Acta Geologica Sinica (English Edition), 2020, 94(3): 612–623

Climate Change, Geopolitics, and Human Settlements in the Hexi Corridor over the Last 5,000 Years

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Abstract: Social responses to climate change over human history have been widely discussed in academia over the last two decades. However, the transformation of the human–environment nexus crossing prehistoric and historic periods and the processes associated with it are not yet clearly understood. In this study, based on published works on radiocarbon dating, archaeobotany, zooarchaeology, and archaeological sites, together with a synthesis of historical documents and high-resolution paleoclimatic records, we trace the extent to which human settlement patterns in the Hexi Corridor in northwestern China evolved in conjunction with climate change over the last 5,000 years. A total of 129 Neolithic, 126 Bronze Age, and 1,378 historical sites in the Hexi Corridor (n=1,633) were surveyed. Our results show that, in the Late Neolithic and Bronze Age periods (~2800–100 BC), climate change contributed to the transformation of subsistence strategies and the subsequent changes in human settlement patterns in the Hexi Corridor. The warm-humid climate in ~2800 –2000 BC promoted millet agriculture and helped the Majiayao, Banshan, and Machang Cultures to flourish. The cold-dry climate in ~2000–100 BC resulted in the divergence and transformation of subsistence strategies in the Xichengyi–Qijia–Siba and Shajing–Shanma Cultures and in a shift in their settlement patterns. However, in the historical period (121 BC–AD 1911), human settlement patterns were primarily determined by geopolitics related to the alternating rule of regimes and frequent wars, especially in the Sui–Tang dynasties. We also find that trans-Eurasian cultural exchange since ~2000 BC improved social resilience to climate change in the Hexi Corridor, mediating the human–environment nexus there. Our findings may provide insights into how human societies reacted to climate change in arid and semi-arid environments over the long term.

Key words: climate change, human-environment nexus, historical period, trans-Eurasia cultural exchange, Neolithic and Bronze Age, Hexi Corridor

Citation: Yang et al., 2020. Climate Change, Geopolitics, and Human Settlements in the Hexi Corridor over the Last 5,000 Years. Acta Geologica Sinica (English Edition), 94(3): 612–623. DOI: 10.1111/1755-6724.14529

1 Introduction

The evolution of human societies in relation to, and the societal impacts brought by, climate change have been a focus of academia over the last two decades (Weiss and Bradley, 2001; Hao et al., 2009; Kawahata et al., 2009; Trauth et al., 2010; Bowles, 2012; Wiener, 2014). How does climate change influence the development of human societies? Does climate change play a decisive role in social, economic, and cultural transformation? Answers to the above questions may provide insight into and help us better understand the evolution of the human–environment nexus, future trends in human–environment interaction, and the opportunities and challenges brought by climate change. Ancient civilizations rose and fell in many parts of the world in prehistoric and historic times; however, there are opposing views and hypotheses about the primary causes of this phenomenon. Several scholars have shown that climate change is a crucial factor in determining the path of human civilization (An et al., 2005; Xu, 2014; Dong et al., 2017a; Chen et al., 2019): climate deterioration led to the decline and collapse of ancient civilizations (Weiss et al., 1993; Kerr, 1998; Haug et al., 2003; Staubwasser et al., 2003; Buckley et al., 2010; Tung et al., 2016), while a mild climate was a major driving force in the prosperity of some ancient cultures (Mo et al., 1996; An et al., 2004; Lee et al., 2008; Cremaschi and Zerboni, 2009; Büntgen et al., 2011; Li Z Q et al., 2016). Climate change, especially prolonged drought, can induce mass migration (deMenocal, 2001; Di Cosmo, 2002; Büntgen et al., 2011; Jia et al., 2016). Similarly, drought events resulted in the transformation, hiatus, or decline of prehistoric cultures in the Gansu–Qinghai region in northwestern China (Dong et al., 2012; Dong et al., 2013). However, some recent research findings substantiate the theory that cultural evolution in the Heihe River valley of the Hexi Corridor was mainly driven by geopolitics rather than climate change in the historical period (Shi et al., 2018), while other studies have shown that climate change may have caused geopolitical shifts in China during the

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historical period (Ge et al., 2013; Zhang et al., 2015; Yin et al., 2016). It is difficult to investigate the respective effects of climate change and geopolitics on human civilizations due to their interconnectedness.

The emergence of the practice of agriculture is one of the most significant milestones in the history of human civilization. During the early Holocene, several individual centers of domestication emerged on the eastern and western margins of Eurasia (Zeder, 2008; Riehl et al., 2013). Barley, wheat, cattle, and sheep were first domesticated in the Fertile Crescent in Western Asia, while rice and broomcorn/foxtail millet were domesticated in the Yellow and Yangtze River basins in China (Lu et al., 2009; Riehl et al., 2013). The resulting steady food supply led to the shift from migratory to sedentary lifestyles, promoting agricultural development and, subsequently, population growth, mass migration, and cultural expansion in Eurasia (van Geel et al., 2004; Kuzmina, 2008; Anthony, 2010; Gignoux et al., 2011; Dong et al., 2019). Various kinds of crops, livestock, and advanced technologies also spread from the domestication center with the diffusion of Neolithic groups, which promoted cultural exchanges between East and West in prehistoric Eurasia, thus laying an important foundation for the opening of the overland routes of the Silk Road during the historical period (Franck and Brownstone, 1986).

The Hexi Corridor, located on the central part of the eastern Silk Road, played a key role in cultural exchange between East and West during the prehistoric (Flad et al., 2010; Long et al., 2016; Dong et al., 2018) and historic periods (Frankopan, 2015; Barisitz, 2017), and further facilitated the formation of the Silk Road civilizations. Moreover, it was the intersection between the agricultural dynasties and the nomadic polities in China during the historical periods. As the Hexi Corridor is located in the arid and semi-arid region on the margin of the Asian Summer Monsoon, its ecological environment is highly sensitive to climatic changes. However, the long-term evolution of the human–environment nexus in this region across the prehistoric and historic periods, and the forces that drove it, remain insufficiently explored. In this study, we investigated the responses of human societies to climate change in the Hexi Corridor, covering all periods from the Majiayao Culture (~2850–2500 BC) to the Qing dynasty (AD 1644–1911), with particular attention to the spatiotemporal changes in human settlement patterns in the Hexi Corridor. We wished to provide a regional case study to illustrate the relationship between climate change and the evolution of the Silk Road civilizations. The associated findings may have important implications for understanding the long-term dynamics and mechanisms of the human–environment nexus in arid and semi-arid regions in the past.

2 Study Area

Our study area is delineated as the Hexi Corridor (92°21′E–104°45′E, 37°15′N–41°30′N), which is located along the Silk Road and was an important transportation and trade route between East and West during the prehistoric and historic periods. Geographically, the Hexi Corridor is a long, narrow corridor in northwestern China spanning approximately 1,000 km from the Wushaoling Mountains in the east to the Yumenguan (Jade Pass) in the west (Li, 1995). It is bounded by the Mazong Mountains and the Badain Jaran Desert in the north and the Qilian Mountains in the south. The three main inland rivers in this region—the Shule, Heihe, and Shiyang Rivers—are fed by snow meltwater from the Qilian Mountains (Feng, 1981). The Hexi Corridor is a typically arid continental climate region in northwestern China. Annual precipitation in the Hexi Corridor is 40–200 mm, with the highest amounts in the east and lowest in the west.

3 Methods and Data

3.1 Archaeological site data

In this study, we reviewed a total of 1,633 archaeological sites in the Hexi Corridor. Some of these sites have been dated to the Late Neolithic and Bronze Ages (~2800–100 BC); 129 Neolithic sites and 126 Bronze Age sites were included in the study. The cultural history of this region has been relatively well established by archaeologists (Flad et al., 2010; Li, 2011; Zhou et al., 2016; Dong et al., 2017b; Yang et al., 2019a). The Neolithic Cultures in the Hexi Corridor include the Majiayao (~2800–2500 BC), Banshan (~2500–2300 BC), and Machang (~2250–2050 BC), and their respective number of sites are 11, 4, and 114 (Fig. 1a). The Bronze Age Cultures in this region include the Xichengyi (~2050–1650 BC), Qijia (~2050–1650 BC), Siba (~1750–1350 BC), Dongjiatai (~1250–1050 BC), Shanma (~950–150 BC), and Shajing (~750–150 BC), and their respective number of sites are 16, 21, 56, 2, 12, and 19 (Fig. 1b, c). In addition, the number and the geo-referenced location of archaeological sites (including those of ancient tombs) in the historical period, spanning from the Han to the Qing dynasties (121 BC–AD 1911), were obtained from the Second National Archaeological Survey conducted in Gansu Province (Bureau of National Cultural Relics, 2011), including 635 Han (Fig. 1d), 140 Wei–Jin Southern and Northern (Fig. 1e), 60 Sui–Tang (Fig. 1f), 152 Western Xia–Yuan (Fig. 1g), and 391 Ming–Qing (Fig. 1h) sites.

3.2 Paleoclimate data

Climate and the environment have had a significant effect on human evolution and societal development; temperature and precipitation are two crucial climatic elements that determined the fates of ancient societies. The Hexi Corridor is located on the margin of the Asian monsoon region and, hence, monsoon intensity is a good indicator of precipitation in the Hexi Corridor. In this study, we selected several paleoclimate reconstructions to capture changes in temperature and precipitation in the Hexi Corridor in the past. To ensure the reliability of the records, only those published in international, peer-reviewed journals were considered. Our chosen paleoclimate records include proxy-based Northern Hemisphere temperature record reconstruction (Pei et al., 2017), $\delta^{18}O$ records from the Puruogangri ice core (Duan et al., 2012), the flux of >25 μm fraction from Qinghai

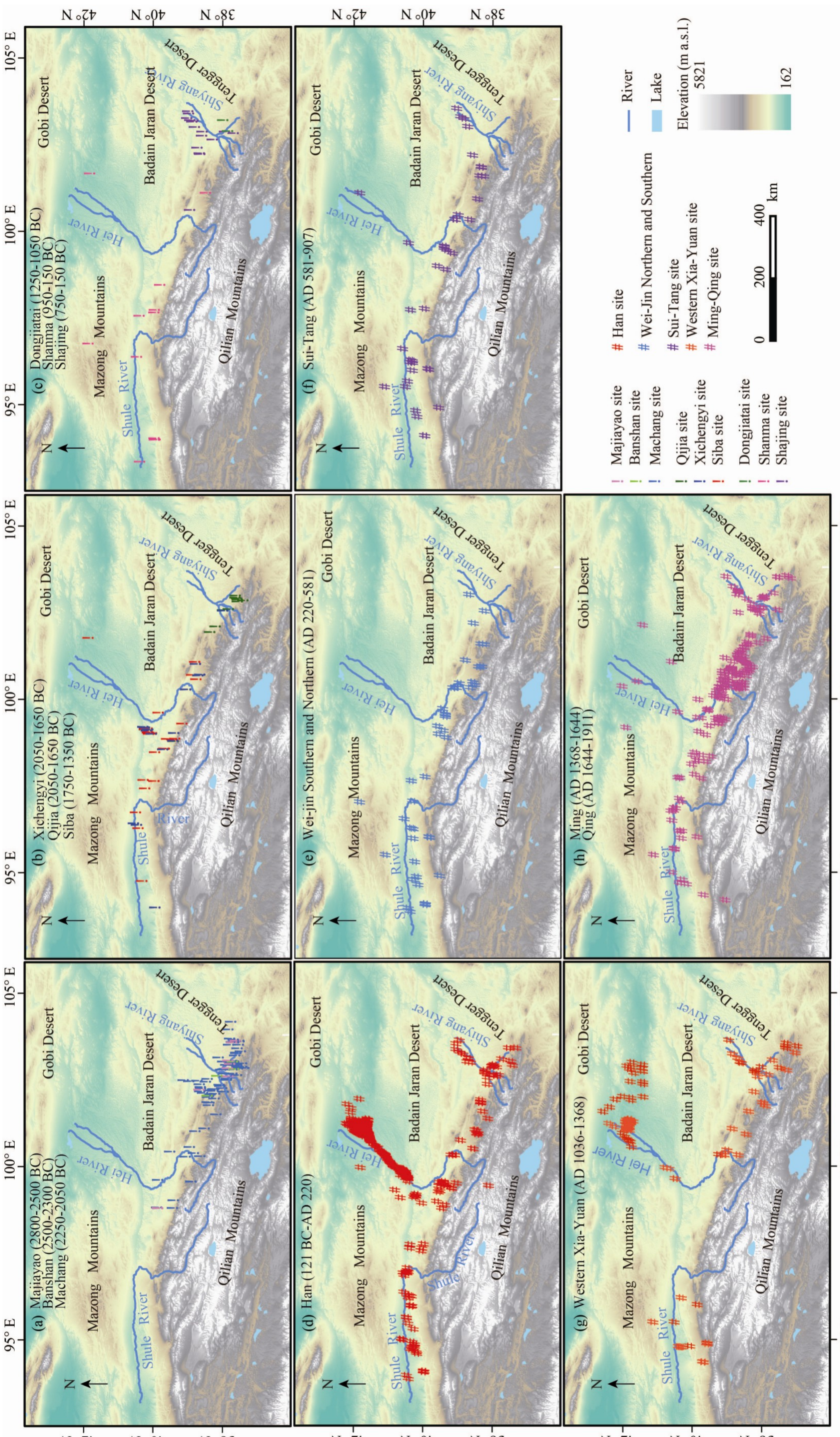

Fig. 1. The spatiotemporal distribution of archaeological sites in the Hexi Corridor from the Majiayao Culture to the Qing dynasty.

Lake (An et al., 2012), and multiple paleoclimate proxy records in China (Yang et al., 2002) as the temperature series, and Jiuxian Cave speleothem oxygen isotopes (Cai et al., 2010), Dongge Cave speleothem oxygen isotopes (Dykoski et al., 2005), pollen-based climate reconstructions of Qinghai Lake (Li et al., 2017), and tree-ring–based reconstructions of summer precipitation in the Qilian Mountains (Yang et al., 2014) as the precipitation series. These paleoclimate records were compared with archaeological data to illustrate the effect of climate change on human settlement patterns in the Hexi Corridor.

3.3 Subsistence strategy data

Various subsistence strategies were employed during different phases of the prehistoric period in the Hexi Corridor (Zhou et al., 2016; Yang et al., 2019b). During ~2800–2000 BC, people in the Hexi Corridor adopted a sedentary lifestyle, cultivating millet and raising pigs, sheep/goats, cattle, and dogs. Moreover, they began to cultivate wheat and barley beginning ~2000 BC. By ~2000–1000 BC, the strategy had shifted to semi-sedentary agro-pastoral production, based on the utilization of sheep/goats, pigs, cattle, dogs, and horses. During ~1000–200 BC, wheat and naked barley replaced millet as the major crops (Zhou et al., 2016; Yang et al., 2019b).

Historical materials and ancient documents were the primary sources for the records of crop and livestock species utilized in the Hexi Corridor used in this study. Crops and livestock from abroad were introduced into the region in three waves during the historical period (Zhou et al., 2016; Yang et al., 2019b). The first wave was during the Han dynasty, when, according to historical records, more than 20 crop species were planted in the Hexi Corridor and people began to raise chickens there. The second wave was during the Tang dynasty, when communication between China and Central and South Asia was strengthened by missionaries and merchants. Most of the crops introduced were vegetables, and people began to raise donkeys and mules. During the Ming and Qing dynasties, owing to the development of marine transportation, some crops from the Americas, such as corn, peanuts, sweet potatoes, and potatoes, were introduced into China, leading to the third wave (Zhou et al., 2016; Yang et al., 2019b). Supplementary Table S1 provides the numbers and names of those plant and animal species in the Hexi Corridor at various stages between the prehistoric and the historical periods.

3.4 Socio-economic data

The data for agricultural acreage and population in the historical period were extracted from Cheng (2007), which has a study area overlapping with ours and examines the period between 135 BC and AD 2004. Cheng estimated the cultivated land area in the Hexi Corridor in the historical period based on historical records of cultivated land area, population size, and production capacity. He also estimated the population data of the Hexi Corridor in the historical period using various historical records, as well as various methods from demography and historical geography. Data for wars were extracted from a multi-volume compendium of ancient Chinese wars (Local Historiography Committee of Gansu Province, 1989; Editorial Committee of Chinese Military History, 2003), in which the inception year, location, participants, proceedings, and results of wars that took place in China in 200 BC to AD 1911 were recorded in detail. We calculated the frequency of the wars that took place in the Hexi Corridor.

4 Result and Discussion

4.1 The spatial-temporal pattern of the archaeological sites in the Hexi Corridor

The spatial-temporal pattern of the archaeological sites dated between ~2800 BC–AD 1911 is shown in Fig. 1. Overall, the number of sites in the Hexi Corridor fluctuated over different periods. Only 255 archaeological sites were dated between ~2800–150 BC (including 11 Majiayao, 4 Banshan, 114 Machang, 16 Xichengyi, 21 Qijia, 56 Siba, 2 Dongjiatai, 12 Shanma, and 19 Shajing sites), far fewer than those in the historical period (including 635 Han, 140 Wei–Jin Southern and Northern, 60 Sui–Tang, 152 Western Xia–Yuan, and 391 Ming–Qing sites). The earliest agricultural culture in the Hexi Corridor was the Majiayao Culture (Shui, 2001; Li, 2009; Dong et al., 2013). The latest radiocarbon dating results show that people began to settle in the Hexi Corridor in the Majiayao cultural period (~2800 BC; Dong et al., 2018), and reached unprecedented levels of prosperity during the Machang cultural period, with the largest number of ancient sites. Sites of the Majiaoyao Culture and the Banshan Culture were scattered in the eastern part of the Hexi Corridor. The broadest spread of prehistoric sites occurred in the Machang Culture, when the majority of the sites spread westward along the Hexi Corridor, and some of the sites even extended to the Badain Jaran Desert (Wang et al., 2016).

The Qijia–Xichengyi Culture later gradually declined in terms of the number of archaeological sites. The sites of the Qijia Culture were mainly distributed along the eastern Hexi Corridor. Most of the Qijia sites were distributed near the Shiyang River and gullies, but some were on mountain ridges. At the same time, the sites of the Xichengyi Culture were distributed along the western Hexi Corridor. The sites of the Siba Culture were mainly distributed in the Heihe River basin and Shule River basin in the mid-west of the Hexi Corridor, and some of its sites reached the Badain Jaran Desert in the north. However, the number of archaeological sites in the Hexi Corridor fell significantly in the Bronze Age. Only two Dongjiatai (~1250–1050 BC) sites were found in the Hexi Corridor. In addition, 19 Shajing sites and 12 Shanma sites were distributed in the east and the west of Hexi Corridor, respectively.

In the historic period, the spatial distribution of ancient sites varied remarkably from one dynasty to another. The Second National Archaeological Survey conducted in Gansu Province (Bureau of National Cultural Relics, 2011) found 635 archaeological sites that were stylistically dated to the Han dynasty (121 BC–AD 220) and distributed across the entire Hexi Corridor region, particularly in the piedmont zones (Fig. 1). During the

Wei–Jin Southern and Northern (AD 220–589) and Sui–Tang (AD 581–907) dynasties, the number of sites declined (Figs. 1–2), and the majority of the sites were distributed in the middle reaches of the three river basins. Fewer than 200 sites associated with these periods have been discovered, and only 60 of them were built during the Sui–Tang dynasties, making that period the one with the fewest sites in the entire historic period. Compared with the Sui–Tang dynasties, the sites of the Western Xia–Yuan dynasties were not only distributed in the existing areas but also extended to the lower reaches of the Heihe River Basin. During the Ming–Qing (AD 1368–1912) dynasties, the sites were mainly distributed at relatively high altitudes, and only a few sites were distributed in the Shule, Shiyang, and Heihe River basins.

4.2 Human settlement patterns in the Hexi Corridor in response to climate change

High-resolution paleoclimate records from ice cores and tree rings show that climatic shifts did occur within the late Holocene and often coincided with twists and turns in human history (deMenocal, 2001). In prehistoric and historic times, human societies were still in a relatively primitive state of development, as they had low levels of agricultural productivity and were heavily dependent on the environment. Therefore, the physical environment had an important impact on the development of agriculture and culture (Tan et al., 2018; Wu et al., 2018). The impact of climate change on the economic boom and bust cycles of historical dynasties has attracted the attention of some scholars in recent years. For instance, in the 4th–6th centuries, the cold and wet weather led to poor harvests and famines, which triggered the great migration of Germanic peoples in northern Europe (Hsu, 1998). Climate change brought a widespread economic and social crisis to Europe in the 17th century (Zhang et al., 2011; Pei et al., 2013). The warm and humid climate affected agricultural productivity, health risks, and conflict magnitude, thus contributing to the prosperity of the Roman Empire (Büntgen et al., 2011). Past societies also benefited from a mild climate: ancient societies in the arid and semi-arid regions are often found in river valleys, where rivers played an essential role in supporting agriculture (Enzl et al., 1999; Harrower, 2016).

Located in the arid transitional eco-zone, the Hexi Corridor is very sensitive to climate change. Moreover, the water from the mountainous areas has a critical influence on the lower parts of the river basins. Precipitation and meltwater account for 89% and 11%, respectively, of the surface runoff in the Hexi Corridor (Shen et al., 2001). The amount of local precipitation and glacial meltwater coming from the Qilian Mountains changes with changes in the climate, thus affecting the total volume of streamflow in the Hexi Corridor (Yang et al., 2011; Sakai et al., 2012; Xu et al., 2014; Li Z X et al., 2016) and having a significant influence on the water supply to human settlements in the Hexi Corridor.

The climate was, overall, much warmer and wetter in the Hexi Corridor between ~2850 and 2000 BC. The development of the Majiaoyao Culture was facilitated by a favorable climate. From the Majiayao phase to the Banshan phase, the number of sites fell slightly, probably due to the drought in the Hexi Corridor between ~2500 and 2300 BC, as recorded in the Qinghai Lake sediments and the Dongge Cave and Jiuxian stalagmite records (Fig. 2). The prosperity and development of the Machang Culture (Fig. 2) were fostered by the relatively high and stable temperature and precipitation levels during ~2300–2050 BC. The number of sites increased, and the distribution of sites shifted westward to the middle of the Hexi Corridor (Fig. 1). For the Machang Culture, the economy reached unprecedented levels of prosperity when the primary economic activities were marked by agricultural production (Yang et al., 2019b), which indirectly indicates the relative abundance of natural resources as well as the warm and humid environment during this time.

In contrast, climate deterioration can cause changes in the economic strategies and settlement patterns of cultures. The temperature in the mid- and high-latitude regions in the Northern Hemisphere dropped gradually after ~2500 BC and reached its lowest point around ~1650 BC (Marcott et al., 2013). During the Qijia–Xichengyi cultural period, the climate was not as favorable as it was during the Machang cultural period, which triggered a reduction in the number of human settlements (Fig. 2). Subject to the impact of climate change, there was increasing desertification during this time, and agriculture was geographically confined to those river valleys in the Hexi Corridor (An et al., 2003; Zhou et al., 2012; Shen et al., 2018). Furthermore, many Qijia sites were located on mountain ridges, and the high elevation of those sites may reveal that a more complex subsistence strategy was adopted during the time. The number of Siba cultural sites was much greater than that of other cultures, due mainly to the relatively strong monsoon during that time (Dykoski et al., 2005; Cai et al., 2010). This also indicates that the agricultural economy was relatively prosperous because of the abundance of monsoonal precipitation.

After ~1500 BC, the climate became cold and dry, which caused the shrinkage of river systems and land degradation (Shen et al., 2005; Zhou et al., 2012). The agricultural culture was entirely replaced by a pastoral culture (Yang et al., 2019b), and the numbers of archaeological sites of the subsequent Shajing and Shanma Cultures are significantly smaller than that of the Siba Culture (Figs. 1 and 2). During the subsequent millennium (Shui, 2001; Bureau of National Cultural Relics, 2011; Li, 2011), Human settlement in the Hexi Corridor remained low, especially during 1350–950 BC—a period from which only two sites from the Dongjiatai Culture were found—and there were no cultural sites dating 100 years before and after the Dongjiatai Culture.

As the factors influencing the human–environment relationship are more complex during the historical periods, we compared the number of ancient sites with historical records of agricultural acreage, war, population, and paleoclimate to account for changes in human settlement patterns in the Hexi Corridor. Prior to the Han dynasty, the Hexi Corridor was mainly controlled by the Xiongnu. People began to settle intensively in the Hexi Corridor following the defeat of the Xiongnu by Emperor

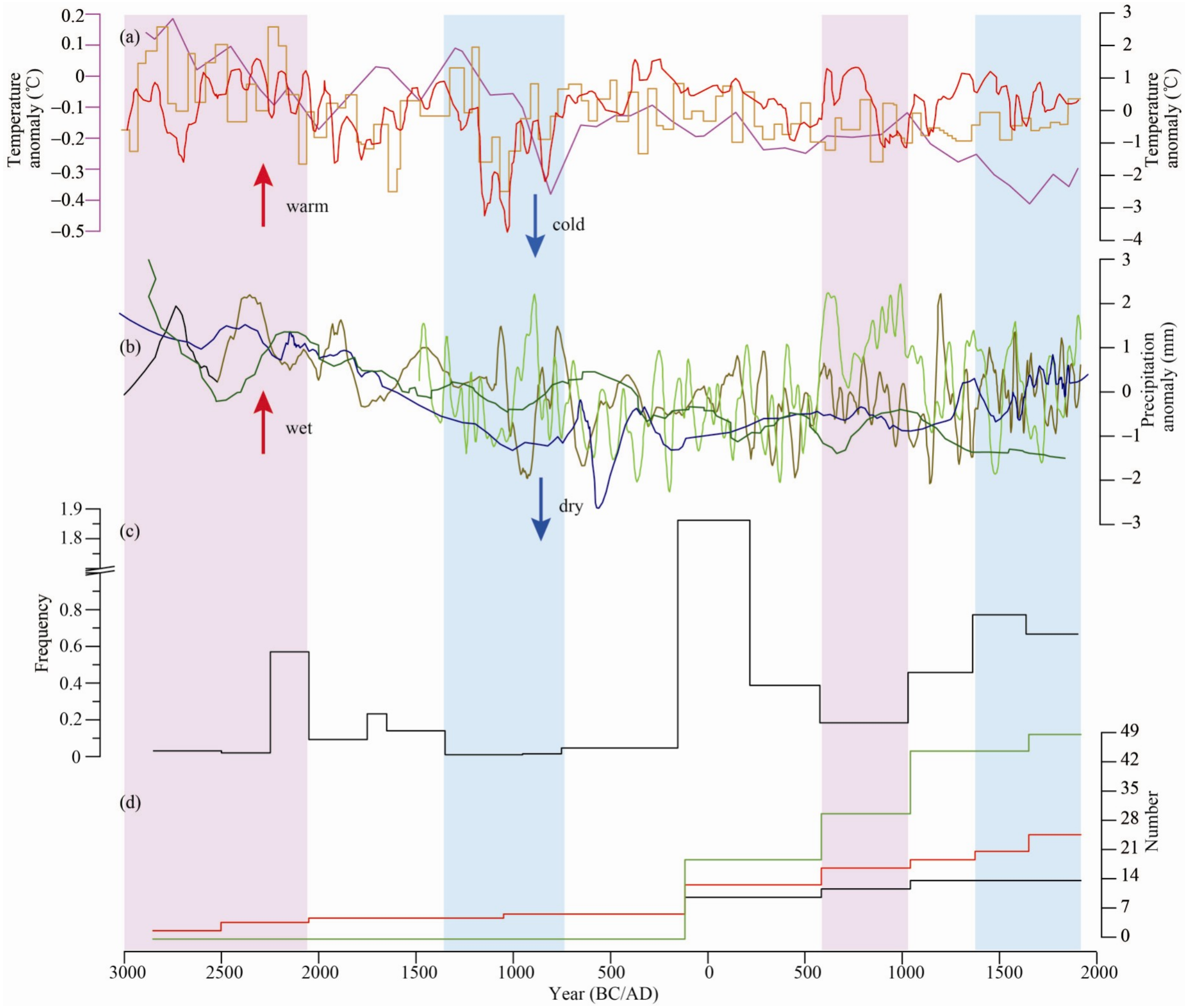

Fig. 2. Comparisons of paleoclimate records in the vicinity of the Hexi Corridor and the number of archaeological sites and the species of animal and plant resources.

(a) Proxy-based Northern Hemisphere temperature record reconstruction (purple line, Pei et al., 2017); $\delta^{18}O$ records from Puruogangri ice core as a proxy for temperature (yellow line, Duan et al., 2012); the flux of > 25 μm fraction from Qinghai Lake as a proxy for temperature (red line, An et al., 2012); (b) $\delta^{18}O$ record of the Asian monsoon strength from Dongge Cave stalagmite (blue line, Dykoski et al., 2005); precipitation reconstructed by speleothem oxygen isotopes of Jiuxian Cave (olive line, Cai et al., 2010); precipitation reconstructed by tree-ring in the Qilian Mountains (green line, Yang et al., 2014); precipitation reconstructed by pollen in the Qinghai Lake (dark green line, Li et al., 2017); (c) the frequency of ancient sites in the Hexi Corridor; (d) cumulative changes in plant and animal species in the Hexi Corridor from the Majiayao Culture to the Qing dynasty. The black line is the number of livestock species; the green line is the number of economic crop species; the red line is the number of crop species.

Wu of Han (141–87 BC) and occupation of the area to further the military and political purposes of the central government of the Han Empire. Moreover, according to 2,000-year multiproxy paleoclimate records in China (Fig. 3) and other evidence, the climate was warm during the Han dynasty, and the rainfall was also more abundant than during previous periods. Suitable climatic conditions facilitated rapid agricultural development in the Hexi Corridor from the reign of Han to the Early Jin dynasties, and the number of archaeological sites in the Hexi Corridor dated to the Han dynasty was the largest and most widely distributed over the last 5,000 years, especially in the lower reaches of the rivers (Fig. 1). The same phenomenon also occurred in the Western Xia–Yuan period, when the climate was warm but dry. Even though rainfall during the time was not abundant, it may have been compensated for by the increasing amount of meltwater from the Qilian Mountains brought by the warm climate (Yang et al., 2011; Sakai et al., 2012; Ding, 2015).

The precipitation reconstructed by tree-ring in the Qilian Mountains indicates that the climate was cold and dry during the Wei–Jin Southern and Northern dynasties (Figs. 2 and 3). Compared with the Han dynasty, the number of ancient settlements, population size, and agricultural acreage significantly declined in the piedmont zones. The human settlement area shrank sharply, and its center of distribution moved south. Water resources in the Hexi Corridor were an imperative factor limiting the development and sustainability of ancient settlements because precipitation and meltwater strongly determined the amount of river runoff and the course of rivers in the arid and semi-arid regions. The cold and dry climate during the Wei–Jin Southern and Northern and Ming–Qing dynasties may have been responsible for the decrease

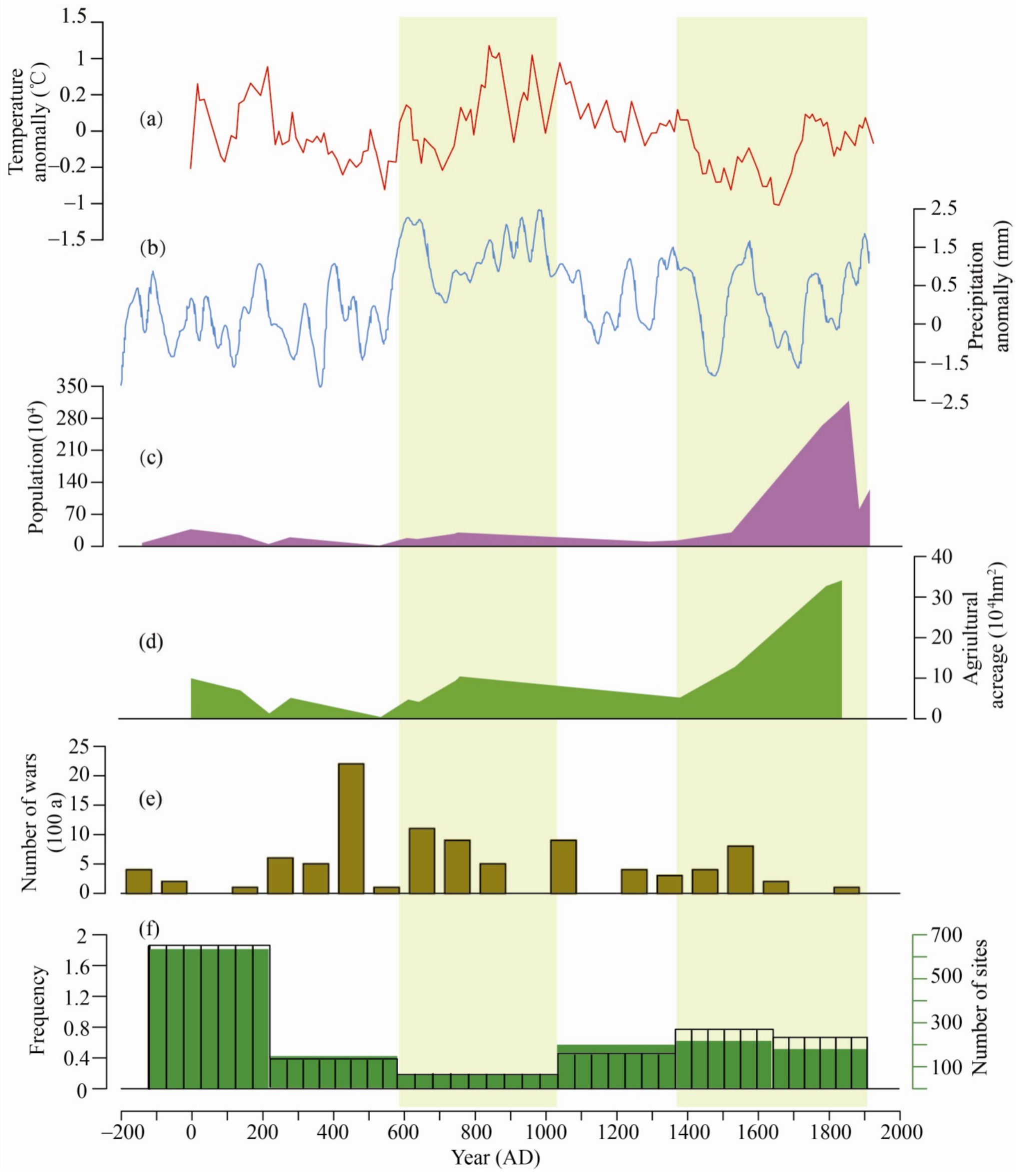

Fig. 3. Comparisons of paleoclimate records and the number of archaeological sites and the variation of population, agricultural acreage, and wars from the Han dynasty to the Qing dynasty in the Hexi Corridor.

(a) Precipitation reconstructed by tree-ring in the Qilian Mountains (Yang et al., 2014); (b) temperature reconstructed by multiple paleoclimate proxy records in China (Yang et al., 2002); (c) the population in the Hexi Corridor (Cheng, 2007); (d) agricultural acreage of the Hexi Corridor (Cheng, 2007); (e) frequency of wars in the Hexi Corridor (Local Historiography Committee of Gansu Province, 1989; Editorial Committee of Chinese Military History, 2003); (f) the number of ancient sites, as well as their settlement density in the Hexi Corridor.

in the number of ancient sites and the massive site abandonment in the lower reaches of rivers. The cold and dry climate that lasted for centuries since ~AD 270 may have been responsible for the subsistence shortage, political instability, and frequent wars.

The Ming–Qing period was during the Little Ice Age (c. AD 1400–1900) and had a cold and dry climate. However, the population and agricultural acreage during the time were the largest in our study period. In parallel, although the paleoclimate records suggest that the Sui–Tang period was warm and humid, the number of ancient settlements in the Hexi Corridor is the lowest in the historical period. These results suggest that, although climate change is an important factor affecting social development, it is not the only factor accounting for the changes in human settlement patterns in the Hexi Corridor at all times, at least in the historic period.

4.3 The influence of environmental and social factors on human settlement patterns in the Hexi Corridor

Located in the arid and semi-arid agro-pastoral ecotone, the Hexi Corridor was a key hub of trans-Eurasian cultural exchange in both prehistoric and historic periods. Climate change, geopolitics, and technological innovation may all have been important factors shaping the social development of this region. We compared the paleoclimate records with the number of human settlements and the plant and animal species utilized by humans in the Hexi Corridor. The results show that the patterns of human-environmental interaction were different between prehistoric and historic periods. There were distinct warm and cold phases in both prehistoric and historic periods, respectively. However, such climatic fluctuation produced different social outcomes in terms of human settlement patterns. In the prehistoric period, the warm climate facilitated the increase and spread of human settlements; in the historic period, the opposite was the case. This reveals the influence of non-climatic factors in mediating the climate–human nexus in the Hexi Corridor in the historic period. We try to explain this phenomenon.

4.3.1 The influence of trans-Eurasian cultural exchange on human settlement patterns in the Hexi Corridor

The earliest settlements and the beginning of agricultural culture in the Hexi Corridor in the prehistoric period were during the Majiayao phase of the Majiayao Culture in the Late Neolithic period (Li, 2009, 2011; Shui, 2001). According to published radiocarbon data (Zhou et al., 2016; Dong et al., 2017b), no Fertile Crescent crops, but only East Asian indigenous crops, such as foxtail and broomcorn millet, were cultivated in the Hexi Corridor during the Majiayao (~2850–2050 BC) and Machang (~2250–2050 BC) cultural phases. Later, drought-resistant crops such as wheat and barley, a variety of animals such as sheep and cattle, and cultural elements such as metallurgy, were introduced from Western Asia to the Hexi Corridor around 2000 BC (Flad et al., 2007, 2010; Dodson et al., 2013; Dong et al., 2017b; Zhang et al., 2017). The emergence and intensification of trans-Eurasian cultural exchanges after ~2000 BC contributed to the agricultural transformation and human subsistence diversification in the Hexi Corridor (Zhou et al., 2016; Dong et al., 2017b). The dietary isotopic analyses of proteins from human and animal skeletal remains excavated in the region (Atahan et al., 2011; Liu et al., 2014; Liu et al., 2016) are also evidence of this. With the diversification of human subsistence strategies, human resilience to climate change and natural disasters increased, which facilitated the development of the Qijia, Xichengyi, and Siba Cultures in this region. Despite the advances of human societies, people were still limited by the physical environment. With the arrival of the New Ice Age (Cui, 1979; Wu, 1984), which corresponded exactly to the first cold period (~1300–950 BC), human settlements in the Hexi Corridor dropped to their lowest number (Fig. 2).

The Silk Road played an important role in cultural exchange between East and West in the historic period since the Han dynasty. The rise of the Silk Road resulted in the first peak in the introduction of plant and animal species in the Hexi Corridor during the Han dynasty (Liu, 2012). *Hanjian* (Bamboo Book of Han) (Ban and Han, 2009; Gao, 2014) mentions more than 20 cereal, vegetable, and cash crop species. In addition, a large number of people migrated to the Hexi Corridor after Emperor Wu of Han (141–87 BC) defeated the Xiongnu. Advanced agricultural production technologies were also introduced into the Hexi Corridor by the influx of migrants and troops. Thanks to preachers such as Xuanzang (AD 602–664) and merchants, communication between the Central Plain, Central Asia, and South Asia was strengthened. Cultural exchanges were at their highest level in Chinese history during the Tang dynasty. The introduction of a large number of exotic plants, animals, and advanced technologies into China via the Silk Road had a profound impact on Chinese civilization (Liu, 2012).

The second cold period in the Hexi Corridor occurred during the Ming and Qing dynasties, which coincided with the Little Ice Age. Despite the cold and dry climate, the number of human settlements in the region increased (Fig. 2). This may be attributable to the introduction of high-yield and cold/drought-resistant crops to the Hexi Corridor (Lv, 2000; Liu, 2012). Moreover, a variety of agricultural disaster-mitigating measures were implemented (e.g., building irrigation canals and dredging trenches, unifying water conservation projects, and controlling the flooding of rivers) (Lu, 1991; Peng, 2009; Yan, 2009). This resulted in another large-scale wave of development in agriculture and a drastic increase in the population of the Hexi Corridor. Traditional crops such as wheat, millet, and beans were replaced by American crops such as corn and potatoes. The traditional planting structure was transformed, and the grain yield was greatly improved (Li et al., 1984; Wang, 2006; Peng, 2009). The historical records and the plant and animal remains excavated from archaeological sites reveal that people cultivated more varieties of crops, vegetables, and cash crops during this time (Fig. 3). Meanwhile, the development of farm tools was rapid in the Ming–Qing period, and the use of manual tilling tools, daigeng frames, and trench plow made agricultural production more efficient. Intensive tillage techniques and shallow-deep-shallow cultivation significantly improved crop yields (Peng, 2009). Agricultural development and advanced farming methods improved social resilience to climate deterioration and weakened the influence of the climate on human settlements in the Hexi Corridor.

4.3.2 The influence of geopolitics on human settlement patterns in the Hexi Corridor

The largest number of archaeological sites in the prehistoric period date from the Majiayao–Banshan–Machang Cultures, corresponding with the first warm period (about ~2850–2000 BC). When ancient people first arrived in the Hexi Corridor, they mainly engaged in hunting and gathering and primitive agricultural activities until ~2850 BC, when the Majiayao Culture spread to the region. The Majiayao was followed by the Banshan, Machang, Qijia, Xichengyi, Siba, Dongjiatai, Shanma, and Shajing Cultures. During the first warm period, the Hexi Corridor had only a small number of cultures and no sizable polities, while the favorable climate facilitated the spread of human settlements during this time.

Due to the unique geographic and strategic location of the Hexi Corridor, the conflicts between the agrarian and the nomadic polities became more frequent during the historical period. According to historical documents such as *Shiji* (Records of the Grand Historian) and *Hanshu* (Book of Han), Emperor Wu of Han (157–87 BC) defeated the Xiongnu, occupied the Hexi Corridor, and established four counties (*Jun*) in 121 BC. The Han dynasty established a garrison in the Hexi Corridor to protect the Silk Road and the Central Plain from nomadic invasion. During the Wei–Jin Southern and Northern dynasties, this region experienced frequent changes in political regimes, and wars between the Chinese dynasties and nomadic polities frequently occurred—as many as 31 times—during this period. Together with the cold and dry climate, this caused the population and agricultural production in the region to shrink drastically (Gao, 2003). During the Song–Yuan dynasties, the Hexi Corridor was occupied by the Western Xia and then the Yuan dynasties. The number of archaeological sites increased significantly during this period due to the policies of the Western Xia and Yuan dynasties toward developing agriculture and animal husbandry and the introduction of advanced farming methods in the region (Li, 2001; Shi et al., 2014).

The Tang dynasty coincided with the second warm period. Although high-resolution paleoclimate records show that the climate during this period was warm and humid (Yang et al., 2002, 2014; Qiang et al., 2005), the number of sites decreased from the previous stage and reached its lowest point in the historical period, suggesting that climate change is not the only factor determining human settlement patterns. According to the *Suishu* (Book of Sui) and the *Jiutangshu* (Old Book of Tang), during the Sui–Tang period, the Central Plain was surrounded by nomadic polities, such as Turkestan in the northern steppe and the Tubo and Tuyuhun in the Tibetan Plateau. In particular, the Tubo was the strongest rival of the Tang dynasty for nearly two hundred years, posing a profound threat on the Central Plain. The climate was warm and humid during the Sui and Tang dynasties, which promoted the development of agriculture. The reigns of Zhenguan and Kaiyuan marked the golden days of the Tang dynasty. In parallel, the warm climate also made the high-latitude northern frontier regions suitable for agricultural production. A large number of people moved to the frontier regions for farming, and oasis agriculture in the Hexi Corridor was developed on a large scale. At the same time, nomadic groups such as the Turkic peoples and Uighurs also inhabited the north of the frontier.

In the Tibetan Plateau, where Tubo was located, the main food crop was highland barley. The physical environment was harsh in the Tibetan Plateau, and the yield of highland barley was relatively low. Moreover, the arable area was not extensive, which was the major constraint on population growth and the expansion of the Tubo. However, during the Sui and Tang dynasties, the warm and humid climate facilitated the rise of the Tubo. The favorable climate significantly promoted the growth of highland barley and local herbage (Wan et al., 2018), and the yield improved greatly. Furthermore, highland barley could also be grown in areas in which it could not previously be grown. The development of agriculture and animal husbandry significantly enhanced the national and military strength of the Tubo, enabling them to compete with the Tang in the east and the Arabs in the west. Therefore, although the climate of the Sui–Tang dynasties was favorable, it still resulted in territorial conflicts between the Tang and the Tubo because the latter had been strengthened by the favorable climate. Thus, wars became more frequent, leading many people to either abandon their lands or leave the Hexi Corridor. The number of archaeological sites was also at its lowest in the historical period during the Sui–Tang dynasties.

5 Conclusion

This study examines the interplay between climate change, human settlement patterns, subsistence strategies, and geopolitics in order to explicate the diverse patterns of human–environment interactions in prehistoric and historical periods. The results show that climatic fluctuation produced different social outcomes in terms of human settlement patterns. The warm and humid climate during ~2800–2000 BC may have promoted millet agriculture and thus allowed the Majiayao, Banshan, and Machang Cultures to flourish. The cold and dry climate during ~2000–100 BC probably resulted in the divergence and transformation of subsistence strategies in the Xichengyi–Qijia–Siba and Shajing–Shanma Cultures and then influenced human settlement patterns in the Hexi Corridor. Afterward, the change of human settlement patterns was not directly associated with climate change, indicating that the latter was no longer the sole factor determining the fate of human societies in the Hexi Corridor. In the historic period (121 BC–AD 1911), technological innovation brought by trans-Eurasian cultural exchange since ~2000 BC enriched human subsistence strategies, improving social resilience to climate deterioration. However, the alternating rule of various regimes and frequent wars caused by geopolitical conflicts significantly affected human settlement patterns during this time, especially during the Sui–Tang dynasties. The findings illustrate the transformation of the human–environment nexus and its associated processes across prehistoric and historic periods and may provide insights into how human societies reacted to climate change in arid and semi-arid environments over the long term.

Acknowledgments

This study was supported by the National key R&D Program of China (Grant 2018YFA0606402), the Strategic Priority Research Program of Chinese Academy of Sciences, Pan-Third Pole, Environment Study for a Green Silk Road (Pan-TPE) (grant no. XDA20040101), the second Tibetan Plateau Scientific Expedition and Research Program (STEP) (Grant No. SQ2019QZKK2201), the Improvement on Competitiveness in Hiring New Faculties Funding Scheme (4930900) and Direct Grant for Research 2018/19 (4052199) of the Chinese University of Hong Kong.

Manuscript received Mar. 1, 2020
accepted Apr. 2, 2020
associate EIC: CHEN Fahu
edited by FEI Hongcai

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