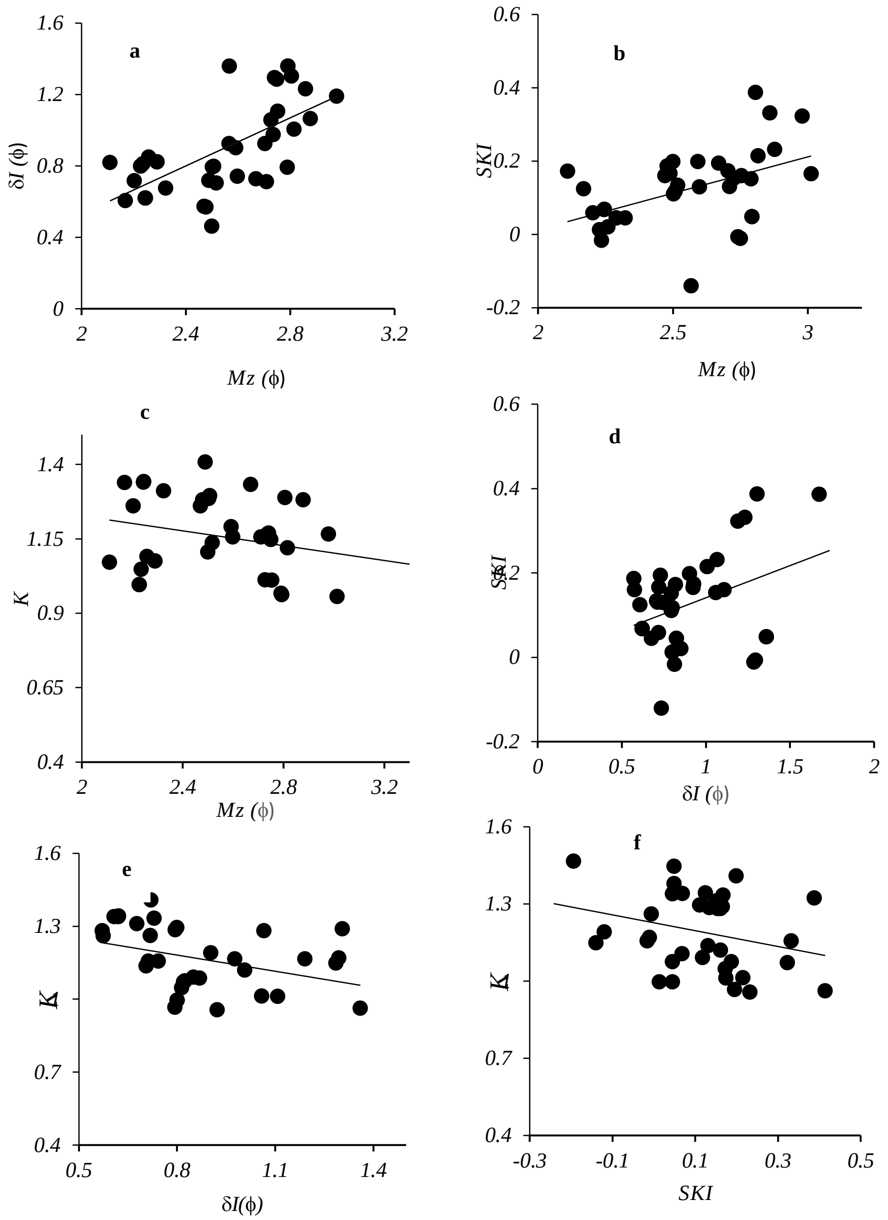

Fig. 5. Bivariate plots of grain size characteristic

3.4. Micro-texture

The shape and micro-texture of sample 42 at about 22km on the left side of the river is presented in Figure 6. Most of the grains are equant with few planar shapes with rounded edges (Figure 6a, b and c).

Low relief, crescent gouges, conchoidal, and V-shape fractures are frequently observed on quartz grains (Figures 6d and 6e). The dissolution etching features indicated that the grains were affected by either a chemical dissolution of the source or during transport. The grains in sample 16 (near the river) are mostly prolate (Figure 7). The micro-texture features are similar to those in sample 42 but with more abundant etchings dissolutions.

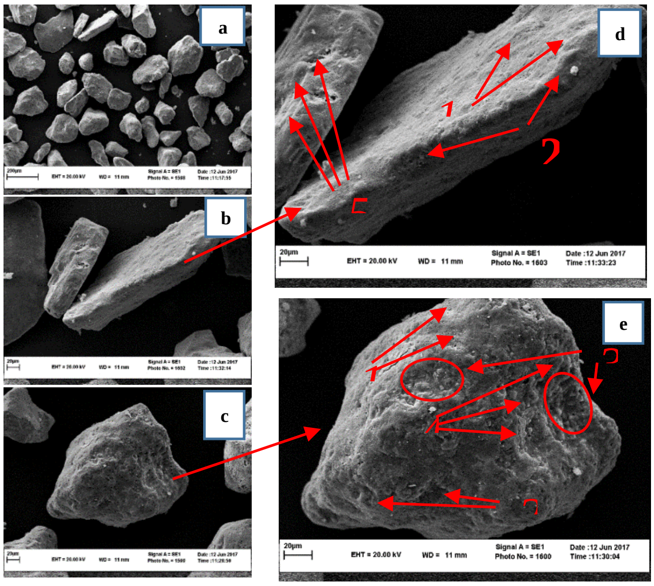

Fig. 6. Microtexture of quartz grains of sample 42 in the studied transect; 1. low relief, 2. conchoidal fractures, 3. weathering and dissolution etching, 4. V-shaped fracture and 5. Liner fractures

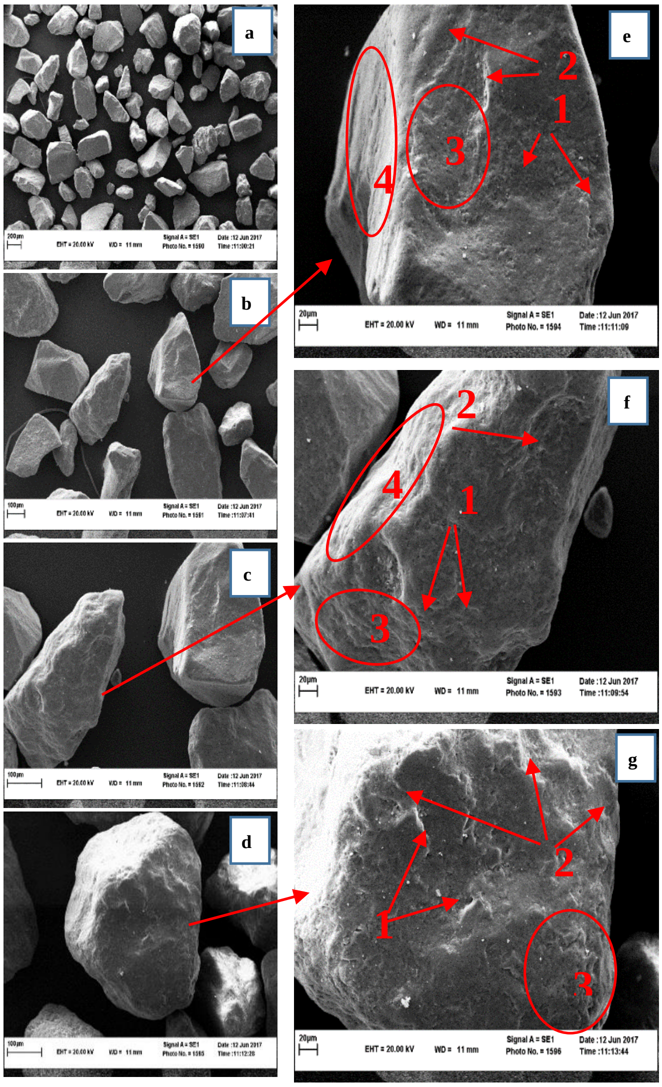

Fig. 7. Microtexture of quartz grains of sample 16 in the studied transect; 1. low relief, 2. conchoidal fractures, 3. weathering and dissolution etching and 4. V-shaped fracture

3.5. Mineralogy

The mineralogy analysis results indicated the presence of single mineral grains and fragments of a sedimentary to igneous rock. Quartz with an average of 40-60% was the dominant mineral and plagioclase (10-15%) was present in all samples (Table 2).

Table 2. Mineralogy composition of the studied sediments

Sample	Quartz	Plagioclase	Opal	Biotite	Loadstone	Orthoclase	Zircon	Tourmaline
					%			
1-8	40	10-15	-	-	-	<5	<5	-
9-17	50	10	-	-	<5	<5	<5	-
18-30	60	10	-	<5	-	-	-	-
31-45	60	10	5	-	-	-	-	1-2

Quartz was the dominant mineral in the studied sediments and *is* also observed in the majority of sandy sediments of the world, such as in the Kalahari Desert, Namibia in South Africa (Billingsley, 1987), the United Arab Emirates (Howari *et al.*, 2007), and in the Arabian Desert (Garzanti *et al.*, 2013). The quartz hardness was marked 7 in the Mohs scale and had a tectosilicate structure, which made it resistant both to physical and chemical weathering,Therefore, it is amongst one of the most abundant minerals in the sediments. Orthoclase, loadstone, biotite, opal, zircon, and tourmaline were the other minerals (>5%) in the studied sediments (Table 2).

Muhs (2004) classified the sand deposits based on a mineralogical composition of four groups of carbonate-rich, gypsum-rich, volcanic sand, and quartz-feldspar sand that originated from volcanic and metamorphic rocks. Considering the dominance of the quartz and the feldspar (Table 2), the studied sediments were quartz-feldspar sand. Mineralogy in our area was similar to sand dunes in the Moenkopi plateau in North America (Billingsley, 1987), the sandstorm mineralogy in Iraq (Awadh, 2012) and the Namibian Desert in Africa (Garzanti *et al.*, 2012). These results are also comparable to the sand dune in the Southwest of the United Arab Emirates (Howari *et al.*, 2007) and in the Arabian Desert (Garzantani *et al.*, 2013) which have a 50-60% of quartz.

4. Dissection

4.1 Sedimentation and Accumulation Processes

The studied sediments are distributed perpendicular to Karkheh river and this geomorphic makes a doubt on fluvial or aeolian nature of these sediments. Grain size characteristics are one of the most important features of sediments that reflect the sedimentation processes (Sun *et al.*, 2007; Zhu *et al.*, 2014; Wang *et al.* 2017). Aeolian deposits are usually unimodal and have a narrow range of particle size distribution, whereas fluvial sediments are usually multimodal (Zhu and Yu, 2014; Li *et al.*, 2014). The particle size distribution of the studied sediments is unimodal (Figure 3) which can be considered as an indication of the aeolian origin. The directional fining trend in sandy sediments is another evidence of the aeolian nature of the sediments (Zhu *et al.*, 2014; Karim *et al.*, 2017). Although in our investigation, the sediments on the left side of the river were a little coarser and there were no distinct variations of Mz along the studied transect (Figure 4). It is likely due to the disturbance of the sediments by fluvial processes, which is confirmed by the difference in the morphology of the grains near the river (prolate shape) versus the samples in the far distance (equant shape) (Figure 6). Furthermore, both aeolian and alluvial signs were observed on the quartz grains' micro-texture (Figure 7).

Bivariate plots of grain size characteristics were useful to understand sedimentation conditions. Li *et al.*, (2014) indicated that samples with different sedimentation processes compose separate clusters. The distinct relationship between the parameters indicated a dominant accumulation process. According to the lines of evidence, the sediments were transported to the area by wind and were affected by post-deposition of the alluvial processes.

4.2. Origin

Due to the direction of particle size fining (Figure 4), the sediments originated from the west of the area. The mineral composition is a useful index for the determination of the origin of sediments. Polycrystalline and monocrystalline are two types of quartz. Polycrystalline has a lower stability than monocrystalline and its relative abundance indicates its transportation conditions (Tucker, 2011). The analysis of the thin sections showed a higher abundance of monocrystalline than polycrystalline quartz in the studied sediments (Figure 8), which indicated a relatively long distance from the origin. The presence of quartz with a direct extinction and also that of zircon and tourmaline, indicated the contribution of volcanic materials in the studied sediments.

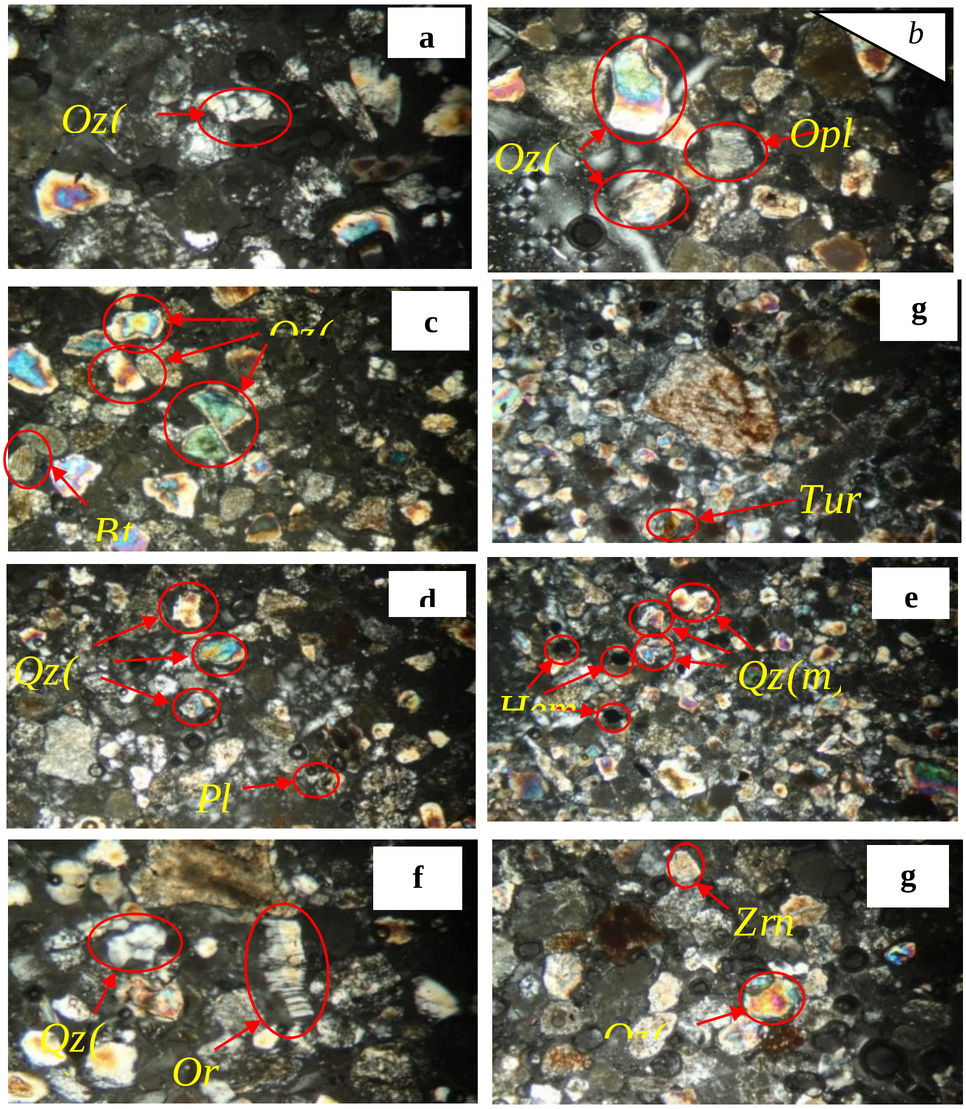

Fig. 8. Thin section images showing the mineralogy of selected samples; Qz(p): polycrystalline quartz, Qz (m): monocrystalline quartz, Opl: opal, Bt: biotite, Pl: plagioclase, Hem: hematite, Tur: tourmaline, Or: orthoclase, Zm: zircon

Based on mineralogy characteristics, the studied sediments originated from an area of volcanic formation. There was a volcanic area in the far west (~1000km) of the study area (Figure 9) in Saudi Arabia (Howari *et al.*, 2007; Garzanti *et al.*, 2013). Garzanti *et al.* (2013) determined the mineralogy composition of the Great Nafud Sahara zone and the Dena Sahara in the Arabia plate. The comparison of the mineralogy of studied sediments and the Arabian plate indicated a high similarity of the mineralogical composition (Table 3).

Table 3. Comparing the mineral composition of the study area and Arabian shield

Area	Tourmaline	Starlit	Rutile	Garnet	Zircon	Opal	Mica	Epidote	Sanidine	Plagioclase	Amphibole	Chert	Quartz
This study	✓				✓	✓	✓		✓	✓		✓	✓
Arabian shield	✓	✓	✓	✓	✓		✓	✓		✓	✓	✓	✓

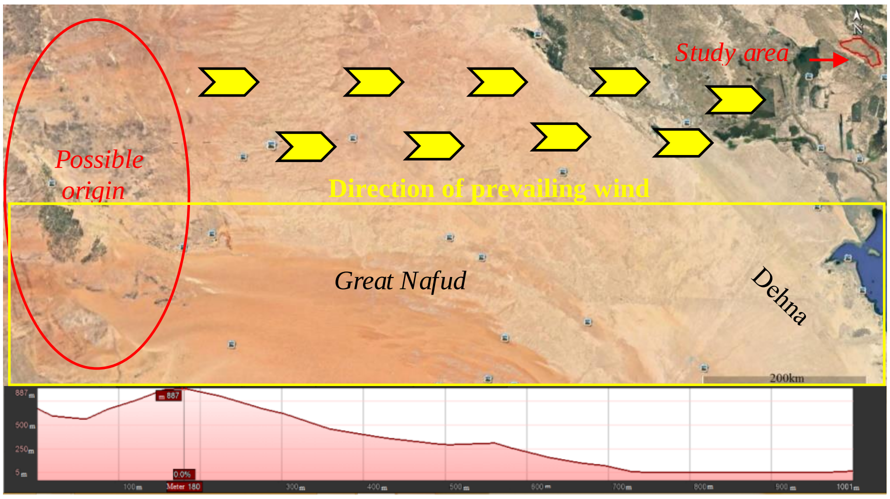

Fig. 9. Pathway of sediment transport from Arabian shield to southwestern Iran

As shown in Figure 9, the prevailing wind had a western direction which transported the eroded materials from the volcanic source towards the study area. The gentle decreasing elevation of the Arabian plate towards Iran provided suitable conditions for this process. Accordingly, the Arabian plate can be considered as the likely origin of the studied sediments.

5. Conclusion

Grain size distribution characteristics, micro-texture of quartz grains and mineralogy composition indicated the processes of accumulation and origin of sand dunes in southern Iran. The sandy sediments, especially near the Karkheh river, were accumulated by aeolian processes that were later affected by alluvial post-deposition processes, The sediments were unimodal with a mod in fine sand fraction. Although the sediments showed an overall fining trend along the prevailing wind, the river stream caused a disturbance in this trend. The micro-texture analysis of the quartz grains indicated the results of the aeolian and alluvial processes on the surface of the quartz grains. The presence of minerals of volcanic origin and its similarity to the mineralogy of sediments of Saudi Arabia, showed that the sediments in the study area likely originated from the Arabian plate.

Reference

Anton, D., 1983. Modern eolian deposits of the eastern province of Saudi Arabia. Developments in Sedimentology, 38; 365-378.

Awadh, S.M., 2012. Geochemistry and mineralogical composition of the airborne particles of sand dunes and dust storms settled in Iraq and their environmental impacts. Environmental Earth Sciences, 66; 2247-2256.

Barnard, W.S., 1973. Duinformasies in die Sentrale Namib. In: Tegnikon, PP. 2-13, (Pretoria).

Billingsley, G.H., 1987. Geology and geomorphology of the southwestern Moenkopi Plateau and southern Ward Terrace, Arizona. U.S. Geological Survey Bulletin 1672.

Blott, S.J., K. Pye, 2001. GRADISTAT: a grain size distribution and statistics package for the analysis of unconsolidated sediments. Earth Surface Processes and Landforms, 26; 1237-1248.

Blount, G., N. Lancaster, 1990. Development of the Gran Desierto sand sea, northwestern Mexico. Geology, 18; 724-728.

Chen, W., 1993. Grain size parameters of aeolian sediments in the vicinity of the longitude 84 E, Taklamakan Desert. Acta Geographica Sinica, 48; 33-46.

Dong, Z.B., Z.Z. Su, G.Q. Qian, W.Y. Luo, Z. Zhang, J.F. Wu, 2011. Aeolian geomorphology of the Kumtagh Desert. Science Press, Beijing, 484 pp. (in Chinese with English Summary),

Farahi, M., A. Shahryary, S. Fakhoreh, A. Pahlavanrvy, G. Noori, 2013. Identification of wind affected regions in Zabol district (Sistan va Baluchestan province, southeast of Iran). European Journal of Experimental Biology, 3; 624-630.

Folk, R.L., W.C. Ward, 1957. Brazos River bar: a study in the significance of grain size parameters. Journal of Sedimentary Research, 27; 3-26.

Garzanti, E., S. Andò, G. Vezzoli, M. Lustrino, M. Boni, P. Vermeesch, 2012. Petrology of the Namib Sand Sea: long-distance transport and compositional variability in the wind-displaced Orange Delta. Earth-Science Reviews, 112; 173-189.

Garzanti, E., P. Vermeesch, S. Andò, G. Vezzoli, M. Valagussa, K. Allen, K.A. Kadi, A.I. Al-Juboury, 2013. Provenance and recycling of Arabian desert sand. Earth-Science Reviews, 120; 1-19.

Hamdan, M.A., A.A. Refaat, E.A. Anwar, N.A. Shallaly, 2015. Source of the aeolian dune sand of Toshka area, southeastern Western Desert, Egypt. Aeolian Research, 17; 275-289.

Hasi, E., G.Y. Wang, 1996. Grain-size variation on transverse dune in connection with slope morphology at southeastern fringe of Tengger Desert. Journal of Desert Research, 16; 216-221.

Howari, F.M., A. Baghdady, P.C. Goodell, 2007. Mineralogical and gemorphological characterization of sand dunes in the eastern part of United Arab Emirates using orbital remote sensing integrated with field investigations. Geomorphology, 83; 67-81.

Karimi, A., H. Khademi, M. Kehl, A. Jalalian, 2009. Distribution, lithology and provenance of peridesert loess deposits in northeastern Iran. Geoderma, 148; 241-250.

Karimi, A., F. Khormali, X. Wang, 2017. Discrimination of sand dunes and loess deposits using grain-size analysis in northeastern Iran. Arabian Journal of Geosciences, 10; 275.

Kasper-Zubillaga, J.J., H. Zolezzi-Ruiz, 2007. Grain size, mineralogical and geochemical studies of coastal and inland dune sands from El Vizcaíno Desert, Baja California Peninsula, Mexico. Revista Mexicana de Ciencias Geológicas, 24; 423-438.

Lancaster, N., 1986. Grain size characteristics of linear dunes in the southwestern Kalahari. Journal of Sedimentary Research, 56; 395-400.

Li, J., Z. Dong, Z Zhang, G. Qian, W. Luo, J. Lu, 2015. Grain-size characteristics of linear dunes on the northern margin of Qarhan Salt Lake, northwestern China. Journal of Arid Land, 7; 438-449.

Li, Z.S., G.T. Chen, Z.B. Dong, Z.B. Q. Feng, Q.1998. Grain size parameters along the transaction of a complex longitudinal dune in the center of Taklimakan Desert. Journal of Arid Land Resources and Environment, 12; 21-28.

Livingstone, I., A. Warren, 1996. Aeolian geomorphology: An introduction. Harlow: Longman, 211 pp.

Mahaney, W.C., 2002. Atlas of Sand Grain Surface Textures and Applications. Oxford University Press, New York, 237pp.

Mahaney, W.C., A. Stewart, V. Kalm, 2001. Quantification of SEM microtextures useful in sedimentary environmental discrimination. Boreas, 30; 165-171.

Muhs, D.R., 2004. Mineralogical maturity in dunefields of North America, Africa and Australia. Geomorphology, 59; 247-269.

Purkait, B., 2010. The use of grain-size distribution patterns to elucidate aeolian processes on a transverse dune of Thar Desert, India. Earth Surface Processes and Landforms, 35; 525-530.

Qian, G.Q., Z.B. Dong, W.Y. Luo, Z.C. Zhang, S.C. Xiao, A.G. Zhao, 2011. Grain size characteristics and spatial variation of surface sediment in the Badain Jaran Desert. Journal of Desert Research, 31; 1357-1364.

Rusk, B., M. Reed, 2002. Scanning electron microscope-cathodoluminescence analysis of quartz reveals complex growth histories in veins from the Butte porphyry copper deposit, Montana. Geology, 30; 727-730.

Sun, J., S.H. Li, D.R. Muhs, B. Li, 2007. Loess sedimentation in Tibet: provenance, processes, and link with Quaternary glaciations. Quaternary Science Reviews, 26; 2265-2280.

Sweet, D.E., G.S. Soreghan, 2010. Application of quartz sand microtextural analysis to infer cold-climate weathering for the equatorial Fountain Formation (Pennsylvanian–Permian, Colorado, USA). Journal of Sedimentary Research, 80; 666-677.

Pye, K., H. Tsoar, 2009. Aeolian sand and sand dunes. Springer-Verlag Berlin Heidelberg.

Tucker, M.E., 2011. Sedimentary petrology, An Introduction to the Origin of Sedimentary Rocks, 3rd edition, John Wiley & Sons, 272pp.

Vos, K., N. Vandenberghe, J. Elsen, 2014. Surface textural analysis of quartz grains by scanning electron microscopy (SEM): From sample preparation to environmental interpretation. Earth-Science Reviews, 128; 93-104.

Vosoo, M., G. Mirab Shabestari, A. Amini, 2015. Mineralogy and Geochemistry of Sand Dunes of the Southern Coast of the Caspian Sea. Journal of the Persian Gulf, 19; 29 -42.

Wakindiki, I.I.C., M. Ben-Hur, 2002. Soil mineralogy and texture effects on crust micromorphology, infiltration, and erosion. Soil Science Society of America Journal, 66; 897-905.

Wang, X., Z. Dong, J. Zhang, J. Qu, A. Zhao, 2003. Grain size characteristics of dune sands in the central Taklimakan Sand Sea. Sedimentary Geology, 161; 1-14.

Wang, X., H. Wei, F. Khormali, M. Taheri, M. Kehl, M. Frechen, T. Lauer, F. Chen, 2017. Grain-size distribution of Pleistocene loess deposits in northern Iran and its palaeoclimatic implications. Quaternary International, 429; 41-51.

Yang, X., M. Williams, 2015. Landforms and processes in arid and semi-arid environments. Catena, 134; 1-3.

Zhang, Z., Z. Dong, 2015. Grain size characteristics in the Hexi Corridor Desert. Aeolian Research, 18; 55-67.

Zhang, Z., Z. Dong, J. Li, 2015. Grain-size characteristics of dune networks in china's tengger desert. Geografiska Annaler: Series A, Physical Geography, 97; 681-693.

Zhu, B., J. Yu, 2014. Aeolian sorting processes in the Ejina desert basin (China) and their response to depositional environment. Aeolian Research, 12; 111-120.

Zhu, B.Q., J.J. Yu, P. Rioual, X.Z Ren, 2014. Particle size variation of aeolian dune deposits in the lower reaches of the Heihe River basin, China. Sedimentary Geology, 301; 54-69.