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ORIGINAL ARTICLE

Cultivation strategies at the ancient Luanzagangzi settlement on the easternmost Eurasian steppe during the late Bronze Age

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Abstract A significant body of recent research shows that the first east–west transmission of cereal crops, *Triticum* spp. (wheat) and *Hordeum* spp. (barley) from the west and millets (*Setaria italica*, foxtail millet, and *Panicum miliaceum*, common millet) from the east, took place sometime around the start of the 5th millennium BP, with part of the most likely route lying along the Tianshan mountains in northern Xinjiang, China. Here the dominant economic adaptation is, and was in prehistory, not crop-based agriculture but transhumant pastoralism. The site of Luanzagangzi (ca. 3,300–2,900 cal BP) on the northern slope of the Tianshan is one of only a handful of Bronze Age sites in Xinjiang with evidence for well-established crop cultivation. In this paper, we report on ten samples collected for phytolith analysis from a 4 m deep profile at Luanzagangzi. The results show evidence that a range of cereal crops was being grown (multi-cropping), *Triticum* spp., *Hordeum* spp., *Setaria italica* and *Panicum miliaceum*. Pooideae, Paniceae woody plants, *Phragmites* (reed) and Cyperaceae (sedges) were presumably also exploited for subsistence purposes in this area. We speculate that the strategy of growing a range of crops, wheat/barley, common millet and foxtail millet was adopted by the Bronze Age population in this region as a supplement to herding. The findings of this study help us to understand the dispersal of cultivation strategies across the Eurasian steppe via the Xinjiang region, and the communication between China and the West in the late Bronze Age.

Keywords Phytoliths · Agriculture · Wheat · Barley · Millet · Xinjiang · Eurasian steppe · Bronze Age

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Introduction

Understanding subsistence strategies is of major importance in archaeological research (Cosmo 1994; Gerling 2015). A key part of this is to discover which plant and animal resources were available to individual cultural groups. From the Bronze Age and into recent historical periods, the dominant subsistence practice in the Eurasian steppe has been mobile pastoralism, the herding of sheep, goats, cattle and horses. This was an economic choice reflecting adaptations to local topographies and environments (Shishlina and Hiebert 1998; Vainshtein 1980; Koryakova and Epimakhov 2007). For some time, however, archaeologists have also recognized the use of domesticated grains such as *Panicum miliaceum* (common millet), *Setaria italica* (foxtail millet), *Triticum* spp. (wheat) and *Hordeum* spp. (barley) in the subsistence strategies of pastoralists living across the wider steppe zone from the late 5th to 4th millennia cal BP (Kuz'mina 2007; Spengler et al. 2014). Although studies from central and western parts of the Eurasian steppe suggest that pastoralist economies can be complex and involve agriculture (Rosen et al. 2000; Chang et al. 2003; Frachetti et al. 2010; Murphy et al. 2013; Spengler et al. 2014), pastoralist subsistence economies and their role in the use and spread of domesticated grains at the eastern end of the Eurasian steppe are still poorly understood (Kohl 2007; Frachetti 2009; Murphy et al. 2013; D'Alpoim Guedes et al. 2014, 2015; D'Alpoim Guedes 2015).

The Jungar (Zhunga'er) basin, the easternmost extension of the Eurasian steppe, together with the Tarim (Talimu) basin to the south, make up much of the territory of Xinjiang (Fig. 1). These vast arid inland basins were crossed in historical times by the Silk Road and throughout history they constituted areas with vital links between eastern agricultural and steppe herding communities. Consequently, they have played an important role in understanding the relationship between early China and Western Asia since the Bronze Age (Cosmo 1994; Jia et al. 2011). However, to date, most archaeological evidence of agriculture is concentrated in the Tarim basin and surrounding areas (Qiu et al. 2014; Yang et al. 2014; Zhang et al. 2015a; Chen et al. 2016), while very limited attention has been paid to the Jungar basin. Due to the lack of systematically collected and regionally comparable archaeobotanical data from the easternmost regions (Frachetti et al. 2010), little is known about the subsistence strategies of ancient communities during the transition from the Bronze Age to the Iron Age (Jia et al. 2011). The Luanzagangzi site, which is located on the southeastern edge of the Jungar basin, is a settlement that provides us the opportunity to address issues concerning subsistence strategies of ancient communities in this region.

Poaceae grasses prevail across the Eurasian steppe and are closely related to human activities, not only because most cereal crops belong to this taxon, but because herding activities depend on grasses as forage. Although pollen data can reflect vegetation, the interpretation of the grass signal and reconstruction of the ecosystems that this signal probably represents is hampered by the limited ability to identify pollen more exactly than to family level. This factor has restricted interpretation of human subsistence strategies and limited the pollen-based reconstruction of vegetation around sites across the Eurasian steppe (Bush 2002; Schüler and Behling 2011).

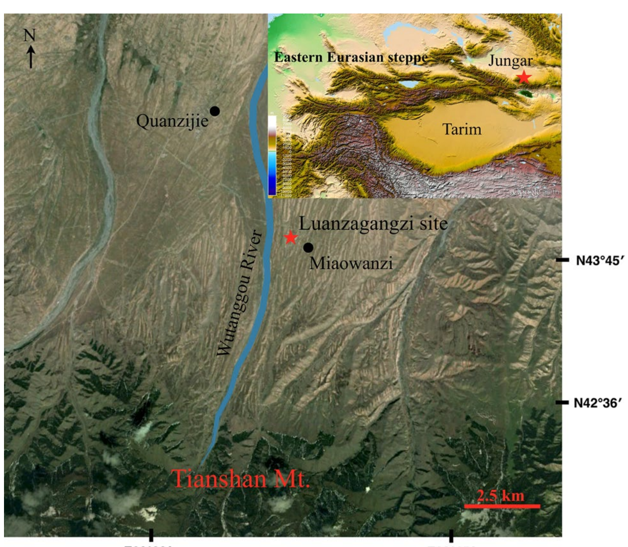

Fig. 1 Location of the Luanzagangzi site, northwest China. (The base map uses imagery from Google mapping)

Since phytoliths are replicas of plant cells (Piperno 2006), they can be used to identify a certain genus or species according to shape, size and other anatomical features (Piperno 1988; Pearsall 2000; Lu and Liu 2003a; Lu et al. 2005; Ball et al. 2016). Based on phytolith morphology, certain genera or species of Poaceae can therefore be securely identified (Piperno 2006; Ball et al. 2016), especially for some crops, such as *Zea mays* L. (maize) (Piperno 1984), *Triticum* spp. and *Hordeum* spp. (Rosen 1992; Rosen and Weiner 1994; Ball et al. 1999, 2009), *Panicum miliaceum, Setaria italica* and related wild grasses (Lu et al. 2009; Zhang et al. 2011; Yang et al. 2015).

This paper presents phytolith records from the newly investigated Luanzagangzi site. The results prove that the late Bronze Age population at the eastern end of the Eurasian steppe used a multi-cropping pattern of wheat, barley and millet and other plant resources. Our findings contribute to insights into crop spread across the Eurasian steppe and have broader implications for understanding economic and cultural communication between west and east since the late Bronze Age.

Materials and methods

Luanzagangzi (43°45′22″N, 89°11′30″E) is located in Jimusaer (Jimusa'er) County, at the southeastern edge of the Jungar basin. The site lies on the northern slope of the Tianshan mountains at 1,486 m a.s.l., 500 m from the river Wutanggou, and about 8 m above the riverbed (Fig. 1; Jia et al. 2011). Today the average annual precipitation in the region is 200–300 mm and the annual mean temperature is 4–7 °C (Yan et al. 2004b). The landscape is desert steppe with vegetation that includes *Artemisia, Stipa glareosa, Ceratoides, Ceratocarpus, Peganum, Cirsium, Caragana leucophloea*, Brassicaceae, *Carex, Iris, Trifolium, Populus* and *Ulmus*, among other taxa. The dominant crops in this area are now wheat and maize, but that was not the case in the past (Yan et al. 2003, 2004a).

A unit of 1×2.5 m was excavated at Luanzagangzi in 2007. Ten stratigraphic layers were distinguished in the profile exposed by the 4 m deep profile (ESM 1 Fig. S1). The stratigraphy of this profile has been detailed elsewhere (Jia et al. 2011). The cultural layers were rich in charcoal and fragments of pottery, bone, ground stone tools and bronze fragments. We collected one sediment sample for phytolith analysis from each stratigraphic layer of the profile to give a series of ten samples in total (ESM 1 Fig. S1). Eight radiocarbon dating samples from Layer 4 to Layer 10 and from a gulley under Layer 6 provide secure chronologies from ca. 3,300 to 2,900 cal BP (Table 1; Jia et al. 2011; Tong et al. 2013).

Each 2 g sample taken for phytolith analysis was prepared as described by Piperno (2006) and Runge et al. (1999), with slight modifications. The procedure consisted of treatment with 30% hydrogen peroxide (H_2O_2) and cold 15% hydrochloric acid (HCl), separation with zinc bromide ($ZnBr_2$, density 2.35 g cm^3) heavy liquid and mounting on a slide with Canada Balsam. Phytolith counting and identification were performed using a Leica microscope with phase contrast at 400× magnification. About 400 phytoliths (single and multi-cells, if multi-cells were silicified together, we counted them as a single phytolith) were counted in most samples (see raw data in ESM 2). Identification was aided by the use of reference materials (Mulholland and Rapp Jr 1992b; Wang and Lu 1993; Lu and Liu 2003b; Lu et al. 2006) and published keys (Kondo et al. 1994; Runge et al. 1999; Pearsall 2000; Piperno 2006).

In this study, a total of 21 phytolith types, including millets, wheat/barley, Paniceae and Pooideae were identified according to the classification system of Lu et al. (2006) and in three other classifications (Fig. 2; Twiss et al. 1969; Wang and Lu 1993; Kondo et al. 1994). For the identification of crop phytoliths, additional references were employed (Rosen 1992; Wang and Lu 1993; Lu et al. 2009; Zhang et al. 2011; Madella et al. 2014). Phytolith abundance is expressed as a percentage of all phytoliths counted.

Results

According to the references for phytolith taxa in China (Lu et al. 2006), specific phytolith types are predominantly, although not restricted to, those produced by certain plants. For example, scutiform-bulliform (extremely large and shield-like bulliform) and middle-saddle types are from *Phragmites* (reed) (Wang and Lu 1993), trapeziform-sinuate and rondel from Pooideae, bilobate from Paniceae and β-undulated epidermal long cell walls from *Echinochloa* sp. (cockspur, barnyard millet) (Ge et al. 2016). Accordingly, we classified types of phytoliths into nine groups, identified with the corresponding plant names in Fig. 3. Phytolith types which cannot be identified to a single plant but have ecological meanings, such as bulliform, trapeziform and acicular hair cell, are also differentiated in Fig. 3, whereas phytoliths without any systematic significance, for example smooth-elongate and elongate-echinate types, are not shown.

Table 1 Radiocarbon dates on charcoal from the Luanzagangzi site (calibrated using Oxcal5.05.); modified according to Jia et al. (2011); Tong et al. (2013)

Cultural layer	Lab. code	^{14}C dates BP	Cal. ages (95.4%)(BC)
4	UBA-9066	2,777 ± 23	999–890
5	UBA-9065	2,877 ± 26	1188–1182
G1	UBA-9067	2,819 ± 23	1038–1034
6	UBA-9064	2,870 ± 23	1125–975
7	UBA-9063	2,883 ± 24	1189–1180
8	UBA-9062	2,948 ± 24	1261–1110
9	UBA-9061	3,000 ± 24	1372–1343
10	UBA-9060	2,917 ± 23	1210–1019

The phytolith assemblages from the cultural layer were mostly well enough preserved to enable confident identification (Fig. 3). Our results show that crop phytoliths include common millet, foxtail millet and wheat/barley. The common non-crop phytolith types were scutiform-bulliform (reed bulliform), middle-saddle, rondel, bilobate, trapeziform-sinuate (tooth), smooth-elongate, elongate-echinate, acicular hair cell (point shaped), trapeziform (square) and some woody and unidentified phytoliths, as well as some dendritic phytoliths from *Echinochloa*.

According to the presence of crop phytoliths, the profile can be divided into three phases: P1 (Layer 10, dated to 3,210–3,019 cal BP), P2 (Layer 9 to Layer 4, dated from ca. 3,200 to 2,900 cal BP) and P3 (Layer 3 to Layer 1). No crop phytoliths are present in P1 or P3, whereas P2 includes crop phytoliths. The percentage of wheat/barley phytoliths peaks at 2.8% in Layer 9 and gradually decreases to 0.2% in Layer 5, while the concentration ranges from ca. 330,000 to 6,000 phytoliths/g. The common millet percentage ranges from 0.5 to 0.2% and concentration from 55,000 to 5,500 phytoliths/g. *Setaria italica* peaks in Layer 7, and ranges from 0.5 to 0.7% and 55,000 to 6,500 phytoliths/g (Fig. 3).

Concerning non-crop phytoliths, Pooideae (27.6%) dominate in P1 with minor contributions of Paniceae (0.4%) and woody plants (5.0%). In P2, remarkably, 0.7% of *Echinochloa* spp. is present in Layer 7. *Phragmites*, Paniceae, Pooideae and woody plants range from 0.9 to 0.3%, 3.1–0.9%, 36.1–20.9%, 1.2–0.8% respectively. In P3, Pooideae dominates and peaks at the level of the topsoil at 60.6% with plenty of woody phytoliths (3.5%) (Fig. 3).

Discussion

Crops in the ancient settlement of Luanzagangzi

A secure identification of millet, wheat and barley phytoliths is possible at the genus level using morphotypic

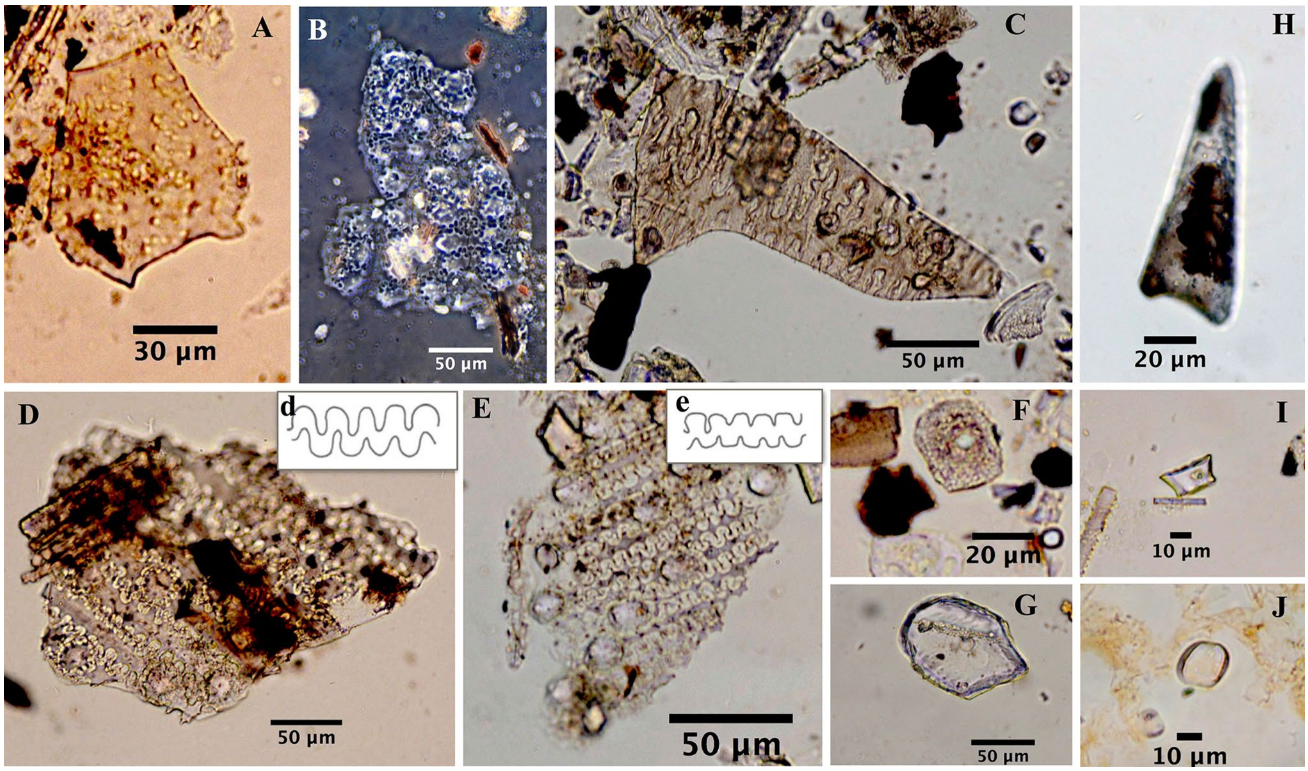

Fig. 2 Main phytolith types at the Luanzagangzi site; **A** *Panicum miliaceum* (common millet); **B** *Setaria italica* (foxtail millet); **C** *Echinochloa* sp. (cockspur, barnyard millet); **D** phytoliths that resemble *Triticum* spp. (wheat); **d** wave patterns in conjunctions from wheat, modified from Rosen (1992); **E** phytoliths that resemble *Hordeum* spp. (barley); **e** wave patterns in conjunctions from barley, modified from Rosen (1992); **F** Cyperaceae (sedges etc.); **G** scutiform-bulliform from *Phragmites* (reed); **H** acicular hair cell; **I** rondel; **J** middle-saddle from *Phragmites* (reed)

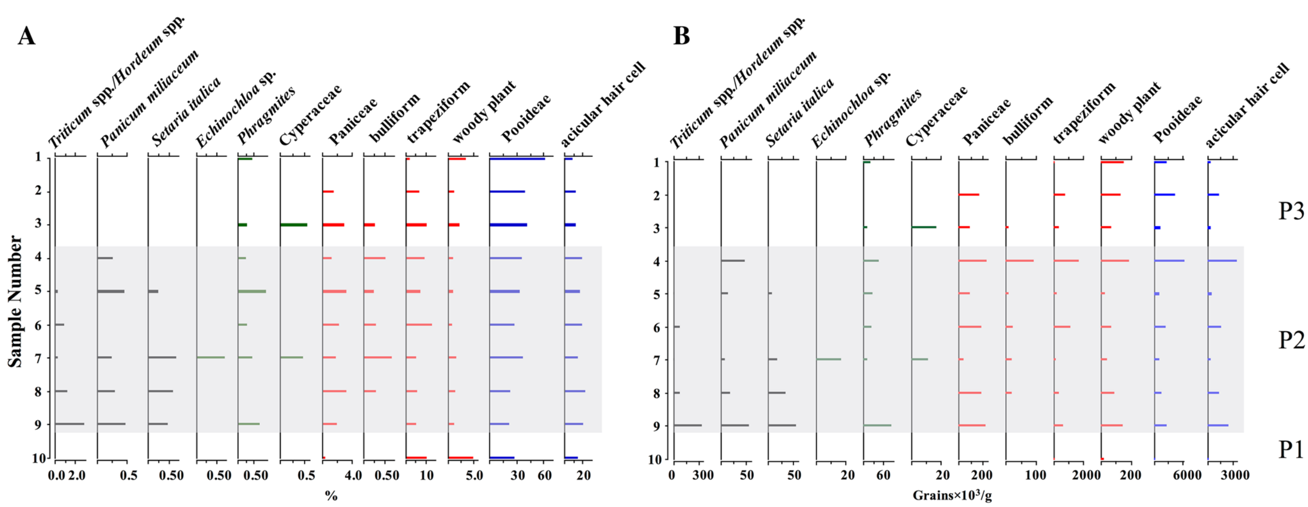

Fig. 3 **A** Variations in percentages; **B** concentrations of main plant phytoliths in the Luanzagangzi profile

analyses, even if there are no macrobotanical remains present (Rosen 1992; Tubb et al. 1993; Ball et al. 1996, 1999, 2016; Lu et al. 2009; Zhang et al. 2011; Out and Madella 2016; Weisskopf and Lee 2016). For the identification of *P. miliaceum* and *S. italica*, we follow the work of Lu et al. (2009) and Zhang et al. (2011). Generally, the epidermal long cell walls are Ω-undulated (Ω -I, II, III) in *S. italica* (Fig. 2), and η -undulated (η -I, II, III) in *P. miliaceum*, and papillae characteristics always present in *S. italica* but absent in *P. miliaceum*. However, as there are still many uncertainties related to species differentiation in *Setaria* spp. (Weisskopf and Lee 2016), we suggest concentrating more efforts on inflorescence phytoliths from major constituents of the *Setaria* genus in the north, such as *S. pumila, S. plicata, S. faberi* and *S. pallidifusca*.

Identifiers of wheat/barley include a combination of the wave height, amplitude and frequency of the joined dendritic long-cell walls, the size and configuration of the papillae, and the shape of the cork cells (Rosen 1992). Based on the criteria of wave patterns in conjunction between two joined dendritic long cells proposed by Rosen (1992) (Fig. 2D-E), we can confirm that both wheat (long and loose wave) and barley (short and tight wave) were present in the samples, and this is also supported by the wheat and barley grains recovered by flotation at this site (Jia et al. 2011; Tong et al. 2013). Because confidence in wheat/barley determinations varies by the numbers of characteristics visible on an individual multi-cell phytolith, no further differentiation of wheat and barley based on phytoliths has been done, due to the lack of cork cells and a limited number of identifiable multi-cell phytoliths, which are essential for the accurate differentiation of wheat and barley (Rosen 1992; Tubb et al. 1993; Ball et al. 1999, 2001, 2016). Phytolith results throughout the profile indicate that wheat/barley were most dominant among the cereals present, accounting for 58% of the total crop phytoliths (Fig. 4), while *S. italica* and *P. miliaceum* were present in quantities of 22 and 20% respectively.

Wheat/barley has been a particularly important staple cereal in communities across Eurasia starting from at least 8,000 cal BP (Harris 1998). Both were spread across the Eurasian steppe and introduced into East Asia largely via Xinjiang and subsequently through the Hexi corridor in China's Gansu Province (An et al. 2013; Barton and An 2014; Dodson et al. 2013; Flad et al. 2010). Other early sites have had preserved wheat/barley remains in Xinjiang, the Hexi corridor and the Central Plain of China from the 5th and very beginning of the 4th millennium BP (Li 2008; Flad et al. 2010; Li et al. 2011; Dodson et al. 2013; Dong et al. 2013), and these crops played an important role in the establishing of agricultural communities in new environments surrounding the Tibetan plateau (D'Alpoim Guedes et al. 2014, 2015; Chen et al. 2015).

Owning to the higher temperature requirement of millets, they were difficult to grow following the end of the climatic optimum (D'Alpoim Guedes et al. 2014, 2015; D'Alpoim Guedes 2015). Compared with the present day, the temperature and precipitation in northern Xinjiang were a little lower in the period from 3,500 to 2,500 BP. A recent pollen based palaeoclimate reconstruction indicates that the mean annual temperature varied between ca. 4 and

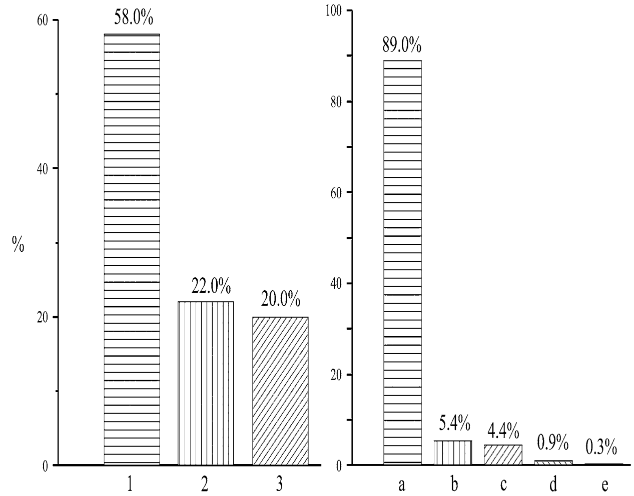

Fig. 4 A comparison of phytolith assemblages from the Luanzagangzi profile. All the samples are agglomerated throughout time. The left chart shows the relative percentages of cereal crops in *1 Triticum* spp. or *Hordeum* spp. (wheat/barley), *2 Setaria italica* (foxtail millet); *3 Panicum miliaceum* (common millet); the right chart shows the percentages of all identified plants according to the taxa of subfamily/genus/plant type: *a* Pooideae; *b* Paniceae; *c* woody plants; *d* *Phragmites*; *e* Cyperaceae

2 °C, while mean annual precipitation changed between ca. 170–270 mm, respectively (Zhang et al. 2015b). This would have given wheat/barley advantages in this zone, and may partly explain why the percentages of millets are much lower than those of wheat/barley throughout the profile (Fig. 3). However, the lowest temperature at 3,000 BP was similar to that of the present day (Zhang et al. 2015b). Considering the Active Accumulated Temperatures (the sum of the daily mean temperatures above the minimum required temperature for the growth of crops in a given period), that of *P. miliaceum* is between ca. 1,700–2,300 °C d (Ma and Wei 1984) and that of foxtail millet is between ca. 2,100–3,000 °C d (Gu and Du 1981). Thus both fall within the range of the present Annual Accumulated Temperatures (≥10 °C) in the southern Jungar basin (3,000–3,500 °C·d) (Wang 1992). The geographical distribution of both *S. italica* and *P. miliaceum* in China shows that both can be cultivated in northern Xinjiang (ESM 1 Fig. S2). Thus we speculate that, although wheat/barley accounted for a major part of the diet of the ancient population at this site, millets seem to have served as subsidiary crops for mobile herders, not only because millet has more protein and vitamins per grain compared with wheat/barley (Rachie 1975), but also because *P. miliaceum* has the lowest water requirement of all grain crops (Prance and Nesbitt 2012). The practice of millet cultivation seems suitable for mobile herders or as a way to reduce agricultural risk (Spengler et al. 2014; Miller et al. 2016). In most cases where wheat/barley have been reported in Xinjiang, they always occur together

with *P. miliaceum* or *S. italica*, not only at this site, but in Xintala, Gumugou, Sidaogou, Xiaohe and Yuergou Xinjiang (Cosmo 1994; Li 2008; Jiang et al. 2013; Yang et al. 2014) and also elsewhere (An et al. 2010; Jia et al. 2013; D'Alpoim Guedes et al. 2014).

Considering wheat/barley and millet cultivation, we speculate that multi-cropping strategies would have permitted optimal use of landscapes with long winters and/or dry summers in arid regions and would have produced as much grain as possible in a year to support the subsistence of communities (D'Alpoim Guedes 2011; Jones et al. 2011). When considered together with wheat/barley remains in northwest China from the early 4th to the late 3rd millennium BP, it seems that this multi-cropping system was not only a case of ecological opportunism (Jones et al. 2011), but it played an important role in the transition from the Bronze Age to the Iron Age for local cultural groups, and supported the creation of increasingly complex connections between west and east in the area that would develop into part of the historical Silk Road. A parallel development can be seen in the rice-millet complex pattern, simultaneously farming dry crops and rice in one region, established in the Yellow River region as at the Tanghu site from as early as the Peiligang culture (9,000–7,000 cal BP), which might have played a role in the growth of early Chinese civilization (Zhang et al. 2010, 2012).

Local available plant resources around the Luanzagangzi settlement

The local vegetation is a critical factor that affects the types of subsistence strategies of people, especially related to agricultural practices and human diet (Wang and Lu 1993; Cosmo 1994; Qin et al. 2010). Although information derived from cultural layers cannot be taken to reflect the natural vegetation of an area, since the data relate to disturbance associated with human activities and possibly a biased record reflecting cultural practices, they can still provide insight into the overall past vegetation of the region, local ecosystems, and, more directly, the plant materials that ancient people utilized.

Since phytoliths are replicas of plant cell bodies, phytolith analysis has contributed significantly towards identification of monocotyledons, especially towards identification of the Poaceae family. Compared with other identifiers from sediments, such as pollen, Poaceae can be identified as subfamilies (Wang and Lu 1993; Piperno 2006). Using phytolith analysis, certain genera or species can be securely identified (Mulholland and Rapp Jr 1992a; Piperno 2006; Ball et al. 2016). The data from Luanzagangzi reveal that grasses of Pooideae (89%), Paniceae including *Echinochloa* (5.4%) (Yang et al. 2015) and woody plants, as well as possibly some shrubs (4.4%), occupied the surrounding landscape during the period 3,300–2,900 cal BP (Fig. 4). Because the outputs of phytoliths by woody plants are significantly lower than those of grasses, the past importance of shrubs might have been more than shown by these data (Wang and Lu 1993). Small amounts of hygrophilous plants were also identified, such as *Phragmites* (0.9%) and Cyperaceae (0.3%), suggesting that there were some bodies of water near the site (Fig. 4). Considering the reconstructed plant resources, we argue that the surrounding ecosystem was suitable for the cultivation of wheat/barley as well as millets.

Previous studies of environmental substitutive indexes have revealed that although there has been climatic oscillation of cold/warm and dry/wet since the beginning of the late Holocene, local arid features basically did not change (Zhang et al. 2007; Feng et al. 2012), and thus a desert steppe landscape prevailed around the northern slope of the Tianshan mountains during the period 4,000–2,000 cal BP, accompanied by a wet high lake level stage (Yan et al. 2003, 2004a, b; Liu et al. 2008; Zhang et al. 2015). The regional vegetation would have been dominated by Chenopodiaceae desert vegetation and sporadic woods composed mainly of *Picea* in the surrounding mountains and a small amount of wetland environment that was present at that time (Liu et al. 2008). This environment accords substantially with the results of our phytolith analysis.

Conclusion

Our data provide new evidence that the herders in the easternmost extension of the Eurasian steppe possibly adopted a range of crops such as *P. miliaceum, S. italica* and wheat/barley into their subsistence strategy at Luanzagangzi in the period between ca. 3,300 and 2,900 cal BP. This mix of subsistence strategies may have provided a successful model for early agricultural communities in a steppe environment. Due to the limitation of samples and sampling locations, the question of which crop was dominant at the site needs further investigation. These findings deepen our cultural understanding of the strategies of pastoralists across the Eurasian steppe from the late Bronze Age onwards.

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