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# ENVIRONMENTAL EVOLUTION OF ORDOS DESERT IN CHINA SINCE 1.1MA B. P. AS INDICATED BY YULIN STRATIGRAPHICAL SECTION AND ITS GRAIN-SIZE ANALYSIS RESULTS

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**ABSTRACT**: Yulin section is a typical sedimentary record for reflecting the environmental evolution of Ordos Desert, China in the past 1.1Ma. By analyzing its sequence and grain-size composition some views have been put forward in this paper as follows. The layers of sand, loess and palaeosol in Yulin section were respectively formed by wind and the pedogenesis on parent material of the sand and loess. Since 1.1Ma B. P., Ordos Desert has alternately experienced 11 stages of shifting dunes under extreme cold-dry climatic environment, 7 stages of fixed and semi-fixed dunes and 8 stages of dust (loess) under cold-dry climatic condition; and the pedogenesis environment under 15 times of warm-humid climate and 3 times of temperate-humid climate (brownish-drab soils and black soils formed respectively). The aeolian sand had already existed in Ordos Desert at latest by 1.1Ma B. P., and from that time on it has undergone a series of alternative processes of shifting sands, fixed and semi-fixed dunes, loess and soils. Ordos Desert has been situated in the transitional belt of the Mongolian High Pressure and margin of the southeast summer monsoon since 1.1Ma B. P., and influenced repeatedly by migration of the lithofacies belts of shifting sands, fixed and semi-fixed dunes, loess and soils, which have been caused by the climatic fluctuations of glacial and interglacial periods.

**KEY WORDS**: Ordos Desert; Yulin stratigraphical section; past 1.1Ma; grain-size composition; environment evolution

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## 1 INTRODUCTION

Ordos Desert is a general appellation of Qubqi Desert on the north, Hedong Sandy Land on the southwest and Mu Us Desert on the southeast (Fig. 1). It is situated on a transitional zone from arid desert steppe to semi-arid steppe between arid desert in North China and the semi-humid forest steppe (The Editing Committee of Chinese Physical Geography, Chinese Academy of Sciences, 1982), covering an area about 53 000km$^2$. Here, elevation is 1300m a. s. l. or so, the highest over 1700m, mean annual precipitation 250–450mm and aridity 1.6–2.8.

As early as the 1920s and 1930s, when surveying the Ordos geology, scholars at home and abroad had already taken notice of the desert existence in the past geological period. In 1924, TEILHARD *et al*. pointed out the aeolian sand underlying the HoloceneYangshao cultural layer (TEILHARD and LICENT, 1924). Afterward, TEILHARD and YOUNG published a bookmaking *Preliminary Observation on the Pre-loessic and Post-pontian Shansi and Northern Shensi*, in which they named a set of 10–20m thickness of sediment, similar to loess, with abundant sands as "Yulin Formation" of the Early Pleistocene, and looked upon the origin of the abundant sands as that of existence of the Ordos Desert at that time (TEILHARD and YOUNG , 1930). Unfor-

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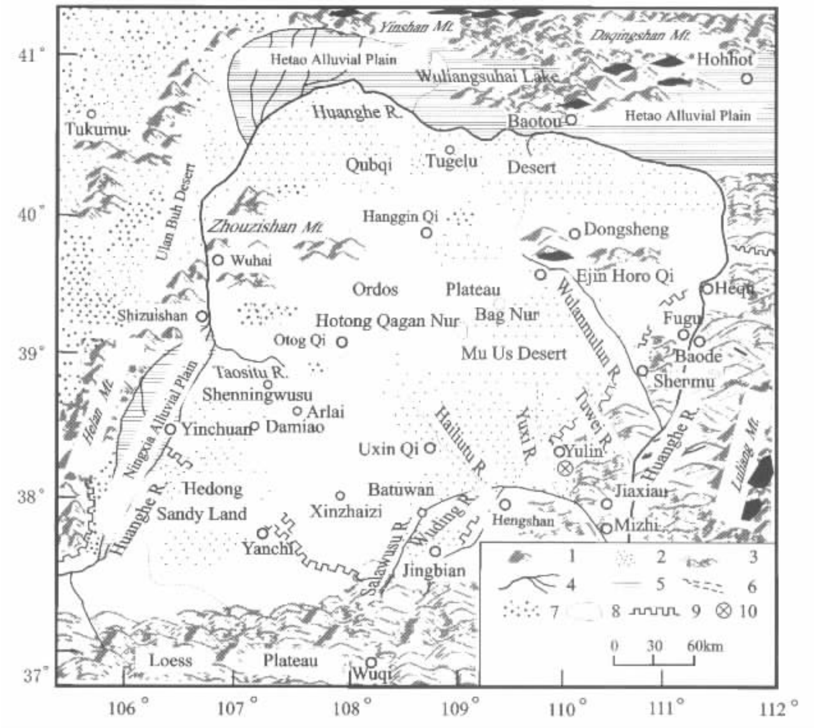



Legend: 1. mountains; 2. desert; 3. loess plateau and hill; 4. river; 5. alluvial-proluvial and lacustrine plain; 6. ephemeral river; 7. gobi; 8. lake; 9. the Great Wall; 10. location of Yulin section

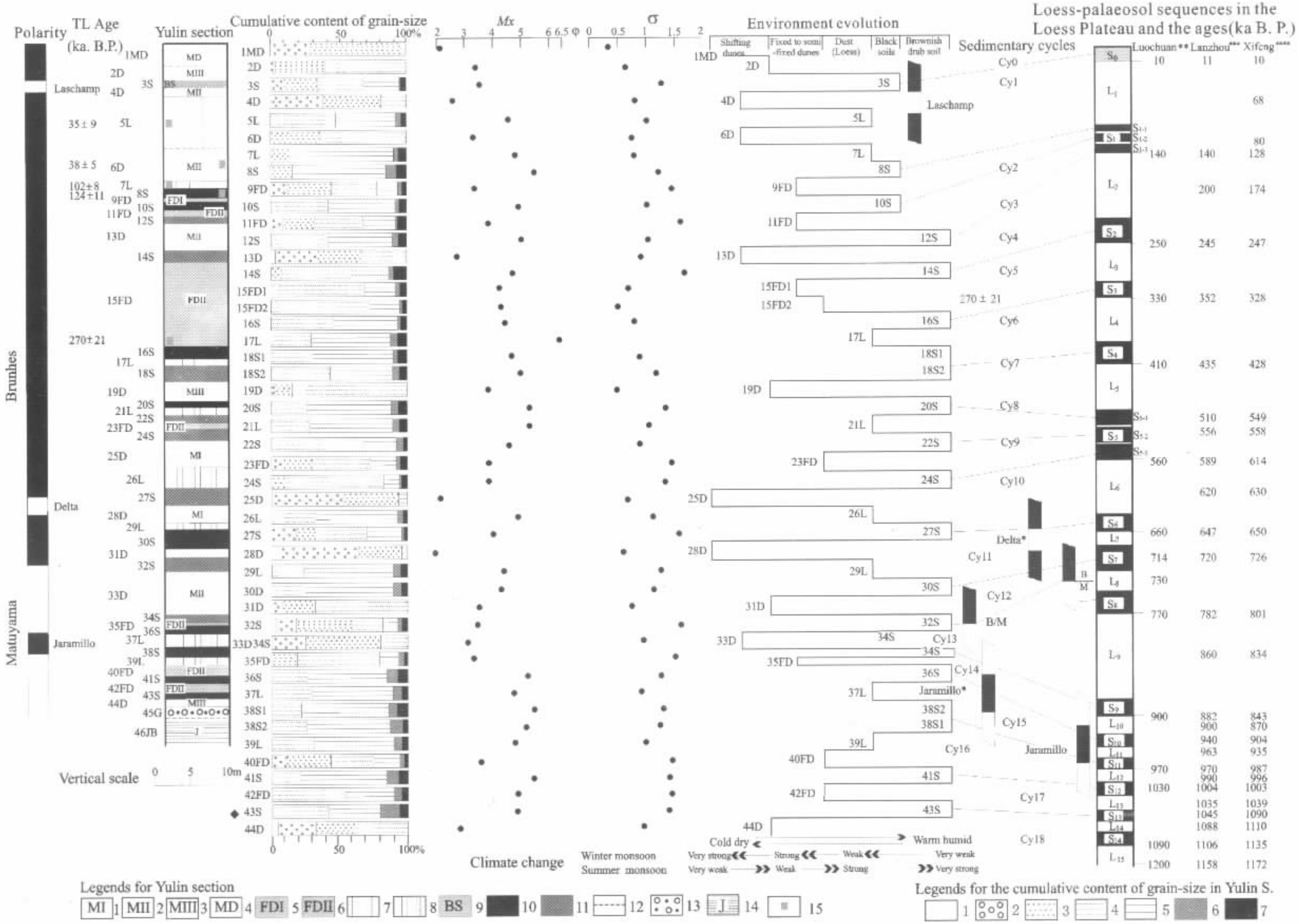
Fig.1 Map showing Ordos Plateau and the location of Yulin section

turenately, for a long time since then such a scientific judgment was unable to arouse adequate recognition. Therefore, some progresses on formation and evolution of Ordos Desert were acquired chiefly after the 1980s, such as subdivision on the desert sedimentary periods (DONG *et al*., 1983, 1985; LI *et al*., 1993), TL dating for aeolian sands (LI, 1983), environmental vicissitudes since 150ka B. P. (LI *et al*., 1998, 2000) and palaeomonsoon activities (LI *et al*., 2001). In the present paper, taking Yulin section stratigraphical sequences in the northern part of Shaanxi, China as a typical sedimentary record for Ordos Desert, some opinions on environmental evolution of the region in the past 1.1Ma have been put forward mainly according to the grain-size analysis results in the profile.

## 2 OVERVIEW OF YULIN SECTION

Yulin section (38°07′N, 109°32′E) is located on the southeastern margin of Mu Us (*Maowusu* in Chinese) Desert, Ordos Plateau, about 17km to the south of Yulin City in the northern Shaanxi Province, China (Fig. 2), and its elevation is roughly below 1200m a. s. l. It adds up to 100m or so in thickness and has 45 layers. Above the cemented gravel layer of the Early Pleistocene, there is a mutual superposition sequence consisting of 18 layers of sand, 8 layers of loess and 18 layers of palaeosols (Fig. 2). The 18 layers of palaeosols with their underlying layers of sand or loess have formed 18 depositional cycles. In several kilometers′ extension, transversely the aeolian sands sometimes have a facial change to loess and several layers of palaeosols amalgamate into one. The latter is very distinct in sequences of 8S–12S and 20S–24S in Yulin section, both of them contain 3 layers of brownish-drab palaeosols and aeolian sands or loess are interbedded in. Horizontally these become complex palaeosols severally. In addition, the brownish-drab palaeosols and black palaeosols as well as the fixed and semi-fixed dune sands all in different degrees contain plant root tissues, and the structure shapes of aeolian sand layers are obvious, such as distinct aeolian forest laminaes and accretion laminaes and the dishing pits on quartz surface formed by bump of storm, etc. (DONG *et al*., 1989).

Magnetostratigraphic mensuration of the section has been determined by LIU Chun and CAO Ju-xiu of the Palaeo-magnetostratigraphic Laboratories of Geology Research Institute, Chinese Academy of Sciences and Geography Department of Lanzhou University. The result shows that the boundary between Brunhes Normal Polarity Zone and Matuyama Reversal Polarity Zone lies in 28D in the section. Besides, by comparing with the




Legends for the section: 1. palaeo-mobile dune sands (medium grain sands); 2. palaeo-mobile dune sands (fine sands); 3. palaeo-mobile dune sands (very fine sands); 4. recent mobile dune; 5. palaeo-fixed and semi-fixed dune (fine sands); 6. palaeo-fixed and semi-fixed dune (very fine sands); 7. Malan Loess; 8. Lishi Loess; 9. black loam palaeosol; 10. silty brownish drab palaeosol; 11. sandy brownish drab palaeosol; 12. denudation plane; 13. cementation gravel layer; 14. Jurassic sand stone and shale; 15. sample of the thermoluminescene date

Legends for the cumulative content of grain size in the section: 1. coarse sands; 2. medium grain sands; 3. fine sands; 4. very fine sands; 5. coarse silt; 6. fine silt; 7. silt

Sources: * After the doctor's degree thesis by GAO Shang-yu, 1992: Preliminary study of the desert evolution on the northwest margin in the monsoon region of China, Geography Department of Lanzhou University, China; **,*** and **** respectively after CHEN Fa-hu *et al.*, 1993, LIU Tung-sheng *et al.*, 1987 and LIU Xiu-ming *et al.*, 1987

Fig. 2 Grain-size analytical result of Yulin section and the correlation with the loess-palaeosoil sedimentary sequences in Loess Plateau known loess-palaeosol sequence in Loess Plateau of China (LI *et al*., 2002), we have obtained stratigraphical ages in the profile (Fig. 2), showing that the age of first aeolian sand 44D is in geochronology equivalent to the layer about 1.1Ma B. P. (LIU *et al*., 1987; CHEN *et al*., 1993) in the Loess Plateau. Therefore, we may look upon the sequences laid above 45G as those deposited in the past 1.1Ma. Obviously, it is an ideal profile for the study on sedimentary environment changes in Ordos Desert, even whole sandy desert of China during long term of geological processes.

## 3 RESULTS

### 3.1 Results of Grain-size Analysis

Grain-size of the sediment in Yulin section was obtained by mesh analysis and pipette analysis. The method used to determine the particle grade is: the classifying of the decimal system for 1 to 0.1mm particles; and of loess in the middle reaches of the Huanghe (Yellow) River for the particles smaller than 0.1mm (WANG and BAO, 1964). Particle diameter is represented by its logaritm$\varphi$, and using calculative formulas to determine the averaging particle diameter and standard deviation are respectively $Mx=(\varphi16+\varphi50+\varphi84)/3$ and $\sigma=(\varphi84-\varphi16)/4+(\varphi95-\varphi5)/6.6$, which were established by FOLK and WARD in 1957 (FOLK and WARD, 1957 ). Results of the grain-size analysis of Yulin profile are shown in Fig. 2, Fig. 3 and Table 1.

### 3.2 Sedimentary facies

The comparison between Table 1 and Table 2 shows that the medium, fine and very fine sands and silty fine and silty very fine sands in the section are respectively similar to the grain-size composition of recent shifting dunes and fixed and semi-fixed dunes in the Ordos. Both the recent shifting dunes and the medium, fine and very fine sand layers in the section are composed exclusively of <4.32$\varphi$ gains, with distribution ranges being 1.94–3.39$\varphi$ and 1.83–3.75$\varphi$ in *Mx* respectively and 0.35–1.03 and 0.32–0.94 in $\sigma$ in turn. Among the recent fixed and semi-fixed dunes and the silty fine sand and silty very fine sand in the section < 4.32 $\Phi$sand grain is the highest in content, the silt of 4.32–7.64$\varphi$ subordinate and the clay of > 7.64$\varphi$ comparatively low, with distribution ranges being 2.76–3.81 $\Phi$and 3.28–4.22$\varphi$ in *Mx* respectively and 0.53–2.37 and 0.54–1.65 in $\sigma$ in turn. Such analytical result suggests that the sandy sediments were chiefly formed by wind action.

There is a considerable similarity in grain-size composition between loess of the section (Yulin Loess hereafter) and the known Pleistocene aeolian loess (WANG and BAO, 1964; GUO and LU, 1966) in Loess Plateau (Fig. 4). In these two, grains of 3.32–6.64$\varphi$ are the highest, and even more obvious is their similarity to the recent dust(MOLDVAY, 1962) and the first belt of aeolian Malan Loess in the middle reaches of the Huanghe River. As for the difference in grain-size formation, for example, a difference in the grain contents

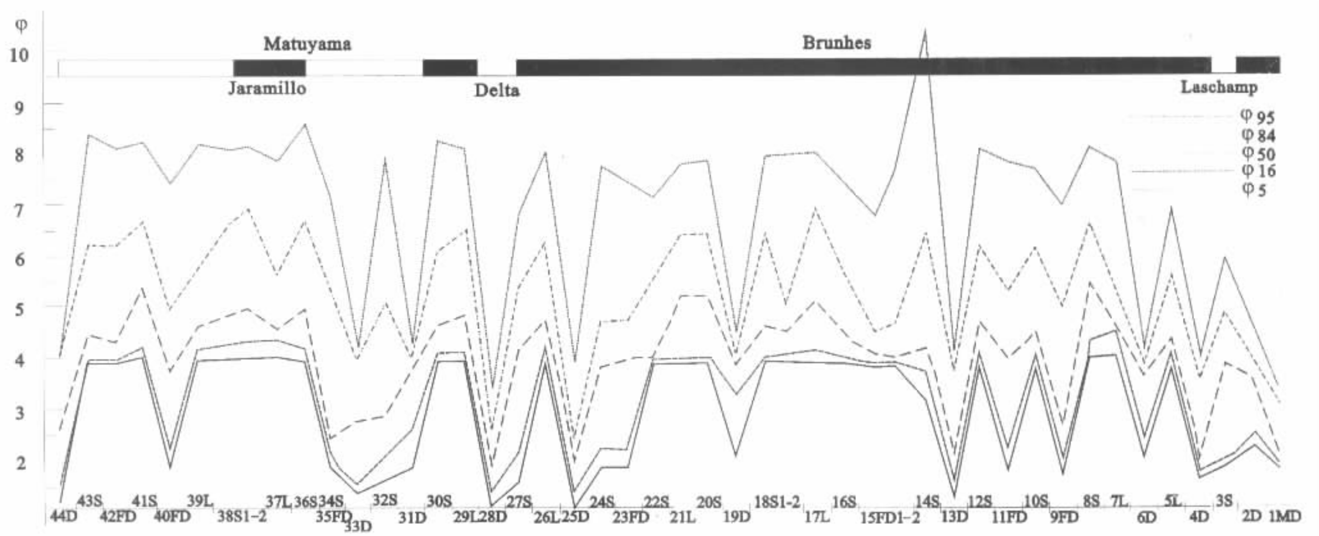



Fig. 3 Variations of the characteristics—φ95, φ84, φ50, φ16 and φ5 of grain-size in Yulin section

of >6.64$\varphi$, it might be caused by different bio-climatic zones in different areas during and after the loess sedimentary period, and hence we can attribute the Yulin Loess to the wind-derived losses.

The palaeosols in the profile can be classified as brownish-drab soil and black soil. Generally, there are clayized layers, illuvium of calcium carbonate and the parent layers composed of aeolian sand or loess. These palaeosol layers are, on the whole, roughly similar in main grain-size composition to their underlying aeolian sand

Table 1 Grain size variations of the different kinds of strata in the profile

| Sampling site | Grain size content of the sand dunes in Ordos Desert (%) | | | | | | | | Mx (Φ) | σ |
|---|---|---|---|---|---|---|---|---|---|---|
| | −1–0φ very coase sand | 0–1 Φ coase sand | 1–2 Φ medium size sand | 2–3.32 Φ fine sand | 3.32–4.32 Φ very fine sand | 4.32–6.64 Φ coase silt | 6.64–7.64 Φ fine silt | >7.64 Φ clay | | |
| Taostu River Valley of Otok Prefacture, shifting dune | 0.12 | 2.10 | 16.19 | 44.56 | 37.14 | – | – | | 3.36 | 0.62 |
| Around Sharlig Commune, Wushen Prefacture, shifting dune | – | 17.77 | 40.32 | 27.91 | 14.00 | – | – | – | 1.94 | 1.03 |
| Batuwan, Salawusu River valley, shifting dune | – | – | 2.46 | 33.58 | 63.96 | – | – | – | 3.39 | 0.56 |
| North of Chengchuan Commune, shifting dune | – | – | 0.99 | 92.60 | 6.38 | – | – | – | 2.50 | 0.35 |
| Northwest of Chabu Commune, Otok Prefacture, fixed to semi-fixed dune | – | 3.69 | 18.25 | 7.91 | 19.20 | 7.53 | 2.41 | 10.69 | 3.31 | 2.03 |
| Aobaoliang 13 of Chabu Commune, Otok Prefacture, fixed to semi-fixed dune | 0.18 | 2.08 | 9.09 | 32.64 | 38.12 | 11.20 | 0.56 | 6.41 | 3.32 | 1.90 |
| Around Maogaitu Commune, Otok Prefacture, fixed to semi-fixed dune | 1.89 | 12.25 | 15.07 | 28.00 | 33.60 | 2.03 | 0.28 | 8.40 | 2.94 | 2.17 |
| Erdaojie of Chengchuan Commune, Otok Prefacture, fixed to semi-fixed dune | – | – | 5.43 | 47.84 | 21.45 | 21.16 | 0.50 | 3.61 | 3.23 | 1.11 |
| Dishaogouwan, Salawusu River valley, fixed to semi-fixed dune | – | – | 1.72 | 78.51 | 16.95 | 0.38 | 0.04 | 2.39 | 2.76 | 0.58 |
| Around Yulin, fixed to semi-fixed dune | – | – | 0.95 | 37.75 | 50.23 | 5.16 | 0.54 | 5.36 | 3.42 | 1.48 |
| Around Chengguan Commune, Hengshan County, fixed to semi-fixed dune | – | – | – | 7.25 | 85.60 | 2.18 | 0.35 | 4.63 | 3.81 | 0.53 |

Table 2 Grain size variations of shifting sand dunes, fixed and semi-fixed sand dunes of the present period in the Ordos Plateau

| Lithofacies | 0–4.32φ sand | 4.32–6.64φ coase silt | 6.64–7.64 Φ fine silt | >7.64 Φ clay | Mx(Φ) | σ |
|---|---|---|---|---|---|---|
| Medium size sand to very fine sand layers | 100–100 | – | – | – | 1.83–3.75 | 0.32–0.94 |
| Silty fine and very fine sand layers | 51.07–81.00 | 15.66–37.37 | 0.33–4.76 | 3.34–6.80 | 3.28–4.22 | 0.54–0.94 |
| Loess | 14.88–48.14 | 45.60–76.13 | 2.73–6.87 | 3.43–6.80 | 4.51–5.34 | 0.80–2.07 |
| Sandy palaeosols | 58.83–81.87 | 10.67–28.13 | 0.13–6.27 | 2.20–11.04 | 3.20–4.76 | 0.91–1.75 |
| Silty palaeosols | 17.80–46.60 | 44.20–67.30 | 2.13–8.37 | 4.10–8.29 | 4.36–5.37 | 0.80–1.46 |

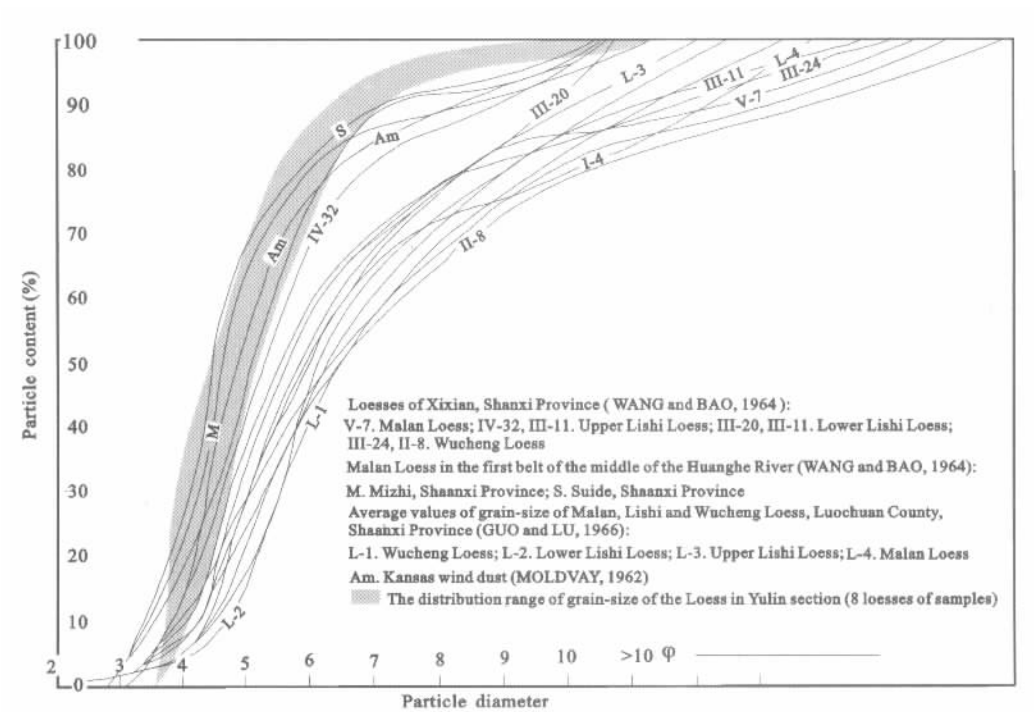



Fig. 4 Grain-size distribution curves of the aeolian loess in Shaanxi and Shanxi and of present period dust and Yulin Loess

or loess, except that their $Mx$ φ value and clay contents are comparatively higher and their sorting degree becomes lower, indicating that they have developed on the parent layers of aeolian sand or loess.

According to the standard for division laid down by FOLK and WARD (1957), only a few of different sedimentary facies in the secyion are well sorted or poorly sorted as indicated by σ, and generally, their sorting degrees vary from medium to poor ( σ 0.5–0.2 ). Without considering the sorting of some isolated loess, the layers of aeolian medium sand, fine sand and very fine sand are, comparatively speaking, very well sorted, while the sandy palaeosols are poorly sorted, and sorting degree of the other facies varies approximately in between these two groups.

### 3.3 Palaeoclimate

The difference of the grain-size composition in aeolian sand, loess and palaeosol indicates that the climates and circumstances when they formed were different. Studies of palaeoclimate records preserved in the Quaternary layers of the Ordos suggest that the climatic fluctuations during the glacial and interglacial are not only the main cause of the advancing and receding of glaciers, the developing and melting of permafrost and the rising and falling of sea level, but also that of the expansion and retreat of the desert and the deposition of loess as well as its interruption (DONG *et al*., 1992).

Analysis on the movement of the present wind-drift sand and dust in Ordos and the southeastward also shows that intense movement of wind-drift sand and dust are mainly related to the dry, cold winter monsoon (northwest wind system), which caused by the increasing intensity of the Mongolia High Pressure in winter and spring. That movement of wind-drift sand and dust has a tendency to stop due to active running water, and flourishing vegetation is mainly related to the precipitation coming with the summer monsoon (southeast wind system) caused by increasingly active oceanic air mass in summer and autumn.

It is thus obvious that the difference in grain-size composition of the aeolian sand, loess and palaeosol in the section is chiefly related to the intensity of the Mongolia High Pressure and the dominance of oceanic air mass during glacial and interglacial ages. During the glacial, the stronger the Mongolia High Pressure, the stronger the winter monsoon, and the lower the air humidity and temperature, and thus there was less precipitation, and meanwhile, vegetation was sparse and withered. The intense action of frequent winter monsoon is advantageous to the deposition of shifting sand, thereby forming strata of the medium sand, fine sand and very fine sand. As the Mongolia High Pressure became relatively weak, the winter monsoon reduced relatively, and the humidity, temperature and precipitation also increased relatively, which provided good conditions for the growth of some herb and bushes. Dry cold winter monsoon under this circumstance was advantageous for fixation and semi-fixation of dunes, the deposition of wind dust, and the formation of a strata of silty fine sand and silty very fine sand. If this kind of climatic condition continued for a considerable period, it would be possible for more herbs and bushes to grow and there would be more wind dust sediment and thus the loess strata would be formed.

On the other hand, when the activities of oceanic air mass strengthened in the interglacial ages, increasing temperature and precipitation brought by the summer monsoon would greatly weaken the activities of wind drifted-sand and dust, and would be beneficial to the growth of various plants, to soil-formation process, and thereby to formation of the brownish-drab soil and black soil. It is obvious that the climatic condition for forming the brownish-drab soil is warmer and more humid than that for forming black soil. And the difference in the grain-size formation of palaeosols indicates that they have developed from different parent materials—sandy palaeosol from aeolian sand, but silty palaeosol from loess.

Because the primary grain of the palaeosols is aeolian, $Mx$ φ value and clay content of the palaeosol are greater than those of the underlying sand and loess. At the same time, σ value also shows an increase change, which is determined by four characteristic parameters—φ95 and Φ5, Φ84 and Φ16, with the result that, on account of pedogenesis, the sum of the differences of the two σs will be naturally greater than that of the underlying sand or loess, and thus the sorting of the palaeosol will be comparatively poor (Fig. 3).

Change in the palaeosol in comparison with underlying sand or loess may indicate that during their deposition process, the winter monsoon changed from strong to weak, and that the action of biogenic and chemical weathering under a warm, humid climatic condition is more stronger than that under a dry, cold climatic condition.

Because sand and loess are aeolian, sand, silty sand and loess can reflect that average condition of wind forces were different as mentioned above, and in addition, size of the grain in each of them can also reflect different wind forces. The experiment of MOLDVAY (1962) demonstrated that coarse silt of 4.32–6.64φ can drift easily in the air, and drifting ability of the grains of less than 4.32φ will be lower and lower as their grain-size becomes coarser and their transportation coefficient smaller. The content of easily drifting grains in Yulin Loess is higher than all other grades of grain and grains of 3.64–4.32φ have low drifting ability, and the content of them varies greatly, from 48% to 15%. Apparently, the percentage of easily drifting grains and grains of low drifting ability will increase or decrease respectively as the wind force decreases.

So, although Yulin Loess was deposited under a dry, cold climate with a weak wind, there were variations in wind force when the wind dust was deposited as reflected by the variations in percentages of easily drifting grains and grains of low drifting ability. In the silty sand layers formed by fixed and semi-fixed dunes, the contents of grains of less than 4.32φ (including grains of low drifting ability) are 51%–78%, and the contents of easily drifting ones, 16%–37%. Thus, we can conclude that higher content of the former indicates a stronger wind, and that of the latter indicates a weak wind. If there is no easily drifting grain in a sand layer, it means the wind force, on the whole, was stronger. But if *Mx* or *Md* (median) is medium sand, or fine sand or very fine sand, the coexistence of coarse and fine grains indicates that the wind force also had some changes when shifting sands were deposited.

## 4 EVOLUTION OF ENVIRONMENT IN PAST 1.1 MA

Based on the above discussion, the climatic and environmental change in Ordos Desert in the past 1.1Ma indicated by Yulin section is shown in Fig. 2.

It is obvious from Fig. 2 that from the 43D, 1.1Ma B. P. to present Ordos Desert has alternately undergone 11 stages of extremely dry-cold shifting dunes, 7 stages of dry-cold fixed and semi-fixed dunes, 8 stages of dry-cold aeolian dust sediment, and 18 stages of soil formation (15 stages of brownish-drab soil formation under a warm-humid climatic condition and 3 stages of black soil formation under a temperate-humid condition). Following conclusion were drawn:

(1) The aeolian sand of the Ordos had existed at least in the time about 1.1Ma B. P., up to now, it has undergone a series of alternative processes of shifting sands, fixed and semi-fixed dunes and soil formation. The present desertification in the region is only a latest episode in a long-term evolutionary course of the wind-drift sand and dust activities under dry-cold climate condition and pedogenesis process under warm-humid condition.

(2) Since 1.1Ma B.P., this region has been in the transitional zone between the Mongolia High Pressure and the southeast summer monsoon. It has been repeatedly influenced by movements of the petrographical facies zones caused by climatic fluctuation during glacial and interglacial periods. It is well known that loess is mainly the sediment of wind dust on the southeastern border of the desert; shifting sand is the typical sediment of the desert environment in the northwestern part of this region; and fixed and semi-fixed dunes are often found in areas between a shifting sand zone and the sedimentary zone of wind dust. During glacial age, when the Mongolia High Pressure moved southward and climate became extremely dry and cold with a strong winter monsoon, this region would have shifting sand sediments, shifting sand, fixed and semi-fixed dunes, and the boundary line between the latter and wind dust sediment would certainly shift southeastward into the loess area. On the other hand, when the climate became less cold and dry and the winter monsoon decreased, the boundary line would certainly move northwestward to the shifting sand area. During interglacial ages when the oceanic air mass became more active and penetrated further to the north, here climate became warmer and more humid, the vegetation became denser, and thus the processes of aeolian accumulation and aeolian erosion would be replaced by the processes of running water and soil formation, and sandy palaeosol and silt palaeosol (loess palaeosol) would develop at least in the area，extending from the southeast of the loess area to the northwest of the Ordos, which would force all the petrographical facies zones of shifting sand, fixed and semi-fixed dunes, and wind dust farther to move to the northwest. It was climate fluctuation that caused the horizontal movement of different petrographical facies zones. The winter monsoon-force of Ordos Desert situated farther north was stronger than that when loess in the Loess Plateau was accumulated, even in the period when the sedimentary boundary line of wind dust was moving northwestward. This is why the frequency of the grains of 4–5φ is lower than that of 5–6φ in the Loess Plateau, but in the Yulin Loess, the frequency of 4–5φ grains is higher than that of 5–6φ (GUO and LU, 1966).

On the basis of the above discussion, it can be concluded that the vast area from the northwestern margin of the first Malan Loess belt in the middle reaches of the Huanghe River to the Ordos has been a transitional zone of wind-drift sand and wind dust sediment since ca. 1.1Ma B. P. And thus, they were distributed alternately with palaeosols both horizontally and vertically in the section. The fact that aeolian sand has appeared many times in the grain size composition of Yulin section has also provided an absolute petrologic proof for the argument that China's loess is at least partly from the Ordos desert (LIU, 1985).

(3) The fact that the number of layers of aeolian sand in Yulin profile, especially since the Late Pleistocene, increases upward indicates that climate of the region has been getting drier and colder. This may be caused by increasingly strong atmospheric circulation as a result of the uplift of the Qinghai-Tibet Plateau (LI *et al*., 1979) since the Pleistocene.

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