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, impede 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 hominid 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 archaeological and paleoenvironmental records of the Peking Man site and indicated that the proportions of silvicolous 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 hominid habitat in this region to long-term changes in underlying climatic conditions. Such climatic records are crucial in the

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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](#)).

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 fluvio-lacustrine 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 glauca*. 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 wolfii*, *Lespedeza bicolor*, *Corylus*, and *Spiraea* ([Compilatory Commission of Vegetation of China, 1980](#)).

Fig. 2. Mean monthly temperature and precipitation data collected from a Beijing climate station over the period from 1971 to 2000.

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*,

Fig. 3. Lithology and magnetostratigraphy of the Changping core sequence adapted from Cai et al. (2014), in which magnetostratigraphy of the core is correlated with the Geomagnetic Polarity Timescale (GPTS; Cande and Kent, 1995). Events/excursions in the Brunhes Chron are shown according to Champion et al. (1988); Worm (1997); Langereis et al. (1997); and Laj and Channell (2007).

Rosaceae, Ranunculaceae, *Urtica* and *Ephedra*. The main arboreal taxa were *Pinus*, *Alnus*, *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

Fig. 4. Pollen percentage diagrams of the Changping core showing selected taxa and indices. (AP: arboreal pollen; NAP: nonarboreal pollen).

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 pollens 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 their 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 been 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 fluvio-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 *Artemisia* and the abrupt decrease in the AP/NAP values imply that an *Artemisia*-steppe was dominant and the climate became drier during this stage. Moreover, a decrease in the broadleaved trees suggests that temperatures synchronously fell ca. 0.6 Ma ago. From 0.44 to 0.23 Ma (zone III), the highest proportion of Chenopodiaceae and the lower percentage of *Artemisia* indicate that a Chenopodiaceae-Asteraceae steppe covered the plain. During this stage, the climate became much drier, which manifested in strong increases of xerophilous Chenopodiaceae and Asteraceae. A decreasing trend of the AP/NAP values provided further evidence of this drying pattern. From 0.23 Ma (zone IV), the Beijing plain was covered by *Artemisia*-Asteraceae steppe. The climate may have changed to colder and drier conditions since the amount of tree pollen was reduced to its minimum while herbs reached their maximum. The lowest AP/NAP values and highest percentage of Asteraceae in the core confirm this interpretation.

The trends of vegetation cover decline and long-term climate drying revealed by this pollen record were also observed in other records. The long-term decrease in chemical weathering intensity suggested by the chemical index of alteration (CIA) values from the same core supports the pollen record (Fig. 5c; Cai et al., 2014). Records from other parts of the Beijing plain also corroborate our interpretations. Through a reconstruction of the vegetation change from the X5 core of the Beijing plain, Jiang (2013) suggested a stepwise decline of vegetation cover in the study area since 0.9 Ma, which indicates that the climate changed from warm and humid to cold and dry in the Middle Pleistocene (Fig. 5e). The pollen records obtained from the Tianzhu core of the Beijing plain indicate a cooling and drying trend since 0.8 Ma (Yao et al., 2007). The $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values of deer enamel from Zhoukoudian

decreased substantially from about 0.72 Ma, which indicates a trend of climate deterioration since the Middle Pleistocene (Gaboardi et al., 2005; Fig. 5f). These results all support the inferred transition from a relatively warm and humid climate to a cold and dry climate during 0.9–0 Ma in the Beijing plain. The drying trend in North China since the Middle Pleistocene has also been reported in other sites of North and East China such as the Huanghe drainage basin (Yang et al., 2006); the Nihewan Basin (Ao et al., 2010); the Loess Plateau (Sun, 2000; Ding et al., 2002; Xiong et al., 2010); and the Yangtze River (Zhang et al., 2013; Fig. 5h, i).

5.2. Implication for *Homo erectus* occupation of North China

Fossils attributed to *Homo erectus* attest to the occupation of the Beijing plain by hominids during the Middle and Late Pleistocene (Wu and Dong, 1985). Wu (2001) suggested that the earliest age for *Homo erectus pekinensis* was 0.58 Ma BP. Shen et al. (2001) performed $^{230}\text{Th}/^{234}\text{U}$ dating of the intercalated speleothem samples from the limestone cave occupied by *Homo erectus* in Zhoukoudian, China. They suggested that the age of the hominid fossils from the lower strata is at least 0.6 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 Chenjiawo. 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 S5 (0.5 Ma). Using the cosmogenic $^{26}\text{Al}/^{10}\text{Be}$ 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 Chenjiawo and Gongwangling 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 of humans that enhance adaptive variability. Most environmental hypotheses of hominin

Fig. 5. The AP/NAP ratio, thermophilic pollen percentage, CIA values (Cai et al., 2014), and vegetation types in the Changping core and comparison with records from the Beijing X5 core (Jiang et al., 2013); Zhoukoudian (Gaboardi et al., 2005); Nihewan (Ao et al., 2010); Yangtze River (Zhang et al., 2013); and LR04 (Lisiecki and Raymo, 2005). AP/NAP: ratios of arboreal pollen to nonarboreal pollen; Thermophilic taxa: *Ulmus* + *Betula* + *Quercus* + *Castanea* + *Juglans* (%).

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/cooling 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 $\delta^{13}\text{C}$ values of deer enamel from the Zhoukoudian 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 Zhoukoudian (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 $\delta^{18}\text{O}$ 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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