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CHRONOLOGY AND PLANT UTILIZATION FROM THE EARLIEST WALLED SETTLEMENT IN THE HEXI CORRIDOR, NORTHWESTERN CHINA

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ABSTRACT. The development and subsistence strategies adopted in ancient settlements are crucial to the understanding of long-term human–environmental interaction in the past. Here, we reassess the chronology of the ancient walled settlement of Sanjiao in the Hexi Corridor in northwestern China through accelerator mass spectrometry radiocarbon (AMS ^{14}C) dating and explore the subsistence of the settlers inside through the identification of carbonized seeds and charcoal. In addition, high-resolution paleoclimate records in the Hexi Corridor and nearby regions are employed to explore the reason for the construction of Sanjiao. Our results show that Sanjiao was built around 828 cal BC and remained inhabited through 384–116 cal BC. This indicates Sanjiao is the earliest known walled settlement in the Hexi Corridor. Ancient people at Sanjiao consumed crops such as barley, broomcorn millet, and foxtail millet, and used wood from *Tamarix chinensis*, *Tamarix*, *Salix*, *Picea*, *Hippophae*, *Betulacea*e, and *Poaceae* as fuel. The construction date of Sanjiao correlates with climate deterioration and social upheavals in the Hexi Corridor, potentially suggesting a defensive purpose for the site.

KEYWORDS: ancient walled settlement, Hexi Corridor, radiocarbon dating, subsistence strategy.

INTRODUCTION

Ancient walled settlements are considered important symbols of human civilization (Redfield and Singer 1954; Sun 1990; Wang 1995; Yan 1999; Qian 2000; Xu 2009; Gates 2011). The research of ancient walled settlements has not only revealed information about military, religion, and the economy in the past (Zuiderhoek 2016), but also provided valuable knowledge of human–environmental interaction in human history (Dong et al. 2016a). The ancient walled settlements in China are of great scientific value as China is the locus of the first empire to be established in East Asia, which has undergone gradual sociopolitical transitions from conflicting territorial states to a prosperous empire. The investigation of the ancient walled settlements in China may help understand the social evolution, rising social complexity, and the emergence of early states in East Asia.

The earliest ancient walled settlement in China appeared in the north-central region during the late Yangshao Period (3500–3000 BC) (Zhang et al. 1999). During the Longshan Period (2600–2000 BC), numerous walled settlements emerged along the Yellow River and Yangtze River valleys (Qian 2000), which indicate a dramatic transformation of social structure, possibly brought by a relatively cold and dry climate (Marcott et al. 2013; Wanger et al. 2013; Chen et al. 2015a; Hosner et al. 2016). This transformation preceded the emergence of ancient civilizations in the Xia and Shang Dynasties in the second Millenium BC. Later, the Zhou Dynasty (Western Zhou and Eastern Zhou) (1046–221 BC) witnessed a further significant change in politics, society, and scholarship. Also, conflicts became more frequent, while

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more walled settlements were built for the protection of inhabitants (Qian 2000). Despite the considerable academic value of ancient walled settlements in China, they remain insufficiently explored, especially those in the Hexi Corridor in northwestern China.

The ancient Silk Road played a critical role in the transcontinental cultural and technological exchanges that took place from the second millennium BC. In Chinese history, the Hexi Corridor was a crucial military node and the key section of the ancient Silk Road connecting China and Central Asia (Dong et al. 2018). Most ancient walled settlements in the Hexi Corridor are dated between Han (202 BC–AD 220) and Qing (AD 1644–1911) Dynasties, which are thousands of years later than those in the Yellow and Yangtze River valleys. The notable exception is the Sanjiao walled settlement in Jinchang, which has been dated between 1110–430 cal BC. Sanjiao is generally considered as "the earliest walled settlement" in the Hexi Corridor (Pu and Pang 1990; Li 1997).

Nevertheless, there is uncertainty around the dated age of Sanjiao. So far, only two charcoal samples from the cultural units at Sanjiao have been collected for dating, with the liquid scintillation counting (LSC) dating method employed (IACASS 1981; Table 1). Although those samples give the approximate time range from the foundation to abandonment or destruction of Sanjiao, they may not be sufficient to determine the precise age of the initial construction of the site (Shao 2012). Also, the age of the walls rather than that of potentially later contexts within those walls (i.e., cultural units) could give a more accurate estimate about the age of the settlement. Hence, there is a need to reassess the chronology of Sanjiao (Schiffer 1986; Dong et al. 2014). Furthermore, other issues pertinent to Sanjiao such as how the inhabitants of Sanjiao adapted to local environmental conditions and why Sanjiao was built remain unexplored. Resolving the above issues is vital in supplementing the history of the Hexi Corridor and tracking the historical development of the ancient Silk Road. In this study, we employ accelerator mass spectrometry radiocarbon (AMS ^{14}C) dating to remeasure samples from Sanjiao and reassess its chronology. Also, we explore the subsistence strategies of the site inhabitants according to the identification of charred plant seeds and charcoal. Finally, the purpose of building Sanjiao itself is explored.

STUDY AREA

Sanjiao is located near the modern city of Jinchang, in the east-central section of the Hexi Corridor, surrounded by the Qilian Mountains and Badain Jaran Desert (Figure 1). The altitude of Jinchang decreases gradually from the southwest to the northeast, with a mean altitude of 1500 m asl. The climate in the region is arid and windy, with a mean annual temperature of 9.5°C and mean annual precipitation of 122.3 mm (Huang et al. 2018). The Dongda and Xida Rivers flow from the Qilan Mountains through this region.

Sanjiao was first discovered and excavated in the 1980s. Pu and Pang (1990) considered Sanjiao to be an ancient city. However, in comparison to other ancient settlements in central China, Sanjiao appears to have been less developed and somewhat smaller, which is better to be considered as a walled settlement. Sanjiao is oriented toward the south, with an irregular triangle-shape. The site measures 154 m from north to south and 132 m from east to west. The walls of Sanjiao are made of piled earth and are 6–8 m thick at their base (Figure 2).

Sanjiao is classified as part of the Late Bronze Age Shajing Culture (1000–400 BC) based on the unique ceramics unearthed there (Pu and Pang 1990). This places the site later than the

Table 1 Radiocarbon dates from Sanjiao.

Lab no.	Dating method	Dated material	^{14}C age (BP)	Calibrated age (cal yr BC) (68.2%)	Calibrated age (cal yr BC) (95.4%)	Site	Reference
BK-79062	LSC	Deadwood (species unknown)	2730 ± 95	980BC (68.2%) 804BC	1206BC (0.1%) 1202BC 1196BC (2.0%) 1140BC 1134BC (93.1%) 758BC 678BC (0.2%) 672BC	Hamodun	Xie 2002
BK-79063	LSC	Deadwood (species unknown)	2680 ± 125	1024BC (62.9%) 751BC 682BC (1.7%) 668BC 636BC (1.1%) 626BC 614BC (2.6%) 592BC	1192 (0.7%) 1173BC 1164 (0.8%) 1144BC 1131 (93.2%) 476BC 462BC (0.2%) 456BC 444BC (0.5%) 431BC	Hamodun	Xie 2002
BK-79064	LSC	Deadwood (species unknown)	2570 ± 100	826BC (27.1%) 726BC 720BC (3.0%) 704BC 695BC (38.0%) 540BC	898BC (95.4%) 412BC	Hamodun	Xie 2002
ZK-0789	LSC	Deadwood (species unknown)	2540 ± 80	802BC (23.6%) 728BC 693BC (44.6%) 542BC	815BC (95.4%) 414BC	Hamodun	Xie 2002
ZK-0739	LSC	Charcoal	2675 ± 100	978BC (68.2%) 770BC	1110BC (95.4%) 540BC	Sanjiao	IACASS 1981
BK-79030	LSC	Charcoal	2600 ± 90	892BC (2.7%) 878BC 846BC (36.1%) 736BC 688BC (6.2%) 663BC 647BC (23.3%) 548BC	924BC (95.2%) 430BC	Sanjiao	IACASS 1981
LZU-14218	AMS	Barley	2230 ± 20	364BC (9.0%) 352BC 295BC (54.5%) 229BC 220BC (4.7%) 212BC	380BC (17.1%) 346BC 321BC (78.3%) 206BC	Sanjiao	This study
LZU-14219	AMS	Barley	2165 ± 25	350BC (38%) 304BC 210BC (30.2%) 173BC	358BC (47.5%) 278BC 259BC (2.0%) 242BC 236BC (43.5%) 156BC 134BC (2.5%) 116BC	Sanjiao	This study

Table 1 (*Continued*)

Lab no.	Dating method	Dated material	^{14}C age (BP)	Calibrated age (cal yr BC) (68.2%)	Calibrated age (cal yr BC) (95.4%)	Site	Reference
LZU-14221	AMS	Barley	2230 ± 30	366BC (10.1%) 351BC 300BC (58.1%) 210BC	384BC (20.8%) 339BC 328BC (74.6%) 204BC	Sanjiao	This study
LZU-17056	AMS	Charcoal	2540 ± 25	794BC (47.6%) 752BC 682BC (9.3%) 668BC 621BC (11.3%) 592BC	798BC (50.3%) 744BC 686BC (11.3%) 665BC 644BC (33.8%) 551BC	Sanjiao	This study
LZU-17057	AMS	Charcoal	2580 ± 25	800BC (68.2%) 776BC	810BC (93.9%) 756BC 679BC (1.0%) 672BC 603BC (0.5%) 598BC	Sanjiao	This study
LZU-17059	AMS	Charcoal	2650 ± 25	821BC (68.2%) 800BC	888BC (1.1%) 882BC 842BC (94.3%) 792BC	Sanjiao	This study

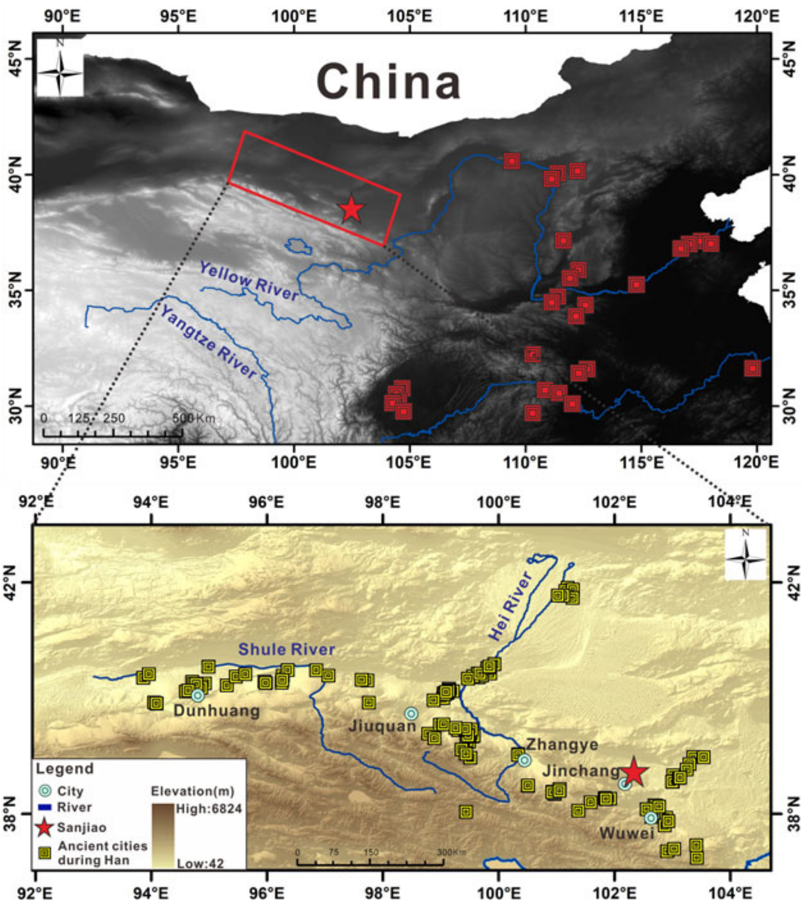

Figure 1 The distribution of ancient walled settlements in China and the Hexi Corridor: yellow squares represent the walled settlements built in the Han Dynasty; red squares represent the walled settlements built before the Han Dynasty; the star represents the Sanjiao walled settlement. (Please see electronic version for color figures.)

Machang type of the Majiayao Culture (2300–2000 BC), Qijia Culture (2300–1500 BC), and Siba Culture (1900–1400 BC) in the Hexi Corridor.

MATERIALS AND METHODS

Fieldwork was conducted at Sanjiao in 2014 and 2017. During the 2014 fieldwork, we collected 10 soil samples from different cultural contexts inside the Sanjiao walled settlement. Three were obtained from ash pits and seven were derived from different cultural layers as shown in Figure 2A. During the 2017 fieldwork, we collected three soil samples from the base of the walls in the northwestern part of Sanjiao. One of them was taken from the surface of the wall (Figure 2D), and two of them were taken inside the wall (Figure 2C). All of the soil samples were processed by the flotation method. The soil was washed over in a bucket with a #80 mesh sieve (aperture size of 0.2 mm) to gather any carbonized remains. The carbonized remains were dried in the shade and then sorted. Charred plant seeds were

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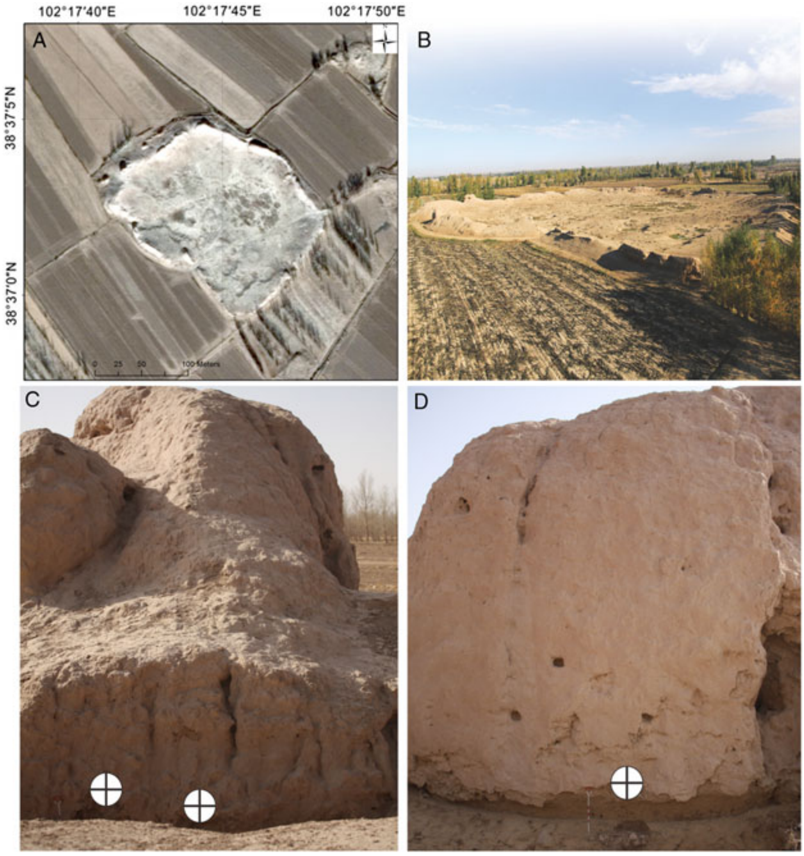

Figure 2 Remote-sensing image and photographs of Sanjiao: remote-sensing image of Sanjiao; (B) photograph of the whole Sanjiao walled settlement; (C) and (D) the walls of Sanjiao from which the charcoal samples are collected (white dots).

identified by Professor Jingang Yang at the Paleoethnobotany Laboratory, Institute of Archaeology, Chinese Academy of Social Science. Charcoal was identified according to its cellular structure under a reflected light microscope in the MOE Key Laboratory of Western China's Environmental Systems at the Lanzhou University.

Charcoal from the walls as well as charred barley seeds from three different contexts (including an ash pit and two cultural layers) were dated. The two types of material were dated to cross check and validate the resulting ages. All samples were prepared with the standard pretreatment (acid-alkali-acid) in the MOE Key Laboratory of Western China's Environmental Systems at the Lanzhou University. The carbonated samples were treated in 2 mol/L hydrochloric acid (HCl) at 60ºC. The HCl solution was refreshed every two hours until no effervescence was observed. Then, samples were rinsed with distilled water, soaked in 0.5 mol/L NaOH at 60ºC. The NaOH solution was also refreshed every two hours until the liquid became clear. Third, those samples were treated under 1 mol/L hydrochloric acid (HCl) at 60ºC for 2 hr and rinsed again with distilled water. Lastly, the samples were dried for 48 hr for AMS ^{14}C dating performed at Peking University. Ages were calibrated using the OxCal v4.3.2 online program (Bronk and Lee 2013) and the IntCal13 calibration curve

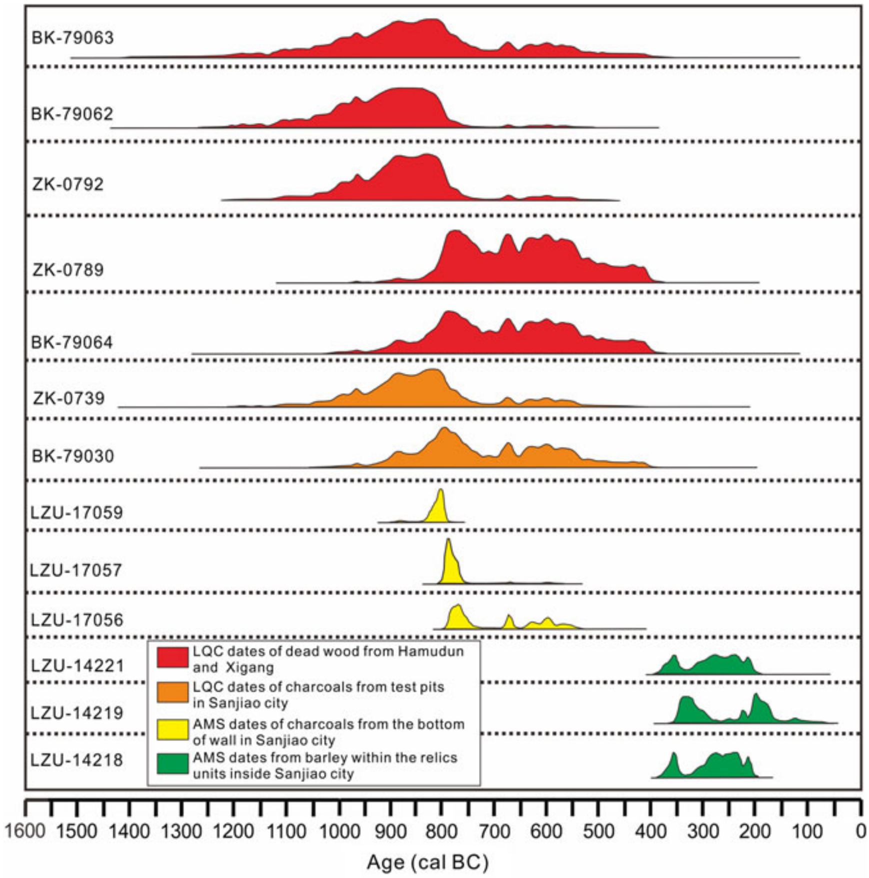

Figure 3 The comparison of the probability of ^{14}C dates from Sanjiao and the tombs nearby: the red ones represent the LSC dates of dead wood from Hamudun and Xigang tombs by Xie (2002); the orange ones refer to the LSC dates of charcoal from test pit in Sanjiao by Xie (2002); the yellow ones are the AMS dates of charcoal from the walls in Sanjiao (this study); the green ones are the AMS dates of barley from the Shajing cultural layers inside Sanjiao (this study).

(Reimer et al. 2013). Also, phase modeling in the OxCal v4.3.2 program was employed to give a more robust estimate of Sanjiao's initial construction date. All ages are reported as "cal. AD/BC."

RESULTS

Archaeologically, the ages the walls of Sanjiao could give a better chronology of Sanjiao's initial construction date. The three AMS ^{14}C ages derived from the charcoal from the walls are relatively close and fall into the period 888–551 cal BC (Figure 3; Table 1), which coincides with the Western Zhou (1046–771 BC) and spring and autumn periods (770–476 BC). The result of the phase modeling further shows that the walls of Sanjiao were built in the period 855–797 cal BC, with the median age of 828 ± 92 cal BC (Figure 4). The ^{14}C dates from the contexts inside Sanjiao more likely reflect the length of occupation. For the three AMS ^{14}C dates derived from charred barley seeds in the Shajing contexts within

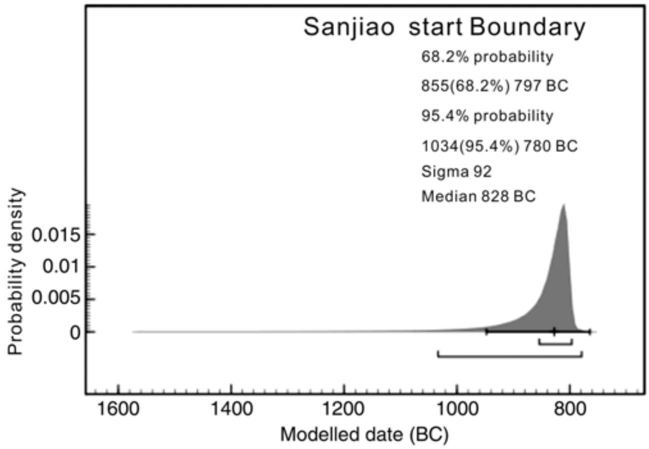

Figure 4 The modeled age ranges of Sanjiao's walls and their median: the start boundary of wall construction is shown with 68.2% and 95.4% probability range.

Sanjiao, one in the ash pit is dated 380–206 cal BC. The two others in cultural contexts are dated at 358–116 and 384–204 cal BC, respectively (Figure 3; Table 1). Our AMS dates from the charred barley seeds fall between the mid-late Warring States Period (475–221 BC) and early Qin-Han Dynasties (221 BC–AD 9), indicating Sanjiao was inhabited during the mid-late Warring States and early Qin-Han Dynasties in China.

Through the flotation of soil samples from different contexts inside Sanjiao, 469 charred plant seeds of 17 taxa were identified (Figure 5; Table 2). Among these charred seeds, the crop seeds including broomcorn millet, barley, and foxtail millet are found in the largest proportion (Figure 5; Table 2). Charred grass seeds of 14 taxa were identified, including Squarrose Agriophyllum (*Agriophyllum squarrosum (L.) Moq*.), Lambsquarters (*Chenopodium album L*.), Common Russian Thistle (*Salsola collina Pall*.), Salsola ruthenica (*Salsola ruthenica lljin*), Green Bristlegrass (*Setaria viridis (L.) Beauv*.), Barnyardgrass (*Echinochloa crus galli (L.) Beauv*.), Garden Sorrel (*Rumex acetosa Linn*.), Dockleaved Knotweed (*Polygonum lapathifolium L*.), Sphaerophysa salsula, Alhagi sparsifolia, Nitraria sibirica Pall., Chinese Iris (*Iris lacteal pall. var. chinensis Koidz*), Vittaria flexuosa, and Carolina Geranium (*Geranium carolinanum L*.) (Figure 5; Table 2). Additionally, a total of 894 pieces of charcoal of seven taxa were identified, including Tamarix chinensis, Tamarix (*Tamarix L*.), willow (*Salix L*.), spruce (*Picea*), sea buckthorn (*Hippophae*), Poaceae, and birch (*Betulaceae L*.) (Figure 6; Table 3).

DISCUSSION

Sanjiao is the Earliest Walled Settlement in the Hexi Corridor

Previous studies, which were based on conventional ^{14}C dates from Sanjiao and the nearby Hamodun and Xigang tombs, stated that Sanjiao was built during the Shajing Period (1000–400 BC; Table 1; Pu and Pang 1990; Xie 2002). Yet, those ^{14}C dates may be inaccurate due to the "old wood effect" (Dean 1978; Schiffer 1986; Dong et al. 2014). The ^{14}C dates obtained from charcoal or dead woods unearthed from archaeological sites may

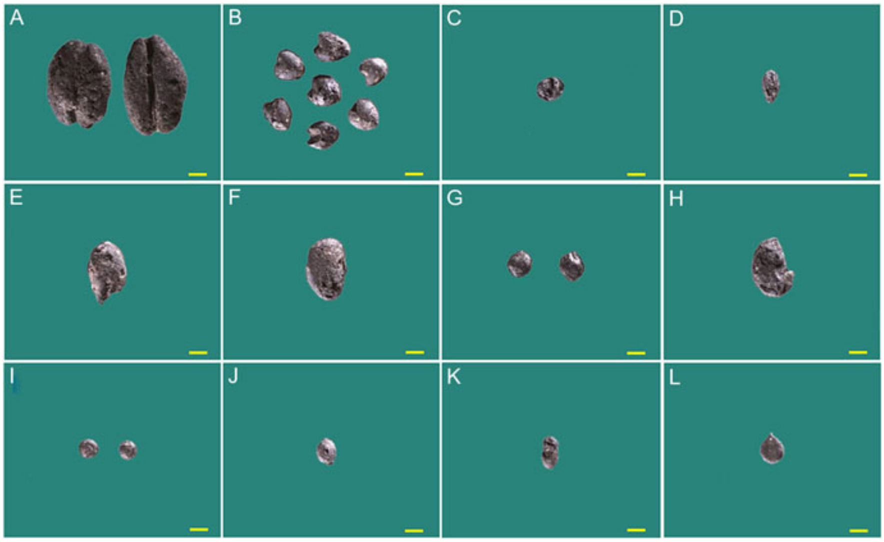

Figure 5 Charred seed remains from Sanjiao: (A) *Hordeum vulgare*; (B) *Panicum miliaceum*; (C) *Setaria italica*; (D) *Setaria viridis* (*L.*)*Beauv*.; (E) *Nitraria sibirica Pall*.; (F) *Iris lacteal pall. var*.; (G) *Agriophyllum squarrosum* (*L.*)*Moq*.; (H) *Sphaerophysa salsula*; (I) *Salsola collina Pall*. (J) *Echinochloa crus galli* (*L.*)*Beauv*.; (K) *Geranium carolinanum L*.; (L) *Polygonum lapathifolium L.*

be much older than the actual age of those sites, as the dated material could have originated from long-lived trees that grew decades or centuries before their utilization by settlers (Dong et al. 2014). Additionally, the dates from Sanjiao were all measured through LSC. Compared to LSC, the advantage of AMS is that only tiny amount of carbon-containing material is required for dating, which decreases the chance of mixing carbon from different sources (Lanting and van der Plicht 2015).

The AMS ^{14}C dates of our charcoal obtained from the walls of Sanjiao match very well. Also, they correspond with the previous LSC ^{14}C dates of charcoal obtained from the cultural contexts of Sanjiao (Figure 3), suggesting a minimal "old wood effect." Their good match may be related to the absence of old trees or forests around the site. Taking northeastern Tibetan Plateau as an example, the farmers of the Majiayao Culture in the Loess Plateau started to settle in that area during the mid-late Holocene (Chen et al. 2015b), a time when the forest was abundant according to the tree pollen record of the Qinghai Lake (Shen et al. 2005). At different Majiayao sites, there is a considerable disparity of ^{14}C dates between charcoal and charred seeds, even though those materials are obtained from the same cultural contexts. This could be attributable to the utilization of old trees in those sites, subjecting the dating materials to the "old wood effect" (Dong et al. 2014).

The climate became cold and dry during 4200–2800 BP (Mischke and Zhang 2010), and the reduction of tree pollen suggests that forest was gradually replaced by the shrubs and herbs (Shen et al. 2005). This coincides with the establishment of the agro-pastoral economy and the associated expansion of grazing on the northeast Tibetan Plateau (Chen et al. 2015b; Dong et al. 2016b).

Due to continuous cultural exchange across Eurasia during the Bronze Age, in the Hexi Corridor, the subsistence strategies were changed from millet agriculture to the

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Table 2 Taxa of charred plant seeds and their total number and relative frequencies from Sanjiao.

Taxa		Ash pit 1	Ash pit 2	Ash pit 3	Cultural layer 1	Cultural layer 2	Cultural layer 3	Cultural layer 4	Cultural layer 5	Cultural layer 6	Cultural layer 7	Frequency (%)	Total number
Agriculture crop	*Hordeum vulgare L.*	9	21	15	19	22	1	13	38	22	9	100	169
	Panicem miliaceum	5	4	23	24	26	4	8	61	7	5	100	168
	Setaria italica					2					2	20	4
Chenopodiaceae	*Chenopodiaceae album L.*					1			3		4	30	8
	Salsola collina Pall					2	13		3		1	40	19
	Salsola ruthenica			7								10	7
	Agriophyllum squarrosum								61			10	61
Poaceae	*Setaria viridis*			1			3		4			30	8
	Echinochloa crusgalli							1				10	1
Polygonaceae	*Rumex acetosa Linn.*							1				10	1
	Polygonum lapathifolium L.							1				10	1
Leguminosae sp.	*Sphaerophysa salsula*				5							10	5
	Alhagi sparsifolia Shap							2				10	2
Zygophyllaceae	*Nitraria tangutorum Bor*		1		2				1	1		40	5
Iridaceae	*Iris lacteal Pall. Var. chinensis*		1		2					2		30	5
Cyperaceae	*Carex tristachya*								1	1		20	2
Geraniaceae	*Geranium sibiricum L.*								1			10	1

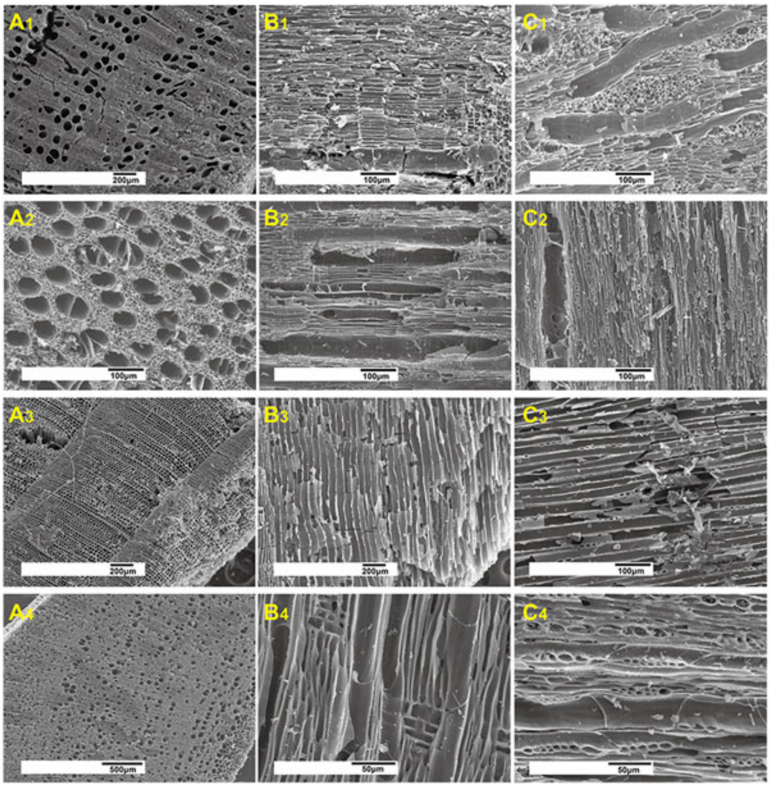

Figure 6 Fossilized charcoals identified in Sanjiao: (A1, B1, and C1) *Tamarix L.*; (A2, B2, and C2) *Salix L.*; (A3, B3, and C3) *Picea*; (A4, B4, and C4) *Hippophae*. A is the transverse section of charcoal; B is the radial section of charcoal; C is the tangential section of charcoal.

Table 3 Taxa of charcoal and their relative frequencies and abundance ratio from Sanjiao.

Taxa	Ash pit	Cultural layer	Absolute fragment count	Abundance ratio (%)	Ubiquity	Frequency (%)
Tamarix chinensis	3	24	27	3.02	4	40
Tamarix	257	539	796	89.04	10	100
Salix	9	34	43	4.81	9	90
Picea		14	14	1.57	3	30
Hippophae	2	5	7	0.78	3	30
Betulaceae		1	1	0.11	1	10
Poaceae		6	6	0.67	1	10

combination of agro-pastoral activities and barley agriculture. Bronze-smelting activities also started to take place. This led to deforestation and the desertification in the Hexi Corridor (Li et al. 2011; Zhou et al. 2012), and only drought-tolerant shrubs were found there in the Bronze Age and the historical period (Liu et al. 2018). Also, the agro-pastoral economy

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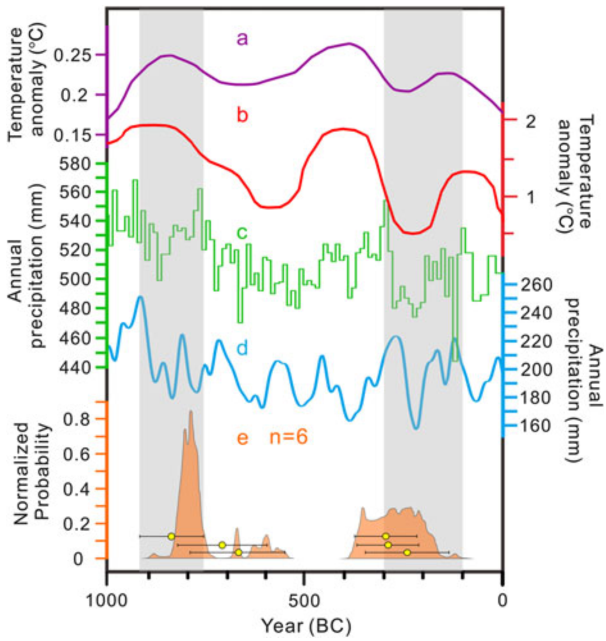

Figure 7 Comparison between the probability of ^{14}C dates from Sanjiao and the paleo-climatic records in the Hexi Corridor and its nearby regions: (a) temperature anomaly of the North Hemisphere (30–90°N) by Marcott et al. (2013) (purple); (b) $\delta^{18}O$ temperature anomaly of Agassiz cap on Ellesmere Island by Lecavalier et al. (2017) (red, smoothed with the Gaussian filter [$\sigma = 50$y]); (c) Asia monsoon record of the stalagmite from Dongge Cave by Dykoski et al. (2005); (d) annual precipitation reconstructed from tree-ring in eastern Qilian Mountains by Yang et al. (2014); (e) probability of ^{14}C dates from Sanjiao (orange). The yellow circle represents the dates of Sanjiao obtained in this study. The gray shadow indicates the periods of climate deterioration.

facilitated human mobility and hence, fewer permanent structures were built and fewer trees were consumed. The settlement at Sanjiao was primarily composed of portable yurts (Pu and Pang 1990). Those portable yurts together with the piled-earth walls at Sanjiao may further evidence the dominance of the agro-pastoral economy during the time (Pu and Pang 1990). Our AMS dates from charcoal and the previous LSC dates support the hypothesis that settlement was built during the Shajing Period (1000–400 BC), as indicated by our phase modeling suggesting that the walls of Sanjiao were built in the period of 855–797 cal BC, with the median age of 828 ± 92 cal BC.

Based on the historical records such as *Shiji* (The Records of the Scribe) and *Hanshu* (The Book of Han), the Hexi Corridor was conquered and controlled by various nomadic regimes, including *Rouzhi*, *Wusun*, and *Xiongnu*, before it was under the rule of the central government of China during the reign of Emperor Hanwu (141–87 BC). After the victory over *Xiongnu*, the Han Dynasty government set up four counties in the Hexi Corridor. In addition, several walled settlements were built there when the Silk Road was established.

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According to dozens of ^{14}C dates from multiple ancient cities in eastern Qinghai (Dong et al. 2016a) and archaeological investigation in ancient Juyan Oasis (Hu and Li 2014), there are no walled settlements built earlier than Sanjiao in the Hexi Corridor. Based on these lines of evidence, Sanjiao could be seen as the earliest walled settlement in the Hexi Corridor.

Why Was the Sanjiao Walled Settlement Built?

Climate-induced shortage of subsistence resource could drive social instability or even conflicts among regions (Lee et al. 2017; Lee 2018). This might eventually induce the need for walled settlements for the protection of settlers (Wu 2002; Qiu and Yao 2003). The construction of walled settlements in northern China is coincident with frequent conflicts in the region (Qian 2000; Qiu and Yao 2003). It is worth noting that the period of widespread construction of walled settlements in China corresponds with a cold and dry climate in East Asia (Cao 1996; Ma 1998; Qian 2000; Marcott et al. 2013; Chen et al. 2015a), suggesting climate change to be an essential factor in facilitating the construction of walled settlements. A cold and dry climate lasting for decades or centuries might lead to the shrinkage of agricultural production, causing frequent conflict among different tribes/states and even the transformation and alternation of ancient cultures (Dong et al. 2017b). Such a phenomenon is found all over the world, for example, the collapse of the Akkadian Empire in Mesopotamia (2334–2154 BC; Weiss et al. 1993), the de-urbanization of Harappa Culture in Indus Valley (2600–1500 BC; Staubwasser et al. 2003), and the decline of Maya Culture in Mesoamerica (AD 400–900; Haug et al. 2003; Medina-Elizalde and Rohling 2012).

The Hexi Corridor, located at the margin of the monsoon region, is a transitional zone between farming and pastoral activities. The climate there is much more arid than that in the east of China. This makes local precipitation and water availability critically important to people's livelihoods and societal development in the Hexi Corridor. Increasing aridity during 4000–3500 BP is often emphasized as one of the proximate causes of socio-political chaos in this area (Zhou et al. 2012). To prove whether the construction of Sanjiao was related to climate deterioration, we compared the ^{14}C dates from Sanjiao with various high-resolution paleo-climatic records in the Hexi Corridor and the nearby regions (Figure 7). Those paleo-climatic records indicate that the temperature and the precipitation dropped drastically at the beginning of the first millennium BC, and the change is a macro-regional one (Figure 7) (Dykoski et al. 2005; Yang et al. 2014; Marcott et al. 2013; Lecavalier et al. 2017), potentially leading to social upheaval and conflict, and consequently the emergence of settlement fortification (Li 1995). Given the coincidence between the ^{14}C dates of Sanjiao and the aforementioned climate deterioration (Figure 7), the construction of Sanjiao walled settlement might be a typical example of the settlement fortification driven by climate change. Similar examples can be found in the Mediterranean in the same period (Drake 2012).

What Was the Livelihood in Sanjiao City?

Archaeobotanical studies shed light on human plant-utilization strategies across time (Lee et al. 2007; Hunt et al. 2008; Jin et al. 2011; Yang et al. 2012; Zhang et al. 2012; Chen et al. 2015b; Long et al. 2017). According to archaeological and archaeobotanical studies, human settlements appeared in the Hexi Corridor in the Majiayao Period (3300–2000 BC) (Xie et al. 2002; Dong et al. 2018). Ancient agriculture relied on foxtail millet and broomcorn millet (Zhou et al. 2016), plants first domesticated in northern China around 8000 BC

(Lu et al. 2009; Zhao 2011; Zhang et al. 2012). Barley and wheat, domesticated in southwestern Asia during the early Holocene (Lev-Yadun 2000), was introduced to the Hexi Corridor around 2000 BC (Dosdon et al. 2013; Dong et al. 2017a). While millet crops were initially the dominant subsistence plants (Ma et al. 2013, 2014, 2016), exotic barley and wheat became essential staples in the western part of the Gansu-Qinghai region after 1700 BC (Flad et al. 2010; Chen et al. 2015b; Zhou et al. 2016).

Since the first millennium BC, the pastoral economy flourished in the Hexi Corridor. Kuz'mina (2008) argued that the development of pastoral subsistence strategies and eastward migration by nomads was caused by a cold and dry climate across the Eurasian steppe during the time. The origins of nomadic culture in East Asia can also be dated back to the first millennium BC, with rapid development in the eastern grasslands in northern China (Di Cosmo 2010). During 600–400 BC, the nomadic culture diffused to northwestern China, including Qinghai, Gansu, and Ningxia (Watson 1971; Di Cosmo 2010). Some studies argue that Shajing Culture has its origins in *Rouzhi*, a typical nomadic people (Pu and Pang 1990). The sheep and cattle bones unearthed from Sanjiao and the tombs nearby such as Hamodun and Xigang reveal that the pastoral economy was vital to people's livelihoods in Shajing Culture during the Late Bronze Age.

The three AMS ^{14}C dates of carbonized barley seeds from the ash pit and cultural layers in Sanjiao range between 384–116 cal BC, indicate that Sanjiao was still inhabited in the Late Bronze Age (1000–210 BC). Barley and broomcorn millet were the most important local cultivated crops and the ubiquity of these species reached 100% of the 10 flotation samples (Table 2). Foxtail millet was utilized at Sanjiao, but its ubiquity is only 20% (Figure 5; Table 2). The presence and ubiquity of barley and broomcorn millet indicates the Shajing Culture at Sanjiao engaged not only in agro-pastoralism but also agricultural production.

Charcoal obtained from archaeological sites is critical for understanding human wood-utilization practices in the past (Thiébault 2002; Asouti and Austin 2005; Dufraisse 2006). Charcoal collected from certain cultural relics in archaeological sites could be considered as the proxy of human activities, and its concentration in cultural remains directly reflect the daily practices of people at the time. In general, humans collect wood for firewood, food, medicine, perfume, and building materials (Wang et al. 2016). In the collected floatation samples, we found 894 pieces of charcoal. They originated from seven tree species, including *Tamarix chinensis*, *Tamarix*, *Salix*, *Picea*, *Hippophae*, *Betulacea*e, and *Poaceae* (Figure 6; Table 3).

Tamarix occurred with the highest frequency, and its ubiquity reached 100%. *Tamarix* is often considered a shrub or small tree, and it is mainly distributed in ecologically fragile areas, especially in arid zones such as northwestern China. It is one of the constructive/dominant species of desert and wilderness communities with the advantage of long life expectancy, rapid growth, and high tolerance to aridity and saline/alkaline soil (Yin 2002). *Tamarix* was used by ancient people in the Hexi Corridor at least as long ago as 2000 BC. During the Siba Culture Period (1900–1400 BC), *Tamarix* was used as both building material and fuel at the Xichengyi site (Wang et al. 2014). At the Huoshiliang site, *Tamarix* was gathered as fuel for bronze smelting (Sun et al. 2010). At Sanjiao, *Tamarix* was probably the primary source of fuel due to its local abundance.

Hippophae is a kind of shrub or small tree that grows in alpine shrub environments and stratified alluvial terraces. It is drought-resistant and able to impede wind-drift sands

(Forest Stewardship Council 1997). Due to its highly nutritious fruit, *Hippophae* is a vital food and medicine source, and its archaeological presence is significant for revealing the livelihoods of ancient people. At Sanjiao, seven pieces of charcoal were identified as *Hippophae*, with relatively low ubiquity (30%). Despite its low quantity and ubiquity, the presence of *Hippophae* indicates that its fruit was consumed, and its wood was used as firewood by the inhabitants at Sanjiao. At the Xichengyi site, *Hippophae* was collected for food (Wang et al. 2014).

Tamarix chinensis, *Salix*, *Picea*, *Betulacea*e, and *Poaceae* comprise only a tiny portion of our collected charcoals. *Salix* has a high ubiquity, though its absolute count is small. *Salix* favors moisture and often grows in stratified alluvial terraces. Because of its ecological adaptability, it is widely distributed (Forest Stewardship Council 1997). *Picea*, which favors a cold and humid environment, is often found on mountain slopes in northwestern China, and together with *Betulaceae*, forms the theropencedrymion (Forest Stewardship Council 1997). Our charcoal identification results suggest that these five wood species were seldom utilized by the settlers at Sanjiao. Their remains could probably come from the broad-leaf and coniferous forests that were sporadically distributed around the settlement during the time, with locally available *Tamarix* as the dominant utilized species.

Briefly, most of the archaeo-botanical crop and wood remains found in Sanjiao are cold-dry resistant species, which corresponds to the climate deterioration in East Asia since 1600 BC (Dykoski et al. 2005; Marcott et al. 2013; Chen et al. 2015a). Barley is highly resistant to low temperature, while broomcorn millet has a stronger adaptive capacity to dry environments relative to foxtail millet (Zhang 1986; Guedes et al. 2015). Many barley and broomcorn millet remains were also found at the Nuomuhong site in the Qaidam Basin where the climate is dry and cold (Dong et al. 2016b). The tree species utilized by the settlers at Sanjiao, such as *Tamarix* and *Hippophae*, are also cold-dry resistant. As revealed by the subsistence strategy at Sanjiao, the inhabitants of the settlement might have adapted to the harsh environment in the Hexi Corridor by utilizing cold-dry resistant plant species.

CONCLUSION

Sanjiao is affirmed by AMS ^{14}C dates as the first walled settlement in the Hexi Corridor. It was built around 828 ± 92 cal BC. The settlement was probably constructed for defense purposes in relation to the geopolitics in the Hexi Corridor during the late West Zhou and spring-autumn periods. It was still inhabited in 384–116 cal BC. During that time, people relied on barley, broomcorn millet, and auxiliary foxtail millet for food and utilized trees such as *Tamarix* and *Hippophae* as fuel. These species are cold-dry resistant, suggesting that people adapted their subsistence strategy to the harsh environment in the Hexi Corridor. Subsequent construction of other ancient settlements around Sanjiao might have facilitated the early development of the Silk Road.

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