Biological records of paleoclimate and paleoenvironment changes from Guanzhong area, Shaanxi Province during the last glacial maximum

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Abstract We have collected a suite of *Paleoloxodon naumanni-Coelodonta antiquitatis* fossils from a river terrace profile between Xi' an and Xianyang cities in Guanzhong Area, Shaanxi Province. A detailed examination of the fossils, together with ^{14}C determinations and pollen analyses, have enabled us to reconstruct preliminary features of climate and environment changes and their evolutionary processes, within the last glacial maximum (LGM): about 20 ka ago, the climate was basically cool and wet, and was favourable for the existence of *Paleoloxodon naumanni-Coelodonta antiquitatis* fauna. This was followed by a cold, dry phase which was no longer suitable for this type of faunal suite, causing the death of a large number of mammalian assemblages. The available evidence indicates the existence of cold-dry and cool-wet climate and environment fluctuations during the LGM. The cool-wet stage within the LGM reflects a Heinrich event occurring in the high latitude areas, proving the existence of a teleconnection between polar-high latitude areas and the Loess Plateau.

Keywords: Guanzhong of Shaanxi Province, *Paleoloxodon naumanni-Coelodonta antiquitatis* fauna, last glacial maximum, paleomonsoon precipitation.

Previous work on Late Pleistocene climate and environment features was carried out mainly through the establishment of proxies using techniques such as magnetic susceptibility, pollen, dating, geochemisty, and micromorphology, leading to many achievements [1—3]. However, from a mammalian study viewpoint, few reports are available. Fortunately, during geological investigations within the Xianyang area, the authors discovered a valuable suite of mammalian fossils within terrace two of the Weihe River. This has provided a rare opportunity for this type of study, which has improved our understanding of features of East Asian monsoon variations in the Guanzhong area during the LGM.

1 Qilipu stratigraphy in Xianyang

Excavation of sand for building construction has produced many sand pits having a depth of 15—16 m on river terrace two between Xi' an and Xianyang cities. At the bottom of a sand gravel layer containing mud boulders in several sandpits, we collected a series of fossils such as *Bubalus*, *Paleoloxodon*, *Cervus*, *Equus*, *Ovis*, etc. A stratigraphic description of the profile from top to bottom is as shown by fig. 1.

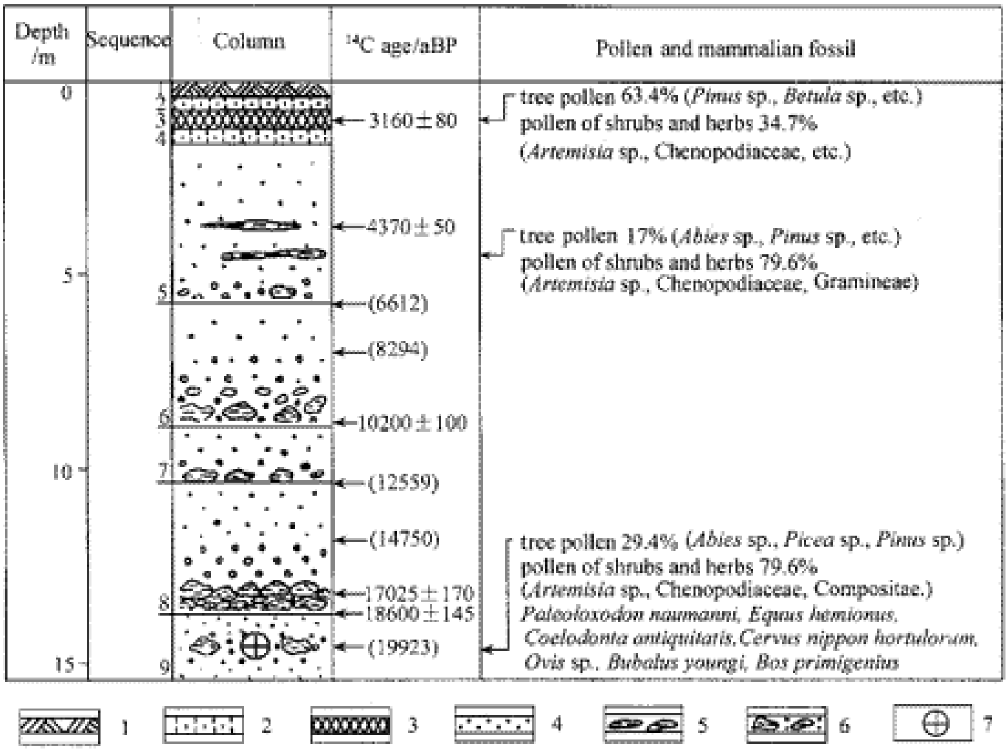

Fig. 1. The geology section of Qilipu, Xianyang, Shaanxi. 1, Surface soil; 2, Holocene loess; 3, black loam; 4, sand; 5, muddy silt; 6, sandy gravel containing muddy boulder ; 7, fossil. (1) Cultivated soil layer, 0.4 m thick. (2) Pale grayish brown loess layer, 0.3 m thick with loose and porous features. (3) Black loam layer, 0.5 m. Grayish black in colour with prismatic features, rich in earth worm droppings. Near the bottom of this layer, we collected two soil samples, then extracted the organic component in the lab for dating. ^{14}C determinations give ages of (3 160±80) and (3 160±55) aBP. Pollen analysis for this layer shows that wood pollen is 63.3%, mainly composed of *Pinus* and *Betula*, with a small amount of *Juglans*, *Quercus* etc.; and that herb pollen is 34.7%, with the majority being *Artemisia* and Chenopodiacia. In addition, a small amount of *Selaginella* and *Filices* spores were found. (4) Pale brown loose loess, 0.4 m thick. (5) Grayish white sand layer, 4.1 m thick. The layer contains a middle-sized sand lens and well-developed large and small platy crossbedding. About 0.5 m thick sand below the top of the layer is cemented to some extent with a brownish rusty coloured component. Plant fragments and a few muddy sand beds 1—2 cm thick are within the lower part of the layer. An AMS ^{14}C age of plant fragments is (4 370±50) aBP. Pollen analysis from the muddy sand layer indicates that this interval was dominated by herb pollen (79.6%), with 64.6% of *Artemisia* and 6.8% of Chenopodiacia. Wood pollen mainly consists of *Pinus*, reflecting a predominance of cold-dry winter monsoon conditions, in contrast with the climate conditions recorded in the black loam. A sand horizon about 0.5 m thick near the bottom of the layer contains quartzite and granite gravel with a few mud boulders. The diameter of the gravel ranges from 1 to 5 cm, with the exception of larger boulder mud. (6) Grayish white sand and gravel layer, 3.25 m thick. The middle-upper part of the layer is grayish white sand within which there is middle-small size platy cross bedding. The small size cross bedding is 3 cm with a normal rhythm. The lower part of the layer consists of sand with gravel having a diameter ranging from 1 to 4 cm in general. The largest gravel pieces reach 6 cm in diameter. There is a wavelet scour surface at the bottom of the gravel, with a large number of mud boulders having a diameter of 10—45 cm distributed along it. Tree trunks having a diameter of 3 cm were excavated from within the gravel. The lower part of the gravel layer containing these trunks and mud boulders is most probably a lag deposit from the river. ^{14}C dating of boulder mud from the bottom of the layer has produced an age of (10 200±100) aBP. (7) Grayish white sand and gravel layer containing mud boulders, 1.4 m thick. In the mid-upper layer, the sand contains a relatively large amount of gravel. The lower part of the layer contains gravel containing mud boulders as well as tree trunks and plant fragments. The size and petrological contents are similar to those of Layer 6. (8) Grayish white sand and grayish brown gravel layer, 3.4 m thick. The upper portion consists of grayish white sand having platy cross bedding with a strike of 295°∠35°, and a fine bedding ranges 4—5 cm thick with normal rhythm. The lower layer is grayish brown gravel, 20—45 cm in diameter, considered to be a lag deposit, distributed along the wavelet scour surface at the layer bottom. Within the gravel layer are large mud boulders with quartzite and granite fragments with a diameter of 2—4 cm, and carbonate nodules. Tree trunks are commonly preserved in the sand-gravel layer. We collected one trunk from 0.8 m above the layer bottom and extracted wood cellulose for AMS dating at the University of Arizona, USA. The age achieved was (17 025±170) aBP. A sample of mud boulder from 0.8 m below the wood trunk provided an organic fraction ^{14}C age of (18 600±145) aBP. (9) A layer of grayish white sand intercalated with gravel containing mud boulders, 1.92 m thick, above the bottom levels. Mammalian fossils such as *Bubalus youngi*, *Paleoloxodon naumanni*, *Cervus nippon hortulorum*, and *Equus hemionus* were excavated from the mid part of the layer. Calculations based on sedimentation rate provides an estimation of the age of the fossils at about 19 900 aBP. It places the existence of mammalian fossils within the period of the LGM. Pollen analysis shows that the vegetation cover for this period was mainly characterized by herb (*Artemisia* and Chenopodiacia), with a certain amount of wood pollen having *Pinus*, *Abies*, *Picea* (the latter two are 7.0%—24% and 3.0%—5.4% respectively). This is a further indication that the cold-dry winter monsoon was punctuated by a cool and wet fluctuation in East Asia during the LGM.

2 The climate and environment record from mammalian fossils

A large number of mammalian fossils were excavated from the sand pits, with major examples being *Paleoloxodon naumanni*, *Equus hemionus*, *Coelodonta antiquitatis*, *Cervus nippon hortulorum*, *Ovis* sp, *Bubalus youngi*, and *Bos primigenius*. Examination of fossil color, degree of fossilization, fossil features and the surrounding sediment indicate that the mammalian specimens have been very well preserved and are typical of Late Pleistocene fauna in North China. Analysis of available samples collected indicates no *Mammuthus*, but *Paleoloxodon naumanni* in Proboscidea fossils. Hence the mammalian assemblages do not belong to the typical *Mammuthus*-*Coelodonta* faunal suite, but to the *Paleoloxodon*-*Coelodonta* faunal suite. A significant difference existed between the eastern and western sides of North China during the late stage of the Late Pleistocene, with the boundary being at about 116°E. The major difference shows Proboscidea consisting mainly of *Mammuthus* to the east of 116°E, and mainly of *Paleoloxodon* to the west. This difference was caused by a climate and environment contrast between east and west of 116°E, which is further reinforced from spore pollen results. Because *Mammuthus* is an animal associated with the tundra zone, the association of *Mammuthus* with *Coelodonta antiquitatis* during the Late Pleistocene has been regarded as an indicator of a cold climate and environment[4]. However, in China, *Coelodonta antiquitatis* had a wider distribution than *Mammuthus*. In addition to the association with *Mammuthus*, *Coelodonta antiquitatis* is also associated with *Paleoloxodon naumanni*, which had quite a different ecological typology. In this sense, *Coelodonta antiquitatis* in China can be considered to have a wider ecological suitability. *Mammuthus primigenius* in China is limited to the northeastern area and neighbouring Wulumuqi, occasionally reaching Shandong Peninsula. While *Coelodonta antiquitatis* is distributed over the whole of North China, even in Aarba , western Sichuan Province. In addition to Northeast China and the Xinjiang Uighur Automonous Region, the association of *Coelodonta antiquitatis* means *Paleoloxodon* among Proboscidea. The *Paleoloxodon* of the Late Pleistocene in North China is mainly *Paleoloxodon naumanni*, which is normally associated with warm and wet forest environments, based on analysis of *Paleoloxodon's* sructure, geographical distribution, and similar features with similar European fauna during the same period, living under an interglacial forest environment.

Mammalian assemblages from the Xianyang sand pit, together with Late Pleistocene fauna from Shalawusu and Huanxian-Qingyang areas, belong to the *Paleoloxodon*-*Coelodonta* faunal suite. However, Xianyang fauna contains *Cervus nippon hortulorum*, which prefers a warm-wet forest or grassland with forest margin environment, together with *Bubalus youngi*, that was also discovered at Mengxian County, Henan Province. The examples mentioned above reflect a cool and wet living environment with more water and forest, corresponding to relatively warm and wet or cool and wet conditions within the glacial period.

3 Discussion

From climate and environment reconstructions aided by Xianyang faunal data, we postulate a dominant summer monsoon precipitation increase event within a background of global cooling in East Asia during the LGM (20 000 ka). The climate would have been favorable to the existence of *Paleoloxodon*-*Coelodonta* fauna. This concept is further substantiated by pollen data from Layer 9. *Abies* and *Picea* are 7.0%—24.2% and 3.0%—5.4% respectively. If the sum of *Abies* and *Picea* became more than 20%, it would be expected that sparse *Abies* and *Picea* forests existed in the area during that time[3]. The timing of the precipitation increase event can be correlated with the Heinrich 2 (H2) event[5]. After this period, the climate returned to cold and dry winter monsoon dominance typical of the LGM. Because of the severe cold and dry conditions, a large number of mammalian fauna were not able to withstand the environment change and died out. Because of the degree of preservation of fossils, we can presume that water energy conditions at that time were relatively weak, hence the faunal remains stayed within the river course. From a geomorphological point of view, we suggest that the sand gravel layer containing mud boulder was produced by a cold and dry climate and environment. Frost weathering and arid disintegration were strong, and vegetation cover was scattered under the cold and dry conditions. Both banks of the river would have been susceptible to collapse thus providing clastic materials caused by small water volume and a large river loading. This would happen particularly in small rivers (for example, the Weihe River and its tributary) which are susceptible to overload or overload saturation. Downcutting would have decreased and accretion accumulation occurred. Trimming and widening of the river valley occurred, causing a collapse of mud from the river bank, producing boulder clay via short distance transportation.

The Early Holocene climate recorded in the profile is representative of cold and dry conditions, with grassland together with deposition of sand gravel containing boulder clay. The Late Holocene is characterized by the resumption of river downcutting and deposition of eolian sediments; at the same time, water and temperature conditions were favorable to blackloam development. Wood pollen occupied 63.4% of the total pollen, reflecting warm and wet climate conditions. However, there were periodic cold and dry fluctuations within the warm-humid Late Holocene climate.

Various geological and biological records from inland China indicate that during the LGM, there was desert expansion, rapid deposition of loess, shrinkage of arid-semi arid lakes, mountain glacial advance, and permafrost conditions. The tundra and steppe belt advanced southeastward 8^{o} further in latitude than the present and the coastline retreated eastward 800—1 000 km compared with the present position. Annual temperatures in central and eastern China were 10—12℃ lower than those of the present day[1]. Paleobiological records for this study suggest that the LGM was not a continuous cold and dry period, but was punctuated by cool and wet periods, similar to those indicated for Heinrich events, discussed in recent studies, and characterized by global precipitation trends. For example, humid events reflected by *Pinus* pollen from Lake Tulane in Florida, USA correlate well with H1-H5[6], because the Gulf of Mexico region is influenced by trade winds, producing a wet environment with high precipitation. Cold and wet events found in the Chinese Zhujiang River outlet and the South China Sea provide a good correlation with the H1 event[7]. Yao Tandong suggested that the temperature change of last glacial maximum ranges from 3 to 7℃ from Guliya ice core, reflecting the frequent fluctuations of glacial climate[8]. Porter and An proposed the correlation of winter monsoon strengthening events with H1-H6 on the basis of grain size analysis of Luochuan sequences from Loess Plateau[9]. Based on the above evidence, global climates have not completely followed the cold and dry pattern indicated by Heinrich events. Because of the interaction between south and north polar cold sources, ocean thermal circulation and the atmosphere, some places reflect cold and dry, others reflect wet-cool, and still others reflect an interalteration of cold-dry with cool-wet conditions. A spacial variation study of the same global event can only be carried out when more reliably dated material becomes available. The cool-wet fluctuation from the Xianyang profile within the LGM sequence correlates with H2, indicating a fingerprint of the high latitude Heinrich event in the southern Loess Plateau. The precipitation increase of east Asian monsoon during the LGM may be related to an interaction of the cold airmass from high latitudes with warm moist air from the low latitude tropical oceans[10]. We believe that our understanding will be improved with more data available.

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