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The Formation of Yardangs Surrounding the Suoyang City Ruins in the Hexi Corridor of Northwestern China and Its Climatic–Environmental Significance

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Abstract: The yardangs surrounding the Suoyang City ruins are proven to be wind-eroded landforms developed in an oasis which was used for agriculture in history. According to OSL and ^{14}C dating, as well as historical records of local human activities, we suggest that the formation of yardangs in the Suoyang City oasis probably started in the mid-Yuan Dynasty of China (AD 1291). After being abandoned, the Suoyang City oasis quickly evolved into desert land with yardangs and nebkhas under the background of desertification enlargement in a cold, dry climate in the Hexi Corridor. Although human factors are considered to have played an important role in the process of desertification, the effect imposed by climatic changes should not be ignored. Desertification constitutes a serious threat to human survival and development, we should reasonably develop and utilize water and land resources, effectively prevent and control desertification, and promote the harmonious development between man and nature in arid areas.

Keywords: yardangs; wind erosion; climatic–environmental significance

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1. Introduction

The word yardangs are used in geomorphology to describe elongated, streamlined landforms that are produced by wind erosion [1–4]. Yardangs are present in many of the world's major deserts, including the Sahara Desert in Africa, the Namib Desert in Namibia, the Lut Desert in Iran, and the Taklimakan Desert in China, as well as on planets such as Mars and Venus [3,4]. Early explorers and geographers were attracted by the unique morphology and mysterious origin of these landforms and referred to them as Dragon City or Demon Castle. For example, yardangs in the Lop Nur region of China were described as "White Dragon Dunes" in the *Book of the Han Dynasty* 2000 years ago [3,5]. Li Daoyuan, a Chinese geographer during the Wei Dynasty 1500 years ago, proposed that the yardangs in the Lop Nur region were formed by water erosion and subsequently sculpted by wind [5]. The Swedish explorer Sven Hedin proposed the name "yardangs" (a Turkmen word that means "steep hills") in the Lop Nur region of Northwest China in 1903 [1]. This word subsequently became the standard terminology that is widely accepted and used by scholars in geomorphology.

Previous studies have mostly focused on yardangs formed in Gobi desert [3–8] rather than in agricultural areas. Suoyang City and its surrounding oasis are typical representatives of the ancient cities and oases that suffered from severe desertification in the Hexi

Corridor. The occurrence of yardangs indicates an important climatic and environmental change in this region. In this study, we investigated the yardangs around the Suoyang City ruins in the Hexi Corridor, which was a famous agricultural region in history. Our aim was to explore the formation process of the yardangs and their climatic–environmental significance, as well as provide a reference for the development of agriculture, the prevention and control of desertification, and the harmonious development between man and nature in arid areas.

2. Study Area

The yardangs around the Suoyang City ruins (Figure 1) are located in Guazhou basin of the Hexi Corridor. The Guazhou basin (39°52′N–41°53′N and 94°45′E–97°00′E) is located in Northwestern China. Since the Cenozoic, the collision and compression between the Indian and Eurasian plates have resulted in rapid uplift of the Tibetan Plateau, forming a wide range of basin mountain tectonic patterns in both the interior and the edge of the plateau. The Guazhou basin (Figure 1) is located in the basin mountain tectonic pattern on the northeast edge of the Tibetan Plateau, with the Qilian Mountains to the south and the Beishan Mountains to the north. Therefore, the terrain has a high elevation in the south and north, is low in the middle, and gradually inclines toward the center of the basin. The Guazhou basin is located in the hinterland of the Eurasian continent, with an arid climate, scarce precipitation, and low vegetation coverage. The main river in this region is the Shule River. The annual average temperature is 6.79 °C (1998–2018) (Figure 2), with a warm temperate continental arid climate. The annual average precipitation is 64.96 mm (1998–2018), of which 60% occurs during the summer [9]. The zonal soil is gray-brown desert soil.

Guazhou was located at a bottleneck of the old Silk Road and was a hub for economic and cultural exchange between China and the West in history. The Suoyang City ruins (Figure 3a) were listed as a world cultural heritage site in June 2014.

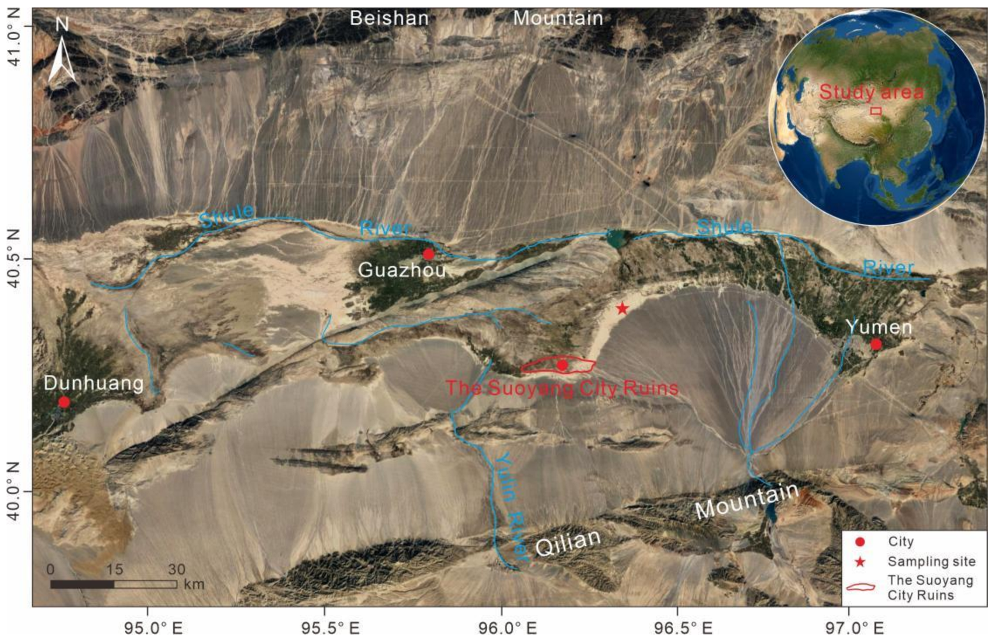

Figure 1. Locations of the Suoyang City ruins in Guazhou basin and the sample site.

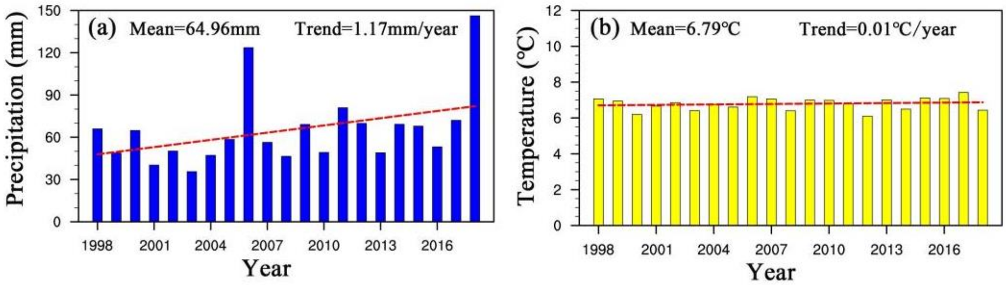

Figure 2. Average annual precipitation (**a**) and temperature (**b**) of the study area in 1998–2018.

In the past, the oasis reclamation area around the Suoyang City ruins (Figure 3a) was a prosperous agricultural region. Even today, the remains of ancient irrigation channels and field ridges are still visible. A dam of about 100 m wide was found 8 km to the southeast of the Suoyang City ruins, and there is an irrigation channel connected to the dam and the upstream mountain pass of the Shule River. In the downstream, the channel is divided into several branches leading to the ancient oasis reclamation area around the Suoyang City ruins. On the basis of remote sensing images of field ridges and irrigation channels, we calculated that the ancient reclamation area around the Suoyang City ruins covered roughly 3.42×10^2 km^2. Although the Suoyang City oasis was a prosperous region in history, the geomorphic landscape of this area is currently dominated by vast yardangs (Figures 3b and 4a), nebkhas (Figure 4b), and saline–alkaline land; in some areas, the nebkhas are as high as the ramparts.

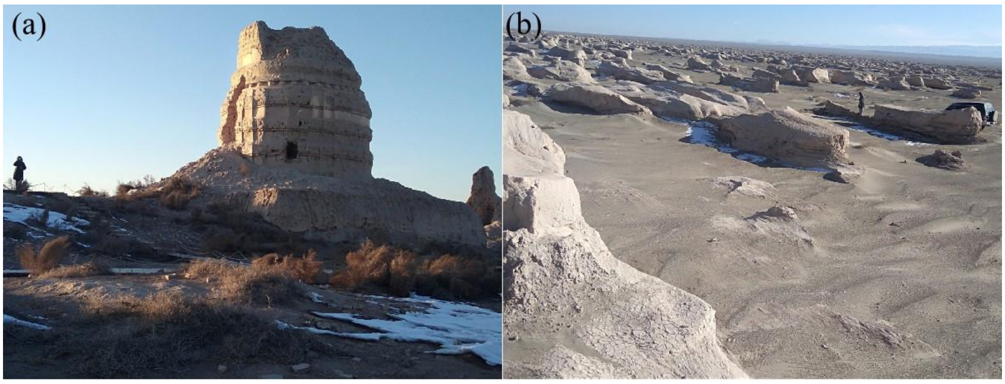

Figure 3. The Ta er Temple (**a**) in Suoyang City ruins, and the surrounding yardangs (**b**).

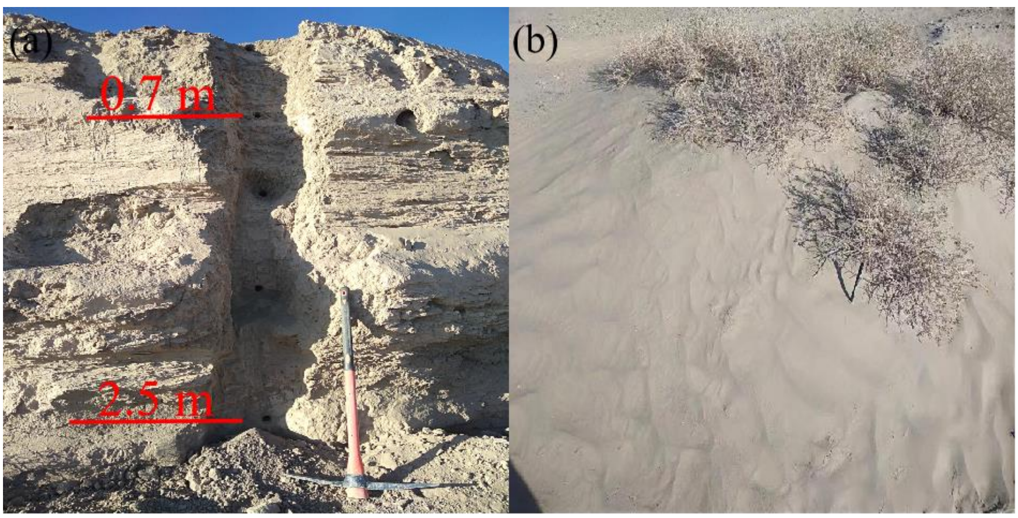

Figure 4. The dating sample profile (**a**) and nebkhas (**b**)surrounding the Suoyang City ruins.

3. Materials and Methods

3.1. Temperature and Precipitation

The annual mean precipitation and temperature used to describe climatic conditions in the study area were derived from the TRMM_3B43 and CRU TS4.05 climate datasets, respectively. As shown in Figure 2, the mean annual precipitation from 1998 to 2018 was 64.96 mm, much less than 200 mm (the thresholds for defining arid land), indicating an extreme arid climate in the study area. The average annual temperature in the last 20 years (1998–2018) was low and very stable. Additionally, although the average annual temperature remains low (6.79 °C) and shows little long-term trend, climate change also imposes a great influence on this region for a significant increasing trend ($p < 0.05$) of precipitation, as detected by the Mann–Kendall (MK) trend test, which may have resulted from the impact of global warming [10–13].

3.2. The Age of Yardangs Surrounding the Suoyang City Ruins

Yardangs are wind-eroded landforms that are different from wind accumulation landforms. The strata age is not the same as the age of the yardangs, the age of the yardangs is the time when wind erosion first began to cut into the uppermost strata of the land surface. Therefore, it is very difficult to determine the age of the yardangs. However, the occurrence of yardangs indicates significant environmental changes, especially for the development of yardangs in oasis agricultural areas. Therefore, it is very important to determine the age of the yardangs surrounding the Suoyang City oasis.

In this paper, we attempted to date the existing top stratum of the yardangs using the optically stimulated luminescence (OSL) dating method to obtain an approximate age of the yardangs. Samples were dated using the OSL dating method in Luminescence Research Laboratory, Shandong Provincial Key Laboratory of Water and Soil Conservation and Environmental Protection, School of Resource and Environmental Sciences, Linyi University. We collected a 2.8 m deep yardang profile (Figure 4a) and dated the age at the depths of 0.7 m and 2.5 m; the 0.7 m section showed an age of 0.87 ± 0.04 ka (Table 1), and the 2.5 m section showed an age of 1.62 ± 0.08 ka (Table 1). As the Suoyang City oasis is located at the extreme end of the alluvial fan, the deposition rate is relatively stable, and the sedimentary facies (Figure 4a) also showed that the yardang sedimentary stratum is very uniform; thus, we assume that this section was relatively uniformly deposited, 0.7–2.5 m apart by 1.8 m. It took 750 years to deposit this section; thus, we can calculate that the deposition rate of this section is 0.24 cm/year. According to this deposition rate, we can calculate that the age of the top stratum of the yardang profile seen at present is about 0.578 ka; hence, we can calculate that the top stratum of the yardang formed at about AD 1444. Radiocarbon ^{14}C dating of branches in the top stratum of the yardang in previous studies showed that the yardangs surrounding the Suoyang City oasis started to form at around AD 1410–AD 1460 [14]. Both methods assume that the top strata of the yardangs are the original final sedimentary layers and that the yardangs began to form immediately after the original final sedimentary layer deposit. The two methods also assume that the top stratum of the yardang seen at present has not been eroded. However, since the formation of yardangs, it is impossible for the top strata of the yardangs to have not suffered from erosion over time. Therefore, the stratigraphic ages determined using the two methods are slightly later than the real formation time of the yardangs.

Table 1. K-feldspar pIRIR dating results for samples.

Samples	Depth (m)	Over-Dispersion (%)	U ppm	Th ppm	K (%)	Moisture (%)	Dose Rate (Gy/ka)	CAM De (Gy)	CAM Age (ka)
SYC-02	0.7	8	2.32	9.20	1.59	5 ± 2	3.70 ± 0.10	3.23 ± 0.1	0.87 ± 0.04
SYC-01	2.5	10	2.34	9.00	1.55	5 ± 2	3.59 ± 0.11	5.8 ± 0.2	1.62 ± 0.08

4. Characteristics and Controlling Factors of the Yardangs

4.1. Characteristics of the Yardangs

The yardangs around the Suoyang City ruins are located on the western edge of the alluvial fan of the Shule River in Guazhou basin. Unlike the yardangs reported in previous studies [3,6–8], this region was an oasis reclamation area in the past. Through investigation, we found that the yardangs were mainly yellow in appearance, elongated and streamlined in morphology, and developed on fluvial and lacustrine sediments [11]. It is generally believed that the length of large yardangs is >1000 m, of medium yardangs is 10–1000 m, and of small yardangs is 1–10 m [14]. In this study, 100 yardangs were measured in the study area, and we found that their length was 1.6–25.8 m, width was 0.7–9.2 m, and height was 0.8–3.2 m; therefore, the yardangs around the Suoyang City ruins are small–medium in size. The most important characteristic is that the yardangs surrounding the Suoyang City ruins show obviously directional, parallel, and streamlined characteristics (Figures 3b and 5). The majority of the yardangs extend in the east–west direction (Figures 3b and 5), consistent with the local prevailing wind direction (Figures 5 and 6), but inconsistent with the direction of gullies formed by flooding (north–south) in this region [9]. In Guazhou basin, the North Mountain lies in the north, and Qilian Mountain lies in the south; thus, the terrain is high on both sides and low in the middle. Affected by the terrain, the gullies scoured by local rivers and floods formed by precipitation extend in the north–south direction. A meteorological station was installed in the center of the yardang distribution area surrounding the Suoyang City ruins; the meteorological data (2016–2018) show that the annual sand-driving wind direction in the study area is mainly easterly (Figure 6), followed by westerly, whereas other wind directions are rare [9,15]. Therefore, it is easy to understand that the trend of the yardangs was consistent with the local prevailing wind direction (Figures 5 and 6), but inconsistent with the direction of gullies formed by rivers and flooding (north–south) in this region. The strong local prevailing wind transports a large amount of dust and sand, which grinds and erodes the land surface into long parallel ridges and grooves, forming large areas of yardangs.

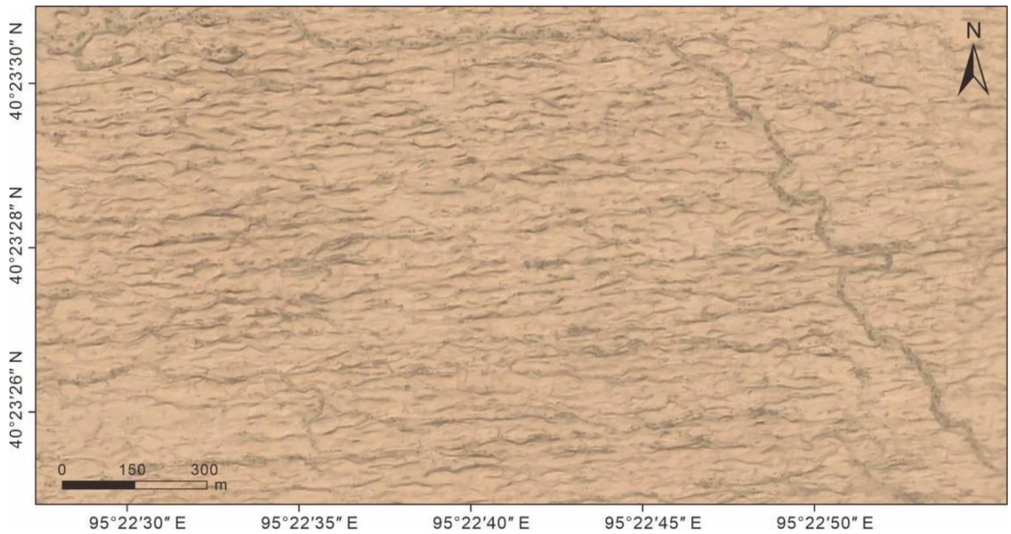

Figure 5. Remote sensing image of the yardangs surrounding the Suoyang City ruins.

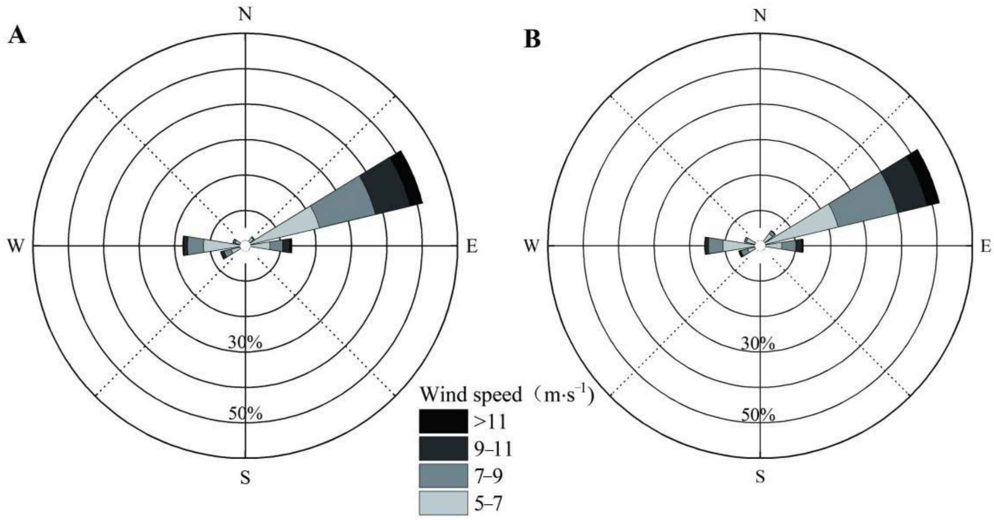

Figure 6. Annual sand-driving wind rose chart: (**A**) 2016–2017; (**B**) 2017–2018.

4.2. Controlling Factors of the Yardangs

4.2.1. Sediment Characteristics

The collision and compression between the Indian and Eurasian plates since the Cenozoic caused rapid uplift of the Tibetan Plateau, forming a range of basin and mountain tectonic patterns. The Guazhou basin is just located in a basin mountain tectonic pattern on the northeastern edge of the Tibetan Plateau, with the Qilian Mountains to the south and the Beishan Mountains to the north. The Shule River, one of the big three inland rivers in the Hexi Corridor, runs through the basin. The Shule River sediments and the proluvial deposits brought from the Beishan and Qilian mountains formed a huge piedmont alluvial fan. These thick Quaternary fluvial and lacustrine sediments provide material conditions for the development of agriculture and the formation of yardangs.

4.2.2. Fluvial Erosion

Yardangs are considered to be among the most typical wind-eroded landforms, but the role of water flow should not be ignored. Despite an extreme arid climate, the intermittent water flow formed by precipitation plays an important role in the development of yardangs. Although the average annual precipitation in Guazhou is only 64.96 mm (Figure 2), the precipitation during rainstorms is sufficient to form surface runoff and erode the surface, forming dense gully systems, which provides conditions that are conducive to enhance wind erosion.

4.2.3. Wind Erosion

Wind erosion is the most significant agent responsible for the formation of yardangs in the Suoyang City oasis reclamation area. As Guazhou basin is located in the hinterland of the Eurasian continent and is far from the sea, the Kunlun Mountains, Qilian Mountains, Himalayas, and Qinling Mountains block the flow of humid air from the Indian and Pacific Oceans, resulting in an extremely dry climate, highlighting wind as the most important external force in this region. Guazhou basin is located in the Shule River valley between the Beishan Mountains and the Qilian Mountains. When airflow enters the valley, the air duct narrows, and the wind speed increases; thus, Guazhou is known as the "wind reservoir of the world" [15]. Accordingly, wind erosion in Guazhou basin is very strong. Previous studies have shown that the threshold velocity for sand movement in Guazhou basin is mainly composed of two groups of wind with opposite directions. The main wind direction is northeast, accounting for 68.86% of the annual threshold velocity for sand movement, followed by southwest wind, accounting for 27.67% of the annual threshold velocity for sand movement (Figure 6) [9]. Through field investigations, we found that the long axis of yardangs in the Suoyang City oasis reclamation area mostly extends in the east–west direction, consistent with the local prevailing wind direction but inconsistent with the north–south direction of ravines scoured by rainstorms and floods in this area [9]. Wind erosion is obviously the main external force for the formation of yardangs surrounding the Suoyang City ruins.

4.2.4. Weathering and Collapse

Physical weathering and collapse are also important factors in the development of yardangs. Physical weathering caused by annual and diurnal temperature variations greatly influences the fluvial and lacustrine sediments, thereby impacting yardangs. Guazhou is deeply inland, with big annual and diurnal temperature variations, meaning that physical weathering is significant to the yardangs in the Suoyang City oasis reclamation area. The temperature changes create mechanical stress that generates horizontal and vertical fractures, potentially leading to the collapse of sediments. Wind and water erosion of the underlying soft and loose sediments can also lead to the collapse of overlying strata.

5. Results and Discussion

5.1. Desertification Process of the Oasis in the Hexi Corridor

The Hexi Corridor is located in Northwest China, with an extreme arid climate, low precipitation, and sparse vegetation. The agricultural production is mainly concentrated in oasis areas in the lower reaches of rivers. In the past, desertification of oasis in the Hexi Corridor occurred frequently, causing the loss of agricultural land resources, a sharp reduction in biomass, and even the destruction of the whole oasis ecosystem. Therefore, the Hexi Corridor is one of the most severe desertification areas in Northwest China [16–18].

There are ten large desertification areas that evolved from the oasis in the Hexi Corridor. These desert areas are all located in the lower reaches of rivers, with poor water resources and potential instability in ecosystems, meaning that they are prone to desertification. For thousands of years, strong winds swept across the ground like a comb, eroding the farmland into yardangs and nebkhas; some areas were almost completely swallowed by quicksand, and people's homes became places where wind and sand raged. The Hexi Corridor in Gansu Province, through which the famous old Silk Road used to pass, is one of the areas with the most ancient city ruins. These ruins are considered to be the best historical specimens of China's ancient civilization and Silk Road culture, as well as the most direct historical evidence of environmental changes in the ancient oasis.

Over the last 2000 years, the agricultural production and social development in the Hexi Corridor made brilliant achievements, especially in the Han, Sui, and Tang Dynasties (202 BC–AD 907). However, there have been stages of environmental changes with serious desertification in the Hexi Corridor. The desertification process is mainly concentrated in the Wei, Jin, and North–South Dynasties (AD 220–AD 589), the late Tang and Five Dynasties (AD 907–AD 960), and the Ming and Qing Dynasties (AD 1644–AD 1912). The desertification area was 1070 km^2 in the Wei, Jin, and North–South Dynasties, 1765 km^2 in the late Tang and Five Dynasties, and 6884 km^2 in the Ming and Qing Dynasties [18]. Moreover, over the past 2000 years, among the 38 ancient cities abandoned through desertification in the Hexi Corridor, 21.05% were abandoned during the Wei, Jin, and North–South Dynasties, 21.05% were abandoned during the end of the Tang and Five Dynasties, and 57.9% were abandoned during the Ming and Qing dynasties [16]. It has been reported that there is a good relationship between climate changes and desertification in history of the Hexi Corridor [19]. The general characteristics of climate changes over the last 2000 years in China show that there have been four warm periods since the Qin Dynasty, namely, the western and eastern Han Dynasties (200 BC–AD 180), the Sui and Tang dynasties (AD 541–AD 810), the Song and Yuan dynasties (AD 931–AD 1320), and the 20th century (AD 1921–AD 2000). Moreover, there were three cold phases including the Wei, Jin, and North–South Dynasties (AD 181–AD 540), the late Tang and Five Dynasties (AD 811–AD 930), and the Ming and Qing dynasties (AD 1321–AD 1920) [19].

Throughout China's history, the warm period often brought a warm, wet climate, social stability, and prosperity, as well as a good ecological environment, while the cold period was often accompanied by a cold, dry climate. In addition, climate changes could bring about serious social and ecological problems, such as war and desertification. The relationship between climate and wars in the past 2000 years of China show that most of the wars occurred in low-temperature periods. There were seven relatively cold periods (AD 180–AD 360, AD 420–AD 540, AD 840–AD 960, AD 1110–AD 1200, AD 1290–AD 1500, AD 1560–AD 1680, and AD 1830–AD 1890) in Chinese history. Except for the period of AD 420–AD 540, the other six period all correspond to the high-frequency period of wars [19]. The Wei, Jin, and North–South Dynasties and the Ming and Qing Dynasties were the two coldest periods in Chinese history, as well as the periods with the highest incidence of wars in Chinese history. In the former period, 595 wars occurred, while, in the Ming and Qing Dynasties, 810 wars occurred. Moreover, in cold periods, the ethnic minorities in border areas often moved inward, leading to wars breaking out [19]. During the years of wars, people either died in the war or fled and moved to other places, while the nomadic lifestyle of the ethnic minorities usually replaced the agricultural lifestyle of the Han people. Therefore, large areas of farmlands in the oasis were abandoned and exposed to the surface, without the protection of vegetation; the ancient oasis then became desert land under strong wind erosion in cold periods, and the surrounding cities usually declined or were abandoned.

5.2. Desertification Process of the Suoyang City Oasis

The Suoyang City ruins are among the most representative desertified ancient city ruins in the Hexi Corridor. Suoyang City was built in the Western Jin Dynasty (AD 295) and was the capital of Guazhou county from the Tang Dynasty to Yuan Dynasty (AD 618–AD 1291). The Suoyang City oasis was a very prosperous area in history, especially flourishing during the Tang Dynasty [17]. On 1 August 2022, People's Daily Online of China reported that the latest archaeological evidence confirmed that the Ta er Temple in the Suoyang City ruins was a high-level temple on the old Silk Road, which was built during the Sui and Tang Dynasties (AD 581–AD 907) and flourished in the Western Xia Dynasty (AD 1038–AD 1227), indicating that the Suoyang City oasis should be a relatively prosperous area without desertification in this period, whereas Guazhou experienced some changes during the Yuan Dynasty. In the early Yuan Dynasty, Guazhou still existed. However, soon after, the residents of Guazhou were ordered to move out. In AD 1288, the government ordered the residents of Guazhou to move to Gan State, and, in AD 1291, the Guazhou residents were ordered to move to Su State. After these large migrations, the residents of Guazhou were very few, and historical document reported that Guazhou only existed in name [17]. From then on, Suoyang City became empty; the surrounding farmland was abandoned and suffered from strong wind erosion. Therefore, we can infer that the desertification process of the Suoyang City oasis probably started in the mid-Yuan Dynasty (AD 1291).

In the early Ming Dynasty (AD 1368–AD 1644), the decline of Suoyang City and its surrounding oasis was very serious; the government reopened Suoyang City and repaired it twice during 1435–1494 [17]. In 1472 AD, the Hami Wei (a military organization) moved to Suoyang City. In the third year of Jiajing (AD 1524), the government could not resist the attack of border ethnic minorities; hence, it officially abandoned the large areas west of Jiayuguan State (including Dunhuang and Guazhou) and moved all residents inland [13]. In the following 200 years, Dunhuang and Guazhou were repeatedly occupied by nomadic tribes from Turpan, Hami, and Mongolia, and the oasis surrounding Suoyang City no longer operated [17]. In 1738 of the early Qing Dynasty, it was recorded that there was little arable land around Suoyang City, and the former irrigation channels were all dry and covered with sand [15], indicating that the Suoyang City oasis had evolved into desert land.

In the Qing Dynasty (AD 1644–AD 1912), the government gradually recovered vast areas west of Jiayuguan State and resumed the management of Guazhou, whereas the development of the drainage area of the Shule River focused on the east and north of the alluvial fan, and the waste land in the east and north of the alluvial fan was extensively reclaimed [17]. It was recorded in the 58th year of Kangxi (AD 1719) that the government built Yumen City, blocked the Shule River estuary, and drove the water to the southeast to irrigate the newly reclaimed waste land. From then on, the river channel that originally flowed to Suoyang City in the west of the alluvial fan was cut off and dried up [17]. The limited discharge of the Shule River was used to irrigate the newly reclaimed waste land to the east. Therefore, the Suoyang City oasis was completely dried up, and it quickly evolved into desert land with yardangs and nebkhas under strong wind erosion.

In conclusion, Suoyang City was first built in the Western Jin Dynasty (AD 295) and was the capital of Guazhou county from the Tang Dynasty to the Yuan Dynasty (AD 618–AD 1291). In 1291, the residents of Guazhou moved to Su State, after which Guazhou only existed in name. Hence, we suggest that the desertification of the Suoyang City oasis started in the mid-Yuan Dynasty (AD 1291), accelerated following the abandonment of Guazhou in the mid-Ming Dynasty (AD 1524), and completely evolved into desert land after the diversion of the Shule River in the early Qing Dynasty (1719 AD). Coupled with the OSL dating results, we suggest with some confidence that the occurrence of yardangs in the Suoyang City oasis started in the mid-Yuan Dynasty (AD 1291).

5.3. Environmental Significance of Desertification and the Occurrence of Yardangs Surrounding the Suoyang City Ruins

The Hexi Corridor is an important agricultural production base and a densely populated area in Northwest China. Therefore, desertification of the oasis and the ancient cities in the Hexi Corridor has important environmental significance. Over the last 2000 years, desertification of the Hexi corridor mainly occurred in the Wei, Jin, and North–South Dynasties, the late Tang and Five Dynasties, and the Ming and Qing Dynasties [16]. Moreover, the abandonment of all 38 ancient cities through desertification in the Hexi Corridor in history also occurred in these cold periods [16]. The reasons can be divided into natural factors and human factors. In terms of natural factors, climate change, especially a cold, dry climate, can easily cause desertification. With regard to human factors, war, river diversion, the increasing intensified human activities such as over-deforestation, overgrazing, reclaiming waste land, and building reservoirs for water storage are responsible for the desertification in the Hexi Corridor [16]. In addition, population is also an important factor, especially for an arid area located in NW China with a weak environmental carrying capacity. In history, the population of the Hexi Corridor rarely exceeded 4×10^5 from the Han to Tang dynasties (202 BC–AD 907); even in the mid-Ming Dynasty, the total population was about 3.5×10^5, and water resources were mainly used to meet the needs of irrigation and everyday life. Thus, water and land resource exploitation did not play a leading role in environment changes of the Hexi Corridor [16]. However, by the early Qing Dynasty, a great deal of immigrants came to the Hexi Corridor. It was reported that, during the Year of Jiaqing (AD 1796–AD 1820) in Qing Dynasty, the total population of the Hexi corridor was about 1.274×10^6 [16]. For the first time, the population density in the Hexi region rose to 8.8 per square kilometer and broke through the critical index of population pressure in an arid region (seven persons per square kilometer set by the United Nations in 1977) [16]. Human activities gradually replaced natural factors and became the primary factor on environmental changes in the Hexi corridor. Subsequently with the development of science and technology, human activities become the principal cause during the process of desertification over the last 300 years [16,19].

In history, Guazhou was rich in water resources, such as the Han Dynasty (202 BC–AD 220) and the Tang Dynasty (AD 618–AD 907) [20]. It was reported that, during the Han and Tang Dynasty, a large tributary of the Shule River (named Ming River) flowed to the Suoyang City oasis area, forming a big swamp (namely a lake) 130 km long and 30 km wide in the downstream [17]. The large tributary and the big swamp provided sufficient irrigation water for the Suoyang City oasis. By the mid-Yuan Dynasty, the ecological environment of Guazhou was much worse than the Tang Dynasty, with infinite dunes [21]. Moreover, when the Swedish Explorer Sven Hedin passed through Guazhou in 1933, local people reported that the discharge of the Shule River was much larger 100 years ago; Sven Hedin believed that this change was not completely caused by the increase in irrigation [21]. In history, the Shule River transported a large amount of water and would terminate in Lop Nur in Xinjiang. The Shule River became a seasonal river below Guazhou in the first half of the 19th century at the latest [21], because Qi Yunshi and Lin Zexu recorded that the Shule River was dry near Guazhou when they were demoted to Ili of Xinjiang in 1810 and 1842, respectively, indicating a reduction in river volume and a more arid climate [21].

Both natural factors and human factors are responsible for the desertification of the Suoyang City oasis and the occurrence of yardangs. In terms of natural factors, in the last 1000 years, the climate in China gradually turned cold and dry, and the discharge of rivers and lakes decreased as well [16,19], especially during the Ming and Qing dynasties, which occurred in the Little Ice Age. Historical records also show an obvious increase in sand and wind disasters all over the world in this period [14]. On the other hand, the increasing intensified human activities also played an important role in the process of desertification [16–18]. For example, after the construction of Shuangta reservoir in 1960, the river volume in the lower reaches of the Shule River was greatly reduced. Furthermore, once the oasis turned into a desert, people often left the oasis and moved to a new oasis [22]. Over time, the area of desertification became larger and larger, as land resources in arid areas are very limited; desertification not only leads to a reduction in people's living space but also seriously threatens human survival and sustainable development of the society. For example, the reduction in river discharge in the lower reaches of the Shule River caused the retreat of downstream lakes, the shrinkage of wetlands, a reduction in biodiversity, an increase in soil salinization, and other serious ecological and environmental problems [23]. Therefore, we should reasonably develop and use land and water resources, effectively prevent and control desertification, and promote harmonious development between man and nature in arid areas.

6. Conclusions

The yardangs surrounding the Suoyang City ruins were proven to be wind-eroded landforms developed in an oasis which was used for agriculture in history. According to OSL and ^{14}C dating, as well as historical records of local human activities, we suggest that the formation of yardangs in the Suoyang City oasis probably started in the mid-Yuan Dynasty of China (AD 1291). After being abandoned, the Suoyang City oasis quickly evolved into desert land with yardangs and nebkhas under the background of desertification enlargement in the cold, dry climate in the Hexi Corridor. Although human factors are considered to have played an important role in the process of desertification, the effect imposed by climatic changes should not be ignored. Desertification constitutes a serious threat to human survival and development; we should reasonably develop and utilize water and land resources, effectively prevent and control desertification, and promote the harmonious development between man and nature in arid areas.

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