Quaternary Science Reviews 26 (2007) 954–957

AMS ^{14}C chronology of the world's southernmost woolly mammoth (*Mammuthus primigenius* Blum.)

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Received 5 June 2006; received in revised form 21 November 2006; accepted 5 December 2006

Abstract

The world's definite southernmost woolly mammoth record is a molar from Ji'nan (around 36°N), Shandong Province, China. AMS ^{14}C dating of the specimen, gave a conventional ^{14}C age of $33{,}150 \pm 250$ BP. The period of 40–30 ka BP corresponds to the later phase of the Marine Oxygen Isotope Stage 3 (MIS 3a), recognized as the global interstadial of the last glacial period. However, it is known that the winter monsoon strengthened in Asia during the period 35–33 ka BP, and the age of the woolly mammoth specimen from Ji'nan corresponds to that age. The specimen suggests that this area became cold and dry in 33 ka BP, and grassland or open forest, suitable habitat for woolly mammoths, developed during this short time span. This age is similar to the age of the southernmost woolly mammoth record in Europe, therefore supporting a hypothesis by Porter and An [1995. Correlation between climate events in the North Atlantic and China during the last glaciation. Nature 375, 305–308] that an important component of Chinese palaeoclimates may be linked to changes in North Atlantic oceanic conditions.

1. Introduction

During the late Pleistocene woolly mammoths were very widely distributed across Northern Eurasia and North America. They ranged mostly within the latitudes of 40–75°N, with their southern-most records from the eastern part of Eurasia (Kahlke, 1999). According to Liu and Li (1984), woolly mammoths in China reached as far south as approximately 35°N, as evidenced by specimens recovered at Ziyang in Sichun, Tongwei in Gsngsu, and Ji'nan in Shandong.

The specimen from Ziyang was reported as an upper molar of a woolly mammoth, and was found with a Paleolithic human skull (Ziyang man) and other vertebrates including *Stegodon orientalis, Rusa unicolar, Rhinoceros* cf. *sinensis, Rhizomys, Hystrix, Arctonyx*, etc. (Pei and Woo, 1957). However, the molar has too much folding in the enamel layers and the lamella frequency is too low to be from a woolly mammoth. The fauna found with the molar is also out of keeping with the typical mammoth fauna, and is characteristic of the southern fauna of the late Pleistocene. It is considered herein that the strong enamel folding of this molar indicates that it belongs to the genus *Elephas*.

The record from Tongwei consists of two upper molars that were reported as a new subspecies *M. primigenius liupanshanensis* by Zhou and Zhang (1974). However, the morphological characters of the enamel loops of the molars show the typical upper molar features of the genus *Palaeoloxodon*.

The existence and the source of the specimen from Ji'nan reported by Liu and Li (1984) are not clear and thus it cannot be confirmed as a woolly mammoth specimen. However, an additional fossil molar was discovered from Ji'nan in 1992, and this could definitely be confirmed as being from a woolly mammoth on account of its

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0277-3791/$ - see front matter
doi:10.1016/j.quascirev.2006.12.001

morphological features. This specimen, recovered from a latitude of 36°N, represents the world's most southerly record of a woolly mammoth. Herein are presented the result of AMS ^{14}C dating conducted on this specimen and discussion of the relationship between distribution and climate.

2. Description of specimen

Specimen: Left upper third molar, kept by Shandong Provincial Museum. Specimen number 92009 (Fig. 1).

Locality: The bank of the Beidasha River, Gushan, Changqing district, Ji'nan City, Shandong Province, China (36°35′N, 116°50′E) (Fig. 2).

Horizon: Unknown

Description: The medial portion of the original molar has been lost. This molar consists of ten well-worn plates. The whole enamel loops are narrow in mesial–distal section, and mesial and distal parts of the enamel loops are parallel to each other. The enamel is thin (1.9–2.2 mm), and enamel folding is visible in the mesial part of the enamel loop in the forth to seventh plate. Lamella frequency is 9. These features are characteristic of *M. primigenius*. Measurements of the specimen are given in Table 1.

3. Dating method

The collagen for ^{14}C dating was extracted from the molar specimen by the following process based on the method of Longin (1971) (Yoneda et al., 2002).

The sample was washed by ultrasonic cleaning and soaked in 0.2 M sodium hydrate (NaOH) over night to remove attached organic soil matter. The sample was crushed into a powder by a SPEX freezer mill, and the powder sample was sealed in a cellulose tube. The tube was submerged in 1 M hydrochloric acid (HCl) for 12 h to eliminate mineral matter. The contents of the cellulose tube were centrifuged to separated undissolved matter from dissolved matter. The undissolved matter was heated in pure water at 90 °C for 12 h, and the gelatin solution was vacuum-filtered by a glass filter. The filtrate including gelatin was freeze-dried for 2 days to collect the remaining organic matter, which is generally regarded as "collagen".

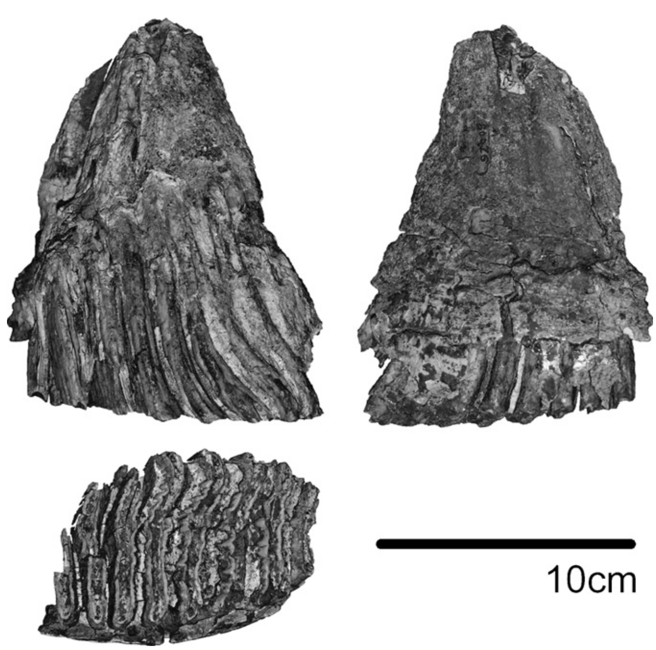

Fig. 1. Mammoth molar specimen no. 92009 from Shandong Provincial Museum.

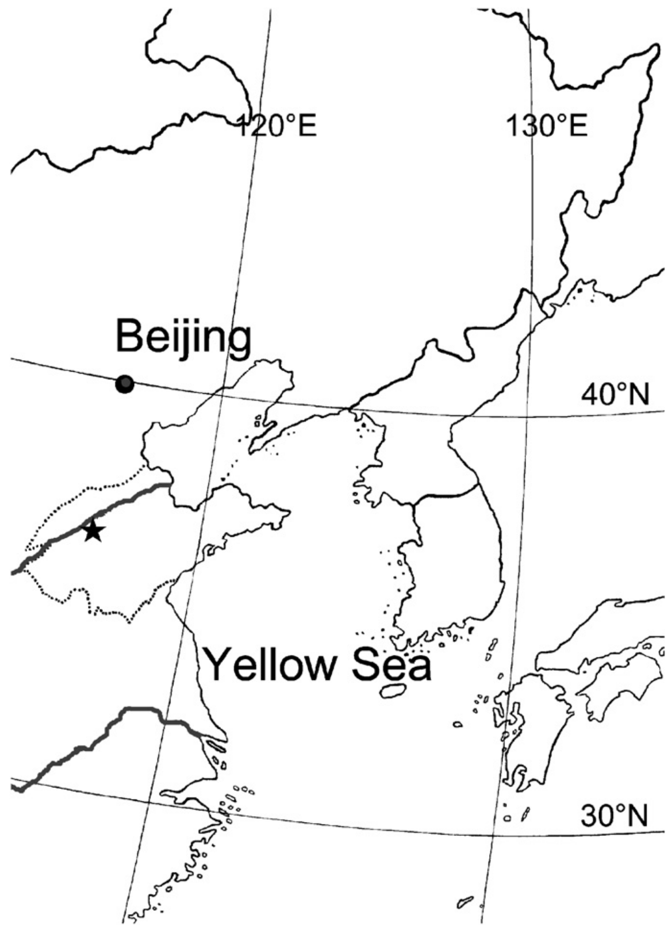

Fig. 2. Map showing location of find at Beidasha River, Shandong Province, China.

Table 1

Plate number	10
Using palate number	8 +
Maximum length of crown	111 mm
Occlusal surface length	107 mm
Height of crown	93 mm
Width of crown	73 mm
Masticatory face width	68 mm
Enamel thickness	1.9-2.2 mm
Lamella frequency	9 (buccal side)
	9 (lingual side)

The collagen was converted into CO_2 by an elementar analyzer (Elementar Vario EL (Yoneda et al., 2004), and the CO_2 was reduced by hydrogen with iron catalysis into graphite (Kitagawa et al., 1993). The $^{14}C/^{12}C$ ratio of the graphite was measured by the AMS system at NIES-TERRA (National Institute for Environmental Studies, Tsukuba, Japan) (Tanaka et al., 2000). Stable carbon isotope analysis ($\delta^{13}C$) of the collagen was analyzed by the EA-IRMS system; Carlo Erb NA-1500, Finnigan Mat ConFlo III interface and Finnigan MAT 252 isotope ratio mass spectrometer.

4. Results

The collagen of the molar sample formed 3.72% of the molar sample weight. The ratio of carbon and nitrogen (C/N ratio) was 3.21, and carbon and nitrogen contents in the collagen were 43.34 and 15.77%, respectively. Well-preserved bone contains at least 1.0% in weight ratio of collagen and has a C/N ratio of 2.9–3.6 (DeNiro, 1985). The weight and C/N ratios of the collagen from this molar sample represent good preservation. The carbon stable isotope ratio was −21‰ ($\delta^{13}C_{PDB}$). The conventional ^{14}C age is 33,150 ± 250 BP. This includes correction for isotope fractionation using the stable isotope ratio $\delta^{13}C$, and correction for the ^{14}C background.

5. Discussion

The distribution of woolly mammoths in China over time, based on ^{14}C dating, was discussed by Jin et al. (1988). They concluded that the woolly mammoth expanded its range from Siberia to about 44°N during 34–26 ka BP and then further south to Heilongiang, Jilin, Lioing and the Yellow Sea, about 40°N, during 32–11.8 ka BP. However, the result of AMS ^{14}C dating of the woolly mammoth molar from Ji'an in our study does not correspond with the conclusions reached by Jin et al. (1988); our result indicates that the woolly mammoth had already migrated as far south as 36°N by 33 ka BP.

Previous palaeoclimate studies in China based on ice cores, lake and river sediments, pollen and macrofossils, paleosols from loess and deserts, stalagmites from karst caves, and sea level changes all indicate that precipitation and humidity during 40–30 ka BP were higher than those today (Shi and Yu, 2001). The period 40–30 ka BP corresponds to the later phase of the Marin Oxygen Isotope Stage 3 (MIS 3a), considered to be the global interstadial of the last glacial period. However, there are several studies that provide evidence of variable climatic conditions during this period. Firstly, palynological studies in the north part of the Taihu Plain, East China, during the period 70–30 ka BP suggest that the average annual temperature was only about 8 °C in the main cold stage, although it fluctuated dramatically. Vegetation of this period was typical of open forest and steppe, implying a cold and semi-dry climate (Zhou et al., 2001). Secondly, stalagmites revealing millennial time-scale climate fluctuations from Hulu karst cave in Nanjing, suggest that the East Asian Monsoon intensity changed in step with the temperature of Greenland between 11,000 and 75,000 BP (Wang et al., 2001). Thirdly, according to Porter and An (1995), the quartz median diameter and >40 μm size fraction of loess/palaeosol in the Luochauan succession show one of the most prominent peaks during the period 33–35 ka BP. Modern dust storms and dust-fall events in China are associated with strong northwesterly winds that occur as a result of a strengthened winter monsoon in Asia, and historically are associated with dry and cold intervals. The age of the woolly mammoth fossil from Ji'nan corresponds to the grain size peak of the Luochauan loess/palaeosol succession. This suggests that for a short period 33 ka BP this area became cold and dry and developed grassland or open forest suitable for woolly mammoths.

The southernmost records of the woolly mammoth are located in east Eurasia and may be related to the development of the East Asian Winter Monsoon that occurred over a short period of time.

Recently, Gracía and Arsuaga (2003) reported an age of 35, 790 ± 960 BP for woolly mammoth molars from the Padul peat bog, Granada, South Spain (latitude 37°01′N). A second study by Alverez-Lao et al. (2005) on additional woolly mammoth specimens from the same site gave a similar age of 35.8 ka BP, and they correlated the Palul deposit with Heinrich 4 (35.3–33.9 ka BP). It therefore seems that approximately 30–40 ka BP woolly mammoths inhabited the Iberian Peninsular, reaching even the southernmost territories in Europe. This southern expansion of woolly mammoths in Europe was mirrored along the eastern margin of Eurasia during the same period. This similarity at each extreme end of Eurasia supports a hypothesis by Porter and An (1995) that an important component of Chinese palaeoclimates may be linked to changes in North Atlantic oceanic conditions.

6. Conclusion

A molar recovered from the banks of the Beidasha River, Gushan, Changqing district, Ji'nan City, Shangdong Province, China (36°35′N, 116°50′E) is the world's definite southernmost woolly mammoth specimen. AMS ^{14}C dating of the specimen gave a conventional ^{14}C age of 33,150 ± 250 BP. It is known that the winter monsoon strengthened in Asia 35–33 ka BP during MIS 3, and the woolly mammoth specimen from Ji'nan corresponds to that period. The specimen suggests that for a short period of time this area became cold and dry and developed grassland and open forest suitable for woolly mammoths. This age is similar to the age of the woolly mammoth recovered from the Padual peat bog, Granada, South Spain, which is the southernmost woolly mammoth record in Europe. It therefore supports a hypothesis by Porter and An (1995) that an important component of Chinese palaeoclimate may be linked to changes in North Atlantic oceanic conditions.

Acknowledgements

We thank Dr. T. Saito, Meijo University and Ms. C. Yamakawa, curators of the Lake Biwa Museum, for useful advice on pollen and plant fossils. We also thank Dr. R.J. Smith for improving English expression. This study has been financially supported by Lake Biwa Museum Joint Research Project (Project no. Joint Research 04-03).

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