ESTABLISHING A FIRM CHRONOLOGICAL FRAMEWORK FOR NEOLITHIC AND EARLY DYNASTIC ARCHAEOLOGY IN THE SHANGLUO AREA, CENTRAL CHINA

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ABSTRACT. Technological and theoretical advancements in modern radiocarbon chronology make the precise dating of archaeological and geological events possible. Here, we show examples of how these state-of-the-art methods can be used to establish and refine the archaeological cultural chronology for the Shangluo area in the Qinling Mountains of central China. In this study, the Donglongshan and Zijing sites were dated using the high-precision accelerator mass spectrometry (AMS) ^{14}C method. Also, detailed magnetic-susceptibility measurements were conducted at both sites to gain preliminary information about past climate changes. The ^{14}C dates, after being treated with Bayesian statistics, provide a firm constraint on the archaeological chronological framework for this area. Within this framework, the Malan loess-Holocene soil transition can be placed at 10,400–10,090 BC, while the duration of the Yangshao and Longshan cultures was dated to ~4200–2900 and ~2900–2100 BC, respectively, revealing an undisrupted history of human occupation in this area until the early dynastic period. Magnetic susceptibility values began to increase in the early Holocene, indicating a progressive amelioration of regional climate. The widespread development of paleosol during the middle Holocene indicates that warm and wet climate conditions prevailed, providing a favorable environmental context within which the Yangshao culture thrived. Magnetic susceptibility values then decreased from ~2100 BC when the Xia Dynasty started, and loess accumulated again, pointing to cooling and drying climate conditions that may have led to a cultural transition from the Neolithic to the dynastic civilization.

INTRODUCTION

Radiocarbon dating, as a precise chronological method, has been being widely used to determine the absolute age of geological and archaeological strata. The emergence of AMS (accelerated mass spectrometry) opens new avenues for the application of this method in archaeological and geological sciences. For example, a state-of-the-art AMS facility can yield precise ^{14}C dates of samples containing trace amounts (e.g. ~1 mg) of organic carbon, making non-intrusive dating of invaluable archaeological samples possible. In addition to this technical advancement, there appears to be an increasing use of Bayesian statistics in ^{14}C chronologies, including tree-ring calibration of ^{14}C dates (e.g. Buck et al. 1991, 1992, 2006; Christen and Litton 1995; Goslar and Madry 1998; Bronk Ramsey et al. 2001; Aguilar et al. 2002; Bronk Ramsey 2009), as well as age-depth modeling (e.g. Christen et al. 1995; Blaauw and Christen 2005; Blaauw et al. 2007; Bronk Ramsey 2008).

Software developed in a Bayesian paradigm, e.g. OxCal (Bronk Ramsey 1995, 2001) and BCal (Buck et al. 1991), can usually give a more accurate representation of the age than those following a frequentist viewpoint (e.g. the intercept method). This is because Bayesian statistics is capable of making use of some *a priori* information (e.g. stratigraphic order of the ^{14}C dates or their approximate calendar ages determined independently from other indicators in the tree-ring calibration process; Bayliss et al. 2007a,b; Navarro 2005; Nicholls and Jones 2001) in order to more precisely pinpoint possible age ranges. For example, OxCal and BCal can give a much narrower probability distribution of the calibrated ages, if the stratigraphically ordered ^{14}C dates were dealt with simultaneously rather than individually (Zeidler et al. 1998; Steier and Rom 2000; Palonen and Tikkanen

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2007). This is particularly important for dating short-lived events, e.g. volcanic eruptions (Buck et al. 2003; D Lowe et al. 2007; J Lowe et al. 2008; Petrie and Torrence 2008) and earthquakes (Scharer et al. 2007), if more ^{14}C dates are available from the surrounding levels of interests.

In conjunction with systematic ^{14}C dating, Bayesian statistics has exhibited great potential in refining archaeological chronology (Blackwell and Buck 2003; Fuller et al. 2007; Beramendi-Orosco et al. 2009; Higham and Higham 2009). However, the advantage of this method has not been widely appreciated in the archaeological communities yet, and there are only very a few studies that have made use of this method in China (e.g. Xia-Shang-Zhou Dating Project Group 2000; Zhang et al. 2007; Boaretto et al. 2009). Given the long history of human settlement in China, precise dating of cultural sequences at some key archaeological sites is of great importance for understanding the origin and dispersion of agriculture as well as the emergence and development of complex society.

The Qingling Mountains of central China has a long history of human occupation from the Neolithic Age onwards (Yang 2003). Archaeological excavations in this area since the 1980s revealed a continuous human occupation (Library of Shang County and Banpo Museum of Xian 1981), as indicated by gradual and uninterrupted changes in artifact assemblages. However, the regional cultural sequence has not been well constrained due to the lack of systematic ^{14}C dating, and the continuity of cultural changes in this area has not been verified using other geoarchaeological proxies. Here, we aim at establishing a reliable chronological framework for the regional archaeology based on detailed AMS ^{14}C dating of soil and charcoal samples collected from 2 cultural sites in the Shangluo area. Bayesian analyses were also performed on the ^{14}C dates to obtain refined tree-ring calibrated ages using the computer program OxCal (Bronk Ramsey 1995, 2001).

CULTURAL AND PHYSICAL SETTINGS

Shangluo (108°34′20″ to 111°1′25″E, 33°25′40″ to 34°25′40″N) is located in the upper Danjiang River area of the Qinling Mountains, central China. Archaeologically, this area is marked by a transition zone from Yellow River to the Yangtze River cultural types, as indicated by the typology of the artifacts. From the Neolithic onwards, the regional archaeological cultures developed continuously, as marked by a gradual transition from the Neolithic Laoguantai (6500–5000 BC), Yangshao (5000–3000 BC), and Longshan (3000–2000 BC) cultures to the dynastic Xia (~2100–1600 BC), Shang (~1600–1100 BC), and Zhou (~1100–256 BC) cultures (Yang 2003). This uninterrupted cultural sequence is of great importance for understanding the rise and fall of human civilization and the possible connection with Holocene climatic changes. However, little is known about the precise timing of this archaeological cultural sequence, particularly the existence of the Xia Dynasty, which remains as one of the most significant debates in the international archaeological community.

Climatologically, this area lies on the boundary between the warm temperate and the subtropical zones. The mean annual temperature is ~12.9 °C, and mean annual precipitation is ~750 mm. The annual number of frost-free days is 206. The natural vegetation is dominated by mixed forests with deciduous broadleaved and coniferous trees. According to our geological investigations in this area over the years, exposure of loess-paleosol sequences are common on the second and third terraces of the Danjiang River. These sediment sequences are usually ~2 m thick and are composed of 2 distinct lithic units: the lower one is loess-like sediments, while the upper one is a paleosol dual complex containing abundant remains of human activities such as colored potsherds and charcoal. In collaboration with the Archaeological Institute of Shaanxi Province, the Donglongshan (109°49′E, 33°52′N) and Zijing (109°50′E, 33°51′N) sites were excavated and studied following a multidisciplinary approach. Detailed archaeological and geological data related to Holocene vegetation and environmental changes will be published elsewhere. Here, we only focus on the chronological issue.

MATERIAL AND METHODS

Sampling and Pretreatments

To gain a better stratigraphic perspective of these 2 sites, archaeological trenches were excavated at the margin of the sites in collaboration with the Archaeological Institute of Shaanxi Province in 2007. Magnetic susceptibility was measured at 2-cm intervals in the field using a portable handheld magnetometer along the cleaned exposure at both sites. Charcoal and bulk soil samples were collected at certain depths. Both charcoal and bulk soil samples were dated in this study. Charcoal is derived from the incomplete combustion of terrestrial plants used by the colonizers as fuel, and thus is not subject to reworking. Therefore, it is an ideal material for ^{14}C dating and can provide precise age constraints for the archaeological cultural sequence. The samples of charcoal were treated using the conventional acid-alkali-acid method. First, the samples were rinsed with deionized water, and treated with 1N HCl in a water bath at constant temperature (60 °C) for 2 hr to remove carbonates. The samples were rinsed repeatedly with deionized water to get rid of excess HCl, and then treated with 1N NaOH in a water bath for another 2 hr to ensure a complete removal of humic and fulvic acid. For some samples, this procedure was repeated several times until the supernatant looked clear. The samples were rinsed repeatedly with deionized water until neutral and 1N HCl was added to the samples to neutralize any remaining NaOH. The samples were rinsed repeatedly with deionized water again until neutral, and then dried in an electric oven at 60 °C.

The bulk soil samples were treated in a slightly different way. Detailed procedures are given in Zhou et al. (1990, 1992). First, the soil samples were soaked in deionized water overnight, then transferred to an ultrasonic bath for 30 min to completely disintegrate and homogenize them. The wet samples were sieved using a 180-μm mesh to get rid of root fragments. Then, 1M HCl was added to the samples, and they were placed in a water bath at 70 °C for 2 hr to remove carbonates. The samples were rinsed repeatedly until neutral, then dried overnight in an electric oven at 60 °C. Finally, the desiccated samples were transferred into glass vials and sealed tightly for subsequent combustion and graphitization.

Combustion and Graphitization

Conventional combustion and step combustion were used to obtain CO_2 gas for charcoal and bulk soil samples, respectively. For conventional combustion, a subsample of the charcoal (~5 mg) along with cuprous oxide was placed in a quartz tube and evacuated using a high vacuum system. (CuO mass was determined using the equation $m_{CuO} = \%$ yield $\times m_s \times 100$, where % yield is the approximate carbon content of the sample, and m_s is the mass of the subsample.) Once the vacuum level reached -1×10^{-5} Torr, the sample tube was isolated from the vacuum line. The sample was combusted using a natural gas jet burner for about 20 min and the resulting gas was then passed through several cleaning elements to purify it. The purified CO_2 was then collected using liquid nitrogen and reduced to graphite for AMS dating.

Soil samples underwent step combustion at 400 and 900 °C to ensure a thorough deliberation of CO_2 from different components of the total organic matter. Most of organic matter can be burnt at 400 °C. First, samples were combusted at 400 °C to obtain CO_2 from the volatile organic component. Then, we increased the temperature to 900 °C. At 900 °C, the organic matter included in the lattice of some minerals will be released. Note that we did not go beyond 900 °C, as most of the calcium carbonate minerals will be decomposed above this temperature and thus CO_2 from inorganic carbon will be released. First, a subsample of the soil (~500 mg) was put into the quartz tube and evacuated to -1×10^{-5} Torr using a high vacuum system. Once the desired vacuum level was achieved, the sample tube

was isolated from the vacuum line, and 12 Torr of high-purity oxygen was introduced. The sample was then combusted using an electrical furnace at 400 °C for 30 min. The liberated CO_2 was purified, collected using liquid nitrogen, and reduced to graphite for AMS dating. The entire vacuum system was again evacuated to 10^{-5} Torr, and purified oxygen was introduced into the sample tube. The sample was then combusted using an electric furnace at 900 °C for 20 min. The liberated CO_2 was purified, collected using liquid nitrogen, and reduced to graphite for AMS dating.

The Zn/Fe catalytic reduction method was employed for the preparation of graphite targets in this study. The residual radioactivity of the samples with respect to that of the modern ^{14}C standard was measured in the Xi'an AMS Center of the Chinese Academy of Sciences. For this work, we used China's sugar beat carbon as the modern ^{14}C standard, which in turn was converted to the international modern ^{14}C standard (i.e. oxalic acid) for calculation of ^{14}C age. The ratio of radioactivity of this secondary standard to that of the international standard is 1.362 ± 0.002, and the $\delta^{13}C$ value of this secondary standard is -19.32 ± 0.56‰ with respect to the PDB standard belemnite.

Data Analyses

The probabilistic approach, in terms of Bayesian statistics, has emerged gradually and tends to become a leading method in ^{14}C calibration. Given the wiggly nature of the tree-ring calibration curve, this method deals with the relationship between a ^{14}C age and its corresponding calibrated ages in a probabilistic sense (Bronk Ramsey 1995). This is conceptually different from deterministic approaches, such as the intercept method. The advantage of the Bayesian method is that it can incorporate prior information about the calibrated age of a ^{14}C date into the calibration process, thereby significantly reducing the uncertainty of the calibrated age through extensive iterations using the Markov chain Monte Carlo (MCMC) algorithm. The most striking feature of the Bayesian-oriented calibration software (e.g. OxCal and BCal) is the use of stratigraphic information of the ^{14}C dates to constrain the posterior probability of the calibrated age (Buck et al. 1992; Christen 1994; Buck and Christen 1998; Bayliss et al. 2007a; Bronk Ramsey 2008). Specifically, this method takes into account the stratigraphic context of these ^{14}C dates and expresses this stratigraphic relationship as a priori information, which is then incorporated into the tree-ring calibration process, thereby significantly reducing the uncertainty of the calibrated age. OxCal 3.0 (Bronk Ramsey 1995, 2001) was used to calibrate the ^{14}C dates. First, we grouped the ^{14}C dates into several archaeological phases according to typological characteristics of the stratigraphic units from which the ^{14}C dates were obtained. Then, we used the Sequence analysis module of this program to evaluate the stratigraphic consistency of the ^{14}C dates and perform the calibration. The calibrated dates were rounded to the nearest 10 yr and reported as an age range with a 2-σ standard deviation.

RESULTS

Lithological and Magnetic-Susceptibility Stratigraphies

The Donglongshan site is located on the second terrace of the north bank of the upper Danjiang River. It is known to be the biggest site containing relics of the Xia Dynasty (possibly the first dynasty of China) in Shaanxi Province. A 2×1.5 m^2 archaeological trench running N-S was excavated near the center of the site. The southern exposure was sampled for ^{14}C dating, as well as geochemical and palynological analyses. The lithology and magnetic stratigraphy of this site is shown in Figure 1, and can be described as below. Unit 1 (0–35 cm) is a dark-brown modern soil with abundant plant roots and relatively low magnetic-susceptibility; Unit 2 (35–60 cm) is a brownish loose soil with higher magnetic susceptibility and contains rich charcoal and charred particles. Stone tools and gray potsherds are common, while red ceramic utensils are very rare; Unit 3 (60–100

cm) and Unit 4 (100–130 cm) form a paleosol dual complex with a firm structure and the highest magnetic susceptibility along the exposure. The upper layer is red-brown containing less iron-manganese nodules, whereas the lower one is dark red-brown with massive iron-manganese nodules and films. Earthworm burrows and root penetration can be seen in this layer. Unit 5 (130–250 cm) is a yellowish-brown Malan loess with a loose structure and relatively high magnetic susceptibility. Iron-manganese nodules with a diameter of ~0.5 cm occur occasionally below 200 cm.
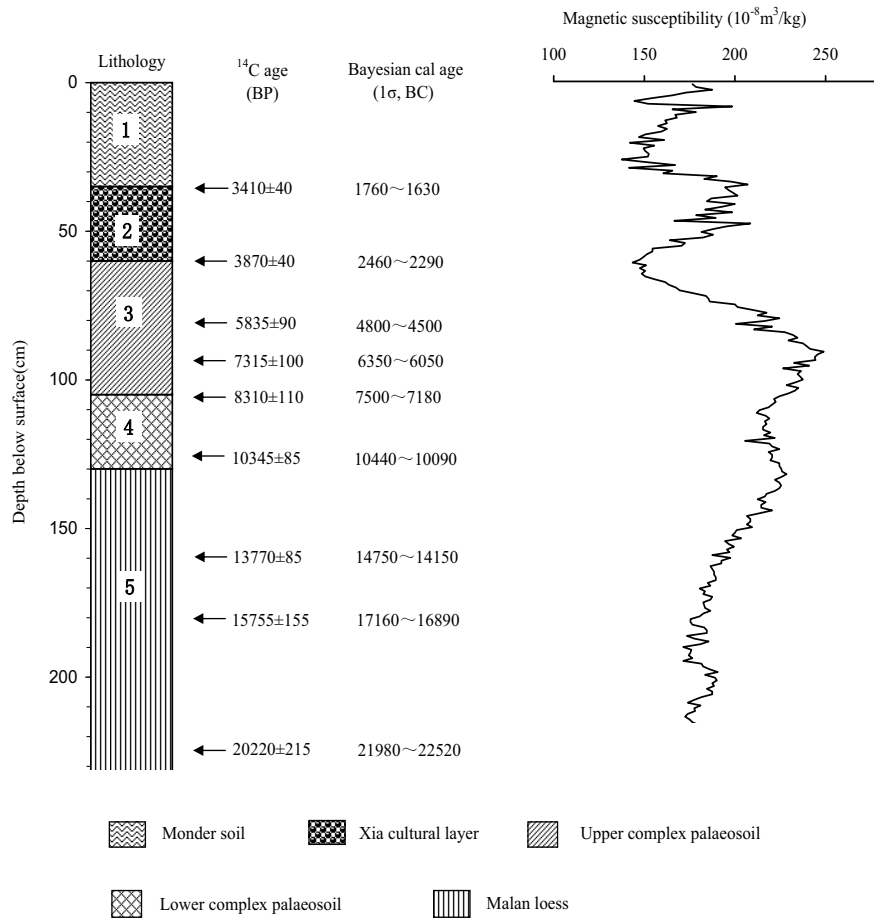

Figure 1 Lithologic and magnetic-susceptibility stratigraphies of the Donglongshan site. Numbers denote stratigraphical units. For details of these units and ^{14}C dates, see text and Table 1.

The Zijing site is situated on the second terrace of the south bank of the upper Danjiang River. This site represents the longest and most continuous known archaeological cultural sequence in the Shangluo area, consisting of the Yangshao and Longshan cultures, as well as the Xia, Shang, Zhou, Qin, and Han dynasties. A loess-paleosol exposure was also found nearby. Both the cultural layers of this site and the loess-paleosol sequence were sampled. Magnetic susceptibility was measured in the field at ~2-cm intervals as well (Figure 2). A detailed stratigraphical description of this archaeological site is given below. Unit 1 (0–20 cm) is a brownish modern soil with a loose structure and abundant plant roots. Unit 2 (20–60 cm) is a dark-brown loess layer containing white porcelain shards and pieces of gray tiles, probably from the Qin and Han dynasties. Units 3 (60–110 cm) and 4 (110–

Table 1 Pyrolytical ^{14}C dates of the Donglongshan archaeological site, Shangluo area of central China.

Depth (cm)	Lab code	Sample code	400 °C fractions		900 °C fractions		True age (yr BP)	Bayesian model age (1 σ, BC)
			AMS ^{14}C age (yr BP)	MVC age (yr BP)	AMS ^{14}C age (yr BP)	MVC age (yr BP)		
35	AA78660	DLSI35	3520 ± 40		4100 ± 40		3410 ± 40[a]	1760~1630
60	AA78662	DLSI60	3910 ± 40	3870[a]	4160 ± 40	3870[a]	3870 ± 40[a]	2456~2292
80	AA78663	DLSI80	4770 ± 40	5813	10,770 ± 80	5900	5856 ± 90	4832~4604
95	AA78664	DLSI95	5040 ± 50	7270	10,260 ± 90	7422	7346 ± 100	6352~6080
105	AA78665	DLSI105	6740 ± 60	8241	11,350 ± 90	8437	8339 ± 110	7530~7194
125	AA78666	DLSI125	8340 ± 50	10,183	13,070 ± 70	10,467	10,325 ± 85	10,426~10,051
160	AA78667	DLSI160	11,640 ± 60	13,583	16,780 ± 170	14,019	13,801 ± 180	14,777~14,192
180	AA78668	DLSI180	15,280 ± 100	15,526	18,520 ± 120	16,049	15,787 ± 155	17,186~16,917
225	AA78669	DLSI225	19,280 ± 120	19,896	24,000 ± 180	20,616	20,256 ± 215	22,568~22,014

[a]Date on charcoal, which is assumed to be the true age of a dated level.

175 cm) form a paleosol dual complex. The upper unit is a red-brownish paleosol with a loose structure and contains cultural remains of the Xia, Shang, and Zhou dynasties (occurring at 60–80 cm) as well as the Longshan culture. An ash pit occurs at 80–110 cm, which is partly filled with gray potsherds of the Longshan culture. The lower unit is a brownish loose paleosol containing red potsherds of the Yangshao culture as well as red soil concretes formed with the use of fire. Unit 5 (175–380 cm) is marked by a layer of yellowish-brown loess-like sediments (i.e. the Malan loess) with a firm structure. There are not any cultural remains found in this unit. Calcareous nodules of various sizes are common at ~200 cm. The sediments below 350 cm are dominated by fluvial coarse sand and pebbles. Changes in magnetic susceptibility along this profile exhibit a cyclic pattern (Figure 2). Generally speaking, loess sediments (units 2 and 5) are characterized by lower magnetic susceptibility values, whereas the paleosol complex (units 3 and 4) is marked by higher magnetic susceptibility values.

Chronology

[14]C dates of the low-temperature (400 °C) and high-temperature (900 °C) fractions are given in Table 1 for the Donglongshan site, along with modeled "true" ages using the mean value concept (MVC) as detailed in Zhou et al. (2007). According to the stratigraphic division from field observation, the Holocene/Pleistocene boundary lies at ~130 cm depth. However, our dating of paleosol at a depth of 125 cm gives a ^{14}C age of 8340 ± 50 yr BP for the low-temperature and 13,070 ± 70 yr BP for the high-temperature fraction, respectively (Table 1), indicating a potential contamination of younger and older carbon. Before applying Bayesian calibration to these raw ^{14}C dates, first we try to remove the contamination of average younger and older carbon using the MVC.

In the Donglongshan profile, the uppermost 60-cm-thick strata is the modern plowing layer mixed with cultural remains, and ^{14}C dates from this layer are useless due to human disturbance. Therefore, we perform the regression calculation using ^{14}C ages of the low-temperature fraction from 60 cm down to 270 cm. We obtain a model age of 2668 yr at 60 cm depth. According to the MVC, this estimated age is the sum of the ^{14}C age and the average younger carbon age. Meanwhile, at 60 cm depth, we found a charcoal fragment that was taken from the lower boundary of the Xia cultural layer and dated to 3870 ± 40 yr BP. This date is consistent with the age of the Xia Dynasty (Xia-Shang-Zhou Dating Project Group 2000), indicating that the ^{14}C age of charcoal is reliable and presumably represents the true age of this level. Subtracting 2668 from 3870, we obtain a ~1200-yr error for the average younger carbon effect. In a like manner, our analyses for the ^{14}C ages of the high-tempera-
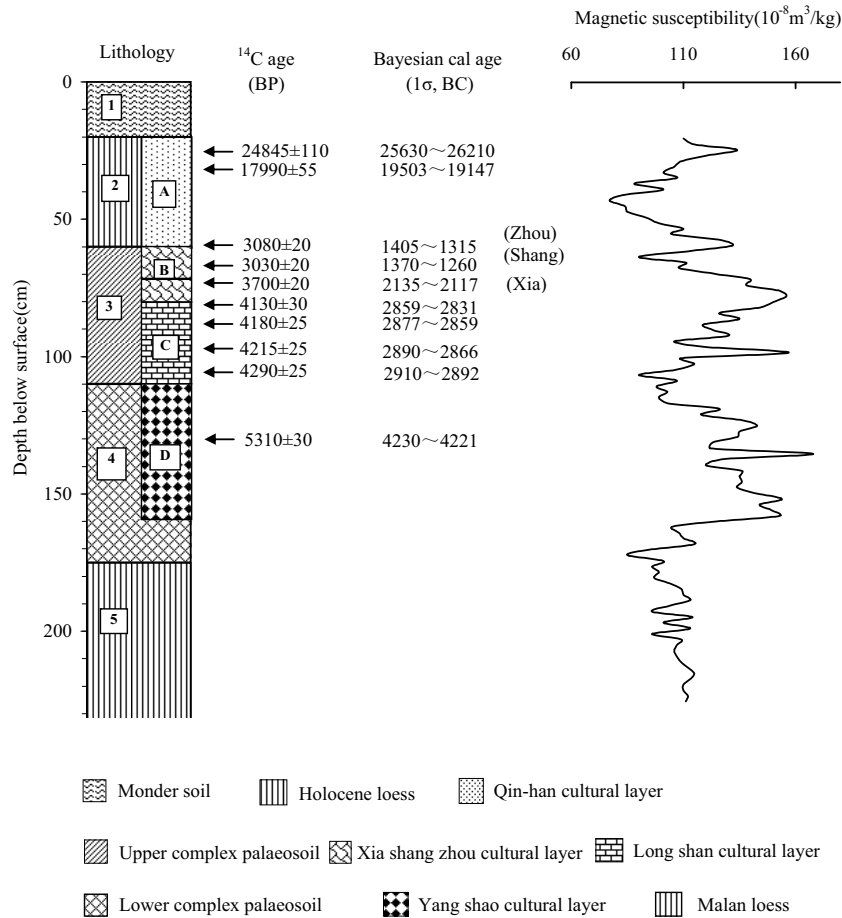
Figure 2 Lithologic and magnetic-susceptibility stratigraphies of the Zijing site. Numbers and letters denote stratigraphical and cultural units, respectively. For details of these units and ^{14}C dates, see text and Table 2.

Table 2 ^{14}C dates of Zijing archaeological site, Qingling Mountains of central China.[a]

Cultural layer	Lab ID	Sample nr	Depth (cm)	$\delta^{13}C$ (‰ vs PDB)	^{14}C age (BP)	Bayesian cal age (1 σ)
Qin-Han	XA3253	ZIJ25	25	−25.67	24,845 ± 110*	25,630–26,210 BC
Qin-Han	XA3252	ZIJ30	30	−22.93	17,990 ± 55*	19,500–19,150 BC
Shang	XA3248	ZIJ60	60	−24.73	3080 ± 20	1410–1370 BC
Shang	XA3260	ZIJ65	65	−26.15	3030 ± 20	1370–1350 BC
Xia	XA3259	ZIJ70	70	−26.05	3700 ± 20	2135–2035 BC
Longshan	XA3258	ZIJ75	75	−28.63	4130 ± 30	2860–2830 BC
Longshan	XA3257	ZIJ80	80	−28.38	4220 ± 25*	2890–2870 BC
Longshan	XA3256	ZIJ85	85	−29.20	4180 ± 25	2880–2860 BC
Longshan	XA3255	ZIJ90	90	−28.58	4240 ± 25*	2900–2880 BC
Longshan	XA3254	ZIJ95	95	−26.82	4215 ± 25	2890–2870 BC
Yangshao	XA3268	ZIJ105	105	−26.11	4290 ± 25	2910–2890 BC
Yangshao	XA3264	ZIJ130	130	−25.78	5310 ± 30	4230–4220 BC

[a]Asterisks indicate dates rejected.

ture fraction from 60 cm down to 270 cm yield an error of 2670 yr for the average older carbon effect. Systematically removing these values of the carbon reservoir effect from the raw data, 2 sets of the "true" ^{14}C ages—one from the low-temperature fraction, the other from the high-temperature fraction—are obtained for the Donglongshan site (Table 1). Our results indicate that these 2 sets of ^{14}C chronologies are consistent with each other; with a deviation <4% and match well with the stratigraphy. We simply take the mathematical mean of theses 2 data sets as the true age of the dated levels with 1-σ standard deviation defined by the square-root rule (see Table 1).

Regarding the calibration, we do not treat these samples individually. Rather, first we assemble the dates into a sequence according to their stratigraphic order, then we perform tree-ring calibration using the Bayesian Sequence analysis module of OxCal 3.0. The posterior distribution of the calibrated ^{14}C ages was obtained after 30,000 iterations, a point where the Markov chains converge. The results are presented in Table 1 as Bayesian modeled ages. Figure 3 illustrates how this method can yield a precise estimate of the calibrated age. As can be seen, the posterior distribution of the calibrated ^{14}C dates was substantially narrowed down compared to their prior distribution. Both the overall and individual agreement indices, the *A* value parameter, exceed the threshold value (i.e. 60%), suggesting a high coherency of this data set. Sample DLSI125 was taken from the boundary between Malan loess and Holocene paleosol at this site. It is dated to 10,440–10,090 BC in this sequence. This date is compatible with the initiation of the Holocene epoch in the Loess Plateau (Liu 1985; Lei 1999). Sample DLSI60 was taken from the lower boundary of the Xia cultural layer. It is dated to 2460–2290 BC in this sequence, representing the onset of the Xia Dynasty. The termination of the Xia Dynasty can be determined by sample DLSI35, which was taken from the upper boundary of the Xia layer and dated to 1760–1630 BC in this sequence.
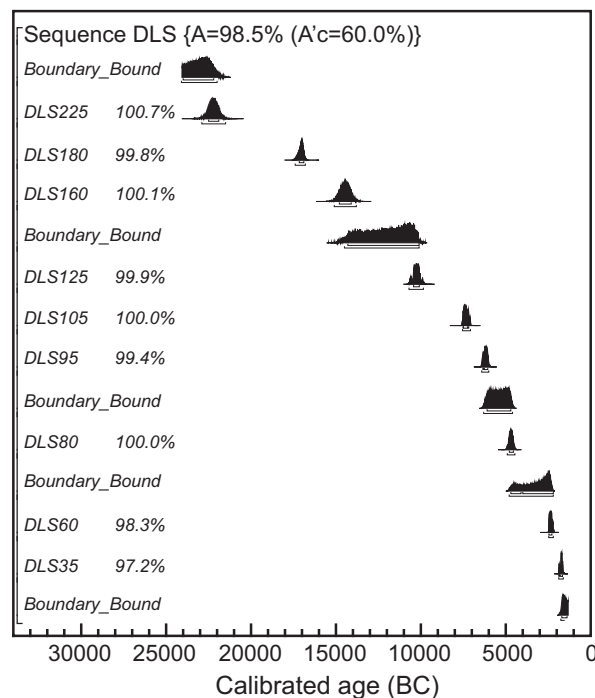

Figure 3 Bayesian tree-ring calibration of sequential ^{14}C dates for the Donglongshan site.

The ^{14}C dates on charcoal and their Bayesian modeled ages are presented in Table 2 for the Zijing site. Note that the ages at 25 and 30 cm are significantly older than those underneath these depths. This reversal is due most likely to human disturbance. Therefore, caution should be taken when dating topsoil using charred particles. As with the Donglongshan dates, we obtain the tree-ring calibration by assembling the dates into a sequence according to their stratigraphic order. Results of the Bayesian analyses are presented in Figure 4. Note that the overall agreement index does not exceed the threshold value. This is caused by samples ZIJ80 and ZIJ90, which have a low *A* value parameter and thus appear to be problematic. To increase the consistency, we remove these 2 outliers from the sequence, and then conduct Bayesian calibration again (Figure 5). As we can see in Figure 5, the agreement index increased to 81.2%. Figure 5 and Table 2 show that the calibrated age of sample ZIJ130 in this sequence is 4230–4220 BC; this slightly postdates the beginning of the Yangshao culture, as expected since it was collected slightly above the lower boundary of Unit 4. Sample ZIJ105 was collected precisely at the boundary between the Yangshao and Longshan cultures (i.e. Units 4/3), and was dated to 2910–2890 BC. Therefore, the duration of the Yangshao culture can be determined to ~4200–2900 BC. Sample ZIJ70 gives a calibrated age of 2140–2120 BC. This provides a narrower constraint (i.e. ~2100 BC) on the termination of the Longshan culture and hence the onset of the Xia Dynasty than that given by sample DLSI60 from the Donglongshan site.
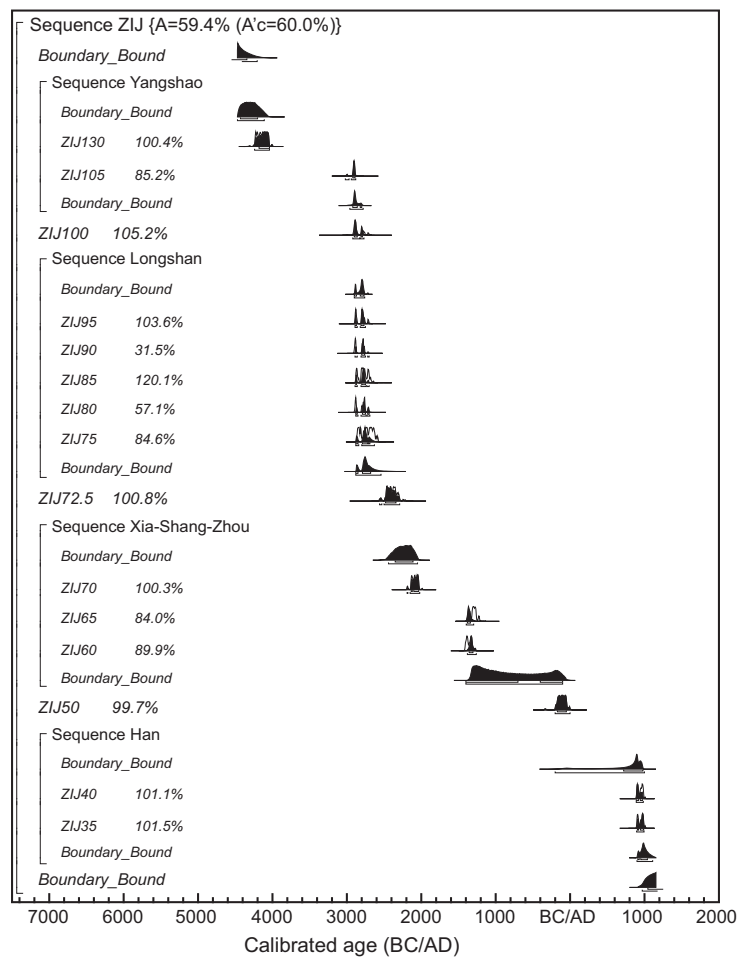

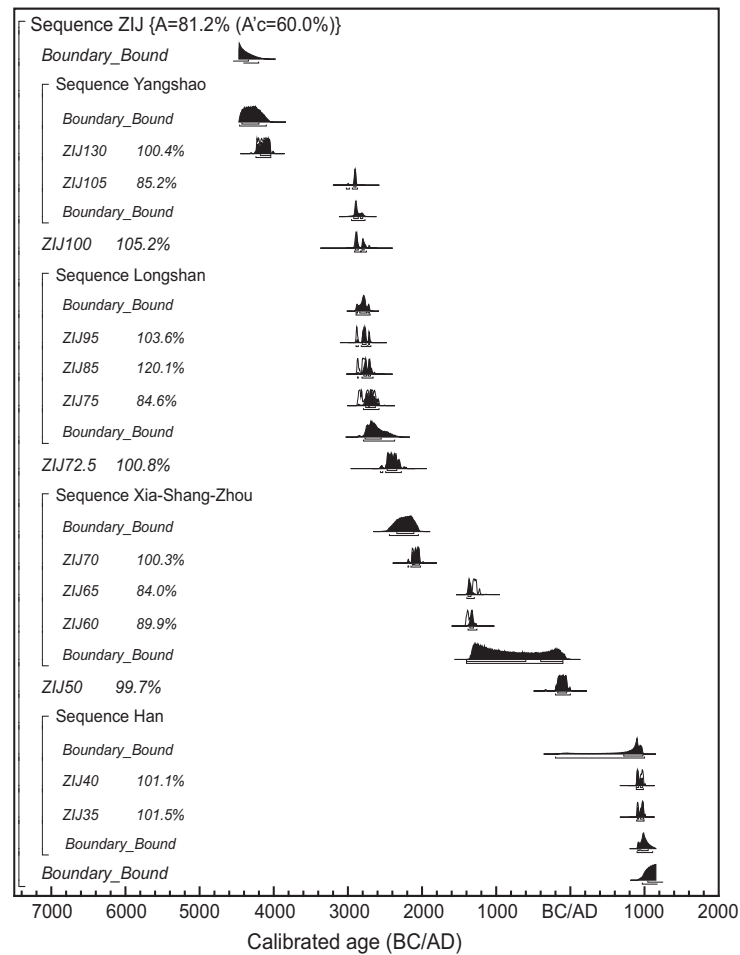Figure 4 Bayesian tree-ring calibration of sequential ^{14}C dates for the Zijing site

Figure 5 Bayesian tree-ring calibration of sequential ^{14}C dates for the Zijing site, after removing samples ZIJ80 and ZIJ90.

DISCUSSION

Detailed AMS ^{14}C dating and statistical analyses of both bulk soil and charcoal samples from the Donglongshan and Zijing sites provide a firm constraint on the timing of the Neolithic and early dynastic history of China in the Shangluo area of the Qingling Mountains. The Xia Dynasty has long been regarded as the first empire of China. However, the existence of the Xia Dynasty is very speculative because of the lack of detailed written and archaeological evidence. Thus, its duration is still debated in the archaeological community. Archaeological excavations at the Erlitou site, Henan Province, since the early 1960s tend to suggest a gradual transition from the Neolithic to the early dynastic period in the middle Yellow River area. This site is of great archaeological importance in the search for China's early dynastic history (Xu et al. 2007). The cultural sequence of this site can be subdivided into 4 stages. The first 2 stages are marked by the termination of the Neolithic and thus most likely can be correlated to the Xia Dynasty. The latter 2 stages represent the emergence of the Bronze Age as well as the origin of cities and nations corresponding to the Shang Dynasty. Nevertheless, debates still continue, and the key issues are about the societal structure and economic

complexity of the Xia Dynasty if it existed in the form of a nation. Information from the Xia sites in the Shangluo area will provide new perspectives on this debate. For example, the surface decorative pattern of potsherds from the Xia layer of the Zijing and Erlitou sites is quite similar, implying that the Xia Dynasty may have existed, but most likely in the form of loosely united clans with a common cultural identity in central China.

Our chronology of the Holocene sediment sequence of the Donglongshan site is mainly based on bulk soil samples. In this study, only 2 combusted fractions were separated, which represents the end members of ^{14}C-enriched and ^{14}C-depleted carbon. For our age modeling, the younger and older carbon reservoir age was calculated separately using the mean value concept (MVC). After removing these errors, 2 sets of the true age for each sample were obtained. We take the average value of these 2 sets as the true age of the dated level. Our results indicate that this simple treatment can yield a precise estimate of the true age for each sample. For example, the transition of the Malan loess-Holocene soil is well known as a regional stratigraphic marker, which represents the onset of the Holocene in central China (Liu 1985). This transition at the Donglongshan site was dated to 10,440–10,090 BC, which in general agrees with the accepted age for this event (Lei 1999). Our results for the onset of the Xia Dynasty are consistent with that proposed by the Xia-Shang-Zhou Dating Project Group (2000).

Our results reveal a continuous development of Neolithic and dynastic cultures in the Shangluo area of central China. However, it does not mean that there are no changes of the civilization in this area. Climatic changes during the Holocene may have exerted a strong impact on human livelihood in central China (Wu and Liu 2004) as in other parts of the world (Cullen et al. 2000; deMenocal 2001; Staubwasser et al. 2003). This is particularly true for the Neolithic people, as their economy totally relied on the availability of natural resources and climate conditions. Magnetic-susceptibility records of the Zijing and Donglongshan site show significant variations at each cultural transition. However, we are not sure whether these variations are caused by millennial-scale Holocene climate changes or human disturbances. Cultural remains at the Zijing site show a gradual change in economic style, from fishing-hunting-gathering to agriculture during the Neolithic. Both Heller and Liu (1982) and Liu et al. (1985) concluded that magnetic susceptibility can be taken as a proxy of paleoclimatic change in terms of variations of the Asian summer monsoon. High magnetic susceptibility correlates to a strong summer monsoon, whereas low magnetic susceptibility correlates to a weak summer monsoon. This cultural succession could be possibly ascribed to climate forcing, e.g. the gradual retreat of the summer monsoon front during the Late Holocene. For example, widespread paleosols, corresponding to high magnetic-susceptibility values, developed in central China prior to ~2100 BC, indicating warmer and wetter monsoonal climate conditions than those of today. This climate setting provides favorable living conditions for the Neolithic people. Regional climate then became dry and cold from ~2100 BC when the Xia Dynasty started, as loess started to accumulate again. Crop remains at the Zijing site indicate that agriculture had to be introduced to deal with the shortage of natural resources. This severe climatic interval can be correlated to the substantial decay of the Asian summer monsoon (Wang et al. 2005; Yancheva et al. 2007), which ultimately pushed China's Neolithic civilization into the dynastic period.

CONCLUSIONS

Detailed AMS ^{14}C dating and statistical analyses of cultural layers within the stratigraphic context of loess-paleosol sequences at 2 sites yield a reliable chronological framework for Neolithic and early dynastic archaeology in the Shangluo area of central China. Our results reveal a continuous human occupation in this area during the second half of the Holocene. The development of regional

Neolithic and early dynastic cultures experienced 3 stages from the Yangshao (~4200–2900 BC), through the Longshan (~2900–2100 BC), to the Xia-Shang-Zhou dynasties. A close correlation of this cultural sequence with the loess-paleosol sequence suggests that climate may have played a major role in the rise and fall of civilization in this area. The Yangshao and Longshan cultures developed under warm and wet climate conditions, indicated in the stratigraphic sequence as a continuous pedogenetic process during the middle Holocene. A significant change in regional climate conditions occurred at ~2100 BC, as marked by the transition from paleosol to loess in the stratigraphic sequence. This climatic shift from warm and wet to cold and dry conditions coincides with the termination of the Neolithic and the emergence of dynastic civilization in this area.

ACKNOWLEDGMENTS

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