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New progress in ^{14C} dating of Chinese mammoth and woolly rhino fossils

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New radiocarbon evidence on the woolly mammoth and rhinoceros in China

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Summary

Mammoth (*Mammuthus primigenius*) and woolly rhinoceros (*Coelodonta antiquitatis*) are the main members of the late Pleistocene fauna in the high latitudes of the northern hemisphere . In this paper, the AMS ^{14}C dating of 5 mammoths and 5 woolly rhinoceros newly unearthed in Yingxian Village, Qinggang County,

Heilongjiang Province was carried out . . By sorting out and comparing the published ^{14}C dating data of two animal fossils in China, this paper argues that the age values obtained by the early conventional ^{14}C dating methods need to be reconsidered for their accuracy. The burial strata and the latest AMS ^{14}C dating data show that the fossil age of the true mammoth in China is mainly concentrated in the MIS3 stage; the woolly rhinoceros may have died out later than the true mammoth in China, at least until the last glacial extinction period. The Chinese mammoth-woolly rhino fauna fossils still require more chronological studies.
Key words: Qinggang County; MIS3 stage; Last Glacial Maximum; extinction of large mammals; Buried strata

Abstract

The woolly mammoth (*Mammuthus Primigenius*) and the woolly rhinoceros (*Coelodonta antiquitatis*) were the dominated members of the late Pleistocene fauna in the high latitude of northern Hemisphere. The age and causes of their extinction are still controversy. In this study, five woolly mammoth and 5 woolly rhinoceros fossils unearthed recently from Yingxiancun, Qinggang County, Heilongjiang Province were dated by AMS ^{14}C methods. The dating results were all over 40,000 years, and some fossils may have exceeded the current limit of radiocarbon dating. Based on comparing the published radiocarbon data of two animal fossils in China, we argued that the accuracy of the dating results obtained by the conventional ^{14}C dating method should be reconsidered. The dating results of woolly mammoth fossils were mainly in MIS3, and the woolly rhinoceros survived in China until the last deglacial period. More chronology data of *Mammuthus Primigenius* and *Coelodonta antiquitatis* fossils were still needed for the research on the late Pleistocene megafauna extinction in China.
Keywords: Qinggang County; MIS 3; Last glacial maximum; Megafauna extinction; Buried strata

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1 Introduction

The late Pleistocene to the early Holocene is an important period for the transformation of the global terrestrial ecological environment. During this period, many large terrestrial mammals went extinct, plant communities underwent structural changes, and human livelihoods gradually transitioned from hunter-gatherer to agricultural planting. Large mammal groups represented by mammoths and woolly rhinoceros once occupied the middle and high latitudes of the northern hemisphere and were an important part of the northern hemisphere ecosystem in the late Pleistocene [1] . However, after entering the Holocene, most of the members of this fauna became extinct, such as the extinction ratio of Eurasia was about 36%, and the extinction ratio of North America was 72% [2] .

There are still many controversies about the reasons for the extinction of large mammals . The main theoretical hypotheses are climate change, human influence and the combined effect of the two [1, 3-4] . Accurate chronological data are key to understanding the mechanisms of the extinction of large mammals in the late Pleistocene. Based on a large number of ^{14C} data, the extinction of large animals such

as mammoths and woolly rhinos in Eurasia is considered to be closely related to climate and environmental changes, and has less impact on human activities [5⇓⇓-8]. In North America, because the extinction of large mammals and the arrival of humans in the Americas and climate change are relatively consistent in age, the reasons for their extinction are quite controversial [9⇓-11].

Some studies believe that the single climate change or human hunting hypothesis is difficult to explain the extinction of large mammals in the late Quaternary, and the combination of the two in different regions is the main reason for the extinction of different types of mammals in various regions [2,12]. Stuart [1] published a research review and pointed out that on the basis of accurate identification of animal remains, the establishment of reliable radioactive ^{14C} databases in different regions is the key to understanding the causes of the extinction of large mammals in the late Quaternary. Only in the framework of systematic and precise chronology, it is possible to achieve accurate comparison of mammalian records with paleoclimate and archaeological records.

Northeast China and North China are rich in fossils of late Pleistocene animals, which are important areas for Eurasian mammoth-woolly rhino fauna [13]. Liu Dongsheng and Li Xingguo [14] discussed the survival time, burial strata and the reasons for the extinction of true mammoths in China based on the fossil dating records available at that time. Jin and Kawamura [15] comprehensively sorted out the age and burial records of mammoth and woolly rhinoceros fossils published before 1996 in Northeast China, and found that the two animals were widely distributed in Northeast China before and after 21 kaBP, and each became extinct at 12 kaBP and 10 kaBP. In recent years, some studies have pointed out that the extinction time of large mammals in China occurred in the late Pleistocene, which was synchronized with the occurrence time of Eurasia and the Americas [16]. Due to the lack of relevant chronological research work, there is still a lack of clear understanding of the living time,

environmental background and extinction process of the mammoth, woolly rhinoceros and other animals in my country.

There are rich fossils of late Pleistocene mammals unearthed in Qinggang county of Heilongjiang province , the representative species are mammoth, woolly rhinoceros, Przewalskii (*Equus przewalskii*), Wang's buffalo (*Bubalus wansjocki*), Northeast bison (*Bison exiguous*), The antelope (*Gazella przewalskyi*), the Hetao bighorn deer (*Megaloceros* (*Sinomegaceros*) *ordosianus), the wolf,* the last spotted hyena (*Crocuta crocuta ultima)* · etc. [17-18] . This paper mainly studies the ^{14}C dating of the mammoth and woolly rhino fossils unearthed in Yingxian Village, Qinggang County in 2015 and 2016 , and collects and compares the published fossil ^{14C} dating data and burial stratigraphic records (Fig. 1).), analyzed the research status of chronology and burial of large mammals in China, and provided new chronological data for understanding the extinction process and mechanism of large mammals in the late Pleistocene in Northeast Asia.

figure 1

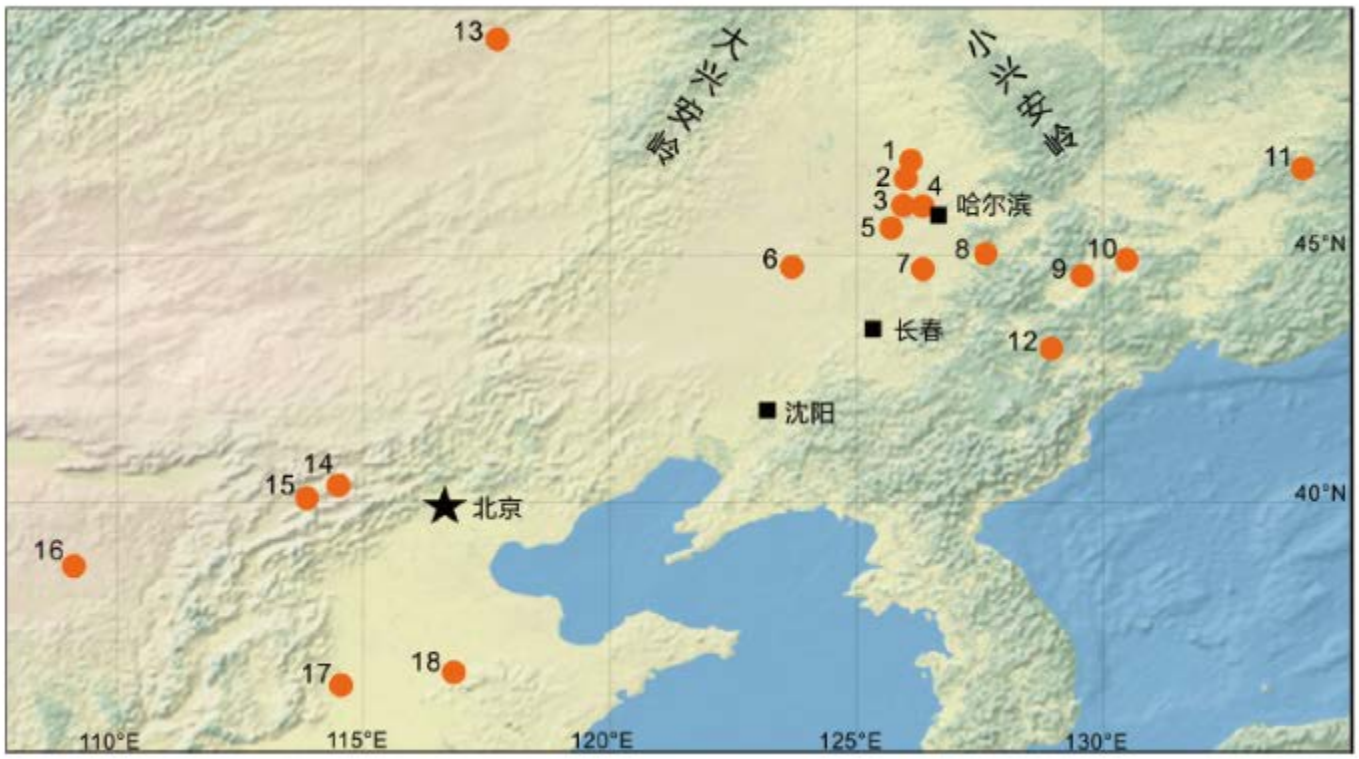

Fig.1 ^{14}C dating sites of Chinese mammoth and woolly rhino fossils

1. Yingxiancun, Qinggang, Heilongjiang; 2. Hongqi Village, Qinggang, Heilongjiang; Hongqicun, Qinggang, Heilongjiang; 3. Zhaodong, Heilongjiang; 4. Yanjiagang, Heilongjiang; 5. Sanzhan, Zhaoyuan, Heilongjiang , Zhaoyuan, Heilongjiang;6. Dabusu, Qianan, Jilin;7. Zhoujiayoufang, Yushu, Jilin;8. Xuetian, Wuchang, Heilongjiang;9. Mudanjiang, Heilongjiang ;10. Xinxingcun, Muling, Heilongjiang;11. Xiaonanshan, Raohe, Heilongjiang;12. Mingyuegou, Antu, Jilin;13. Zhalainuoer, Inner Mongolia;14.Hutouliang,Yangyuan,Heibei,Yangyuan,Hebei;15.Xujiayao, Yanggao, Shanxi,Yanggao,Hebei;16.Salawusu,Inner Mongolia;17.Xiaonanhai,Anyang,Henan,Xiaonanhai, Anyang, Henan;18. Jinan, Shandong

Fig.1 The ^{14}C dating sites of woolly mammoth and rhinoceros fossils in China

2 Research materials and methods

2.1 ^{14}C dating of mammoth and woolly rhino fossils

In this study, the AMS ^{14}C (AMS-Accelerator Mass Spectrometry, accelerator mass spectrometry) dating of the true mammoth and woolly rhino fossils unearthed from the fossil site in Yingxian Village, Qinggang County was conducted at the Carbon Fourteen Laboratory of Oxford University and the Beta Laboratory of the United States. Finish. In addition, during the development of this study, the real mammoth plate tooth samples collected by the Cultural Relics Management Office of Muling City, Mudanjiang City and unearthed in Xinxing Village, Hexi Town, Muling City, were also sent to the Beta Laboratory in the United States for testing. In the laboratory, the fossil bones or teeth are treated with hydrochloric acid-sodium hydroxide-hydrochloric acid, and the collagen is purified for AMS ^{14}C dating. The carbon fourteen laboratory of Oxford University uses ultrafiltration technology to analyze the extracted collagen. Filter [19⇓⇓-22] . The dating results were corrected using the OxCal 4.3 software IntCal20 [23] . In this paper, the corrected age is represented by BP cal or kaBP cal, and the uncorrected age is represented by BP or kaBP.

2.2 Collection of published ^{14}C data

In order to compare with the latest dating results, this paper collected the published direct ^{14}C dating data of mammoth and woolly rhinoceros fossils in China . Since the establishment of the ^{14}C laboratory in China in 1965, a lot of ^{14}C dating work has been carried out for the fossils of the Late Pleistocene fauna

, and the main method is the conventional ^{14}C decay counting method. Dating materials mostly use organic parts or collagen extracted from bone or tooth material and then tested. The ^{14}C dating data of some locations have been reported by multiple literatures, and the data reported by the same laboratory number in different articles have different values, which may be caused by the selection of different approximations. When collecting the ^{14}C dating data of mammoth and woolly rhinoceros , literatures with detailed description of dating material types, preprocessing methods and data correction were used. Two kinds of dating results calculated by using 5568 a and 5730 a as the half-life of ^{14}C were also reported in some literatures, and both are collected in this paper. According to international practice, the dating results calculated with the half-life of ^{14}C in 5568 years were used for discussion, and the dating results were corrected using the OxCal 4.3 software IntCal20 curve [23] .

3 Findings

3.1 The ^{14C} age of true mammoth fossils

In this paper, AMS ^{14}C dating was performed on 5 true mammoth samples from the fossil site of Yingxian Village, Qinggang County , and the dating results were all more than 40,000 years old. There are two fossils (OxA-37718, Beta-482698) whose dating results are >44800 BP and >43500 BP, respectively, and no definite age can be obtained. The dating result of one sample (OxA-37719) is 48800±3400 BP. Although the median age is 51340 BP cal after correction with IntCal20, it is very close to the upper limit of the current ^{14C} dating, and the correction result is very different. Certainty. The other two fossils (Beta-476497, Beta-482695) obtained relatively definite dating results, which are 41560±500 BP and 41030±460 BP, respectively, and the corrected ages are 43359-45241 BP cal and 43131-44676 BP cal. The dating result of the real mammoth fossil (Beta-530980) in Xinxing Village, Muling, Heilongjiang, is > 43500 BP, and no definite age can be obtained (Table 1).

Table 1 ^{14}C dating data of true mammoth fossils

Fossil sites	NumberLab ID	materials _	^{14}C S Age (BP) /5730	^{14}C S Age (BP) /5568	Calibrated age (BP cal/ 2σ)	Adjusted Median age (BP cal)	Document Ref
Yingxiancun, Qinggang, Heilongjiang(Hei)	OxA-37718	Skull Skull/AMS	-	>44800	-	-	This article
	OxA-37719	Molar Molar /AMS	-	48800±3400	47124-?*	51340	This article
	Beta-476497	Tooth/AMS	-	41560±500	43359-45241	44453	This article
	Beta-482695	Bone Bone /AMS	-	41030±460	43131-44676	43997	This article
	Beta-482698	Bone Bone /AMS	-	>43500	-	-	This article
	Beta-439349	Bone Bone /AMS	-	>43500	-	-	[18]
Xinxingcun, Muling, Hei	Beta-530980	Tooth plate/AMS	-	>43500	-	-	This article
Xiaonanshan, Raohe, Hei	PV-179	Bone Bone / Conventional method	13285±410	12910±410	14055-16650	15397	[24]
Xuetian, Wuchang, Hei	AECV-1405C	Bone Bone /AMS	-	38800±3500	39423-52831*	44528	[25]
	AECV-1406C	Bone Bone /AMS	-	40200±3500	41037-52859*	45638	[25]
	AECV-1407C	Bone Bone /AMS	-	39600±3000	40473-52677*	44759	[25]
Mudanjiang, Hei	ZK-118-0	Dental Tooth/ Conventional method	21540±1000	20900±1000	23014-27345	25179	[26]
Sanzhan, Zhaoyuan, Hei	ZK-425-0	Bone Bone/ Conventional method	21200±600	20610±600	23369-26243	24823	[27]
	ETH-98609	Metacarpal/AMS	-	38204±225	42145-42530	42339	[28]

Fossil sites	NumberLab ID	materials _	^{14}C S Age (BP) /5730	^{14}C S Age (BP) /5568	Calibrated age (BP cal/ 2σ)	Adjusted Median age (BP cal)	Document Ref
Yanjiagang, Heilongjiang	ETH-98608	Humerus Humerus /AMS	-	41103±313	43311-44590	44123	[28]
	ETH-98610	Bone Bone /AMS	-	› 41964	-	-	[28]
# Zhalainuoer, Inner Mongolia	PV-170	Coprolites / Conventional method	33765±1700	32810±1700	34565-41638	37880	[24]
	PV-175	Bone Bone/Conventional method	26695±1300	25940±1300	27794-33671	30357	[24]
	Kia34350	Bone Bone/AMS	-	43500+1000/-800	45400-48800	47100	[29]
	Beta313528	Stomach remains/AMS	-	>43500	-	-	[29]
Dakangjiatun, Yushu , Jilin	ZK-1193	Incisor/Conventional method	-	38290±2000	39595-48100*	42849	[30]
Zhoujiayoufang, Yushu , Jilin	NU-138	Limb Limb / Conventional method	-	30810±1385	32246-39439	35571	[31]
	OxA-21001	Molar Molar /AMS	-	51600±1400	52063-?*	53479	[16]
	WB78-45	Bone Bone/Conventional method	29750±1220	28910±1220	31036-36230	33342	[32]
Mingyuegou, Antu, Jilin	WB78-41	Scapula Scapula/Conventional method	26560±550	25810±550	29106-31110	30098	[32]
	WB78-42	Molar Molar/Conventional method	35370±1850	34370±1850	35572-42826	39353	[32]
Jinan, Shandong	-	Molar Molar/AMS	-	33150±250	37019-38945	37825	[33]

Note: * indicates that the dating samples have approached or exceeded the upper limit of the current ^{14}C dating, and the calibration results have great uncertainty. Indicates that the dating sample approach to or exceed the maximum age of ^{14}C dating, and the calibration results are uncertain. #Recent research classifies Zhalainuoer mammoth fossils (such as Zalainuoer III and ZLNE001 samples) as steppe mammoths (*Mammuthus trogontherii*) [34,35] . The mammoth fossil

samples (eg ZhalainuoerIII and ZLNE001) from Zhalainuoer were identified as *Mammuthus trogontherii* in the latest studies [34,35]

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At present, the published direct carbon 14 dating data of mammoth fossils (including coprolites) in China come from 12 different locations (Table 1). Among the 27 collected ^{14}C dating data, 17 were determined by AMS method, and the remaining 10 were obtained by conventional ^{14}C dating method. Among them, the largest age is from Zhoujia Oil Factory in Jilin, and the determination result is 51600±1400 BP [16] . The minimum age comes from Xiaonan Mountain, Raohe, Heilongjiang, the measured age is 12910±410 BP, and the corrected age is 14055-16650 BP cal [24] .

3.2 ^{14}C dating of woolly rhino fossils

The woolly rhinoceros fossils that have been publicly reported so far are directly dated from 13 different locations. Among the 22 ^{14}C dates collected , 16 were dated by AMS method, and 6 were dated by conventional method. The dating results of five woolly rhinoceros fossil samples in Yingxian Village, Qinggang County are all older than 40,000 years old, and only one sample (Beta-476496) has a confirmed age of 43610±630 BP, which is 44882-47497 BP cal after correction (Table 1). 2). Two of the three woolly rhino fossil samples from Hongqi Village, Qinggang County are older than 40,000 years old, and the other sample is dated to 16975±75 BP, and the corrected age is 20332-20764 BP cal [7, 12] , which is in the last glacial maximum period. . The smallest age fossils were unearthed in Hutoulang, Nihewan, Hebei. The dating result is 10690±210 BP, and the corrected age is 11972-13085 BP cal, which corresponds to the last deglacial period.

Table 2 ^{14}C dating data of woolly rhino fossils

Fossil sites	Dating materials and methods	^{14}C S Age (BP) /5730	^{14}C S Age (BP) /5568	Calibrated age (BP cal/2σ)	Adjusted Median age (BP cal)	Lab ID Lab ID	Document Ref
Yingxiancun, Qinggang, Heilongjiang (Hei)	Bone Bone /AMS	-	>44700	-	-	OxA-37720	This article
	Bone Bone /AMS	-	>46000	-	-	OxA-37721	This article
	Tooth/AMS	-	43610±630	44882-47497	46018	Beta-476496	This article
	Bone Bone /AMS	-	>43500	-	-	Beta-482696	This article
	Bone Bone /AMS	-	>43500	-	-	Beta-482699	This article
Hongqicun, Qinggang, Hei	Bone Bone /AMS	-	16975±75	20322-20764	20507	AAR-11030	[12]
	Bone Bone /AMS	-	41150±500	43139-44827	44097	OxA-20104	[12]
	Bone Bone /AMS	-	>44000	-	-	AAR-11031	[12]
Qinggang , Heilongjiang	Bone Bone /AMS	-	35085±180	39763-40684	40238	-	[36]
Taipingxiang, Zhaodong, Hei	Bone Bone /AMS	-	39625±250	42605-43230	42899	-	[36]
Yanjiagang, Heilongjiang	Bone Bone /AMS	-	40441±579	42820-44476	43616	ETH-102509	[28]
	Bone Bone /AMS	-	42241±721	43854-46346	44991	ETH-102511	[28]
	Mandible/AMS	-	42310±726	43949-46447	45024	ETH-102512	[28]
Salawusu, Inner Mongolia	Bone Bone /AMS	-	37800±900	41012-43249	42165	AAR-11043	[12]

Fossil sites	Dating materials and methods	^{14}C S Age (BP) /5730	^{14}C S Age (BP) /5568	Calibrated age (BP cal/2σ)	Adjusted Median age (BP cal)	Lab ID Lab ID	Document Ref
	Bone Bone /AMS	-	42230±370	44399-45544	44899	-	[36]
Dakangjiatun, Yushu, Jilin	Bone Bone / Conventional method	31800±910	30900±910	33604-37840	35445	WB78-46	[32]
Zhalainuoer, Inner Mongolia	Bone Bone / Conventional method	27005±800	26240±800	28806-32181	30500	PV-220	[24]
Mingyuegou, Antu, Jilin	Molar Molar/Conventional method	28720±750	27910±750	30939-34143	32248	WB78-43	[32]
Dabusu, Qianan, Jilin	Bone Bone / Conventional method	-	20530±465	23784-25804	24731	-	[37]
Hutouliang, Yangyuan, Hebei	Bone Bone / Conventional method	11000±210	10690±210	11972-13085	12614	PV-0156	[32]
Xiaonanhai, Anyang, Henan	Bone Bone / Conventional method	13075±220	12710±220	14203-15757	15091	ZK-0170	[32]
Shanxi Yanggao XujiayaoXujiayao, Yanggao, Shanxi	Bone Bone / Conventional method	16920±2000	16450±2000	15628-26946	20551	ZK-0670	[38]

3.3 Burial stratigraphy of the mammoth and woolly rhino fossils

In Guxiangtun, Harbin, mammoth fossils are mainly buried in silty sand and silty soil, while woolly rhino fossils are preserved in silt sand, silty soil, loess-like loite and loess (Figure 2) . Fossils of mammoths and woolly rhinos in the barren hills of Harbin were both unearthed in the black silt. Woolly rhinoceros fossils have been unearthed in the silt and loess deposits of Zhoujiayoufang in Jilin, but age evidence shows that the woolly rhinoceros fossils in the loess were transported secondary; For fossils such as woolly rhinoceros, only woolly rhinoceros fossils are found in the loess-like silty clay

of Qunli Formation [39]. The mammoth and woolly rhinoceros fossils at Mingyuegou cave site in Antu, Jilin, are mainly unearthed in grayish-yellow sub-clay [40]. The animal fossils at the Xiaogushan cave site in Liaoning are mainly buried in breccia, gravel and yellow-brown clay silt layer.

figure 2

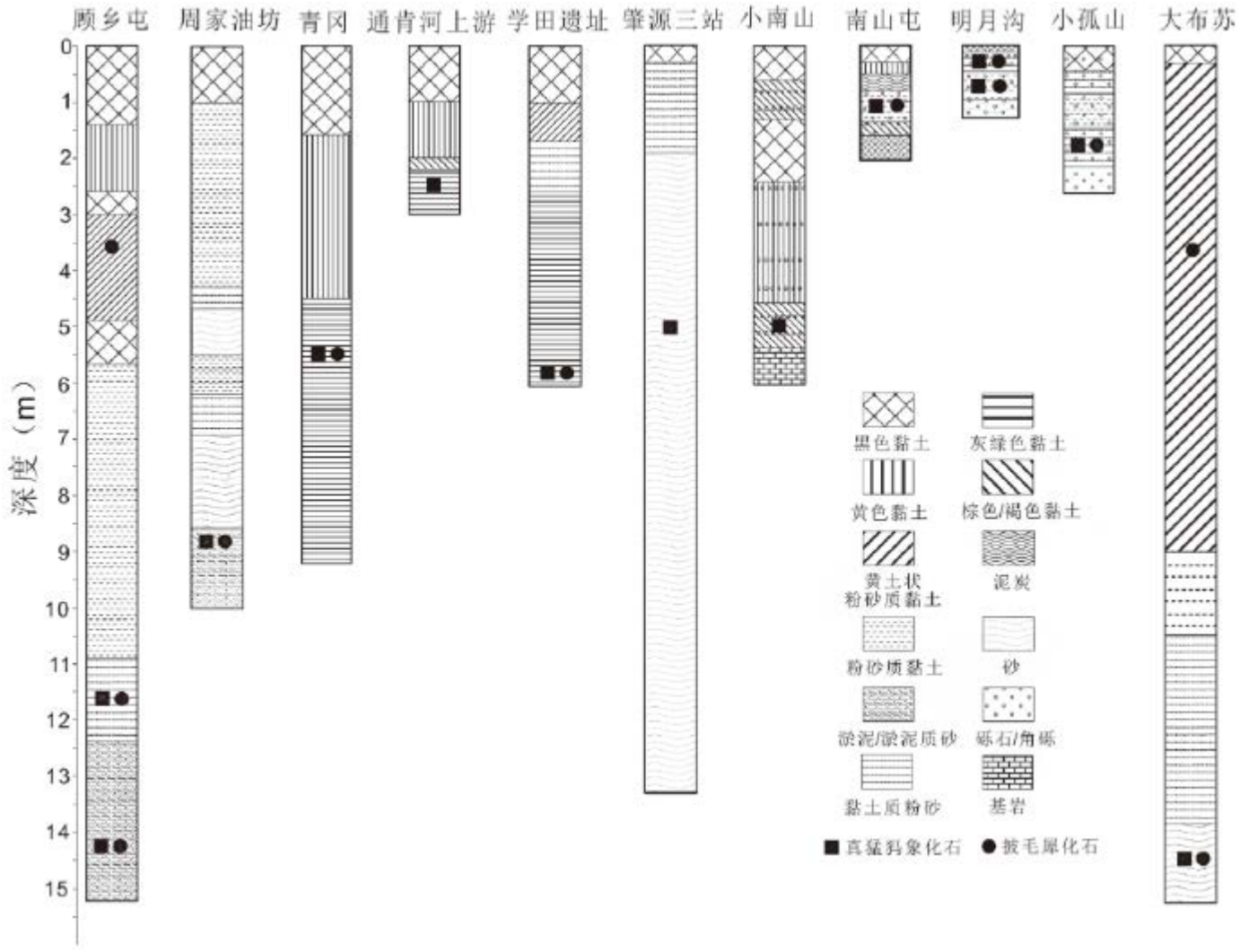

Fig. 2 Partial burial strata of the fossil mammoth and woolly rhinoceros (modified from references [14, 39])

The fossil evidence unearthed so far shows that the woolly rhinoceros fossils appeared in the loess deposits of the Qunli Formation in addition to the muddy deposits

of the Guxiangtun Formation, while the true mammoth fossils only appeared in the Guxiangtun Formation. The unearthed stratum of the mammoth and woolly rhinoceros fossils in Qinggang is gray-green clay, which is consistent with the previously published stratum of mammoth fossils unearthed in the upper reaches of the Tonken River [43] .

4 Discussion

4.1 The living age of the mammoth and woolly rhinoceros in China

The true mammoth, also known as the woolly mammoth, originated in Siberia about 700,000 years ago, and completed its evolution around 400,000 years ago, and then spread to the entire northern Eurasian continent and North America [44 ⇓ - 46] . At 50-12 kaBP, mammoths existed throughout northern Asia, from the Arctic to southern Siberia to northeastern China. Most mammoths disappeared in Eurasia around 10,000 years ago, and some dwarfed species Survived in the Arctic Wrangel Island to around 4000 years ago [5, 6] . The ^{14}C age of the mammoth fossils unearthed in eastern Siberia is mostly concentrated in 28.6-22.5 kaBP cal, which is in the Last Glacial Maximum (LGM) period [8] . Chronological records reveal that mammoths died out in the Japanese archipelago or migrated northwards after the LGM stage [47] .

There are more than 100 mammoth fossils unearthed in China [14, 48] , but only 12 fossil sites have been directly dated by ^{14}C. According to the existing ^{14}C dating results, true mammoths have appeared in northeastern China at least 50,000 years ago, and most of the dating results are concentrated in the deep-sea oxygen isotope stage 3 (Marine Isotope Stage 3, MIS). 3) and the LGM stage, in which climatic cold events such as Heinrich, may have promoted the proliferation of mammoths in China [49] (Fig. 3). An obvious feature of these ^{14}C dating results is that the corrected median values of the AMS dating results of eutherian mammoth fossils are all greater than 36 kaBP cal, while the corrected median values obtained by conventional dating methods are mostly less than 36 kaBP cal. (Figure 3).

image 3

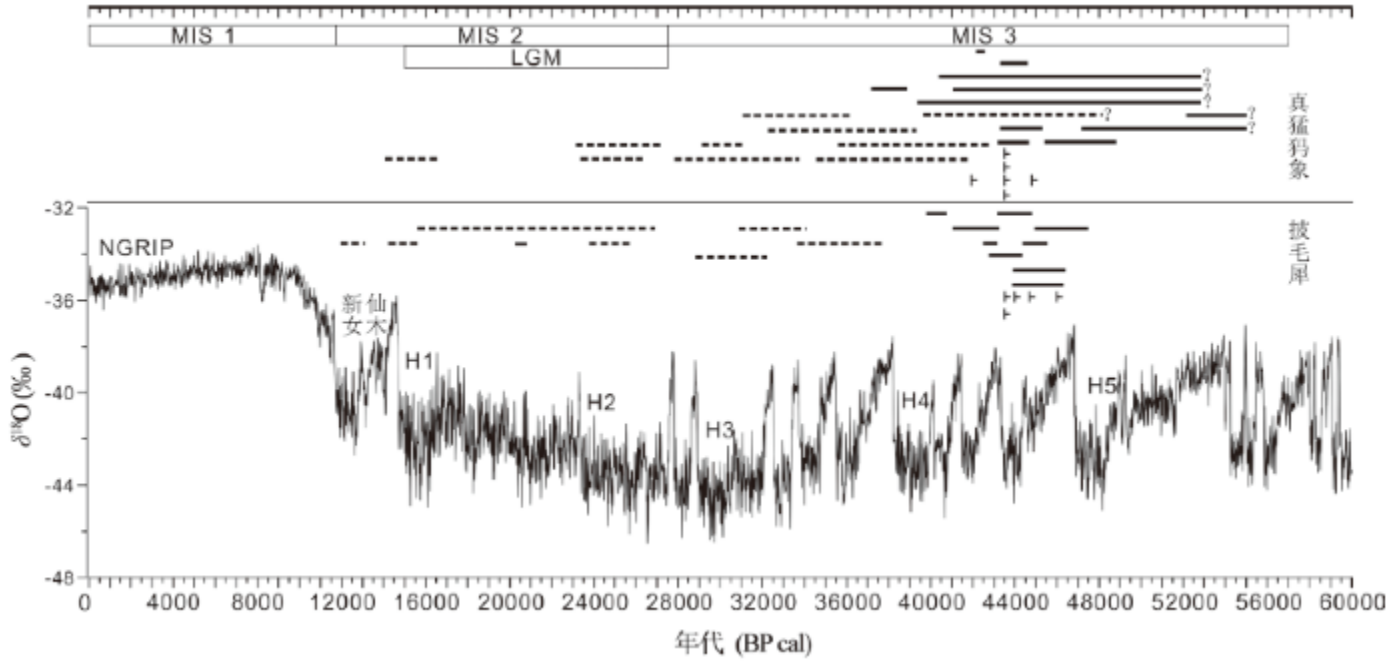

Fig. 3 The ^{14}C dating results of Chinese mammoth and woolly rhinoceros fossils and the oxygen isotope curve of Greenland ice core (NGRIP) [50]

Note: The solid line represents the results of the AMS ^{14}C dating method, the dashed line represents the conventional ^{14}C dating method, "⊢" indicates that the dating is older than this age and "?" indicates that the calibration results are uncertain; H1-H5 indicate Heinrich cold event.

At the same fossil site, there are differences in the results obtained by AMS ^{14}C dating and conventional ^{14}C dating. For example, the latest 14C result of the real mammoth fossil in Zhoujiayoufang, Yushu, Jilin , is 51600±1400 BP, while the previous maximum dated value is 30810±1385 BP [16, 31]. The same phenomenon also appears in the Zhalainuoer fossil site in Inner Mongolia [24, 42]. Although these two sites did not measure the same sample twice, in recent years, with the improvement of dating accuracy, the extension of calibration curves, and the improvement of preprocessing technology, we have a new understanding of the age of these late Pleistocene mammalian groups. provides opportunities [51]. Some earlier fossils obtained by conventional ^{14}C dating methods need to be re-dated.

The woolly rhinoceros originated from the Qinghai-Tibet Plateau in the middle Pliocene, appeared in Siberia in the Middle Pleistocene after continuous migration and evolution, and was widely distributed in northern Eurasia in the late Pleistocene [6, 7, 52]. Studies have shown that the last extinction sites of woolly rhinoceros and mammoths are not consistent. The woolly rhinoceros went extinct in the Eurasian border area, and the mammoths went extinct in the Arctic region; in terms of extinction time, the woolly rhinoceros was about 13.9 kaBP. cal disappeared before and after, but the mammoth survived on Wrangel Island until about 4000 years ago [7]. Fossil dating of Hutooliang in Xiaonanhai and Nihewan in Anyang reveals that woolly rhinos lived in my country until the last glacial extinction period. From the perspective of burial strata, woolly rhino fossils can still be found in the primary loess deposits in the upper part of the Guxiangtun Formation in Northeast China, but it is difficult to find real mammoth fossils. It likely died later than the real mammoth. Compared with the real mammoth, the chronological study of the woolly rhinoceros is still lacking, and more dating results are still needed to explore the age of the woolly rhinoceros' demise and the reasons [7].

The extinct species of mammoth-woolly rhinoceros fauna in my country mainly include mammoth, woolly rhinoceros, bison, Wang's buffalo, Hetao bighorn deer, and finally spotted hyena. Stratigraphic research will help us to understand the laws and characteristics of ecological environment changes in the late Pleistocene, and to understand how ancient humans adapted to these changes. In the book "Biostratigraphy of the Chinese Cenozoic" [53], it is written that most of the specimens in the northeast have no exact location and their horizons are unclear. The lack of systematic chronology and burial stratigraphic studies hinders our understanding of the evolution of this important fauna and its relationship with the environment in the late Pleistocene ecosystems of the Northern Hemisphere.

4.2 Distribution of mammoths and woolly rhinos in Eurasia at MIS3 and LGM stages

The ^{14}C-corrected ages of the mammoth and woolly rhinoceros fossils determined in this paper are concentrated at 50-15 kaBP cal, corresponding to the MIS 3 stage (MIS 3, 59-28 kaBP cal) and the Last Glacial Maximum (LGM, 28-15 kaBP cal). . Therefore, this paper collects the published direct ^{14}C data of the mammoth and woolly rhinoceros fossils, and focuses on investigating the distribution range of the mammoth and woolly rhinoceros in Eurasia during the MIS 3 stage and the LGM period. During the MIS 3 and LGM stages, mammoths and woolly rhinos were mainly distributed in eastern and southern Europe, northern, southern and eastern Siberia. During the MIS 3 stage, Northeast China was one of the main areas where the mammoth, woolly rhinoceros and other fauna were active (Fig. 4 ; Fig. 5).

Figure 4

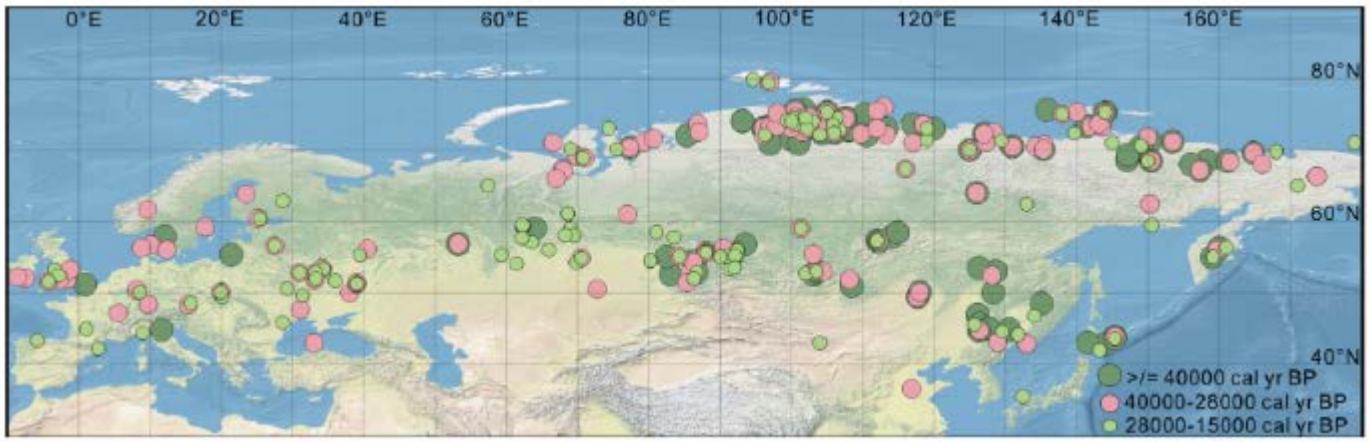

Fig. 4 Distribution of mammoths in Eurasia at MIS 3 and LGM stages (data sources [5, 7, 12] , this paper)

Figure 5

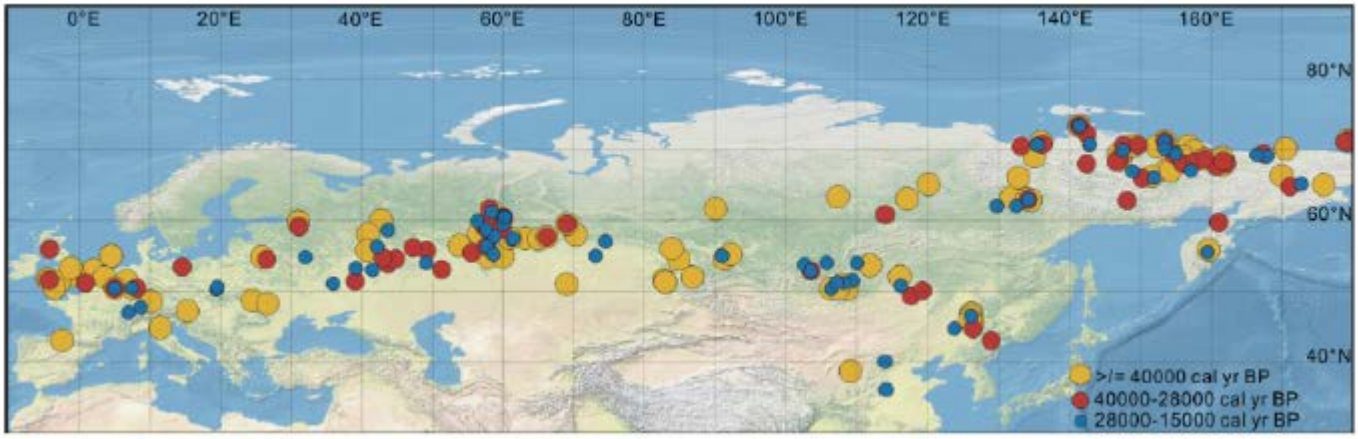

Fig. 5 Distribution of woolly rhinoceros in Eurasia at MIS 3 and LGM stages (data sources [5,7,12], this paper)

Before 40,000 years ago, true mammoths were mainly distributed in southern and northern Siberia, as well as northeastern China and Hokkaido, Japan (Figure 4). In the late MIS 3 period (40-28 kaBP cal), the mammoth population increased in eastern and western Europe; while in eastern Siberia, the mammoth population peaked at the LGM stage (28.6-22.5 kaBP cal) [8] . During the LGM period, mammoths spread from both ends of the Eurasian continent to the south. For example, mammoth fossils have been found in the Japanese archipelago and the Iberian Peninsula, but after the LGM stage, the real mammoths disappeared in the Japanese archipelago [47]] . The time and mechanism of the extinction of true mammoths may be different in different regions, and more chronological and stratigraphic evidences are needed to study the time and mechanism of the extinction of mammoths in Northeast my country.

Before 40,000 years ago, woolly rhinos were mainly distributed in eastern and western Europe and eastern and southern Siberia. At 40-28 kaBP cal, the distribution range of woolly rhinoceros in southern Siberia and eastern Europe decreased. During the LGM period, the distribution range of woolly rhinoceros further decreased in eastern Europe, but expanded to the south of 40°N in China (Figure 5). The woolly rhinoceros originated in the Qinghai-Tibet Plateau [52] . However, whether its living

space may have spread to the Qinghai-Tibet Plateau in the late Pleistocene still needs more research.

5 Conclusion

The ^{14}C age of the real mammoth and woolly rhinoceros unearthed in Yingxian Village, Qinggang County, Heilongjiang Province are all more than 40,000 years old, and some fossils may have exceeded the current ^{14}C dating range. The ^{14}C dating data has shown that the real mammoth began to appear in northeastern China at least 50,000 years ago. The period of woolly rhinoceros survival in China may last until the last glacial extinction period, but the southern boundary and age of its spread in my country still need to be further studied. Due to the limitation of chronological data, it is still difficult to clearly understand the temporal and spatial process and mechanism of the extinction of the mammoth-woolly rhinoceros fauna in my country in the late Pleistocene. In view of the improvement of bone and tooth fossil preprocessing technology and AMS ^{14}C dating accuracy in recent years, as well as the extension of the corrected chronology, some fossil age data obtained by conventional ^{14}C dating methods in China need to be re-determined. There will also be new progress in the study of the ^{14}C age of the real mammoth and woolly rhino fossils .

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