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A COMPARATIVE STUDY OF ^{14}C DATING ON CHARCOAL AND CHARRED SEEDS FROM LATE NEOLITHIC AND BRONZE AGE SITES IN GANSU AND QINGHAI PROVINCES, NW CHINA

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ABSTRACT. The chronology of the Neolithic and Bronze Age cultures in Gansu and Qinghai provinces, northwest China, is mainly based on conventional radiocarbon dates from unidentified charcoal, which may be inaccurate in view of the possible "old wood" problem of ^{14}C dating. To discuss the reliability of the chronology of those prehistoric cultures, accelerator mass spectrometry (AMS) dates of short-lived charred seeds were compared to conventional ^{14}C dates of unidentified charcoal from the same flotation samples in 15 Late Neolithic and Bronze Age sites in the area. The results show that ^{14}C dates of unidentified charcoal are obviously older than those of charred seeds in 5 of the 15 flotation samples. This work suggests that the old-wood problem of ^{14}C dating might be related to human subsistence strategies and local vegetation variation during different prehistoric cultural periods in Gansu and Qinghai provinces, which should be discussed before establishing the chronology of Neolithic and Bronze Age cultures in the area.

INTRODUCTION

Radiocarbon dating has been widely adopted in archaeological research since the inception of the technique in the 1950s by Libby (1955), contributing greatly to construction of cultural chronologies across the world. Charred plant remains, easily obtained during excavations of archaeological sites, are the most widely used materials in ^{14}C dating. However, such dates on unidentified wood charcoal may not accurately reflect the true age of the human behavior that produced the charcoal because the wood could have come from long-lived trees or wood preserved for long periods in cold or arid conditions. These problems have been understood and discussed since the 1970s (Dean 1978; McFadgen 1982; Schiffer 1982, 1986; Gavin 2001). The consensus is that whenever they are present, seeds and parts of short-lived plants and twigs of identified trees will provide dates more closely tied to human activities (Schiffer 1986; Rieth et al. 2011; Wilmshurst et al. 2011).

In contrast to the remains of long-lived or unidentified trees, charred seeds are the most reliable materials for ^{14}C dating, and their use can result in a high-precision chronology of archaeological cultures, such as the case studies from Egypt or east Polynesia (Bronk Ramsey et al. 2010; Wilmshurst et al. 2011). The development of accelerator mass spectrometry (AMS) ^{14}C dating enhanced the precision and reduced carbon content needed for ^{14}C dating, guaranteeing that even a single charred plant seed can be directly dated. With the increasing application of flotation and archaeobotanical studies in archaeological studies in the past decade, a large number of charred seed assemblages have been obtained for studying the origins and development of agriculture in China (Zhao 2010, 2011), providing reliable materials for building a more robust chronology of prehistoric cultures.

In the Gansu-Qinghai region, NW China, the chronology of prehistoric cultures was built on the basis of 125 published ^{14}C dates, 114 of which dated unidentified wood charcoal using conventional liquid scintillation counting (IA, CASS 1991, 2003, 2005). For the last decade, that chronology, which might be questionable due to the "old wood" problem, has been the basis for studying the development of Neolithic and Bronze cultures and their relationships to climate change (Xie 2002;

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An et al. 2004, 2005; Hou et al. 2009; Liu et al. 2010; Dong et al. 2012a). This article evaluates the old-wood problem of ^{14}C dates in unidentified charcoal, and discusses the reliability of the chronology of Neolithic and Bronze cultures in this area by comparing AMS ^{14}C dates of charred seeds and conventional ^{14}C dates of unidentified charcoal from the same flotation samples in 15 Late Neolithic and Bronze Age sites in the Gansu and Qinghai provinces.

STUDY AREAS AND SETTING

The study area (35°20′–37°32′N, 96°23′–107°07′E) is located in the western part of the Loess Plateau, NW China. The investigated sites are located in the eastern Qaidam Basin, Qinghai Lake Basin, Huangshui River Valley, upper Yellow River Valley, Tao River Valley, Tianshui Basin, and Longdong Basin from west to east (Figure 1), a region stretching about 1500 km from Dulan County, Qinghai Province, in the west to Zhenyuan County, Gansu Province, in the east. The mean annual temperature ranges from –0.6 to 9.5°C and mean annual precipitation ranges from 37.9 to 580 mm. The altitude gradually declines from west to east: the highest elevation is 5536 m above sea level (asl) in Dulan County and the lowest elevation is 1011 m asl in Zhenyuan County.

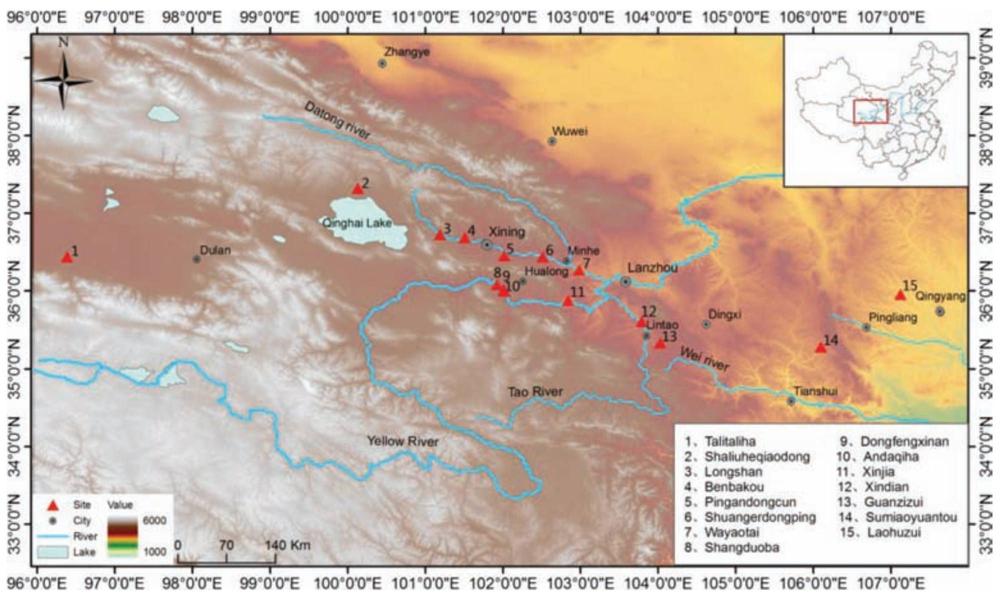

Figure 1 Location of the study area and the investigated sites

According to the results of the Second National Archaeological Survey, thousands of Neolithic and Bronze Age sites are located in the Gansu and Qinghai provinces (Bureau of National Cultural Relics 1996, 2011). These cultures include Majiayao (5900–4000 cal BP), Qijia (4100–3600 cal BP), Kayue (3600–2600 cal BP), Nuomuhong (3000–2800 cal BP), and Xindian (3400–2700 cal BP) (Xie 2002).

MATERIALS AND METHODS

The dated pairs of charcoal and charred plant seeds were obtained from 15 Late Neolithic and Bronze Age sites in the study area (Figure 1). We investigated these prehistoric sites in 2008–2012 and found ash pits or cultural layers that are overlain by geological sediments. Fifteen samples were collected from one ash pit or cultural layer from each investigated site, and then floated using the manual bucket flotation technique. Carbonized remains including wood charcoal and charred plant seeds were collected by a sieve with #80 mesh (aperture size 0.2 mm), then dried naturally. Charred plant seeds were identified in the Paleoethnobotany Laboratory, Institute of Archaeology, Chinese Academy of Social Sciences.

From each of those 15 flotation samples, one unidentified charcoal sample and one charred crop seed sample were selected for ^{14}C dating. All 15 charred plant seeds samples were dated using the AMS method. Twelve samples were dated at Peking University, and the other three were measured at Beta Analytic, Miami, USA. All 15 unidentified charcoal samples were dated using the conventional liquid scintillation counting (LSC) method at the MOE Key Laboratory in Lanzhou University; four of them have been previously published (Dong et al. 2012b). Ages were calibrated using CALIB (v.6.0.1) (Stuiver and Reimer 1993) and the IntCal09 calibration curve (Reimer et al. 2009). All ages reported are relative to AD 1950 ("cal BP").

RESULTS

The ^{14}C dating results are shown in Table 1. The difference was calculated between the ^{14}C dates of unidentified charcoal and charred seeds from the same flotation samples; the uncertainties in the difference of these 15 paired dates (Table 1) were calculated by the method of Zhou et al. (2009). In 13 flotation samples, the midpoints of uncalibrated ^{14}C dates of unidentified charcoal are 781 to 14 yr older than those of charred short-lived plant seeds, while in the other two samples from the Wayaotai and Talitaliha sites, the midpoints of uncalibrated ^{14}C dates of unidentified charcoal are 45 and 8 yr younger than those of charred short-lived plant seeds.

Based on the calculation of all 30 ^{14}C dates (Table 1) from those 15 flotation samples, the uncalibrated and calibrated (2σ) ^{14}C dates of unidentified charcoal are on average 176 ± 82 and 244 ± 258 yr older than those of charred plant seeds, respectively (Figures 2 and 3; Table 1). In the five flotation samples from the sites Andaqiha, Shangduoba, Pinganxincun Majiayao, Shangliuheqiaodong Qijia, and Dongfengxinan Kayue, the difference of midpoints between uncalibrated and calibrated (2σ) ^{14}C dates of unidentified charcoal charred seeds are larger than those of the uncertainties (Table 1).

DISCUSSION

We hypothesize that the charred plant remains including charcoal and charred plant seeds from the same flotation samples were basically formed during the same cultural period. We also examined the impact of the old-wood effect on the ^{14}C dates of unidentified charcoal through comparison with dates of charred seeds. The results indicate that in 5 of the 15 investigated sites, ^{14}C dates of unidentified charcoal are obviously older than those of charred seeds from the same flotation samples (Figures 2 and 3).

The maximum difference between the uncalibrated ^{14}C dates of unidentified charcoal and charred seeds from the same flotation sample is 781 ± 97 yr, in the Andaqiha Majiayao site in Hualong County, Qinghai Province. The ^{14}C date of unidentified charcoal in the site (LUG10-185) is evidently older than that of other Majiayao sites in the region (Dong et al. 2012b), which might have been induced by the old-wood effect. The chronology of the Majiaoyao culture (5900–4000 cal BP) is determined on the basis of 39 conventional ^{14}C dates from unidentified charcoal (Xie 2002), which may be inaccurate considering the impact of the old-wood problem, for only two calibrated ^{14}C dates from Majiayao sites are older than 5500 cal BP (IA, CASS 1991).

The old-wood problem in ^{14}C dating may be affected by the conditions of the wood preservation (Schiffer 1986), which can vary in different areas. However, it is difficult to estimate how much variation can be contributed by old wood in different regions in the study area since samples and ^{14}C dates are scarce. For example, in the Talitaliha Nuomuhong site in Dulan County, which is the driest site in the study area, the difference between the uncalibrated and calibrated (2σ) ^{14}C dates of

Table 1 Calibrated ^{14}C data of the 15 sites in Gansu and Qinghai provinces.

Lab nr	Dating material	Method	$\delta^{13}C$ (‰)	^{14}C age (BP)	cal BP 1σ (IntCal09)	cal BP 2σ (IntCal09)	Site	Cultural style	Reference	Difference# (yr)
Beta-292120	Charred millet seeds	AMS	–9.9	4340 ± 41	4907 ± 54	4937 ± 98	Andaqiha	Majiayao	This paper	781 ± 97[a]
LUG10-185	Charcoal	LQC		5121 ± 88	5865 ± 119	5914 ± 262	Andaqiha	Majiayao	Dong et al. 2012b	977 ± 280[b]
BA120187	Charred millet seeds	AMS		4035 ± 30	4502 ± 64	4600 ± 178	Shangduoba	Majiayao	This paper	333 ± 94[a]
LUG10-215	Charcoal	LQC		4368 ± 90	5048 ± 209	5015 ± 286	Shangduoba	Majiayao	Dong et al. 2012b	415 ± 337[b]
BA110908	Charred millet seeds	AMS		4135 ± 25	4696 ± 113	4695 ± 126	Benbakou	Majiayao	This paper	40 ± 97[a]
LUG11-76	Charcoal	LQC		4175 ± 78	4706 ± 128	4655 ± 207	Benbakou	Majiayao	This paper	–40 ± 242[b]
BA120201	Charred millet seeds	AMS		3980 ± 25	4466 ± 46	4467 ± 54	Pinganxincun	Majiayao	This paper	265 ± 69[a]
LUG11-140	Charcoal	LQC		4245 ± 64	4758 ± 112	4773 ± 193	Pinganxincun	Majiayao	This paper	306 ± 200[b]
BA110887	Charred millet seeds	AMS		3690 ± 30	4032 ± 51	4035 ± 109	Xinjia	Qijia	This paper	67 ± 80[a]
LUG10-71	Charcoal	LQC		3757 ± 74	4112 ± 124	4161 ± 246	Xinjia	Qijia	Dong et al. 2012b	126 ± 269[b]
BA120217	Charred millet seeds	AMS		3630 ± 30	3939 ± 40	3964 ± 112	Guanzizui	Qijia	This paper	45 ± 91[a]
LUG12-117	Charcoal	LQC		3675 ± 86	4019 ± 128	4005 ± 280	Guanzizui	Qijia	This paper	41 ± 302[b]
BA110879	Charred millet seeds	AMS		3600 ± 25	3916 ± 47	3978 ± 65	Sumiaoyuantou	Qijia	This paper	154 ± 83[a]
LUG12-119	Charcoal	LQC		3754 ± 79	4111 ± 125	4156 ± 251	Sumiaoyuantou	Qijia	This paper	178 ± 259[b]
BA110866	Charred millet seeds	AMS		3870 ± 30	4324 ± 82	4287 ± 127	Laohuzui	Qijia	This paper	62 ± 118[a]
LUG12-118	Charcoal	LQC		3932 ± 114	4342 ± 183	4404 ± 406	Laohuzui	Qijia	This paper	117 ± 425[b]
Beta-303693	Charred caper seeds	AMS	–21.1	3380 ± 30	3632 ± 51	3605 ± 94	Shaliuheqiaodong	Qijia	This paper	232 ± 78[a]
LUG11-61	Charcoal	LQC		3612 ± 72	3954 ± 121	3930 ± 214	Shaliuheqiaodong	Qijia	This paper	325 ± 234[b]
BA120199	Charred millet seeds	AMS		3410 ± 30	3658 ± 40	3694 ± 121	Wayaotai	Xindian	This paper	–45 ± 67[a]
LUG11-143	Charcoal	LQC		3365 ± 60	3589 ± 101	3636 ± 184	Wayaotai	Xindian	This paper	–58 ± 220[b]
Beta-292121	Charred barley seeds	AMS	–23.1	3010 ± 40	3203 ± 119	3207 ± 129	Dongfengxinan	Kayue	This paper	366 ± 77[a]
LUG10-188	Charcoal	LQC		3376 ± 66	3592 ± 105	3643 ± 184	Dongfengxinan	Kayue	Dong et al. 2012b	436 ± 225[b]
BA120176	Charred barley seeds	AMS		2840 ± 30	2938 ± 52	2964 ± 99	Talitaliha	Nuomuhong	This paper	–8 ± 80[a]
LUG12-121	Charcoal	LQC		2832 ± 74	2959 ± 104	2988 ± 211	Talitaliha	Nuomuhong	This paper	24 ± 233[b]
BA120683	Charred barley seeds	AMS		2805 ± 35	2908 ± 42	2897 ± 102	Xindian	Xindian	This paper	153 ± 93[a]
LUG12-123	Charcoal	LQC		2958 ± 86	3125 ± 127	3121 ± 234	Xindian	Xindian	This paper	244 ± 255[b]
BA110910	Charred barley seeds	AMS		2790 ± 20	2890 ± 34	2882 ± 73	Longshan	Kayue	This paper	126 ± 53[a]
LUG11-132	Charcoal	LQC		2916 ± 49	3066 ± 90	3064 ± 173	Longshan	Kayue	This paper	182 ± 188[b]
BA110903	Charred barley seeds	AMS		2770 ± 25	2860 ± 61	2867 ± 78	Shuangerdongping	Xindian	This paper	63 ± 69[a]
LUG11-36	Charcoal	LQC		2833 ± 64	2959 ± 101	2968 ± 184	Shuangerdongping	Xindian	This paper	101 ± 200[b]

Note: LQC = liquid scintillation counting; Difference# = difference between the uncalibrated[a] and calibrated (2σ)[b] ^{14}C dates of unidentified charcoal and charred seeds from the same floatation samples; the weighted uncertainty is the root of the sum of squares of the errors of the dates of unidentified wood charcoal and charred plant seeds ages.

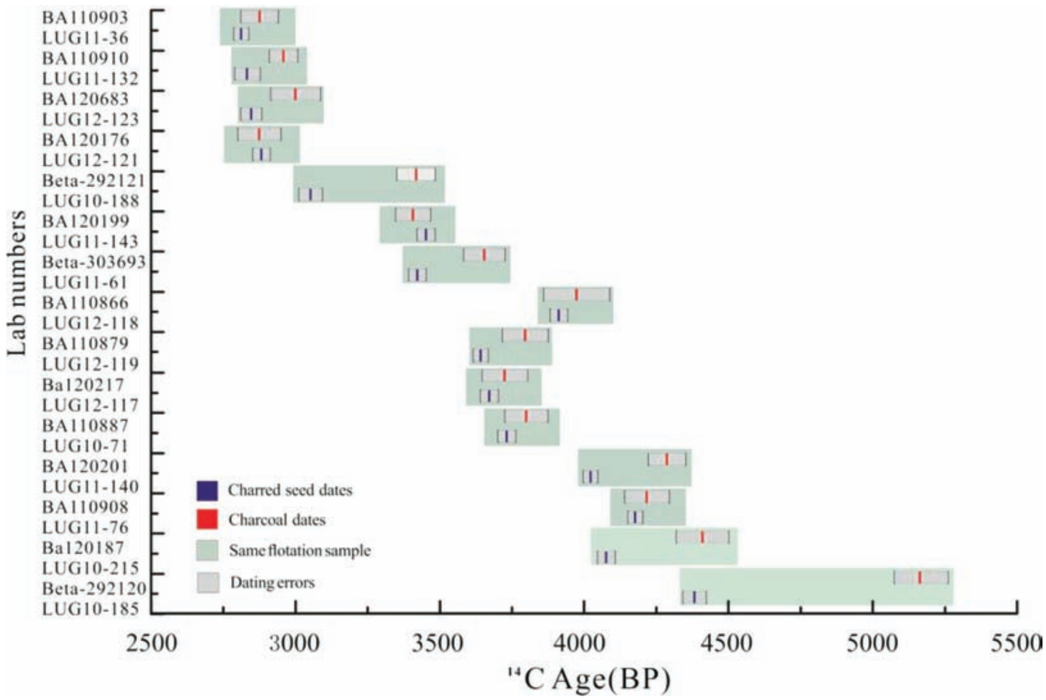

Figure 2 Comparison between the uncalibrated ^{14}C dates of charred seeds and those of unidentified charcoal from the same flotation samples.

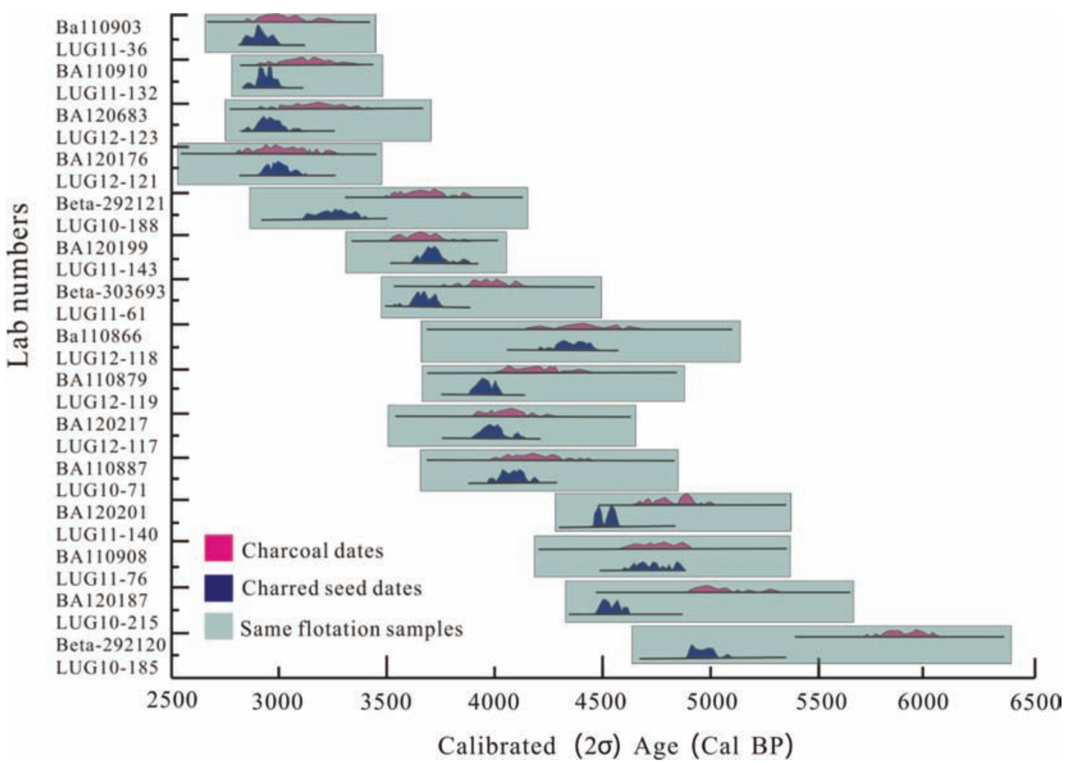

Figure 3 Comparison between the calibrated ^{14}C dates (2σ) of charred seeds and those of unidentified charcoal from the same flotation samples. Ages were calibrated using CALIB (v.6.0.1) (Stuiver and Reimer 1993).

unidentified charcoal and charred seeds from the same flotation samples are –8 ± 80 and 24 ± 233 yr, respectively. Nevertheless, that result does not indicate that the old-wood problem in the region is small. For example, note the two ^{14}C dates from the excavation of Nuomuhong sites in east Qaidam Basin. One is an uncalibrated ^{14}C date (ZK-0061) of a stake is 3670 ± 90 BP, while the other uncalibrated ^{14}C date (2720 ± 115 BP, ZK-0062) was dated from a towel that was made by short-lived plants (IA, CASS 1991), which is younger than the former one by 950 ^{14}C yr, suggesting that the old-wood problem of ^{14}C dating in this Gobi region could be more than 1000 yr.

The differences between the ^{14}C dates of unidentified charcoal and charred seeds from the same flotation samples in the 15 investigated sites suggest that the old-wood problem of ^{14}C dating from the Late Neolithic and Bronze Age sites in the area might be different due to the variety of subsistence strategies and local vegetation. Hunting was an important strategy in the early-mid Majiayao (Shilingxia and Majiayao phases, 5900–4800 cal BP) societies (Shang 1987; Xie 2002), and tree pollen was relatively high in Qinghai Lake during 5900–4800 cal BP (Liu 2002), indicating the growth of forests. If people used wood from big trees, it could have resulted in the old-wood problem reflected in the ^{14}C dating. During the Qijia period (4100–3600 cal BP) and Xindian period (3400–2700 cal BP), tree pollen was low in Qinghai Lake (Liu 2002), and agriculture was the most important human strategy during that period (Shang 1987; Zhao 2010; Jia et al. 2013). Humans mainly settled on the terraces of the big rivers to engage in agricultural production, and it might not have been convenient to utilize primary forest resources. Though the Kayue (3600–2600 cal BP) and Xindian cultures existed almost synchronously, many Kayue sites are distributed on slopes and ridges of mountains where big trees could be obtained, in east Qinghai Province (Bureau of National Cultural Relics 1996; Dong et al. 2012b), probably for sheepherding, which has been suggested was an important strategy during the Kayue period (Shang 1987; Xie 2002).

CONCLUSION

From the same flotation samples in 15 Late Neolithic and Bronze Age sites in Gansu and Qinghai provinces, the uncalibrated and calibrated (2σ) ^{14}C dates of unidentified charcoal are on average 176 ± 82 and 244 ± 258 yr older, respectively, than those of charred short-lived plant seeds. In 5 of these 15 flotation samples, ^{14}C dates (both uncalibrated and calibrated 2σ ranges) of unidentified charcoal are evidently older than those of charred seeds. These results suggest that the 114 published conventional ^{14}C dates of unidentified charcoal from the excavations of prehistoric sites might be partly inaccurate and potentially affected by the old-wood problem of ^{14}C dating, which should be discussed before establishing the chronology of Neolithic and Bronze Age cultures in the area. With the increasing application of flotation and archaeobotanical methods in archaeological studies in Gansu and Qinghai provinces, more AMS ^{14}C dates of plants (especially crops) should be obtained. The old-wood problem of ^{14}C dating in Gansu and Qinghai provinces might be related to subsistence strategies and local vegetation during different prehistoric cultural periods.

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