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New evidence for early presence of hominids in North China

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The Nihewan Basin in North China has a rich source of Early Pleistocene Paleolithic sites. Here, we report a high-resolution magnetostratigraphic dating of the Shangshazui Paleolithic site that was found in the northeastern Nihewan Basin in 1972. The artifact layer is suggested to be located in the Matuyama reversed polarity chron just above the upper boundary of the Olduvai polarity subchron, yielding an estimated age of ca 1.7–1.6 Ma. This provides new evidence for hominid occupation in North China in the earliest Pleistocene. The earliest hominids are argued to have lived in a habitat of open grasslands mixed with patches of forests close to the bank of the Nihewan paleolake as indicated from faunal compositions. Hominid migrations to East Asia during the Early Pleistocene are suggested to be a consequence of increasing cooling and aridity in Africa and Eurasia.

Knowing the precise age ranges of early hominid habitation and stone technologies in different regions of the world is a key component for a comprehensive understanding of human evolution. The Nihewan Basin in North China is an intermontane basin about 150 km west of Beijing (Fig. 1). It comprises one of the most detailed sets of Early Pleistocene Paleolithic evidence from the whole of Asia[1]. Therefore, it has become a major area of archaeological research and a prime focus of investigations into early human evolution in East Asia[1–3]. During the past decades, more than 60 Paleolithic sites associated with thousands of *in situ* Oldowan-like stone tools (i.e., Mode 1 core and flake technologies) were found in the basin[4–6]. The Nihewan fluvio-lacustrine sediments do not contain material suitable for radio-isotopic dating (e.g., tephra). The exact ages of these Paleolithic sites thus have long been considered controversial. Only recently, reliable ages were assigned to some Early Pleistocene Paleolithic sites based on high-resolution magnetostratigraphy; sites include Majuangou (MJG) dated at 1.66–1.55 Ma[7], Lanpo (LP) at 1.6 Ma[8], Xiaochangliang (XCL) at 1.36 Ma[9], Xiantai (XT) at 1.36 Ma[10], Banshan (BS) at 1.32 Ma[7], Feiliang (FL) at 1.2 Ma[8,11] and Donggutuo (DGT) at 1.1 Ma[12]. These recently established magnetostratigraphic ages of the Paleolithic sites in the basin have dramatically increased our understanding of early human colonization of 40° N East Asia[1,7,9,13].

The Shangshazui (SSZ) locality (40°15.3′ N, 114°40.8′ E) was uncovered in 1972 and represents an early documented Paleolithic site in the Nihewan Basin[14]. During the initial excavation in 1972 only one artifact was found[14]. It has, however, very clear characteristics of man-made lithic technology (Fig. 2a). It is a single-platform core, which shows at least three flake scars. The detached flakes would have been sufficiently thin and sharp to allow for cutting and scraping. Gai and Wei (1974)[14] suggested an Early Pleistocene age more or less equivalent to 1 Ma for the SSZ Paleolithic site based on its Oldowan-like technology. Further excavation in 1975 yielded three blade-like tools, which were made from good quality flints[15]. According to the blade technology and conventional wisdom that early hominids did not reach the 40° N East Asia before 1 Ma[16], the SSZ Paleolithic site was reassigned a Late Pleistocene age later on[17]. During later excavations in the 1990s and 2000s, more than 20 *in situ* Oldowan-like stone artifacts associated with some mammalian bone fragments were found. The excavated artifacts include cores, flakes, chunks and retouched pieces. For example, a single-platform core with three flake scars (Fig. 2b), a double-platform core with six flake scars (Fig. 2c) and a multi-platform core with seven flake scars (Fig. 2d) are shown here. Further shown are: 1) two so-called type VI flakes (Fig. 2 e, g) characterized by a non-cortical striking platform (surface surrounding the point of percussion) and non-cortical dorsal (exterior) surface, and 2) one type II flake (Fig. 2f) characterized by a cortical platform and partially cortical dorsal surface[18]. Most artifacts from the SSZ site are similar to those found in the MJG site with an age as old as ca 1.66 Ma[7]. Reanalysis of the stratigraphy and stone tools of the SSZ site and recent progress in the paleomagnetic dating of the Early

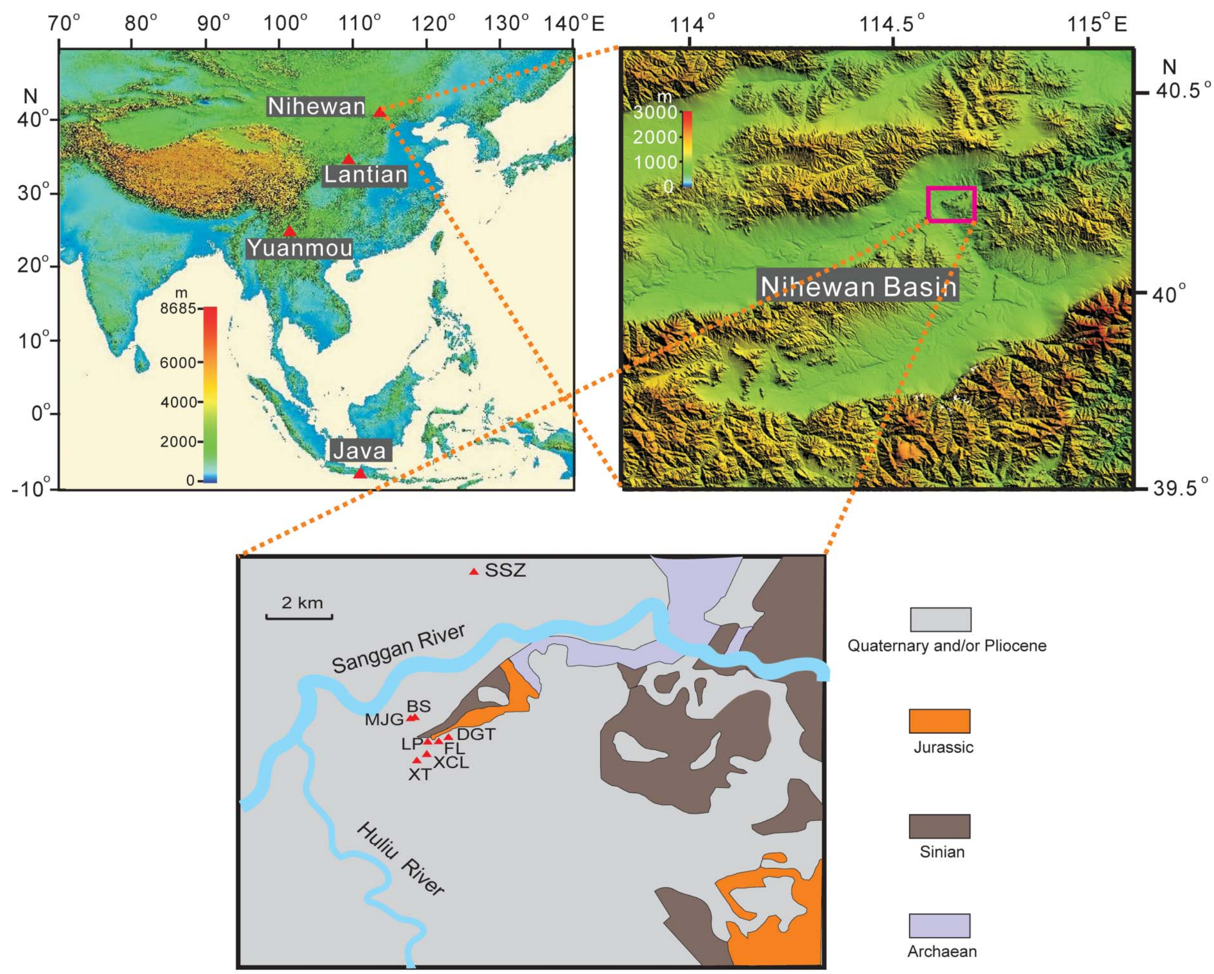

Figure 1 | **Schematic map showing the Nihewan Basin and mentioned Paleolithic sites (red triangles) in this paper (modified from Zhu et al.** (2008)[21] and Ao et al. (2013)[40]). SSZ, Shangshazui; XT, Xiantai; XCL, Xiaochangliang; LP, Lanpo; FL, Feiliang; MJG, Majuangou; BS, Banshan; DGT, Donggutuo.

Paleolithic sites in the Nihewan Basin imply that the SSZ Paleolithic site possibly has an Early Pleistocene age. In addition, the SSZ artifact layer also preserves a rich vertebrate fauna, such as *Palaeoloxodon namadicus*, *Equus* sp., *Coelodonta antiquitatis*, *Ochotona* sp., *Struthio* sp. and *Bos primigenius*[14,15,19]. Based on the fauna, however, both Early and Late Pleistocene ages are possible. Thus a precise age for the SSZ Paleolithic site has remained controversial. In this study, we present a high-resolution magnetostratigraphic record of the SSZ

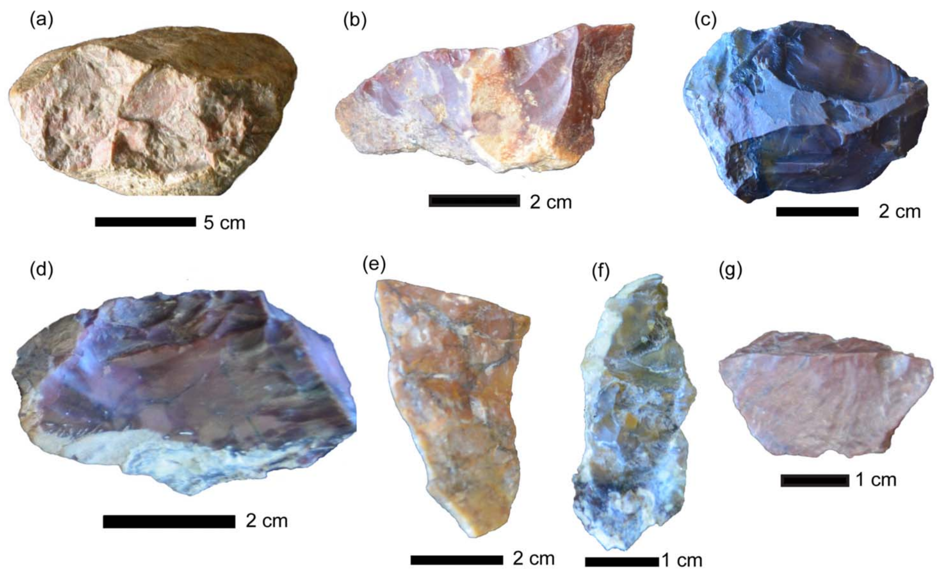

Figure 2 | **Examples of stone tools from the SSZ Paleolithic site: (a–d) cores and (e–g) flakes.**

section that hosts the SSZ stone artifact layer, aiming to provide a precise age estimate and to improve our understanding of hominid occupation of North China.

The SSZ section, the topic of the present contribution, is located at the northeastern margin of the basin; natural outcrop consists of 85.5 m thick fluvio-lacustrine sediments. To extend the magnetostratigraphic record a well was dug down to a stratigraphic level of 92.2 m (0 m stratigraphic level indicates the top of the section). The sedimentary sequence consists mainly of grayish-green and grayish-yellow silty clays and clayey silts, intercalated with silty sand that grade occasionally to coarse-grained and even conglomeratic sands (Fig. 3a). The artifact layer is located in a layer of coarse-grained and conglomeratic sands at 63–64.3 m stratigraphic level of the composite SSZ section.

We collected 738 oriented block samples from the SSZ section (stratigraphic interval: 5–20 cm). Orientation in the field was done by magnetic compass. Two cubic specimens of 2 cm × 2 cm × 2 cm were subsequently cut from each block sample in the laboratory for thermal demagnetization treatment to isolate the characteristic component of the natural remanent magnetization (NRM).

Results

Generally, the secondary NRM components in the fluvio-lacustrine sediments of the SSZ section are removed by thermal demagnetization to 150–250°C (occasionally up to 300–400°C, cf. Fig. S1). After removal of the secondary overprint, the characteristic remanent magnetization (ChRM) is unblocked during steps up to 680°C. From the 738 demagnetized levels, 462 yield reliable ChRM components (cf. Table S1) based on strict selection criteria: (1) at least 4 (but typically 8–15) consecutive demagnetization steps starting at least at 250°C (with upper temperatures of ≥500°C), (2) maximum angular deviation (MAD) of <15°, and (3) calculated virtual geomagnetic pole (VGP) latitude of >30° (or <−30°)[20,21]. The remaining 276 samples were excluded, because they have unstable demagnetization trajectories, MAD values ≥15°, VGP latitudes between −30° and 30°, or declinations trending roughly north (or south) but with upward (or downward) inclinations inconsistent with the expected geomagnetic field. These excluded samples are randomly distributed over the section; they are not confined to certain parts. Excluded samples tend to be associated with the coarser grained lithologies; silty sand layers occur frequently in the section (Fig. 3a), this might provide an explanation for the rather high proportion of excluded samples (37%). The 462 reliable ChRM directions result in an antipodal distribution of 131 normal and 331 reversed orientations on an equal area projection passing the reversals test (Fig. S2). Finally, the VGP latitudes from all the 462 ChRM directions are used to establish the magnetostratigraphy of the SSZ section (Fig. 3). Our paleomagnetic results allow us to recognize six main polarity intervals in the SSZ section: three normal and three reversed.

Combining the recent magnetostratigraphic records of the Nihewan fluvio-lacustrine sequences from nearby sections, such as the MJG[7], XT[10] and XCL[9] sections, we can readily correlate the SSZ magnetostratigraphy to the Pleistocene Geomagnetic Polarity Time Scale (GPTS)[22]. The correlation suggests that the SSZ section records a geomagnetic polarity sequence that spans from the early Matuyama polarity chron to the early Brunhes polarity chron (Fig. 3). The Matuyama–Brunhes boundary is located at 7.6 m. The Jaramillo and Olduvai polarity subchrons are identified at 14.2–18.7 m and 73.7–85.7 m, respectively.

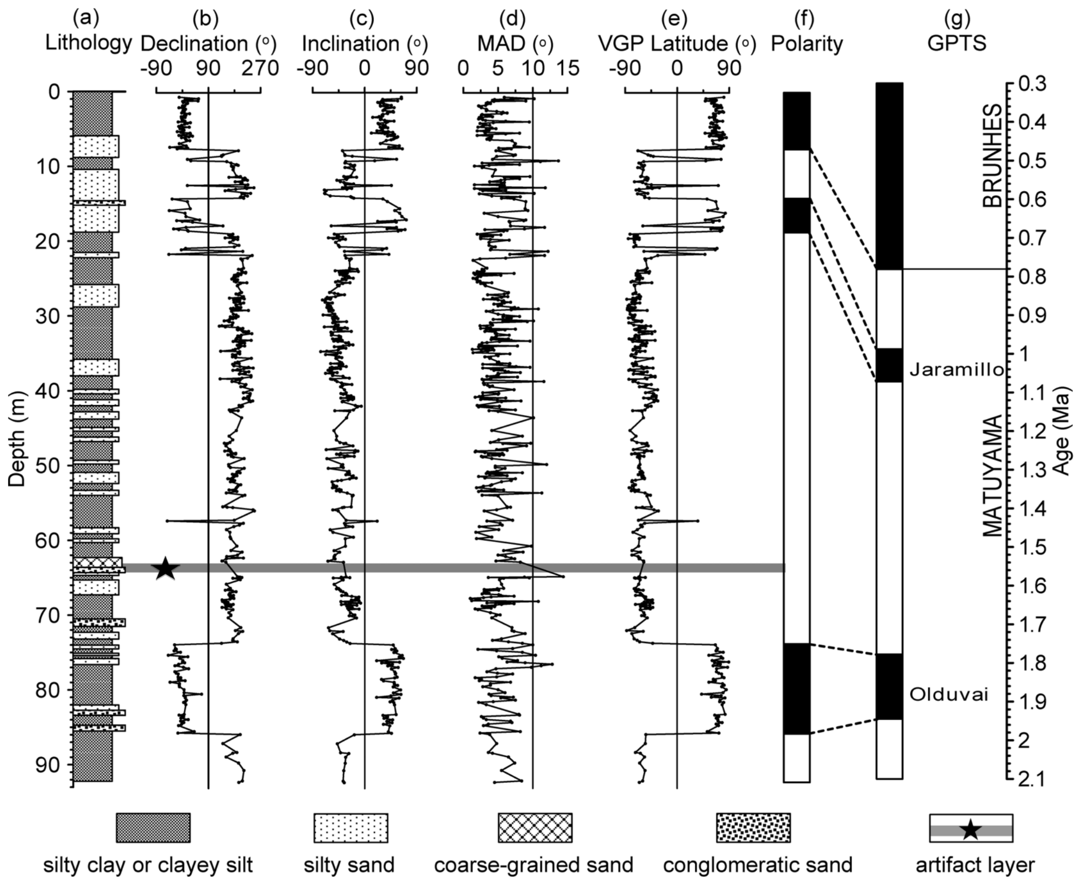

Figure 3 | Lithostratigraphy and magnetostratigraphy of the SSZ section and correlation to the geomagnetic polarity timescale (GPTS). (a) Lithology, (b) declination, (c) inclination, (d) maximum angular deviation (MAD), (e) virtual geomagnetic pole (VGP) latitude and (f) paleomagnetic polarity sequence of the SSZ section. (g) GPTS[22].

Discussion

Our magnetostratigraphy indicates that the SSZ artifact layer is located in the Matuyama reversed polarity chron just above the Olduvai polarity subchron (Fig. 3). Hence, this does not support a Late Pleistocene age for the SSZ Paleolithic site as suggested by Jia and Wei[17]. The duration between the lower boundary of the Jaramillo polarity subchron (1.072–0.988 Ma) and the upper boundary of the Olduvai polarity subchron (1.945–1.778 Ma) is ca 706 kyr[22]; this yields an average sedimentation rate of 7.8 cm/kyr for this interval in the SSZ section. Thus the interpolated age for the SSZ artifact layer (63–64.3 m) is ca 1.65 Ma. This estimate is supported by extrapolation of the average sedimentation rate (7.2 cm/kyr) in the Olduvai polarity subchron. This extrapolation would provide a slightly younger age of ca 1.64 Ma. Taking into account the uncertainties of interpolation and extrapolation (i.e., variable sedimentation rates), we conservatively suggest an age of 1.7–1.6 Ma for the SSZ Paleolithic site. This is much older than earlier age estimates. Possibly because of previously underestimated ages, little attention has been paid to this early found Paleolithic site in the Nihewan Basin. This study, however, establishes an age within the time range of the earliest hominid colonization of East Asia. In particular, the recognition of the Olduvai polarity subchron below the SSZ artifact layer significantly reduces uncertainties in the age estimate and distinctly improves its accuracy. Therefore, our magnetostratigraphic dating of the SSZ Paleolithic site provides new evidence of the earliest hominid occupation in North China prior to 1.6 million years ago. It indicates as well that the blade-like technology may have occurred much earlier (i.e. Early Pleistocene) in the Nihewan Basin than previously known. Actually, similar blade-like tools were also found in the nearby XCL Paleolithic site[23] with an age of ca 1.36 Ma[9]. In addition, it suggests that the SSZ locality should be considered as the first Early Pleistocene Paleolithic site found in the Nihewan Basin. Our revised age of the SSZ Paleolithic site is contemporaneous with the oldest Paleolithic sites[7] in the Nihewan Basin (MJG-III with an age of 1.66 Ma and MJG-II with an age estimate of 1.64 Ma[7]) and only slightly younger than the Yuanmou *Homo erectus* site (ca 1.7 Ma) in South China[21]. The notable convergence of age estimates to 1.7–1.6 Ma for the earliest hominid evidence across China indicates that early humans have possibly occupied a vast area in China by 1.7–1.6 Ma (from the Nihewan Basin in North China to the Yuanmou Basin in South China).

Up to now, direct evidence of the climatic and environmental setting of the earliest hominid occupation in the Nihewan Basin (i.e., the SSZ and MJG Paleolithic sites) is not available. However, the associated faunal remains from the SSZ[14,15,19] and MJG-III[7] sites imply dominant grasslands with patches of woodlands in the Nihewan Basin during the earliest hominid occupation. Five of the six taxa in the SSZ fauna (i.e., *Equus* sp., *Coelodonta antiquitatis*, *Ochotona* sp., *Struthio* sp. and *Bos primigenius*) and five of the eight taxa in the MJG-III fauna (i.e., *Coelodonta antiquitatis*, *Equus sanmeniensis*, *Gazella* sp., *Pachycrocuta* sp. and *Struthio* sp.) are taxonomically affiliated with typical grazing species indicative of an open grassland environment. Only one species in the SSZ fauna (i.e., *Palaeoloxodon namadicus*) and two in the MJG-III fauna (i.e., *Cervus* sp. and *Elephas* sp.) imply a woodland habitat. Especially the presence of elephants in both faunas is characteristic of a perennial warm and humid climate. In addition, the SSZ artifact layer contains a large number of molluscous fossils, such as *Corbicula* sp., *Bradybaena similaris, Radix auricularia, Bllamya* sp., *Gyraulus compressus* and *Parafossatulus striatulus*[15]. The occurrence of numerous mollusks, fine-grained sands and conglomerates in the SSZ artifact layer indicates that the early hominids possibly lived in a lakeshore setting with fresh or semi-saline water. The presence of an intermountainous lake seems to have been a major attraction for early hominid occupation during the Early Pleistocene. First, the lake provided water, and secondly, it would have attracted a substantial range of mammals and other food sources. Furthermore, the mountains and exposed bed rocks at the eastern margin of the Nihewan Basin are envisaged to have been important material sources for making stone tools[4,6]. Therefore, the Nihewan Basin was undoubtedly an attractive place for early humans, with a fortunate combination of water, food and stones. This line of thought explains why Paleolithic or hominid sites of the Early Pleistocene are usually found near or on lake shores, such as Olduvai and Lake Turkana in East Africa, and in Eurasia: Ubeidiya, Gesher Benot Ya'aqov, Dursunlu, Dmanisi and Nihewan Basin.

The Early Pleistocene dispersal of early humans from Africa, or perhaps from the southern Caucasus[24,25], to 40° N East Asia was not only a significant biogeographic event but also a major evolutionary threshold in hominid evolution[1,7]. These earliest human dispersals were possibly a consequence of climate changes in Africa and Eurasia[26]. Consistent with the increasing global cooling and aridity during the Pleistocene[27], an enhanced shift from closed woodland forest C_3 vegetation toward more open arid-adapted C_4 savannah grassland vegetation is observed after the Pliocene[28,29], associated with increasing arid-adapted faunal compositions[30]. For example, a trend towards increasing aridity and grasslands was found to peak at Olduvai (East Africa) during the Early Pleistocene[31]. The decrease in closed woodland forests and increase in open grasslands might have promoted a prominent flourishing and population increase of savanna-adapted hominids in Africa as well as the southern Caucasus. This could have resulted in enhanced competition for food in these areas, which in turn led hominids to migrate into similar savanna settings in East Asia such as the Yuanmou[21] and Nihewan basins in China, and Java[32,33] in Indonesia. Consistent with the dispersal of Proboscidea out of Africa at 2.5–1.5 Ma[34], *Hipparion* sp. was also found in the Nihewan Basin during the Early Pleistocene[35]. Therefore, favorable global (especially Africa and Eurasia) climatic and environmental conditions make it not illogical to expect to find hominid emigrants in the Nihewan Basin at ca 1.7–1.6 Ma: similar mixed savanna and woodland habitats as in Africa and southern Caucasus are shown to be present here. Up to now, the ~40° N latitude seems to be the most northerly hominid occupation in East Asia during the Early Pleistocene, because no evidence of Early Pleistocene hominid activities have been found at higher latitudes. From a global perspective, the significantly decreased daylight length and temperature in winter may have significantly limited their further northward expansion during the Early Pleistocene[1,36]. In addition to the overwintering problem of the 40° N temperate zone, climate and ecology of the Tibetan Plateau may have formed an impenetrable barrier for early hominid colonization and expansion as well. Furthermore, early humans might have inhabited high-latitude Asia only during warm seasons (i.e., they probably avoided cold winters) rather than year-round during the Early Pleistocene[36]. In contrast, South Asia had relatively fine climate and abundance of food/water resources. This may suggest that early humans dispersed to East Asia from southwest Eurasia possibly via a southern route across the Indian subcontinent, although we cannot exclude the possibility of a northern route[1,24,25] at the moment. Additional evidence for hominids in South China during the Early Pleistocene is crucial for clarifying the true dispersal scenario.

Methods

Progressive thermal demagnetization of the natural remanent magnetization (NRM) was conducted using an ASC TD-48 thermal demagnetizer at the Institute of Earth Environment, Chinese Academy of Sciences (IEECAS, Xi'an, China) and the Institute of Geology and Geophysics (IGGCAS, Beijing, China). All samples were stepwise heated with 10–50°C temperature increments to a maximum temperature of 680°C, which includes 18 steps of demagnetization. After each demagnetization step, remaining NRM was measured using a 3-axis 2-G Enterprises Model 755-R (in Xi'an) or 760-R (in Beijing) cryogenic magnetometer housed in a magnetically shielded space (<300 nT). The NRM intensity of the samples was usually of the order of 10^{-4}–10^{-6} A/m, while the instrumental background (or noise) magnetization level in the magnetometer was generally of the order of 10^{-8}–10^{-9} A/m. Samples were fixed on the tray of a horizontal pass-through magnetometer in groups of eight, and we did not rotate or invert the samples during the measurement procedure in the magnetometer. Only, individual measurements with drift values of $<10^{-8}$ A/m were used for paleomagnetic analyses; if drift appeared to be higher samples were remeasured. Demagnetization results were evaluated by orthogonal diagrams[37]; the principal component direction for each sample was computed using a least-squares fitting technique[38]. The principal component analysis (PCA) was done using the PaleoMag software developed by C.H. Jones[39]; the least-squares fits included the origin.

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Author contributions
H.A. designed the study, performed the fieldwork and paleomagnetic measurements, and led the writing of the paper. M.D. and G.X. contributed to data analysis and interpretation. W.Q. contributed to the archaeological interpretations. X.Q. helped with laboratory work. All authors contributed to discussion, interpretation of the results and writing of the manuscript.

Additional information
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