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Analysis of loess sediment texture in Golestan province according to the microstructure parameters

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Abstract

This study was performed to recognize the loess texture in Golestan Province, Iran using the microstructure analysis according to the electron microscopic images. Loess microstructure study allows for investigating the characteristics of particle shape, fabric, cement and porosity in microscopic images. In recent years, computer analysis has been replaced with manual calculation due to its high speed, precision and ease of use. Since the scanning electron microscope (SEM) digital image analysis method can quantitatively determine the loess microstructure and identify the microstructure changes, it was used to analyze the loess texture. The obtained results showed that the loess microstructure changed from north and northeast to south and southwest of Golestan Province. According to microstructural and sedimentology parameters, Golestan Province loess can be divided into 4 zones. The results also showed that microstructural study of loess sediments in Golestan Province could be a useful tool for loess zoning and separating loess sediments from loess-like deposits.

Keywords: *Loess, Microstructure Analysis, Particle Shape, Fabric, Scanning Electron Microscope (SEM)*

1. Introduction

Studies have shown that real loess is a sediment with large silt particles, which is loose, often non-layered, porous, permeable, and light yellow due to limonite particles (iron hydroxide). Quartz as the main mineral (40-80%), feldspar in variable amounts, clay minerals (5-20%) and carbonate (1-20%) are present in loess (Pécsi 1990). One of the basic characteristics of sediment particles that are widely considered to describe the sedimentary environment and transfer mechanism is particle size (Wentworth 1922; Folk and Ward 1957; Vandenberghe 2013). Particle shape is also a major characteristic of sediments, which is widely used for understanding the transfer processes of sediments (Wadell 1935; Riley 1941; Blott and Pye 2008; Suzuki et al. 2015). Combining the particle size and shape can be highly useful for reconstructing wind transfer processes and separating loess sediments which are formed by wind forces of varying intensity and under various climatic conditions (Tysmans et al. 2009). In recent years, the computer analysis has been replaced with the manual method due to its high speed, precision and ease of use (Rodriguez et al. 2013; Campaña et al. 2017),and digital image processing can quantitatively determine the loess microstructure and identify the changes in microstructure (Hu et al. 2005). The microstructure consists of four structural factors of particle shape, fabric, porosity and bonding (Hu et al. 2001). Loess microstructure studies allow for investigating the characteristics of particle shape, roundness,sphericity and porosity in microscopic images (Matalucci et al. 1970).Grabowska-Olszewska (1988) studied the loess microstructure using the scanning electron microscope (SEM) digital image analysis and detected the changes in engineering properties, geology, porosity, water compressibility and susceptibility. Gao (1984) studied the relationship between the loess microstructure in China and its geological and geographic environment, and concluded that the loess microstructural characteristics were subject to climatic conditions and distribution of grading. Hue and Phile-Wej (2010) evaluated the microstructure of hard clay using the SEM digital images. They employed the factors such as the mean surface area of particles and pores, the mean length of particles and pores, and the ratio of total area of particle and pore to total image area, and reached a good relationship between microstructure parameters and consolidation results. Rezaei (2013), in his dissertation, introduced 4 components of particle characteristic, fabric, porosity and bonding (cement) as the main components of loess microstructure, and studied them using fractal geometry. In this paper, the sedimentology and microstructure of loess texture in Golestan Province have been studied by analyzing the SEM digital images. Despite the numerous studies on various belts of loess in the world, loess yet has not been thoroughly studied in Iran. In this study, it has been attempted to investigate the texture characteristics in 3 zones of loess in Golestan Province using two grading and microstructural methods based on the SEM images. Also, the dispersion process, similarities and differences in loess are studied.

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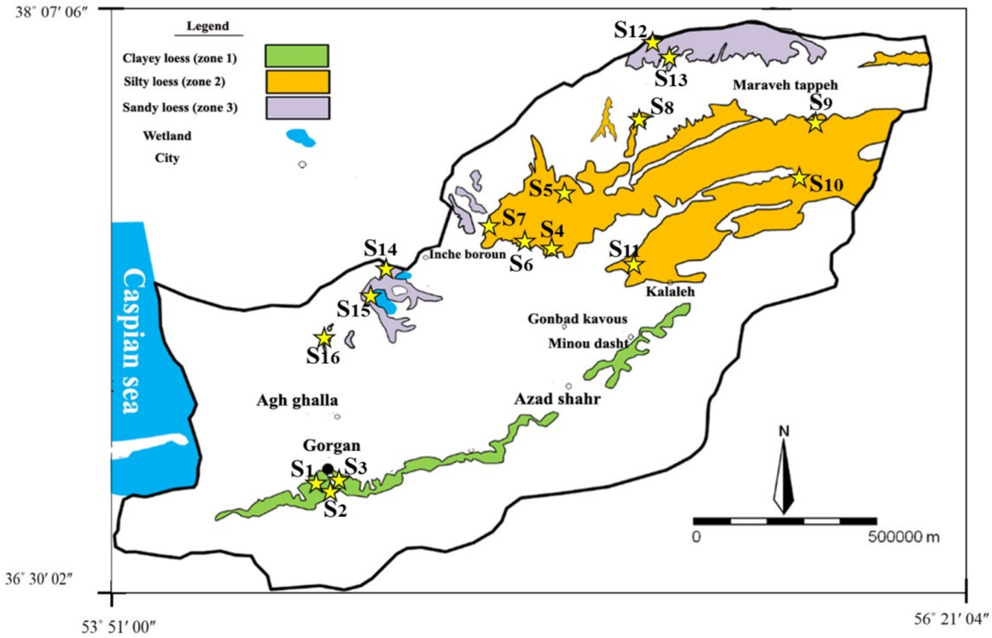

Fig 1. Distribution map of three loess types in Golestan Province (Rezaei 2013) and sampling stations

2. Materials and Methods

2.1. Study area

Golestan Province, which is located at the northeast of Iran and southeast of the Caspian Sea, covers about 1.3% of the total area of the country and has one of the widest loess sediments . This province, with an area of 20,043 Km2, lies between latitudes of 36° 30′ to 38° 8′ N and longitudes of 53° 57′ to 56° 22′ E. Golestan loess has been divided into three zones based on the characteristics of particle size (Khadjeh et al. 2005) and engineering properties (Rezaei 2013) (Fig1). Zone 1, with an area of about 60,000 hectares, is known as the mountainous loess. Zone 2, with an area of about 338,000 hectares, is expanded in the center and eastern part of the province. Zone 3, with an area of about 78,000 hectares, is related to the northern Maraveh tapeh loess sediment at the vicinity of Atrak River on the border between Iran and Turkmenistan and close to Alagol and Almagol lakes and barchans at the northeast of AqQala village (Khadjeh et al. 2005; Rezaei 2013). In this study, 16 stations were sampled as presented in Table 1.

2.2 Methods

Using the distribution map of Golestan Province loess (Fig 1) and studying the access routes and the existence of trenches, 16 stations were selected and the intact and non-weathered surface areas were sampled. To study the distribution of the size of constituent particles, the wet sieving granulometry and a hydrometer were used for large particles and small particles, respectively. Moreover, to perform microstructure analysis, 5 images with different scales of 2, 10, 20, 100 and 200 microns were prepared for each sample by a SEM of Leo 1450VP model at Ferdowsi University of Mashhad. In order to calculate the microstructural parameters of the samples, the image tool management software version 3 was used and the microstructure parameters including particle shape, fabric, cement and porosity were studied and analyzed in 30 samples of each image. The methods for calculation of the parameters are presented in Table 2 and Fig 2.The particle density was determined according to the pixel intensity: The SEM images varied from 0 to 255 pixels, indicating three components of particles, pores and contact zone.

Table 1. The name and location of sampling stations

Station	Station name
S1	Saadabad
S2	Gland fakhrabad
S3	Nasrabad
S4	The tree wayas of Aqband
S5	Aqband
S6	Gonbad-e Qabus
S7	Dashliburun
S8	Hootan
S9	Maraveh tapeh
S10	Chenarli
S11	Tamar-e QarehQuzi
S12	Aqtaqe-ye jadid
S13	MakhtomqoliFaraqi
S14	Almagole
S15	Alagole
S16	AqQala

Table 2. Description of the methods for calculating the microstructural parameters

Factor	Parameter	Definition	Method of calculation
Particle shape	Maximum diameter	The maximum particle diameter	The diameter is the largest circle in the particle
	Roundness	The particle round or angled corners	The ratio of the radius of the sharpest corners of the particle to the radius of the largest circle in the particle
	Sphericity	The particle distance to a sphere	The second root of the diameter ratio is the largest circle in the particle to the diameter of the smallest circle in the seed particle
	Projection elongation	The particle distance to a sphere	The ratio of the lowest width to the lowest length of the image
Fabric	Grain packing density	The particle density along with an assumed line	The ratio of total particle length crossed in the line length to total line length
	Area density	The particle density at the image level	Total area of 30 particles to total image area
Porosity	Maximum pore diameter	The maximum pore diameter	The diameter of the largest circle in the pore
	Grain packing density	The pores' density along with an assumed line	The ratio of total pore length in a line to total line length
Cement	Cement packing density	Cement density along with an assumed line	The ratio of total cement length in a line to total line length
Density pixel	Pixel number	The particle pixel distribution, contact zone and pore	The number of particle pixels, contact zones and pores

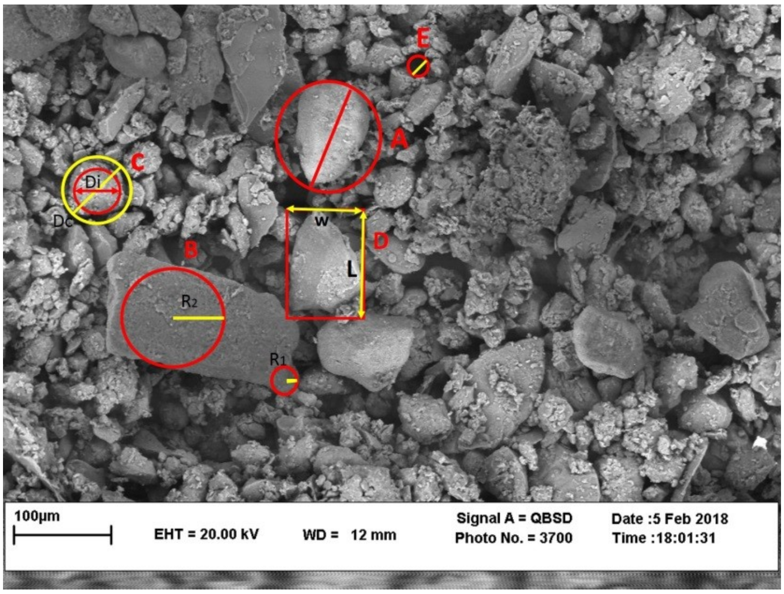

Fig 2. The methods for calculating some of the microstructure parameters of Sample S4: A) The maximum particle diameter, B) Roundness (R_1/R_2), C) Sphericity (D_i/D_c), D) Projection elongation (W/L) and E) Pore diameter.

According to the existing pixel brightness, the distribution of particles, pores and their contact zone can be explained as follows (Hue and Phile-Wej 2010):

1. The particles are a single or aggregate of several minerals. They are usually observed in white in 3D SEM images.
2. Pores are soil free spaces. They are usually observed in black in 3D images.
3. The contact zone between particles or pores can be formed by cement between the particles or outskirts. Each SEM image can be converted into a 3D image and clearly represent three components of particles, pores and contact zone with two thresholds for the configuration of Q1 and Q2. The three components are defined in Fig 3 (Hu et al. 2005).

3. Discussion

3.1. Sedimentology parameters

Golestan Province loess is divided into three parts: sand, silt and clay according to sedimentary and geotechnical characteristics. Previous studies showed that the origin of the loess in Golestan was barren lands of the Qara Qum desert and it was transferred by north and northeast wind to the south and southwestern parts.

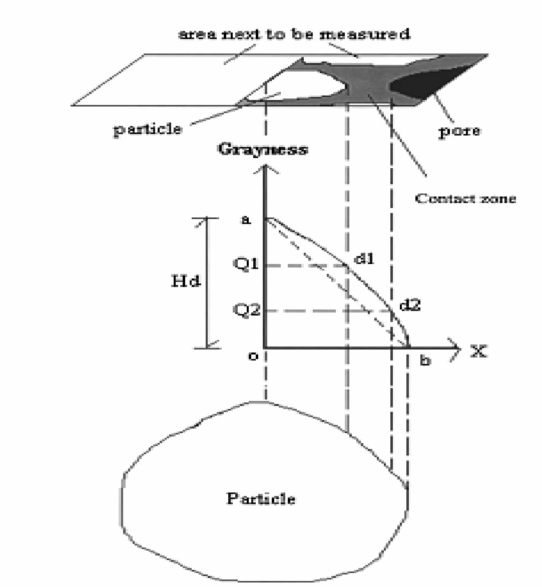

Fig 3. The method for determining particles, pores, and contact zone from SEM image (Hu et al. 2005): Q1 ≤ gray levels of particles' pixel ≤ 255, Q2 ≤ gray levels of contact pixels ≤ Q1, Q2 = 1/3 Hd, and Q1 = 2/3 Hd (Hd is the largest number of gray levels of pixels in an image). Finally, the Excel software was used to analyze the results and plot the diagrams.

Far from Qara Qum desert, the particle size reduced with the reduction of wind speed (Khadjeh et al. 2005). The distribution of the particle size in sediments depends on the origin, erosion among the particles, and carrier force. The environment can be interpreted based on the mean particle size obtained (Moussavi-Harami2006). According to the results from grading test in the three studied zones (Eq. 1), the mean values of 4.37 microns (7.8ø), 14.35 microns (6.4ø) and 49.56 microns (4.7ø) were obtained for zones 1, 2 and 3 respectively. The obtained results indicate that the particle diameter reduced with the increase of distance from the origin (Fig 4).

$$MZ = \frac{Ø16 + Ø50 + Ø84}{3} \qquad (1)$$

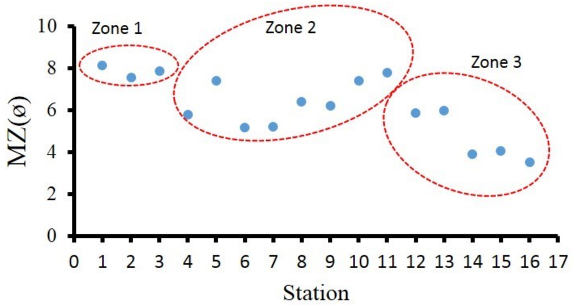

Fig 4. Mean variation of the samples' diameter in the grading.

Pye and Sherwin (1999) also found similar results in their research, and stated that loess far from the original had a less mean particle size than the loess close to the origin. Therefore, the reduced particle diameter from zone 3 to zone 1 can be attributed to the distance traveled. In other words, the particle size is smaller in lower latitudes, because the general direction of the wind with loess was from the northeast to the southwest. Knowing that the origin of loess sediments in Golestan Province is Qara Qum desert, the particle size in three stations of S14, S15 and S16 should be smaller than the particle size in other stations in zone 3 and some stations in zone 2. However, the particle diameter was found to be greater in the 3 stations than in other stations. The different particle diameters and presence of cross-lamination (Fig 5) in desert studies, confirm the existence of different origins in the three stations.

The loess might be sand hills with the origin of the Caspian Sea. The studies performed by other researchers also confirm this finding (Pashaeiaval 1997; Feyznia et al. 2005; Khadjeh et al. 2005; Rezaei 2013).

Another index which is important in the sedimentology parameters is particle sorting. Sorting shows the uniformity of the sediment-constituent particles and the proportion of particle size. In fact, the standard deviation indicates the degree of sorting and can be calculated by Eq. 2. Study of loess sorting and classification based on Folk sorting coefficient (Moussavi-Harami 2006) indicated very poorly sorted particles in zones 1 and 2 and moderately to very poorly sorted particles in zone 3 (Fig 6).Rezaei (2013) and Sanaei-Ardakani et al. (2008) reported the similar results in their study. Moussavi-Harami (2006) concluded that a good sand sorting was due to high-density difference with air. Therefore, the poor sorting of loess sediments can be attributed to the low-density difference between loess particles and air. Comparison of sorting versus loess diameter in Golestan Province and other provinces in China and the United Kingdom (Derbyshire and Mellors 1988) shows the poorly sorted particles in zones 1 and 2 (Fig 7).

Fig 5. Images of cross-lamination in zone 3, station S15

$$SDI(\sigma)=(\phi84-\phi16/4)+(\phi95-\phi5/6.6) \quad (2)$$

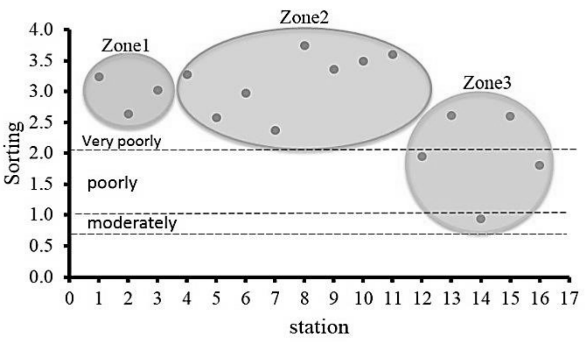

Fig 6. Changes in sorting at the studied stations

The range of the loess in the three stations in zone 3 was different from that of the loess in other zones, indicating the difference of origins or the particles transferred by water. These loess types can be regarded as loess-like deposits as they are not within the mean diameter range compared to another loess in the world (Fig 7).

Skewness, as one of the sedimentology parameters, is the asymmetry of the particle distribution curve determined by the curve sequence. Using Eq. 3, the skewness of the studied loess was calculated to be in the range of 0.16 and 9.05. According to Folk (1974) classification, the loess is very fine-grained and fine-grained and positive (Fig 8). The reason for the positive skewness can be sedimentation in a quiet environment. The results of this study are consistent with the results obtained by Sanaei-Ardakani (2008). Skewness curve versus sorting represented poor sorting of the fine-grained loess, contributing to the assumptions that the samples have not been formed in the same period with the same intensity and the storm sequence in different periods can confirm the results. On the other hand, the loess might have different origins or polymodal wind flows were involved in carrying the particles with different power (Sanaei-Ardakani et al. 2008).

Kurtosis is obtained from the ratio of the curve sequence sorting to the sorting of the middle part of the curve and shows the length of the curve (Moussavi-Harami 2006). Using Eq. 4, the kurtosis was obtained to be in the range of 1.24 and 5.22. According to Folk kurtosis coefficient (Moussavi-Harami 2006), the entire loess of zone 1 was leptokurtic and the loess of zones 2 and 3 varied between leptokurtic and extremely leptokurtic due to the existence of high percentage of silt (Fig 9).The loess of zone 1 appeared to be less elongated than the loess of zones 2 and 3 due to the effect of moister climate and clay formation (Feyznia et al. 2005).

3.2. Microstructural parameters

3.2.1. Parameters of particle shape

The particle shape parameters include maximum particle diameter, roundness, projection elongation, and sphericity. The results of calculating the maximum particle diameter showed that the loesses of zones 1, 2 and 3 had mean values of 27.07 microns, 51.05 microns, 71.25 microns, respectively (Fig 10).The microstructure analysis of the particle diameter indicated the reduction of particle size from zone 3 to zone 1 and confirmed the grading results. Shang et al. (2017) concluded that during the transfer by wind, first heavy and coarse particles are deposited in the proximal zone near the origin zone, while light and small particles are carried to the middle and distant (distal) zones. The results of the present study are consistent with the results reported by Shang et al. (2017).

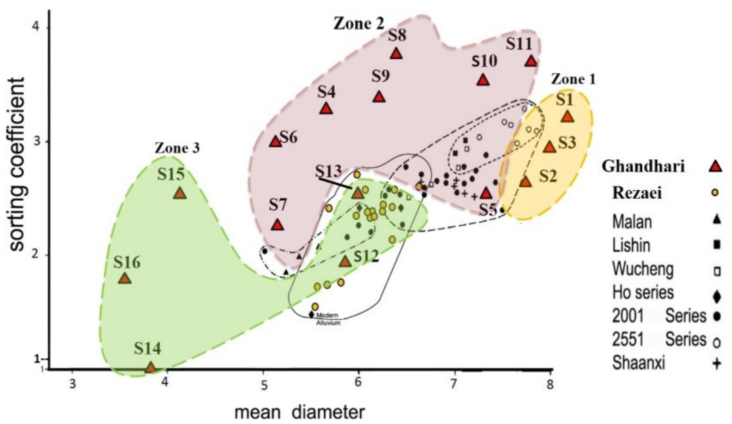

Fig 7. Changes in sorting versus mean diameter at the studied stations

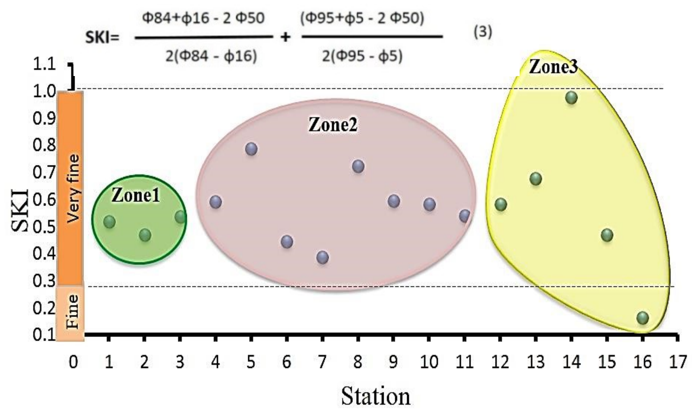

Fig 8. Changes in skewness at the studied stations

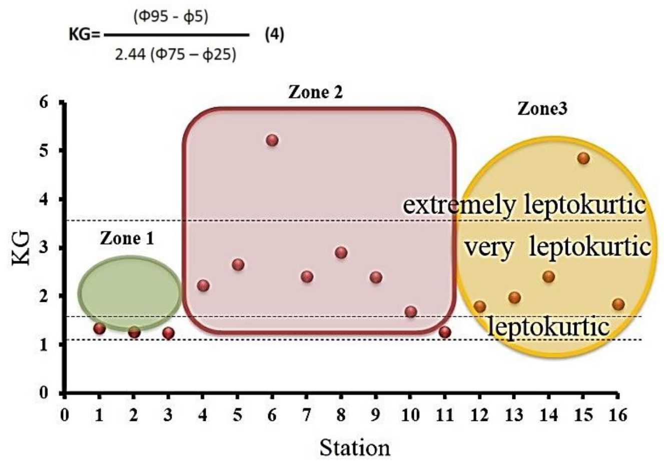

Fig 9. Changes in kurtosis at the studied stations

Therefore, the loess of zone 3 had a larger diameter due to the proximity of zone 3 to the origin, whereas the loess of zone 1 had a smaller diameter due to the long distance of zone 1 from the origin. The three stations of S16, S15, S14 had a greater diameter compared to other stations in zone 3, which could be attributed to the different origins or transfer of the loess (Khadjeh et al. 2005). Khadjeh et al. (2005) indicated that during the blowing of heavy winds, silt and sand particles were carried, trapped in ridges of Sanganeh and Sarcheshmeh formations, and often covered the northern and eastern slopes while the smaller particles were transferred as suspended particles and trapped only at higher altitudes of Alborz.

Evaluation of the roundness of the three zones in the study area indicated that the mean values of roundness varied from 0.151 to 0.504 microns. The loess of zone 1 had the highest level of roundness, whereas the loess of zone 3 had the lowest level of roundness (Fig11).

The results also showed that the particle roundness in the sampling zones increased with the reduction of particle diameter (Fig12).

Li et al. (2018) concluded that the distant particles became smaller and rounder probably due to the erosion among the particles. Moussavi-Harami 2006, in addition to the distance and degree of erosion, considered the effect of particle size on roundness and obtained the similar results. Mazzullo et al. (1992) reported that the transfer by wind was done selectively according to the particle size and shape. During the transfer by wind, the rounded particles are carried more than angled particles and have more acceleration forward. Therefore, rounded particles undergo faster transfer than angled particles, and are transferred to distant zones. In this study, the increased roundness from zone 3 to zone 1 can be attributed to the distance from the origin. As a result, the greater the impact of erosion on the particles' edges, the faster transfer of rounded particles.

Study of the minimum projection elongation ratio showed that it was relatively high and almost close to 1 at all the studied stations. According to the projection elongation classification (Folk 1974), about 37.5% of the samples were sub-equant with a mean of 0.709, 43.75% were equant with a mean of 0.734, and 18.75% were very equant with a mean of 0.757 (Fig13).

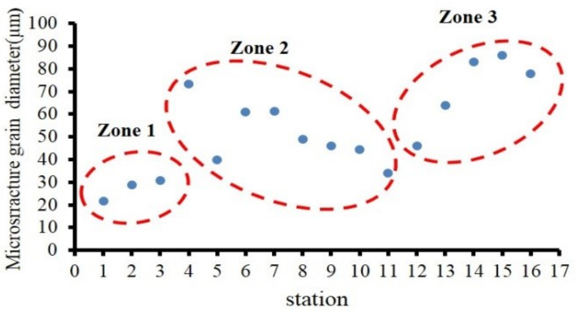

Fig 10. Changes in particle diameter in SEM images at the studied stations

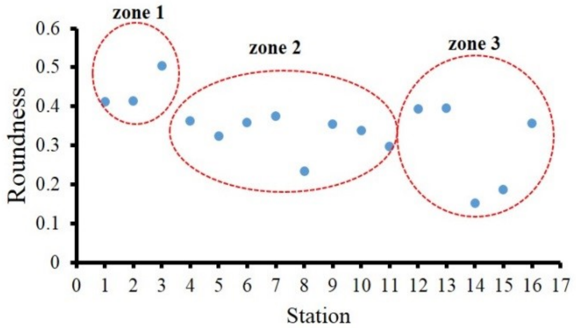

Fig 11. Changes in the roundness at the studied stations.

The mean projection elongation was lower in zones 1 and 3 than in zone 2. The projection elongation did not show a specific relationship with the particle diameter.
Sphericity values vary from 0 to 1 (0 for minimum sphericity and 1 for maximum sphericity). In the present study, the sphericity rate in all the studied zones was relatively high. The loess types in zone 1 and zone 3 had the lowest and the highest sphericity values (Fig 14).
The results showed that, unlike roundness, sphericity reduced with the reduction of diameter. Seemingly, the sphericity was larger in the particles with a larger size. Assallay et al. (1998) considered the significant ratio of the silt quartz particles in loess sediment and suggested that the particles become flat and sharp during the transfer by wind due to the crushing process occurring in the formation of the silt quartz particles. However, Pye (1994) believed that a small amount of energy is released from collision of the silt quartz particles during the suspended transfer due to the relatively small size of the particles. As a result, erosion due to particles collision does not seem to be significant, and the main factor which affects the sedimentation speed is the particles flatness. According to the results obtained in the present study and the findings of Assallay et al. (1998) and Pye (1994), the sphericity of the particles is reduced if they are transferred to distant zones. Considering the high sphericity in all the samples, a slight difference in the three zones and a small number of sharp particles have been observed in the studied samples. Therefore, the low sphericity in the loess of zone 1 and the reduced sphericity from zone 3 to zone 1 are more consistent with the results obtained by Pye (1994).
According to the climate classification of Golestan Province by De-Martton method, zone 1 is semi-moist with a quantitative index of 24-28, zone 2 is semi-arid with a quantitative index of 10-20 and zone 3 is dry with a quantitative index of 7.2- 10. The intensity of weathering, pedogenesis processes and secondary clay frequency increase with the increase of drought index (Feyznia et al. 2005). Moreover, (Yang and Li (2012)) claimed that after sedimentation, the dissolution of water-soluble materials causes particle deformation. Therefore, the lower sphericity from zone 3 to zone 1 can also be attributed to the climate and dissolution of non-resistant minerals due to chemical weathering.

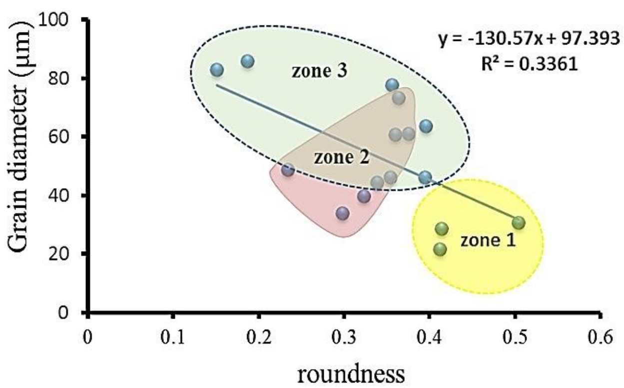

Fig 12. Changes in the particle diameter versus roundness at the studied stations

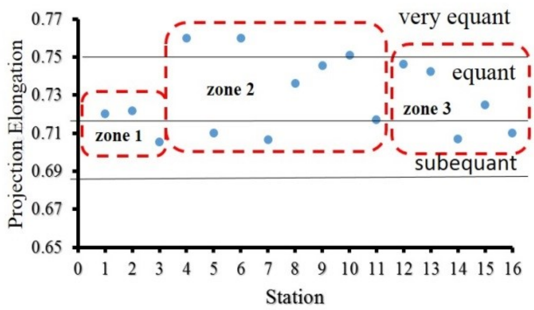

Fig 13. Changes in projection elongation at the studied stations

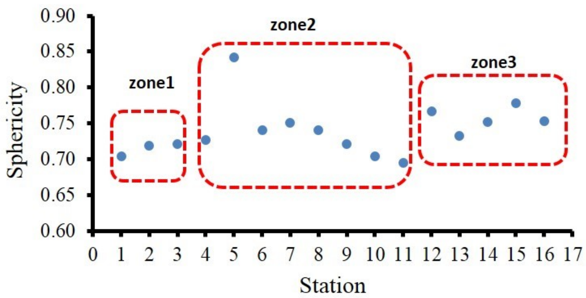

Fig 14.Changes in sphericity at the studied stations

3.2.2. The particle fabric

The study results of the particle fabric include the grain packing density and level density (Moussavi-Harami 2006). The grain packing density depends on compression, cement, and constituent rubbles. The results of studies conducted on the electron microscopy images showed that the mean grain packing density reduced from zone 3 to 1. In zones 1 and 2 loess, the grain packing density in the vertical direction is higher than the grain packing density in the horizontal direction, but in most stations in zone 3, the grain packing density in the horizontal direction is higher than the grain packing density in the vertical direction (Fig 15). Given that the increase in humidity from zone 3 to 1 increases the clay minerals (Feyznia et al. 2005), as well as the increase in clay minerals, will increase the bonding between the particles and cement (Rezaei et al. 2011) and, consequently, the increase in cement reduces the grain density (Moussavi-Harami 2006), therefore, the increase in the grain density from zone 1 to 3 will be due to a reduction in humidity from zone 1 to 3. Also, high grain packing density in the vertical direction relative to the horizontal direction in zones 1 and 2 is probably due to the destructive impacts of animals and plants in the vertical direction, and low grain packing density in the vertical direction relative to the horizontal direction in zone 3 can be due to different climate relative to zones 1 and 2, and thus the reduction in the biological activity in the zone.

The results of the grain area as the second measured parameter of the particle size showed that the stations of zone 1 with a mean of 0.056 microns had the lowest grain area, the stations of zone 2 had the mean grain area of 0.092 microns and zone 3 had the highest mean grain area 0.219 microns (Fig. 16).

Accordingly, Pye (1994) the particle size and frequency of quartz always reduced in the direction of the wind; therefore, the lower grain level density can be attributed to being away from the origin, which the size of the particle and its area reduced with the distance from the origin. Also, the high mechanical strength of quartz causes not easily deforming, and since the quartz value increased from zone 1 to 3 (Khadjeh et al. 2005), the very large difference in the level density of the three stations from zone 3 loess can probably be due to the small distance of transfer due to the different origins and, consequently (Khadjeh et al. 2005), high quartz value. As mentioned early, unlike zones 1 and 2, in zone 3, the grain density in the horizontal direction is greater than the vertical direction. Accordingly, it can be concluded that the density in the vertical direction causes more compression and reduction in the grain level and density.

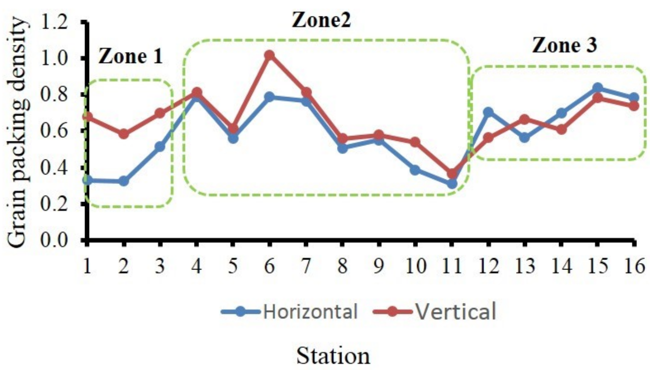

Fig 15. Changes in the grain packing density at the studies stations. The red color shows changes in the grain packing density in the vertical direction and the blue color shows changes in the grain packing density in the horizontal direction.

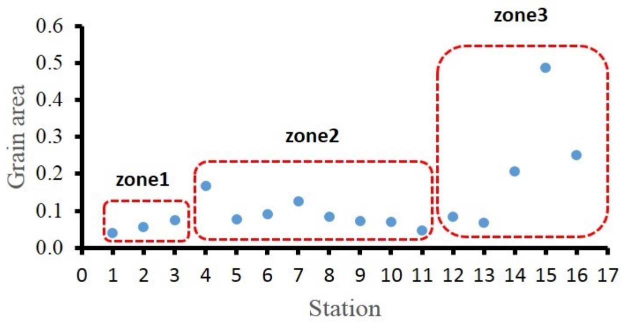

Fig 16. Changes in the grain packing density at the studied stations.

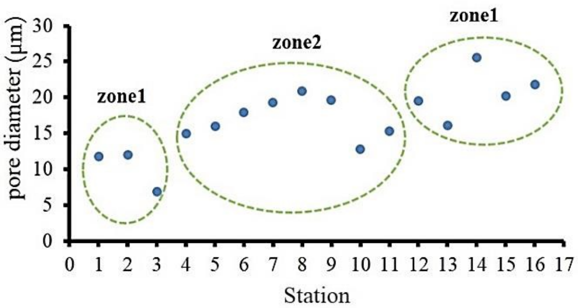

Fig 17. Changes in the pore diameter in the stations studied with increasing the particle diameter, the pore diameter increased.

3.2.3. Porosity

Loess porosity was studied according to the electron microscope images with two measures of the pore diameter and grain packing density. The mean diameter of the pore in zone 1 is 10.19 microns, 17.10 microns in zone 2 and 20.65 microns in zone 3, so the pore diameter increased from zone 1 to 3 (Fig 17).

This is due to an increase in the particle diameter. Also, the pore density reduced from zone 1 to 3 (Fig 18), which is evident, given the increase in the particle density from zone 1 to 3, on the other hand, with increasing humidity and rainfall from zone 1 to 3, the amount of clay increased and is placed between pores and reduced porosity (Feyznia et al. 2005).

3.2.4. Cement

The most important factor is the bond between loess particles of silt and clay particles. Of course, calcium carbonate, salt (Karstunen and Leoni 2008) and iron oxide (Jefferson et al. 2003) in the weathered zones can also be a bonding agent. In this study, silt and clay bridges are considered as cement. The results showed that the mean density of cement reduced from zone 1 to 3 (Fig 19).

The reason for this can be attributed to the difference in humidity in the three zones of the study, so that with moving from zone 3 to 1 we had a greater potential for chemical weathering and decomposition of non-resistant minerals such as feldspar and mica, and clay minerals increase in situ (Feyznia et al. 2005). Rezaei et al. (2011) also stated that the percentage of clay in zone 1 is more than 30% and in zone 3 is about 15%, which confirms the increase of clay minerals with the distance from zone 3 and approaching zone 1 and is consistent with the results obtained in this study.

3.3. The grain packing density according to the number of pixels

According to the particles' pixels in the images of the electron microscope (Fig 2) and the number of each pixel, the histogram diagram is plotted for each image (Hu et al. 2005). In the histogram diagram, the horizontal axis shows the gray level (from 0 to 255 pixels) and the vertical axis shows the number of pixels (dots) per gray level (Fig 20).According to histogram diagrams and the results in each zone, the particle percentage, contact zone and pores were calculated in three zones (Table 3) and its circular diagram was drawn (Fig 21).

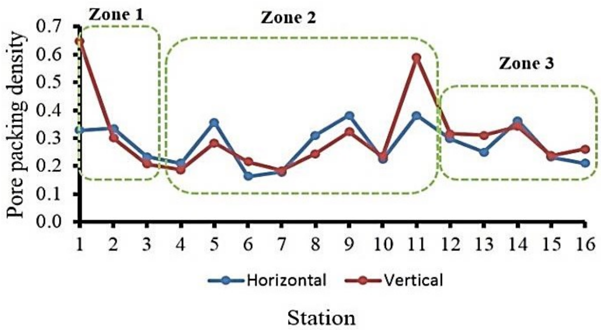

Fig18. Changes in the pore packing density in the stations studied. The red color shows changes in the pore packing porosity in the vertical directions and the blue color shows changes in the pore packing porosity in the horizontal direction.

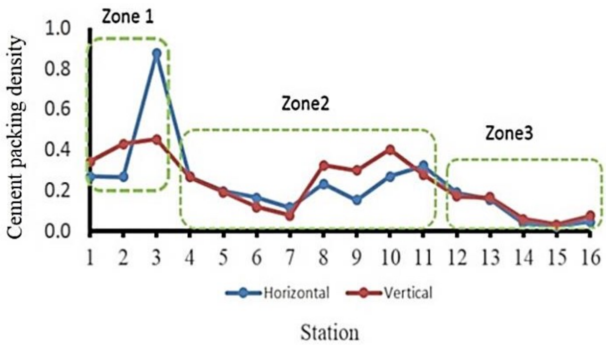

Fig 19. Changes in cement at the studied stations. The red color shows changes in cement in the vertical direction and the blue color shows changes in cement in the horizontal direction.

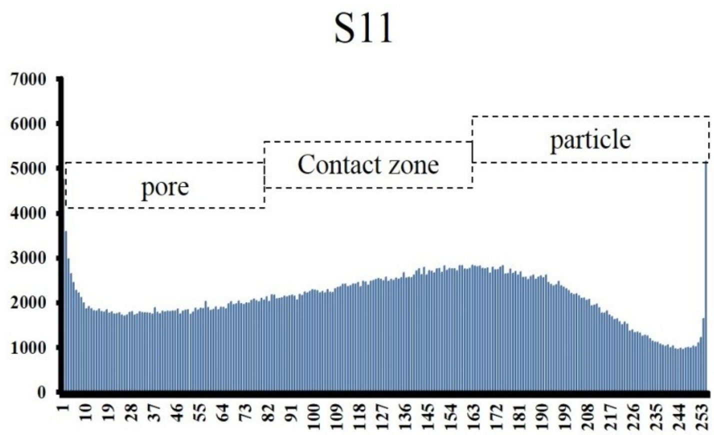

Fig 20. It is an example of a histogram diagram plotted for station 11. The horizontal axis shows the pixel of the particles and the vertical axis represents the number of each pixel. The pore, contact zone and particles are approximately specified.

Table 3- The results of the number of the particle pixels, contact zones, and pores at the studied stations

Station	The percentage of the total number of pixels in the particle zone to the total image zone	The percentage of total number of pixels in the pore zone to the total image zone	The percentage of the total number of pixels in the contact zone to the total image zone
S1	0.84	46.62	52.54
S2	8.33	49.89	41.77
S3	3.96	57.22	38.82
S4	7.97	56.99	35.05
S5	22.59	38.80	38.62
S6	23.28	43.48	33.25
S7	9.37	58.45	32.18
S8	21.66	46.40	31.94
S9	29.50	39.48	31.02
S10	14.02	56.01	29.96
S11	6.38	39.93	53.69
S12	14.87	45.90	39.23
S13	25.25	39.11	35.64
S14	22.06	42.40	35.54
S15	16.71	52.04	31.25
S16	30.51	38.47	31.02

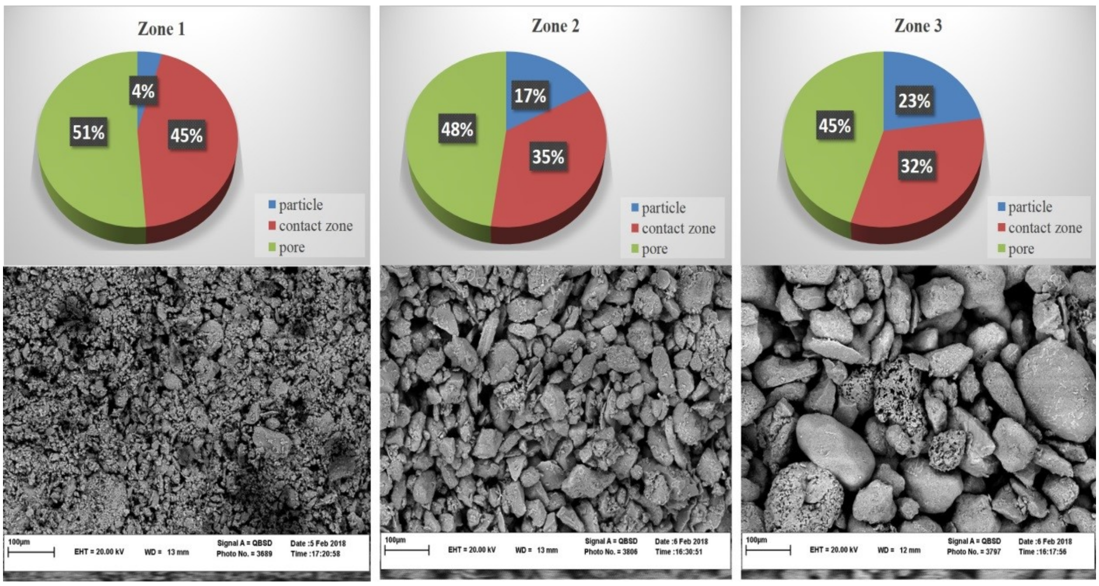

Fig 21. Circular diagram of the particle percentage, contact zone and pore in the three zones and SEM image sample in each zone.

Zone 1 has less particles and more cement than zones 2 and 3, as well as the particle percentage increased from zone 1 to zones 2 and 3, and the percentage of cement reduced. As shown, the clay is a bonding agent between the particles (Rezaei et al. 2011) and, with increasing humidity, the unstable minerals are decomposed and converted to the clay (Feyznia et al. 2005), which is consistent with the results of the present study. According to the circular diagram (Fig 21), the pore values in the three zones are not significantly different and the values of particle and cement in zones 2 and 3 are approximately equal. According to the microstructural results obtained and emphasizing the effect of the origin difference on these results, it seems that the transfer distance and the particle size do not affect the density of particles significantly based on the number of pixels.

4. Conclusion

The purpose of this study was to identify the loess texture in Golestan Province using microstructural analysis according to the scanning electron microscope (SEM) images. The loess grading test showed the reduced particle size from the north and northeast to the south and southwest. The studied loess was very poorly and poorly sorted with a positive skewness and classified as very fine-grained and fine-grained. The particle Kurtosis index was found as leptokurtic to extremely leptokurtic. The loess microstructure analysis of showed that the value of diameter reduced from the north and northeast to the south and southwest. Moreover, the roundness increased and the sphericity reduced with the increase of the diameter. The results showed that the grain packing density and porosity reduced and the cement increased from zone 3 to zone 1. Also, the grain level density reduced with the increase of distance from the origin and reduction of quartz frequency and particle size from zone 3 to zone 1. The granular study showed the significant difference in terms of diameter among the three stations of S14, S15 and S16 and other stations in the same zone and the non-compliance of the reducing trend of the particle diameter from the north to the south of the province. The results of microstructural analysis while confirmed the difference in the diameter of the three stations and other stations in zone 3, and showed their low cement density and high particle level density compared to other stations in zone 3 and other zones, so Golestan Province loess based on microstructural parameters can be divided into 4 zones.

In general, the results showed that microstructural studies on loess sediments can be a useful tool for loess zoning in Golestan Province and separating loess sediments from loess-like deposits. Finally, sampling of the same age horizons is suggested in order to determine the changes in texture and shape of the sediments more accurately. The relationship among composition of the particles, particle size and origin of the loess can be comprehensively investigated through geochemical analysis in another study as a complementary to the present work.

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