Analysis of the ecological environment around 10000 a BP in Zhaitang area, Beijing: A case study of the Donghulin Site

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The transition from Paleolithic to Neolithic around 10000 a BP was a significant event in human history. We have analyzed the paleoenvironment in the Zhaitang area (Beijing) based on samples from an early Neolithic site at Donghulin. This site is considered to demonstrate the Paleolithic-Neolithic transition in this area. The site yielded burials with several human skeletons, known as "Donghulin man". We conducted a geomorphological and quaternary geological investigation in the Donghulin area, and also analyzed sediments and pollen, enabling us to discuss the living environment of the local people. Donghulin man lived mainly from 11100–9600 cal a BP; a period of warming following the Younger Dryas. The climate was good, the land was covered by dry temperate grassland, and later, wet temperate meadow steppe. "Donghulin man" usually inhabited the floodplain; this was flat, warm, and wet, with abundant plants and animals for a favorable living environment. Our research helps to rebuild the living environment of humans in the Beijing area around 10000 a BP, and to understand more about the environmental setting in north China during the Paleolithic-Neolithic transition.

"Donghulin man" was first found in 2003, in the Zhaitang Basin, 60 km from Beijing; in the area of the famous Malan loess sediments. Since 1923, many Quaternary geomorphologic and geologic investigations have been conducted in the area by geologists and geographers. Their work included research into fluvial landform evolution, loess deposition, and physiographic stages. As a result, the Zhaitang Basin became an important area in north China for research into stratal and landscape evolution during the Epipleistocene [1–7].

In 1966, Hao found some poorly-fossilized human bones and shell necklaces on the terrace 3 above the Qingshui River [8]. The Institute of Vertebrate Paleontology and Paleoanthropology of the Chinese Academy of Sciences carried out a dig, and their preliminary hypothesis was that this was a Neolithic burial site [9]. Between 2000 and 2008,

the site was excavated many times by researchers from the School of Archaeology and Museology of Peking University, and from the Institute of Cultural Relics of Beijing City. It yielded stone implements, animal bones, and early pottery, as well as ashes and fireplaces. Preliminary results again indicated that it was a Neolithic site. Two complete human bones were unearthed from coinstantaneous tombs; the past human inhabitants were named "Donghulin man". [14]C dating indicated an age of 11100–9600 cal a BP [10].

Many early Neolithic sites dating from 9000–12000 a BP have now been found in the North China area. These include the Nanzhuangtou Site in Xushui, the Yujiagou Site in Yuanyang, Hebei Province; the Donghulin Site in Mentougou, the Zhuannian Site in Huanrou, Beijing; and the Shizitan Site in Jixian, Shanxi Province [11,12]. Among these, only Donghulin includes stone artifacts, potteries, fire places, and graves. The Donghulin Site was occupied during the warm period following the Younger Dryas (traditionally the

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estimated age was 11000–10000 a BP, the latest estimated age is 12900–11500 a BP) [13–16]. This is also recognized as the transitional period between the Paleolithic and Neolithic [17]. The Donghulin Site has therefore aroused attention all over the world. We hope that our research into its paleoenvironment will be helpful in exploring the characteristics and environmental background of the cultural transition from Paleolithic to Neolithic.

In 2002, Hao researched the strata, grain size, chemical composition, spore and pollen levels, and the relative abundance of snails, in a profile near the Donghulin Site [18]. He proposed that the climate of this area was cold and dry during the Epipleistocene, and was obviously warming up before 9281±120 a BP. The average temperature of north China around 8500 a BP was probably 2–3°C higher than the present average. Hao also proposed that the descendants of "Shandingdong man" began their new life in this environment, on the terraces of the Qingshui River. Official excavation of the Donghulin Site had not yet been carried out, and the geomorphology, depositional strata and cultural characteristics were not clear; thus Hao's research can be termed a pilot study. During 2000–2008, we carried out paleoenvironmental research at Donghulin, to explore the living environment of "Donghulin man", and to understand the environmental background of the cultural transition from Paleolithic to Neolithic.

1   Geomorphological structure of the site

The site is located to the northwest of Donghulin Village, at 360 m in altitude. The Qingshui River runs to the south of the village. On a rocky hill to the south of the river are a loess plateau and three river terraces.

The loess plateau is 32 m above the riverbed, and 16–100 m in width. The surface of plateau has been transformed into artificial terraces. The front edge of the plateau is exposed with a 2–4 m high, steep profile, while the back edge joins the rocky hill. The plateau is mainly composed of Malan loess, inside of which there are two layers of paleosol. The upper layer of paleosol is 0.50 m thick, red-brown in color and dense, and has been dated to 21.05±0.41 ka BP using thermoluminescence dating (TL). The lower layer of paleosol is 0.50 m thick, red-brown in color and dense, and the TL age is 62.9±1.93 ka BP [18,19]. The top of the plateau is covered with 1–2-m-thick Holocene loess.

Below the loess plateau are three river terraces. The terrace 3 is about 30 m in width, 24 m higher than the riverbed, and is a base terrace of Malan loess. In the terrace sediments (4–5 m thick), a dual structure is clearly visible. The Donghulin Site is located on the river terrace 3, and the relics are mainly found in the river deposits that comprise this terrace (Figure 1).

2   Stratigraphy and sediments

A typical profile is the west wall of T8, in the east of the site. This is 5.86 m thick, and divided into 12 layers (from top to bottom):

1. Yellow-grey loess sediments, with loose texture and mural joint structure, including small caliche nodules. The lower sediments have paleosol layers (L_0S) formed during the Holocene.   150 cm
2. Yellow-grey silt, including a little charcoal, small gravel, caliche nodules, and also a few stone implements.   36 cm
3. Hard, brown-grey clay, with a little gravel at the bottom, and also stone implements, animal bones, and charcoal.   16 cm
4. Yellow-grey silt, including a lot of white carbonate fake fungi, a few brown lumps and small gravels (0.5 mm). No cultural remains were observed.   36 cm
5. Brown-grey clayey silt, with vertical joints, containing a lot of small gravel (1–2 cm), and relatively large limestone breccia (5–6 cm). A large number of cultural remains were recovered, including bone fragments, charcoal, snails, shells, and a few burnt soil particles. Many ash heaps and ash pits were found distributed over the surface of this layer, indicating that this was an activity surface.   60 cm
6. Yellow-brown fine sand, with small-scale oblique bedding, including a few pieces of charcoal, much tiny gravel, and large quantities of shells. There were small scale sand ridges on the top surface. This layer was without cultural remains except for a tomb (M2) near the surface.   16 cm
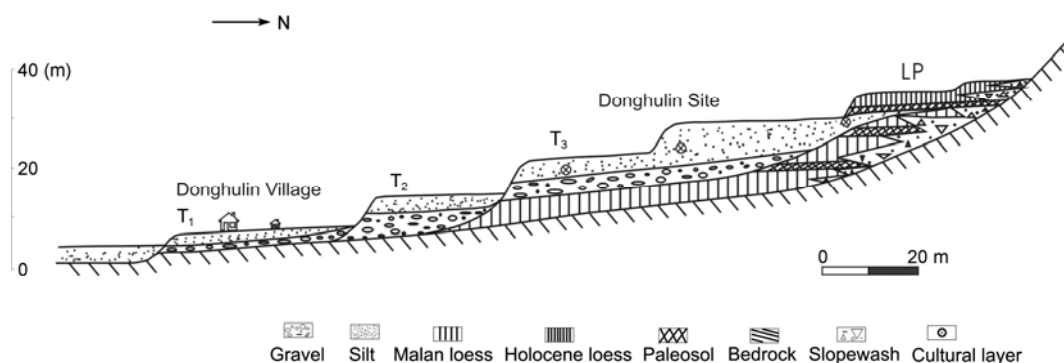

Figure 1   Geomorphological map of the Donghulin Site, Zhaitang.

7. Yellow-brown fine sand, with a little small gravel, visible but small oblique bedding, and also charcoal and a few shells. In the northern part there was an ash heap (80 cm diameter, 16 cm high) near the surface.   12 cm

8. Chocolate-brown clayey silt, including large quantities of white carbonate fake fungi, and a few rounded gravels. Cultural remains are abundant, including stone artifacts (stone saddle-quern), pottery, animal bones, human bones, shells, and charcoals. Many ash heaps (HD1–5, HD11) were found distributed across the top of this layer, indicating an activity surface.   28 cm

9. Chocolate-brown clayey silt, compact, and with locally horizontal beddings, containing large quantities of white carbonate fake fungi, a little grey-green small breccia, and caliche nodules. A few animal bones, shells, and a little charcoal were found. Some ash pits (H5), ash heaps (HD12, F2), and tombs (M1), were distributed across the top of this layer, indicating an activity surface.   56 cm

10. Yellow-brown fine sand, hard, and dark, including a large number of carbonate spots and nodules, and a little small gravel (2 mm in size).   16 cm

11. Gravel, mixed with thin pieces of clayey silt, including various types of gravel: grey-green to purple-red volcanic rock, and some limestone. These were 2–5 cm in diameter, well rounded, of grade II–III.   60 cm

12. Yellow-grey Malan loess, mixed with brownish-red paleosol. An erosion surface is obvious between this and the overlying layer, indicating the base of the terrace. 100 cm

We have concluded that layers 2–10 are river sediment comprising the terrace 3. Layer 1 is loess sediment formed in the Holocene, which has accumulated after the formation of the terrace. Layer 12 is Malan loess sediment, forming the base of the terrace.

Dating indicated an AMS ^{14}C age of 9570±70 a BP for layer 9 (at the bottom of the river sediment). The calendar age was 11090 cal a BP. The AMS ^{14}C age of layer 2 (at the top of the river sediment) was 8535±80 a BP, while the calendar age was 9560 cal a BP (Table 1). We can conclude

that the river cut down around 11090 cal a BP, and the terrace sediment formed between 11100 and 9600 cal a BP, corresponding to the warming period after the Younger Dryas. Human remains were mainly found in the terrace deposits. We chose this river sediment as the focus of our exploration of the environment of "Donghulin man". We thus collected a series of samples, carried out granularity analysis, and spore and pollen analyses in our laboratory, in the hope of gaining paleoenvironmental information.

3 Granularity analysis

Granularity analysis is an important way of researching the hydrology and landform evolution of a river. Grain size is measured and grain size frequency curves are created; dividing the sedimentary facies and microfacies of river sediment [21]. Human remains at the Donghulin Site were mainly found deposited on terrace 3, and were in different layers. As a result, we were able to speculate on the position of landforms during the different periods in which "Donghulin man" lived, and also the changing course or the river. We were thus able to explore the geomorphological paleoenvironment of "Donghulin man".

Sixty-eight continuous samples were collected from the top of layer 2 to the bottom of layer 10; the width of each sample was 4 cm, the total height sampled was 272 cm (layer 11 was river deposited gravel, so samples were not collected from this layer). A particle size analyzer (RS 1000, made by Malvern Corp. of England) was then used, grain size was examined, and frequency curves were drawn.

3.1 Grain size

We chose grain size parameters such as average size, modal particle size, median size, standard deviation, sorting

Table 1 AMS ^{14}C dating data of the profile at the Donghulin Site[a)]

Layer	Lab. No.	Material	AMS ^{14}C age (a BP)	Calendar age (cal a BP)	
				68.2% probability	95.4% probability
2	BAO7788	charcoal	8535±80	9560 (68.2%) 9440	9350 (1.1%) 9320 9700 (95.4%) 9400
3	BA05890	charcoal	8775±40	9890 (68.2%) 9690	10150 (2.3%) 10050 9950 (93.1%) 9550
4	BA02146	charcoal	8780±90	10150 (6.3%) 10050 9950 (61.9%) 9600	10200 (95.4%) 9550
5	BAO5891	charcoal	8805±50	10120 (7.2%) 10090 9920 (65.5%) 9700	10200 (95.4%) 9550
7	BA05887	charcoal	9155±40	10380 (26.5%) 10310 10300 (41.7%) 10240	10480 (1.2%) 10460 10430 (94.2%) 10230
8	BA02150	charcoal	9180±80	10480 (2.3%) 10460 10420 (65.9%) 10240	10560 (95.4%) 10220
9	BA03420	M1 human bone	9570±70	11090 (38.4%) 10920 10890 (29.8%) 10860	11170 (95.4%) 10700

a) Tested in the Chronology Laboratory and AMS Laboratory of Peking University. The half-life of ^{14}C is 5568 years. BP represents the time up to 1950. Calibration involved an IntCal04 curve [20] and OxCal v3.10 (Ramsey B. Christopher 2000 OxCal V3.5, online: http://rlaha.ox.ac.uk/orau.html).

coefficient, skewness, and kurtosis (Table 2). The grain size values obtained were coincident with field observations (Figure 2). The profile was able to be divided into two parts, with a boundary at the top of layer 8. In the lower part, layers 8–10 showed the smallest grain size and worst sorting, making a grain size cycle which was rough in the lower part and fine in the upper part, with the lower gravel layer 11. In the upper part, layers 6–7 showed the largest grain size and best sorting except for the gravel layer. However, in layers 3–5, the grain size was smaller and the particles were less well sorted; these also formed a grain size cycle which was rough in the lower part and fine in the upper part (Figure 2).

3.2 Characteristics of grain size curves

By analysis of the grain-size frequency curves and the probability curves, we were able to divide the samples into two types. Type B can be further divided into two subtypes, indicating different depositional environments [22–24] (Table 3).

Type A. Grains were coarse, and gritty. The frequency curve is bimodal and the distribution shows a positive skew. The peak grain size was 4–4.5 Φ. The coarse tail is steep, forming a low peak between −1–1 Φ; the fine tail is steep in the upper part and flat in the lower part, forming a gentle plateau between 6–7 Φ. The grain size probability curve is a three-step curve. The rolling section (−1.0–1.0 Φ) is 1%–5%, the rate of slope is large, indicating good sorting. The saltation section (1–5.0 Φ) comprises about 60%–70%, and is composed of two parts with different slope rates. This indicates a reciprocating movement in the stream. The suspension section (>5.0 Φ) is around 30%, the slope rate is small, indicating bad sorting. The high peak of the coarse tail in the frequency curve, the existence of the rolling section, and the major saltation section in the probability curve (composed of two parts with different rates of slope), indicate that the water was traveling quickly, and most of the grains underwent saltation, influenced by the reciprocating movement of the water. The two parts with different rates of slope indicate beach sediments. Type A only appears in layers 6 and 7.

Type B. Grains were fine and the major component was silty sand. The curve has unimodal distribution. Peak grain size was about 4.5 Φ. The coarse tail is steep; the fine tail is steep in the upper part (4.5–6.0 Φ) and flat in the lower part (6–10 Φ). The probability curve of grain size shows a two-step pattern. The major part is composed of a saltation section and suspension section, and does not have a rolling

Table 2 Mean grain size values

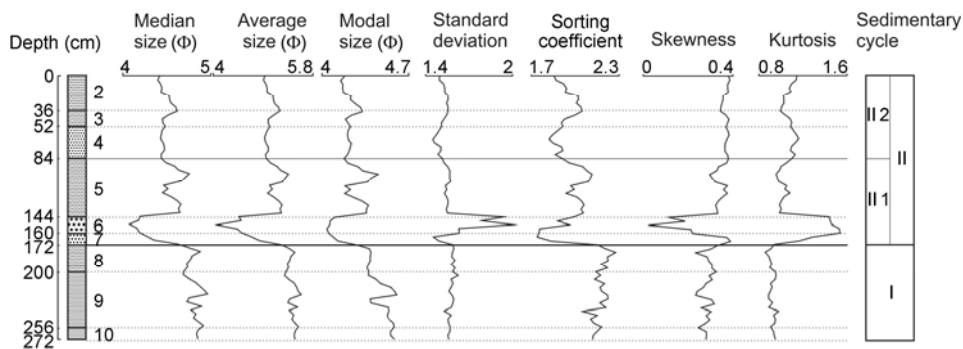| Layer	Grain size parameter							General characteristics		Grain size cycle
	Average size (Φ)	Modal size (Φ)	Median size (Φ)	Standard deviation	Sorting coefficient	Skewness	Kurtosis	Granularity	Sorting	
2	5.01912	4.20766	4.67369	1.53128	1.95551	0.36805	1.07053	smaller	worse	
3	5.06734	4.23913	4.71964	1.53330	1.97019	0.36771	1.05553	smaller	worse	II 2
4	4.96770	4.21747	4.63900	1.48669	1.87412	0.37231	1.12172	bigger	better	
5	5.15168	4.29798	4.82376	1.54811	2.02700	0.34226	1.01727	smaller	worse	
6	4.37485	4.06869	4.21382	1.83786	1.89812	0.13599	1.47155	biggest	best	II 1
7	4.68734	4.08965	4.38657	1.52564	1.77652	0.32775	1.33205			
8	5.36085	4.36688	5.05615	1.58848	2.20705	0.29438	0.90435	smallest	worst	
9	5.42561	4.4918	5.13782	1.57602	2.1585	0.28515	0.93081			I
10	5.48268	4.56683	5.21631	1.5608	2.14041	0.27187	0.93376			

Figure 2 The curve lines of grain size parameters of layers 2–10.

Table 3 Characteristics of grain size from different deposition layers

Type	Grain size frequency curve					Grain size probability curve				Layer	Depositional environment
	Kurtosis	Main peak (Φ)	Skewness	Coarse part	Fine part	Figure	Rolling section (Φ)	Saltation section (Φ)	Suspension section (Φ)		
A	two peaks	4.3 narrow	positive	steep, subpeak	leaning flat table	three-scetions	−1.0–1.0 (2%–5%)	1–5.0 (70%)	>5.0 (30%)	6–7	beach of riverbed
B1	one peak	4.5 wide	positive	steep	leaning flat	two-sections	no	2.3–5.0 (50%)	>5.0 (50%)	9–10, 5	floodplain, nearshore environment
B2	one peak	4.5 narrow	positive	steep	leaning flat table	two-sections	no	2.3–5.0 (50%)	>5.0 (50%)	4–2, 8	flood plain

section. The saltation section (2.3–5.0 Φ) is about 40%–50%, and is composed of two parts with differing rates of slope, indicating reciprocating movement. The suspension section (>5.0 Φ) is around 50%. The slope rate is small, indicating bad sorting. Because the rolling section is missing, the saltation section (composed of two parts with differing rates of slope) is equivalent to the suspension section. We therefore speculated that this part was floodplain sediment.

Type B was able to be divided into two subtypes. The frequency curve of grain size of Type B1 has a wide main peak, and the fine part forms a nicely graded curve, showing graded suspension, an indication of poor sorting and floodplain sediment (Figure 3, middle). Type B1 can usually be seen in layers 9–10 and the lower part of layer 5. The curve of Type B2 has a narrow main peak, and in the fine part there is an obvious flat part between 6–8 Φ, indicating good sorting and floodplain sediment (Figure 3, lower). Type B2 can usually be seen in layer 8, in the upper part of layer 5, and in layers 2–4.

Based on the grain size analysis and field observations, we can divide the river sediments into two parts. The lower part, from the gravel layer (layer 11) to layer 8, indicates a fluvial course of riverbed deposition (layer 11) to a nearshore deposition (layers 9–10), to farshore deposition (layer 8). The upper part, from gravel layers 7 to 2, indicates another fluvial course of beach deposition (layers 6–7), to nearshore deposition (layer 5), to farshore deposition (layers 2–4). The dating of layer 8 indicates that the boundary between the two parts was around 10500 cal a BP. The distribution of human remains shows that "Donghulin man" mainly lived during the flood plain depositional period, especially the farshore depositional period. These humans lived on the floodplain after floods had retreated, and changed their encampments as the river course and the landforms changed, probably having a semi-sedentary lifestyle.

4 Sporopollen analysis

Sporopollen analysis is able to reflect the composition and change of vegetation in a region, and hence this is an important way to explore paleoenvironment and paleoclimate.

We collected 68 samples from the bottom of layer 10 to the top of layer 2 in the north profile of grid 8 at the Donghulin Site. Each sample was 4 cm in thickness (as were the grain size samples). During sample collection, we attempted to avoid the human activity surfaces, and thus reduce the influence of human disturbance. Samples were prepared for analysis (acid-alkali chemical reactions and д-6 heavy liquid flotation [25]).

Thirty-one families and genera were identified. Woody plants were represented by 12 families or genera, including *Pinus*, Moraceae, *Quercus*, *Juglans*, *Betula*, *Rhus*, *Tilia*, Oleaceae, *Ulmus*, *Salix*, *Carpinus*, and Pressaceae. Herbaceous pollen indicated 17 families or genera, including *Artemisia*, Gramineae, Chenopodiaceae, Cruciferae, Leguminosae, Ranunculaceae, *Thalictrum*, Solanaceae, Compositae, Convolulaceae, *Humulus*, Labiaceae, Cyperaceae, Scrophulariaceae, *Polygonum*, Rosaceae, Euphorbiaceae. Fern spores were represented by Polypodiaceae and *Selaginella*. Today these families and genera are common in the area.

Pollen and spore concentrations in all 68 samples were low (no greater than 23 grains/g), indicating that the vegetation was probably sparse. Abundance of herbs, woody plants and ferns was relatively consistent between samples. The major components were herbs (80%–90% of samples, with a maximum of 100%), and the main genus was *Artemisia*. The Chenopodiaceae and Gramineae were less well represented; the A/C (the ratio of *Artemisia*/Chenopodiaceae) of most samples was greater than 1. Woody plants were not common (only 0–20%), and were mainly *Pinus*, Pressaceae and broad-leaf trees. A few ferns spores (0–3.7%) appeared in some samples; ferns might have grown in small ponds that remained on the flood plain. It is thought that the pollen of herbs and broad-leaf trees is usually dropped on or near its origin, however, the pollen of *Pinus* species has air cells enabling it to be wind transported for long distances [26]. The spore and pollen analysis showed there were only a few *Pinus*, so we think the result could basically represent the vegetation of Donghulin area.

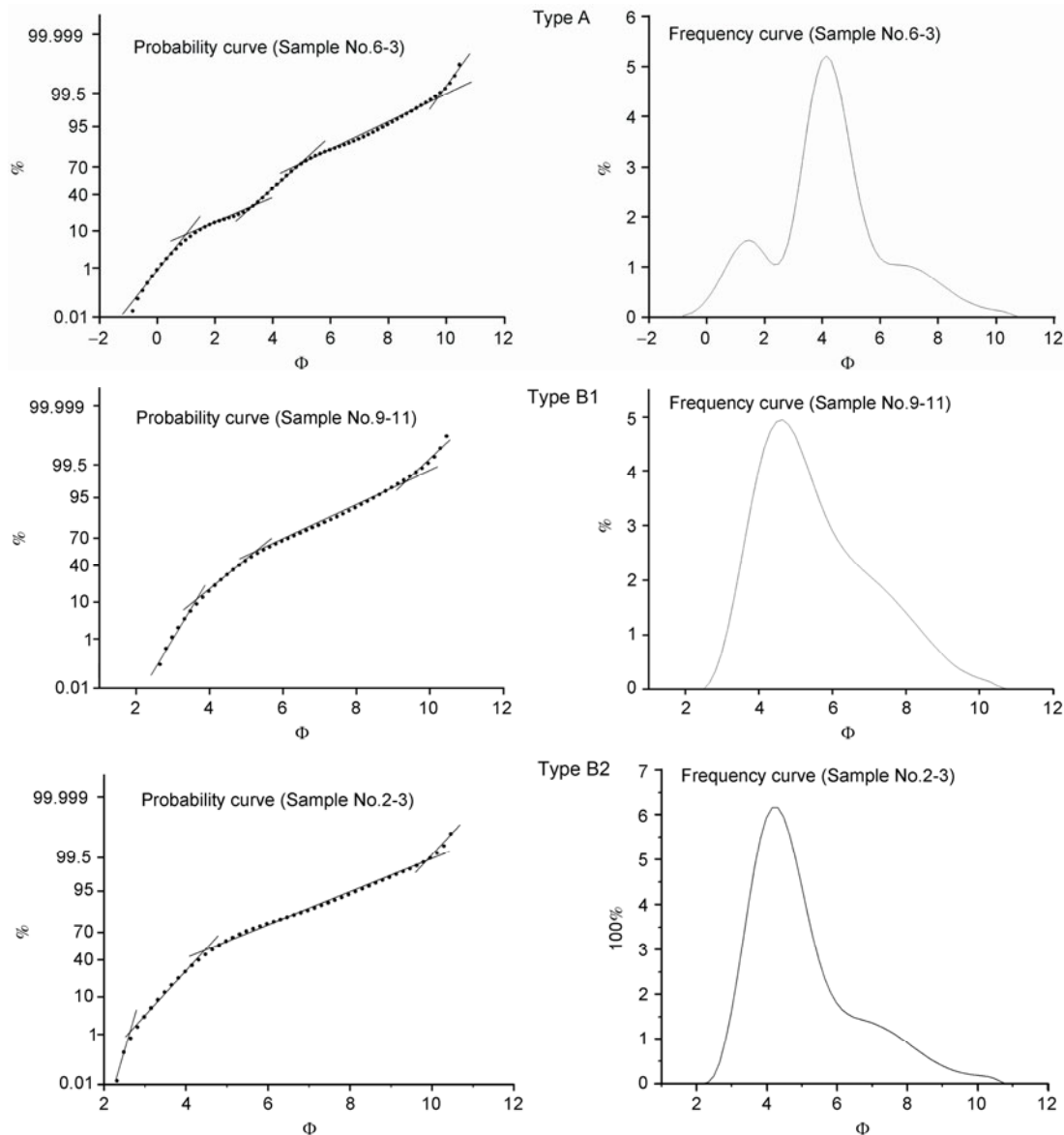Based on the pollen and spore analysis, we divided the profile into seven pollen-spore zones (Figure 4, Table 4):

Figure 3 Typical grain size probability curves and frequency curves of different sediments. Type A: The probability curve (left) and the frequency curve (right) of the grain size of beach sediments; Type B1: the probability curve (left) and the frequency curve (right) of the grain size of nearshore sediments; Type B2: the probability curve (left) and the frequency curve (right) of the grain size of farshore sediments.

Zone I (0–52 cm, corresponding to layers 2 and 3). The pollen concentration was 6.3–47.8 grains/g. The major component was herbs (71.1%–100%), and the main genus was *Artemisia* (44.3%–61.9%). The Chenopodiaceae (3.6%–20.4%) and Gramineae (6.0%–21.4%) were less well represented, and the A/C was large (2.28–16.00). Other herbs included members of the Compositae, Ranunculaceae, *Thalictrum*, Rosaceae, Solanaceae, Cruciferae, Leguminosae, *Humulus*, Convolulaceae, and Cyperaceae. Woody plants comprised 0–26.8% of the pollen. Besides *Pinus* and Pressaceae, many deciduous broad-leaf trees, such as *Betula*, *Carpinus*, *Quercus*, *Juglans*, *Ulmus*, *Rhus*, *Salix*, Moraceae, and Oleaceae were identified. Ferns spores represented 0–2.9%, and were of *Selaginella* and Polypodiaceae, both of

which were widely recorded. This pollen composition indicates a temperate meadow steppe under warm and wet conditions.

Zone II (52–120 cm, equivalent to layer 4 and upper layer 5). The pollen concentration was 8.1–18.4 grains/g. The major component was herbs (88.2%–100%), of which the main genus was *Artemisia* (36.4%–70.4%). Chenopodiaceae (11.1%–39.4%) and Gramineae (2.8%–22.9%) were less well represented, and the A/C was large (0.83–6.33). Other herbs included members of the Ranunculaceae, *Thalictrum*, Solanaceae, Cruciferae, Leguminosae, *Humulus*, Scrophulariaceae, and Labiaceae. There were only small amounts of woody plant pollen (0–11.5%), comprised of *Pinus*, and a few pollen grains of *Rhus* and Moraceae. The
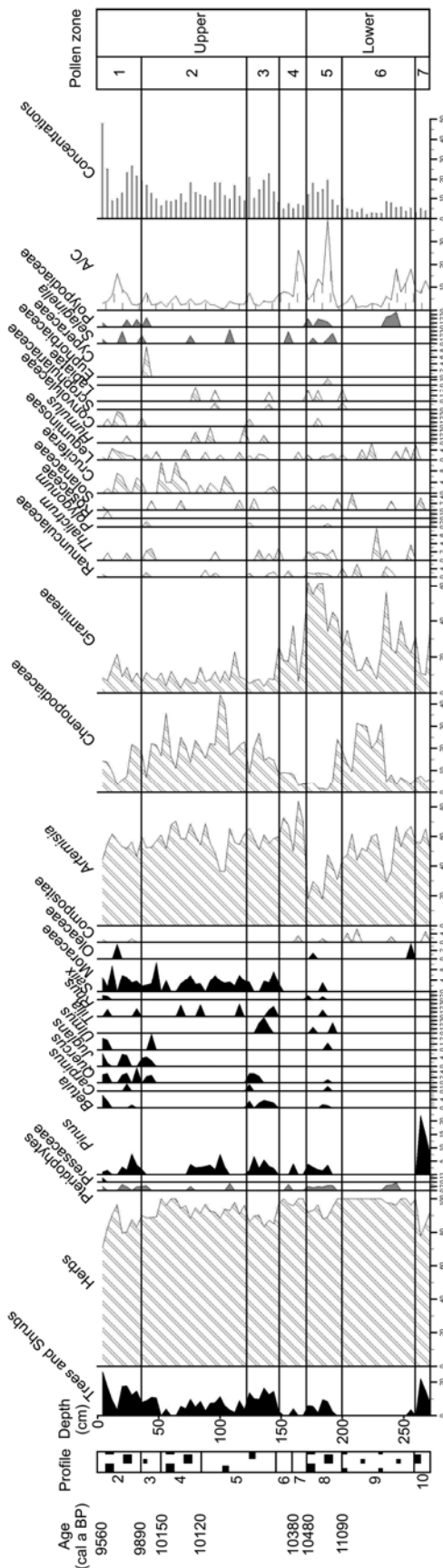
Figure 4   Pollen diagram of the profile at the Donghulin Site.

only fern spores were from *Selaginella* (0–3.4%), and were unevenly distributed. This configuration suggests a temperate grassland environment with a warm and dry climate.

Zone III (120–144 cm, corresponding to lower layer 5). The pollen concentration was 10.2–22.8 grains/g. The major component was herbs (83.3%–90.2%), and the main genus was *Artemisia* (51.2%–65.5%). The Chenopodiaceae (8.6%–26.8%) and Gramineae (3.7%–7.9%) were less well represented, and the A/C was large (1.91–7.60). Other herbs included members of the Ranunculaceae, *Thalictrum*, Leguminosae, *Polygonum*, Solanaceae, Cruciferae, *Humulus*, Convolulaceae, Scrophulariaceae, and Labiaceae. The numbers of woody plants increased (9.8%–16.7%). Besides *Pinus* and Pressaceae, there were many deciduous broad-leaf trees, including *Quercus*, *Betula*, *Tilia*, *Carpinus*, *Rhus*, and Moraceae. No fern spores were found. This configuration indicates a temperate meadow steppe under warm and wet conditions.

Zone IV (144–172 cm, corresponding to layer 6 and layer 7). The pollen concentration was 4.8–12 grains/g. The dominant component was herbs (92%–100%), of which the main genus was *Artemisia* (18%–83.9%). The Gramineae (6.5%–62%) and Chenopodiaceae (3.2%–9.1%) were less well represented, and the A/C was large (4.50–26.22). There were a few other herbs including members of the Compositae, Ranunculaceae, *Thalictrum*, Leguminosae, Labiaceae. There were only a few woody plants (0–6.0%), including *Pinus* and Moraceae. Ferns, including members of *Selaginella* and the Polypodiaceae, were sparse (0–2.9%). This configuration indicates a warm and dry temperate grassland environment.

Zone V (172–200 cm, corresponding to lower layer 8). The pollen concentration was 6.5–19.6 grains/g. The dominant component was herbs (88.7%–100%), of which the main family was the Gramineae (25.5%–61.3%). *Artemisia* (17.7%–44.7%) and Chenopodiaceae (1.2%–24.1%) were less well represented, and the A/C was large (1.28–39.67). Other herbs included members of the Ranunculaceae, *Thalictrum*, *Polygonum*, Compositae, Leguminosae, Solanaceae, Convolulaceae, Labiaceae, Euphorbiaceae, and Scrophulariaceae. The numbers of woody plants increased (0–9.7%). Besides *Pinus*, there were several deciduous broad-leaf trees, such as members of *Betula*, *Carpinus*, *Quercus*, *Ulmus*, *Tilia*, *Salix*, *Rhus*, Moraceae, and Oleaceae. Fern spores also increased in abundance (0–2.5%), and were mainly *Selaginella* and Polypodiaceae. This configuration indicates a warm and wet temperate meadow steppe environment.

Zone VI (200–256 cm, corresponding to layer 9). The pollen concentration was 2.0–8.6 grains/g. The dominant component was herbs (96.3%–100%), of which the main genus was *Artemisia* (29.3%–66.7%). The Gramineae (7.7%–56.1%) and Chenopodiaceae (3.7%–30.8%) were less well represented, and the A/C was large (1.40–18.03). A few other herbs including members of the Compositae, Ranunculaceae, *Thalictrum*, Leguminosae, and Solanaceae, were

Table 4 Characteristics of pollen and spores in each zone and likely environmental conditions

Profile	Zone	Layer	Spore and pollen characteristic				Environment
			Major	Woody plant	Fern	A/C	
Upper part	I	3–2	*Artemisia*–Gramineae–Chenopodiaceae, other herbs (many)	the proportion is 0–26.8%, containing many deciduous broad-leaf trees (8)	many	2.28–16.00 mean value 5.41	warm and wet temperate meadow steppe
	II	5$_{up}$–4	*Artemisia*–Chenopodiaceae–Gramineae, other herbs (a few)	the proportion is 0–11.5%, containing a few deciduous broad-leaf trees (*Rhus*, Moraceae)	a few	0.83–6.33 mean value 2.96	warm and dry temperate grassland
	III	5$_{low}$	*Artemisia*–Chenopodiaceae–Gramineae, other herbs (many)	the proportion is 9.8%–16.7%, containing many deciduous broad-leaf trees (6)	no	1.91–7.60 mean value 3.99	warm and wet temperate meadow steppe
	IV	7–6	*Artemisia*–Gramineae –Chenopodiaceae, other herbs (a few)	the proportion is 0–2.9%, containing a few deciduous broad-leaf trees (*Salix*)	some	4.50–26.22 mean value 11.20	warm and dry temperate grassland
Lower part	V	8	Gramineae–*Artemisia*–Chenopodiaceae, other herbs (many)	the proportion is 0–9.7%, containing several deciduous broad-leaf trees (4)	many	1.28–39.67 mean value 11.86	warm and wet temperate meadow steppe
	VI	9	*Artemisia*–Gramineae–Chenopodiaceae, other herbs (a few)	the proportion is 0–3.7%, no deciduous broad-leaf tree	a few	1.40–18.03 mean value 6.33	warm and dry temperate grassland
	VII	10	*Artemisia*–Gramineae–Chenopodiaceae, other herbs (a few)	the proportion is 2.6%–2.72%, no deciduous broad-leaf tree	no	7.51–13.00 mean value 9.52	cool and dry temperate grassland

also identified. Woody plants were only represented by a few Oleaceae. Fern spores were found in the middle part of the zone, but only Polypodiaceae (0–3.7%). This record points to a warm and dry temperate grassland.

Zone VII (256–272 cm, corresponding to layer 10). The pollen concentration was 3.1–10.1 grains/g. The major component was herbs (77.8%–100%), of which the main genus was *Artemisia* (51%–65%). The Gramineae (10.0%–35.3%) and Chenopodiaceae (5.0–7.4) were less well represented, and the A/C was large (7.51–13.00). There were also a few Leguminosae and Solanaceae. Woody plant pollen (0–22.2%) was solely from *Pinus*. No fern spores were found. This indicates an environment of cool and dry temperate grassland.

From the overall patterns indicated by the pollen and spore analysis, we can see that during the period of "Donghulin man" (11100–9600 cal a BP), the vegetation mainly included *Artemisia*, but that some members of the Chenopodiaceae and Gramineae were present. A few deciduous broad-leaf trees were also present, indicating warm to cool, dry temperate grassland, and warm and wet, temperate meadow steppe environments. The latter environment was more common during the late "Donghulin period" (10500–9600 cal a BP) (Table 4).

5   Discussion

The Donghulin Site is an early Neolithic site, with clear landforms, a complete stratum and abundant cultural relics. From analysis of the stone implements unearthed here, ar-chaeologists have speculated that in the Donghulin period, the microlith, an important symbol of Paleolithic-Neolithic transition, was well developed. The number of neoliths increased as well, indicating a typical Paleolithic-Neolithic transition culture.

There are many reasons for the Paleolithic-Neolithic transition. Our research shows that "Donghulin man" lived during the warm period following the Younger Dryas. The climate is the same in other places of North China [27–30]. The environment clearly changed during this period; the land was initially covered by dry temperate grassland and transformed to wet temperate meadow steppe. Previous analysis of the physiographic stages shows that around 10000 a BP, along with the climate becoming warmer and wetter, the river cut down through the intermountain loess plain which had emerged during the Malan period, and formed a new river valley and Malan loess platform along both sides (this was called the "Banqiao Erosion"). Aggradation was strong in the new valley, and thick fluvial deposits accumulated, forming widespread floodplains (this was called the "Gaolan Accumulation period") [31–34].

Other Paleo-Neolithic transition sites in the North China area, such as the Yujiagou Site in Yuanyang, Hebei Province; the Shizitan Site in Jixian, Shanxi Province; and the Lijiagou Site in Xinmi, Henan Province, are probably similar to the Donghulin Site. Places of human habitation all had a strong relationship with the valley formed by the Banqiao Erosion and the Gaolan Accumulation. We speculate that the warm period following the Younger Dryas, and also the river valley landscapes formed by the Banqiao Erosion, are probably the most important environmental factors during

the transition from Paleolithic to Neolithic in this area.

6   Conclusion

Our integrated study included a geomorphological survey, profile observation, sediment analysis, and palynological analysis, and incorporated data from chronological dating and archaeological records. It is able to provide the following insights:

(1) "Donghulin man" occupied the site between 11100–9600 cal a BP. This was the warm period after the Younger Dryas, and the "Gaolan Accumulation" period following the "Banqiao Erosion".

(2) The remains of "Donghulin man" were mainly distributed in the river deposits on the terrace 3 of the Qingshui River; most are on top of floodplain sediments. This suggests that "Donghulin man" mainly lived on the floodplain of the paleo-Qingshui River, and probably changed encampments as the river and landforms changed.

(3) During the "Donghulin man" period, the climate was good; warm and dry to warm and wet. The vegetation was temperate grassland and changing to temperate meadow steppe. There were abundant animals and plants that were appropriate for human hunting and gathering.

(4) The geomorphology and climate changed around 10500 cal a BP, during the period of "Donghulin man". The river evolved from the first river course to the second one, and the warm and dry temperate grassland changed to warm and wet temperate meadow steppe. At the same time, the microlith, an important symbol of Paleolithic-Neolithic cultural transition, significantly developed. Further research is required to clarify the relationship between this changing culture and its changing environment.

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