Climatic Change (2009) 93:55–67
DOI 10.1007/s10584-008-9541-7

Environmental significance of RSL in ancient city wall: historical desertification of Ordos Plateau, Northern China

Yinzhou Huang · Nai-ang Wang · Tonghui He · Hongyi Chen · Wenyong Feng · Hao Long

Received: 15 December 2006 / Accepted: 27 October 2008 / Published online: 5 February 2009
© Springer Science + Business Media B.V. 2009

Abstract Scholars in China have long debated whether the desertification during the past two millennia of the Ordos Plateau was caused primarily by climatic or anthropogenic factors. Focusing on the ancient cities of the Ordos Plateau, and especially on the discovery of Rammed Sand Layer (RSL) in the city wall which proved to be from sand dunes by grain size and scan electron microscope analysis, this study combined the use of historical records and methods of environmental archaeology to clarify the history of the deserts on the Ordos Plateau. The results indicated that some of the ancient cities were built originally in the desert, thus failing to represent a good condition of landscape. Therefore, abandonment of these cities cannot be simply attributed to anthropogenic desertification.

http://ir.isl.ac.cn

1 Introduction

The transitional zone between the agriculture and animal husbandry in northern China is a hypersensitive ecotone that can be easily altered by climate and human activities. Stratigraphical sections of earlier studies showed that the desert had ebbed and flowed many times since the quaternary in such regions (Dong et al. 1983; Li et al. 1993). However, the geologic sediment is insufficient to reflect desert change of past

Y. Huang (✉) · N.-a. Wang · T. He · H. Chen · W. Feng · H. Long
College of Earth and Environmental Sciences, Lanzhou University, Lanzhou, 730000, China
e-mail: huangyinzhou@yahoo.com.cn

T. He
College of Resource and Environment, Ningxia University, Yinchuan, 750021, China

W. Feng
Department of Geography, Xinzhou Teachers University, Xinzhou, 034000, China

H. Long
Qinghai Institute of Salt Lakes, Chinese Academy of Sciences, Xining, 810000, China

two millennia because there are not any high resolution sedimentary profile reported. Currently, as well as in other countries (Pickup 1998), two extreme viewpoints about the causation of desert change exist. One is human-induced, stating that desert expansion springs from unreasonable human cultivation since the Qin and Han dynasty (Shi 1980; Sun and Ding 1998), or the Tang dynasty (Ai 2004) or the Ming and Qing dynasty (Yan 1954; Gu 2003). The other is climate-induced, claiming that human activities exert little influences on landscape in history stands (Zhao 1981; Wang 1983; Niu and Zhao 2000; Hou et al. 2001; Wang et al. 2006). Moreover, the boundary of the Mu Us desert in history is also in controversy. Han (2003) pointed out that the Ming Great Wall formed the division between grassland and sandy land in the Ming dynasty while Deng et al. (2007) presented his result that the range of the desert changed little in history. Considering the low resolution of stratigraphical evidences and contradiction of textual records, further study should be undertaken to provide more convincing evidences. In our investigation, multidisciplinary methods are employed to study the process of historical desertification of the Ordos Plateau and the result would shed new insight on this issue.

2 Study area

The Ordos Plateau is located in Inner Mongolia, North China (from 106° E to 109° E and 36°30′ N to 41°30′ N), and is surrounded by the Yellow River to the north, east and west, and on the south is adjacent to the Loess plateau. There are three deserts over the Ordos Plateau, namely the Hobq Desert in the north, the Mu Us Desert in the south and the Hedong Sandland to the east of the Yellow River, southwest of the Mu Us Desert (Fig. 1). Administratively, it falls under the jurisdiction of Ordos County, Inner Mongolia, and Yulin County, Shaanxi. Climatically, the area is dry and windy. Mean annual rainfall is 160 mm in the west and 400 mm in the east, with 60–80% of rain falling in summer. The strongest wind velocity ranges from 18 to 28 m/s with the average wind velocity from 2.0 to 4.3 m/s. Strong winds blow about 30 days/year, resulting in serious wind erosion.

Population density is highly differentiated in this region. In 1989, the average density was 13.5 people per square kilometer, with only 1.4 in the west Otog steppe desert and 148 along the Yellow River north of the Dalad banner. Vegetation varies with climate, land-surface materials and landforms. From east to west, the vegetation proceeds from steppe to steppe desert. Vast areas of the Mu Us Sandland and Hobq Desert, except for their exposed sand, are covered with azonal sandy steppe on sand dunes, *Salix* shrub in interdune locals, and meadow in valleys. According to a 1992 UNESCO report, the Ordos plateau is one of the nine environmentally most sensitive regions in the world (Jeanne et al. 1995).

There are many ancient cities scattering in the desert on the Ordos plateau, ranging in date from the Qin through the Qing dynasties, and varying greatly. Some of these cities still remain in an excellent state of preservation, with city walls intact, while others can only be recognized from fragments of pottery or clayware on the surface. Some cities were built on hills, others beside rivers. Some were constructed for trade, others as military outposts and garrisons. However, they are all surrounded by dunes now. The reasons for the abandonment of them are drastically discussed by Chinese scholars.

http://lir.nsl.ac.cn

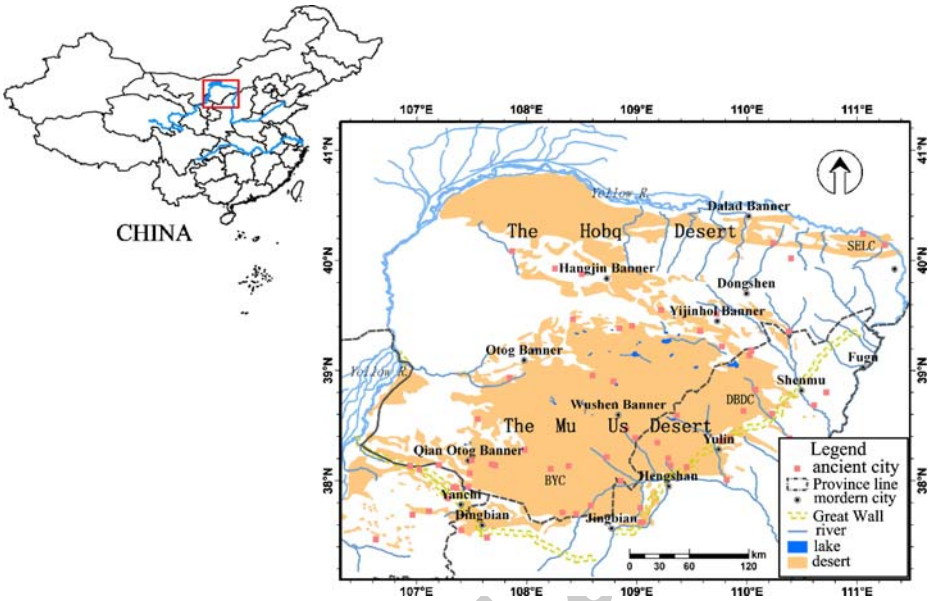

Fig. 1 Location of the Ordos Plateau

http://ir.isl.ac

3 RSL in city wall

3.1 Description and sampling

Three ancient cities which are typical of RSL were selected to investigate historic desertification of the Ordos Plateau, namely Shi'er Lian city (SELC), Dabaodang city (DBDC) and Bayanhurih city (BYC).

With its north side on the first terrace of the Yellow river, the SELC is located in Zhunger banner, Inner Mongolia, which is in the Hobq Desert (Kubuqi desert, Fig. 1). Though most of Shi'er Lian is now inhabited and cultivated, areas to the east and south of the city are surrounded by stable and semi-stable dunes. The rammed layers of the north part of city wall are apparent, and the structure of alternating RSL (Rammed Sand Layer) and REL (Rammed Earth Layer) is so clear that it can be seen from a distance (Fig. 2). The color of the RSL is buff and the thickness is between 5 and 8 cm while the color of REL is lark and the thickness is between 8 and 13 cm. Thirty-four samples tagged as SEL01–SEL34 were collected. SEL01 to SEL12 were collected from the sand dune beneath the city wall with every 10 cm a sample, and other samples were collected from the rammed layers with each rammed layer a sample.

The DBDC lies at the southeast margin of Mu Us Sandland, which administratively belongs to Dabaodang town, Shenmu County, Shaanxi Province. A small river called Yeji River, branch of the Wuding (or Salawusu) River, divides the city into two parts. About ten houses are scattered in and around the site. None of the city wall is exposed, though fragments of ancient clayware or pottery are seen on the surface.

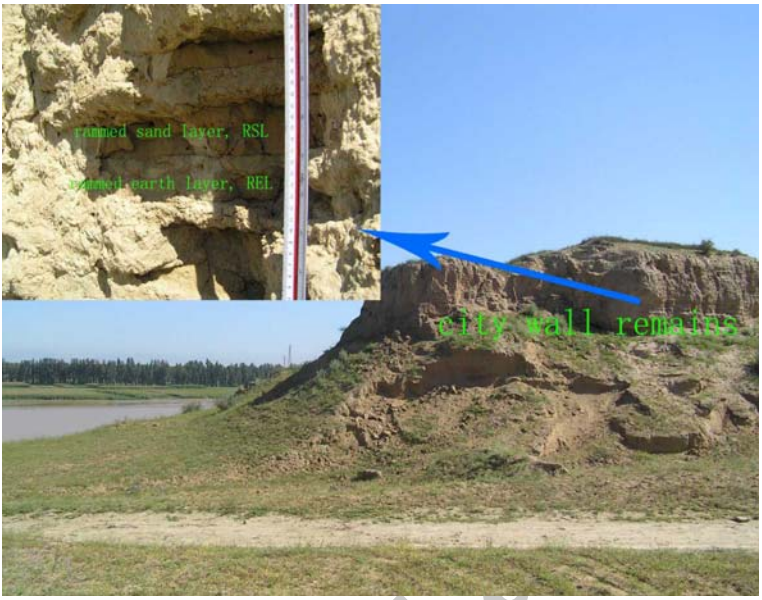

Fig. 2 The RSL in city wall of SELC

A section of the city wall had been excavated by archaeologists, who clearly marked the alternate rammed layers. A thinner layer of sand is clearly distinguished between every two REL. The REL is 8–12 cm, between which the RSL is 2–4 cm (Fig. 3). Ten samples were collected, with each layer a sample.

The BY city lies at the southwest of the Mu US Sandland, about 20 km away from Angsu town, Etuoke frontier banner, Inner Mongolia. According to ancient pottery fragments and clayware on the surface, the site was inhabited from the Tang to the Song dynasty. Its wall is preserved relatively well. The site is surrounded by stable and semi-stable dunes but, because of obstruction of the city wall to the wind, its north wall is covered with mobile dunes (Fig. 4). Four samples were collected from the city wall. The chief difference of BYC from SELC and DBDC is that the city wall of the former has no obvious RSL but is rammed with approximately 75% of fine sand.

3.2 Methodology

Grain size analysis and scanning electron microscope analysis were employed. The grain size was examined by a Malvern mastersizer 2000 laser diffraction particle size analyzer in the Key Laboratory of Western China's Environmental Systems (Ministry of Education), Lanzhou University, and calculated using the method of Folk and Ward (1957). The scanning electron microscope (SEM) experiment was carried out in Lanzhou Institute of Chemical Physics, Chinese Academy of Sciences with JSM-5600LV Vacuum Scanning Electron Microscope.

Fig. 3 The RSL in the city wall of DBDC

3.3 Results

3.3.1 Grain size analysis

Statistically, the size distribution of a transported grain population followed a natural distribution for a given transport medium and transport process (Ashley 1978; Bagnold and Bamdorff-Nielsen 1980). The frequency curves of the grain size of the RSL from the three city walls were shown in Fig. 5 and they all presented a bimodal asymmetrical distribution with a coarse and a fine component (Fig. 5, RSL).

Fig. 4 City wall remains of the BYC

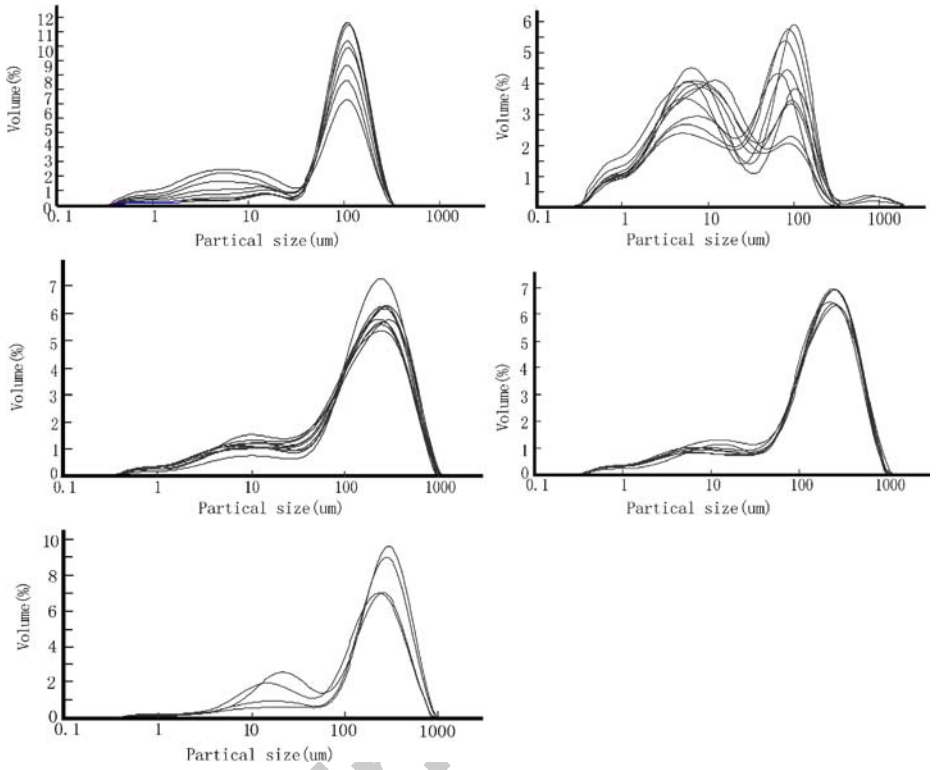

Fig. 5 Frequency curves of the grain size distribution of the sample from the city wall. The *left* part which is marked with RSL represents the sample from the RSL and the *right* from the REL

The coarse component indicated that the mode size of the sand ranged between 100 and 280 μm, which could be considered fine sand. The average content of sand (>63 μm) was 78.5%, 77.5%, 78.4% in SELC, DBDC and BYC, respectively. The fine component varied between 5 and 20 μm, belonging to fine silt and very fine silt. The average content of silt (2–63 μm) was overall about 20% and its average was 19.761% in SELC, 21.3% in DBDC, and 20.3% in BYC. The average content of clay (<2 μm) was very low in all the samples: 1.8% in SELC, 0.2% in DBDC and 1.3% in BYC. Additionally, the valley between the fine and the coarse component presented a low content of silt between 20 and 60 μm.

The frequency curves of the REL from the SELC exhibited a polymodal distribution which was of great difference from that of the RSL (Fig. 5, REL). Such result was consistent with our eyes judgment. However, those of the REL from the DBDC displayed a bimodal distribution with a coarse and fine component, but its fine component had a higher content than that of the RSL from the DBDC.

It is generally agreed that the frequency curve of grain size from Aeolian sand shows a bimodal distribution with a coarse and a fine component (Sun et al. 2004; Long et al. 2007). Our results obtained from present sand dunes also supported this view (Fig. 6). The frequency curve of the grain size distribution of the samples from present dunes is similar in shape to that of the samples from the RSL. By

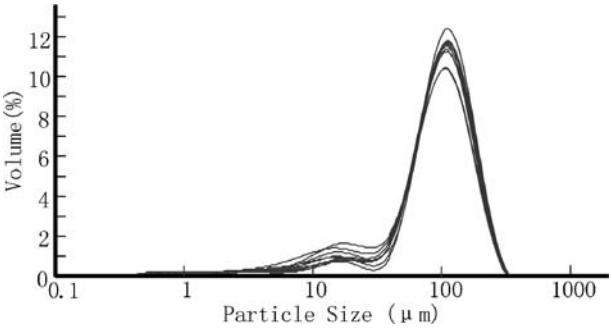

Fig. 6 Frequency curves of the grain size distribution of the sample from the modern-day dunes

combining the result of comparison of kurtosis and skewness of the two types of sample (Table 1), it can be inferred that the sand in the city wall is aeolian.

3.3.2 The SEM analysis

The SEM micrographs of the sand grains from the RSL were shown in Fig. 7. They were selected to explore the origin of the sand in the RSL. The results indicated that the sand grains had rounded outline and relative smooth surface (Fig. 7a, b, c, e, f, h, i, j and k) with dish-shaped and V-shaped percussion pits (Fig. 7c, e, f, h, i and j). Many samples contained upturned cleavage plates (Fig. 7b, d, g and h) and some of them were rounded (Fig. 7h). Other particles showed subrounded properties and abraded edges (Fig. 7a, c, g and k). Silica precipitated (Fig. 7e) in the depression and conchoidal fractures (Fig. 7l) were observed in most of the samples.

Since 1962, electron micrographs of sand grains have been studied with increasing interest and in a variety of problems (Fitzpatrick and Summerson 1971). As far as aeolian grain is concerned, the grains would experience the circulation between edge abrasion and precipitation, which corresponds with leaping and resting of the grain (David and John 1973). Therefore, Aeolian sand grains always have rounded edges, smooth surface and rounded outline with dish- and v-shaped collision pits on the surface (Xie 1984). Moreover, silica precipitation and solution synchronously take place with chemical and mechanical functions when the sand grains deposit. In all, surface textures discussed above can to some extent represent the features of Aeolian sand grains. Hence we can arrive at the conclusion that the sand in the RSL is formed by wind rather than by water flowing.

http://www.ibcas.ac.cn

Table 1 Kurtosis and skewness of RSL and modern sand dune's grain size

Parameters	SELC	Present dunes around SELC	BYC	Present dunes around BYC	DBDC	Present dunes around DBDC
Skewness	−0.466	−0.330	−0.468	−0.442	−0.453	−0.432
Kurtosis	1.021	1.119	0.885	1.011	1.098	1.050

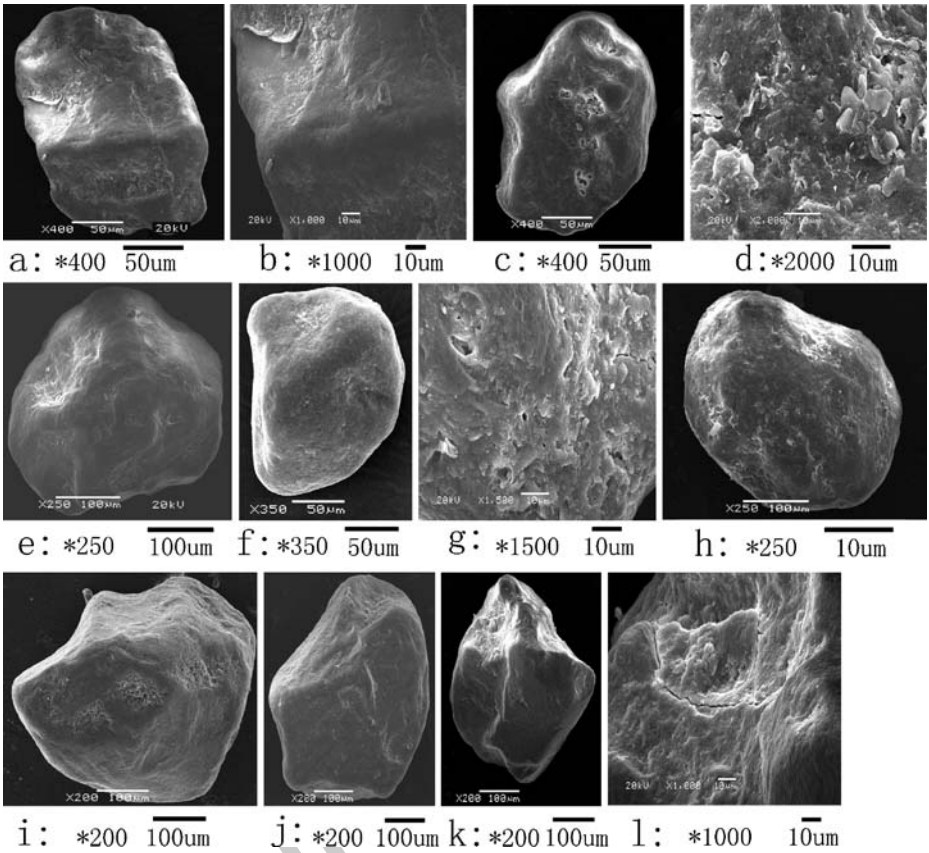

Fig. 7 Selected SEM micrographs of the sand grains from the RSL. **a**–**d** are from the RSL of the SELC, **e**–**h** the BYC and **i**–**l** the DBDC. **b** is an enlarged micrograph of **a**, **d** of **c**, **g** of **f** and **l** of **k**

http://

4 Source of the sand

Earlier studies have demonstrated that there are antique aeolian sands underground (Dong et al. 1983, 1997) which might be the source for the RSL. However, as few sections of past two millennia are reported, it needs to be further studied. Here in the following are evidences which can contribute to our understanding of the problem.

4.1 Dunes beneath the SEL city wall

As shown in Fig. 2, the city wall of the SELC is directly built on a sand dune. Thirty-four samples were collected in the SELC in which 12 samples were collected from the sand dune beneath the city wall. The grain size result (Fig. 8) showed that these 12 samples had a high content of sand which was similar to that of the RSL, therefore indicating that the city wall was built on the sand dune, and that the sand in the city wall was from the surface in and around the city.

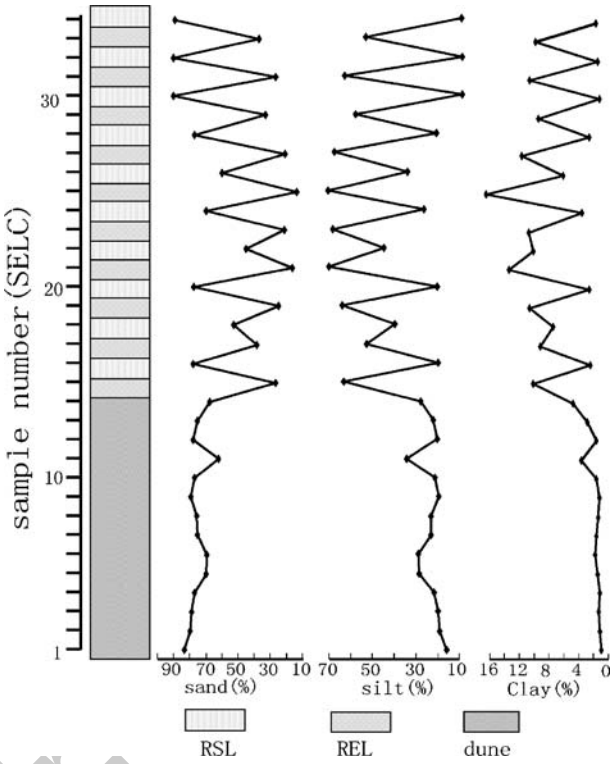

Fig. 8 Variation of content of the clay, silt and sand. The *lower* part, with sample number ranges from SEL01 to SEL12, represents the sample from sand dunes beneath the city wall of SELC

http://ir.

4.2 Environmental archaeological evidence

A Neolithic site profile, 4 km southeast of the DBDC, would promise to enhance our understanding of the problem. According to its archaeological report (Archaeology Institute of Shaanxi Province 2005), the site was used from the Longshan period (3,000–2,000 BC) to the Xia dynasty (2,070–1,600 BC). The Neolithic cultural remains overlaid on a sand dune and are covered with sand. Regardless of whether the site was abandoned due to abrupt climate change at about 4,000 a BP (An et al. 2004; Wang et al. 2004) or not, the sand overlying the Neolithic cultural remains can not be attributed to anthropogenic factors because limited human activities at that time have little impact on the environment. Xue et al. (2005) studied the animal bones in the Neolithic cultural remains and pointed out that, deer, roes, antelopes, as well as sheep which adapted to grassland lived around the site when the Xia people lived there. He also pointed out that the antelope is a kind of *G. subgtturosa* which used to be in desert. Xue's results suggested that dunes had existed at least before the Xia period (2,070–1,600 BC) and the ancients lived between sand dunes. Therefore, sand in the city wall of DBDC is from the surface.

4.3 Sand in the tomb passage

Aeolian sand discovered in the tomb passage of the Han tomb near the DBDC (Wang 2002) offered evidence that aeolian sand in city wall is from the surface. In old

times of China, especially in the Han dynasty, the corpse was buried underground with depth of 8–10 m. People first dug a sloping passage (tomb passage), then at the end of the passage constructed a grave, in which the coffin was put. After the coffin was put in the grave, people stuffed the tomb passage. Generally, the stuffing materials are partially from the earth which was previously dug out and others are from the ground in the vicinity. We found that there is much sand stuffed in the tomb passage. The sand, which is different from the paleosol (Malan loess) of passage wall in color and grain size, represented that sand dune had been there in people's livelihood in the Han period, which explained why sand was used to fortify the city wall.

5 Environmental significance of the RSL

In Chinese history, the Ordos plateau is a transitional region where wars frequently took place between Han people and the nomad. When Han people controlled the place, they built forts for defense and then Han people immigrated into the region, therefore the existence of the sand dunes before the city can not be attributed to Han people's cultivation. According to the study of its cause of formation and source analysis, the appearance of the RSL in the city wall demonstrates that the deserts have been already there before the cultivation, which proves that human activities do not trigger the desertification. Additionally, considering that the SELC was set in the Han dynasty but kept in use from the Han through the Ming dynasty, that the DBDC is a Han city and that the BYC a Tang city, we can infer that cultivation by Han people in the Han dynasty and that the Tang dynasty contribute little to the process of desertification.

6 Textual evidence of historical desertification

There are numbers of ancient books in China that give descriptions of landscapes of regional geography. Many historical documents, rather than recording desertification *per se*, provide indirect evidence to the desertification study. The volume of *He Shui* (the Yellow River) in the *Shuijing Zhu* records: "There are sand dunes standing at the south of Anyang city (an ancient city built in the Han dynasty, at the north side of the Yellow River. It can be seen in the atlas of the Chinese historical geography, edited by TAN Qixiang), Bei River and Nan River (the Yellow River), and no mountains. Therefore, the book *Guang Zhi* (a geographical text written prior to the *Shuijing Zhu*) recorded that 'seven belts of drifting sand dunes, which were peerless to other hills, stand to the north of Shuofang city'." This record indicates that the Hobq desert was at the north of Shuofang city in the Han dynasty and was covered with drifting dunes. *Shuijing Zhu* also includes references to the Mu Us and Hedong Sandland. According to the interpretation of Shaling in a Chinese ancient dictionary *Shuowen Jiezi*, the Shaling through which the Hei River flowed, a branch of the Sheyan River (the Wuding River at present), and the Zhuci River (the Nalin River at present), both in the south of the Mu Us desert, must have been covered in huge sand dunes. These textual records indicate desertification from the Han to the Northern Wei dynasty. Moreover, there is an event recorded in the *Biography Of Diao Yong* (a general in the Wei dynasty) in *Wei Shu* giving us indirect information

http://irsl.gig.cn

of desertification. In 446 AD, the North-Wei government ordered the officials of Bogulv town (Lingwu County, Ningxia at present), after a fruitful harvest, to send 50 million liters of food from Gaoping, Anding, Tongwan and Bogulv town to Woye Town (now in the region of Linhe County, Inner Mongolia) where food was in short supply. Woye town, as well as Bogulv Town, is at the east side of the Yellow River. The troops had to deliver the food by river because of the sand dunes on land. This event shows that the sandy land in Hedong was extensive enough in the early North-Wei dynasty to impede the passage of carriages.

By the Tang dynasty, the desert in the south of the Ordos plateau was a threat to the daily life of inhabitants. The *Wu Xingzhi* section in the *New Tangshu* records: "In the second year of the Changqing era (822 A.D.), wind blew strongly in Xiazhou (Now Tongwan city in the south of the Mu Us desert), sand accumulated and formed into sand dunes as high as the city wall". The geography section of the same history cited the diary of Tang dynasty geographer Jia Dan, *From Bianzhou To Siyi*, in which he described the Mu Us desert surrounding the Baligan Lake (an ancient lake in the Mu US desert) and the Hehugan Spring (an ancient spring in Hangjin banner) to the south of Hobq Desert. By the fifth year of the Chunhua era (994 AD), the Tongwan city, capital of the Xiazhou, which had been originally built in 413 AD as the capital of Daxia by its emperor Helianbobo, had to be abandoned because it was besieged by the desert and frequently harried by robbers. Moreover, verses in Li Yi's (748–829 AD) *Song of Liuhu Barbarians for Passengers on the Tongwan City Wall* (*Liuhu* represents the six tribes of nomads who capitulated to the Tang government at the beginning of the Tang dynasty and were then relocated to the southwest margin of the Ordos Plateau) read: 'among dunes horses grazing, lonely swallow flying by', 'strong Wind blowing, in eyes sands coming, passengers lost'. The poetry was written on the city wall of Tongwan city, probably depicting contemporary reality, another image of the desertification of the region in the Tang dynasty. Overall, based on the descriptions in various histories and poems, the sandy desertification in the Ordos Plateau in the Tang was already serious. Therefore, the ancient textual evidence reveals the environmental significance of the RSL, which, conversely, corroborate the historical records.

http://iglas.cn

7 Conclusion

Understanding the problem of historical desertification of the Ordos Plateau is an interdisciplinary objective, requiring analytical techniques and collation of historical literatures. With respect to the understanding of this problem in the ancient cities on the plateau context, our focus on the RSL, archaeological excavation and historical literature has enabled us, to some extent, to explore the complex interactions between human and the environment. The results demonstrate that the RSL in city wall was rammed with Aeolian sand from the surface around the city, which offer new insights into the environmental background under which these cities were set. Considering the location of these cities, namely the SELC at the north–east margin of the Hobq desert, the DBDC at the East margin of the Mu Us sandy land and the BYC at south–west of the Mu Us sandy land, as well as their building times, we argue that some ancient cities were originally built in the desert, and that human activities should not impose much impact on the landscape.

Care should be taken when using historical literatures as evidence to explore the environmental conditions. Records of regional geography are often vague or contradictory. They are recorded by different people with different experiences, and not always for environmental use but as complementary data for military affairs, economic purposes or something else. Therefore, there must be some misrepresentations in these records that mislead us into understanding the historical desertification. Additionally, whereas ancient cities likely convey information that they should be built under well environment, researchers are apt to come to the conclusion that human activities must be responsible for the environmental change taking place in history. However, stratigraphical sections have some deficiencies in terms of low resolution and thus have limitations to explore historical desertification. But the combination of textual records with the analysis of the sand in the RSL overcomes these limitations and establishes a more reliable record for the region's environment.

Acknowledgements This work was supported by the Key Project of Ministry of Education of China (107107) and the National Natural Science Foundation of China (40661014). The authors would like to thank two reviewers for their helpful suggestions and Breeze Chen and Tao Lee for their help in improving the English expressions.

http://www.isl.ac.cn

References

Ai C (2004) The relationship between the shaping of the Mu Us Desert and utility of land in the six barbarous states in the Tang Dynasty. Journal of Shaanxi Normal University (Philosophy and Social Sciences Edition) 33(3):99–105

An C, Feng Z, Tang L (2004) Environmental change and cultural response between 8000 and 4000 cal. Yr BP in the western Loess Plateau, northern China. J Quat Sci 19(6):529–535

Archaeology Institute of Shaanxi Province (2005) Shenmu Dabaodang. Science, Beijing, China

Ashley GM (1978) Interpretation of polymodal sediments. J Geol 86:411–421

Bagnold RA, Bamdorff-Nielsen O (1980) The pattern of nature size distributions. Sedimentology 27:199–207

David HK, John CD (1973) Atlas of quartz sand surface textures. Cambridge University Press, Cambridge, pp 12–14

Deng H, Shu SG, Song YQ et al (2007) Distribution of sand dunes and sand shifts along the southern fringe of the Mu Us Desert since the Ming Dynasty. Chin Sci Bull 21(21):2556–2563

Dong GR, Li BS, Gao SY et al (1983) Aeolian sand of Ordos in the Quaternary. Acta Geogr Sin 4:341–347

Dong GR, Cheng Z, Wang G et al (1997) The evolution of deserts with climatic changes in China since 150 ka BP. Sci China, Ser D 40(04):370–382

Fitzpatrick KT, Summerson CH (1971) Some observations on electron micrographs of quartz sand grains. Ohio J Sci 71(2):106–119

Folk RL, Ward WC (1957) Brazos River bar: a study in the significance of grain size parameters. J Sediment Petrol 26:3–32

Gu L (2003) A primary analysis on the cause of the sand invasion to the Yulin City recorded in historical literatures. Collections of Essays on Chinese Historical Geography 18(04):52–56

Han ZQ (2003) Change of the Mu Us sandy land and its relationship with the cultivation in the Ming Dynasty. Soc Sci China 23(05):191–204

Hou YJ, Zhou J, Wang Y (2001) The national and humane landscape in the Ordos Plateau during the Bei-Wei dynasty(A.D386–A.D534). Journal of Desert Research 21(2):189–194

Jeanne X, Roger E, Turner BL II (1995) Regions at risk: comparisons of threatened environments. United Nations University Press. Available at http://www.unu.edu/unupress/unupbooks/uu14re/uu14re00.htm

Li BS, Dong GR, Wu Z et al (1993) The establishment of the upper Pleistocene Chengchuan Formation in northern China. Geological Review 39:91–100

Long H, Wang NA, Li Y et al (2007) Particle size characteristics of deposits from PJHZ section in Northern edge of Mu Us desert and their environmental significance. Journal of Desert Research 27(02):187–193
Niu J, Zhao S (2000) Origin of desertification of Ordos Plateau in historic times. Journal of Desert Research 21(01):67–70
Pickup G (1998) Desertification and climate change—the Australian Perspective. Clim Res 11:51–63
Shi NH (1980) Forest distribution and change of the Ordos Plateau and Hetao Plain in past 2300 years. Journal of Beijing Normal University (Social Sciences) 27(06):1–14
Sun J, Ding Z (1998) Process and cause of land desertification in Northern East China. Quaternary Sciences 18(2):156–164
Sun D, Jan B, David KR et al (2004) Bimodal grain-size distribution of Chinese loess, and its palaeoclimatic implications. Catena 55:325–340
Wang BC (1983) The historical changes of the land areas in south edge of Mu Us sandy land. Journal of Desert Research 3(4):11–21 (in Chinese)
Wang WL (2002) When Maowusu become a Desert? View through new archaeological finds. Archaeology and Cultural Relics 22(5):80–85
Wang S, Zhou T, Cai J et al (2004) Abrupt climate change around 4 ka BP: role of the thermohaline circulation as indicated by a GCM experiment. Adv Atmos Sci 21(2):291–295
Wang NA, He TH, Huang YZ et al (2006) Discovery of Liuhu state relics and its significance of environmental indication. Collections of Essays on Chinese Historical Geography 21(3):36–46
Xie Y (1984) Atlas of quartz sand surface textural features of China micrographs. Haiyang, Beijing, pp 96–101
Xue X, Li Y, Yu X (2005) Shenmu Xinhua—animal remains in Xinhua site in Shanxi province, China. Chinese Science Press, Beijing, pp 355–367
Yan QS (1954) Drifting dunes in Dingbian and Yulin and their alteration. Chin Sci Bull 1(11):28–34
Zhao YF (1981) Change of the Mu Us desert in history. Hist Geogr 1:36–46

http://ir.isl.ac.cn