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Deposition of sandstorms in a vegetation-covered sand dune in Ejin Oasis and its characteristics

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Abstract: "Ejin Section" found in a typical vegetation-covered sand dune in Ejin Oasis was investigated. In this study, 263 samples were taken from the section for grain-size analysis, 25 for chemical analysis, 11 for ^{14}C dating and 6 for scanning electron microscope (SEM). The results of the study indicate that 3 types of the sediments in the section can be identified, YS, LS and ST. YS, homogeneous yellow-brown dune sands, is equal to those of inland deserts, LS, loess-like sandy soils, is the same as the sandy loess in the middle Yellow River and modern falling dusts, and ST, sandy sediments interbeded with the deadwood and defoliation of *Tamarix spp*, represents the depositional process of the section interrupted by abrupt changes in climate. The Ejin Section has recorded the repeated dust-storms or sandstorms since 2500 yr BP and the peak periods of the dust-storms or sandstorms revealed by the section are consistent with the records of "dust rains" in historical literatures, indicating that the change of climate is a key factor to increase sandstorms or dust-storms, whereas, "artificial" factor may only be an accelerating one for desertification.

Key words：Ejin Oasis; vegetation-covered sand dune; dust storm; sandstorm; grain size; major chemical element
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1 Introduction

Oases are unique ecosystems and important residences for our ancestors in arid and semiarid regions of the world, and have deeply been imprinted by human actions, such as Jericho oasis of Jordan Valley, Jarmo oasis of the Euphrates River and the Tigris River in Asia, Maqta oasis in Oman, Dakhleh oasis in Egypt, Luolan oasis in China, etc. (Dupras and Schwarcz, 2001; Siebert *et al*., 2005; Huang, 2003). In the past two decades, more and more Chinese researchers have focused their attention on the ecological environment and evolution of these oases in Xinjiang, Inner Mongolia, Gansu, etc. (Tian, 1988; Zhu Zhenda *et al*., 1988; Fan *et al*., 1993; Li, 2002). But most of them have conducted their studies in terms of historical geography and landuse/over changes. However, some geological evidences indicate that the oases' evolution had been dominated by nature processes (Mischke, 2002; Li, 2002). Thereinto, an important natural phenomenon is the deposition of repeated sandstorms. Especially in recent years with the frequent occurrences of sandstorms in northern China, both oases' ecosystems and sandstorms have attracted great attention of the Government and the academic communities (Branch of Earth Science, CAS, 1996; Liu, 2003; Jie, 2004; Sun, 2004; Yang, 2004; Zhang, 2001; Zhuang, 2001; Zhou, 2003).

These oases, as "front belts" of the sandstorms, situated in the arid and extremely arid desert regions of Northwest China and on the pathways of Siberia-Mongolia anticyclone, have suffered serious desertification. The recent field investigations support that the desertification in some oases, such as Zhangye, Minqin, Jiuquan and Ejin, is accelerating. The fluviatile-lacustrine sediments once distributed

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wildly in these areas (Mischke, 2002) are nowadays covered by sands or dunes of different sizes. So far disordered and excessive human reclamation is often considered to be a key factor to intensify the desertification happening within these oases. However, the physical or chemical properties of such sands or sand dunes, regarded as a symbol of the desertification, are rarely studied in detail. Since 2001, plenties of samples have been collected from these oases and analyzed in the laboratory. In this paper a sedimentary section of a sand dune in Ejin Oasis, also named "Ejin Section", is selected as an example to discuss the characteristics of the sands or dunes in respects of granularity, chemical elements, scanning electron microscope (SEM), etc.

2 Materials and methods

2.1 Study area and sampling location

The Ejin Oasis is located at the terminal region of Heihe River, bounded to the north by Mongolia and surrounded by Gobi-deserts in the west, south and east (Figure 1). Now the oasis covers an area of approximately 3328 km^2 (Huang, 2003) and Heihe River, running from the south, is the only water resource, the surface runoff of which often disappeared about 100 km before reaching Ejin Banner (Qi) in recent years. According to the records from Ejin Meteorology Station (Compilation Committee of Ejin Banner Chorography, 1998), the Ejin Oasis has an annual mean temperature of 8.2 ^oC, a monthly mean temperature of -11.3 ^oC in January and 26.0 ^oC in July, and with the extreme low temperature of -37.6 ^oC and the extreme high temperature of 42.2 ^oC. The annual precipitation is about 38 mm and the annual evaporation ranges from 3700 to 4000 mm. The prevailing wind direction is W or NW in most time, with annual mean wind velocity of 4.4 m/s. There are more than 52 days of gales (⩾17 m/s) and 16 dust-storm days on annual average. The typical vegetation are *Populus euphratica*, *Tamarix spp*, etc. Fixed and semi-fixed dunes lying in heaps are wildly distributed, with thickness ranging from 1 m to 3 m or from 5 m to 10 m (Huang, 2003). All the features mentioned above indicate an environment of extremely arid deserts under a temperate continental climate.

2.2 Sampling and analysis

The Ejin Section is situated in a shrub sand dune area (41°46.36' N, 101°09.26' E) north of a brickyard, 7 km east of Dalaihubu Town (Figure 1). The features of the section were described in detail in the field, and 263 samples were obtained at 2 cm interval from top to bottom of the section for grain-size analysis, 11 samples for ^{14}C dating and 6 samples for SEM. The chemical treatments for granularity samples followed the procedures described by Konert and Vandenberghe (1997). Particles > 0.063 mm were sieved and those < 0.063 mm were measured by using a SA-CP3 grain-size analyzer. This instrument had a capacity to measure the particles of 0.02–500 um in diameter. The grain-size grade division was of decimalism ranging from 1 to 0.1 mm, and the particles <0.10 mm were classified into different classes according to the general principle of classification of Chinese loess (Shanbei Group of Chengdu Geologic Institute, 1978; Liu, 1985), i.e. the particles of 0.10–0.05 mm for very fine sands, 0.05–0.005 mm for silt, and <0.005 mm for clay. Conventional ^{14}C ages of the 11 samples were determined by the ^{14}C Laboratory of Lanzhou University, Gansu Province, China.

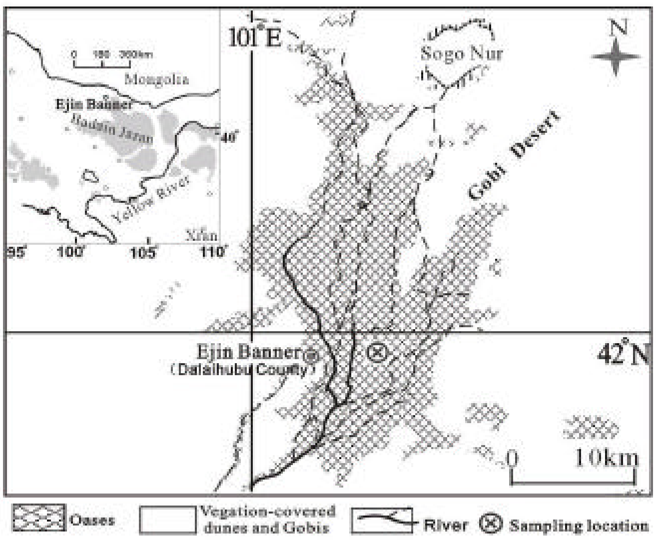

Figure 1 Ejin Oasis and the sampling location

In order to investigate the

characteristics of the sandstorm deposits in different sizes at different depths of the section, the 25 samples, each of which was divided into four groups based on the grain size grades, such as group A (the whole sample containing the particles of all size), group B (particles >0.10 mm including fine sand and those coarser than fine sand), group C (particles <0.10 mm equivalent to those finer than fine sand), and group D (particles <0.05 mm equally as clay- or silt-sized fractions), were analyzed by Japanese X-fluorescence spectrum instrument (Model 3070) in the Central Laboratory, Cold and Arid Regions Environmental and Engineering Research Institute of CAS, Lanzhou, China. In addition, SEM was performed for the 6 samples here.

3 Chronology of the Ejin Section and its material compositions

Shrub sand dunes spreading in the Ejin Oasis witnesses its huge environmental deterioration over the past several thousand years. Here we try to find out some correlation between the desertification and oasissfications by investigating the Ejin Section, its forming age and material compositions.

3.1 Ejin Section and its chronology

The section had a thickness of over 5 m with shrub vegetation on the top and consisted of interbedded homogeneous yellow-brown sand (YS), loess-like sandy soils (LS) and sandy sediments containing the deadwood and defoliation of *Tamarix spp* (ST). The lithological and pedological features of the section recognized in the field revealed that the sequence of it was of aeolian sediments. Like the local and nearby modern mobile dune sands, YS was composed of firstly fine sand and secondly very fine sand, which was pure, loose and well sorted, occasionally with some convex or horizontal aggradational laminae. LS, very similar to modern aeolian falling sands and dusts (Liu, 1985; Quan, 1995), was mainly composed of soil like silt with slight white calcareous spots, and was interbedded with clear and thin layers of fine sand and very fine sand. ST was characterized by interbeds of aeolian silty fine sand and layers of *Tamarix spp* leaves. The thickness of fine sand beds ranged from 1 mm to 5 mm, while some of those containing the deadwood and defoliation of *Tamarix spp* reached up to 11cm.

The sediments at the depths (meters) of the section and their the ^{14}C ages (years before present, abbr: yr BP) derived from the 11 samples were: 0.22–0.24, 180±40; 0.48–0.50, 330±40; 1.18–1.20, 750±40; 1.64–1.66, 1020±85; 2.50–2.52, 1460±85; 3.10–3.12, 1890±90; 3.82–3.84, 2322±85; 4.64–4.66, 2365±85; 4.78–4.8, 2423±85; 4.94–4.96, 2466±85; and 5.10–5.12, 2510±85 (Figure 2). Therefore the chronology sequence was established by inner linear interpolation based on the 11 age control points (Figures 2 and 3).

3.2 Material compositions

3.2.1 Grain-size distribution The percentage contents of the particles in different sizes changed with depths in the Ejin Section (Figure 2 and Table 1). In YS the contents of particles > 0.10 mm were almost above 65%, particles of very fine sands (0.10–0.05 mm) < 30%, and silt- and clay-sized fractions < 10%. LS had 20%–50% of particles > 0.10 mm, 30%–60% ranging from 0.10 to 0.05 mm, and 10%–40% silt- and clay-sized fractions (Table 1). As for ST, the range of the particle contents varying with different grain sizes is smaller than those of YS and LS (Table 1).

3.2.2 Major chemical compositions Major elements, accounting for >90% of the total chemical ones, of the 25 samples were determined. The same oxide had almost the same content in the sediments of YS, LS and ST throughout the whole section (Table 2). However, the contents of different oxides were quite different in the sediments of YS, LS and ST, and also in the different sized portions of the same sediment. The values of SiO_2 for the group A in LS were about 9% lower than those in YS, but except for TiO_2, the values of Al_2O_3 and other oxide were about 1%–1.5% higher than those in YS. In YS, LS and ST, the SiO_2 contents only had a small

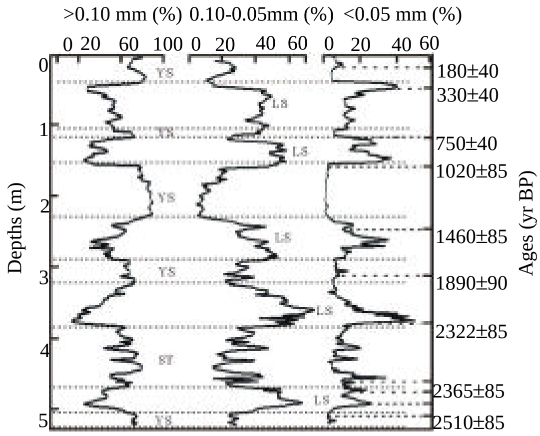

Figure 2 Curves of grain sizes with Ejin Section and ^{14}C ages

Table 1 Grain-size composition of the Ejin Section (%)

Types	Depth (m)	> 0.1 mm	0.1–0.05 mm	< 0.05 mm
Interbedded homogeneous yellow-brown sand	0–0.40	66.94–87.04	9.29–24.03	3.28–11.42
	1.06–1.16	67.41–75.08	19.74–24.67	5.17–7.19
	1.54–2.38	67.28–94.77	4.68–28.15	0.44–5.04
	2.88–3.30	59.22–75.96	18.09–33.45	4.29–12.99
	5.02–5.26	63.65–77.95	20.15–32.54	1.69–6.55
Loess-like sandy soils	0.40–1.06	23.48–61.24	28.52–41.62	10.23–40.35
	1.16–1.54	18.99–45.73	37.75–48.83	13.38–37.39
	2.38–2.88	25.79–66.05	23.77–44.96	8.81–35.63
	3.30–3.84	6.49–64.23	33.41–62.41	2.35–50.47
	4.72–5.02	19.41–59.45	34.45–56.67	6.10–26.54
Sandy sediments containing the deadwood and defoliation	3.84–4.72	41.19–82.72	13.01–40.08	2.21–34.12
Manlan loess in the middle Yellow River (Liu, 1985)	< 10.00	23.60–72.40	8.96–23.93	15.00–25.00

Table 2 Oxide compositions of the Ejin Section (%)

Types		Sample	SiO_2	Al_2O_3	Fe_2O_3+FeO	CaO	MgO	K_2O	Na_2O	TiO_2
A	YS	E01	75.20	7.85	2.67	3.30	1.76	1.84	1.84	0.34
		E94	73.72	8.07	2.89	3.87	1.93	1.81	1.74	0.37
		E106	71.61	8.27	3.15	4.61	2.16	1.78	1.82	0.40
	LS	E24	62.97	9.79	3.46	5.20	3.33	1.98	4.16	0.49
		E74	64.84	9.46	3.60	5.36	3.10	2.04	2.70	0.52
B	YS	E153	77.32	7.50	2.40	2.92	1.54	1.81	1.69	0.30
		E263	77.37	7.48	2.41	2.96	1.42	1.81	1.66	0.30
	LS	E31	73.08	8.46	2.98	3.74	2.06	1.93	1.99	0.37
		E62	71.02	8.53	2.88	3.99	2.30	1.96	2.30	0.38
		E132	74.48	8.13	2.59	3.20	1.80	1.94	1.74	0.33
		E189	63.77	10.51	3.80	5.41	3.18	2.20	1.87	0.53
		E248	71.47	8.21	2.69	4.36	1.86	1.90	1.71	0.36
	ST	E202	76.99	7.57	2.41	2.38	1.51	1.86	1.68	0.30
		E224	76.40	7.63	2.54	3.25	1.55	1.79	1.74	0.31
C	YS	E153	67.31	9.37	3.60	5.25	2.85	2.00	1.95	0.56
		E263	67.24	9.21	3.68	5.41	2.68	1.95	1.89	0.58
	LS	E31	64.12	9.64	3.79	5.73	3.20	2.01	2.89	0.56
		E62	61.57	10.08	3.92	6.02	3.50	2.07	3.13	0.56
		E132	64.85	10.17	3.78	5.45	3.06	2.16	1.86	0.53
		E189	58.84	10.89	4.45	7.09	3.61	2.03	1.89	0.71
		E248	66.11	9.86	3.42	5.12	2.80	2.11	1.83	0.49
	ST	E202	66.87	9.50	3.70	5.25	2.78	2.00	1.96	0.57
		E224	64.39	9.59	4.09	6.05	2.94	1.93	1.95	0.67
D	ST	E132	59.59	10.43	4.37	7.20	3.30	1.94	1.90	0.74
		E248	59.41	10.92	4.43	6.85	3.46	2.02	1.84	0.72

Notes: Group A (the whole sample containing the particles of all sizes), Group B (particles >0.10 mm including fine sand and those coarser than fine sand), Group C (particles <0.10 mm equivalent to those finer than fine sand), and Group D (particles <0.05 mm equally as clay- or silt-sized fractions); YS (interbedded homogeneous yellow-brown sand), LS (loess-like sandy soils) and ST (sandy sediments containing the deadwood and defoliation of *Tamarix spp*)

discrepancy (except for the sample of E189) for group B (particles >0.10 mm) and group C (particles <0.10 mm), whereas the values of Al_2O_3, Fe_2O_3+FeO, CaO, etc. for the two groups in LS were slightly higher than those in YS and ST.

In general, in the same sediment, the values of SiO_2 for group C (particles <0.10 mm) were obviously lower than those of group B (particles > 0.10 mm) while the values of Al_2O_3, Fe_2O_3+FeO, CaO, etc. for group B were higher than group C. This contrast was much noticeable in LS and especially in ST, the silt- and clay-sized fractions. Such a discrimination in the groups suggested that the oxide contents in the particles < 0.10 mm (group C), especially of silt- and clay-sized fractions (group D) were the main factor to determine the chemical characteristics of full sizes particles (group A) in the Ejin Section.

4 Discussion

In terms of both granularities and oxide contents, the sediments of YS mentioned above are similar to modern mobile dune sands in inland deserts (Gao, 1995). For instance, in Badain Jaran Sand Sea next to the Ejin Oasis, the modern mobile dune sands are mainly composed of particles >0.05 mm (94.6% on average), which are mainly fine sands, have only small amount of silt, and are lack of clay. The oxides for modern mobile dune sands also predominantly consist of SiO_2, ranging from 72.26% to 77.80%. The other oxides are Al_2O_3 (7.69%–9.19%), Fe_2O_3+FeO (2.10%–2.76%), CaO (1.24%–2.97%), MgO (1.05%–1.66%), K_2O (1.72%–2.10%), Na_2O (1.68%–2.06%) and TiO_2 (0.30%–0.41%), which are well consistent with those of YS respectively (Table 2). Hence the sediments of YS can be considered to be one kind of sandstorm depositions, i.e. the outcome of wind-drifts in deserts.

The grain-size distributions of LS are similar to those of Manlan loess in the middle reach of Yellow River. Coarse silts (0.05–0.02 mm, 45%–60%) in Malan Loess has priority over clay (<0.005 mm, 15%–25%), and medium or coarse sands are almost absent. Sandy loess is the coarser one among Malan Loess with 23.6%–72.4% of fine sand, 7.0%–20.0% of clay, and fairly high contents of very fine sands, (Liu, 1985). The sediments of LS can also be compared with Malan Loess in respect of oxide contents. For example, the oxide contents of the typical Malan Loess in Luochuan section are 56.54%–59.52% for SiO_2, 11.58%–12.37% Al_2O_3, 4.46%–4.91% Fe_2O_3+FeO, 6.50%–8.77% CaO, 1.98%–2.13% MgO, 1.88%–26% K_2O, 1.40%–1.67% Na_2O, and 0.58%–0.64% TiO_2.

These data show the values of SiO_2 in LS are much higher than those in Luochuan loess, while the contents of Al_2O_3 and Fe_2O_3+FeO are lower, but the rest of the oxides have no distinct discrepancy in their contents. This phenomenon is possibly correlated with the geological locality of the Ejin Oasis, which always faces the front of sandstorms from the past to present. That is to say, the frequent invasions of strong wind-drifts have brought high amount quartzes into the Ejin Oasis and, therefore, it may result in the higher contents of SiO_2 and the relatively lower values of Al_2O_3 and Fe_2O_3+FeO in LS than those in Luochuan loess. Consequently, the LS sediments in the Ejin Section could be the deposits accumulated by dust-storms in association with frequent wind-drifts.

The sedimentary environment for ST was similar to that of LS. However, the depositional process was repeatedly interrupted by abrupt changes in climate. The wet climate favored the growth of vegetation while an abrupt deterioration in the climate could destroy the vegetation in an extremely short time, resulting in the deadwood and defoliation being buried by windblown sand. Such repeated processes created the interbeds of leaves and sands in ST.

Figure 3 illustrates a comparison of the changes in silt and clay contents at depths of the Ejin Section to the curve of "rain dusts" frequencies after 300 AD (Zhang, 1984). Periods of 890–860 yr BP and 790–680 yr BP in "rain dusts" frequencies were regarded by Zhang (1984) as the time with frequent sandstorms, which just match the times when the sediments of LS in the depth from 1.54 m to 1.16 m were deposited, while the periods of 480–390 yr BP, 340–250 yr BP and 130–60 yr BP were equal to the sediments in the depth from 1.06 m to 0.40 m. In other words, the ages of the LS sediments can indicate the corresponding stages of dust-storms occurring in history and the sediments of LS are the records

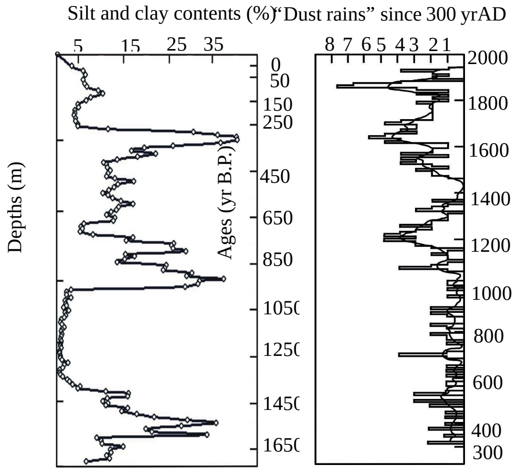

Figure 3 Silt and clay's contents and "rain dusts" frequencies

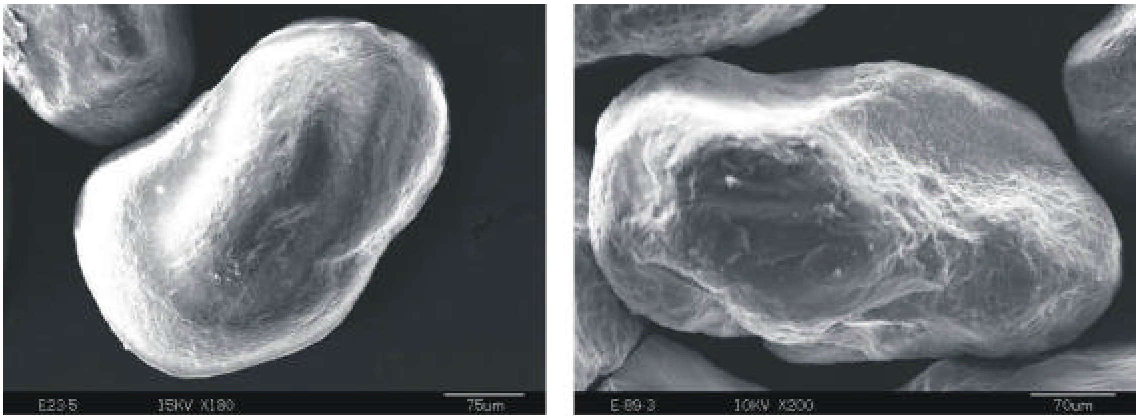

Figure 4 SEM images of typical wind-transported particles

of dust-storms in the past 2500 years.

The sediments of LS also have features of modern aeolian deposits. The super dust-storm event "930505" occurred in Lanzhou can be taken as example to represent chemical compositions of typical modern dusts, which are 52.88% for SiO_2, 11.36% Al_2O_3, 4.84% Fe_2O_3+FeO, 8.57% CaO, 3.71% MgO, 2.33% K_2O, 0.55% Na_2O, and 0.66% TiO_2. Apparently the oxide contents of LS are similar to those of the super dust-storm. Furthermore, 119 of the 236 samples of LS have a bimodal grain size distribution, which always occurs in loess and modern dust-storm or sandstorm sediments (Wang, 2003; Shi, 1995).

Six typical samples (each 2 from YS, LS and ST) are examined under a scanning electron microscope and the results show that sand grains in the Ejin Section have typical wind-transported features, which are "water drop" shape or streamline along the long axis, subrounded shape with mostly smooth undulating surface, many small pits or pockmarks, thick layers of silica and *et al*. (Figure 4). Figure 4 exhibits the typical fusiform or screw-like shapes, which may be the result of long distance wind transport (Xie, 1984; Wang, 1985).

According to a long time observation and experiment in Cele oasis at the southern margin of Tarim Basin in southern Xinjiang, oases are one of the main areas for windblown dusts to fall down. The amount of dust falling down into the oases is 3 times more than that into Gobi regions under the condition of the same time, the same altitude and the same wind direction (Liu, 1994). Developing in the area of an alluvial-fluvial delta plain within the ancient Juyan Lake, surrounded by sands and Gobi deserts under an extremely arid continental climate with frequent dust-storm attacks bringing abundant silt- and clay-sized fractions, the Ejin Oasis has an extremely complicated ecosystem that is in favor of the deposition and preservation of the dusts. Such aeolian sediments, like those in the Ejin Section, support the "rain dusts" record in historical literatures, and may provide some new clues to the research on the evolution of historical sandstorms.

5 Conclusions

The following conclusions can be drawn from the above analysis:

(1) The Ejin Section, composed of homogeneous yellow-brown sand, loess-like sandy soils and sandy sediments interbeded with the deadwood and defoliation of *Tamarix spp*, indicated that the sandy sediments of the Ejin Oasis have the characteristics of both inland desert-sands and sandy loess, which were supported by the analysis of granularities, chemical elements and SEM.

(2) Likely due to nature climate changes, the Ejin Section has recorded at least 2 peak periods when sandstorms or dust-storms frequently occurred, which coincide with the "dust rains" records in history.

(3) Loess-like sandy soil in the Ejin Section is the best recorder for the dust-storms happening in the past 2500 years. Such soil could also be a valuable land resource for oases and, therefore, not only the water resources but the widely distributed loess-like sandy soils also need to be paid attention to in the efficient utilization and preservation of both resources in the sustainable development of oases.

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