Vegetation and climate change in the Beijing plain during the last million years and implications for Homo erectus occupation in North China

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ABSTRACT

Beijing is of great significance in human evolution studies. However, the lack of well-dated records of climate and environmental changes, which are frequently cited as important drivers of early human evolution, impedes understanding of the evolution and dispersal of humans on the Beijing plain. A 150-m deep drill core was collected from the Changping District of the Beijing plain to reconstruct the changes in vegetation and climate during the Middle Pleistocene using pollen records. The results indicated that the tree genus Ulmus and the herb genus Artemisia were dominant in most of the samples from 0.96 to 0.61 Ma, reflecting an open forest steppe covering the Beijing region. Between 0.61 and 0.44 Ma, the vegetation communities shifted to an Artemisia-steppe as the tree cover declined. This was followed by a further shift in vegetation community structure to a Chenopodiaceae-Asteraceae steppe between 0.44 and 0.23 Ma, followed by the conversion to an Artemisia-Asteraceae steppe after 0.23 Ma. The pollen record revealed a long-term deterioration of the vegetation, which indicated an increasing trend of drying and cooling in the Beijing plain during the Middle Pleistocene. This coincides with the Homo erectus colonization of North China during this period. These findings provide supporting evidence that a shift in climate towards cold and dry conditions during the Middle Pleistocene may have directly benefited Homo erectus populations in open habitats of North China. This general pattern of declining vegetation cover in the study area is consistent with climatic and environmental patterns in other regions of North China, which were probably influenced by global cooling during the Middle Pleistocene.

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1. Introduction

The Beijing plain is located in the northwest region of the North China Plain and its environment is influenced by the East Asian Monsoon circulation (Fig. 1a). Beijing is of great significance in human evolution studies. Fossils attributed to Homo erectus (often referred to as “Peking Man”) and plentiful evidence of hominin habitation, including quartzite flakes and choppers, burnt bones, abundant vertebrate fossils and possible ash from fires (Jia, 1980), attest to the occupation of this region during the Middle and Late Pleistocene periods (Wu and Dong, 1985). Climate change is commonly considered an important driver of hominin evolution and dispersal patterns (deMenocal, 1995, 2004; Potts, 1996; Maslin and Christensen, 2007). Thus, in an attempt to better understand the local climate and habitat in which early humans lived, many paleoclimatological studies have been performed at the “Peking Man” site (Wu et al., 1985; Zhu and Zhou, 1994; Goldberg et al., 2001). However, there are significant disagreements concerning the colonization and living environment of H. erectus in this region. Previous studies postulated that H. erectus lived in the glacial age (MIS 16) (Ji, 1989), the interglacial age (MIS 15) (Kong et al., 1981, 1985), or during both of these periods (Liu and Wang, 2004). The climate and vegetation transition of the Middle Pleistocene may play an important role in determining the colonization of H. erectus. Zhang and Tang (2007) synthesized the paleoarchaeological and paleoenvironmental records of the Peking Man site and indicated that the proportions of silicovorous mammals were similar to those of steppe mammals in layer 11 (about 0.66 Ma), showing a forest–steppe–climate pattern. Next, in layer 7 (about 0.41 Ma), the vegetation type changed to shrub-steppe. Moreover, Wang et al. (1997) stated that the relatively “cold-climate-adapted” Paleoarctic fauna were not found until the time of the Chenjiawo (0.65 Ma) and Zhoukoudian (0.5 Ma) hominid relics. However, previous studies only focused on the fossil strata (Kong et al., 1985; Wu et al., 1985; Zhu and Zhou, 1994); therefore, there is currently a lack of both a well-dated and a consecutive record linking hominin habitat in this region to long-term changes in underlying climatic conditions. Such climatic records are crucial in the...
continued development of our understanding of the evolution and dispersal of early humans on the Beijing plain.

In the present study, a 150-m drill core was collected from the Changping District of the Beijing plain (40.8° 22.6′ N, 116.12° 17.1′ E) for pollen analyses. The pollen record obtained from the fluviolacustrine sedimentary archives provides important information on regional vegetation that can be used to infer climate changes in North China during the Middle Pleistocene. Such paleoclimatic information is crucial for gaining a comprehensive view of the East Asian Monsoon circulation in North China that can be used to test key theories of early human evolution and expansion in East Asia.

2. Climate and vegetation of the Beijing plain

The study area is located in the northwest region of the North China Plain, in the warm temperate and semi-humid continental monsoonal zone. The current regional climate (mean annual temperature of 11.6 °C; average annual rainfall of 585 mm; and mean evaporation of 2080 mm) is characterized by cold and dry winters due to the influence of the East Asian winter monsoon that emanates from high-latitude areas. In contrast, the summers are relatively warm and humid under the influence of the East Asian summer monsoon (the rainfall in summer accounts for 75% of the total annual rainfall) (Fig. 2). Under these climatic conditions, the zonal vegetation is warm temperate deciduous broad-leaved forest and grassland. In the flat area, the vegetation is mainly composed of north temperate elements featuring species of the families Asteraceae, Poaceae, Fabaceae, Rosaceae, Ranunculaceae, Apiaceae, and Brassicaceae. Other taxa include Eurasia steppe elements such as Tribulus terrestris, Salsola collina, Tamarix chinensis, and Suaeda glouca. The flora of the surrounding mountains is divided into three groups with respect to altitude. Below an altitude of 800 m, the scrub-grassland of the Verbenaceae and Rosaceae families dominate the area. The original species, such as Quercus variabilis, Pinus tabulaeformis, and Platycladus orientalis, appear sporadically. From 800 to 1000 m, the vegetation is dominated by Quercus liaotungensis, Pinus tabulaeformis, as well as scrubby Betula platyphylla and Betula albo-sinensis. Over 1000 m, the original species was Larix principis-rupprechtii and Picea, but currently, it is mainly shrubs of Salix caprea, Syringa wolffi, Lespedeza bicolor, Corylus, and Spiraea (Compilatory Commission of Vegetation of China, 1980).

Fig. 1. a. Map of China and the study sites; b. Digital elevation map of the Beijing plain; c. Vegetation map showing the location of the studied drill core (Revised from the Compilatory Commission of Vegetation of China, 1980).
3. Materials and methods

A 150-m deep drill core was collected from the Changping region of the Beijing plain (40.8° 22.6′ N, 116.12° 17.1′ E) in 2012. The lithology of the core is mainly composed of layers of blackish-gray and grayish-yellow clay, silty-clay, silt, and a clay/silt layer with a few fine, coarse sand, and gravel layers. In general, the sediments of the core show an alternating sequence of sand and clay-dominated layers (Zhang et al., 2012; Cai et al., 2014).

Prior to laboratory analysis, the core was sub-sampled at 5 cm intervals. A total of 568 oriented block samples were collected at intervals of 20–25 cm for paleomagnetostratigraphic study. The magnetostratigraphic results indicate that the Brunhes/Matuyama boundary is at 134.2 m (0.78 Ma), and the top of the Jaramillo event is at 145.5 m (0.99 Ma) (Fig. 3). The thermoluminescence (TL) age of the upper sand at ~2 m is 10.4 ka (Zhang et al., 2012; Cai et al., 2014). Thus, the ages of the Changping core span from ~0.01 Ma (TL results) to 1.07 Ma (extrapolation of magnetostratigraphic dating). Depth-to-age correlations were performed between the main magnetic polarity boundaries and the TL date using average sedimentation rates.

A total of 235 samples were collected at 0.5~1.5 m intervals for pollen and spore analysis. The preparation procedures follow those described by Moore et al. (1991). In brief, 50–150 grams of samples were treated with 10% HCl and 39% HF to remove carbonates and silica, respectively, and 10% KOH to remove humic substances. The samples were then subjected to heavy liquid floatation (gravity between 1.8 and 2.0) followed by mounting in glycerin jelly before microscope examination. All samples were studied at The Capital Normal University (Beijing, China). Palynomorph identification was aided by the reference texts of Song et al. (1999) and others (Xi and Ning, 1994; Wang et al., 1995). Of the 235 total samples, 108 contained more than 100 pollen grains and therefore had a sufficiently high palynomorph content and diversity for subsequent interpretation of floral community structure. The terrestrial sum of the tree, herb and shrub taxa in each pollen spectrum was taken as 100% for calculating the pollen percentages.

4. Results

Approximately 81 species were identified in the core, mainly nonarboreal taxa including Artemisia, Chenopodiaceae, Asteraceae, Rosaceae, Ranunculaceae, Urtica and Ephedra. The main arboreal taxa were Pinus, Ailms, Corylus, Juglans, Pterocarya, Betula, Carpinus, Ulmus and Quercus, as well as other elements with low percentages. The main families and genera are shown in the pollen diagrams (Fig. 4). The pollen assemblage is characterized by a high percentage of herb and shrub taxa (average 95.5%) and a low percentage of tree taxa (average 4.5%). Artemisia (average 74.9%), Chenopodiaceae (average 12.0%) and Asteraceae (average 5.1%) dominate the pollen assemblages throughout the whole sequence. Most of the tree pollen taxa comprise <1.0% and some occur only in traces. The pollen concentration varies from 8.6 to 5528.4 grains/g. The ratio of arboreal pollen (AP) to nonarboreal pollen (NAP) ranges between 0 and 0.7. Based on variations in the abundance of the dominant taxa and the AP/NAP ratios, the following pollen zones were determined (Fig. 4).

4.1. Zone I (~0.96–0.61 Ma; depth: 145–102 m)

In this zone, arboreal pollen taxa, mainly derived from Ulmus, Quercus, Pinus, Corylus, Betula and Juglans, account for 0–30.5%. Pinus constitutes 0–4.9% (mean of 1.3%), while Ulmus fluctuates between 0 and 15.2% (mean of 5.5%) and Quercus ranges between 0 and 8.5% (mean of 1.7%). Other temperate deciduous broadleaved tree species...
including Juglans, Alnus, Corylus and Betula are present in most samples in this zone. The nonarboreal pollen percentages are the lowest in the whole sequence (59.0–100%, average of 88.1%). Artemisia, Chenopodiaceae, and Urtica constitute 29.0–97.1% (average of 70.0%), 0.8–24.5% (average of 8.7%), and 0–19.5% (average of 4.3%), respectively. Rosaceae and Asteraceae occur in moderately high percentages (each averaging 2.4%). Other mesic and arid herbs appear with low and erratic percentages, including Poaceae, Ephedra, Ranunculaceae, Brassicaceae and Apiaceae. The AP/NAP ratio ranges between 0 and 0.7 with an average of 0.2 (Fig. 4).

4.2. Zone II (~0.61–0.44 Ma; depth: 102–76 m)

This zone is characterized by markedly lower values of arboreal taxa (0–14.8%, average of 5.1%) and a steady increase in nonarboreal taxa (85.0–100%, average of 94.9%). Broadleaved taxa including Ulmus, Quercus, Betula and Juglans show a sharp decline and almost disappear. However, Corylus is present and exhibits high numbers (0–14.8%, average of 7.8%) over the period from 0.47 to 0.48 Ma. Meanwhile, the proportion of the shrub taxon Rosaceae also displays a remarkable decrease to 0–1.3% (average of 0.17%). The pollen of nonarboreal taxa including Artemisia (average of 82.7%) and Asteraceae (average of 3.8%) displays a remarkable increase compared with Zone I. Other mesic pollen including Poaceae and Urtica decreased and only occur in two samples within this zone. The AP/NAP ratio decreases and ranges between 0 and 0.18 with an average of 0.06 (Fig. 4).

4.3. Zone III (~0.44–0.23 Ma; depth: 76–40 m)

This zone is characterized by an abrupt increase in Chenopodiaceae and Asteraceae in comparison with the preceding zone II; the former ranges from 0 to 72.7% (average 22.1%) and the latter from 0 to 47.5% (average 6.0%). Artemisia markedly declines to 14.3–37.2% of the total pollen, with an average of 29.5%. Other mesic herbs and shrubs including Urtica (average of 4.0%), Poaceae (average of 0.2%) and Rosaceae (average of 0.4%) show a slight increase in this zone. There is a gradual decline in arboreal taxa (0–12.6%, average of 3.5%). The levels of tree pollen in this zone, including Betula, Alnus and Quercus, are slightly lower compared with Zone II and comprise less than ~1%. The AP/NAP ratio decreases and ranges between 0 and 0.14 with an average of 0.04 (Fig. 4).

4.4. Zone IV (0.23–0.01 Ma; depth: 40–0 m)

The most striking feature of this zone is an abrupt increase in Artemisia (average of 77.9%), whereas Chenopodiaceae declines to 10.2%. Asteraceae continues to increase and reaches its maximum average percentage (6.3%). The other mesic herb and shrub taxa, including Rosaceae and Urtica, maintain their trend of a gradual decrease. Tree pollen taxa continue to decline and reach the lowest average (2.3%) within this zone. Betula, Alnus, Juglans, Ulmus and Quercus occasionally appear and show a slight decline compared with Zone III. The AP/NAP ratio ranges between 0 and 0.12, reaching the lowest average (0.03) in this section (Fig. 4).

5. Discussion

5.1. Vegetation history and paleoclimate trends

According to modern surface pollen studies, Chenopodiaceae and Artemisia pollen taxa are generally over-represented relative to parent plants present in the vegetation (El-Moslimany, 1990; Ma et al., 2008). Small amounts (~30%) of arid Artemisia and Chenopodiaceae are usually regarded as being derived from exotic sources because of their high productivity (Li and Yan, 1990). Pinus is often over-represented in pollen records because of its high pollen production and long-distance dispersal. A percentage of Pinus less than 30% in the pollen spectrum is generally regarded as exotic and likely to have originated from surrounding mountains (Denton and Karlen, 1973; Li and Yao, 1990; Wang et al., 1996). Percentages of Betula, Ulmus, and Poaceae pollen over 2.5%, 2%, and 3–6%, respectively, suggest that they exist in the vicinity (Tong et al., 1996; Zhao et al., 1998). Based on the distribution patterns of modern vegetation in the Beijing plain, the sporopollen spectra in the fluvo-lacustrine sediments record all communities in the plain and surrounding mountains (Vegetation Map Fig. 1c). We can expect that xeromorphic and mesic herbs such as Chenopodiaceae, Asteraceae, Artemisia, Urtica, Poaceae, Ranunculaceae, Brassicaceae and Apiaceae grew on the plain. Deciduous trees and shrubs such as Ulmus, Betula, Alnus, Quercus, Juglans and Rosaceae likely grew on the middle slope of the surrounding mountains, while Picea and perhaps Pinus were present on higher slopes of the surrounding mountains. Thus, the pollen record from the plain deposits is a plausible reflection of the evolution of the regional vegetation.

Temperature and humidity are the two most useful basic parameters for understanding the paleoclimate pattern of the East Asian Monsoon (Nie et al., 2013, 2014). In general, broadleaved trees, such as Ulmus, Betula, Alnus, Quercus and Juglans, indicate relatively warm conditions in a study area (warm temperate). Thus, the variation in the percentages of broadleaved trees may reflect temperature changes (Hilbig, 1995; Cai et al., 2013). The ratio of arboreal pollen (AP) to nonarboreal pollen (NAP) is used to indicate the density of tree cover. High values of the herbaceous taxa compared with the arboreal taxa are usually regarded as a proxy for dry conditions (White et al., 1997a,b; Wu et al., 2011; Cai et al., 2012). The zonation of sporopollen diagrams and index records in this paper show clear vegetation change and a
long-term drying/cooling trend on the Beijing plain since the Middle Pleistocene.

The high percentages of *Ulmus*, *Quercus*, *Rosaceae*, *Pinus* and *Juglans* as well as the significant representation of *Artemisia* from ~0.96 to 0.61 Ma (zone I) indicate that deciduous broadleaf forest-steppe dominated the Beijing plain. The precipitation was high during this period according to the AP/NAP ratio values. The higher percentages of broadleaved trees and the AP/NAP values suggest that the climate was optimal for vegetation during the period from 0.96 to 0.01 Ma. According to the pollen diagram, we infer that an *Ulmus-Artemisia* open forest-steppe environment with a mild and relatively wet climate existed during the period from ~0.96 to 0.61 Ma. Subsequently, the vegetation between 0.61 and 0.44 Ma (zone II) was very different. The highest percentage of deciduous broadleaf forest-steppe existed during the period from ~0.96 to 0.61 Ma. Liu and Wang (2004) recovered *Homo erectus* fossils from the cave deposits in Tangshan, Nihewan, and Zhoukoudian, as well as the deposits at the *Homo erectus* site in Chjenjiawo. They found that the *Homo erectus* in all of these sites originated from the Early-Middle Pleistocene and flourished in MIS 16 (0.6 Ma) and the major interglacial period of the paleosol stage SS (0.5 Ma). Using the cosmogenic 26Al/10Be method, Shen et al. (2009) obtained an age of Zhoukoudian *Homo erectus* appearance that is in the range of 0.68–0.78 Ma. The other early human records from Chjenjiawo and Congwangning of North China also show that *Homo erectus* appeared at approximately 0.65 Ma (Wang et al., 1997). Some studies indicated that early human evolution was significantly moderated by climate and environmental changes (Vrba et al., 1995; deMenocal, 2004; Maslin and Christensen, 2007). The relationship between climate and human evolution seems intuitive and indeed, environmental factors have been suggested as a driving force in hominin evolution by many authors (Vrba, 1985; Potts, 1996, 1998, 2013; Kingston, 2007; Maslin et al., 2014). Long-term shifts in climate can result in extreme and inconsistent environmental variability, which results in the selection of behavioral and morphological mechanisms that enhance adaptive variability. Most environmental hypotheses of hominin

![Fig. 5.](image-url)
evolution are ‘habitat-specific’ in that they consider that fauna adapt to a specific environment (Maslin et al., 2014). The increased cooling and drying climate may have caused a change in the vegetation type, which would have had a strong impact on faunal distributions (Potts, 1998). Therefore, intensified aridification/drying in North China would reduce tree cover and result in more open savanna grasslands, which may have promoted a prominent flourishing of savanna-adapted early humans (Ao et al., 2010; Fig. 5g). The records from our core, the Tianzhu core (Yao et al., 2007) and the X5core (Jiang et al., 2013; Fig. 5e), both indicate a vegetation transition on the Beijing plain from forest-steppe to steppe at ~0.6 Ma. The δ13C values of deer enamel from the Zhouchouan site show behavioral changes in the deer at ~0.55 Ma, which could be due to the vegetation shift to steppe (Gaboardi et al., 2005, Fig. 5f). The Chenjiawo hominids occupied an environment similar to that of the Gongwangling where the vegetation changed to a mixture of forest and steppe approximately 0.65 Ma ago (Wang et al., 1997). Moreover, the relatively ‘cold-climate-adapted’ Paleoarctic fauna were not found until the time of the Chenjiawo (0.65 Ma) and Zhouchuan (0.5 Ma) hominid relics (Wang et al., 1997). These results indicate that the vegetation and climate in North China experienced transitions during the Middle Pleistocene, where the cold and dry climate produced an abundance of open forest steppe instead of forest (Yuan et al., 1996; Wu et al., 2004; Jiang et al., 2013). This open forest steppe framework between 0.96 and 0.61 Ma may have provided a general setting for early human evolution. Early humans started to acclimatize themselves to a dryer and colder climate in North China (Shen et al., 2009). Then, after 0.61 Ma, the open forest steppe-adapted Homo erectus experienced a prominent flourishing with population growth and migration. Thus, the cold and dry climate during the Middle Pleistocene may have enhanced the occupation and flourishing of Homo erectus populations in open habitats of North China.

As shown in Fig. 5, the long-term decline in the AP/NAP and CIA ratios reflects a decrease in vegetation cover and chemical weathering in the Beijing plain. This is broadly consistent with the long-term cooling trend depicted in the benthic δ18O record (Lisiecki and Raymo, 2005, Fig. 5j) during the Middle Pleistocene. The global cooling induced a weakening of the East Asian Summer Monsoon (EASM), which transports moisture to North China from the Pacific Ocean (Passey et al., 2009; Miao et al., 2012, 2013). Thus, our result suggests that the long-term drying of the Beijing plain since the Middle Pleistocene might have been caused by long-term global cooling. Additional detailed long-term vegetation and climatic records from North China are needed to decipher the major forcing mechanisms of vegetation and climate change and the impact of these changes on Homo erectus colonization throughout the Middle and Late Pleistocene.

6. Conclusion

Pollen analysis of the core from the Beijing plain was used to create a high quality paleo-vegetation record during the Middle Pleistocene. The pollen record suggests that an open forest steppe dominated by Ulmus and Artemisia covered the Beijing region from 0.96 to 0.61 Ma. The vegetation changed from Artemisia-steppe between 0.61 and 0.44 Ma to Chenopodiaceae-Asteraceae steppe between 0.44 and 0.23 Ma, and then to Artemisia-Asteraceae steppe after 0.23 Ma. The change in the vegetation indicates an increasing trend of drying and cooling in the Beijing plain during the Middle Pleistocene. This coincides with the Homo erectus colonization of North China during this period. The vegetation transition and cold and dry climates during the Middle Pleistocene may have enhanced the colonization and flourishing of Homo erectus populations in open habitats of North China. This general pattern of declining vegetation cover in the study area is consistent with climatic and environmental patterns in other regions in North China, which were probably influenced by global cooling during the Middle Pleistocene.

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References

Ao, H., Deng, C.L., Dekkers, M.J., Sun, Y.B., Liu, Q.S., Zhu, R.X., 2010. Pleistocene environmental evolution in the Nihewan Basin and implication for early human colonization of North China. Quat. Int. 223–224, 472–478.
Cai, M.T., Fang, X.M., Wu, F.L., Miao, Y.F., Appel, E., 2012. Pliocene–Pleistocene stepwise drying of Central Asia: evidence from paleomagnetism and sporopollen record of the deep borehole SG-3 in the western Qaidam Basin, NE Tibetan plateau. Glob. Planet. Change 94, 72–81.
Cai, M.T., Wei, M.J., Xu, D.N., Chen, Y.F., Wu, F.L., Pan, B.L. 2013. Vegetation and climate changes during three interglacial periods represented in the Luochuan loess-paleosol section, on the Chinese Loess Plateau. Quat. Int. 296, 131–140.
Cai, M.T., Wei, M.J., Yang, Y.B., Wang, J.P., Xu, D.N., 2014. Long-term cooling/drying record of North China since the Middle Pleistocene from geochemical evidence of a 150 m deep drill core, Beijing plain, China. Quat. Int. 349, 419–427.
Cande, S.C., Kent, D.V., 1995. Revised calibration of the geomagnetic polarity timescale for the Late Cretaceous and Cenozoic. J. Geophys. Res. 100, 6093–6095.
Champion, D.E., Lanphere, M.A., Huntz, M.A., 1988. Evidence for a new geomagnetic reversal from lava flows in Idaho: discussion of short polarity reversals in the Brunhes and late Matuyama polarity chronos. J. Geophys. Res. 93, 11667–11680.
Compilatory Commission of Vegetation of China. 1980. Vegetation of China. Science Press, Beijing. pp. 932–955 (in Chinese).
deMenocal, P.B., 1995. Plio-Pleistocene African climate. Science 270, 53–59.
deMenocal, P.B., 2004. African climate change and faunal evolution during the Pliocene–Pleistocene. Earth Planet. Sci. Lett. 220, 3–24.
Denton, G.H., Karlen, W., 1973. Holocene climatic variations—their pattern and possible cause. Quat. Res. 3, 155–205.
Ding, Z.L., Derbyshire, E., Yang, S.L., Yu, Z.W., Xiong, S.F., Liu, T.S., 2002. Stacked 2.6Ma grain size record from the Chinese loess based on five sections and correlation with the deep-sea d18O record. Paleoceanography 17, 1033. http://dx.doi.org/10.1029/2001PA000725.
El-Moslami, A.P., 1990. Ecological significance of common nonarboreal pollen: examples from drylands of the Middle East. Rev. Palaeobot. Palynol. 64, 343–350.
Gaboardi, M., Deng, T., Wang, Y., 2005. Middle Pleistocene climate and habitat change at Zhouchuan, China, from the carbon and oxygen isotopic record from herbivore tooth enamel. Quat. Res. 63, 329–338.
Goldberg, P., Weiner, S., Bar-Yosef, O., Xu, Q.Q., Liu, J.Y., 2001. Site formation processes at Site 26, 1065–1067 (in Chinese).
Hilbig, W., 1995. The Vegetation of Mongolia. SPB Academic Publishing, Amsterdam, pp. 236–238.
Ji, H.X., 1989. Geographic distribution and environment of mammal fauna. In: Shi, Y.F., ed., The Vegetation of Mongolia. SPB Academic Publishing, Amsterdam, pp. 236–238.
Jiang, H.C., Guo, G.X., Cai, X.M., Xu, H.Y., Ma, X.L., Zhong, N., Li, Y.H., 2001. Pollen record of the Mid-Pleistocene transition from Beijing, North China. J. Quat. Sci. 28 (7), 720–728.
Kingston, J.D., 2007. Shifting adaptive landscapes: progress and challenges in reconstructing early hominin environments. Am. J. Phys. Anthropol. Suppl. Yearb. Phys. Anthropol. 134 (Issue Suppl. 45), 20–38.
Kong, Z.C., Wu, Q.J., Wu, Y.S., et al., 1981. Discussion on the evolution of natural environment around the Sinanthropus’ living period based on pollen analysis. Chin. Sci. Bull. 26, 1065–1067 (in Chinese).
Kong, Z.C., Wu, Q.J., Wu, Y.S., et al., 1981. Discussion on the evolution of natural environment around the Sinanthropus’ living period based on pollen analysis. Chin. Sci. Bull. 26, 1065–1067 (in Chinese).
Kong, Z.C., Wu, Q.J., Wu, Y.S., et al., 1981. Discussion on the evolution of natural environment around the Sinanthropus’ living period based on pollen analysis. Chin. Sci. Bull. 26, 1065–1067 (in Chinese).
Langerer, C.G., Dekkers, M.J., de Lange, C.J., Paternie, M., Santvoort, P.J.M., 1997. Magnetostatigraphy and astronomical calibration of the last 1.1 Myr from an eastern Mediterranean pine core. Geochem. Geophys. Geosys. 350.
