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Phytolith evidence for rice cultivation and spread in Mid-Late Neolithic archaeological sites in central North China

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The history of rice (*Oryza sativa*) cultivation in North China is ambiguous owing to a lack of evidence from rice remains with precise ages in archaeological sites. In this paper, we present rice phytolith evidence from six archaeological sites in the Guanzhong Basin, central North China, dating from *c.* 5500 to 2100 cal. a BP (calibrated/calendar ages) based on 19 AMS-dates. The phytoliths found in the three archaeological sites located on the second river terrace (Quanhu, Yangguanzhai and Anban) include three types of phytoliths from rice, namely bulliform, parallel-bilobe and double-peaked. These findings suggest that the earliest cultivated rice in central North China occurred not later than *c.* 5690 cal. a BP. After *c.* 5500 cal. a BP, the farming pattern in the Guanzhong Basin was characterized by dominant dry crops (e.g. millets) and locally cultivated rice. A likely spread route of rice from the lower reaches of the Huanghe (Yellow) River towards the Guanzhong Basin in central North China is speculated to have happened at *c.* 5690 cal. a BP. The findings of this study help us to understand the farming pattern in the area and how rice spread across the semi-arid regions of East Asia.

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Attempts have been made for decades to understand the mode and process of the spread of rice (*Oryza sativa*) in East Asia, particularly in China (Chen *et al.* 1995; Chen & Jiang 1997; Underhill 1997; Crawford 2006; Jin *et al.* 2007b; Lee *et al.* 2007; Li *et al.* 2007a, b; Zong *et al.* 2007). Much archaeological evidence found more recently supports the idea that cultivated rice spread mainly from southern and central China. However, the dating of specimens is scarce and some rice evidence is ambiguous (Wu 1994; Underhill 1997). Archaeobotanical records show that a possible route of rice spreading in China was from the middle and lower reaches of the Changjiang (Yangtze) River to the lower reaches of the Huanghe (Yellow) River and Huaihe River region during the period *c.* 8000–6000 cal. a BP (Yan 1989; Huang & Zhang 2002; Gong *et al.* 2007). The various hypotheses about the routes of the eastern spreading of rice to Korea and Japan are the 'South China route', 'Central China route' and 'North China route' (Higuchi 1996). The 'North China route' is supported by archaeological evidence from Shandong province, East China (Jin *et al.* 2007b). Our knowledge of the timing and the routes of rice western spread is, however, still incomplete, owing mainly to the limited number of charred grains of rice in archaeological sites in central North China (Li *et al.* 2007a, b).

It has been reported that rice, one of the world's most important staple foods, was first domesticated in the Changjiang River region in southern China (Crawford & Shen 1998; Higham 2005; Crawford 2006), whereas other dry farming crops such as foxtail millet (*Setaria italica*) and common millet (*Panicum miliaceum*) were first domesticated in the regions of the middle and lower reaches of the Huanghe River in North and northeast China (Zeit & Bottema 1991; Zhao 2008; Lu *et al.* 2009a). Some studies for the Peiligang to Longshan Culture (*c.* 8000–4000 cal. a BP) indicate that a rice–millet-complex area existed in eastern China between the lower reaches of Huanghe River and Huaihe River (Underhill 1997; Lee *et al.* 2007). However, owing to the lack of adequate evidence of charred grains of both rice and millet remains in the same archaeological context and the lack of convincing dating, it is still uncertain how far the rice–millet complex diffused towards the northwest and when rice first occurred in the Guanzhong Basin (Wu 1994).

Phytolith analysis has provided substantial empirical evidence regarding the considerable antiquity of food production and crop dispersal in many regions of the world (Chen *et al.* 1995; Chen & Jiang 1997; Lu *et al.* 2002, 2005; Denham *et al.* 2003; Piperno & Stothert 2003; Piperno *et al.* 2007). Rice plants produce three distinctive diagnostic phytolith types: double-peaked, bulliform and parallel-bilobe (scooped bilobes), the former being from rice husks and the others from rice leaves and stems (Pearsall *et al.* 1995; Lu *et al.* 1997;

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Zhao 1998; Zhao *et al.* 1998). The diagnostic characteristics in rice phytolith morphology can be used to distinguish rice from other crops (Zhao *et al.* 1998; Lu *et al.* 2002; Zheng *et al.* 2003; Piperno 2006).

Neolithic cultures in the Guanzhong Basin in central North China were prosperous because of the moderate climate and fertile soil (Liu 1985; Liu *et al.* 1996). This paper presents phytolith records and new radiocarbon ages from newly investigated archaeological sites from east to west in the Guanzhong Basin. The results provide a spatial and temporal pattern of rice–millet-complex cultivation in central North China. Our findings may contribute to insights into rice spread across the semi-arid regions in East Asia and have broader implications for understanding the development of human societies.

Study areas

Guanzhong Basin, a 360-km-long semi-humid and monsoon-climate region in the temperate zone, is located between Qinling Mountain and the Loess Plateau in North China (Fig. 1), and is an important junction between east and west China. The mean annual temperature and precipitation are 12–14°C and 600–750 mm, respectively (Pang *et al.* 2006). This area is an important dry-farming region in China because the flat terrain is composed mainly of the alluvial plains of the Weihe River and has moderate temperatures and rainfall (Sun *et al.* 1996).

A continuous sequence of socioeconomic development characterized by increasing specialization and complexity started in the early Neolithic and continued to the Xia, Shang and Zhou dynasties in the Guanzhong Basin (Li 1979; Luo & Tian 1994; Ba 1996; Zheng 1996; State Administration of Cultural Heritage 1998; Wei & He 1999; Song 2002; Zhang 2007). The earliest Neolithic culture in the Guanzhong Basin is the Laoguantai Culture (*c.* 8000–7000 cal. a BP), which is the predecessor of the Yangshao Culture in the area. Potteries and grinding stone tools, including slabs (metate, *mo-pan*) and mullers (mano, *mo-bang*), were held in the cultural sediments. Yangshao Culture (*c.* 7000–5000 cal. a BP) is a typical culture of the Middle Neolithic in this area. The Middle Neolithic people in the region raised domesticated animals and grew crops such as foxtail millet, common millet and possibly hemp (*Cannabis sativa*) and canola (rapeseed, *Brassica rapa*) (Crawford & Lee 2003). The Late Neolithic in the region is synonymous with the Longshan Culture (*c.* 5000–4000 cal. a BP) in East China. Longshan is an important period because of the nascent characteristics that link to the subsequent dynastic eras of the Xia, Shang and Western Zhou. The evident complexity in the late Longshan continued to develop in subsequent periods.

In this study, we selected six archaeological sites, namely Quanhu (QH), Yangguanzhai (WT), Huxizhuang (HXZ), Anban (AB), Wangjiazui (WJZ) and Shuigou (SG), along the Weihe River in the Guanzhong Basin (Fig. 1). The archaeological sequence includes middle-late Yangshao (*c.* 6000–5000 cal. a BP), Longshan (*c.* 5000–4000 cal. a BP), Xia (*c.* 4000–3600 cal. a BP), Shang (*c.* 3600–3000 cal. a BP), and Zhou (*c.* 3000–2200 cal. a BP).

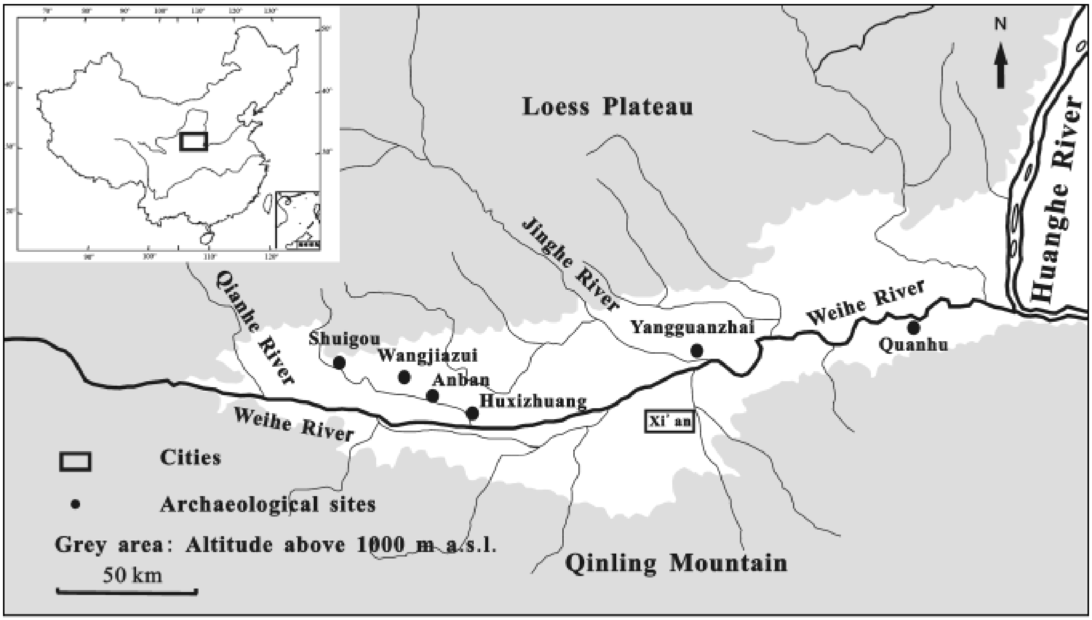


Fig. 1. Maps showing the locations of sampled archeological sites in the Guanzhong Basin, central North China.

Materials and methods

Materials

Forty-six samples were systematically collected from six archaeological sites for phytolith analysis, and 19 of them were selected for ^{14}C dating. Pit features visible in vertical cliffs of the terraces enabled the collection of samples from each archaeological site. We performed flotation experiments for all samples, but no rice remains were found.

Quanhu site (QH) (latitude 34°31.844′N, longitude 109°51.691′E) is located in the eastern part of the Guanzhong Basin (Fig. 1). It was excavated during 1958–1959. The site was attributed to the middle Yangshao and Longshan Cultures (*c.* 6000–4000 cal. a BP) (Zhang & Yang 2003). We successively collected the samples from a 1.8-m-depth pit profile (QH2) in Quanhu site at 10-cm intervals. Six samples were used for radiocarbon dating (QH2–3, 6, 8, 10, 12, 14) (latitude 34°31.844′N, longitude 109°51.691′E, altitude 370 m a.s.l.). In addition, three samples (QH-H1, QH-H3, QH-H4) were collected from three ash pits (QH1, QH3, QH4) (34°31.880′N, 109°51.742′E, 375 m a.s.l.; 34°31.844′N, 109°51.691′E, 370 m a.s.l. and 34°31.844′N, 109°51.691′E, 370 m a.s.l.), for phytolith analysis and radiocarbon dating (Figs 2, 3).

Yangguanzhai site (WT) (34°28.189′N, 109°00.994′E) is located about 76 km west of Quanhu site on the north bank of the Jinghe River (Fig. 1). The site is attributed mainly to middle to late Yangshao Culture (*c.* 6000–5000 cal. a BP) (State Administration of Cultural Heritage 2007). Samples were collected successively at 20-cm intervals along a 3.7-m-deep pit (H629) profile. Three samples (WT2407-5, 11, 19) (34°28.189′N, 109°00.994′E, 378 m a.s.l.) were used for radiocarbon dating. A further radiocarbon sample (WT2407-627) was collected at the bottom of pit H627 (34°28.189′N, 109°00.994′E, 378 m a.s.l.), which partly dissects pit H629 on its southern side (Figs 2, 3).

Huxizhuang site (HXZ) (34°18.061′N, 108°06.721′E) is situated on a triangular terrace about 80 km west of Yangguanzhai site (Fig. 1). It was excavated by the Institute of Archaeology of Chinese Academy of Social Sciences in 1979. The site is attributed mainly to the middle to late Yangshao Culture (*c.* 6000–5000 cal. a BP) (The Institute of Archaeology of Chinese Academy of Social Sciences 1988). The excavated area is about 350 000 m^2. Archaeologists speculated that an agricultural economy appeared in this region based on (i) the presence of plant-processing tools such as grinding stones, stone axes and sickles, and numerous pottery vessels; and (ii) the grain impressions found at the bottom of some storage pits. We collected one sample (HXZ-HH1) (34°18.061′N, 108°06.721′E, 451 m a.s.l.) in a pit for phytolith analysis and radiocarbon dating (Fig. 3).

Anban site (AB) (34°20.749′N, 107°54.617′E) is located in the middle reaches of the Weihe River, about 20 km west of Huxizhuang site (Fig. 1). It is a typical site of middle Yangshao to Longshan Culture

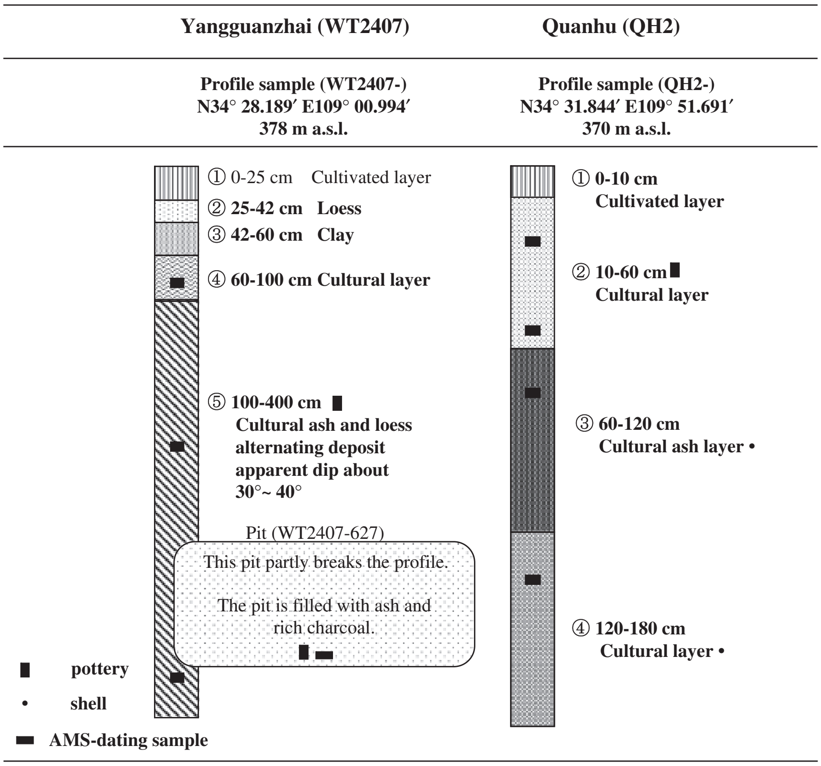
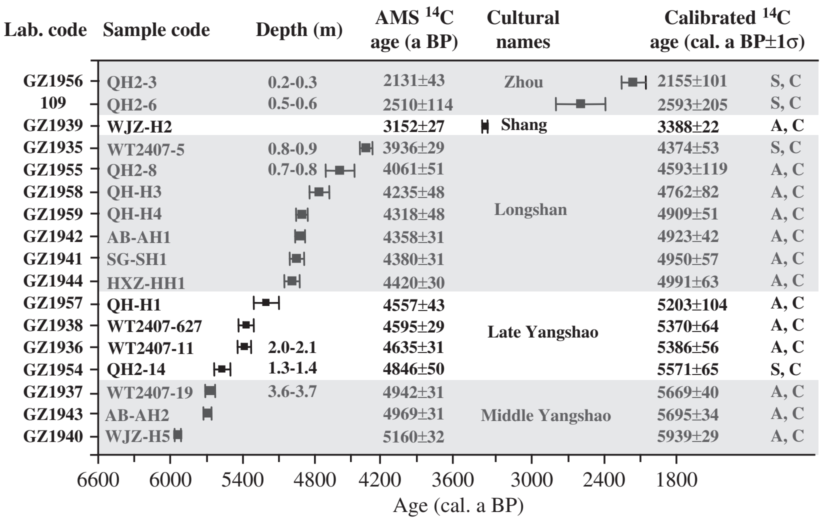


Fig. 2. Archaeostratigraphy of Quanhu (QH2) and Yangguanzhai (WT2407) profiles used for phytolith analysis and dating.



Lab. code	Sample code	Depth (m)	AMS ^{14}C age (a BP)	Cultural names	Calibrated ^{14}C age (cal. a BP±1σ)	
GZ1956	QH2-3	0.2-0.3	2131±43	Zhou	2155±101	S, C
109	QH2-6	0.5-0.6	2510±114		2593±205	S, C
GZ1939	WJZ-H2		3152±27	Shang	3388±22	A, C
GZ1935	WT2407-5	0.8-0.9	3936±29	Longshan	4374±53	S, C
GZ1955	QH2-8	0.7-0.8	4061±51		4593±119	A, C
GZ1958	QH-H3		4235±48		4762±82	A, C
GZ1959	QH-H4		4318±48		4909±51	A, C
GZ1942	AB-AH1		4358±31		4923±42	A, C
GZ1941	SG-SH1		4380±31		4950±57	A, C
GZ1944	HXZ-HH1		4420±30		4991±63	A, C
GZ1957	QH-H1		4557±43	Late Yangshao	5203±104	A, C
GZ1938	WT2407-627		4595±29		5370±64	A, C
GZ1936	WT2407-11	2.0-2.1	4635±31		5386±56	A, C
GZ1954	QH2-14	1.3-1.4	4846±50		5571±65	S, C
GZ1937	WT2407-19	3.6-3.7	4942±31	Middle Yangshao	5669±40	A, C
GZ1943	AB-AH2		4969±31		5695±34	A, C
GZ1940	WJZ-H5		5160±32		5939±29	A, C

Fig. 3. ^{14}C dates on samples from archaeological sites in the Guanzhong Basin. The series of GZ- dates are AMS ^{14}C dates obtained by the Guangzhou Institute of Geochemistry, CAS and State Key Laboratory of Nuclear Physics and Technology of Peking University. CalPal was used to calibrate the dates (Pearson *et al.* 1993; Stuiver & Pearson 1993). The No-GZ series are conventional ^{14}C dates obtained by the Laboratory of Nuclide and ^{14}C Chronology of Institute of Geology and Geophysics, CAS. Calib Rev 5.0.1 was used to calibrate the dates (Stuiver & Reimer 1993). A = ash; S = ancient soil with rich charcoal; C = charcoal.

(*c.* 6000–4000 cal. a BP) (School of Archaeology and Museology 2000). Two samples (AB-AH1, AB-AH2) (34°20.749′N, 107°54.617′E, 555 m a.s.l. and 34°20.800′N, 107°54.695′E, 547 m a.s.l.) were taken from two pits for phytolith analysis and radiocarbon dating (Fig. 3).

Wangjiazui site (WJZ) (34°28.664′N, 107°50.199′E) is situated on a triangular intersected terrace, about 15 km northwest of Anban site (Fig. 1). It was occupied mainly by Yangshao to Longshan Culture (*c.* 7000–4000 cal. a BP), and was excavated by the Banpo Museum in the 1950s (Banpo Museum 1984). We collected two samples (WJZ-H2, WJZ-H5) (34°28.664′N, 107°50.199′E, 666 m a.s.l. and 34°28.434′N, 107°50.242′E, 656 m a.s.l.) from two pits for phytolith analysis and radiocarbon dating, respectively (Fig. 3).

Shuigou site (SG) (34°34.290′N, 107°27.653′E, 902 m a.s.l.) is located in the western part of the Guanzhong Basin, about 40 km west of Wangjiazui site, and about 230 km west of Quanhu site (Fig. 1). One sample (SG-SH1) was taken from an ash pit of Longshan Culture (*c.* 5000–4000 cal. a BP) for phytolith analysis and radiocarbon dating (Fig. 3).

Methods

Each sample (~2 g) was taken for phytolith analysis and prepared as described by Piperno (1988) and Runge *et al.* (1999) with slight modifications. The procedure consists of sodium pyrophosphate ($Na_4P_2O_7$) deflocculation, 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. More than 400 phytoliths were counted in each sample. Identification was aided by the use of reference materials (Lu 1998; Lu & Liu 2003a, b; Lu *et al.* 2006) and published keys (Piperno 1988; Mulholland & Rapp 1992; Kondo *et al.* 1994; Piperno & Pearsall 1998; Runge *et al.* 1999; Pearsall 2000).

In this study, a total of 22 phytolith types, including rice, millet, Panicoideae, Arundinoideae (Fig. 4C, particularly from *Phragmites*), Bambusoideae (Fig. 4D), Eragrostidoideae and Pooideae, were identified according to the classification system of Lu *et al.* (2006) and accounting for three classifications (Twiss *et al.* 1969; Wang & Lu 1993; Kondo *et al.* 1994). For the identification of double-peaked, bulliform and parallel-bilobe rice phytoliths, the reference was the work of Wang & Lu (1993) and Lu *et al.* (2002). Millet phytoliths were identified by reference to Lu *et al.* (2009b). Phytolith abundance was expressed as a percentage of all phytoliths counted.

Results

Chronology

Age data from AMS and conventional ^{14}C age determination are given in Fig. 3. All the 19 ^{14}C determinations dated the occupation to around 6000–2000 cal. a BP. Except for two abnormal dates in the Quanhu profile (QH2-10 and QH2-12), all dates are consistent with the archaeological ages generally deduced from artefacts.

Phytoliths

The phytolith assemblages from the cultural layer were mostly well enough preserved to enable correct identification (Fig. 4). Abundant rice phytoliths include the following forms: double-peaked, bulliform, parallel-

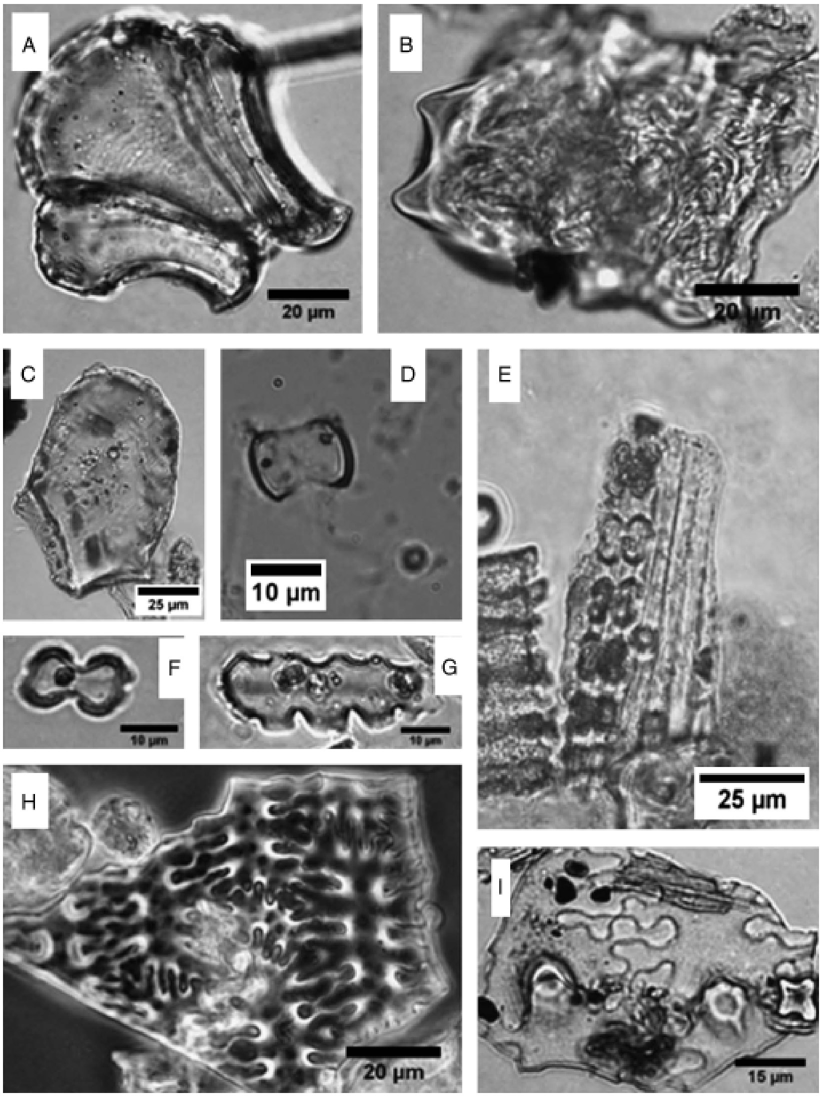


Fig. 4. Main phytolith types in archeological sites of the Guanzhong Basin. A = bulliform from rice leaf; B = double-peaked from rice husk; C = bulliform from reed; D = long saddle from Bambusoideae; E = parallel-bilobe from rice leaf/stem; F = bilobe; G = crenate; H, I = phytoliths from millet husks.

bilobe. The bulliform phytolith is characterized by numerous small shallow scale-like decorations and by two lateral protrusions on the half-round side (Fujiwara 1993). The millet husks, including common millet and foxtail millet (Lu *et al.* 2009b), dominate among crop types in nearly all studied samples. The remaining common phytoliths are reed bulliform, saddle, smooth-elongate, sinuate-elongate, bilobe, acicular hair cell, short-point, square, crenate and rondel, and unidentified phytoliths.

Phytoliths from the Quanhu site (QH). – The Quanhu profile has a thickness of 1.8 m, including two cultural layers at 10–60 and 120–180 cm depth, with the lower layer containing more charcoal than the upper one. The layer in between (60–120 cm) is a typical cultural ash deposit (Figs 2, 5). According to the stratigraphy and phytolith assemblages, the profile can be divided into three phases: Z1 (180–120 cm), Z2 (120–60 cm) and Z3 (60–0 cm) (Fig. 5). All samples from the profile contained abundant diagnostic rice and millet phytoliths. Rice husk phytoliths are distributed from the bottom to the top of the profile. Their percentage increases slightly from Z1 to Z2, with a peak of 9.33% at 80–90 cm depth in Z2. In the upper part of Z2, the percentage of rice husk phytoliths rapidly decreases from 6.62% to 1.46% and then increases to 4.79%, remaining at about 4% in Z3. The percentage of bulliform and parallel-bilobe phytoliths is very low (~0.05%) and they are present only in the middle of Z2 and in the upper part of Z3. Generally, millet phytoliths in Z1 and Z2 are at about 20%, with common millet (*Panicum miliaceum*) dominant (> 10%). In Z3, however, the percentages of phytoliths from both common millet and foxtail millet sharply decrease: the percentage of common millet (average 5.51%) is slightly higher than that of rice (average 4.58%) in general, and foxtail millet almost disappears (< 1%) (Fig. 5).

In QH-H4 (*c.* 4900 cal. a BP), the percentage of rice phytoliths is the highest of all samples of the Quanhu

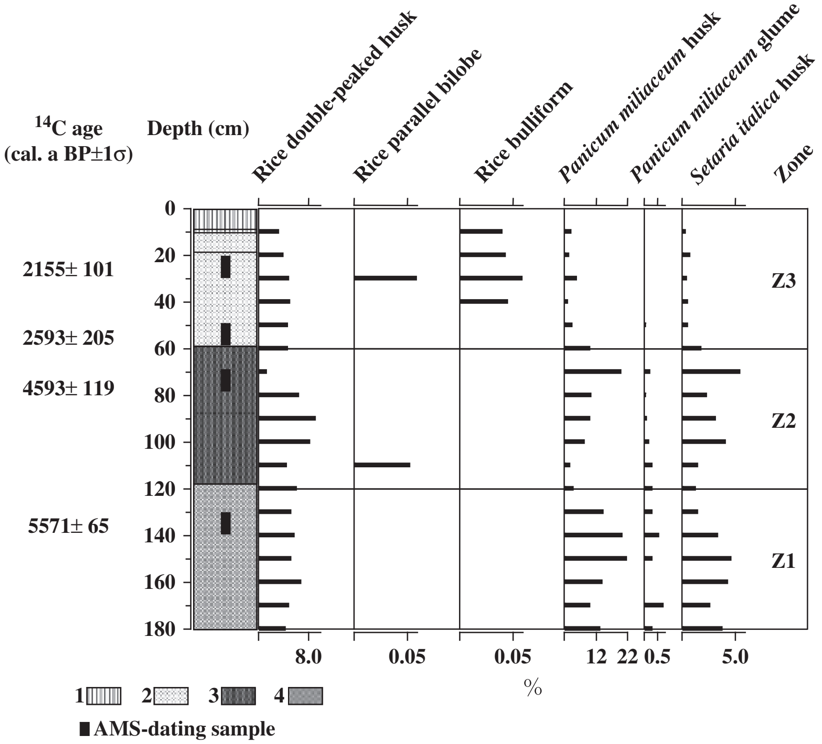


Fig. 5. Variations in percentages of main crop phytoliths in the Quanhu (QH2) profile. 1 = cultivated layer; 2 = cultural layer; 3 = cultural ash layer; 4 = cultural layer rich in charcoal.

site, at 13.38% (double-peaked), 0.24% (bulliform) and 0.73% (parallel-bilobe). However, QH-H1 (*c.* 5200 cal. a BP) contains only a few double-peaked husks (0.74%), and QH-H3 (*c.* 4760 cal. a BP) has a very low percentage of parallel bilobes (0.25%). Overall, the percentage of millet phytoliths in QH-H1 and QH-H4 is high (~13%), but it is low (0.25%) in QH-H3.

Phytoliths from the Yangguanzhai site (WT). – The percentage of rice husk phytoliths is low (0.39%) and only present at the depth of 3.0–3.1 m. In the upper layer, more bulliform phytoliths are present and their occurrence frequency gradually increases, with the percentage reaching 1.85% at 1.5–1.4 m depth. Parallel-bilobe phytoliths only occur at the depth of 2.0–2.1 m (0.20%). The millet phytoliths are dominant in the lower part (10–35%), but disappear almost completely in the upper part of the profile (< 1%) (Fig. 6).

Phytoliths from individual pits. – In AB-AH1 (*c.* 4920 cal. a BP) and AB-AH2 (*c.* 5690 cal. a BP) (Fig. 3), two bulliform and three double-peaked phytoliths were identified among more than 400 phytoliths. In HXZ-HH1 (*c.* 4990 cal. a BP), three double-peaked, one bulliform and one parallel-bilobe phytolith were found among the 400 grain counts. In Shuigou (SG) and Wangjiazui (WJZ) sites, no rice phytoliths were found. Millet phytoliths dominate in these samples (> 10%).

In summary, all three types of rice phytoliths were found as early as about 5500 cal. a BP in the Guanzhong Basin. During *c.* 4000–3000 cal. a BP, rice phytoliths were absent, but were found again at *c.* 2500 cal. a BP. Moreover, the occurrence frequency of bulliform and parallel-bilobe phytoliths increased in the upper part of the Quanhu (QH) and Yangguanzhai (WT) profiles. Regarding spatial distribution, no rice phytolith was found at Shuigou (SG) or Wangjiazui (WJZ) site in the western Guanzhong Basin in any epoch, whereas rice phytoliths were found at Anban (AB) and Huxizhuang (HXZ) sites in the middle of the Basin from *c.* 5500 cal. a BP. At Quanhu (QH) and Yangguanzhai (WT) sites, in the eastern Guanzhong Basin, all three types of rice phytoliths occur abundantly from *c.* 5500 cal. a BP (Figs 3, 5, 6).

Discussion

Rice cultivation in the Guanzhong Basin

Based on the study of phytolith assemblages from Anban (AB-AH2, 34°20.800′N, 107°54.695′E) site, Quanhu (QH) profile (34°31.844′N, 109°51.691′E) and Yangguanzhai (WT) profile (34°28.189′N, 109°00. 994′E), we conclude that the timing of rice appearance in the Guanzhong Basin may be not later than *c.* 5690 cal. a BP. This is potentially the best dating available for the earliest appearance of rice in central North China. It should be noted, however, that rice phytoliths occurred only in some of the bigger archaeological sites such as Anban (AB) (nearly 700 000 m^2;

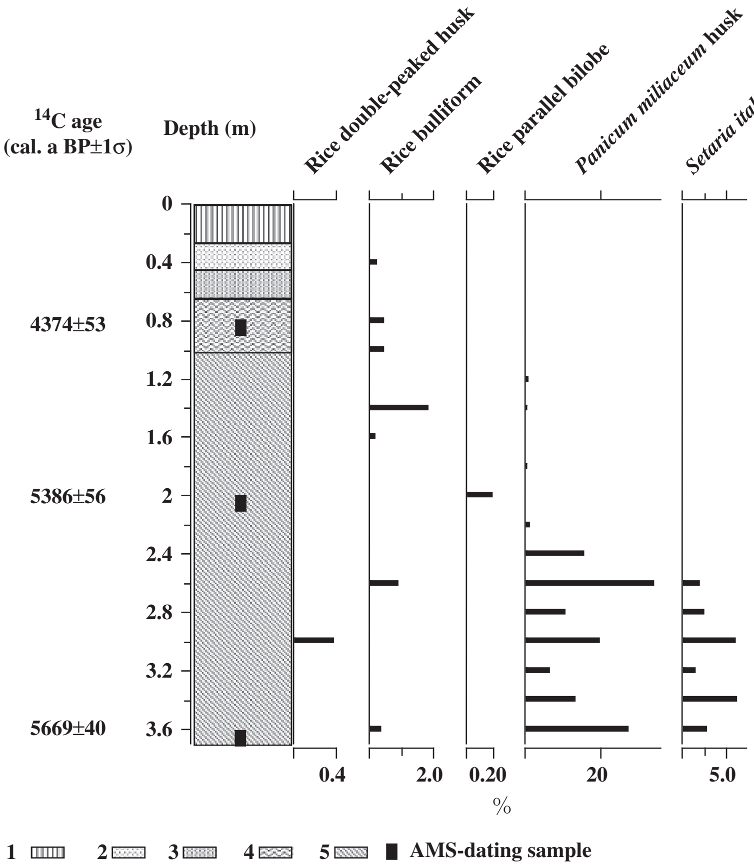


Fig. 6. Variations in percentages of main crop phytoliths in the Yangguanzhai (WT2407) profile. 1 = cultivated layer; 2 = loess; 3 = clay; 4 = cultural layer; 5 = alternating deposits of cultural ash and loess.

State Administration of Cultural Heritage 1998). These sites are commonly situated on the second terrace in the landscape, close to wetlands or floodplains of rivers such as the Quanhu (QH), Yangguanzhai (WT) and Anban (AB). The local geomorphic features permitted ancient people to utilize water conveniently to plant rice and obtain productive harvests. Thus, rice may be the main resource available in these localities.

It has been noted that different rice phytolith assemblages can be used to provide information on cultivation techniques and the purpose of crop processing (Harvey & Fuller 2005). This study shows that the bulliform and parallel-bilobe phytoliths occurred abundantly after *c.* 5500 cal. a BP (Figs 5, 6), implying that more rice leaves and stems should be present at archaeological sites in the period. These two phytolith types from rice leaves and stems together with greater amounts of husks suggest that rice might have been more widely cultivated in the Guanzhong Basin after *c.* 5500 cal. a BP.

The western spread of rice

In the past few decades, many rice remains have been found in the lower reaches of the Huanghe River dating from the Holocene (Fig. 7) (Wu 1994; Zhang 1994; Chen *et al.* 1995; Chen & Jiang 1997; Jin *et al.* 1999, 2004, 2007a, b; Longqiuzhuang Archaeology Team 1999; Wei *et al.* 2000; Jin 2001; Chen & Li 2004; Zhang *et al.* 2004; Zhao 2004; Crawford *et al.* 2006; Zhao & He 2006; Li *et al.* 2007a, b). These remains were considered to be convincing evidence for the northwestward and northeastward spread of rice from the middle and lower reaches of the Changjiang River. However, it is worth noting that rice remains older than 8000 years were found at the Jiahu site, which caused controversy in the archaeological field regarding whether it was a wild or domesticated variety (Fuller *et al.* 2007; Liu *et al.* 2007). We consider that no matter whether the rice remains at Jiahu site were domesticated or wild, this site is still significant for the study of a possible spread route of rice cultivation during the early period of the Holocene. To date, for Jiahu site there has been no widely accepted criterion to distinguish whether its rice remains are domesticated or not, and it is necessary to do more research in the future to clarify this issue.

The phytoliths from the various sites in the Guanzhong Basin provide new evidence that rice might have spread towards the west during the mid-Holocene, and arrived in the Guanzhong Basin around 5500 cal. a BP (Fig. 7). Li *et al.* (2007a, b) reported that both rice

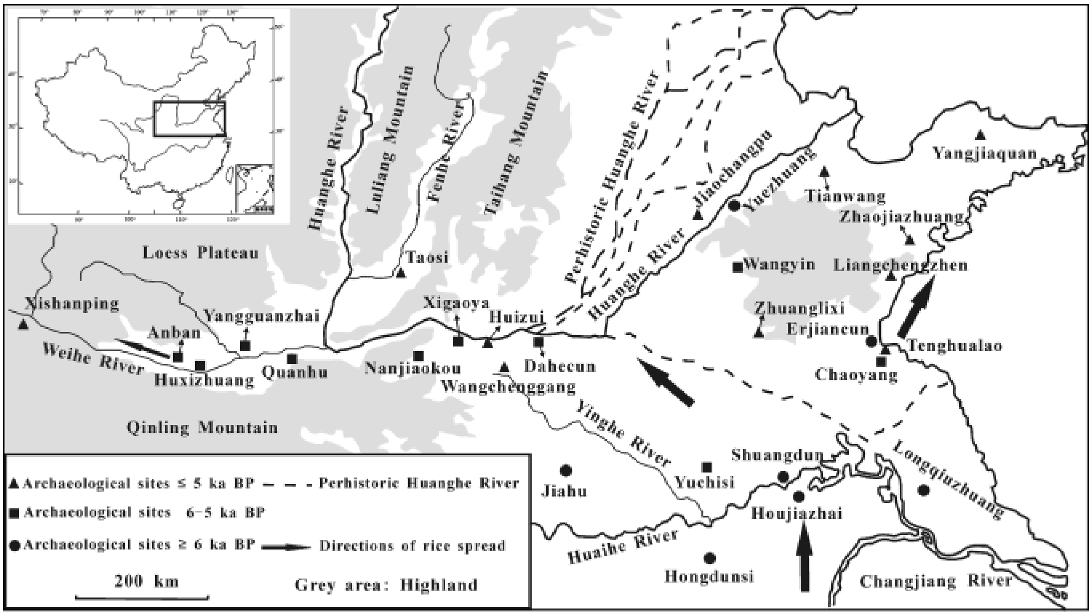


Fig. 7. Possible direction of rice spread in North China (modified from Liu 2007); for other data from archaeological sites see Wu (1994) (Dahecun and Xigaoya sites); Zhang (1994), Chen *et al.* (1995) and Chen & Jiang (1997) (Jiahu site); Jin *et al.* (1999, 2004, 2007a, b) (Tianwang, Liangchengzhen, Wangchenggang and Zhaojiazhuang sites); Longqiuzhuang Archaeology Team (1999) (Longqiuzhuang site); Wei *et al.* (2000) (Nanjiaokou site); Jin (2001) (Eejiancun, Wangyin, Tenghualao, Yuchisi, Yangjiaquan and Zhuanglixi sites); Cheng & Li (2004) (Huizui site); Zhang *et al.* (2004) (Shuangdun, Houjiazhai and Hongdunsi sites); Zhao (2004) (Jiaochangpu site); Crawford *et al.* (2006) (Yuezhuang site); Zhao & He (2006) (Taosi site); Li *et al.* (2007a, b) (Xishanping site).

grains and phytoliths were present at Xishanping site, about 220 km west of Anban site, around 5070 cal. a BP. Their findings indicated that rice might have spread further westwards along the Weihe River during the middle Neolithic. Thus, our rice phytolith evidence from Guanzhong archaeological sites is of great importance for the study of the westward spread route of rice and the agricultural civilization during the Neolithic period in North China. It helps us to understand the spatial and temporal patterns of rice spread along the Huanghe River valley, including along its branches such as the Weihe River (Fig. 7). We infer that the climate during the middle Holocene may be the main cause for the westward spread of rice. During the Holocene optimum (early to middle Neolithic), areas in central and eastern China experienced mainly a warm and humid climate. The strengthened summer monsoon brought much more precipitation to these areas, in which vast regions of wetland and bogs occurred (Shi *et al.* 1993; An *et al.* 2000; Yi *et al.* 2003; Feng *et al.* 2004, 2006; Xiao *et al.* 2004; An *et al.* 2006; Rosen 2008). Guanzhong Basin was also controlled by a warm and wet climate (Lu & Zhang 2008), which was largely beneficial for the spread of rice towards the west along the Huanghe River valley. Moreover, the frequently shifting population and cultural communication between the western and eastern parts of China (such as the Guanzhong Basin and East China) might have accelerated the spread of rice during the middle Neolithic (Liu 2007).

The rice–millet complex in the Guanzhong Basin

It has long been known that the farming pattern in North China was characterized by dry crops. However a rice–millet-complex pattern, namely simultaneously farming dry crops and rice in one region, can be traced back to the Peiligang Culture (early Neolithic) in the area between the lower reaches of the Huanghe River and Huaihe River valley in eastern China (Wu 1994; Underhill 1997; Liu & Xiang 2005). Our phytolith evidence indicates that a rice–millet-complex pattern appeared in the middle Neolithic around 5500 cal. a BP (middle Yangshao Culture) in the Guanzhong Basin, central North China. It was characterized by dominant dry crops such as *Panicum miliaceum* and *Setaria italica* and locally cultivated rice. At about 5500 cal. a BP, the occurrence of bulliform and parallel-bilobe phytoliths together with higher numbers of husk phytoliths may suggest more widely cultivated rice in this region, as favourable climatic conditions in the middle Holocene provided plenty of water for rice development. Even so, the farming pattern in the Guanzhong Basin during this time was still dominated by dry crops, rice being cultivated only locally at the riverside.

The pattern found in the Guanzhong Basin indicates that this planting mode expanded during the middle Holocene (*c.* 5500 cal. a BP) towards northwestern China, which is important for an understanding of the history of planting, cultivation and farming management.

Conclusions

The crop phytolith remains collected from six archaeological sites dated from 5690 to 2150 cal. a BP in the Guanzhong Basin, central North China have been analysed. The phytolith analysis results from Anban (AB), Quanhu (QH) and Yangguanzhai (WT) sites indicate that rice was first planted at least around 5690 cal. a BP in the Guanzhong Basin, which is so far the earliest rice record reported from central North China. Rice phytoliths from six sites show significant differences in abundance, indicating that rice cultivation in this region was not so frequent in the prehistoric period, occurring only at the larger settlements such as Quanhu (QH), Yangguanzhai (WT) and Anban (AB), situated close to rivers. The occurrence of phytoliths from rice stems and leaves together with greater amounts of husks suggest that rice was more widely cultivated after 5500 cal. a BP in this area. We infer that rice in the Guanzhong Basin might have spread westwards from the lower reaches of the Huanghe River along the Weihe River before 5500 cal. a BP. The warm-humid climate and frequent communication of cultures in the middle Neolithic might have promoted the westward spread of rice. The farming pattern of dominantly dry crops with locally cultivated rice was established at least in the middle Neolithic and expanded westwards along the Weihe River. To understand the complexity of the spatial and temporal pattern of rice agriculture in central North China during the Neolithic epoch, more well-dated and high-resolution archaeobotanical records are needed, such as phytoliths, carbonized grains and plant macrofossils.

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