Events of reclaiming marshes for rice fields between 7000BP and 4500 BP in east China

Zheng Yunfei[1†], Sun guoping[1], Qin ling [2], Li chunhai[3], Wu xiaohong [2], Chen xugao[1]

1, Zhejiang Provincial Institute of relics and Archaeology (Jiashan Road, Hangzhou, China)

2, Peking University (Haidian, Beijing, China)

3, Nanjing Institute of Geography & Limnology (East Beijing Road, Nanjing, China)

Abstract: Discovery of the oldest rice fields at the Tianluoshan site in east China has provided data of recovering reclaimation, cultivation, and the ecological system of rice fields between 7000BP and 4500 BP. People opened up marshes of dense reeds with fire and wooden or bone spades, in order to create rice fields. In the rice fields, there was not only rice, but a lot of weeds as well. The excavations proved that little or even no weeding or irrigation was adopted. However, tilling soil by wooden and bone tools was evidenced. The yields are estimated to have been about 8.3 kg for the early period and 9.5 kg per acre for the later period. The cultivation system was low-level. Although the Tianluoshan people cultivated rice, they still obtained a great deal of food by gathering and hunting.

Keywords: Tianluoshan site, Neolithic rice fields, rice cultivation, marsh, origin of rice cultivation, east China

In the Early Holocene epoch, the prologue of cultivation and domestication of rice in China was opened in two core areas，the middle Yangtze basin and the Yangtze delta (1). In the Yangtze delta located, an over-7000-year–old process of cultivation and domestication of rice and a long history of utilization of rice has been demonstrated by morphological research of the short rachillas and spikelets. (2) (3). Recent archaeological research indicates that the initial rice cultivation within this area is even earlier, dating back to at least 10000 years ago (4) (5), much earlier than the appearance of fully domesticated rice (6).

Rice cultivation is a human activity that exerts some selective pressure on the growth and development of rice in specific areas in order to obtain a more stable food supply than the gathering of wild plants. It includes tilling soil, sowing, fertilizing, irrigating, etc. To understand the origins of rice cultivation, not only archaeological remains of rice but also knowledge of culture and ecology in the Neolithic age is important (7). Excavation and research on archaeological evidence of rice cultivation can provide better insight into technology, area, yield and environment of rice cultivation. Also it can be used for estimating the advancements of both cultivation and domestication, being fundamental issues in the study of the origins of rice cultivation.

In the Yangtze delta, small paddy fields with irrigating ditches and wells of 6000 years ago have been found, They were initial modifications of the natural topography (8) (9). Older ones have not been found and excavated,

† Corresponding author: Zheng Yunfei, zhengwh@hzcnc.com

although it was inferred that rice paddies with fire and flood management had appeared based on analyzing pollens, diatoms, and charcoal in the occupation area of the Kuahuqiao site [(10)]. Recently our recovery of prehistoric rice fields around the wooden pile-dwelling features of the Tianluoshan site has been able to sufficiently answer some preliminary questions of rice cultivation system between 7000 and 4500 BP.

The Tianluoshan site [(11)] is located at the edge of the Ningshao plain in the Yangtze Delta, and 30-40 km from the east coastline. It is near the piedmont of the Siming Mountain (Figure1). Presently the land is approximately 2 meters above the sea level. A lot of artifacts recovered from this site include stone, wooden, and bone tools, and pottery. A large number of upright wooden piles indicate that the dwellings were adaptive to wetlands. Due to the good preservation of an anaerobic condition, massive amount of organic remains are recovered, including animal bones such as buffalo, deer, pig, fish etc. as well as seeds and fruit such as rice, acorn, axillary southern wild jujube, peach, plum, water caltrop, fox nut, etc. A substantial number of rice spikelets and short rachillas are morphologically different from wild rice and some spikelets can be characterized as domesticated rice. This is evidence of a mixed economy comprised of hunting-gathering and rice cultivation.

The rice fields associated with the Tianluoshan occupation lie about 1m below the surface and can be clearly distinguished between early and later periods (Figure 2). The early rice fields were dated between 7000BP and 6500BP and are the oldest rice fields known. They are 1000 years earlier than the rice fields revealed at the Caoxieshan site [(12)] in the lower Yangtze region and 3000 years earlier than those of the Zhaojiazhuang site [(13)] in the middle reach of the Yellow River, and also older than ones excavated in the Chengtoushan site [(14)] in the middle regions of the Yangtze River. The later rice fields of Tianluoshan are dated to between 6000 BP and 4500 BP (Table 1, Figure 3). The early fields lie 200 to 230 cm below the surface at Location 1 and 257 to 294 cm below at Location 2. The later fields lie 95 to 150 cm below the surface at Location 1 and 93 to 177 cm below at Location 2.

There are many plant remains including rice remains such as roots, stems, leaves, seeds and microfossils in the strata of rice fields. A few pottery fragments and wooden tools demonstrate that people activities were frequent here in prehistory. High densities of rice spikelets fragments, phytoliths derived from the bulliform cells of rice, and a large number of Gramineae pollens bigger than 38 μm in diameter likely derived from rice, indicate that rice grew here [(15)] (Figure 3). So this can be referred as the fields for rice production. The morphological observation of rice short rachillas and spikelets suggests that the rice is different from wild rice. The short rachillas of domesticated type accounts for 47.1% in the early period and 59.4% in the later period, while wild type accounts for 52.9% in the early period and 40.6% in the later period. This indicates the selection pressure for domesticated forms and that they still have some characteristics of wild rice. It therefore would be recognized that these not only were places of rice production, but also must be ones of planting rice. Through the investigation of stratigraphy, phytoliths and seeds from an area of 14.4 hectares, two rice field strata were found around the occupation. The area of rice fields could have covered 6 hectares for the early period and over 7 hectares for the later period (Figure 4).

Within the investigated area of 350 sq. meters, a 40cm wide path that made it convenient for people to go into the field and manage the rice stands is revealed for the later period. However, no evidence of an irrigation system that is supposed to consist of ditches, field ridges, and bund for sophisticated controls of drainage and irrigation is found. Thus these rice fields are different from those recovered from the Caoxieshan site dated 6000 BP. (16) (17). We suggest that the irrigation of them could have been dependant on rain water and stored water in the marsh. The Yangtze Delta is located in a subtropical monsoon climatic zone. Spring is moist and has some rain. In summer, this region is hot and humid due to the control by warm tropical air currents and typhoons. In autumn it is cool and relatively dry. Winter is cold and moist. The seasonal rainfall responsible for annual flooding might satisfy the need of irrigation of rice growth. The markedly abundant micro-charcoals in the deposits of rice fields compared to other strata imply that firing could be applied to rice cultivation. Two wooden dibbles and one wooden handle of spades were found from both of the two rice fields, suggesting that the technique of tilling soil by wooden and bone tools was developed (Figure 5). Those tools have a lot found in the dwelling trace.

Summarized as Figure 3, the analyses of plant seeds, phytoliths for the soil samples provided the detailed, diagnostic palaeoecological data of prehistoric rice fields. Many plants coexisted with rice in those tilled fields, such as Barnyardgrass (*Echinochloa*), Galingale (*Cyperus*), Bulrush (*Scrirpus*), Fimbristylis (*Fimbristylis*), Spikesedge (*Eleocharis*), Sedge (*Carex*), Hornwort (*Ceratophyllum*), Najad (*Najas)*, Pondweed (*Potamogeton*). Floatingheart (*Nymphpoides*), Arrowhead (*Sagittaria*), Duckleaf Knotweed (*Persicaria*）, Yerbadetajo (*Eclipta*), waterchesnut (*Trapa)*, reed (*Phragmites*). The habitat of most of these plants is wetlands, such as the bank of river and streams, marshes and wasted wetland. These species are also common weeds in rice fields. The analyses of seeds indicate that the seed bank could have been 26,000-228,000 individuals/m^2 for the early rice fields and 26,000-184,000 individuals/m^2 for the later rice fields. It is remarkably higher than 9,140-47,452 individuals/m^2 for modern paddy fields nearby wetland and even higher than 83,499-10,9141 individuals/m^2 for secondary wetland (18). Generally, the seed bank and species number in paddy fields reclaimed from wetland would decrease. High seed banking and species diversity shows that little or even no weeding was applied to the management of the rice fields dating 7000-4500 BP. There are not only a large number of rice phytoliths but also reed phytoliths in two strata of rice fields. This implies that the rice fields could have been altered from reed-marsh and reed probably intruded into the fields and grew with rice.

Climatic amelioration at the end of the Pleistocene markedly altered the ecology in China and led to changes in human adaptations (19) (20).The Yangtze Delta witnessed a period of high sea-level around 7000-6000 BP

[21].During the regression interval, seawater regressed and large areas of land were exposed and left behind a number of lakes. As salinity in soil had fallen, a freshwater environment appeared. Flourished wetland plants dominated the edge of water area and there are also mammals, waterfowl, and freshwater fish. The excavation of occupation provided data for reconstructing resource exploitation. People migrated and settled here 7000 years ago. In addition to planting rice, they lived on gathering wild fruits growing on highlands, such as acorns, peaches, and plums, and nuts in lakes, such as water caltrop, fox nut, and lotus. They hunted buffalo, deer, and birds and harvested carp, snakehead, crucian, and terrapin in lake.

The studies of rice fields permit reconstruction of the rice cultivation system between 7000 BP and 4500BP. High densities of reed phytoliths and the body remains indicated that people opened up wetlands for rice fields, where there were dense grasses mainly comprising reeds. The abundant charcoal implies that fire was possibly used to prepare the fields. Before spring rain, the soil was tilled to a certain extent with wooden and bone spades and seeding was done with dibble sticks after the withered weeds were removed and the ground was cleared by firing. Sprouted rice grew well in wetlands filled by the monsoonal rain while the wetland weeds flourished as well. In the autumn, as the rain decreased, water accumulated in wetland lowered and people harvested mature rice by picking the base of the inflorescences. The wooden knife proved that the harvest sometime was with the help of some tools.

The cultivation system was a form of low-level food production. According to the relationship between rice phytoliths and spikelets [22], According to the ratio of rice phytoliths to spikelets, the rice yields are estimated as 8.3 kg per acre for the early period and 9.5 kg per acre for the later period. Based on this estimation, the annual yields might have been about 5937 kg for the early period and 6175 kg for the later period. This suggests that the rice could support no more than 30 persons. However, some ethnographic data show that a village living dominantly on hunting-gathering subsistence has 25-100 persons while one involved in agricultural economy has 150-300 persons [23]. Obviously, even though people at Tianluoshan cultivated rice, the production was relatively low-level and hunting-gathering provided a substantial proportion of food in their diet.

Domestication of crops is not a rapid, but is a protracted process [24]. The vast early rice fields combined with the mixed wild and cultigen phenotypes indicate that rice cultivation and domestication had originated earlier. Recent discoveries of rice remains between 7000 BC and 9000 BC implied that rice cultivation may have originated in some small basins located in mountainous areas as early as 10000 years ago [25]. The earliest evidence for cultivation of rice in the Yangtze Delta also can be contrasted with the evidence from 2,000 to 4,000 years later in Southeast Asia, indicated that the Yangzte regions are original areas of domesticated rice, and from this areas, rice was carried to Southeast Asia [26]

Acknowledgements: This research is supported by Zhejiang Provincial Department of Finance and the

National Natural Science Foundation of China（No.40572178). The authors would like to thank Ph.D student, Pan Yan of Fudan University, China for providing us with helps of coring investigation and Dr. Dorian Q Fuller of Institute of Archaeology, University College, UK, Dr. Jiao Tianlong of Department of Anthropology, Bishop Museum, USA for giving us with helps and advices.

Figure 1 Location of the Tianluoshan site. Locations of the Tianluoshan site and other archaeological sites dated between 8000BC and 4000BC were showed. The Shangshan[(27)] and Xiaohuangshan[(28)] sites, dated between 9000BC and 7000BC and between 7000BC and 6000BC, respectively, were located in little basins in mountainous areas. The Kuahuqiao site[(29)] dated between 6000BC and 5000BC and the Hemudu[(30)], Tianluoshan sites dated between 5000BC and 3000BC, lied at the gateway from upland valleys to plains. The Lujiajiao site [(31)] was dated 5000BC. The Caoxieshan site [(32)] was dated 4000BC, in which the Neolithic paddy fields were firstly unearthed in China.

Figure 2 Parts of the rice field excavated from No.1 place. A is early rice fields in T705 trench of Location 1 lie hidden in about 2.8m depth below the earth's surface dated between 4650BC and 4490BC and B is later rice fields in T803 and T703 trenches of Location 1 lie hidden in about 1.3m depth below the earth's surface, dated between 3340BC and 3090BC. The places where the pottery fragments were excavated were marked with red flags. The wooden pegs in T705 trench were for preventing the collapse of its walls in the excavation.

Figure 3 Integrated palaeoecological data from rice fields dated between 5000BC and 2500BC at Tianluoshan site. The early and later rice fields at T1041 trench of Location 2 lie hidden in depths between 94-140cm and 200-235cm, respectively. There are not only many chips, short rachillas of rice spikelets, but dense phytoliths derived from motor cells of rice, high percentile gramineous pollens larger than 38μm in the stratigraphical layers, indicated that they have some relationships to rice cultivation. They also contained a large number of charcoals, implied that people were ever frequently engaged in the economic activity there.

Figure 4 Distributions of early and later rice fields. A and B showed the distributions of later and early rice fields, respectively. The figures were made based on aspects of colors, properties, botanical remains of soil samples token out with coring sticks, and their results of phytolith analysis, and showed that the rice fields were located in wetlands with a lot of rivers and lakes. The data of phytolith analysis for places with ○ marks were showed Table 2.

Figure 5 Farming tools. The wooden dibble and knife were excavated from the early rice fields, and bone spades were excavated from the dwelling trace. There are clear frayed traces caused by frequent digging soil in surfaces of bone spades. The scales are 5cm.

Table1 Chronology and the radiocarbon dates for the rice fields at the Tianluoshan site with AMS

Excavation places	Trenches	Depth (cm, below earth's surface)	Number in the lab	Material	^{14}C age (yr BP, ±1δ)	Calibrated age (yr BC, ±1δ)
Location 1	T1041	81-86	BA07762	Plant remains	3760±40	2280-2050
		96-101	BA07761	Yagara bulrush	4015±45	2575-2475
		106-111	BA07760	Bulrush	4195±70	2900-2670
		121-126	BA08203	Bulrush	4470±45	3330-3020
		131-136	BA07758	Yagara bulrush	4765±35	3600-3030
		136-141	BA08895	Yagara bulrush	4830±35	3700-3520
		141-146	BA08894	Yagara bulrush	4965±35	3910-3650
		146-151	BA08893	Yagara bulrush	5040±40	3960-3710
		223-228	BA07764	Flatdstalk bulrush	5785±60	4710-4550
		228-233	BA07763	Flatdstalk bulrush	6045±45	5010-4850
Location 2	T803	135-140	BA08359	Bulrush	4250±40	2890 -2700
	T803	135-140	BA08355	Bulrush	4475±35	3330 -3090
	T803(Road)	135-140	BA08360	Bulrush	4705±40	3630 -3370
	T705	160-170	BA08526	Bulrush	4490±40	3340 -3090
	T705	280-285	BA08527	Triangular Bulrush	5725±40	4650 -4490

AMS, accelerator mass spectrometry, Peking University AMS Laboratory, calibrated by Oxcal 3.10 and INTCAL104

Table 2 Densities of phytoliths derived from bulliform cells of grasses in possible ancient rice fields stratums of 37 coring places

Position	Densities grains/g											
	Depth CM	*Oyriza*	*Phragmites*	*Miscanthus*	*Bambusoideae*	*Panicum*	Depth CM	*Oyriza*	*Phragmites*	*Miscanthus*	*Bambusoideae*	*Panicum*
E1N6	150-170	33411	5896	7861	0	0	230-258	9865	22689	161788	0	0
E1N12	110-141	11262	938	938	0	0	250-280	29749	9597	5758	0	0
E3N3	120-162	209976	2890	27933	0	0						
E3S16	100-118	15634	10050	8934	0	0	220-250	2830	6604	5660	0	0
E3S22	90-121	27784	5954	31753	0	0						
E5S12	90-112	455766	11736	22495	0	0	226-260	125743	4950	13861	0	0
E7N6	100-153	31959	2905	28085	0	0						
E7S16	90-104	78467	6781	11625	0	0	212-260	373447	2687	16120	0	0
E9S10	100-150	232296	3904	16593	0	0	230-290	143522	2990	6977	0	0
W0N9	142-166	23684	2733	2733	0	0	248-261	9587	8629	40266	0	5752
W1S20	75-109	90064	53843	70485	0	0	235-265	34048	25293	20429	0	0
W1S24	93-145	30160	15566	12648	0	0	227-260	6838	34191	42983	0	0
W3S22	156-215	13953	55814	51827	0	0	267-300	14574	58295	54131	0	0
W5N6	134-181	12683	0	906	0	0	270-300	2911	17466	17466.	0	0
W5N9	103-120	6329	2713	3617	0	0	220-233	14408	6724	1921	0	0
W5S2	122-167	20405	10688	12632	0	0	255-277	7504	6566	15946	0	938
W5S12	93-140	26826	18877	37755	0	0	216-247	28838	28838	51908	0	961
W5S16	105-170	3913	8804	19565	0	0	222-260	11650	27184	70874	0	971
W6N0	121-166	10615	2895	2895	0	965						
W7N12	105-150	6816	974	2921	0	0	240-275	8802	36187	41078	0	0
W7S8	100-122	48251	16832	19076	0	0						
W7S18	121-140	44277	48396	0	0	0	292-300	11278	18455	47164	0	0
W10N9	90-130	1013	0	1013	0	0						
W10S4	100-130	14074	8444	3753	0	0						
W10S8	95-147	8854.	3935	147575	0	0	212-232	33458	6506	35317	0	0
W10S12	132-168	33151	0	22682	0	0	206-227	3578	14310	22360	0	0
W10S22	100-135	26500	13250	45429	1893	946	240-250	5884	19613	35303	0	1961
W10S26	74-120	11016	12240	53858	0	0	210-245	6020	25083	27089	1003	0
W12N0	115-151	2766	3688	2766	0	0	248-257	4742	6639	12330	0	0
W12S16	100-180	5934	10879	22746	0	0	211-230	21667	26000	59583	0	2167
W14S6	98-132	5772	2886	8659	0	0						
W14S12	98-192	19543	37131	23451	0	0	212-261	26464	4001881	0	1960	0
W14S22	123-176	2970	56436	38614	0	990	202-232	9857	49285	90684	0	986

W16S18	95-133	12596	20347	63949	0	0	243-273	1952	18545	20497	0	0
W18S6	160-170	10714	9740	27273	0	0						
W18S12	100-143	3862	12552	16414	0	0	220-237	11000	20000	44000	0	0
W22S8	95-128	7673	10551	14388	0	0	280-297	7751	19378	41663	0	0
Means		18923	14120	24461	57	88		13010	180558	38648	119	549

Table showed densities of phytoliths derived from some grasses in possible ancient rice fields stratums of 37 coring places. The densities of rice phytoliths of E3N3, E5S12, E7S16, E9S10 places were unconventionally high, and when the coring were carried out, a lot of wooden remains were also found from those areas as well, so there might be many stacking straws of rice in the ancient dwellings . The means were calculated except for above 4 places.

Materials and Methods

1. Materials

155 coring investigations were carried out around the Tianluoshan trace of dwellings with an interval of 20-40 meter. From results of analysis of phytoliths and seeds for coring samples, the area and hidden depths of prehistoric rice fields were judged. Excavations were done in Location 1 and Location 2. The areas were 200 and 150 sq. meter, respectively.

40 samples of soil for analysis of seeds, phytoliths, pollens, and charcoal were taken from western section of T1041 trench in Location 2, which was about 400m away west from the trace of dwellings in the Tianluoshan site. Samples were continuously taken from 45cm to 250cm depth below the earth's surface with a 5cm interval. Every sample was about 1500ml.   .

2. Methods

Analysis of seeds: 500ml sample of soil was moved to 1000ml beaker, and added 500ml 5% $NaHCO_3$. The sample was placed in 50℃ water bath for 3 hours, while the sample was stirred well to separate soil particles. Through a sieve (Φ450μm), the sample was washed until the water is clear. The remained sample was investigated for plant seeds with a stereo microscope.

Analysis of phytoliths: Soil samples were dried in convection oven at 100 ℃ and then were mechanically crashed. 1g sample of soil and 300,000 glass beads (Φ40μm) were moved to 12ml sample bottle.10 ml of water and 1ml of 5 % sodium silicate were added, and the sample vibrated in an ultrasonic cleaner (38Khz, 250 W) for about 20 minutes to separate particles. Using Stoker's method, the sample was filtered in water, to remove particles less than 20 μm in water, and was dried again. Using EUKITT® mounting medium, the filtered sample was distributed uniformly on microscope slide to facilitate the investigation of densities of phytoliths.

Analysis of pollens: Placed about $2cm^3$ of sample and 27,637 *Lycopodium* makers in 15ml polypropylene boiling tube, and added 10ml of 10%KOH. The sample was placed in 100℃ water bath for 30 minutes, while the sample was stirred well to break any remaining lumps. Through a sieve (Φ160μm), the sample was filtered into a polypropylene centrifuge tube. The samples was washed, centrifuged, and decanted until the liquid is clear. Added 10ml of 40% HF to the sample and placed it in 100℃ water bath for 30-60 minutes, while stirred it well with polypropylene rod to determine when siliceous material is no longer present. Centrifuged and decanted HF. Added 10ml of 10%HCL, and placed the sample in 100℃ water both for 15 minutes to remove colloidal silicon dioxide and silicofluorides. Centrifuged and decanted to rinse the sample in water. Added 10ml of acetolysis mixture (1ml concentrated H_2SO_4, 9ml acetic anhydride) to the sample, and putted it in a boiling water bath for 3 minutes, stirring carefully. Centrifuged and decanted to rinse the sample in water. In the last centrifuge, added a few drops 10% NaOH to be easy to dyeing. Using glycerin jelly, the filtered sample was distributed uniformly on microscope slide for investigations of pollens.

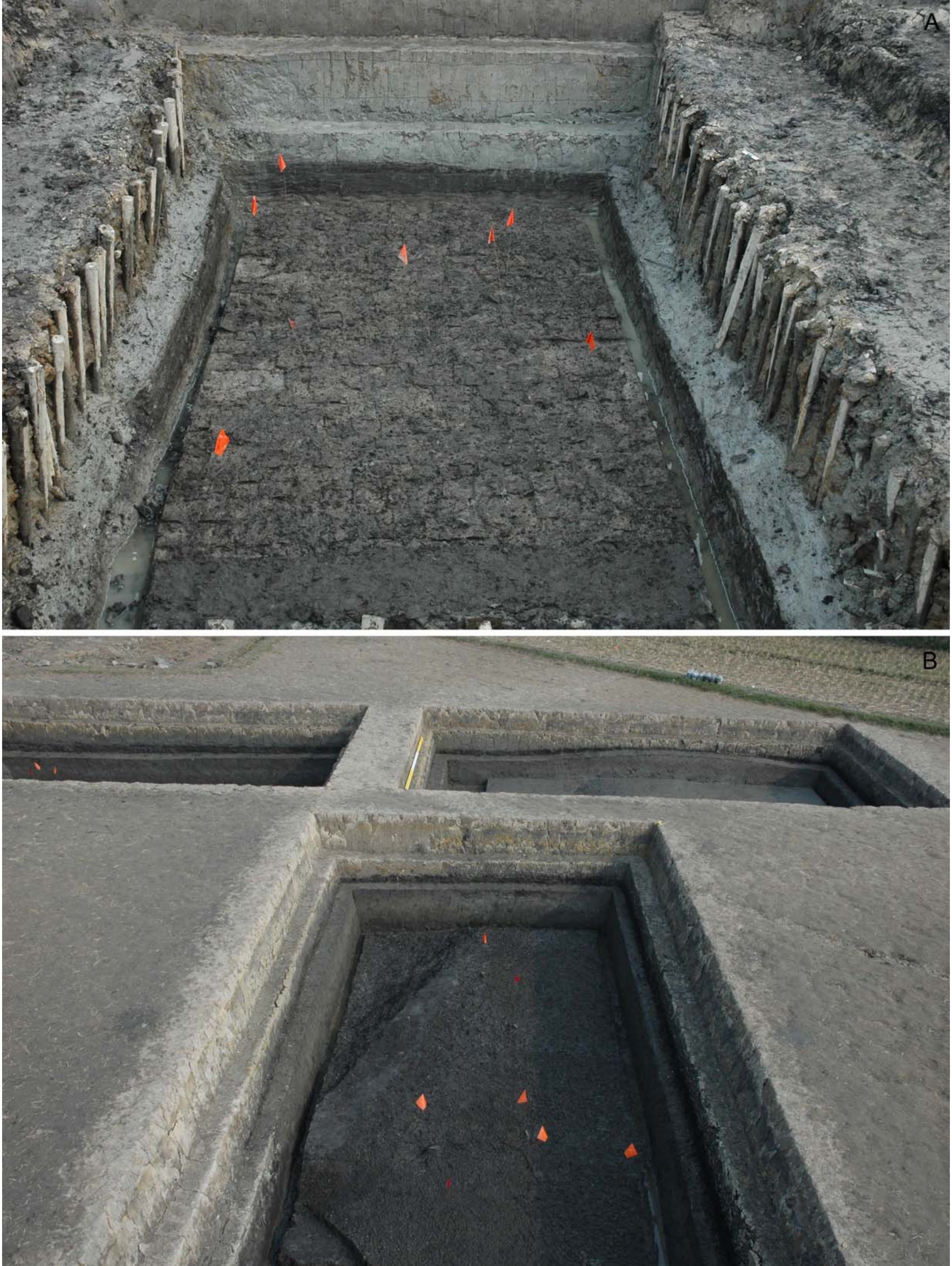
Analysis of charcoal: 20ml sample of soil was moved to 100ml beaker, and added 20ml 35% H_2O_2 to separate soil particulars. Through a sieve (Φ160μm), the sample was washed until the water is clear. The remained sample was investigated for charcoals with a stereo microscope.

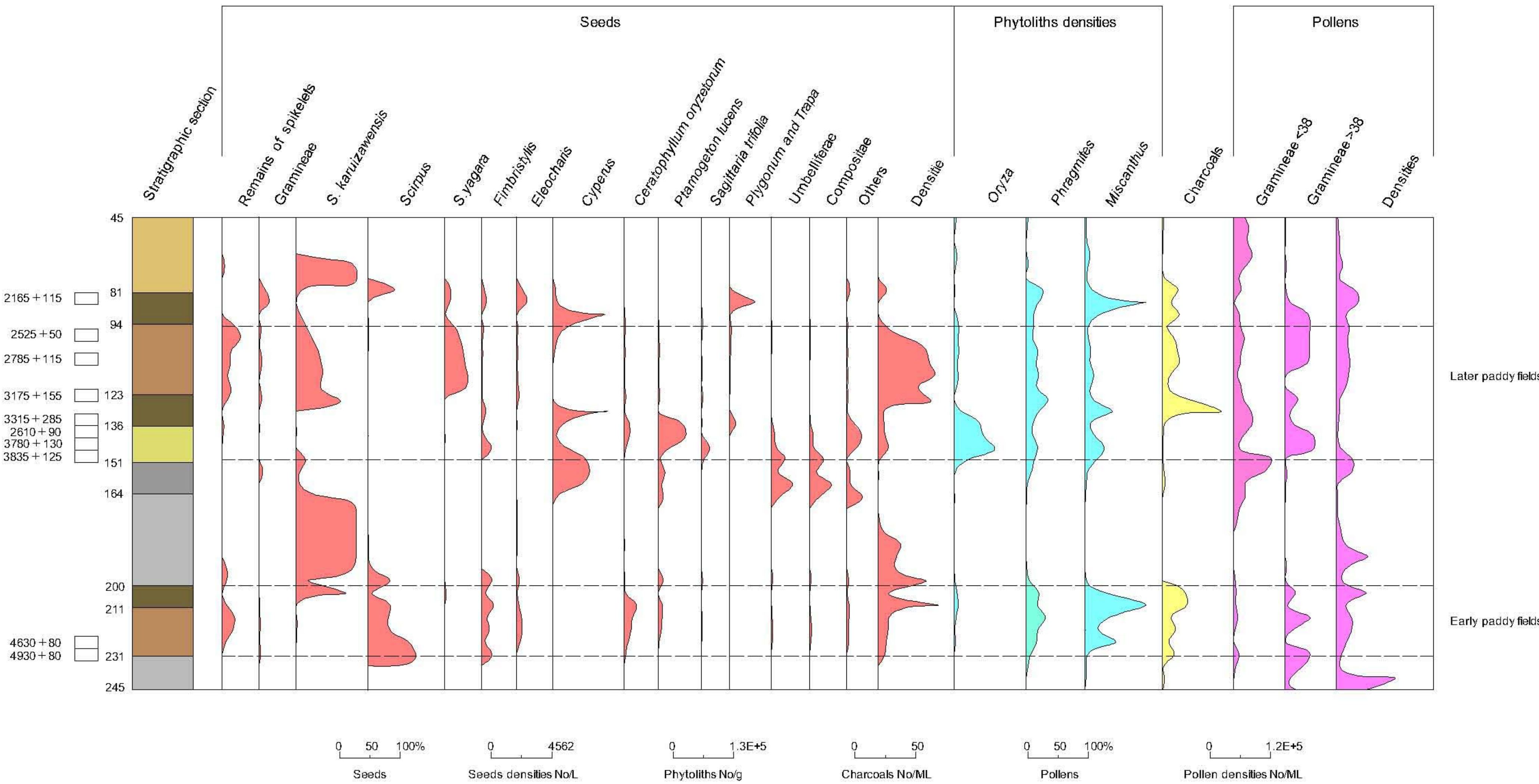
---

1 Charles, H. and Tracey, L. L., The origins and dispersal of rice cultivation, *Antiquity*, 72, 867-77 (1998)
2 Zheng, Y.F., Jiang L.P. and Zheng J.M., Study on the remains of ancient rice from Kuahuqiao site in Zhejiang province, Chinese, *Journal of rice science*, 18, 119-124 (2004)
3 Zheng, Y.F., Sun, G.P. and Chen, X.G. Characteristics of the short rachillae of rice from archaeological sites dating to 7000 years ago, *Chinese Science Bullentin*, 52（12）1654-1660, (2007)
4 Zheng, Y.F. and Jiang, L.P. Remains of ancient rice unearthed from Shangshan site and their significance, Chinese, *Archaeology*, (9)19-25 (2007)
5 Jiang, L., and Liu, L. New evidence for the origins of sedentism and rice domestication in the lower Yangtze River, China, *Antiquity*, 80, 355-361 (2006)
6 Fuller, D. Q., Harvey, E. and Qin, L. Presumed domestication? Evidence for wild rice cultivation and domestication in the fifth millennium BC of the lower Yangtze region. *Antiquity*, 80, 316-337 (2006)
7 Crawford G. W. and Shen, C. The origins of rice agriculture: recent progress in East Asia, *Antiquity*, 72, 858-866 (1998)
8 Fujiwara, H., Exploring origin of rice cultivation, Japanese, Iwanami Press, 137-164 (1998)
9 Cao, Z.H. et al. Ancient paddy soils from the Neolithic age in China's Yangtze River Delta, *Naturwissenschaften*, 93, 232–236 (2006)
10 Zong, Y., Chen, Z., Innes, J. B., Chen, C., Wang, Z., and Wang, H. Fire and flood management of coastal swamp enabled first rice paddy cultivation in east China, *Nature*, 449, 459-462 (2007)
11 Zhejiang provincial institute of relics and archaeology et al. Brief report of the excavation on a Neolithic site at Tianluoshan hill in Yuyao, Zhejiang, Chinese, *Cultural Relics*, (11), 4-24 (2007)
12 Fujiwara, H., Exploring origin of rice cultivation, Japanese, Iwanami Press, 137-164 (1998)
13 Jin, G.Y., Yan, S.D., Udatsu, T., Lan, Y.F, Wang, C.Y. and Tong, P.H. Neolithic rice paddy from the Zhaojiazhuang site, Shandong, China, *Chinese Science Bulletin* 52, 376-3384 (2007)
14 Hunan provincial institute of archaeology and cultural relics, International research center of Japanese culture Chengtoushan in Lixian —China-Japan cooperative research on environmental archaeology in the Lixian plain, Cultural Relics Publishing House 3-17 (2007)
15 Wang, K.., Zhang, Y. and Feng, W. Researches on relationship among Holocene change vegattion environment evolution and human activities in Shanghai region, Chinese, *Marine Geology and Quaternary Geology*, 16, 1-4 (1996)
16 Fujiwara, H., Exploring origin of rice cultivation, Japanese, Iwanami Press, 137-164 (1998)
17 Cao, Z.H. et al. Ancient paddy soils from the Neolithic age in China's Yangtze River Delta, *Naturwissenschaften*, 93, 232–236 (2006)
18 Feng, W., Wu, X.M., Pan, G.X., Xu, X.W., Qiang, S. Comparison of soil seed bank structure in natural wetland and corresponding reclaimed paddy fields at lower reaches of Yangtze River in Anhui, China, *Chinese journal of ecology*, 27(6), 874-879 (2008)
19 Zhao, Z. J.& Piperno, D. R. Late Pleistocene/Holocene environments in the middle Yangtze River valley, China and rice (Oryza sativa L.) domestication: the phytolith evidence. *Geoarchaeology* 15, 203–222 (2000)
20 Lu, H. et al. Rice domestication and climatic change: phytolith evidence from East China. *Boreas* 31, 78–385 (2002).
21 Xu, X. and Shen Z.D. Holocene environments – Changes of environments during last 10000 years, Guizhou renmin Press, 211-250 (1990)
22 Fujiwara, H Fundamenral studies in opal analysis (3), Estimation of the yield of rice in ancient paddy fields through quantitative analysis of plant opal, Japanese, *Journal of Archaeology and Science*, 12, 29-42 (1979)
23 Tanter, J. A. The collapse of complex societies, Combridge University Press, 1988
24 Robin G. A., Dorian Q. F. and Terence A. B. The genetic expectations of a protracted model for the origins of domesticated crops, *PANS,* 105, 13982–13986 (2008)
25 Jiang, L., and Liu, L. New evidence for the origins of sedentism and rice domestication in the lower

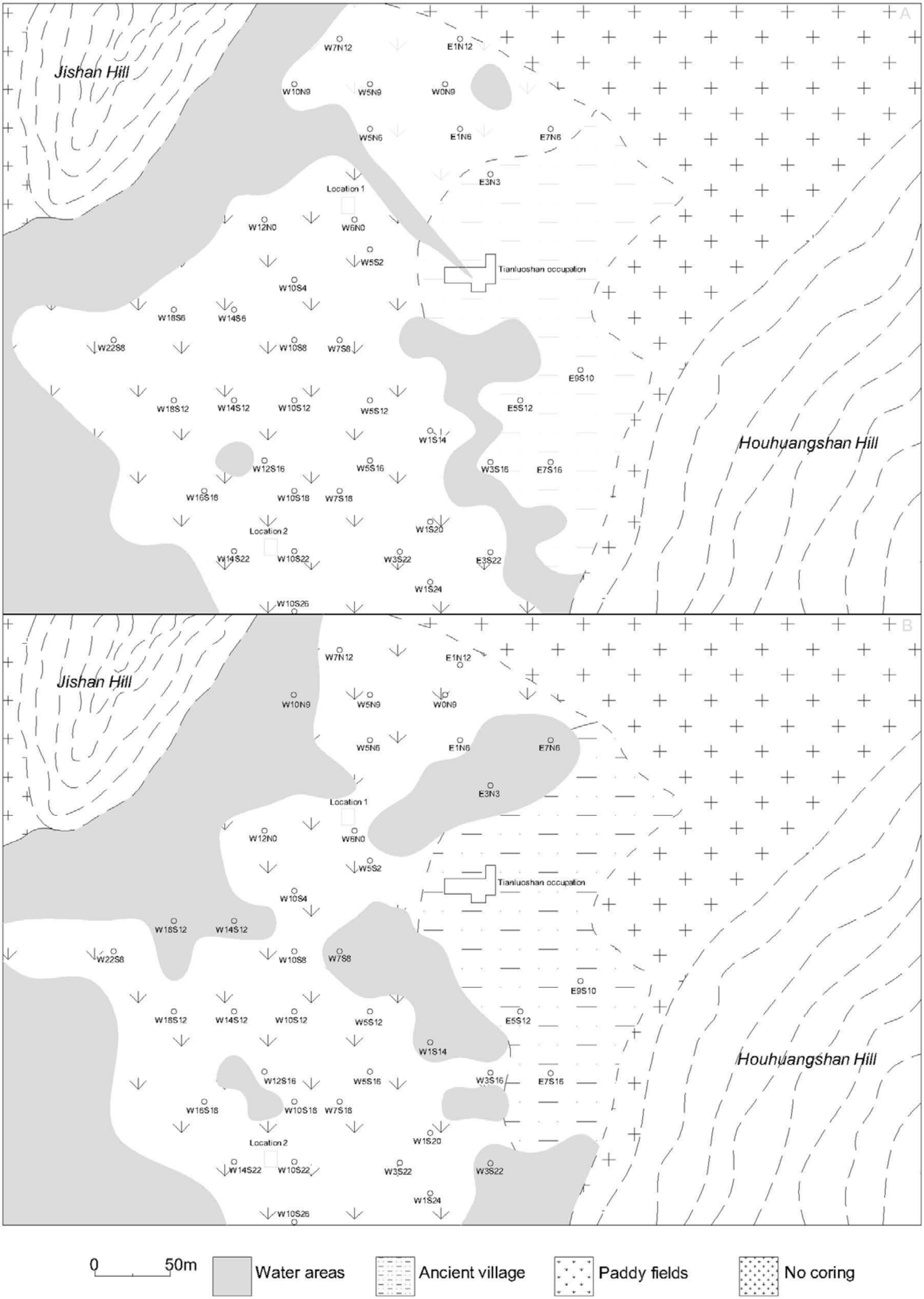
Yangtze River, China, *Antiquity*, 80, 355-361 (2006)
26 Dorian Q F. and Yo-Ichiro Sato Japonica rice carried to, not from, Southeast Asia, *nature genetics*, 40, 1264-1265 (2008)
27 Jiang, L., and Liu, L. New evidence for the origins of sedentism and rice domestication in the lower Yangtze River, China, *Antiquity*, 80, 355-361 (2006)
28 Zhang H., H. Wang and W. Yang The early Neolithic Xiaohuangshan site in Shengzhou City, Zhejiang,， *China Cultural Relics News*, Sep. 30, 2005
29 Zhejiang Provincial Institute of Relics and Archaeology and Xiaoshan Museum *Kuahuqiao site*, Cultural Relics Publishing House (2004)
30 Chekiang Province and Chekiang Provincial Museum Excavation (First Season) at Ho-mu-tu in Yu-Yao County, Chekiang Province, *Acta Archaeologia Sinica*, (1)：39-107 (1978)
31 The work group in Luojiajiao site The Excavation report of Luojiajiao site inTongxiang County, *Academic Publication of Zhejiang Provincial Institute of Relics and Archaeology*, Science Publishing House, 1-42 (1981)
32 Fujiwara, H., Exploring origin of rice cultivation, Japanese, Iwanami Press, 137-164 (1998)


Yangtze River
Suzhoiu
Caoxieshan
Taihu Lake
Shanghai
East China Sea
Luojiajiao
Hangzhou Bay
Hangzhou
Kuahuqiao
Tianluoshan
Shaoxing
Hemudu
Ningbo
Xiaohuangshan
Shangshan
0
50Km


A
B



Seeds
Phytoliths densities
Pollens
Stratigraphic section
Remains of spikelets
Gramineae
S. karuizawensis
Scirpus
S.yagara
Fimbristylis
Eleocharis
Cyperus
Ceratophyllum oryzetorum
Ptamogeton lucens
Sagittaria trifolia
Plygonum and Trapa
Umbelliferae
Compositae
Others
Densitie
Oryza
Phragmites
Miscanthus
Charcoals
Gramineae <38
Gramineae >38
Densities
45
81
94
123
136
151
164
200
211
231
245
2165 + 115
2525 + 50
2785 + 115
3175 + 155
3315 + 285
2610 + 90
3780 + 130
3835 + 125
4630 + 80
4930 + 80
Later paddy fields
Early paddy fields
0 50 100%
Seeds
0 4562
Seeds densities No/L
0 1.3E+5
Phytoliths No/g
0 50
Charcoals No/ML
0 50 100%
Pollens
0 1.2E+5
Pollen densities No/ML


A
Jishan Hill
Houhuangshan Hill
W7N12
E1N12
W10N9
W5N9
W0N9
W5N6
E1N6
E7N6
E3N3
Location 1
W12N0
W6N0
W5S2
Tianluoshan occupation
W10S4
W18S6
W14S6
W22S8
W10S8
W7S8
E9S10
W18S12
W14S12
W10S12
W5S12
E5S12
W1S14
W12S16
W5S16
W3S16
E7S16
W16S18
W10S18
W7S18
Location 2
W1S20
W14S22
W10S22
W3S22
E3S22
W1S24
W10S26
B
Jishan Hill
Houhuangshan Hill
W7N12
E1N12
W10N9
W5N9
W0N9
W5N6
E1N6
E7N6
E3N3
Location 1
W12N0
W6N0
W5S2
Tianluoshan occupation
W10S4
W18S12
W14S12
W22S8
W10S8
W7S8
E9S10
W18S12
W14S12
W10S12
W5S12
E5S12
W1S14
W12S16
W5S16
W3S16
E7S16
W16S18
W10S18
W7S18
Location 2
W1S20
W14S22
W10S22
W3S22
W3S22
W1S24
W10S26
0
50m
Water areas
Ancient village
Paddy fields
No coring